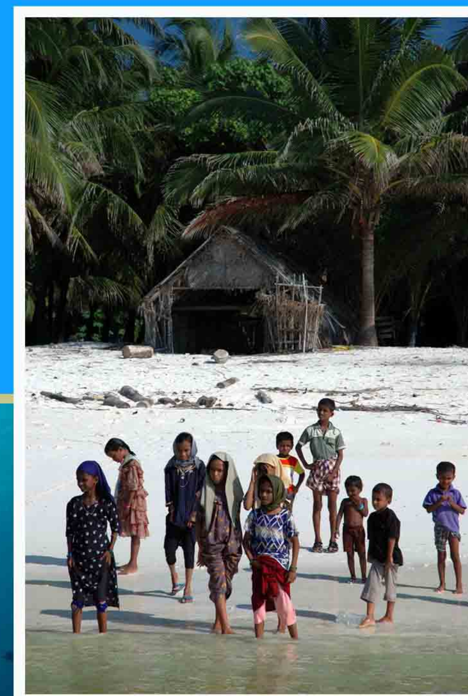
Coastal Oceans Research and Development in the Indian Ocean

Status Report 2008



Part 1
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COASTAL OCEANS RESEARCH AND DEVELOPMENT IN THE INDIAN OCEAN
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EDITORS:
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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

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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,

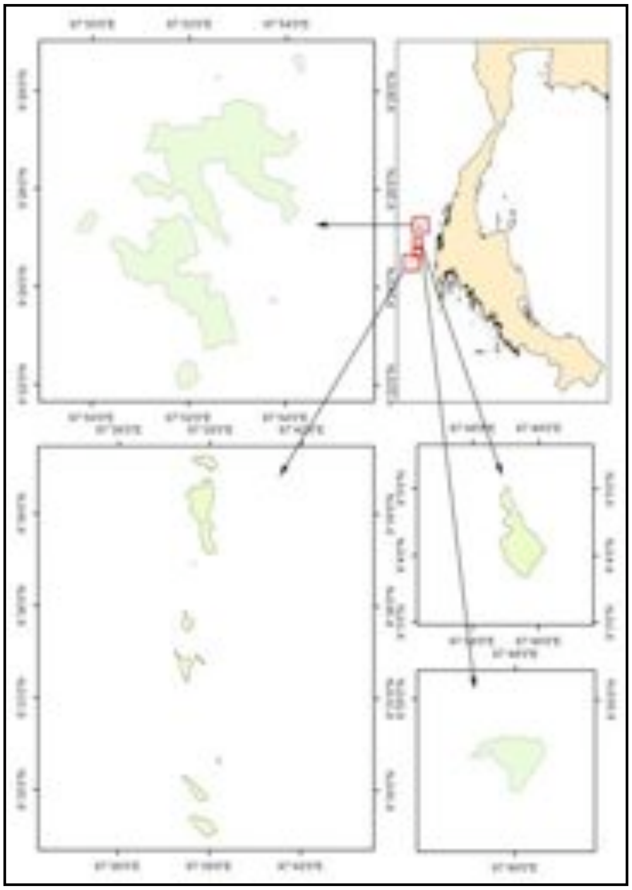

Figure 1. Study sites in Surin and Similan Marine National Parks.

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)**	

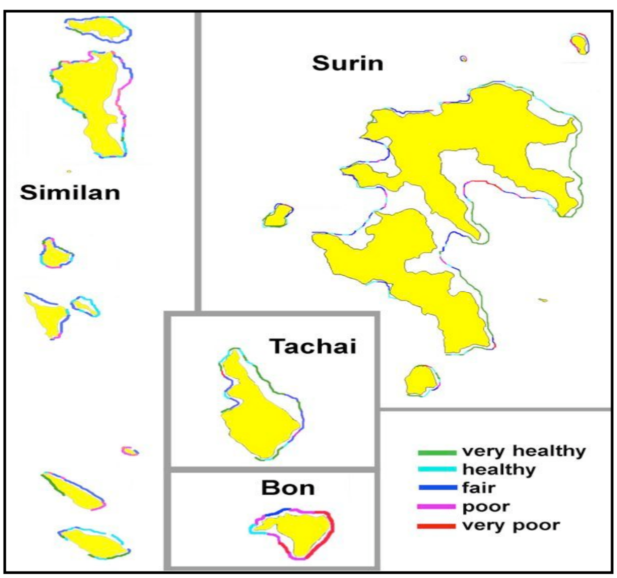

Figure 2. Manta tow results around the Similan islands for 2006.

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 island where an outbreak of crown-of-thorns starfish was recorded during a survey in 1995. The latest

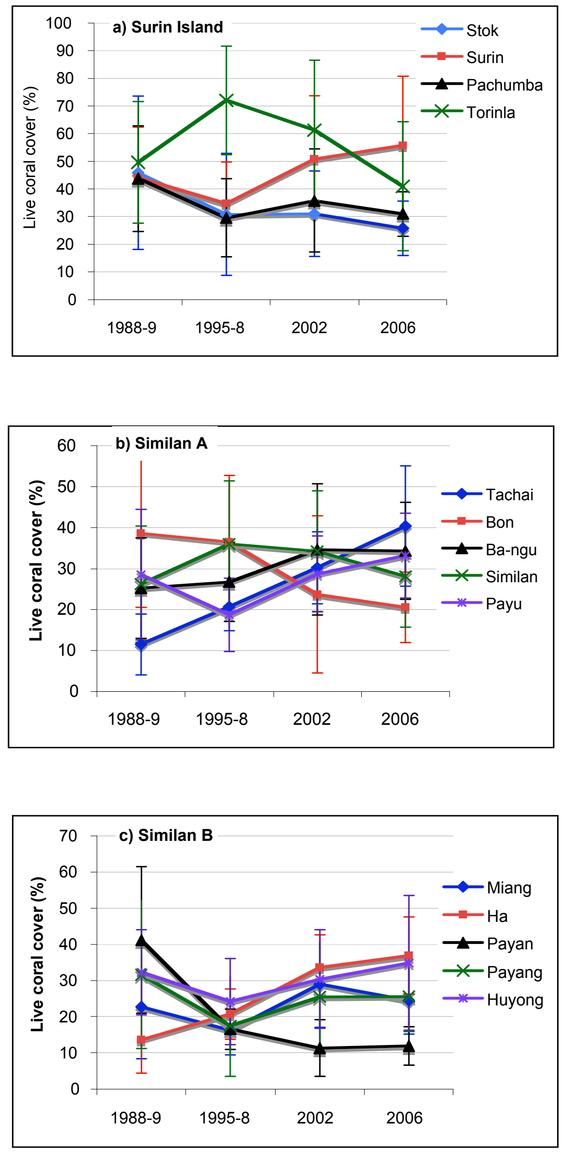

Figure. 3 Average live coral cover at study sites in a) Surin Islands National Park, and b,c) Similan Islands National Park, in the 4 survey periods. Error bars indicate standard deviation. Significant differences in coral cover from one period to the next, based on t-test of two independent samples,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

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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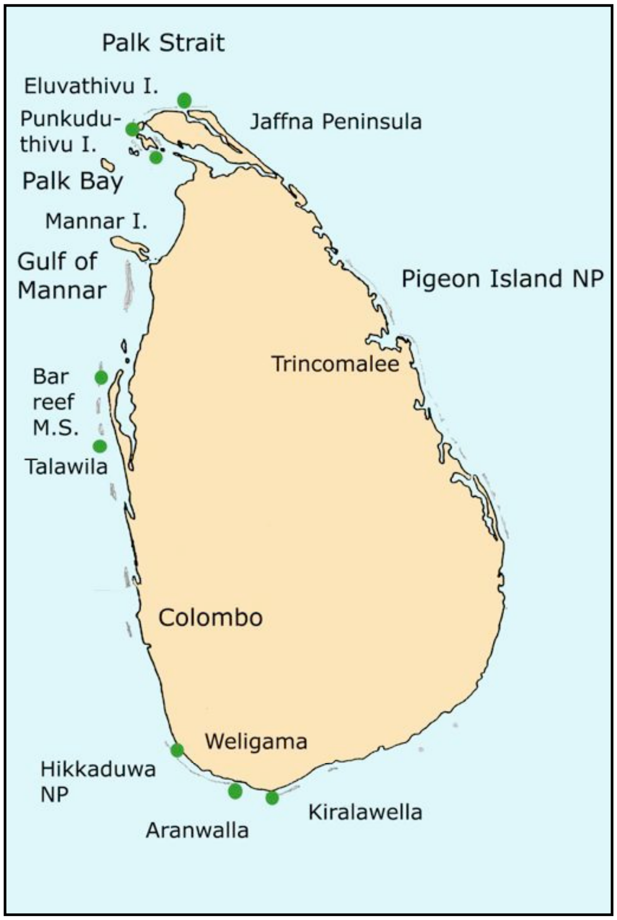

Figure 1. Map of Sri Lanka.

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

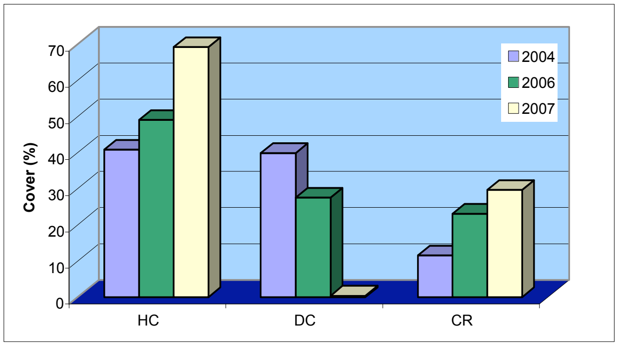

Figure 2. Comparison of cover of the most abundant substrate types in 2004, 2006 and 2007 in the Bar Reef Marine Sanctuary.

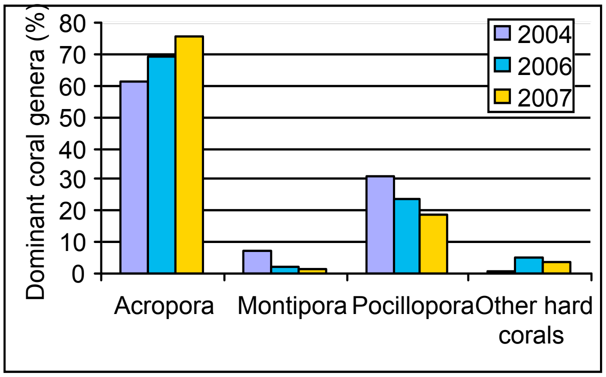

Figure 3. Comparison of the composition of live hard coral cover in 2004, 2006 and 2007 using the most abundant coral genera on the shallow reef flats in Bar Reef Marine Sanctuary.

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

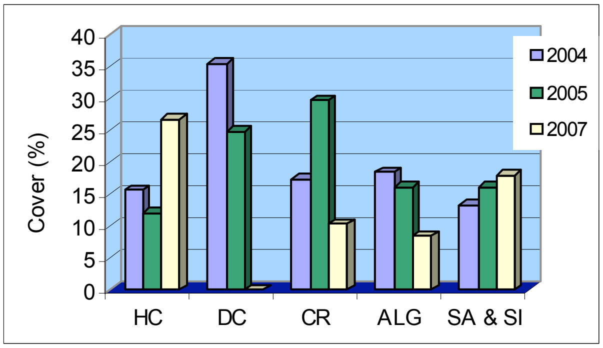

Figure 5. Comparison of cover of the most abundant substrate types in 2004, 2006 and 2007 in the Hikkaduwa National Park.

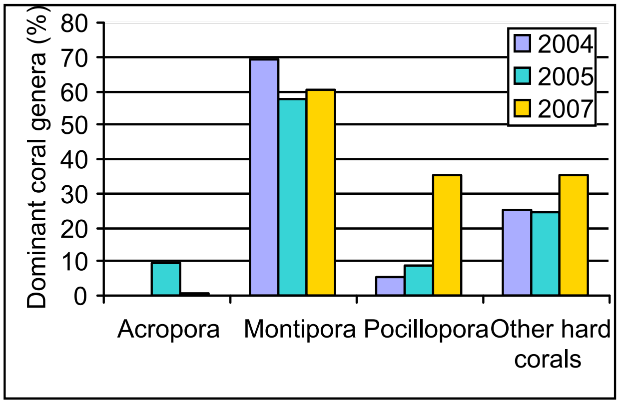

Figure 6. Comparison of the composition of live hard coral cover in 2004, 2005 and 2007 using the most abundant coral genera in the Hikkaduwa National Park.

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

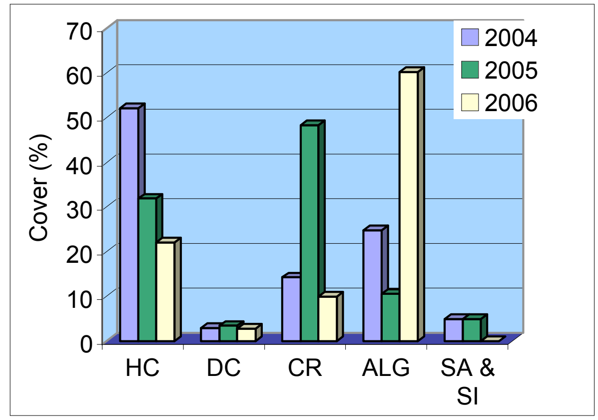

Figure 7. Comparison of cover of the most abundant substrate types in 2004, 2005 and 2006 in Kapparatota, Weligama.

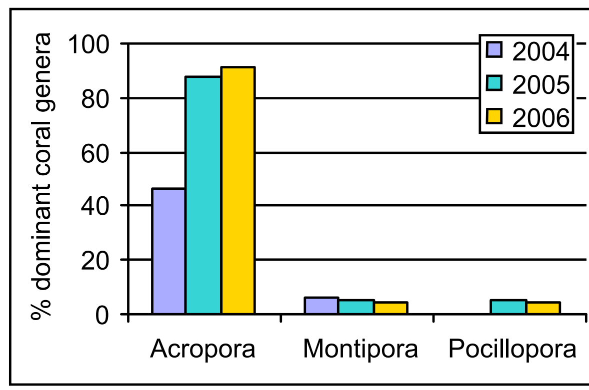

Figure 8. Comparison of the composition of live hard coral cover in 2004, 2005 and 2007 using the most abundant coral genera in Kapparatota, Weligama.

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).

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.

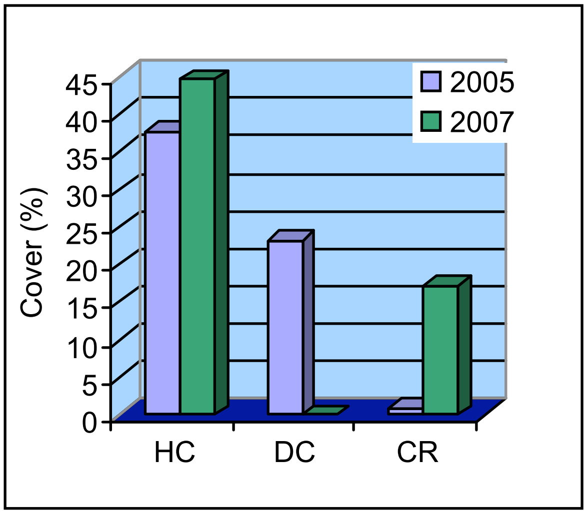

Figure 9. Comparison of cover of the most abundant substrate types in 2005 and 2007 in the Talawila coral reef .

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

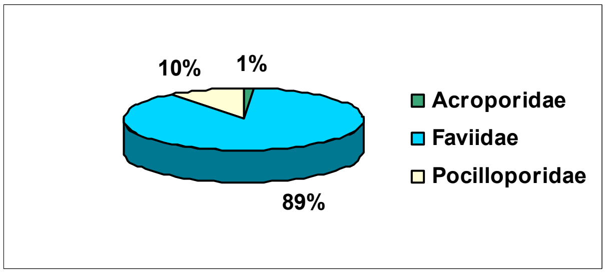

Figure 10. Percent composition of hard coral families at Aranwala, 2007.

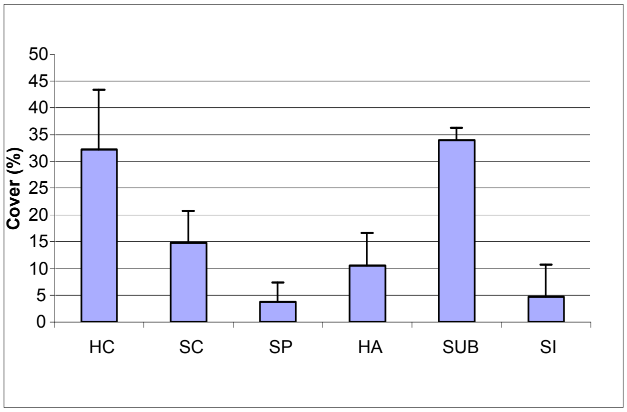

Figure 11. Comparison of the most abundant substrate types in the coral reef at Aranwala, 2007.

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

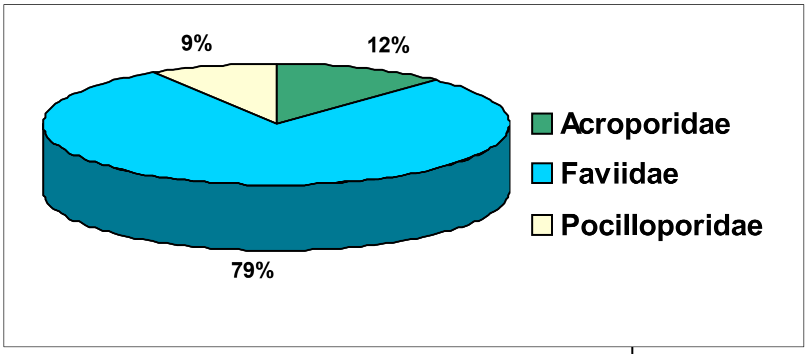

Figure 12. Percent composition of hard coral families at Kiralawella.

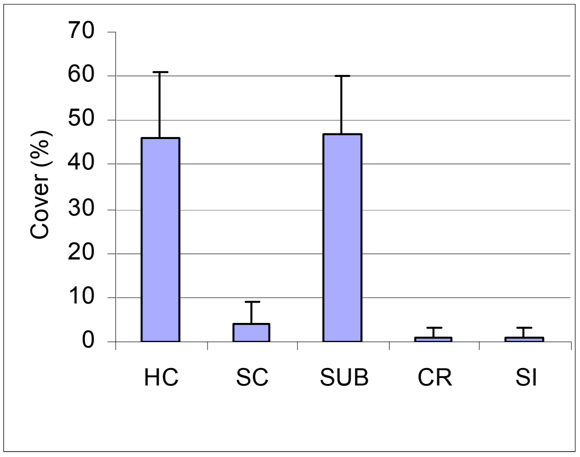

Figure 13. Comparison of the most abundant substrate types in the coral reef at Kiralawella, 2007.

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

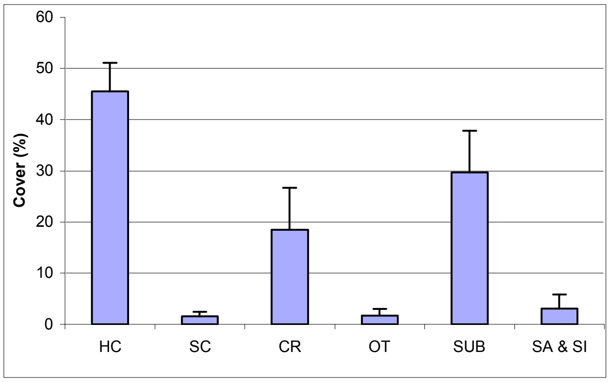

Figure 14. Percent cover of substrate types on coral reefs of Jaffna Peninsula in 2005.

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)

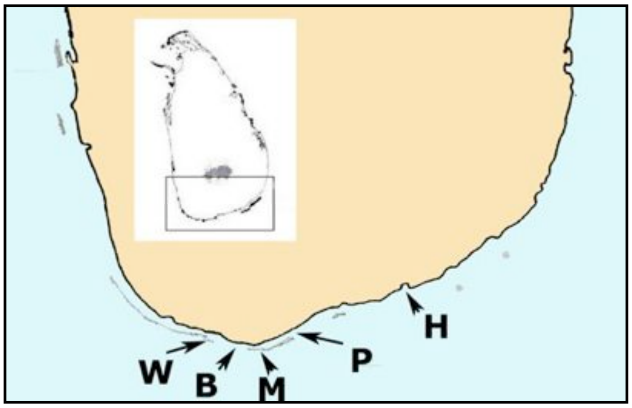

Figure 1. The study areas along the southern coast of Sri Lanka. **W** = Weligama Kapparatota reef, **B** = Bandaramulla reef, **M** = Madiha reef, **P** = Polhena reef and **H** = Hambantota offshore reef.

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,

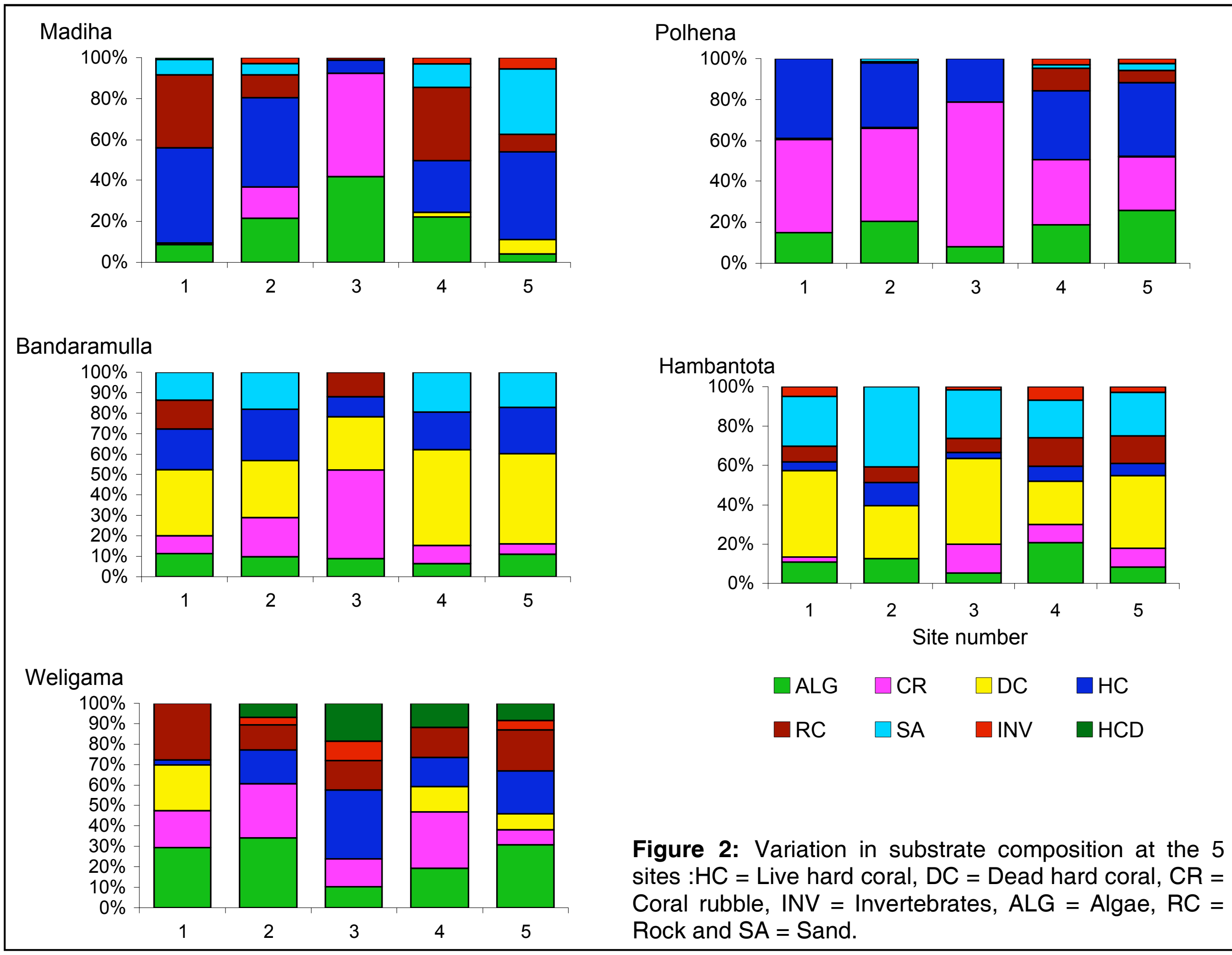

Figure 2: Variation in substrate composition at the 5 sites :HC = Live hard coral, DC = Dead hard coral, CR = Coral rubble, INV = Invertebrates, ALG = Algae, RC = Rock and SA = Sand.

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

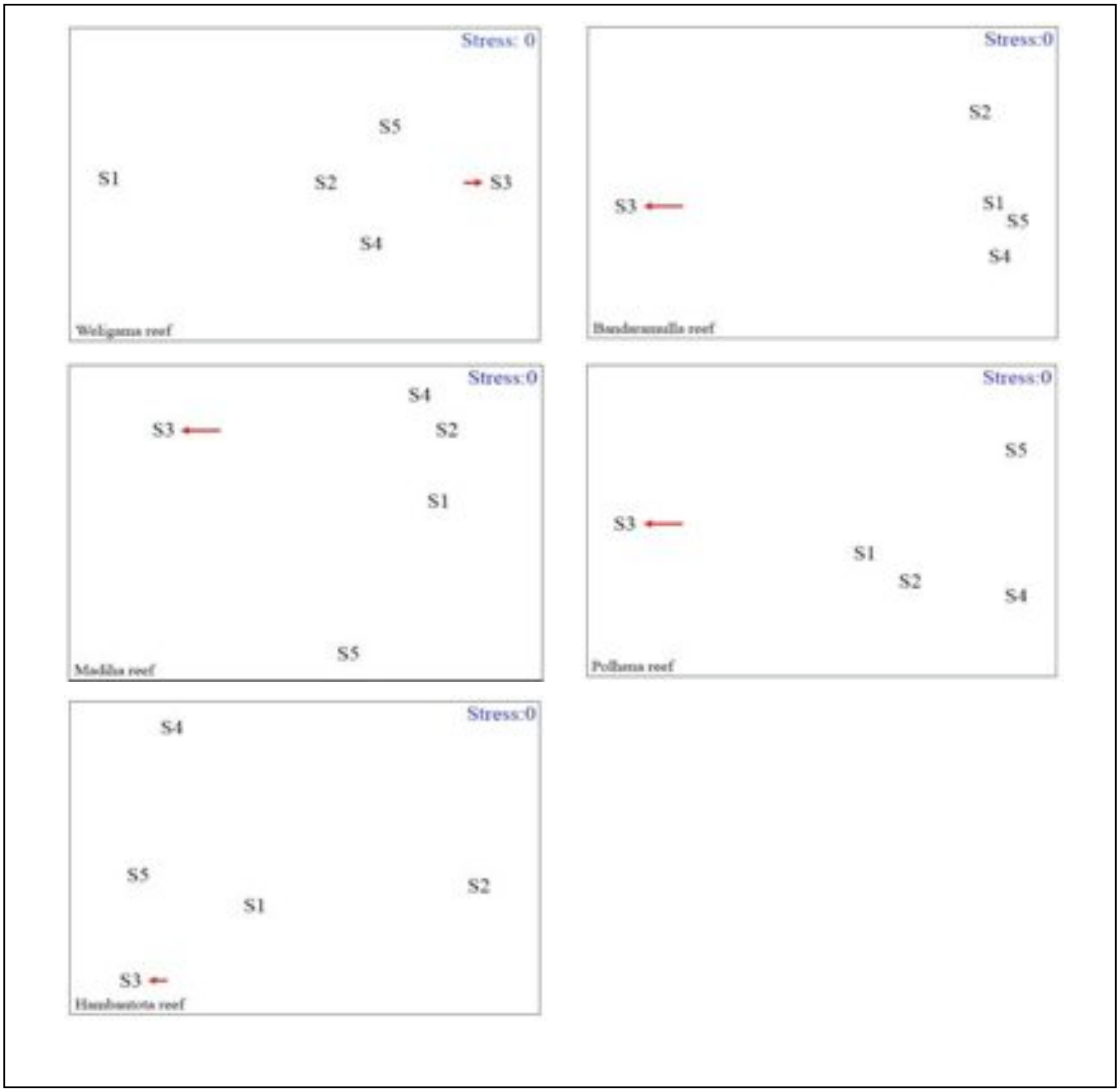

Figure 3: Two dimensional MDS ordinations for five reefs studied. Long arrow indicates a strong deviation and short arrow indicates a weak deviation of the impacted site from the rest.

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,

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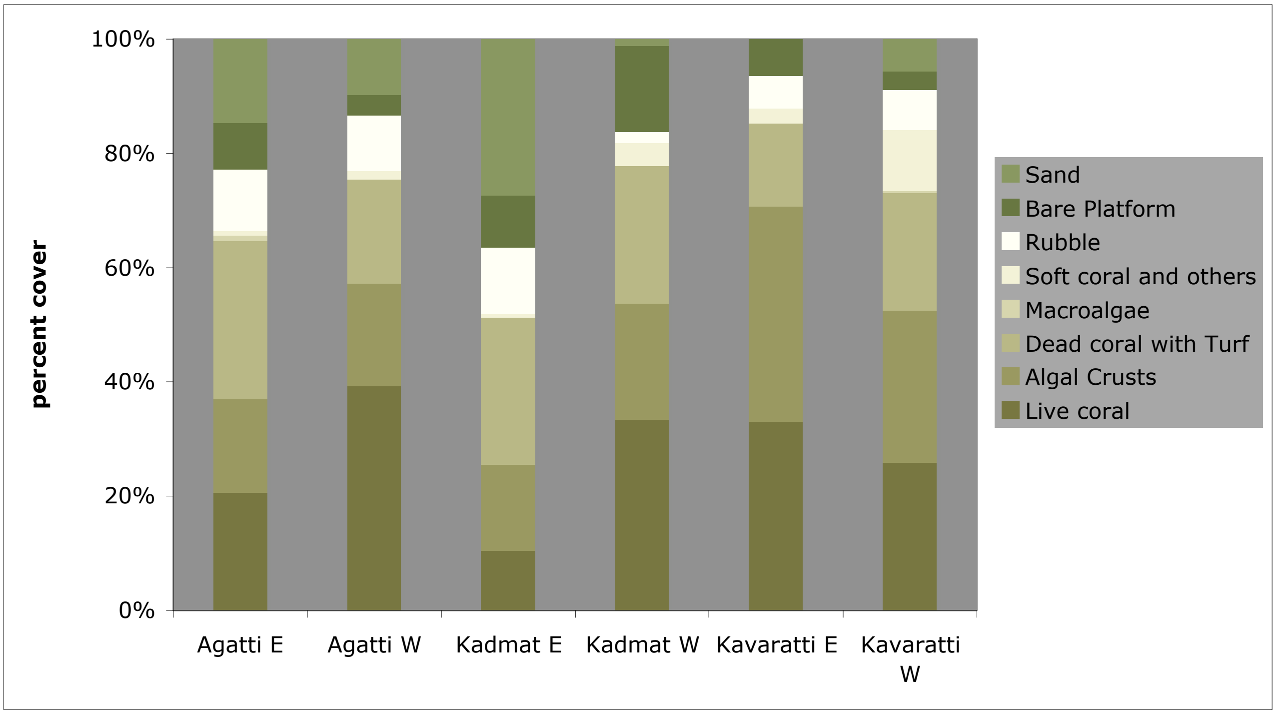

Figure 1. Proportional cover of benthic elements in Lakshadweep reefs, 2007.

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

1m² 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

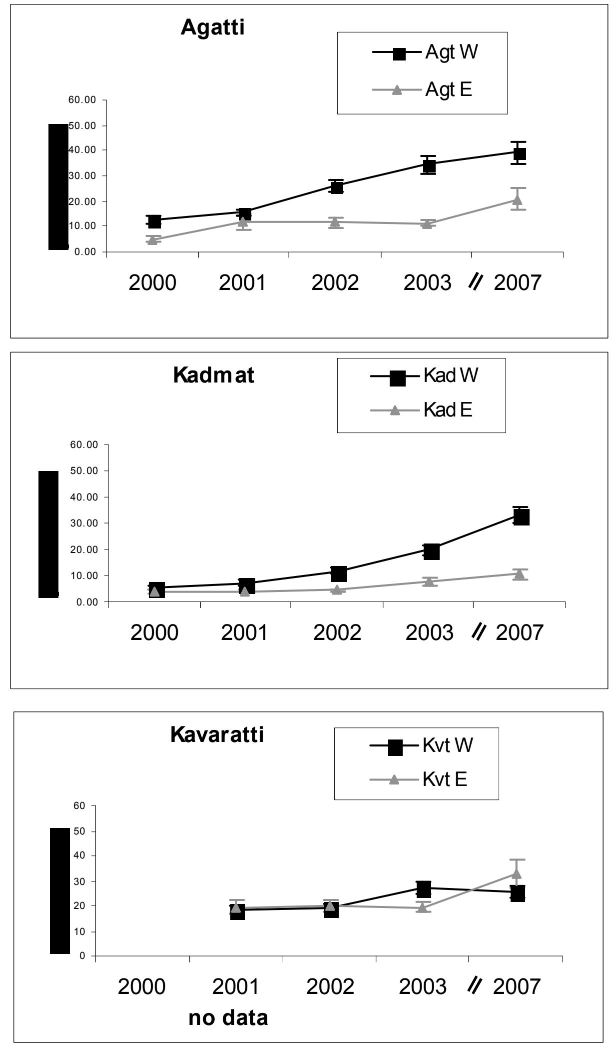

Figure 2. Trends in live coral cover in Lakshadweep islands.

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

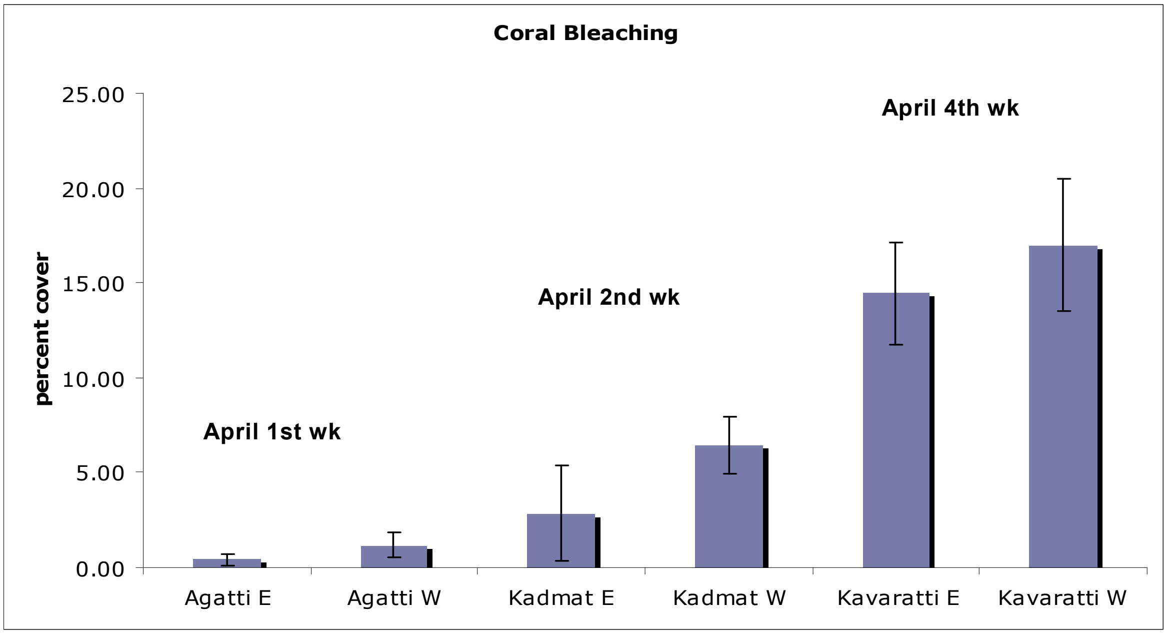

Figure 3. Percentage of bleached coral recorded in the Lakshadweep during the month of April 2007.

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 – 4° 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,

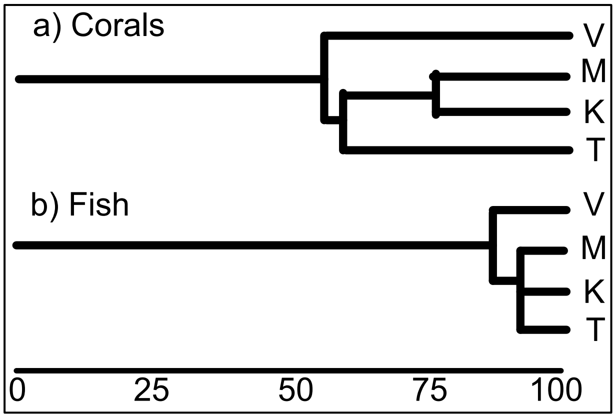

Figure 2. Dendogram of similarity between a) live coral cover and b) fish assemblages between the four island groups: Tuticorin (T), Vembar (V), Keezhakkarai (K) and Mandapam (M).

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 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.

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 *

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 Species	 30 106
Ahermatypic Genera species	 10 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.

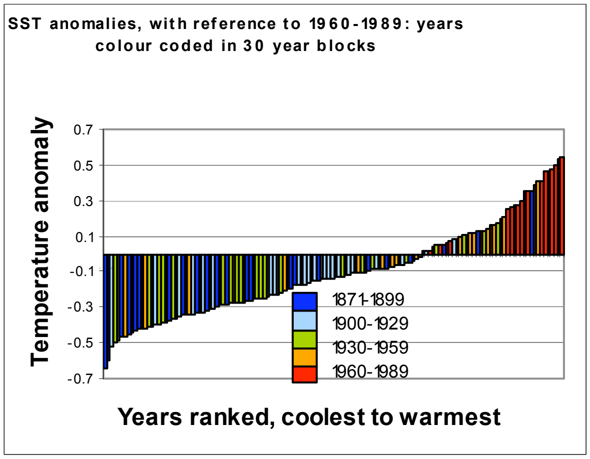

Figure 2. Chagos annual average sea temperature, shown as difference in °C from average 1960-1989 (following Hadley convention). Years are ranked, coolest to warmest. Colours code for 30 year block as shown in the key, except for the most recent block which is 1990 onwards (red bars) which has 17 bars.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

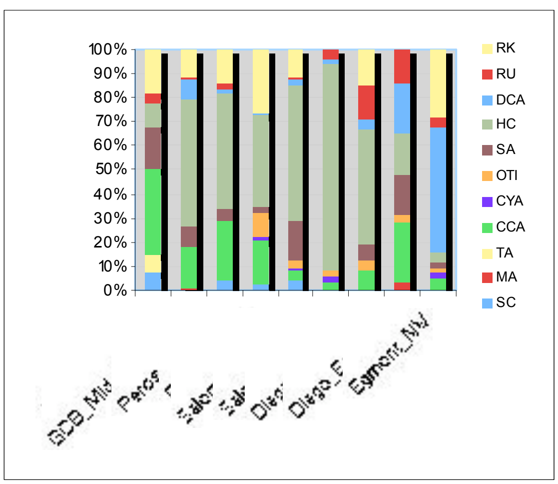

Figure 3. Mean average benthos composition values derived from PIT surveys at 5m depth. Survey codes used in results are as follows: RK (coral rock); RU unconsolidated rubble); DCA (uncolonised dead coral); HC (hard coral); SA (sand); OTI (other acroin-vertebrate); CYA (cyanobacteria); CCA (calcareous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

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

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).

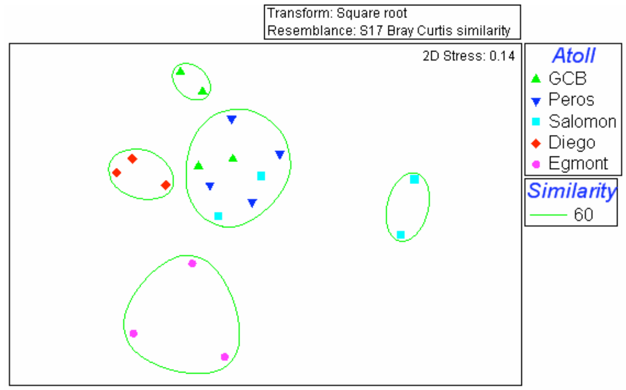

Figure 5. MDS ordination of samples (all atolls) based on benthic community data from 5m survey sites. Index is Bray-Curtis, grouping boundaries are 60% similarity (GCB = Great Chagos Bank).

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

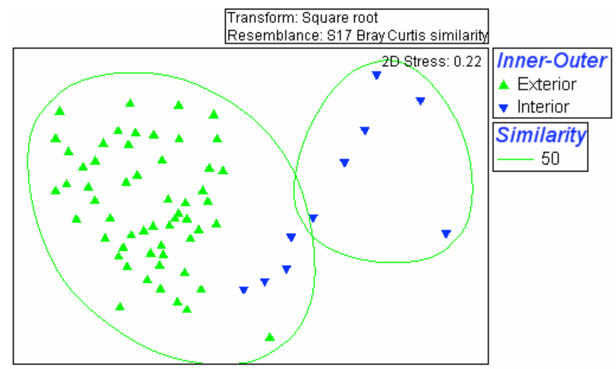

Figure 7. MDS ordination of samples (all atolls) based on coral cover from 15m sites showing dissimilarities of lagoonal patch and outer reefs with Bray-Curtis grouping of samples at 50% resemblance (lagoonal patch = interior; outer reef = exterior).

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

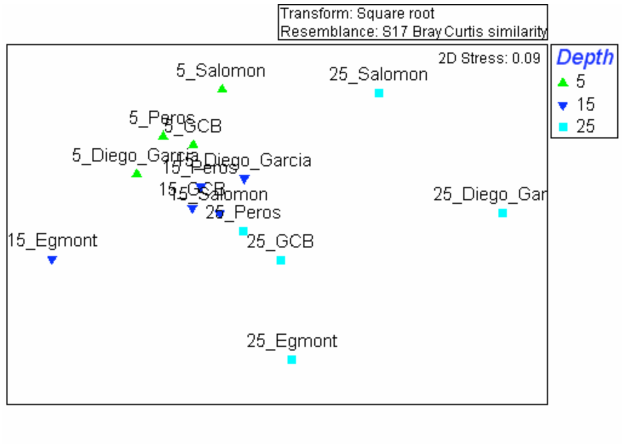

Figure 9. Non-metric MDS ordination of samples (all atolls, all depths) based on hard coral recruit community data (number of recruits per m^2 per genus) (GCB = Great Chagos Bank).

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.

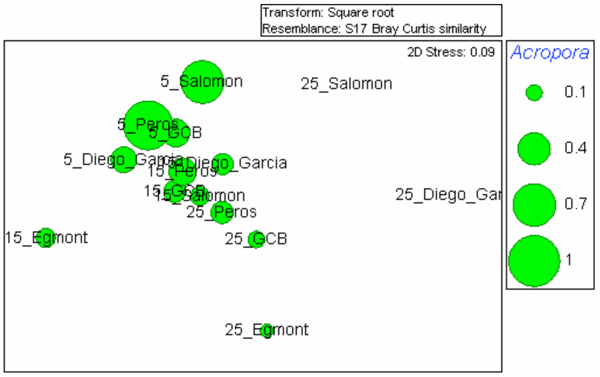

Figure 10. Bubble plot showing variation in relative density (recruits per m^2) of *Acropora* recruits within MDS ordination of Figure 8 (GCB = Great Chagos Bank).

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 (5°-10°S; 45°-56°E) 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 4°53'S (African Banks) to 6°14'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

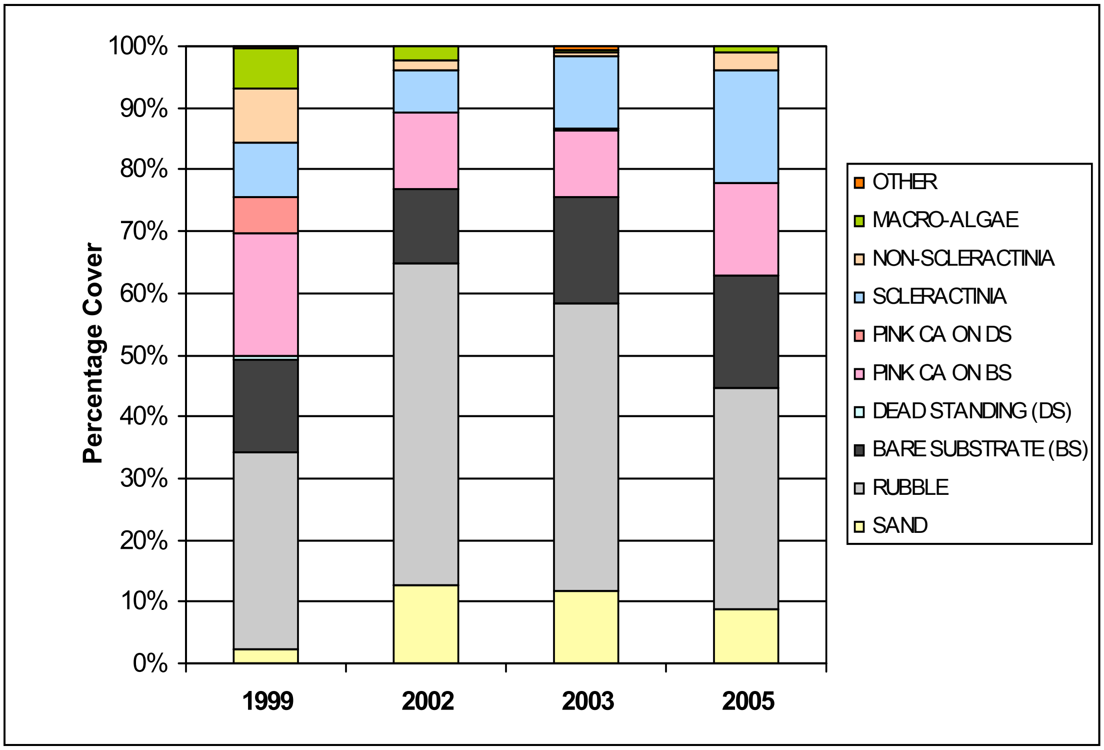

Figure 2. Direct comparison of 1999, 2002, 2003 and 2005 percentage benthic cover at -15 m on the north-east fore-reef slope of Alphonse. Benthic categories data from video surveys. CA = Calcareous Algae, BS = Bare Substrate, DS = Dead Standing.

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

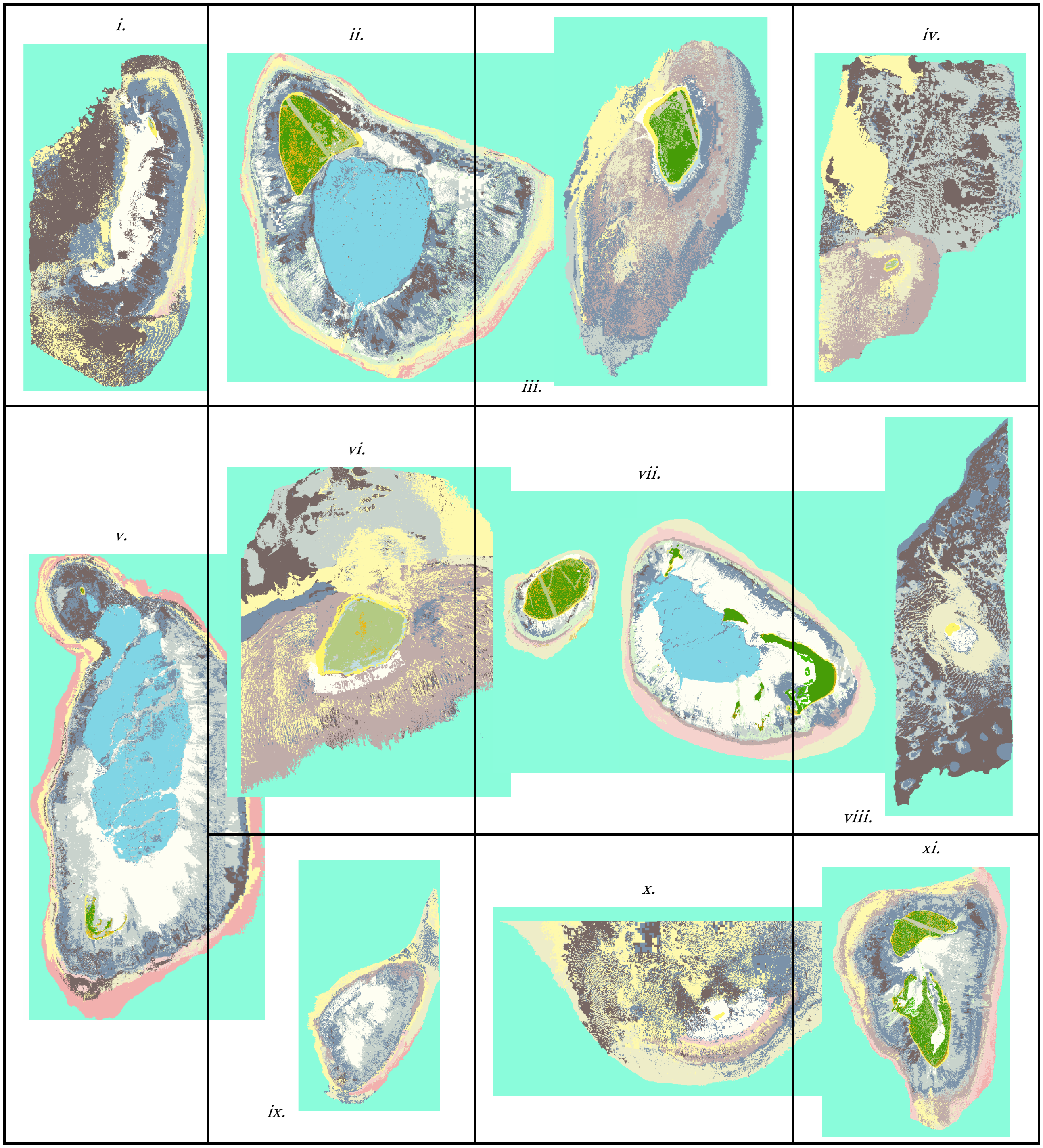

Figure 3. Provisional habitat maps of the Amirante Islands: i. African Banks, ii. Alphonse, iii. Marie-Louise, iv. Boudeuse, v. Bijoutier & St. François, vi. Desnoeufs, vii. D'Arros & St. Joseph, viii. Etoile, ix. Remire, x. Sand Cay, xi. Poivre.

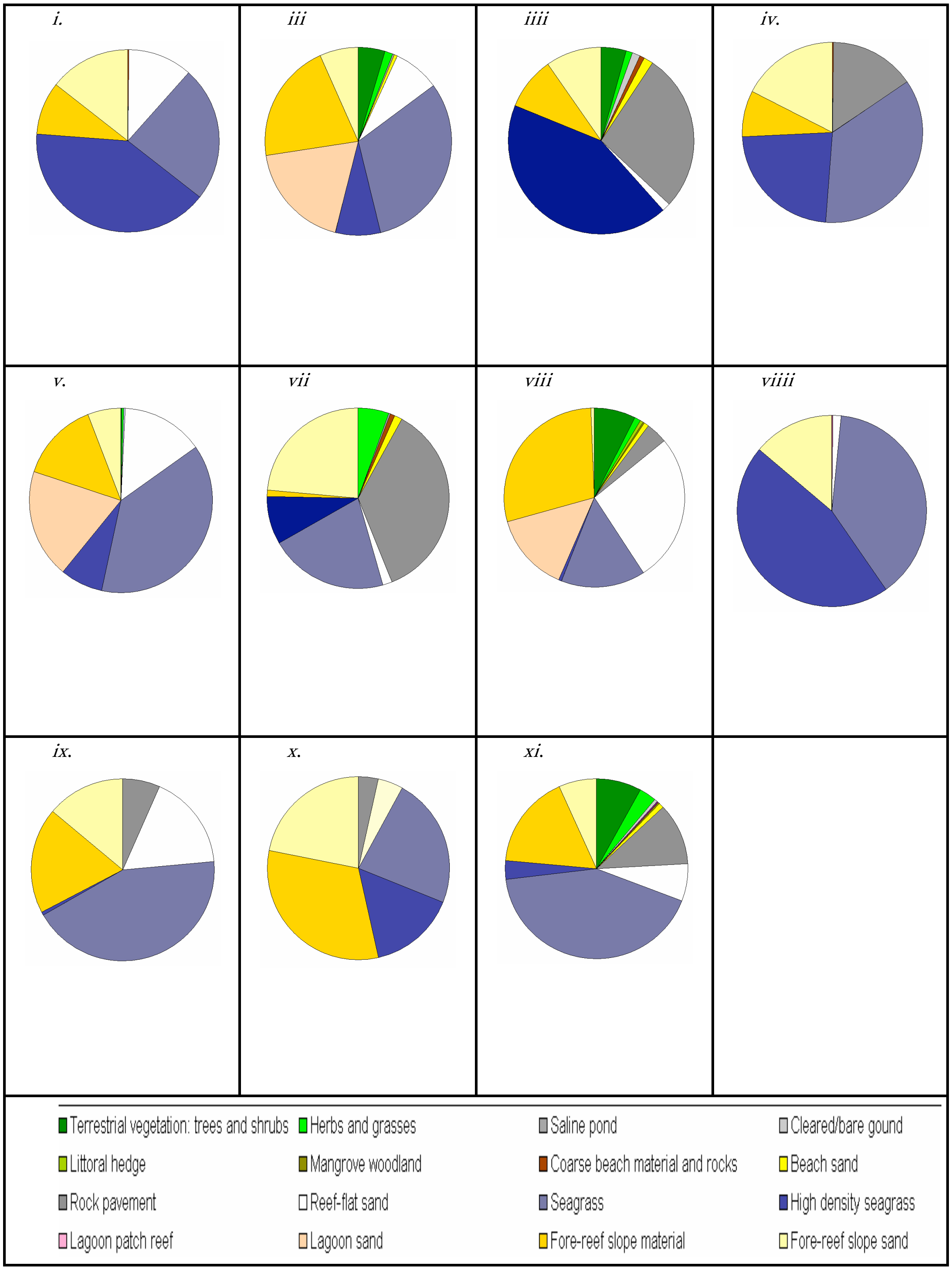

Figure 4. Provisional tier 1 breakdown of habitat coverage in the Amirante Islands: i. African Banks, ii. Alphonse, iii. Marie-Louise, iv. Boudeuse, v. Bijoutier & St. François, vi. Desnoeufs, vii. D'Arros & St. Joseph, viii. Etoile, ix. Remire, x. Sand Cay, xi. Poivre.

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) 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)

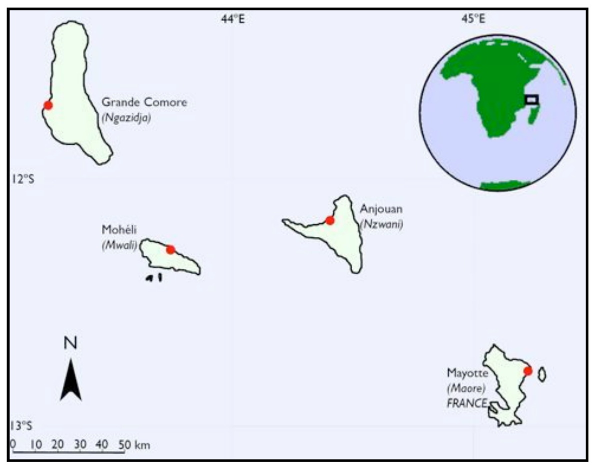

Figure 1. Union of the Comoros and Mayotte.

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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

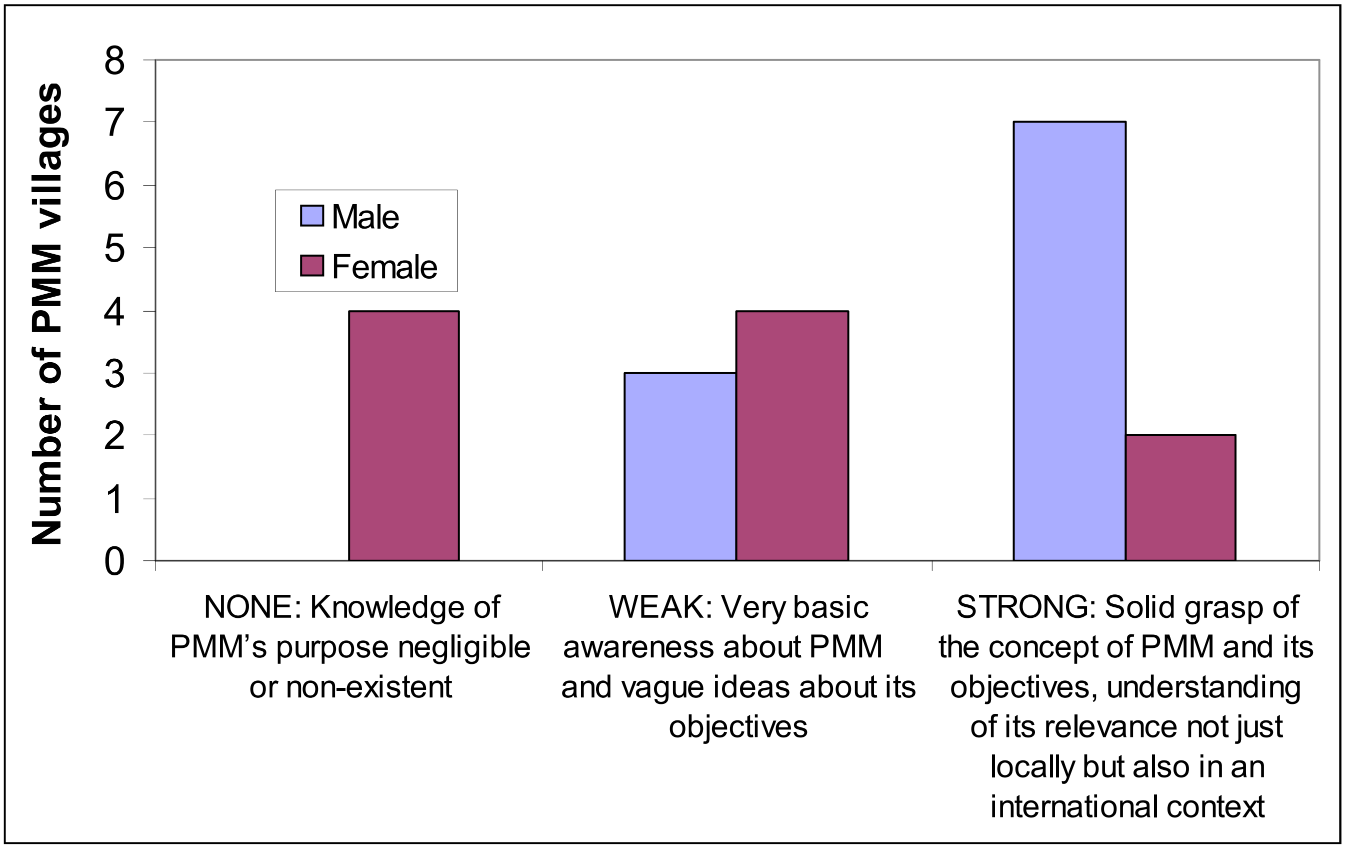

Figure 3. Stakeholder awareness of PMM in male and female focus groups.

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

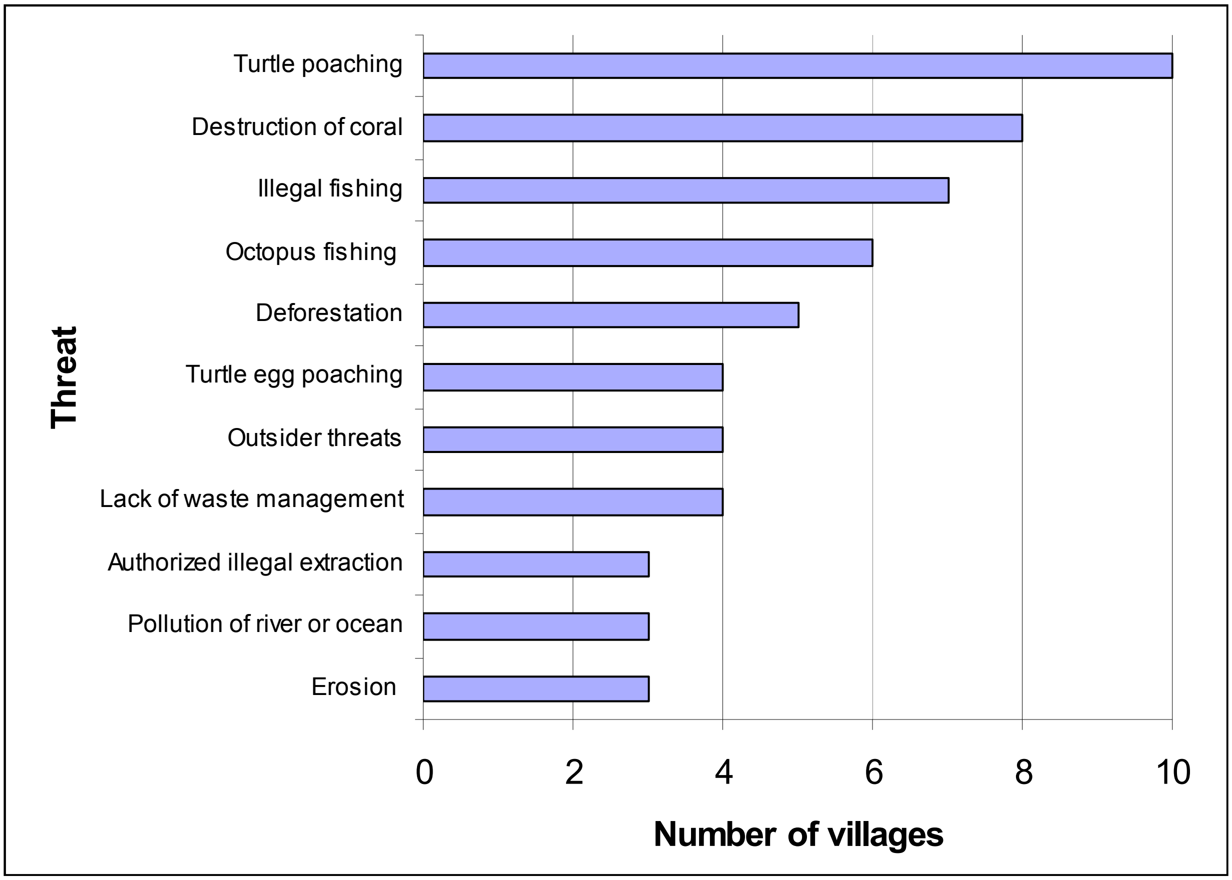

Figure 4. Environmental threats identified during focus group interviews in order of priority.

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

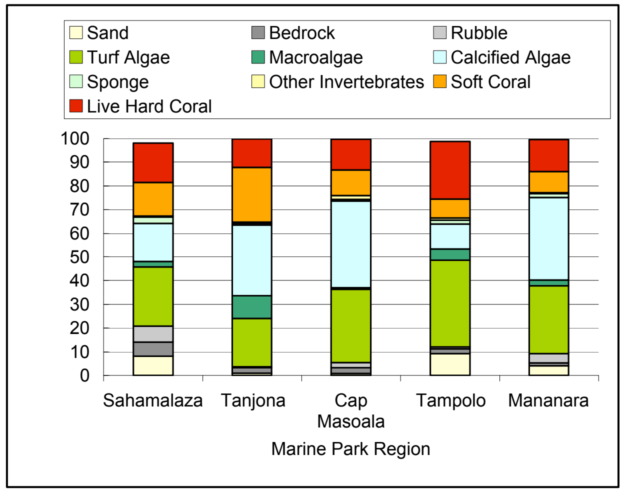

Figure 2. Benthic Composition at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

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.

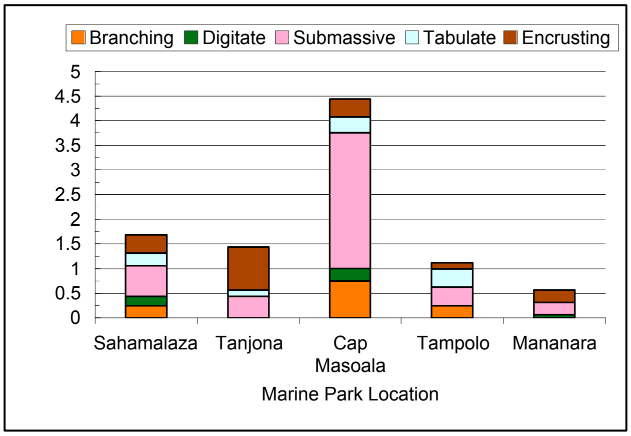

Figure 3. Percentage cover of *Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

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

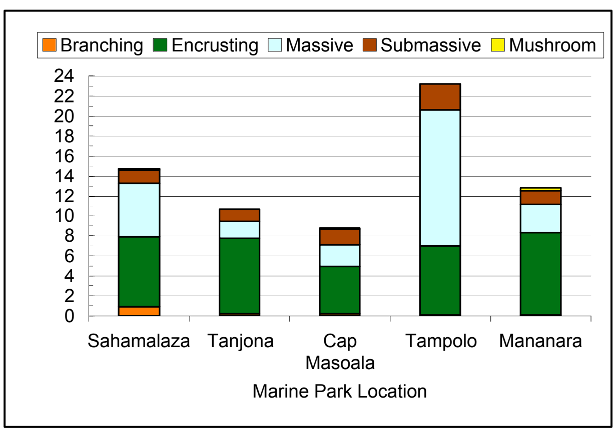

Figure 4. Percentage cover of Non-*Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

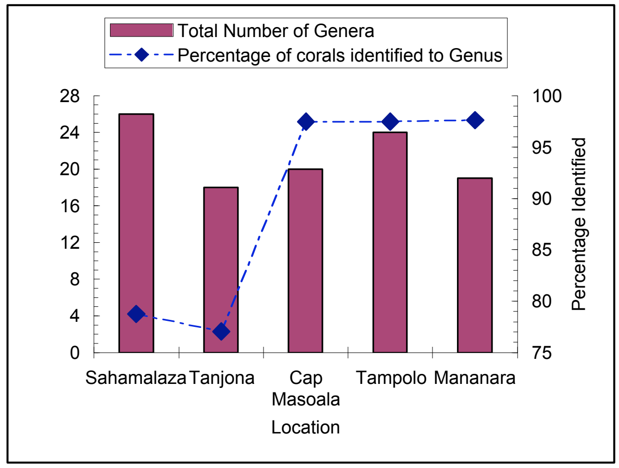

Figure 5. Comparison of hard coral diversity between marine park locations.

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

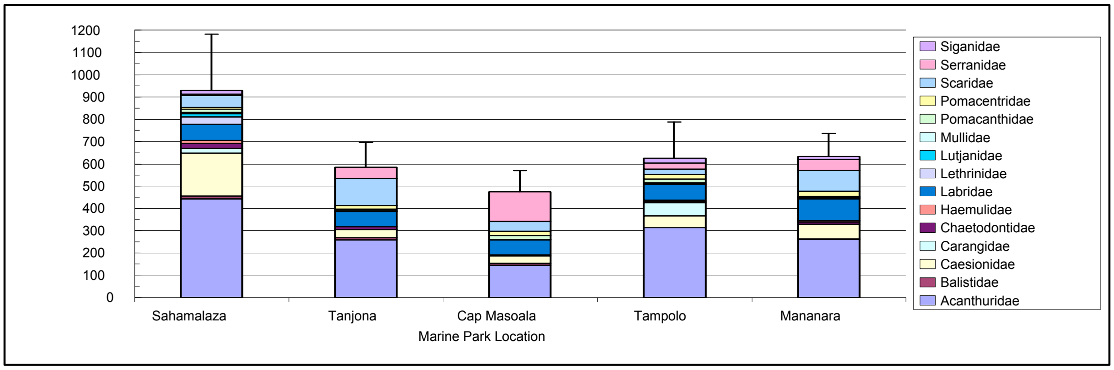

Figure 6. Reef Fish Biomass for Selected Families at Marine Park Locations in Northern Madagascar (Mean values of kg/ha. with standard error shown for total biomass).

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

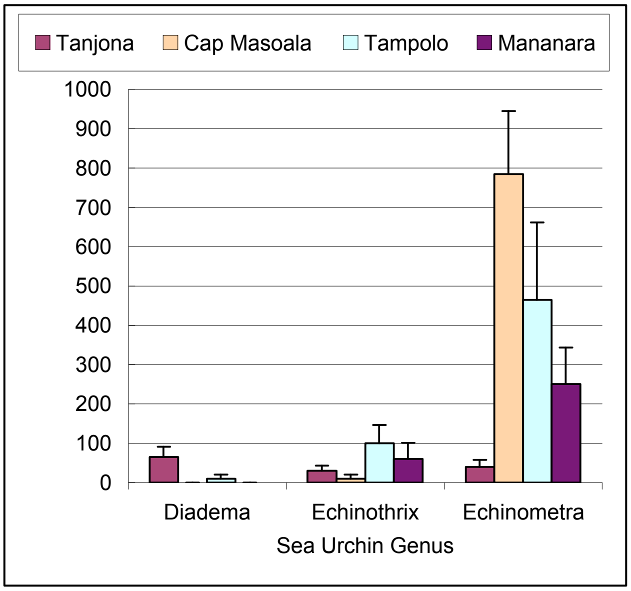

Figure 7. Herbivorous Urchin Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

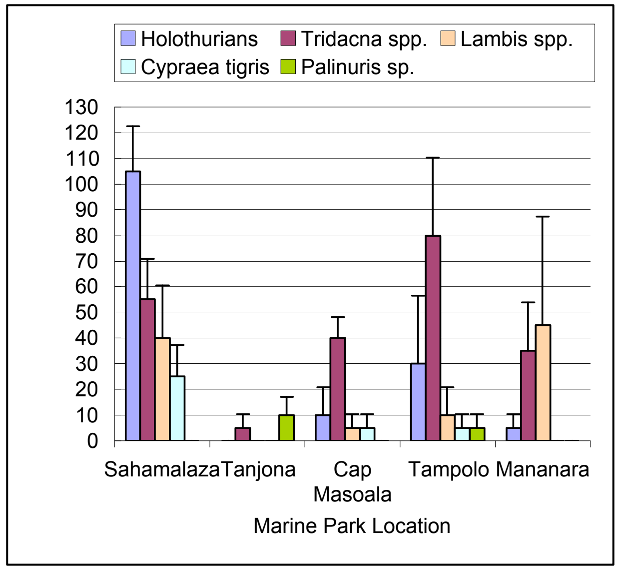

Figure 8. Invertebrate Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

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

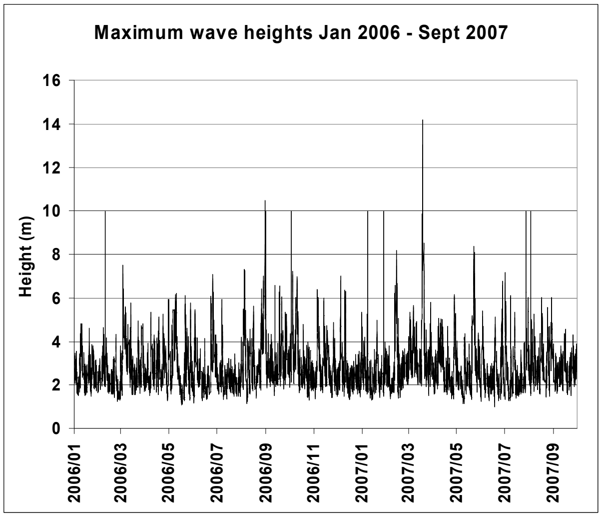

Figure 1. Maximum wave heights recorded between January 2006 and September 2007 at Richards Bay, just over 100 km south of the GSLWP coral reefs. Nine of the ten storms that have generated waves in excess of 8 m occurred in the last twelve months, causing considerable damage to shallow and exposed coral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

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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

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

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

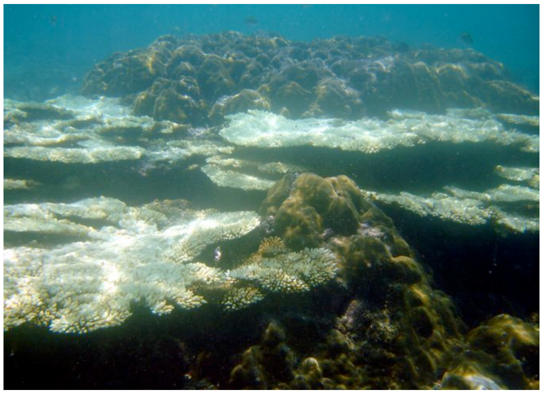

Figure 1. Bleached tabular Acropora colonies at Coral Garden, Bazaruto Archipelago National Park, April 2005. The massive Porites colonies were unaffected (photo: Eduardo Videira).

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

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

(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
Dendrophylliidae	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

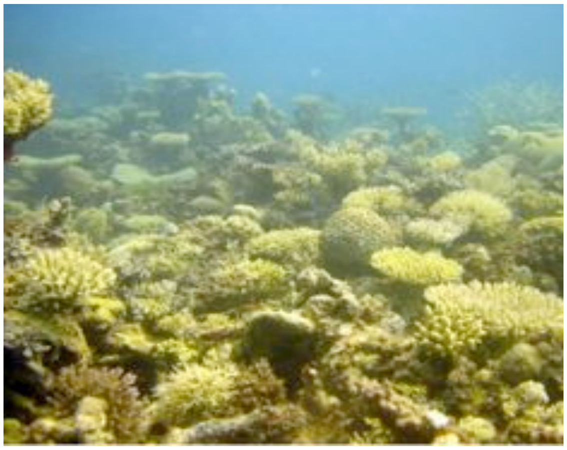

Plate 1. Diversity of coral species at Vamizi reef and extensive habitats.

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

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. 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-

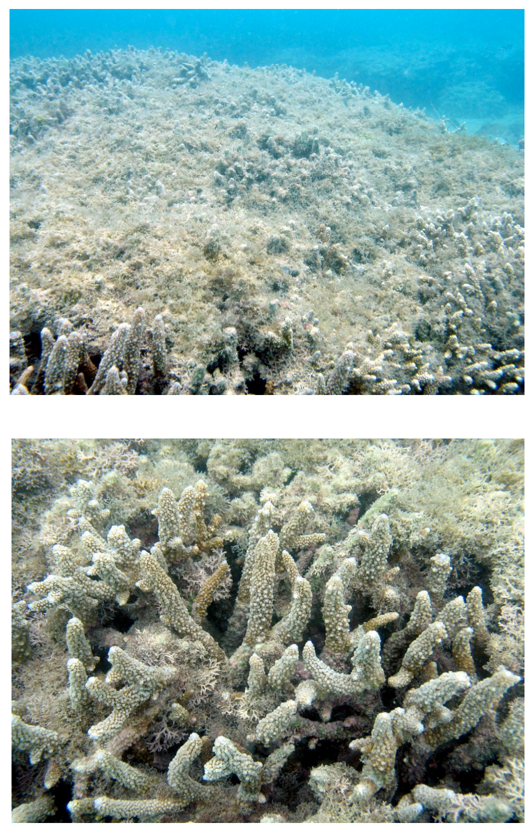

Figure 2a and 2b. Algal proliferation on Bongoyo coral reefs just north of Dar es Salaam. Impacts of eutrophication and sedimentation.

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.

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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

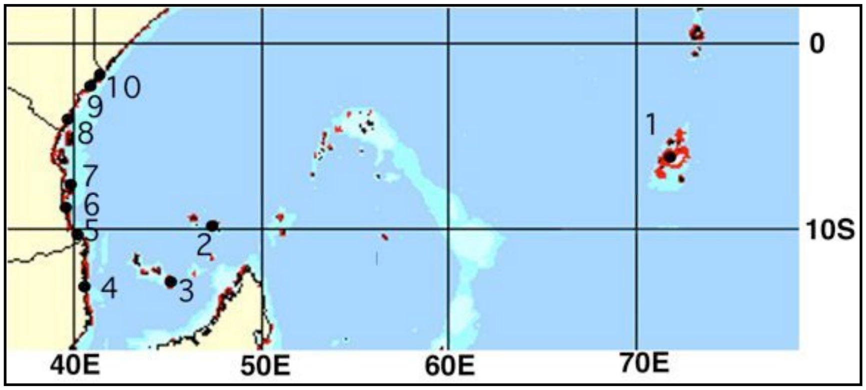

Figure 1. Map of the Western Indian Ocean showing the study sites numbered from 1 to 10 (see Table 1). Map source: Reefbase.

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

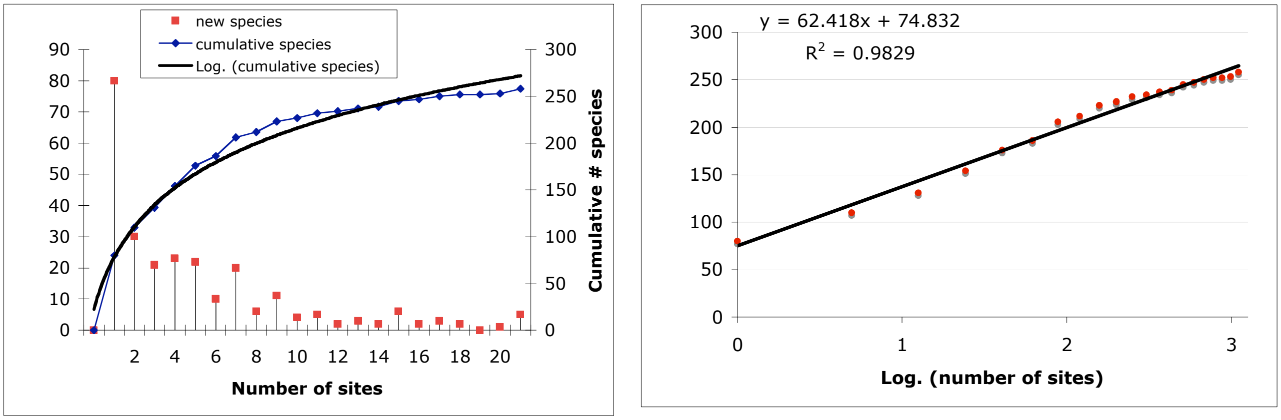

Figure 2. Illustration of number of new species, cumulative curve and logarithm regression of the cumulative species data points (left). Transformation of the logarithmic curve to a straight line (right) with the regression equation and r^2 value.

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

Locations			Sampling			Coordinates			
Area (#)	Country	Year	Days	samples	hours	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

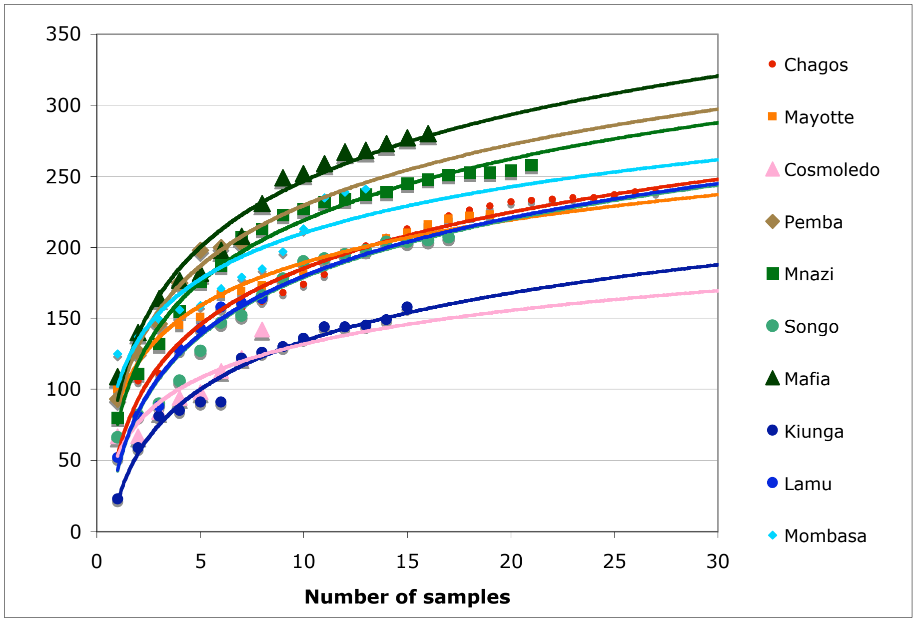

Figure 3. Accumulation curves for all sites coded by colour – red (islands), green (Tanzania-Mozambique), blue (Kenya).

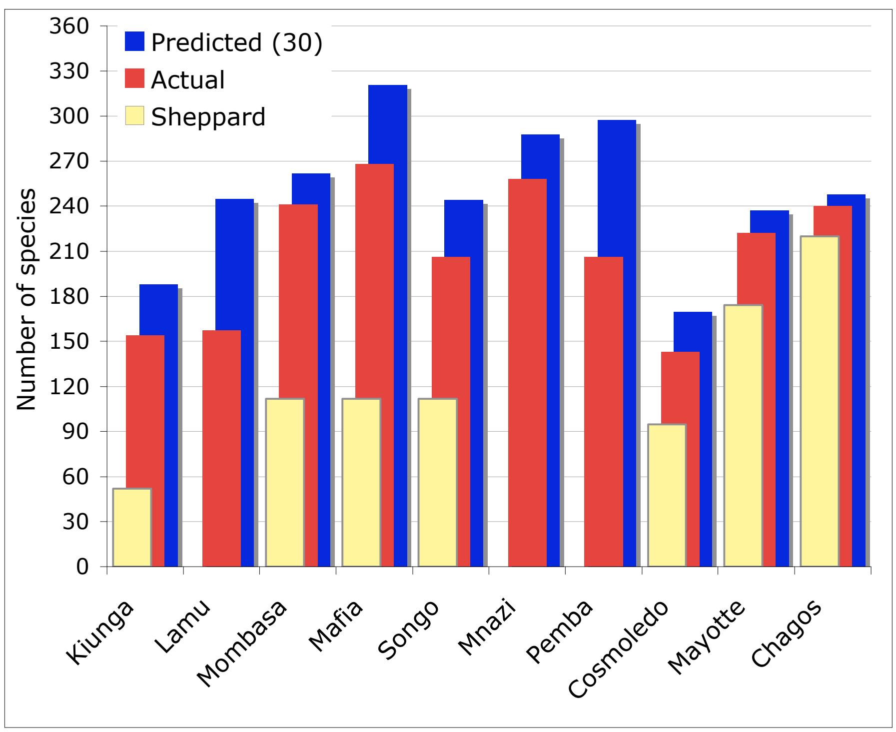

Figure 4. Number of species for each of the sample locations. The predicted and actual numbers are shown, along with values from the literature reported in Sheppard (2002).

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.

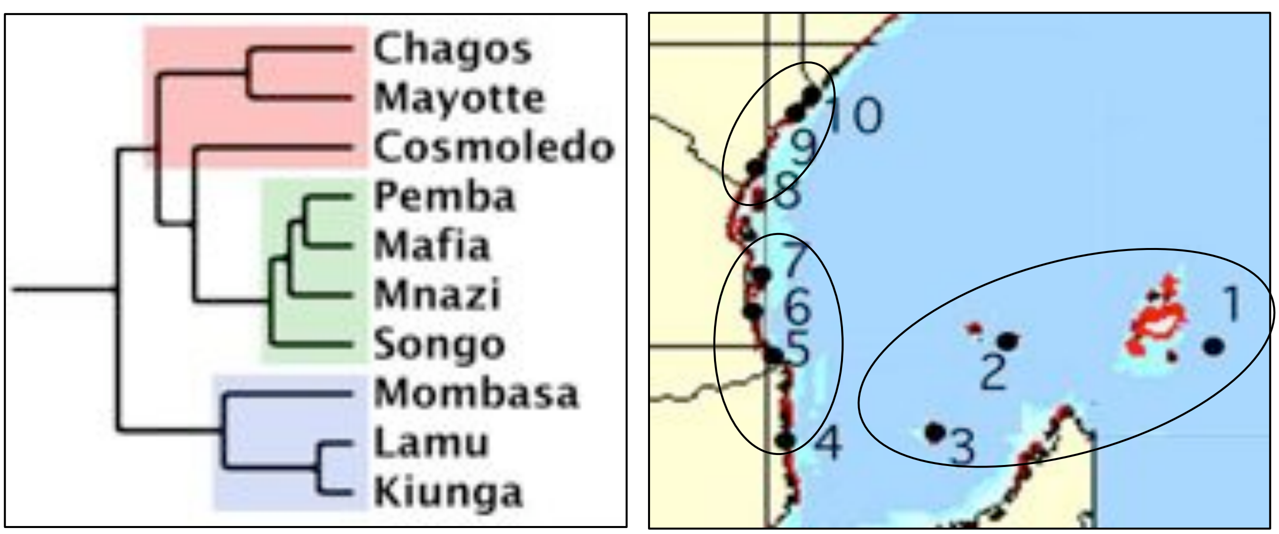

Figure 5. Cluster analysis and regionalization of study sites according by presence/absence of species.

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

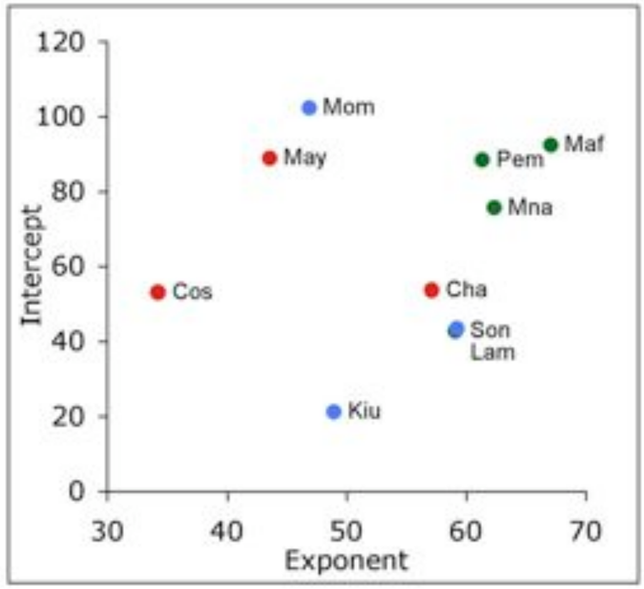

Figure 6. Scatterplot of regression coefficients (exponent vs. intercept).

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.

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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Part 3 – Tsunami Impacts

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Post Tsunami Status of Coral Reef and Fish in Northern Aceh

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keywords: Coral reef, reef fish, tsunami, Acehnese reef, marine protected area

ABSTRACT

The coral reefs of northern Aceh, located in western Indonesia, are productive marine ecosystems that are important for the economies of local communities. The catastrophic tsunami in December 2004 affected local communities, and ways in which they utilized marine resources, while impacts on reef resources were patchy. Limited data and information on coral reef condition prior to the tsunami has highlighted the need for regular long-term coral reef monitoring to assess reef recovery from the tsunami and from previous damage caused by destructive fishing and overfishing. The objectives of this study were to provide reliable data and information on scleractinian corals and reef fish in the northern Aceh region of Weh and Aceh Islands. Using line intercept transects (LIT) and underwater visual census techniques at 21 sites, we found that the mean coral cover in Weh Island was significantly higher (30.0%-fair condition) compared to Aceh Island (10.8%-poor condition). Coral reefs at Rubiah Island, Sumur Tiga and Benteng that were protected under the management of Panglima Laot of Sabang were in the best condition. On Weh Island reef fish abundance (32,505 ha^{-1}) and biomass (748 $kg.ha^{-1}$) were also significantly higher than on Aceh Island (9539 ha^{-1} and 396 $kg.ha^{-1}$, respectively). Pomacentridae (damsel fish) had the highest abundance and biomass among fish families. Macro-invertebrates numbers, in particular sea urchins, were highest on Aceh compared to Weh Island, and in open access areas compared to marine managed areas. The potential for sea urchins to influence coral recruitment and coral reef recovery of Aceh Islands requires further investigation.

INTRODUCTION

Northern Aceh on the Indonesian Island of Sumatra and the surrounding reefs in the Andaman Sea are well known for their extensive shallow reef flats that extend 200–500 m from the shore. The reefs are dominated by massive species (mainly Poritidae and Faviidae) intermingled by patches of branching *Acropora* and *Montipora* in sheltered areas, and mostly branching species at high-energy reefs (Brown 2005). Weh and Aceh Islands are the two main islands in northern Aceh, and also the westernmost reef areas in the Indonesian archipelago. The marine fauna and flora of north-west Sumatra, including the northern Acehnese reefs, are comprised of species from the Indian Ocean and the Pacific Ocean and make the region

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

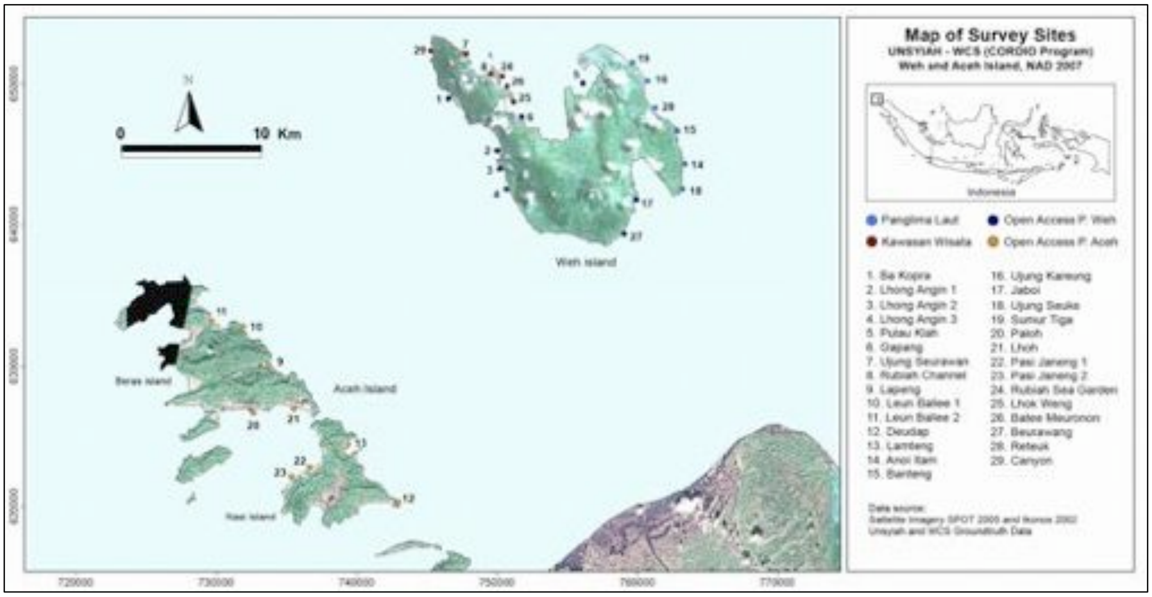


Figure 1. Map showing survey sites at Aceh and Weh Islands, Northern Sumatra, Indonesia.

biogeographically distinct from the eastern Indonesian coral reef fauna and flora.

The reefs ecosystems support a local artisanal fishery as well as a primarily pelagic commercial fishery. The area also has a tourism industry with snorkeling and SCUBA diving and other recreational activities as the main attractions. These activities contribute income to coastal communities, in addition to farming, business, and government sectors (Baird *et al.* 2005b). Although these reefs were subject to substantial disturbance from the tsunami, initial claims that northern Aceh reefs were destroyed or greatly impacted by the tsunami in 2004 (Brown 2005, UNEP 2005) were unfounded (Baird *et al.* 2005a and b). Nevertheless damage to coastal communities was severe with five of thirteen villages in Weh Islands heavily affected by the earthquake and tsunami; mostly on the northern and southern coasts (Baird *et al.* 2005b). Damaged houses, boats, fishing gears, and loss of life paralyzed the northern Aceh fisheries, including destructive fishing activities. However, overfishing and destructive fishing practices had caused serious damage and significantly degraded coral reef ecosystems in Aceh Islands prior to the tsunami (Baird et al. 2005a and b).

The status of reefs of Northern Aceh range from very poor to good condition, but have overall been well documented only recently (Baird *et al.* 2005a and b, Campbell *et al.* 2005, Ardiwijaya *et al.* 2006). Coral reefs of Weh Island are known to be generally in better condition than those on Aceh Island because of past differences in management between these two. To improve the management of these reefs and prevent damaging, unsustainable, and illegal fishing practices from returning, investment is required to implement management practices and strategies that help rehabilitate, restore and protect marine resources through programs of regular monitoring, education, coastal management and establishment and maintenance of marine protected areas. The aim of this research project was to provide reliable data and information on coral reef resources of northern Aceh that will be useful for local people, scientists, tourists, and other stakeholders to evaluate the condition of the reefs, make recommendations for management and be used to evaluate the effectiveness of future coastal management. This report focuses on overall reef condition (benthic, invertebrates and fish) while a more detailed analysis of fish biomass and fishery implications is presented in Campbell et al. (2007).

METHODS

Survey Sites

Coral reef and invertebrate surveys were conducted in 2006 and 2007 at 21 sites, 13 on Weh Island and 8 on Aceh Island (comprising Beras and Nasi islands), while coral reef fish surveys were conducted at 29 sites, 19 on Weh and 10 on Aceh Island (Fig. 1). Sites were selected to represent the reefs of the region and the types of site management, including Marine Protected Areas (consisting of Panglima Laot and Tourism Reserve) where fishing restrictions are in place, as well as areas with unrestricted fishing or open access areas, on both islands.

Survey Techniques

Methods used were manta tow and Line Intercept Transect (LIT) for benthic cover, under water visual census technique (UVC) for reef fishes, and belt transect for invertebrates (English *et al.* 1997, Hill and Wilkinson 2004). In order to obtain representative data of the reef, transects were laid at two depths at 2-3 m (shallow) and 6-8 m (deep).

Coral reefs

Manta tows were used to obtain general descriptions of reef areas, estimating percent cover of hard coral, soft coral, dead coral and sand. Two divers were towed along the reef edge using a boat at a constant speed of 2 knots, with regular stops every 2 minutes to record data on substrate cover. The number of tows varied between locations depending on reef and environmental conditions. Two replicate 30 meter LIT transects were recorded at each site and depth. Reef condition was assessed using percent cover of live hard coral was based on Gomez and Yap (1998): excellent, 75-100%; good, 50-74%; fair, 25-49%; and poor, 0-24%.

Reef fish

Abundance and biomass of reef fishes were recorded using Underwater Visual Census, recorded along the lines used for LIT, plus one additional transect. Data were collected at the species level and 9 size classes visually estimated (0 cm, 5-10cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm and >40 cm). Transect size was 5x50 m for fish >10cm and 2x50 m for fish <10cm. Data is presented as abundance, in number of individuals per hectare (ha^{-1}), as well as biomass, in kilograms per hectare ($kg.ha^{-1}$), estimated using standard length-weight relationships for fish species (FishBase 2000).

Macro-invertebrates

Macro-invertebrates were counted using 2 replicate 5x50 m^2 belt transects at the two depths. Invertebrates were identified to species level and data converted to numbers per unit area (ha^{-1}). Species diversity was analyzed using the Shannon-Wiener index (H') (Krebs 1989), with the following ranges used in this study: H'<1 : low diversity; 1<H'<3 : medium diversity; H'<3 : high diversity

Statistical Analyses

Using two-way nested analysis of variance (ANOVA) we examined the effect of time (fixed; 2 levels, 2006 and 2007) and management areas (fixed; 4 levels, Panglima Laot, Kawasan Wisata, open access Aceh Islands, open access Weh Islands) on mean fish biomass and mean fish abundance. In order to understand the variation in reef fish biomass and abundance between sites within management areas (among sites) and among management areas data from each transect (n = 6) at each site (random; 6 - 9 levels) were nested within each management area. Significance among factors was tested at the P<0.05 levels. Biomass and abundance of reef fish were log transformed prior to ANOVA analyses to improve homogeneity and normality. All analyses were completed using SPSS v11.5.

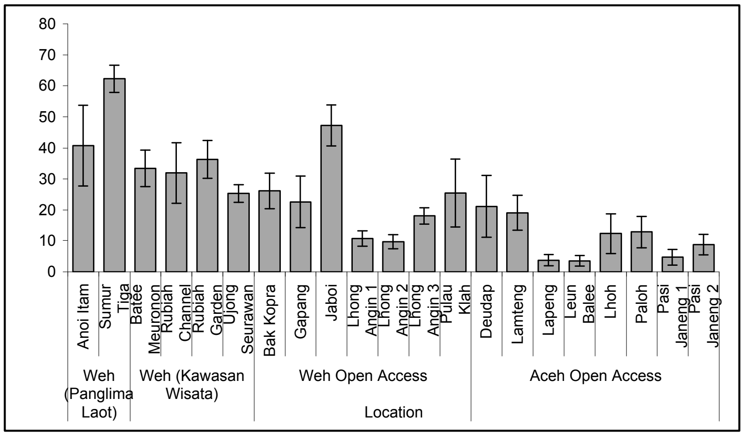


Figure 2. Mean percent cover of hard coral (± SE) at study sites at Weh and Aceh Islands, based on LIT surveys.

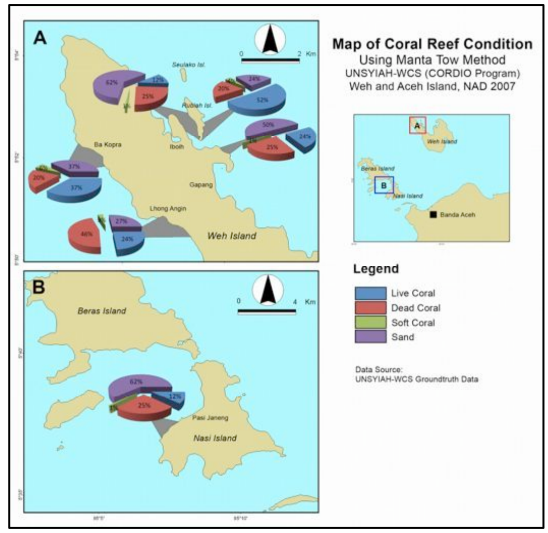


Figure 3. Percent cover of major benthic cover categories at study sites at Weh Islands (A) and Aceh Islands (B), based on Manta Tow surveys.

RESULTS AND DISCUSSION

Coral Reefs

The health of coral reefs varied considerably within the region, with the hard coral cover (pooled for both depths) being higher on Weh Island (30.0% ± 2.4 (standard error of the mean)) than Aceh Island, (10.8% ± 4.0). Hard coral cover on Weh Island was higher on reefs with fishing restrictions, i.e. Panglima Laot (51.5% ± 10.8), and inside the Tourism Reserve (31.7% ± 2.3) compared with open access areas on Weh Islands (22.8% ± 4.8). Using Gomes and Yap (1998) categories to estimate reef condition one site managed by the Panglima Laot authority, Sumur Tiga (site no 19) was categorized as in "good condition" with a coral cover of 62.3% ± 4.4, while 8 sites were in "fair condition" (25.3-47.2%) and 12 sites in "poor condition" (3.6-22.5%, Fig. 2). Results from manta tow surveys indicate that the benthic habitats are dominated by sand and that mean live coral on Weh Islands, ranging between 12 and 52%, was higher than in Aceh Islands (12%) (Fig. 3). These results support findings from the LIT surveys that reefs inside managed areas were in better condition than those in open access areas.

The Aceh Islands suffered severe catastrophic damage from the tsunami in 2004, but many reefs were already dead or in poor condition prior to the tsunami because of a history of destructive fishing including dynamite and cyanide use (Baird *et al.* 2005, Campbell *et al.* 2005). Enormous dead colonies of coral and rubble beds covered with a thick growth of filamentous algae remain common on Aceh Island reefs. However, there was also little evidence of recent coral mortality. To the contrary, an increase in the mean coral cover in Aceh Island from 2006 (8.2% ± 1.8: Ardiwijaya et al. 2006) to 2007 (10.8% ± 2.4: this study), suggests that recruitment of corals is occurring, as has been previously suggested (Ardiwijaya *et al.* 2006, Fig. 4). It is possible that the reduction in fishing effort, and particularly destructive fishing, following the tsunami have allowed reefs on Aceh Island to start to recover from the misuse of the past. Nevertheless, recent reports in 2007 of the use of cyanide fishing show it is starting up again. Sediment run-off from inappropriate and poor agricultural practices also highlights the need for an ecosystem-based approach to these problems, where land use and

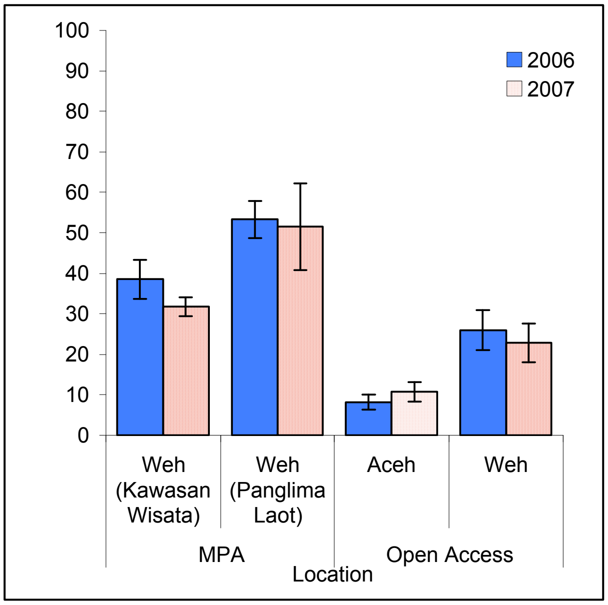


Figure 4. Mean coral cover (± SE) (%) on coral reefs in 4 management areas, in 2006 and 2007.

marine resource use practices are considered in the design and implementation of regulatory controls.

Reef Fishes

In 2006, reef fish abundance was highest in Sumur Tiga (133,050 ha^{-1}), while in 2007 it was highest at Benteng (83,770 ha^{-1}) (Fig. 5). Both sites are located within Panglima Laot management areas, and in an ANOVA (Table 1) both abundance and biomass of fish were significantly highest in management areas in both 2006 and 2007 (Fig. 6). After management type, the abundance and biomass of reef fishes was significantly affected by site characteristics (nested within management) shown by the lower F ratio for site as a factor (Table 1). There was a considerable decrease in fish biomass and abundance in protected areas from 2006 to 2007, while both were stable in fished areas (Fig. 6). However this did not result in a statistically significant difference in the ANOVA of management type by site interaction. There was no significant difference in reef fish biomass between 2006 and 2007 (F= 0.160 p=0.716).

Biomass of reef fishes in 2006 ranged from 118 to 2399 kg.ha^{-1}, with the highest biomass recorded at Sumur Tiga and the lowest at Pasi Janeng 2. In 2007, biomass of reef fishes ranged from 149 to 1562 kg.ha^{-1}, the highest recorded in Canyon and the lowest in

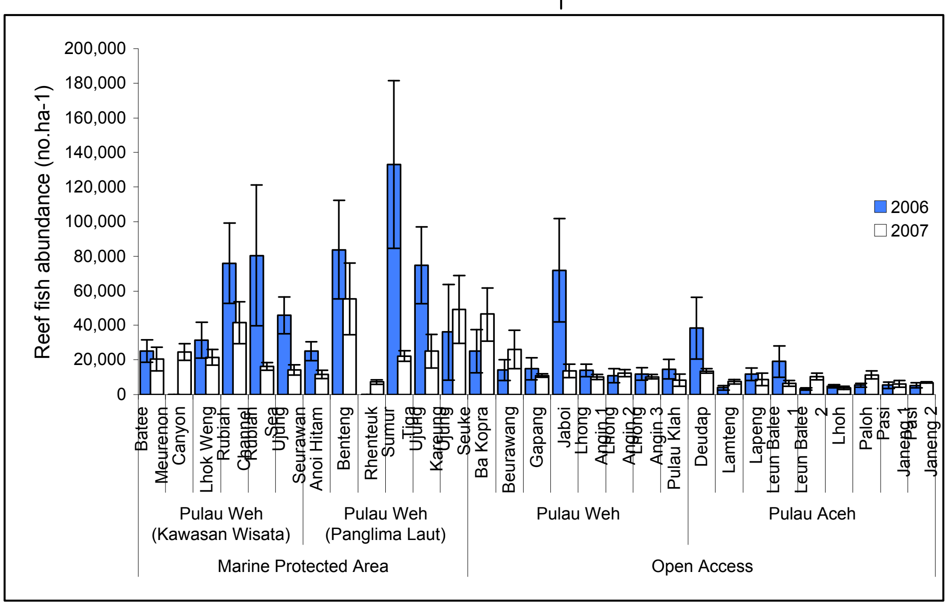
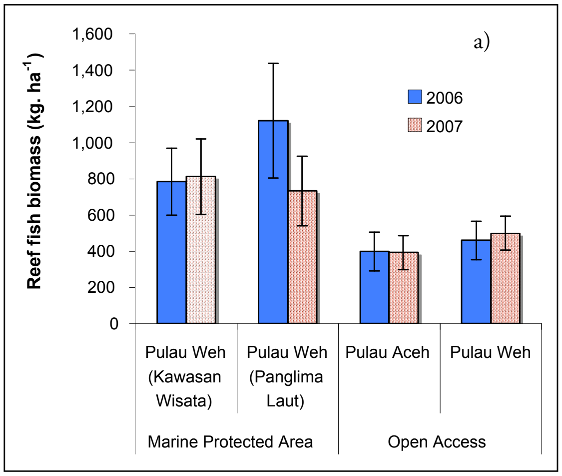


Figure 5. Mean abundance (± SE) (no.ha^{-1}) of reef fishes at study site in 4 management areas, in 2006 and 2007.



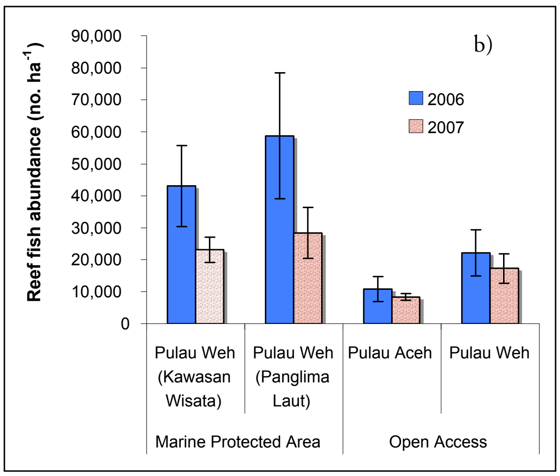


Figure 6. Mean biomass (a)(± SE) (kg.ha^{-1}) and abundance (b) of reef fishes in each management area, in 2006 and 2007.

Lapeng (Fig. 7). Sumur Tiga and Canyon are protected under the authority of Panglima Laot while Pasi Janeng 2 and Lapeng are open access areas on Aceh Islands.

However there were changes in the size class structure of fish from 2006 to 2007 (Table 2) and in the family composition. The number of small size fishes (5-10 cm) decreased, mainly due to a decrease in the number of Pomacentrids, in parallel with an increase in mid-sized fish (15-25 cm), mostly of groupers, snappers, and jacks. Pomacentrids are the most abundant reef fish present on these reefs and a major prey item for large carnivorous fishes, such as groupers, snappers, and jacks. This suggests that predation may be responsible for the overall decrease in fish abundance. Reduced fishing pressure following the tsunami in 2005 may have contributed to the increased numbers of large carnivorous fish. Excluding Pomacentrids, Acanthuridae comprised the largest portion of the biomass (Fig. 7), at all sites.

The cause of the decline in fish in management areas is unknown. As it was found at many sites it is possible that non-anthropogenic factors such as migration, seasonal variation or predation may be responsible to any apparent decline in fish numbers. The decrease in Pomacentrid abundance and increase in the numbers of large fishes requires further investigation.

Macro-Invertebrates

A high density of macro-invertebrates was found at almost all survey sites (Table 3). Sea urchins, worms, and ascidians comprised more than 86% of all invertebrates (Fig. 8). The density of shells, shrimps, cephalopods, and jellyfishes were surprisingly low. The low density of cephalopods and jellyfishes was most likely due to seasonal variation. High economic value species, such as clams, oysters, and sea cucumbers were abundant, which contrasts with the depletion associated with high levels of exploitation of these species in other parts of Indonesia.

The number of species and the abundance of macro-invertebrates were highly variable among sites (Table 3). The highest number of species was found at Lhong Angin 3 and Ba Kopra (25 species), while the highest abundance of invertebrates was found at Paloh (25,600 individuals.ha^{-1}). The diversity index of invertebrates (Krebs 1989) in Rubiah Channel, located within the government tourism reserve, was highest of all sites, (H'=3.89). Most sites within marine managed areas had a medium level of diversity (1<H'<3). In contrast to corals and fish, sites within the open access areas both in Weh Islands and Aceh Islands generally

Table 1. Nested two-way ANOVA of the effects of time, management and site (nested within management) on fish abundance (no.ha^{-1}) and fish biomass (kg ha^{-1}). Data was log transformed prior to analysis.

Source	df	MS	F	P
Abundance				
Time	1	9.730	0.335	0.603
Management	3	29.021	10.630	0.042
Management*Time	3	2.730	1.426	0.261
Site (within Management Type)	23	1.915	2.736	<0.001
Error	251	0.700		
Biomass				
Time	1	2.970	0.160	0.7159
Management	3	18.540	13.572	0.030
Management*Time	3	1.366	0.676	0.576
Site (within Management Type)	23	2.020	2.763	<0.001
Error	251	0.731		

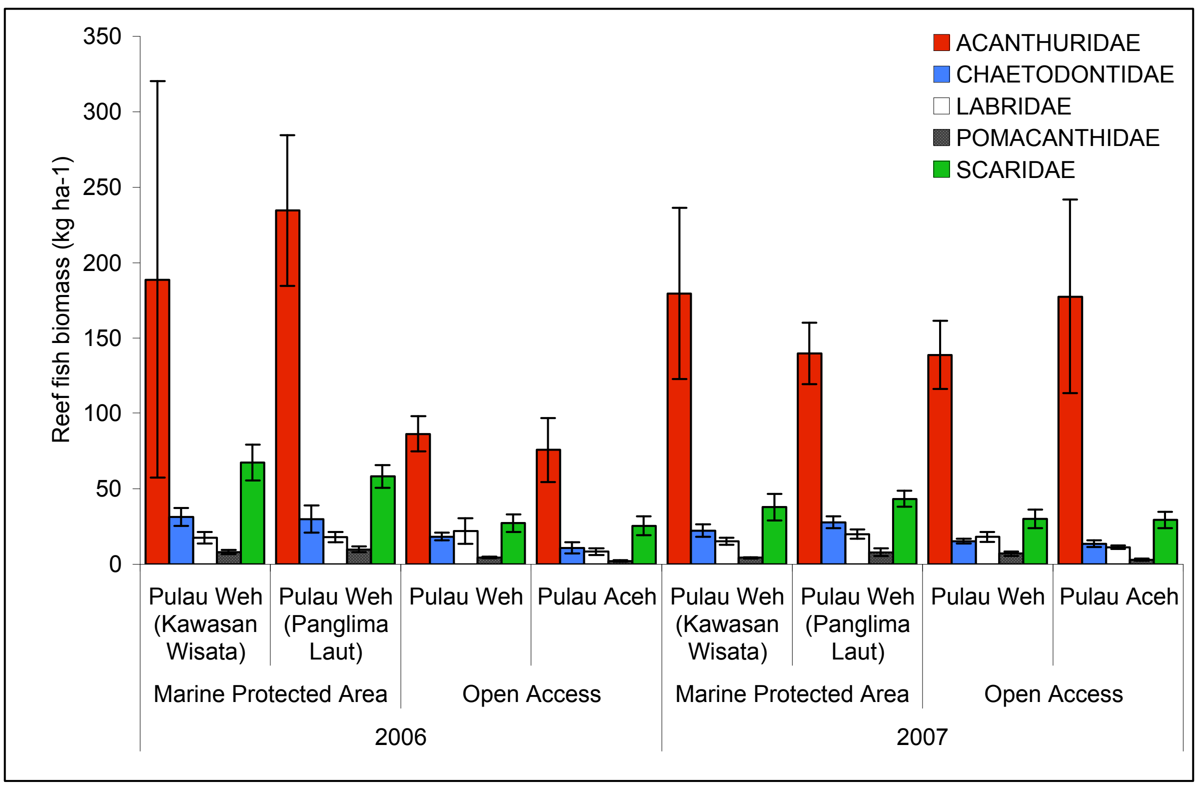


Figure 7. Mean biomass (± se) (kg.ha^{-1}) of the five major reef fish families excluding Pomacentridae, in each of the 4 management areas, in 2006 and 2007.

Table 2. Mean abundance (no.ha^{-1}) of reef fishes in 2006 and 2007.

Parameter	Category	2006	2007
Trophic group	Benthic invert.	1,071	1,534
	Carnivore	1,861	3,653
	Corallivore	712	605
	Detrivore		333
	Herbivore	1,703	1,675
	Omnivore	25,852	9,171
	Planktivore	1,864	1,687
Size	0-5 cm	5,312	2,848
	5-10 cm	23,196	10,947
	10-15 cm	2,050	1,652
	15-20 cm	1,834	1,582
	20-25 cm	290	827
	25-30 cm	60	89
	30-35 cm	16	17
	35-40 cm	9	7
	>40 cm	20	17

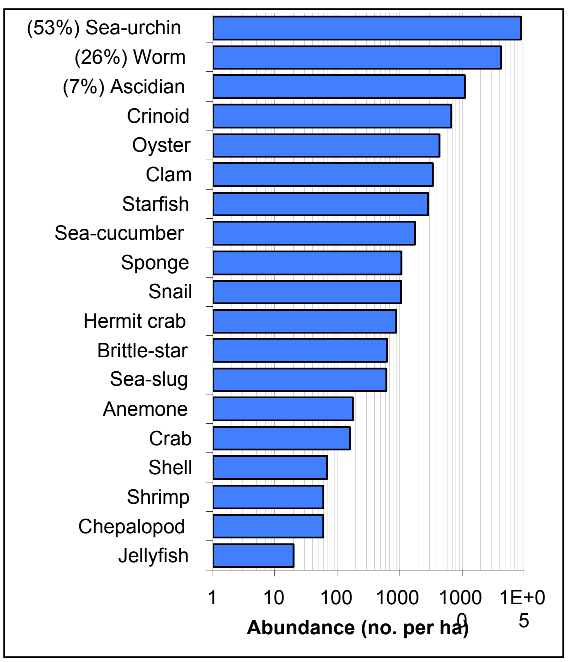


Figure 8. Composition of the macro-invertebrate community on reefs in Northen Aceh. Relative abundance of the top three is shown in parentheses).

had higher abundance of macro-invertebrates than sites within managed areas. These large numbers of invertebrates consisted mainly of sea urchins which are often an indicator of nutrient enrichment. Agricultural runoff is known to contribute nutrients to some areas in the Aceh Islands, although the tsunami would also have contributed high amounts of nutrients that led to the proliferation of turf algae on these reefs and a source of food for the sea urchin population. The high abundance of sea urchins may also be due to low predatory pressure from carnivorous fish. It would appear that on Acehnese reefs both urchins and herbivorous fish are highly abundant and impose high grazing pressure, reducing algal cover and currently creating space for coral recruits. Factors that reduce competition for food between urchins and fish (e.g. fishing) or increase the food supply for urchins (e.g. nutrient enrichment) may change this existing dynamic and enhance urchin population growth. In areas where coral cover and diversity are already at critically low levels, such as the Aceh Island, increases in urchin grazing pressure and space limitations arising from population growth of these and other invertebrates (e.g. *Acanthaster plancii*, *Drupella* spp.) may inhibit coral settlement and have negative consequences for coral recovery.

CONCLUSIONS

Overall the condition of coral reefs in terms of coral cover and reef fish abundance in marine managed areas was considerably better than in open access areas. These areas have been protected from blasting and cyanide fishing while other reefs around Aceh Islands have been subject to unregulated fishing and destructive fishing. The low live coral cover in the Aceh Islands and high abundance of macro-invertebrates, in particular urchin populations, indicates that these reefs have been heavily impacted by a range of anthropogenic factors including overfishing, destructive fishing and eutrophication, undermining the recovery of the reefs. However, the reduction in dynamite and cyanide fishing since 2005

Table 3. Number of species, abundance and diversity index of macro-invertebrates at study sites.

Island	Site Number	Site Name	Number of Species (S)	Abundance (ha^{-1})	Diversity Index (H')
Weh (MPA)	26	Bate Meuronon	19	5,090	3.13
	8	Rubiah Channel	21	1,660	3.89
	24	Rubiah Sea Garden	19	12,840	1.71
	7	Ujung Seurawan	14	3,190	2.39
	14	Anoi Itam	19	4,080	2.88
	19	Sumur Tiga	13	6,090	2.28
Weh (Open Access)	1	Ba Kopra	25	9,920	2.58
	6	Gapang	14	3,510	3.04
	17	Jaboi	15	2,230	3.25
	2	Lhong Angin 1	21	15,570	2.06
	3	Lhong Angin 2	20	9,370	1.96
	4	Lhong Angin 3	25	13,360	2.50
	5	Pulau Klah	27	6,240	3.04
Aceh (Open Access)	12	Deudap	20	10,980	2.29
	13	Lamteng	17	3,530	2.75
	9	Lapeung	7	4,430	1.48
	21	Lhoh	15	15,150	1.91
	20	Paloh	14	25,600	1.24
	22	Pase Janeng 1	10	1,030	1.94
	23	Pase Janeng 2	18	6,070	2.65
	11	Luen Balee 2	9	11,260	1.66

has allowed the reefs in Aceh Islands to begin to recover, with recent reports of high coral recruitment (Ardiwijaya *et al.* 2007). A reduction in destructive fishing activities was indicated by an increase in the number of carnivorous fish from 2006 to 2007, such as groupers, snappers, and jacks, which are target species for local fisheries. Management controls that reduce pressure particularly on carnivorous and herbivorous reef fish species are urgently required to maintain reef diversity, the existing balance between grazing pressure and coral recruitment, and to prevent sea urchin population growth from having negative impacts on coral reefs. Further studies and monitoring are required to examine if recovery of Aceh Islands reefs continues and compare these trends with nearby reefs where existing management controls on fisheries also require support and strengthening.

RECOMMENDATIONS

-Gear restrictions on the use of netting, and enforcement of prohibited and/or destructive fishing methods, in particular blast fishing and cyanide, need consideration in the context of designing marine management areas in northern Aceh.

-Continued monitoring of reef fish, sea urchins and coral reef recovery within and outside of management zones is required for informing management options for the area and evaluating management success.

-The abundance and biomass of carnivorous fish needs to be maintained through effective management controls that reduce pressure and protect target species from overfishing.

-Identifying reef fish spawning aggregation sites of high economic value fish, such as groupers and napoleon wrasse, is required to design MPAs and assist in marine conservation planning.

-Strong support from stakeholders, including the government, private sector, and local communities are required to maintain and strengthen existing Marine Protected Areas and build a network of marine managed areas that represents marine habitats, processes and functions of the region.

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Fishing Controls, Habitat Protection and Reef Fish Conservation in Aceh

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ABSTRACT

In 2006 and 2007 we conducted coral reef and socio-economic surveys in the northern Sumatra islands of Weh and Aceh, to evaluate existing fisheries management practices and the influence of management on coral reefs. Two types of marine resource management were found to exist on Weh Island. A community management system known as the Panglima Laot was being implemented in at least one region of the island and a government tourism reserve or Kawasan Wisata was in place in another region. Both areas had prohibited the use of netting for reef fish over the past 10 years. Areas open to unregulated fishing, except for prohibitions on blast fishing and use of cyanide, also exist on Weh island and a group of islands to the west known as Aceh. In April 2006 and 2007 we examined the structure of coral reef fish populations in each of these 4 areas, the Panglima Laot and Kawasan Wisata and the open access areas of Weh and Aceh islands. The overall biomass of reef fish was greater in marine managed areas than in unmanaged areas but did not differ between years. A separation was also found in the trophic structure of reef fish between managed and unmanaged areas. In managed areas, where cover and diversity of corals was highest, coral dependant reef fish (eg. Chaetodontidae, Pomacentridae) had higher biomass than in unmanaged areas. For fish that are targeted by local fisheries, both carnivorous and herbivorous species showed no difference in biomass among the management areas but both Labrids and omnivores had greater biomass in managed areas where netting was prohibited. The trends indicate a positive influence of management controls on the biomass of some trophic groups. Higher biomass of small size class fish (5-15 cm) were found in the managed areas compared with unmanaged areas, and as such recruitment of fishes is possibly more successful within these areas. Although it is clear that habitat and food availability regulate fish biomass and structure, the prohibition of netting practices and relatively low fishing pressure in managed areas may explain some of the differences in the structure of reef fish between managed and unmanaged areas. Reductions in destructive fishing that occurred in some places years before the introduction of regulations on netting also protected some coral habitats from damage and is likely to have contributed to differences in reef fish population structure. These data together with information on critical habitats, socio-economic conditions and stakeholder perspectives are being used to design a network of marine protected areas for the region.

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

INTRODUCTION

In response to worldwide degradation and collapse of marine resources a growing interest toward more effective management in marine resources is occurring (Dayton et al. 1998, Friedlander et al. 2003). Management agencies are applying concepts of marine resource protection by recommending and implementing marine protected areas that include a variety of regulations aimed at reducing negative impacts from human and natural causes. These areas form an important component of marine conservation whereby certain areas are off limits to extraction of marine resources and provide long term stability of marine ecosystems. They can also halt the decline in marine biodiversity and changes in species and functional groups of marine taxa. The adoption of marine protected areas is a precautionary approach to management that reduces the effects of exploitation and applies an ecosystem based approach to allow ecosystems to function naturally and provide fisheries enhancements. The design and expansion of marine protected areas (MPA's) in response to the continued exploitation of marine resources is considered a necessary management tool for protection of fish populations (Sladek Nowlis and Roberts 1999, Halpern 2003, Sale et al. 2005) and for areas of biodiversity and ecosystem function (Bellwood et al. 2004).

On coral reefs, the intensity and frequency of overfishing contributes to extreme spatial and temporal variability in the biological structure of shallow-water marine communities (Karlson and Hurd 1993, Hughes and Connell 1999). In the extreme, synergistic effects of multiple chronic disturbances such as over-fishing and nutrient inputs can lead to irreversible and fundamental shifts in biological structure from coral-dominated to algal-dominated benthos (McCook, 1999). This in turn may have significant repercussions for the long-term survival of coral associated reef fishes (Wilson et al., 2006). The benefits of MPA protection in providing increased fish stocks and other improvements in resources have been reported globally (Russ 2002) and MPAs are also advocated widely as a management tool to conserve reefs in Indonesia (Mous et al. 2005). Yet although coastal marine habitats in Indonesia have been subject to a long -history of disturbance from destructive fishing practices (Tomascik et al. 1997, Edinger et al., 1998, Pet-Soede et al. 1999) few reports describe ecological benefits that have been attributed directly to MPAs in Indonesia (Christie 2004, McClanahan et al. 2006, Campbell et al. 2007). Such paucity of data in Indonesian MPAs can be attributed to lack of implementation of MPA regulations and lack of enforcement within these areas.

Coral reef fish populations are highly variable in space and time as they exhibit high movement, diel changes, migrations, high spatial variability with changes in habitats. and observer biases. This inherent and near-instant variation in coral reef fish communities makes it difficult to detect temporal changes in these communities and to attribute changes to a given anthropogenic stress. It is therefore important to measure features of reef fish communities that are capable of showing change over relatively long time scales. This may be possible for a few species, yet pooled or aggregated community metrics such as species numbers or densities and biomass at the family, community and functional level have greater potential for detecting change at the sample sizes possible in coral reef studies (McClanahan et al. 2007a).

Coral reefs in northern Aceh gained prominence following the 2004 tsunami where initial reports of widespread damage were grossly unfounded (Baird et al. 2005). It was shown that past management and the misuse of coral reefs was likely to have been the dominant factor structuring coral reef communities (Campbell et al. 2007). Coral reefs of Aceh have been subject to destructive fishing practices, such as cyanide fishing and bombing, over many years with devastating effects on fish stocks as well as the benthic reef habitats. Yet existing conservation management practices have largely been unreported. In this study we examined the status of coral reef communities

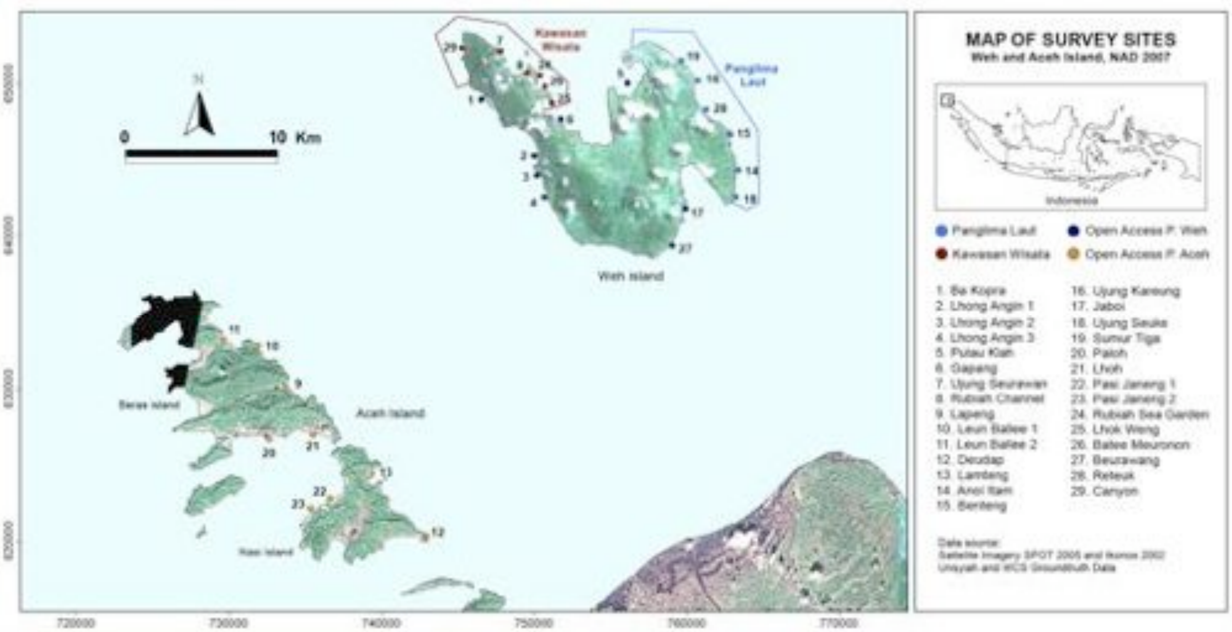

Figure 1. Location of reef fish survey sites in Aceh during 2006 and 2007 surveys.

(both coral and fish communities) inside and outside marine managed areas in Aceh, against a background of considerable prior disturbance from destructive fishing practices. To evaluate if current management practices were working in Aceh we surveyed 29 sites located within 4 management areas; a government gazetted tourism conservation area (Kawasan Wisata) (6 sites), a traditional Achenese management area (Panglima Laot) (6 sites) and inside unmanaged areas with open access to fishing on Pulau Weh island (8 sites) and Pulau Aceh islands (9 sites) with open access to fishing (Fig. 1). In both managed areas regulations prohibiting the use of nets and other destructive practices had been enforced for 10 years while fishing with lines, spears, traps and other artisanal gears occurred. In open access areas fishing was unrestricted and reports of destructive fishing practices from 1970 through to the late 1990's were common. We also examine the level of community compliance and existing fishing effort with existing marine resource regulations.

METHODS

Reefs of Weh and Aceh islands situated off the northern coast of Sumatra, Indonesia for the most part grow on bedrock and in unconsolidated sediments. Reefs surround the islands and are subject to prevailing winds and currents dependant on geographic location and season. A selection of sites that represented the diversity and geography of coral reefs of the region were surveyed in April 2006 (27 sites) and February 2007 (29 sites). The objective was to examine the structure of coral reef fish assemblages within replicate sites inside marine managed areas at 2 locations and outside managed areas at 2 locations. The areas included a government managed tourism conservation area (Kawasan Wisata) (207 ha) (6 sites), a traditional Achenese management area (Panglima Laot) (206 ha) (6 sites) and outside managed areas (>1000 ha) on Pulau Weh island (8 sites) and Pulau Aceh islands (9 sites) (Fig. 1).

Estimates of Coral Abundance

Coral cover was estimated at each site using three 50m transects, and at each 0.5 m interval the scleractinian coral genus under the transect was recorded. Two of these transects were the same as transects used to estimate fish abundance. Cover was then expressed as the number of times a coral genus was recorded along a transect divided by the total number of intercept points (n=100) per transect.

Estimates of Fish Abundance

Visual estimates of reef fish species abundance and size at each site was measured at a depth of 0-2 m and 6-8m along three 50m x 5m belt transects per depth in April 2006 and February 2007. All fish were recorded from a total of 41 families except for sediment dwelling families Gobidae, Blenidae and Tripterigidae. Surveys were conducted during daytime to reduce possible temporal effects on fish abundance among sites. Fish were visually assigned to one of 9 size classes (<5 cm, 5-10cm, 10-15 cm, 15-20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm and >40 cm). Fish less than 10cm and those greater than 10cm were surveyed separately on the same transects. Abundance was expressed as the mean abundance of fish per hectare.

Fishing Intensity

To obtain a standard measure of fishing effort within each management area (except in open access Aceh island where data was not available) the mean number of fishing trips per fisher within 7 lhoks (sub-district) in each management area (identified from household surveys of 143 fishers) was multiplied by the total number of fishers who fished on coral reefs in the lhok and divided by reef area adjacent to each of the lhoks.

Statistical Analyses

Using two-way analysis of variance (ANOVA) we examined the effect of management areas (fixed; 4 levels, Panglima Laot, Kawasan Wisata, open access Pulau Aceh, open access Pulau Weh) and time (fixed; 2 levels, 2006 and 2007) on mean fish biomass, mean biomass of 6 trophic groups at each site, mean biomass of 6 major fish families at each site, mean biomass of 9 size classes of all reef fish pooled and mean coral cover at each site (random; 6 - 9 levels). In order to understand if the variation in reef fish biomass was highest between sites within management areas (among sites) or among management areas we performed separate analyses for each year using nested ANOVA. For these analyses reef fish biomass data from each transect (n = 6) at each site (random; 6 - 9 levels) were nested within each management area (fixed; 4 levels). Significance among factors was tested at the $p<0.05$ level.

RESULTS

Reef Fish Biomass

The mean biomass of reef fishes in 2006 and 2007 (averaged across all families) varied by an order of magnitude among sites. In 2006 the mean (± standard error) biomass ranged from 118.2± 72.3 kg ha-1 at Pasi Janeng (site 23), up to 1193.7± 332.2 kg ha-1 at Ujung Kaureung (site 16). In 2007, biomass ranged from 149.2± 49.2 kg ha-1 at Lapeng (site 9), up to 1561.9± 554.8) kg ha-1 at the Canyon (site 29) (Fig. 2). The families with the highest biomass were the Pomacentridae and Acanthuridae which accounted for 17% and 14% of all fishes counted respectively. The next most abundant families of fishes were the Scaridae, Chaetodontidae, Labridae and Pomacanthidae, although families comprising mostly small or cryptic fishes (e.g., Apogonidae or Blennidae), which comprise a significant component of the ichthyofauna on coral reefs (Munday and Jones 1998), were not surveyed.

Nested ANOVA (site (management area)) were performed to examine variation in reef fish biomass among sites within management areas and among management areas, separately for 2006 and 2007. In this case an effect of management was found in 2006 (df 3,20, $F=7.310$, $P<0.002$) and 2007 (df 3,22, $F=3.378$, $P<0.038$) suggesting that management had an influence on reef fish biomass. Significant variation among sites nested within management zones, in 2006 (df 22,148, $F = 2.746$, $P < 0.001$) and 2007 (df 20,84, $F = 2.216$, $P = 0.006$) was also found indicating high

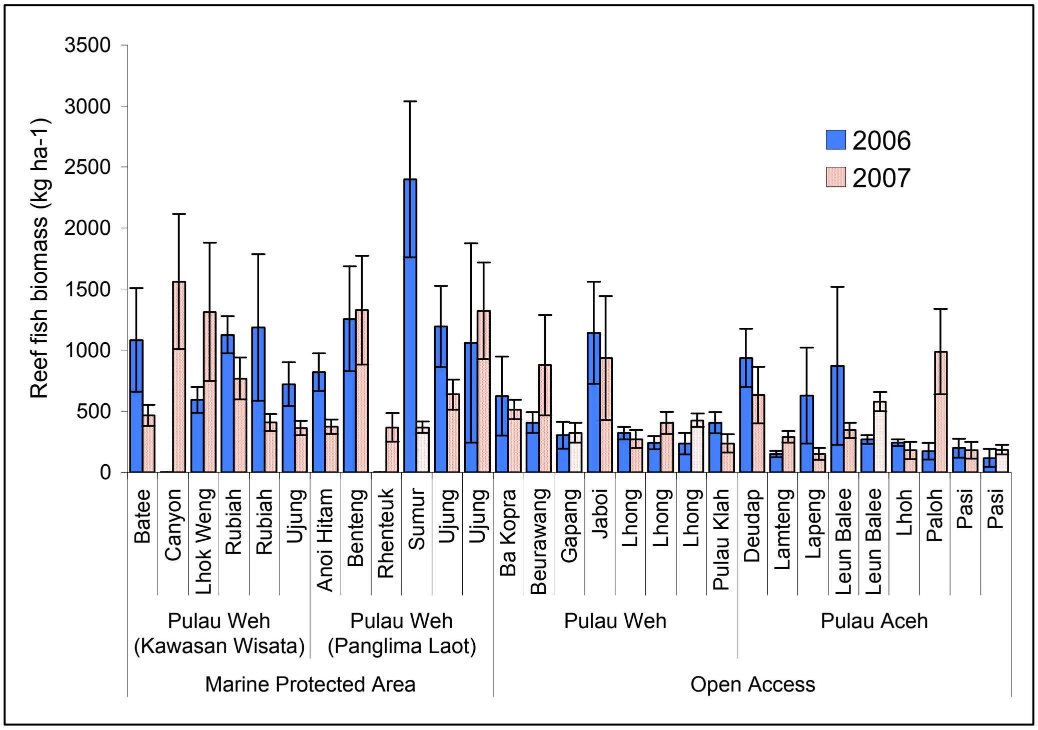

Figure 2. Mean (±Standard Error) reef fish biomass (kg ha^{-1}) of all fish species at 29 sites in 4 management areas of Aceh in 2006 and 2007.

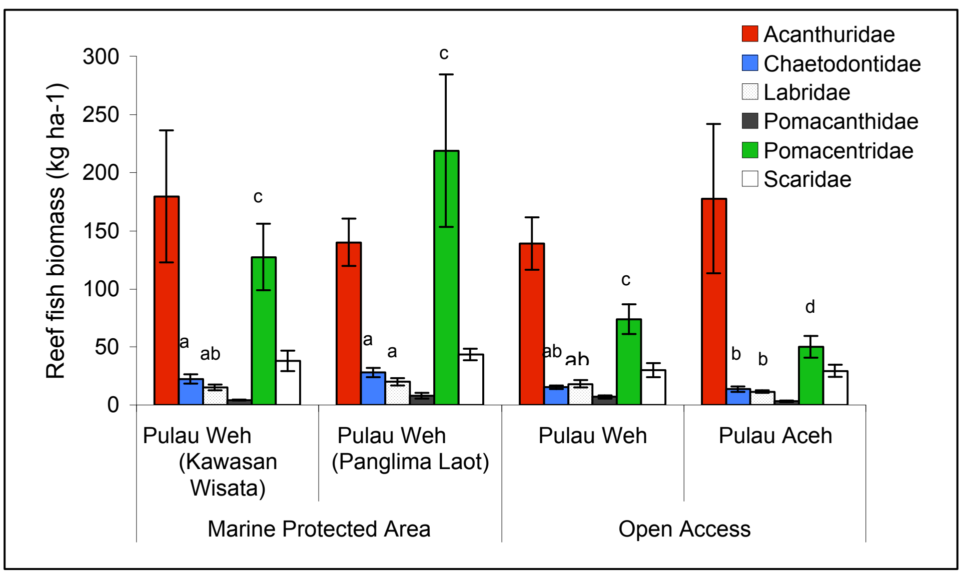

Figure 3. Mean (±Standard Error) reef fish biomass (kg ha^{-1}) of six major families in 4 management areas of Aceh in 2007. Different superscript letters denote significant differences ($P<0.05$) in biomass among management zones for a given reef fish family.

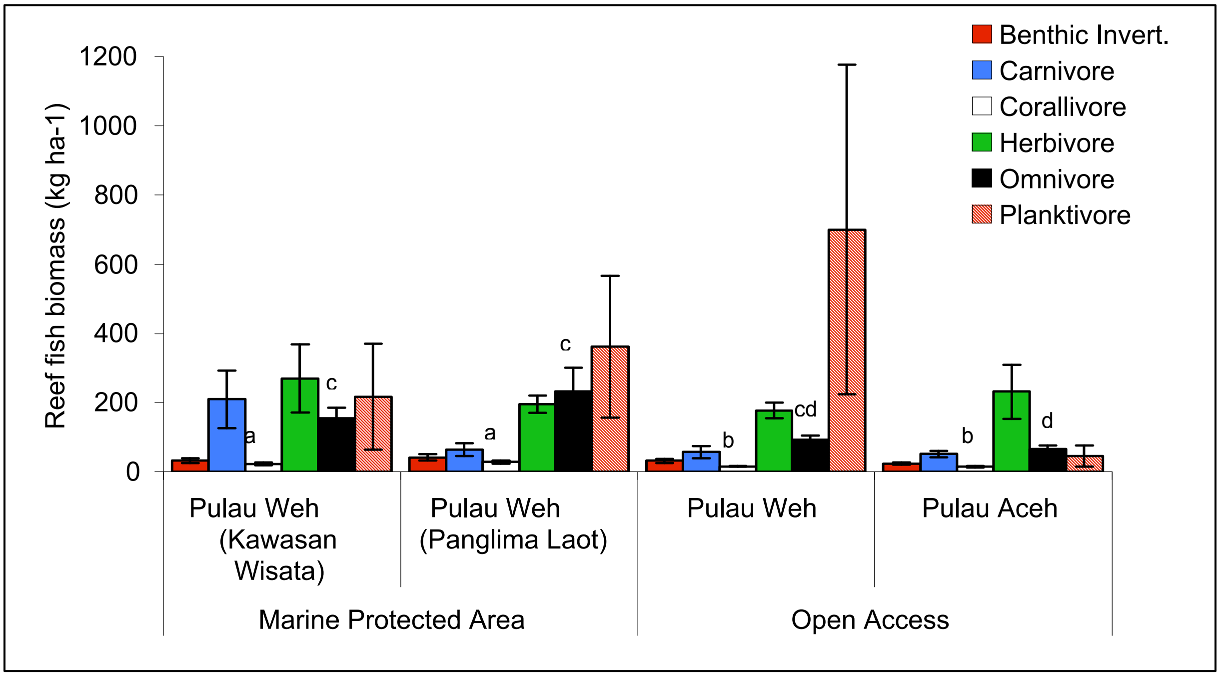

Figure 4. Mean (±Standard Error) reef fish biomass (kg ha^{-1}) of trophic groups in 4 management areas of Aceh in 2007. Different superscript letters denote significant differences (P<0.05) in biomass among management zones for a given reef fish trophic group.

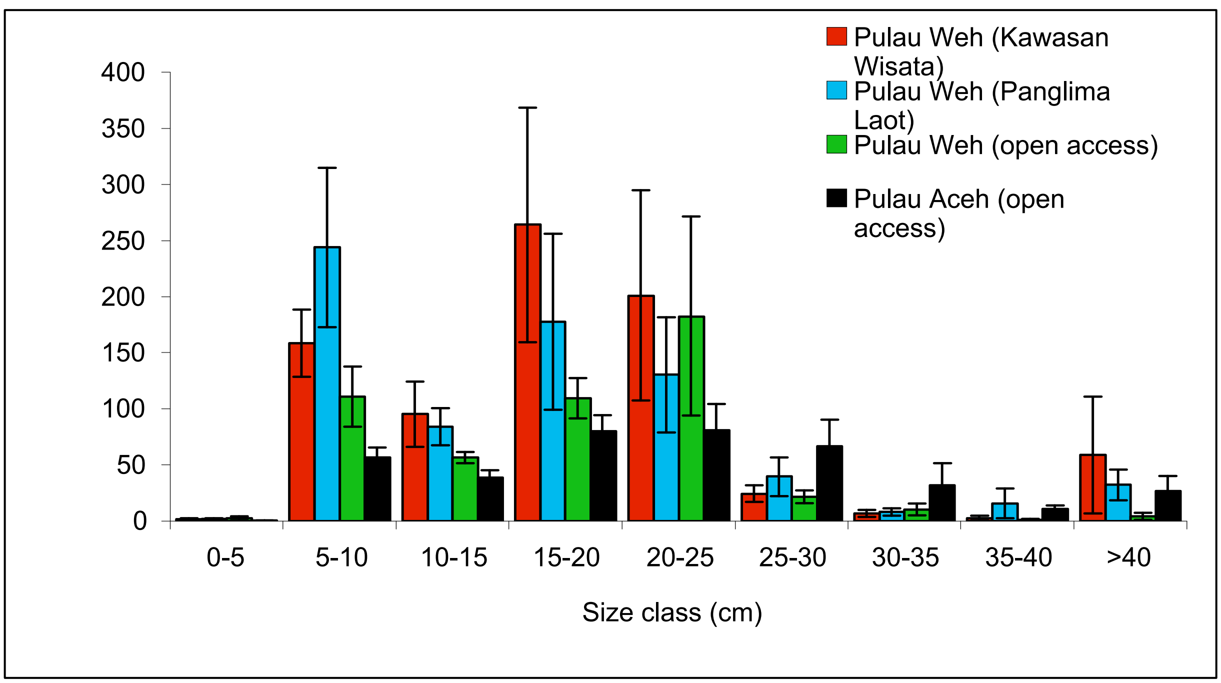

Figure 5. Mean (±Standard Error) reef fish biomass (kg ha^{-1}) of size classes in 4 management areas of Aceh in 2007.

variation in reef fish biomass among sites within a given management area.

Reef Fish Structure

At sites within the Kawasan Wisata and Panglima Laot on Weh island there was higher biomass of Chaetodontidae, Labridae and Pomacentridae compared with open access areas of Pulau Aceh (Fig. 3). This was also reflected in the trophic structure with higher biomass of corallivores (mostly Chaetodontidae) and omnivores (mostly Balistidae and Pomacentridae) in Kawasan Wisata and Panglima Laot areas compared with open access areas of Pulau Aceh (Fig. 4). The size structure of coral reef fish assemblages was characterized by a higher biomass of 5-10 cm, 10-15 cm and 15-20 cm size classes in Kawasan Wisata and Panglima Laot compared with the open access area of Pulau Aceh (Fig. 5).

Coral Cover

There was a significant effect of management area (df 3,48, F = 22.273, P < 0.001) on percentage coral cover with post-hoc tests (Bonferoni) revealing significantly lower coral cover in open access Pulau Aceh (9.16 ± 1.50) compared to open access Pulau Weh (26.0 ± 2.21), Kawasan Wisata (38.8 ± 2.67) and Panglima Laot (53.3 ± 2.82) areas. Coral cover in the Panglima Laot area was also significantly higher than in the open access area of Pulau Weh.

Fishing Pressure

Highest fishing pressure was found in the lhoks of Balohan and Keunekai within open access areas and lowest in marine protected areas in Panglima Laot and Kawasan Wisata lhoks (Fig. 6).

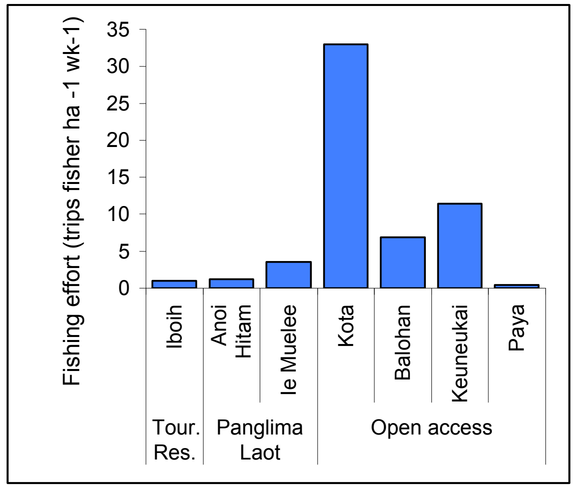

Figure 6. Mean fishing effort (trips fisher^{-1} ha^{-1} wk^{-1}) at seven lhoks (sub-districts) and 3 management areas of Pulau Weh in 2006.

DISCUSSION

Teasing apart the effects of habitat condition and management regulations on reef fish populations is difficult given the complex associations between low coral cover, low fish densities and high fishing pressure and the influence of coral habitat type and area on coral reef fish assemblages (Russ and Alcalca 1996, Bellwood and Hughes 2001). Nonetheless, the lower fish abundance in open access fishing areas of both Aceh and Weh, irrespective of the lower coral cover and diversity, suggests that past fishing practices, including bombing and cyanide poisoning that were common throughout Indonesia (Pet Soede et al. 1999, Tomascik et al. 1997, Hopley and Suharsono 2002) impacted coral cover and fish biomass in Aceh. Because of the national laws prohibiting these illegal practices it is unlikely that fishers will admit to their use. In contrast, local management regulations such as bans of netting are rarely enforced so information from fishers on their use of legal gears are likely to reflect accurate estimates of fishing pressure. The relatively lower fishing pressure inside marine protected areas compared with areas where fishing is unregulated has almost certainly benefited reef fish biomass, despite regulations limiting netting not being fully complied with, enforced or monitored. Alternative income opportunities (ie. tourism, agriculture) in the lhoks adjacent to the marine protected areas have more than likely reduced dependency on fishing in these areas and allowed communities to comply to some degree with fishing regulations.

The enhancement of fish numbers inside marine protected areas is likely to be closely coupled with habitat availability which promotes growth and maturation of fish in post-recruitment phases (Jones and McCormick 2002). Coral dwelling species including Pomacentridae, Chaetodontidae and Labridae showed higher biomass in protected areas where coral cover and diversity was higher than in open access areas (see also Baird et al. 2005). Both Pomacentridae and Chaetodontidae are heavily reliant on coral habitat (Bellwood and Hughes 2001, Jones et al. 2004) which provide shelter from predatory fish species and are likely to improve survival (Jones and McCormick 2002). Coral habitat is also likely to assist in recruitment of reef fishes by providing cues for active habitat selection by reef fish larvae (Montgomery et al. 2001). These coral dwelling families are not targeted by fishing and hence differences in biomass would appear directly related to the quality and quantity of coral habitat.

In Aceh, the first 10 years of marine management has seen Labrids and the faster growing coral dwelling Chaetodontids and Pomacentrids benefit in terms of biomass from the marine management in place, as they are clearly disadvantaged in areas where coral cover and diversity is low and algal growth is high. In contrast families such as Acanthuridae, Scaridae and Pomacanthidae showed no differences in biomass between protected and non-protected areas although both Acanthuridae and Scaridae are targeted by net and handline fisheries. This suggests that the trophic behaviour of reef fish may to some extent explain the observed differences in biomass among management areas. Both Acanthuridae and Scaridae are roaming herbivores that may be supported by high abundance of algae typically found in the open access reefs of Aceh and Weh (Campbell et al. 2007). Ecological succession may also explain differences in reef fish structure as increases in the biomass of some families such as Labridae and Scaridae have been reported during the first ten years of closure from fishing, while increases in the biomass of Balistids and Acanthurids have taken 10-20 years of closure (McClanahan et al. 2007b). In coral reef systems fish biomass may take many years or decades to recover to full diversity and biomass (Micheli et al. 2004, McClanahan et al. 2007b), as the influence of competitive interactions among functional groups alters the rate of change in the biomass of reef fish with time.

The paucity of small fish size classes (5-15 cm) in open access areas of Weh and Aceh islands may be due to the overuse of nets in open access areas and capture of small size fish. However, our observations suggest that exploitation of small sized fish is not a major concern except possibly the targeting in some areas by the reef fish aquarium trade. Interestingly we have noted large numbers of small sized cohorts in both 2006 and 2007 fish surveys in marine protected areas suggesting that recruitment to these reefs may be occurring. Mechanisms responsible for possible recruitment remain unclear although factors linked to habitat availability that affect recruitment and predation, including density dependent post-settlement mortality, food supply, larval growth and larval mortality (Jones and McCormick 2002), may influence reef fish structure in Aceh.

The overall higher reef fish biomass and low fishing effort in protected compared with open access areas, indicates a degree of compliance with fishing regulations and a sensitivity of reef fish populations to community or district based management controls. Yet the low biomass of carnivorous fish found in all management zones indicates that these populations remain in a state of severe depletion. Although fishing effort is low in protected areas and restrictions on netting may be working, a lack of restrictions on handline and speargun fishing and the illegal use of cyanide to target carnivores has undoubtedly contributed to the depletion in large fishes, typical of overfishing in coral reef systems (Russ and Alcalca 1996, Micheli et al. 2004). Controls such as gear restrictions and periodic closures may be popular with local communities but have limits to preserving fishery dependent species and ecological processes. On the other hand, permanent closures have been advocated as the only way to maintain coral reef ecosystems that are representative of unfished ecosystems with high fish biomass (McClanahan and Graham 2005, McClanahan et al. 2007b). Achieving this in Aceh is problematic when fishing dependency is often seasonally high, enforcement of regulations is low, limited monitoring occurs and poor management among responsible agencies persists.

In the absence of data on reef fish populations prior to restrictions on fishing we cannot conclusively attribute the higher biomass of reef fish in the Kawasan Wisata and Panglima Laot protected areas to regulations limiting netting in these areas. The differences may also be due to the history of blast fishing which ceased in the late 1980's in the two managed areas of Pulau Weh but continued unabated until the mid 1990's in some of the open access areas. Nonetheless, whether it be gear restrictions. limiting fishing pressure or the reduction in destructive fishing the conservation practices adhered to by communities would appear to have benefited coral reefs by reducing the harvest of some species of reef fish and protecting coral from damage. Responses of fishes to protection from fishing are influenced by many complex factors, including the size of reef, the structure of reef fish populations, the proximity of other reefs and the level of compliance with protection regulations (Babcock et al. 1999; McClanahan and Mangi 2001; Shears and Babcock 2003) and positive effects of protection may require many years to become manifest (Micheli et al. 2004, Russ et al. 2005, McClanahan et al. 2007b). Nonetheless, local MPAs such as the ones studied in the present study are gaining increasing acceptance among scientists as one of the few effective ways of managing fisheries of coral reef species (Russ 2002), and may be critical in making reefs more resilient to acute natural and anthropogenic disturbances (Bellwood et al. 2004).

The coral reefs of Weh Island more than a year after the tsunami are largely intact. The legacy of traditional and government based marine resource management appears to have protected some reefs from human misuse and afforded refuge for a diverse and abundant suite of reef fish. These reefs have depleted numbers of species targeted by artisanal coral reef fisheries most likely because permanent closures or no take zones have not been part of the management controls in Aceh and continue to lack community support. Nonetheless, the findings of existing community or government based management in reducing unsustainable fishing practices on coral reefs have rarely been documented in Indonesia (Christie 2004, McClanahan et al. 2006). On Aceh Island the condition of many reefs remains a cause for concern, yet the chronic mismanagement of marine resources appears to have abated in the wake of the tsunami and there is evidence that recruitment of corals and fish is occurring. This encouraging response is evidence of the resilience of coral reefs to severe disturbance and the determination of local communities to protect some of the most diverse coral reefs in Sumatra over the past 10 years. Pivotal to achieving sustainable fisheries and coastal livelihoods will be the strengthening of relationships between the communities and institutions involved in marine resource management.

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Status of Earthquake and Tsunami Affected Coral Reefs in the Andaman and Nicobar Islands, India

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INTRODUCTION

The Andaman and Nicobar Islands, located in the south eastern part of the Bay of Bengal between latitudes 6° 45' and 13° 41' S and longitudes 92° 12' and 93° 57' E, are host to a rich biodiversity. The archipelago is one of the few key biodiversity regions in the world surrounded by fringing coral reefs characteristic of the Southeast Asian region, and is the most diverse among Indian subcontinent reef areas (Pillai, 1983, Davidar *et al.*, 1994).

On 26th December 2004, an earthquake measuring 9.3 on the Richter scale hit the region. As a result of tectonic activity, low lying areas from South Andaman to the Nicobar Group of Islands were submerged by 1-2 meters, while large areas, including coral reefs, were uplifted in the northern group of the Andaman islands. The uplift resulted in permanent damage to shallow reefs in the northern group of the Andaman Islands (Kulkarni, 2005). The earthquake also generated tsunamis, the effect of which ranged from a temporary rise in sea level such as in South Andaman, and up to 15 m high waves in parts of the Nicobar Islands. This caused loss of human lives and destruction to infrastructure in the islands (Sankaran et. al., 2005). The environmental impacts of the tsunami were diverse, with damage to coral reefs and

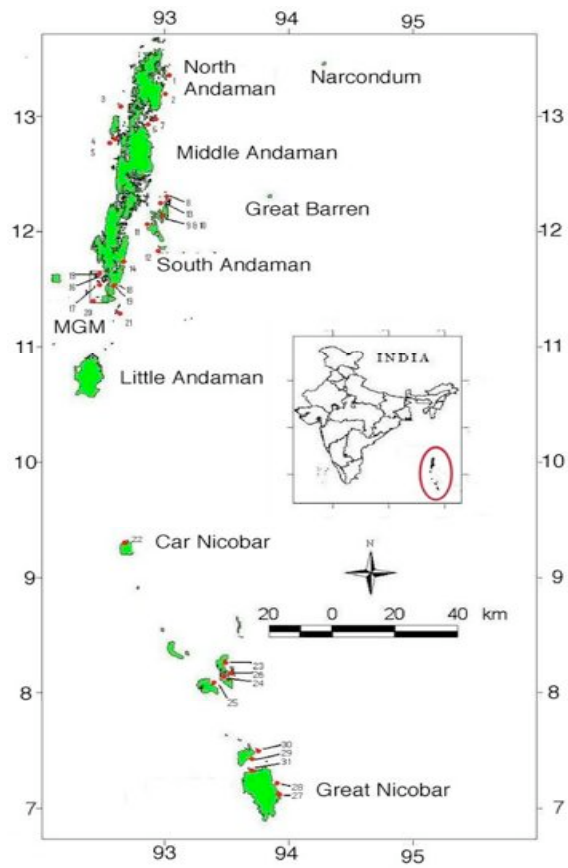

Figure 1. The Andaman and Nicobar Islands. Numbered dots indicate survey sites. See also Table 1.

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

Table 1. Sites where benthic assessment was carried out. Site numbers correspond to numbers in Figure 1.

Nr.	Site
North Andaman	
1	Smith Island
2	Lamia Bay
3	North Reef Island
Middle Andaman	
4	Interview Island
5	South Reef Island
6	Aves Island
7	South Island
Ritchie's Archipelago	
8	Outram Island
9	Henry Lawrence
10	John Lawrence
11	Havelock Island
12	Neil Island
13	South Button Island
South Andaman	
14	North Bay
15	Grub Island
16	Redskin Island
17	Jolly Buoy Island
18	Chidiyatapu
19	Rutland Island
20	Twins Islands
21	Cinque Island
Nicobar Group	
22	Car Nicobar
23	Camorta Island (northeastern)
24	Camorta Island (southeastern)
25	Katchall Island
26	Trinket Island
27	Great Nicobar
28	Pigeon Island
29	Little Nicobar
30	Menchal Island
31	Kondul Island

other coastal habitats in the entire region (Malik and Murti 2005).

This study gives a detailed account of the impact and long-term implications of the earthquake and the tsunami on the reefs of the Andaman and Nicobar Islands.

METHODOLOGY

The study was carried out at 31 sites around 29 islands in the Andaman and Nicobar Islands (Table 1, Fig. 1), between February 2005 and June 2006. The extent of uplift was estimated based on the difference between the new and the old water level as indicated by high-water marks on rocks and structures. The presence of full-grown barnacles at deeper levels of jetties served as an indication of the submergence level. The height of the tsunami was estimated by newly formed high water marks on trees and structures along the coast, referred against previous indications.

Benthic cover was assessed using randomly laid Line Intercept Transects (LIT) (Loya, 1972). Five transects 20 meters long were run parallel to depth contours at each site at depths between 4 and 9 meters. Transects were separated by at least 10 to 30 meters, to cover approximately 150 to 250 m along the reefs. Benthic cover categories recorded were live coral, dead coral, broken corals and rubble, sand, algae, soft coral and other. Relative abundance of coral genera was recorded in permanent LIT and is presented by genera as percentage of total coral cover.

In addition, general visual observation of reefs and associated biota were made using SCUBA down to depths of 30 meters. Damage to the reef was categorized based on type/cause of the damage, and GPS readings of the damaged area were recorded. The areas were then demarcated on high-resolution post-tsunami satellite images (scale 1:2000) obtained from Google Earth Pro Inc. and areas of destruction were approximated by constructing polygons connecting the coordinates, and using Google Earth software for area calculations.

Table 2: Estimated reef damage in North Andaman group of islands. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
Landfall	UL	5.82
West	UL	2.07
White cliff	UL	0.16
Reef	UL	1.08
Paget	UL	1.86
Point	UL	2.61
Snark	UL	0.16
Kwang Tung	UL	0.25
North Reef	UL/TS	13.27
Latuche	UL/TS	0.21
North Andaman	UL/TS	21.8
Thornhill	UL	0.24
Total		49.53

RESULTS

North Andaman

The earthquake resulted in uplift of the west coast of North Andaman, which led to mortality of corals and associated life-forms in shallow waters due to aerial exposure and direct sunlight. Signs of sand deposition were also observed on these exposed reefs. Middle Andaman, including small islands from Landfall Island to South Reef was uplifted by more than one meter and the areas on the eastern coast such as Diglipur, Smith and Ross Islands, by less than one meter. Table 2 summarizes reef damage in the archipelago, including areas not surveyed with LIT. Almost 50 km^2 of reef was destroyed or severely damaged.

Smith island (1 in Fig. 1) has a length of 8.6 km and a width of 5.1 km. It has extensive mangroves on the northwestern side and narrow fringing reefs all around the island. The reef flat contains mainly rocks, sand and dead coral heads. Extensive coral growth starts at a depth of 4 meters and extends along a gradual slope down to 10 meters. The western reef is sheltered and dominated by *Porites* spp. while the eastern reef is dominated by *Acropora* spp.

The island appears to have been raised by half a meter, resulting in exposure of the reef flat on the eastern side. As coral growth on the reef flat was very moderate prior to the Tsunami, the impact, if any, has not been significant. The tsunami was not violent in this area and water only rose by around 2.5 meters. No physical damage, such as broken coral colonies, were seen.

In 2003, prior to the tsunami, live coral cover on the eastern side of the island was 54.0%, dominated by *Acropora* (44.6%) followed by *Porites* (16.1 %), *Favia* (9.3%) and *Montipora* (8.3%). Coral cover in 2006 was 50.5%, with the relative abundance of most major coral genera unchanged (*Acropora* 41.5%; *Porites* 18.3%; encrusting *Montipora* 11.5%).

Lamia Bay (2 in Fig. 1) is situated on the east coast of North Andaman and at the base of Saddle Peak (the highest point in the Andaman and Nicobar Islands). The site is dominated by patch reefs. Eyewitness reports confirm that the tsunami came in the form of a rise in sea water of around 1.9m and did not cause any physical destruction on land. There are also no signs of reef damage. Live coral cover was 41.1% before the tsunami and 39% after. Since 2003 rubble cover has been reduced from 11.8% to 1.3% while the soft coral cover has increased from 0.5 to 9.8%.

Prior to the tsunami, North Reef island (3 in Fig. 1) had luxuriant coral growth all around, and was considered one of the most diverse reefs in the Andaman and Nicobar Islands. The northern side of the island had an inter-tidal reef flat dominated by mono-specific stands of *Acropora formosa*. The reef on the western side of the island was dominated by *Acropora* spp. and *Montipora aequituberculata*. *Millepora dichotoma, Porites lutea* and *Acropora robusta* dominated the southeastern bay.

The tectonic activity caused North Reef to be raised by more than 1.5 meters. This has resulted in exposure of the reef flat on the northern and western sides, resulting in increased turbulence in the sub-tidal reefs and deposition of sand. Destruction of coastal

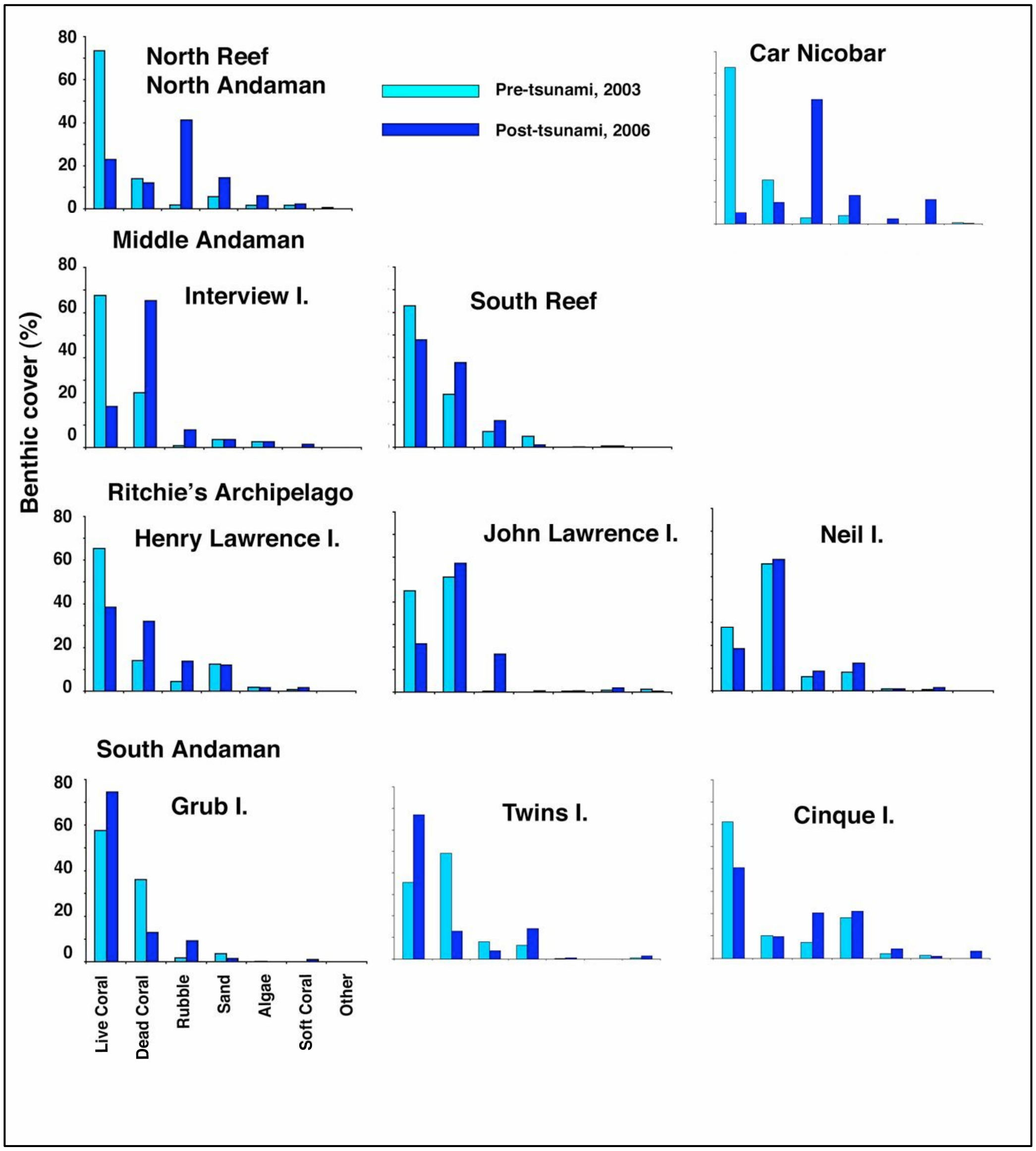

Figure 2. Benthic cover at study sites in the Andaman and Nicobar Islands: North Andaman - North Reef; Middle Andaman - Interview Island, South Reef; Ritchie's Archipelago - Henry Lawrence, John Lawrence, Neil Island; South Andaman - Grub Island, Twins Island, Cinque Island; Car Nicobar.

vegetation indicates that the tsunami was severe with a height of about 3.5 meters on the eastern side of the island.

At the monitoring site (south-eastern), the average live coral cover pre-tsunami was 73.5%, dominated by large colonies of *Acropora* spp. at a relative abundance of 31.7%, followed by *Porites* (21.8%) and *Millepora* (10.7%). By 2006 the live coral cover had been reduced to 23%. The relative abundance of *Acropora* and *Millepora* was reduced to 8.8% and 2.3%

Table 3: Estimated reef damage in Middle Andaman group of islands. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
Middle Andaman	UL/TS	12.32
Spike	UL/TS	0.58
South reef	UL	0.37
Anderson	UL	2.11
Flat	UL	6.67
Total		22.05

respectively. The percentage cover of rubble increased from 2% to 41% (Fig. 2). The area of coral reef destroyed by exposure from the uplift of the landmass and due to the tsunami is estimated to be about 13 km^2.

Middle Andaman

Reef damage in Middle Andaman is summarized in Table 3, including areas not surveyed with LIT. Over 22 km^2 of reef was destroyed or severely damaged.

Interview Island is situated to the south of North Reef Island and to the west of Middle Andaman. Prior to the earthquake and tsunami the western, northern and southern areas of this island had extensive reef flats mainly dominated by *Porites* micro-atolls. The sheltered eastern side showed patchy coral reefs and high turbidity.

Due to uplift caused by the earthquake, reef flats on the northern and western side have become exposed. Waves are breaking directly on the edge of reef flat, resulting in low visibility and deposition of sand mainly along the sub-tidal reefs on the western side.

Live coral cover in the sub-tidal region of the southern reef (4 in Fig. 1) has been reduced from 67.7% (dominated by *Porites* and *Acropora*) to 18.4%. The percentage cover of dead intact coral has increased from 25% to 65.5%, and that of rubble has increased from 1% to 8% (Fig. 2). High water temperature was also observed in the southern reef areas during the surveys in 2006. This is possibly due to localized warming of stagnant seawater in sub-tidal zones of the southern reef during low tide, causing coral mortality.

South Reef Island lies to the south of Interview Island. It is surrounded by a 30 to 70 meter wide reef flat, wider on the western than on the eastern side. This island was raised by 1 meter as a result of the earthquake, causing damage to coral reefs mainly on the western reef flat. The pre-tsunami coral cover on the eastern side (5 in Fig. 1) of the island, 63.2%, was reduced to 48% in 2006 (Fig. 2). The mortality cased a shift in the coral community with the dominance of *Acropora sp.* reduced from a relative abundance of 46.6% to 31.4% in 2006. An increase in relative abundance was recorded in *Porites sp.* (16.8% prior to the tsunami to 21.6% after), *Echinopora* (9.5% to 13.7%) and *Millepora* (7.1% to 9.3%).

Aves Island is situated on the eastern side of Mayabundar. Coral reefs occur all around the island from a depth of 4 meters to 14 meters, except at the southern end, where the seabed is covered mainly by rocks. On the eastern and northern sides, *Acropora* and *Porites* dominate the coral reefs while on the western side coral reefs are dominated by *Porites*. No significant change in live coral cover was recorded at the study site on the eastern side of the island (6 in Fig. 1.) between 2003 (61%) and 2006 (58 %). *Acropora* (40.2%) dominated the live coral cover followed by *Porites* (23.1%), *Hydnophora* (8.9%) and *Echinopora* (6.4%).

Sound Island is situated to the northeast of Mayabundar and Aves Island. Coral reefs were surveyed on the eastern side (7 in Fig. 1.) of the island. Live coral cover was 47% in 2003 and 45% in 2006. *Porites* dominated the live coral cover with a relative abundance of 44.4% followed by *Montipora* (17.3%) and *Acropora* (12.6%).

Ritchie's Archipelago

Ritchie's Archipelago comprises 4 large islands, 7 small islands and several islets, extending in a roughly north-south chain, parallel to the main Great

Table 4: Estimated reef damage in Ritchie's Archipelago, South Andaman and Little Andaman. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
North Sentinel	UL	12.59
South Andaman group	TS	1.00
Ritchies Archipelago	TS	1.11
Little Andaman	UL/TS	12.85
Total		27.55

Andaman Group. Corals reefs at six islands were surveyed. Reef damage is summarized in Table 4.

Outram Island lies to the north of Henry Lawrence. Mangroves are present on the northern and southern side of the island. The island is surrounded by fringing reefs. The western reef flats are narrow, with widths ranging from 50-80 meters, and mainly dominated by *Acropora*. *Porites* and *Acropora* dominated the live coral cover on the southern and eastern sides with a relative abundance of 42.4 % and 31.9 % respectively. The maximum coral growth occurs down to 12 meters, beyond which sea fans, soft corals and some Faviids dominated the rocky bottom.

Coral cover and community composition appear unchanged by the tsunami, with live coral cover on the western side of the island (8 in Fig. 1.) recorded as 67% in 2004 and 64.7% in 2006. A marginal increase in dead intact coral cover was seen, with no increase in rubble.

Henry Lawrence Island is part of the Rani Jhansi Marine National Park. Coral reefs occur all around the island except on the western coast, where mangroves are found. The coral communities are mainly dominated by *Porites lutea* and *P. nigrescens*. On the eastern coast, reef flats range from 50 – 100 meters in width, with gentle reef slopes down to about 13 meters, beyond which the bottom is sandy. The western side of Henry Lawrence and the eastern side of John Lawrence form a narrow channel from south to north.

The tsunami wave's kinetic energy increased in the narrow channels causing high-velocity currents. This caused damage to corals along the edges of reef flats. Large colonies of *Porites lutea* on reef edges were uprooted and some stretches of mangroves were destroyed. Accumulation of rubble was observed on the central-western side of the reef. Qualitative assessment carried out in the monitoring site on the western side (9 in Fig. 1.) revealed that live coral cover was reduced to 21.5% compared to 45.1% in 2003. The percentage cover of rubble has increased to more than 16% in 2006 compared to 2003 (Fig. 2). *Porites* is still the dominant genus, making up more than half of the live coral cover. Dense clusters of *Turbinaria* algae have occupied dead parts of *Porites* colonies.

John Lawrence Island is also part of Rani Jhansi Marine National Park. The entire north-western region is surrounded by extensive mangrove forests. Coral reefs are mainly patchy with narrow reef flats that slope steeply to a maximum depth of 12 meters. The reefs are dominated by large colonies of *Porites*.

The concentrated energy of the tsunami in the channels between John Lawrence, Wilson and Nicholson islands caused mangrove and coral reef destruction. Large patches of mangroves alongside the channel were destroyed, and boulders of *Porites* were uprooted and scattered all over the channel making navigation for dinghies difficult. Coral reefs were studied on the eastern side (10 in Fig. 1.) of the island. Large colonies of *Porites* were tilted and smaller ones were uprooted and smothered. Live coral cover declined from 65.5% in 2003 to 38.5% in 2006, and cover of rubble doubled (Fig. 2). The coral community structure suggests that *Porites* sustained damage with a reduction in relative abundance from 59.9% to 43.2%, with encrusting *Montipora* and foliose *Echinopora* increasing in relative abundance. Large clusters of *Turbinaria* algae were found on dead coral boulders.

Havelock Island is surrounded by fringing reefs with wide reef flats on the western side and narrow on the eastern side. Reef flats are dominated by large colonies of *Porites,* the top portions of which are mostly dead. This island experienced the tsunami mainly in the form of a rise in sea water level. Along the north and north-west coasts the rise in sea water level was about one meter accompanied by strong currents. Corals, mainly in the channel and at the mouth of the channel sustained most of the damage. However, the damage was restricted to smaller colonies of *Porites* and *Acropora*.

The monitoring site, located on the north-western reef (11 in Fig. 1), close to the lighthouse, has a steep reef slope extending down to 21 meters, with a sandy bottom beyond. The average live coral cover at this site declined from 59.7 % in 2003 to 43.2% in 2006. Change in cover of intact dead coral was minimal but rubble cover increased somewhat.

Neil Island is situated to the south of Havelock Island. Fringing reefs occur on the eastern and western side of the island, with patch reefs to the north and south. Reefs studied on the northwestern side of the island (12 in Fig. 1) were *Porites* dominated, making up over two thirds of the live coral cover. A reduction in live coral from 27.8% to 18.6% in 2006 was observed, while the cover of dead standing coral remained unchanged and comparatively high (Fig. 2).

Coral reefs around South Button Island (13 in Fig. 1) studied in 2006 were healthy, with a live coral cover of 80% and high fish diversity and abundance.

South Andaman

In South Andaman, coral reefs around North Bay, Chidiyatapu and some of the islands of the Mahatma Gandhi Marine National Park were studied. Coral reef mortality due to the tsunami was visible in channels and edges of reef slopes. In recent years solar radiation has caused coral mortality in shallow areas (Kulkarni, 2004). The increase in depth due to subsidence may have a positive effect in promoting coral growth. Reef damage is summarized in Table 4.

North Bay is located near Port Blair Harbour, with fringing reefs to the north and south. The tsunami reached a height of around 2.5 meters in this area. Corals on the northern side of the bay were not affected as the community is dominated by massive boulders of *Porites*. The southern side (14 in Fig. 1) sustained around 10% damage that was restricted to primarily *Acropora* colonies, and an increase in coral rubble. *Porites* species, such as *P. solida* and *P. nigrescens,* remain dominant at the site with a relative abundance of 91.4%.

Grub Island is part of M. G. Marine National Park. The reef around this island has a gentle slope and coral growth occurs to a depth of 6 meters, with a higher live coral cover on the eastern than on the western side. The coral community is dominated by *Acropora,* followed by *Porites* and *Echinopora lamellose*; further north, where the reef stretches up to 300 m from the shoreline, by *Porites* and *Millepora dichotoma,* Other common coral genera include *Montipora* and *Hydnophora*. The southern part of this island is sandy with no coral growth.

On reefs studied in 2003 on the eastern side (15 in Fig. 1) the coral cover was about 57.7%, dominated by *Porites* (46%), *Acropora* (22.3 %) and *Echinopora* (22.3 %, mainly *E. lamellosa*). By 2006 coral cover had increased by 17 percentage points (Fig. 2), due to an increase especially in *Acropora,* apparently with aggressive competition from *Echinopora*. A reduction in intact dead coral suggests that new coral growth is covering dead standing reef structure. *Acropora* and *Porites* now dominate the reef, followed by *Echinopora*.

Redskin Island is surrounded by fringing reefs. Reefs to the north have a gentle slope with diverse coral growth that is comparatively healthier in deeper than in shallow water. The dominant species is *Acropora formosa*, unlike the other parts of the island which are dominated by *Porites*. The reef flat on the northeastern side of the island, protected from strong wave action, is wide, while in the rest of the area it is narrow and extends about 30 m from the shore. Reefs to the southeast are patchy and composed of *Porites, Favia, Favites, Acropora* and *Pectinia*. The southwestern and southern areas are mainly rocky with patchy coral growth. The depth of reef areas decreases towards the south. The western reef is narrow with a steep slope to a depth of 15 meters where the seabed is covered by calcareous sand.

Observations made in 2003 on coral reefs in the north, west and eastern sides of the island (16 in Fig.

1) showed an average coral cover 32.6 %, dominated by *Porites* (56.4%), followed by *Echinopora, Acropora, Montipora, Hydnophora, Favia, Lobophyllia, Turbinaria, Pocillopora, Galaxea, Pectinia, Montastrea* and *Symphillia,* with relative abundance ranging from 1 to 8%. Though there was an impact of the tsunami on corals, it is restricted to the outer edge of the reef crest, where some large colonies of *Porites* have been toppled and some of those on the edge of the steep reef slope have slid down into deeper waters. However, many of these colonies have survived in spite of the change in habitat. A moderate reduction in percentage cover was recorded, from 32.6% in 2003 to 25.6% in 2006.

On Jolly Buoy Island coral reefs were surveyed on the north, west and eastern sides of the island in 2003. The average coral cover was 37.4%, with *Porites* dominating the reef (62.3%), followed by *Hydnophora rigida* (11.8%) and *Echinopora* (5.9%). Other genera ranged from 1 to 4% of the coral cover. Post-tsunami surveys revealed an impact only on the eastern side of the island (17 in Fig. 1), with a reduction in coral cover to 28.67% in 2006. The percentage of rubble has increased to 12.8% in 2006 compared to 4.1% in 2003.

Chidiyatapu (18 in Fig. 1) is the southern end of South Andaman Islands. Fringing coral reefs occur mainly in the bay, from about 300m from the shore. The reef ends at Munda Pahad (barren hillock), after which the habitat becomes rocky. The width of the fringing reefs is about 20-30m, followed by a gradual slope down to a depth of 10m and sandy substrate. In 2003 the average coral cover in the area was 51.3%, mainly due to dominance of *Porites solida* and *Porites rus,* and growth of encrusting *Montipora* over dead *Porites* and *Acropora*. The relative abundance of *Porites* was 40.4 %, followed by *Montipora* (28.8%). The relative abundance of *Acropora* was 1.0 %. The survey in 2006 suggests that the tsunami and earthquake had minimal impact on the reefs, recording a coral cover of 47%.

Rutland Island is one of the largest islands in this archipelago. This island has extensive coral reefs, mangroves and turtle nesting beaches. The monitoring site lies on the eastern side of Rutland (19 in Fig. 1). Here, coral growth starts 50m from the shore, the reef slope is gentle and coral growth continues to a depth of 8m, beyond which the bottom is sandy. The coral cover was 26.9% in 2003, dominated by *Porites solida* and *P. lutea* (48.2%) followed by encrusting *Montipora* (10.2%), *Hydnophora rigida and H. microconos* (8.3%) and *Acropora* (7.8%). The tsunami had minimal impact at this site, with the coral cover of 23.2% recorded in 2006.

Table 5 Estimated reef damage in the Nicobar Group of islands. The cause of damage is shown as tsunami (TS) and/or sedimentation (sed).

Island	Cause	Damaged Area (km^2)
Car Nicobar	TS	37.57
Nancowry Group	TS/Sed	88.88
Chowra	TS/Sed	3.37
Trak	TS	0.12
Treis	TS	0.34
Kondul	TS/Sed	0.85
Little Nicobar	TS/Sed	33.11
Great Nicobar	TS/Sed	46.39
Total		210.63

Twins Islands are the southernmost islands in M. G. Marine National Park. Corals occur at a depth of 2 to 12 m. Shallow areas mainly comprise of *Millepora* and *Heliopora,* with a live coral cover around 35-40%. *Porites* was found growing in patches off the southern rocky shoreline. *Acropora* colonies dominated the deeper (10-12m) parts of the reef, with a relative abundance of 10%. Reefs on the eastern side of West Twins Island (20 in Fig. 1) surveyed in 2003 had a coral cover of 35.6%, dominated by encrusting *Montipora* (relative abundance 38.2%), mainly growing over dead *Millepora*. Other major genera were *Millepora* (30.1 %) and *Porites* (19.5 %). Post-tsunami surveys indicated a significant increase in coral cover, to 67% in 2006 (Fig. 2). The reefs have also undergone a change in species composition, with *Acropora, Heliopora, Pocillopora* and *Porites* now dominant. No major changes were evident in algae and soft coral cover.

Cinque Island is situated to the south of Rutland Island. The northern side has a rocky bottom and a steep slope down to 20 m, with sea fans, soft corals and some sporadic growth of sub-massive corals such as *Goniastrea, Lobophyllia, Coeloseris* and *Goniopora*. Currents are strong around the northern tip of the island. Towards the south the gradient of the slope decreases, with sandy bottoms, rubble and coral reefs in the southern portion of the island. Fish diversity is high in this area. Coral reefs were surveyed on the western side of this island (21 in Fig. 1). In 2003 the average coral cover was high (61.2 %), increasing with depth down to 15 m, and dominated by *Acropora* (relative abundance of 46.9%), followed by *Porites* (21.5 %), *Millepora* (5.3 %) and *Favia* (5.0 %).

The 2006 assessment suggests that the reef was affected by the tsunami, with coral cover reduced by a fifth at the monitoring site (Fig. 2). No substantial change in intact dead coral was noticed, but rubble had increased from 7.0 % in 2003 to 20.2 % in 2006, indicating a direct impact of the tsunami.

Nicobar Group

Of the Andaman and Nicobar archipelago, the Nicobar group of Islands was closest to the epicenter of the 2004 earthquake. The resultant displacement of water had a severe impact on these islands, with a tsunami wave height reported at around 12 meters (the seawater first receded to a great extent), causing the death of thousands of people and wiping out coastal habitats. Coral reef destruction was highest in this group of islands, with the submergence of the islands by more than two meters triggering sedimentation that continued for more than 8 months due to the monsoon that followed. Table 5 provides detail on reef area impacted in the archipelago, including sites not surveyed using LIT. Over 200km^2 of coral reef is believed to have been damaged or destroyed.

Car Nicobar Island is surrounded by fringing reefs. Prior to the tsunami the average coral cover in Sawai Bay (22 in Fig. 1) was 72.7%, dominated by *Acropora* spp. and with some large patches of *Millepora dichotoma* and *Porites nigrescens*. The reef profile was a drop to a depth of 4 meters and then a gradual slope to 8 meters over a distance of 60 meters, with the deeper sections dominated by *Porites* colonies.

The tsunami has all but wiped out the shallow reefs in Sawai Bay, with a reduction of coral cover to less than 5% and an increase in rubble to almost 60% of the benthic cover (Fig. 2). The impact was similar on shallow and deeper reefs on the east coast. The damage was restricted to 10 meters in the northern bay and to 25 meters on the east coast, with rubble observed in deeper waters on the eastern coast comprising mainly broken *Acropora* and *Porites* colonies. Debris deposited on the reef included wooden logs and tyres on the northern section, mainly of household materials, window panes and logs in the east.

Some shallow reefs on the eastern side of Car Nicobar survived the tsunami as the orientation of the bay sheltered them from the path of direct as well as refracted tsunami waves. These reefs are now showing signs of recovery from the damage sustained. However, the predominantly sub-massive and slow-growing corals such as Mussids, Faviids and *Porites* are now facing competition from soft corals. While Mussids and Faviids seem to be resisting this competition with some success, *Porites* appears not to be. However, a positive sign is the observation of settlement of juvenile corals on the reefs in Sawai Bay.

The islands of Central Nicobar comprise Nancowry, Camorta, Katchall and Trinket, while Southern Nicobar includes Great Nicobar, Little Nicobar and a few lesser islands. No pre-tsunami data was available for these areas, and due to cyclonic storms and turbulent seas during the post-tsunami surveys methods were limited to rapid assessment and visual estimates of the status of reefs. Results presented below are largely qualitative and indicative in nature and further quantitative studies of the area is recommended.

Live coral cover on the northeastern side of Camorta Island (23 in Fig. 1) was estimated to be around 40%. Reefs in this area are dominated by *Porites, Millepora, Acropora, Pocillopora, Stylopora,* and *Hydnophora*. Physical damage to branching colonies of *Acropora* and *Pocillopora* was observed and evident in the coral rubble, and a few colonies of dead massive and sub-massive *Porites* were seen. This is likely to be an effect of the sedimentation that followed the earthquake and tsunami. An estimated 30% of live coral cover was seen on the southeastern side (24 in Fig. 1) of Camorta, with *Porites* dominating.

The reefs on the eastern side of Katchall Island (25 in Fig. 1) had a live coral cover of c. 40%, mainly comprising *Porites, Millepora, Heliopora Acropora* and *Seriatopora*. Dead massive *Porites* colonies and toppled sub-massive colonies were observed, implying a direct impact of the tsunami waves.

Trinket Island residents reported that 10-12 m high tsunami waves had covered this entire island, causing major damage to the surrounding coral reefs. This was evident from the widespread distribution of rubble on the western side (26 in Fig. 1) dominated by fragmented *Acropora,* interspersed with small patches of live coral.

On Great Nicobar Island, the southernmost island of the Nicobar Group, the western side of Campbell Bay (27 in Fig. 1) was surveyed. The average coral cover was 10% dominated by *Porites*.

Pigeon Island is situated on the north-eastern side of Great Nicobar Island. Surveys on the eastern side of the island (28 in Fig. 1) indicate an average coral cover of 20%. Toppled colonies of massive and sub-massive *Porites* were seen.

Little Nicobar Island has a mountainous terrain and few beaches. Tsunami waves have ploughed into the mountainous terrain destroying vegetation all along the shore. The island has subsided by 2-3 m and land up to 50 m from the previous high tide mark has been engulfed by the sea. Coral reefs have been destroyed by direct wave impact as evidenced by the large amounts of coral rubble under water. Sand and silt deposition on dead corals was observed. Surviving coral species include *Heliopora* and *Millepora*, and *Acropora* and *Heliopora* showed signs of regeneration. Coral cover of approximately 30% was seen on the southeastern side of the island (29 in Fig. 1).

Menchal Island, on the southeastern side of Little Nicobar, is uninhabited and is covered by coconut and banana plantations belonging to the Nicobarese of Little Nicobar. Surveys of the western side of the island (30 in Fig. 1) indicated a coral cover of 20%.

Kondul Island is situated to the north of Great Nicobar Island. The island was inhabited by Nicobarese prior to the tsunami, but as the entire coastline has been destroyed the island has become unsuitable for habitation and people of this island have now permanently shifted to Great Nicobar Island. On the southeastern side of the island (31 in Fig. 1) the average coral cover was 10%. Large colonies of dead *Acropora clathrata* were seen.

DISCUSSION AND CONCLUSIONS

The impact of the tsunami differed between the Andaman and Nicobar groups of island. In the Andaman group, coral reefs in channels between small islands were most affected, while in the Nicobar group reefs all around the islands except those sheltered between islands have been affected. As a result of the tectonic activity, the northern islands of the Andaman group have been raised, causing the death of shallow coral reefs due to permanent exposure. Where coral reefs have been uplifted, shallow water reefs have been affected due to altered wave action and localized warming of stagnant sea water. Coral reef destruction due to the tsunami was restricted to shallow areas (up to a 5-meter depth) in the Andaman Islands. In the Nicobar Islands, destruction of coral reefs occurred up to a depth of 20 meters. Severe damage was caused by the impact of the tsunami and in particular the increased sedimentation that followed. Due to the subsidence of the Islands, changed beach profiles and the monsoon, erosion and sedimentation continued for more than 8 months.

Regeneration patterns also differed between the Andaman and Nicobar Islands. New settlement of corals were recorded at several sites in the Andaman Islands but was negligible in the southern group of the Nicobar Islands. In some parts of the Nicobar Islands, hard corals are facing competition from soft corals.

Coral reef research priorities in the archipelago include: resilience of coral communities to changes in habitats and environmental conditions, coral regeneration patterns. emerging coral community structure, and implications for resource species and dependent communities. There is also a need for documentation of regeneration patterns in coral reef communities that have been completely destroyed. Management and conservation initiatives need to mitigate sedimentation effects caused by altered land-use patterns, deforestation and post-tsunami rehabilitation activities, building on available scientific research. There is also a need to create awareness among local communities, including Nicobari tribes, about the destruction of coral reefs and implications for their livelihoods.

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Assessment of Tsunami Impacts on the Marine Environment of the Seychelles

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ABSTRACT

The tsunami that hit the Seychelles islands on 26 December 2004 had traveled approximately 5000 km from the epicenter, offshore Sumatra, in less than seven hours, and had a wave-height of 2.5-4 m at first landfall. This study was conducted as part of the official UNEP Tsunami damage assessment to affected countries of the Indian Ocean, in February 2005. Two major patterns in coral reef damage were noted, dependent on the geographic location of each island, direction of exposure at each site, and reef substrate. The northern islands clustered around Praslin (including Curieuse, La Digue, Felicite and the rocks of Isle Coco and St. Pierre) showed very high levels of damage (approaching 100%) on carbonate reef substrates. By contrast, sites around Mahe showed much lower levels of impact, generally below 10%, due to the shelter provided by the outer northern islands and dissipation of wave energy as the tsunami traveled over the greater distance of shallow water from the outer edge of the banks to Mahe. Granitic surfaces and reefs suffered little damage due to their density and hardness. On solid carbonate reef surfaces attached corals showed little breakage and mechanical damage or overturning. However the majority of true coral reef sites in the granitic islands have a reef framework that was only loosely consolidated due to coral mortality during the 1998 El Niño and subsequent bioerosion. This reef matrix was not robust enough to resist the tsunami waves, either from direct impact of the force of water, or movement of rubble and rocks. In these areas significant reef rubble was moved by the wave and consequently associated live coral colonies were also displaced and damaged. Thus > 50% of substrate damage and >25% of direct damage to corals in northern and eastern-facing carbonate framework sites was recorded, <10% damage in shallow carbonate substrate sites in central, western and southern locations, and < 1% damage on all granitic substrate sites. Coral reefs are very important to the economy, society and infrastructure of the Seychelles – all the damaged northern sites are prime tourist locations for the country, and the most highly damaged terrestrial locations are adjacent to degraded reef areas. Though impacts from the tsunami was less than other threats, such as coral bleaching, they highlight the differential vulnerability of different locations and the need to implement strong measures for reef and coastal conservation.

INTRODUCTION

Background

The Seychelles comprises 115 islands covering a land area of 455 km^2 in the western Indian Ocean, between

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Figure 1. Map of the inner granitic islands (Mahé and the Praslin-La Digue group showing study sites visited during this survey. Sites visited included: Prasling-Curieuse-La Digue - 1. Isle Coco, 2. Felicite, 3. La Digue, 4. Madarin/Red Point, 5. Grande Anse, 6. Coral Gardens, 7. Baie Launay, 8. St. Pierre, 9. Anse Petit Cours. Mahé – 1. Anse Cimetiere/ Moyenne/ Grand Rocher, 2. Airport, 3. Baie Ternay, 4. Anse Royale,

4 and 11°S (Fig. 1). Forty-one islands comprise the inner granitic group of mountainous islands, within a radius of 50 km from the main island Mahe, with Mahe, Praslin and La Digue being the largest and most important for towns and settlement. The outer islands are all coralline and built of old reef carbonate growth, and rise to only a few meters above sea level.

The tsunami

The tsunami wave that hit the Seychelles islands on 26 December 2004 had traveled approximately 5000 km from the epicenter, offshore Sumatra, in less than seven hours. At 13.00 hours waves ranging from 2.5m to 4m in height hit the east coast of Praslin, La Digue and Mahé islands. The effects were felt all along the east coast of Mahé, propagating over a 30 minute period. Refracted waves hit the west coast of Praslin and Mahé 30 minutes to 1 hour after the respective east coasts were hit. Another wave occurred at 17.00 hours, followed by two smaller waves at 22.00 hours and 05.00 hours (on 27 December). The second wave had more or less the same effect as the first because, although smaller, it occurred at high tide. The two smaller waves caused damage only on the west coast of Praslin. The surges caused by the waves flooded the low lying areas of Mahé, Praslin and La Digue and caused widespread damage to beaches, coastal vegetation, roads, bridges, other infrastructure and houses. The flooding continued for a period of about 6 hours. Two people lost their lives.

The tsunami was followed on 27 December 2004 by extreme weather with rainfall reaching 250 mm in the northern and central areas of Mahé. Torrential rains continued for several days. Runoff from the hills formed virtual rivers that swept across the country, causing widespread landslides, tree and rock fall in the northern and central part of Mahé and in other areas, with associated further damage to infrastructure, dwellings and the vegetation on slopes. The rainfall caused more widespread damage to land areas of the Seychelles, thus hampered immediate mitigation and focus on tsunami impacts. Together, these almost simultaneous incidents caused serious damage to the infrastructure of the Seychelles.

The coastlines of the Seychelles granitic islands are of two types: 1) granitic rock which is often steeply sloping or accidented with large boulders and rockfalls; 2) coralline coastlines backed by flat coastal plains and fronted by fringing coral reefs (of either old or recent construction). On the coralline coastlines, the fringing reef crests break waves sufficiently to enable the coastal plains to form from sediment accumulation. Between the reef crest and shoreline, sheltered lagoons may be present, backed by fine sand beaches. Channels in the fringing reefs allow the passage of water in and out of the lagoons with the tides. The flat land, calm lagoons and ocean access of the coralline shorelines have attracted settlement and development, supporting a large proportion of agriculture, urban development and tourism of the Seychelles.

Fringing coral reefs around the central granitic islands have allowed the development of fine sand beaches and lagoons, and settlement of the sheltered coastal plains behind them. Channels through the fringing reefs provide access to the ocean from safe harbours for artisanal fishing boats and pleasure craft. The same coral reefs provide the primary infrastructure that supports Seychelles' tourism industry, providing beaches and sites for snorkeling and SCUBA diving. Due to stresses from development and overfishing, and then the mass coral bleaching of

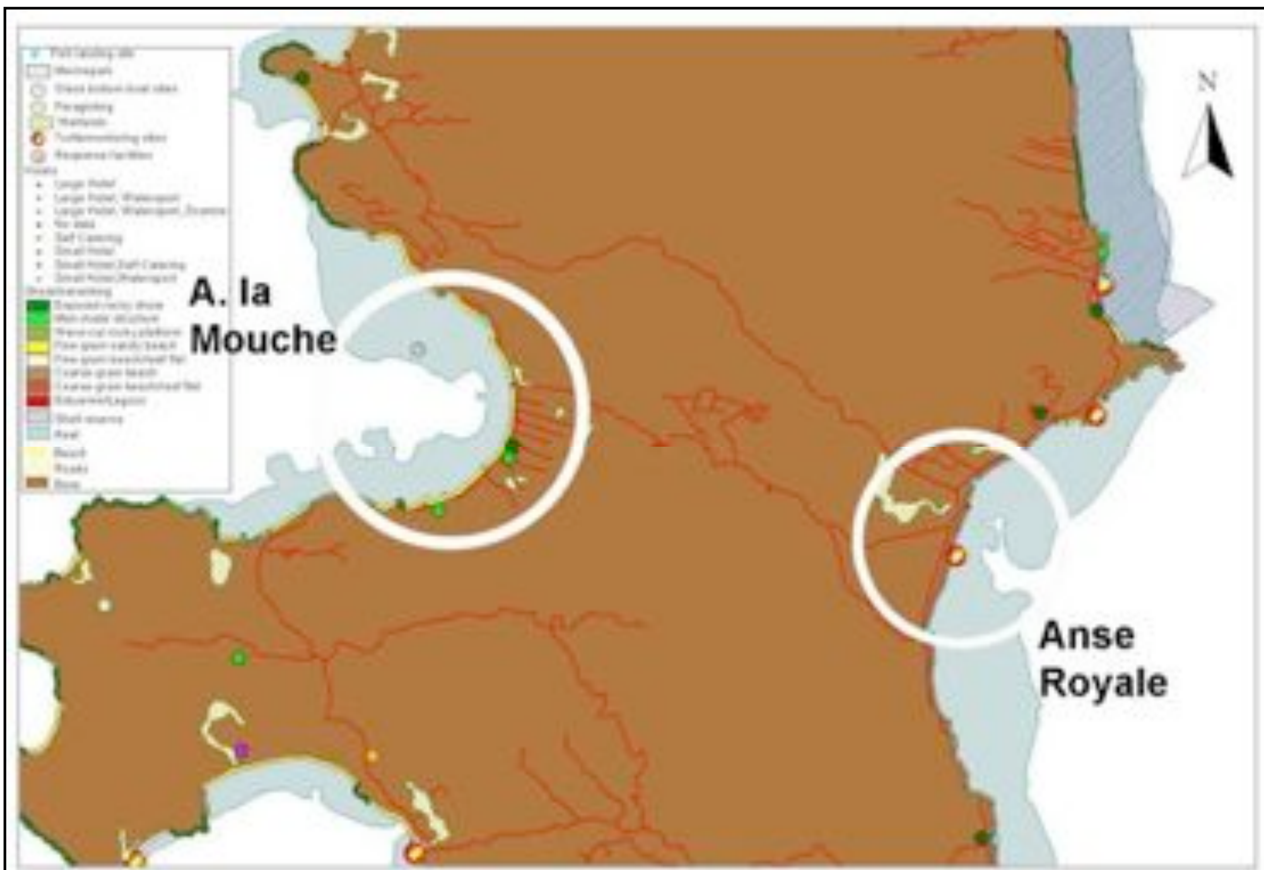

Figure 2. Map of central-southern section of Mahe Island showing areas of maximum terrestrial impacts at Anse Royale and Anse la Mouche channels in the fringing reefs (reefs shown in blue) approach closest to land. Map source: Seychelles Ministry of Environment.

coral reefs in the Indian Ocean in 1998 that caused 80-90% mortality of corals, many of the granitic islands' coral reefs are significantly degraded.

Terrestrial Impacts

Impacts of tsunami waves are strongly affected by the shape and bathymetry of reefs and channels to the open sea –reef crests, complex coral reef surfaces and granitic shorelines absorb and dissipate the wave energy, while deep channels allow focusing of the waves closer to land and lead to higher wave heights. The importance of the coral reefs is shown by the locations of major terrestrial and coastline damage, and the influence of these marine ecosystems on shoreline vulnerability (Fig. 2). The major locations of terrestrial damage, at Anse Royale and Anse Mouche, on Mahe, and to the seawall in Curieuse Marine Park, are located on fringing reef coastlines. Significantly, shoreline damage was focused where deep channels lead through or up to the fringing reefs, focusing and amplifying the wave energy to these points. Thus the combined shelter and ocean access that have allowed coastal development just above the high tide line adjacent to fringing reefs contributed to the high vulnerability of these to the tsunami. This vulnerability will also extend to other wave- and storm-related threats, and intensification of these threats through sea-level rise and changes in storm patterns.

METHODOLOGY

As part of the UNEP fact-finding mission, the IUCN Global Marine Program and CORDIO were requested to assess the tsunami impacts on the marine environments of the Seychelles, undertaken from February 3rd-13th, 2005. The study included stakeholder consultation and site visits to eight of the inner islands of the Seychelles (Fig. 1). It was not possible in the time available to include outer atoll islands.

Two survey methods were used. The first was developed as a rapid assessment tool by the SCMRT-MPA in conjunction with the Marine Unit in the Department of Environment, and conducted by staff and rangers at MPA and other sites on Mahe, Praslin and Curieuse (SCMRT 2005 a,b,c). Four observers conducted approximately 10-minute samples, each assigned some of 7 coral taxa/groups (*Acropora*, other branching corals, foliose, massive, encrusting, fungids and soft corals). Colonies were recorded as damaged or undamaged (broken or overturned) along with general observations on the status of the reef. Colonies completely missing due to wave damage were not possible to differentiate using this method. Because the main coral reef areas in the Seychelles were significantly affected by high mortality in 1998 and had weak eroded frameworks at the time of the tsunami, it is likely that many coral heads were completely removed from the study sites, and thus not recorded. Surveys were conducted in 3 periods covering Mahé (30 December 2004), Curieuse (5 February) and Praslin (5 February).

The second method used was an ICRI/ISRS (International Coral Reef Initiative/International Society for Reef Studies) methodology for assessment of damage from the tsunami to coral reefs, developed during January 2005 (ICRI/ISRS 2005), using a 0-5 semi-quantitative scale (Table 1). This method recorded a broader variety of variables including damage to live corals, damage to the substrate and debris from the terrestrial environment. The method is based on samples of $10m^2$ areas of the bottom, selected haphazardly during swims across the sample area.

Table 1. Classes used for estimation of benthic cover and the incidence / abundance of tsunami damage indicators. Based on Australian Institute of Marine Science long term monitoring programme and English et al. 1997.

Class	*Range (%)*	*Desc*
0	0	None
1	1-10	Low
2	11-30	Medium
3	31-50	Common
4	51-75	High
5	76-100	Extreme

Details of the method can be obtained from the authors and the UNEP website (http://www.unep-wcmc.org/latenews/emergency/tsunami_2004/coral_ass.htm).

RESULTS

In general, the extent of the damage caused by the tsunami will mainly depend on the slope and topography of the seabed. On gradually sloping shorelines, the energy of the wave appears to build up, sucking water away from the shore, followed by powerful flooding waves and surge transporting vast amounts of water and unconsolidated rubble. Direct damage of the tidal waves results from the massive water flows and associated kinetic energy while indirect effects include sediment deposition and land-based pollution (nutrients, pesticides, industrial and urban chemicals, biological material) brought by the backwash. Increases in turbidity and organic carbon, as a result of this pollution, may result in oxygen depletion, potentially detrimental to fish, corals and seagrasses.

Primary Impacts to Coral Reefs

Coral reef damage in the inner Seychelles islands was limited principally to physical breakage due to the tsunami waves, surge and, potentially, backwash. Damage was documented to reef substrates, mobilization of sand and rubble, and damage to live corals. Limited damage from siltation and debris was noted, and no evidence of coral diseases or other effects of pathogens or pollutants was seen. Types of damage are summarized below. The assessment focuses on damage to coral reef habitats, but also mentions associated habitats and species.

Mechanical damage to corals (Fig. 3)

Mechanical damage to corals was documented as breakage of branches and overturning. *Acropora* and *Pocillopora*, being the two main genera of branching corals on Seychelles' reefs were the most frequently observed to be damaged. *Pocillopora* occurs as

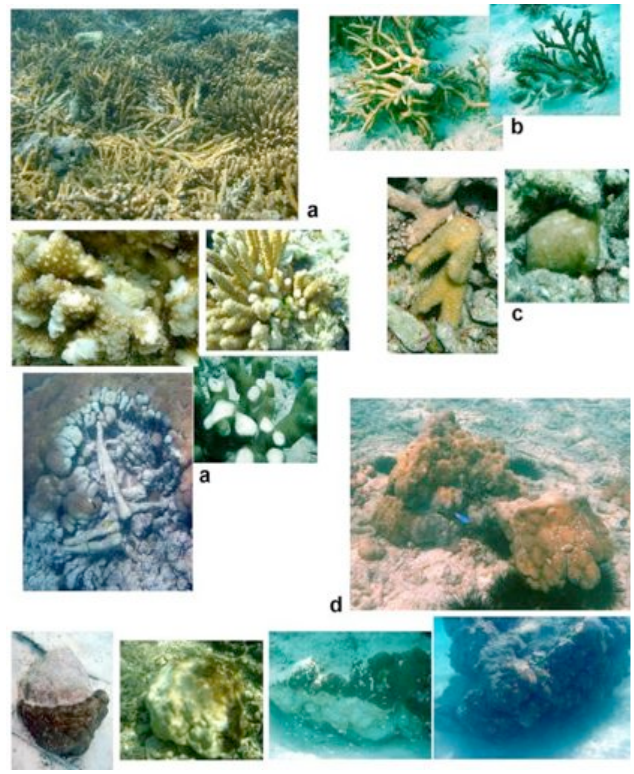

Figure 3. Mechanical damage to corals occurred by breakage of predominantly branching corals and overturning and smothering of massive corals. A) *Acropora* and *Pocillopora* were highly susceptible to breakage, though *Porites* and columnar corals like *Goniopora* also suffered damage. Coral fragments suffered mortality due to partial smothering in sand (b) and in mobile rubble (c). Overturning of massive corals (d) occurred where their bases were only loosely attached, and in sediment where mobilization of sand away from one edge of a large colony could lead to tipping, of boulders > 2 m in diameter. Mortality of massive coral surfaces buried in sand was one of the most significant mortality agents noted.

individual heads up to 30 cm in diameter, and damage was observed as broken branches off a parent colony, and loose branches in the rubble. By the end of these surveys (on February 12, some 48 days or 7 weeks after the tsunami), most broken sections of Pocillopora had not fully healed with incomplete tissue growth over the break. *Acropora* was present as

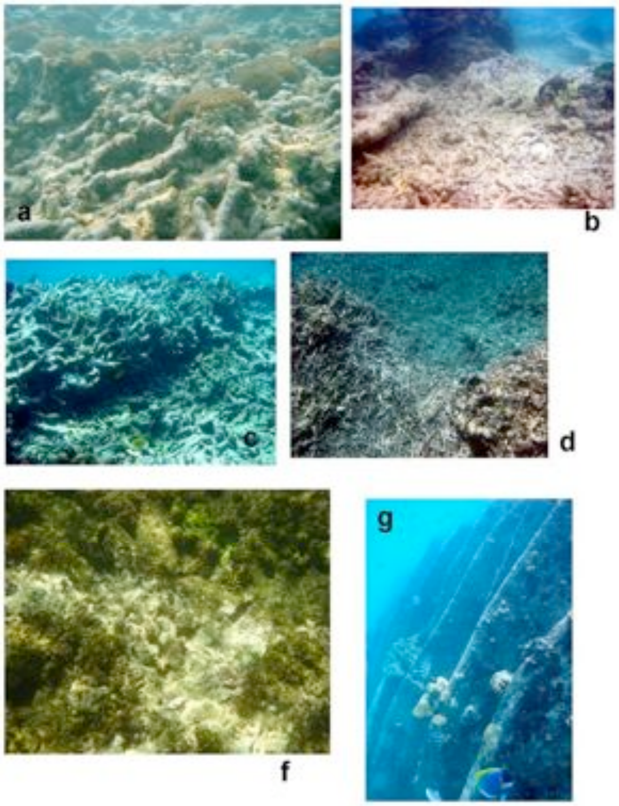

Figure 4. Mechanical damage: a) coralline subtrates showing poorly consolidated framework of branches and rubble, with corals growing on top. This framework was easily damaged (b, c, d) by wave and surge energy, and battering with rubble and rock pieces. F) Damage to consolidate coralline rock shown by scars where protruding corals or rocks torn off. g) No damage was recorded on any granite substrates.

individual colonies and as fields or thickets of staghorn morphologies. The former suffered breaks similar to *Pocillopora*, while for the latter a field could be entirely flattened, with scattered branches in the rubble in all directions, or in a consistent direction.

Mechanical damage to substrate (Fig. 4)

No damage occurred on any granite substrates, nor was there any clear indication of movement of granite rocks and boulders larger than 50 cm or so. Carbonate reef substrates showed considerable signs of damage. In areas of hard old reef framework, minor damage was noted by the presence of scars where rocks and perhaps corals were torn off, but the intensity of damage was low and restricted to areas shallower than 50 cm (e.g. Anse Royale). Coral reefs that were healthy before the 1998 coral bleaching event but suffered high mortality have shown only partial recovery since then, with the result that the reef framework is mostly made up of loosely consolidated coral skeletons and branches. Just before the tsunami, these had a varying degree of live coral attached to the reef or growing on loose rubble pieces of different sizes. These reefs showed severe physical damage by the tsunami waves with widespread rubble, loose rocks, overturned corals and eroded craters showing evidence of movement. Without definitive data before the tsunami it was hard to determine absolute levels of mechanical damage to substrates, however in general it appeared high, and in some cases (e.g. the northerly-exposed sites of I. Coco and St. Pierre) rubble movement and total damage may have been as high as 100%. Before the tsunami many of these areas had low coral cover so damage to coral was minor; however damage to the reef matrix was very high.

Movement of substrate (Fig. 5)

Movement of loose rocks and rubble was a major factor in exacerbating damage to reef substrates and to corals. Granite rocks were too dense and rounded, and showed no evidence of having been moved . Carbonate rocks were extensively moved, in all sizes from small rubble, through large dead *Acropora* tables to massive *Porites* heads over 1 m across. The low density of carbonate skeletons and the often irregular shape of rubble fragments contributed to their ease of movement by waves. In some cases, massive *Porites* heads 2 m in diameter and greater were toppled, though this was likely due to sediment movement, another form of damage described below. In some areas, such as Grand Anse, Curieuse, whole areas of the bottom looked whiter (observation by MPA ranger, Paul Lavigne), due to the overturning of rubble revealing their whiter undersides (with darker algal growth on the upper surfaces).

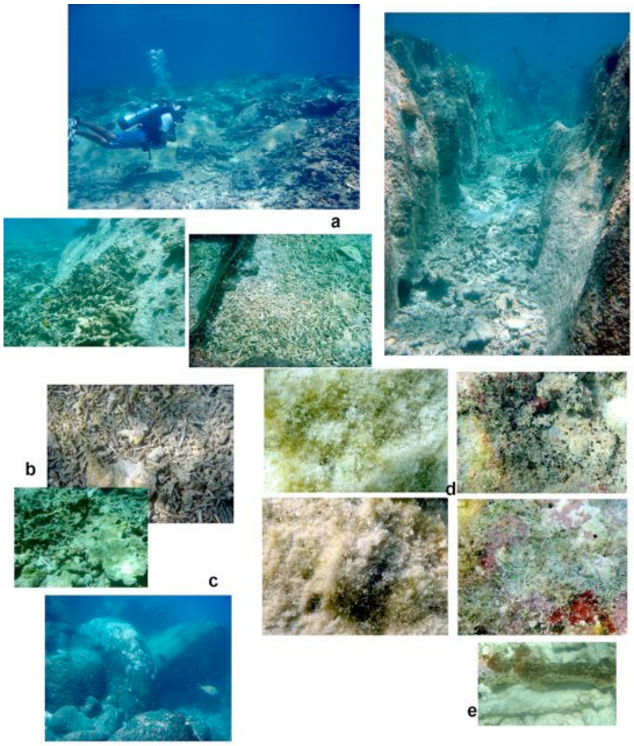

Figure 5. Movement of substrate: a) in areas with rubble and unconsolidated coral framework, extensive movement of broken rubble and pieces occurred, shown by drifts of rubble against immovable granite bedrock. b) detail of coralline rubble showing predominance of branching pieces as well as large flat plates, e.g. from dead *Acropora* tables. c) granite boulders were not moved, being too dense and rounded. d,e) impact of rubble movement visible in algal growth covering the rubble – lower sides (right hand panels and upper branch in e) having coralline algae and other encrusting/boring organisms, upper sides (left hand panels and lower branch in e) covered with fine white sand and short algal filaments representing a few weeks of algal growth. This gave a white appearance to many highly disturbed areas.

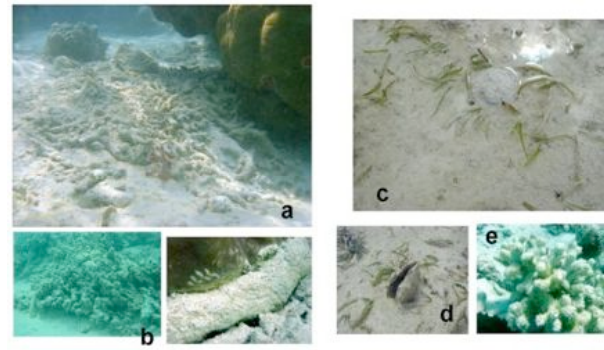

Figure 6. Sedimentation damage: extensive sediment movements occurred due to the surging of waters back and forth by the tsunami, resulting in exposure of buried rubble around many coral bommies, reef structures and channels (a, b). Mobile sediment was deposited over shallow seagrass beds causing high mortality of seagreass and pen shells (d). Fine silt released into the water column by the waves deposited slowly on many rock surfaces, including rubble and newly dead coral surfaces (e).

Sedimentation/siltation (Fig. 6)

The tsunami waves, compounded by heavy rainfall and rough seas in the following week, mobilized extensive amounts of marine and terrestrial sediment. Missing sediment was commonly noted in many reef habitats, where old rubble that had likely been buried in sediment for many years was exposed. These areas were distinguishable because they lacked mature algal communities of filamentous, turf or coralline algae. At distinct reef channels, such as in Baie Ternay, erosion of sediment from the channel edges was noted, up to an estimated 70 cm of sediment lost.

Silt deposition on rock surfaces was noted, in layers up to 2-3 mm thick on surfaces that often had a cover of thin algal filaments. However, because of the time since the tsunami waves, it is possible that more silt had built up because of subsequent factors, or some had been lost. Heavy sedimentation on a seagrass bed was also noted (see above). Interestingly, high siltation was noted only for white carbonate silt, not darker terrigenous soil, suggesting little impact of the heavy rains following the tsunami.

Curieuse Wall and Mangrove Forest

Extensive damage was done to the causeway/wall enclosing a shallow lagoon previously used for turtle farming, and a mangrove forest area in the Marine Park at Curieuse Island. The mangrove forest developed over the approximately 100 years that the causeway has been in place, and is one of the largest in the Seychelles, containing 7 of the 9 species found in the islands. More than one half of the wall was knocked inwards by the tsunami waves, with the principal damage occurring where a channel leads up close to the wall and from this point east to the Park HQ beach. At the time of this study, no damage had been noted to the mangrove forest, as it is sheltered from the winds of the northwest monsoon. However, a wide channel on the beach and near shore was created by the large volume of draining water. This may further develop into erosion of the leading edge of the mangroves, with consequent loss of habitat area and species. The loss of mangrove forests could have major consequences on local marine biodiversity as these areas provide habitats for many juvenile and adult crustacean and fish species. The mangrove forest is one of the primary attractions for visitors to Curieuse Marine Park, accessed using a boardwalk that was also damaged by the tsunami. Without repair to the wall, further damage to the boardwalk will occur during the southeast monsoon and the combined loss of mangroves and boardwalk may significantly reduce financial income from the Marine Park, which subsidizes other protected areas that cannot support themselves.

Site Damage Summaries

Northern islands, north-east exposure

Several sites were surveyed around Curieuse Island, in the Marine Park, including Grand Anse, Baie Launay and sites to the north and west. Overall 8.1% of coral colonies showed signs of tsunami damage and extensive rubble movements were noted on shorelines facing east, south and north. On a deeper site at 8 m east of Curieuse (Coral Gardens), many massive corals were overturned and exposed due to their eroded bases and weak framework. Many live coral colonies (*Acropora*, *Pocillopora* and *Tubipora*) were washed up on the beach. Other damage included broken *Acropora* stands in Resort bay, and damaged turtle nests (see later section).

The coral reef at I. Coco was the farthest-east reef surveyed, and faced directly the path of the oncoming tsunami. St. Pierre is more sheltered, but both sites share a morphology of exposed granite rocks on their seaward side, and an extensive development of reef corals and carbonate framework in the shallows and in the lee of the islands. In both areas, corals on granite substrates showed little damage. However the reef frameworks of dead staghorn *Acropora* exhibited a near-total devastation. Signs of damage included: mobile rubble pieces and broken coral fragments, the accumulation of large amounts of carbonate rubble in drifts up the sides of granite boulders and in depressions, loose dead *Acropora* tables (their large surface area making them easy to move) and craters/depressions in the branching framework where back and forth movement of such pieces by the waves caused erosion of circular depressions. There were also erosion gullies through the framework where large sections of rubble framework may have been transported to deeper water. Damage to the reef framework was consistently estimated at > 50%. Corals close to the bottom on granitic surfaces showed evidence of breakage, likely due to rubble movement along the bottom.

The bay at La Reserve/Anse Petit Cours is west-facing. It was surveyed for two reasons: first, the shoreline and hotel suffered extensive damage, and second, this reef area suffered some of the lowest mortality of coral during 1998. Reef structure is slightly similar to Baie Ternay, with an extensive area of shallows leading out from the beach, and a sloping reef with high coral cover to a sand base at 6 m leading into deeper water. The island shoreline leading west from the bay is steeply sloping, with a fringe of coral growth at 1-10 m depth. Coral diversity was observed to be higher than other locations. Extensive rubble damage was found in the shallows, and because of the higher abundance and diversity of corals, higher levels of breakage of live coral. In particular, flattened areas of staghorn *Acropora* were common (e.g. *A. austera*), and damaged stands of the extensive columnar growth forms of *Goniopora*. Because of the sloping sand base, many *Porites* colonies in waters > 6 m were toppled, due most likely to erosion of sand from under one side and tumbling of the colony/ boulder.

Mahe, north-east exposure

Among all sites on Mahe, damage to coral reefs was highest at Anse Cimetiere with at least 27% of colonies showing signs of physical and mechanical damage. The damage to this site is likely underestimated as most of the coral colonies that were damaged were completely destroyed and therefore were not included in the sampling methodology employed by SCMRT. Historical data of this site show that the reef slope has experienced an 80% reduction of coral cover as a result of the tsunami, from 20% to < 5%.

The coral reef of Baie Ternay Marine National Park, on the northwest tip of Mahe Island, was among the most damaged sites on Mahe (Fig. 7), and illustrated the different types of damage (above) based on habitat and depth. It is a highly enclosed bay, with a reef crest dividing the inner seagrass/beach area from the outer deep bay, the reef crest being just below the surface and reef growth down to 8-10 m. Damage to corals was negligible below about 3 m, but > 10% of vulnerable branching corals at the reef crest were broken. A large proportion of the reef crest is dead branching corals from 1998, however the sheltered bay has enabled complete consolidation of branches and rubble by coralline algae, which prevented re-breaking of the framework by the tsunami. See 'seagrass' section, below, for a description of sedimentation impacts, and beaches around the east and west boundaries of Baie Ternay were built up by sand deposition. Overall, compared to long term damage caused by coral bleaching during the El Niño of 1998, damage from the tsunami event was minor.

Figure 7. Aerial photograph of Baie Ternaie, western point of Mahe, showing major habitats and illustration of primary points of damage: green – shallow seagrass, extensive smothering by sediment and mortality of seagrass and pen shells; black – reef crest and shallow rock/rubble/sand environments with high pre-existing coral mortality from 1998, showing mechanical damage to corals and substrated; red – main coral reef and growth areas, good recovery from mortality in 1998, minor damage to corals little to no damage to substrate; blue – channel, extensive sand-scouring and transport of sand out of channel.

The reef at Anse Royale is an old carbonate platform dominated by fleshy algae (*Sargassum*, *Turbinaria*) due to its highly exposed position to waves from the east and long term degradation from coastal land use. Tsunami damage was surveyed from a depth of 6 m, but was limited to the shallowest 50 cm at the reef crest where scars on the framework show where rocks (or perhaps corals) were ripped off.

Mahé, south-west exposure

Damage to granite reefs at the southern-most point of Mahe and in Port Launay was negligible. In the large bay of Anse la Mouche/Anse Copra corals grow in typical sheltered backreef areas, dominated by opportunistic species on eroding substrates in the shallows, and deeper reefs dominated by large massive corals. The area is impacted by eutrophication from land and overfishing, with large sea urchin populations. Damage was patchy, with some areas showing no damage. However in some locations on the deeper reefs below 5 m staghorn *Acropora* coral heads were broken by the waves. In the shallows large massive corals were toppled as their bases are highly bioeroded and likely also be sediment displacement from underneath. In the shallows small branching corals were completely undamaged. Overall, coral damage was less than 5%. A layer of sediment appeared to have been removed from the reef, with extensive fields of fine rubble visible in the channels between coral heads.

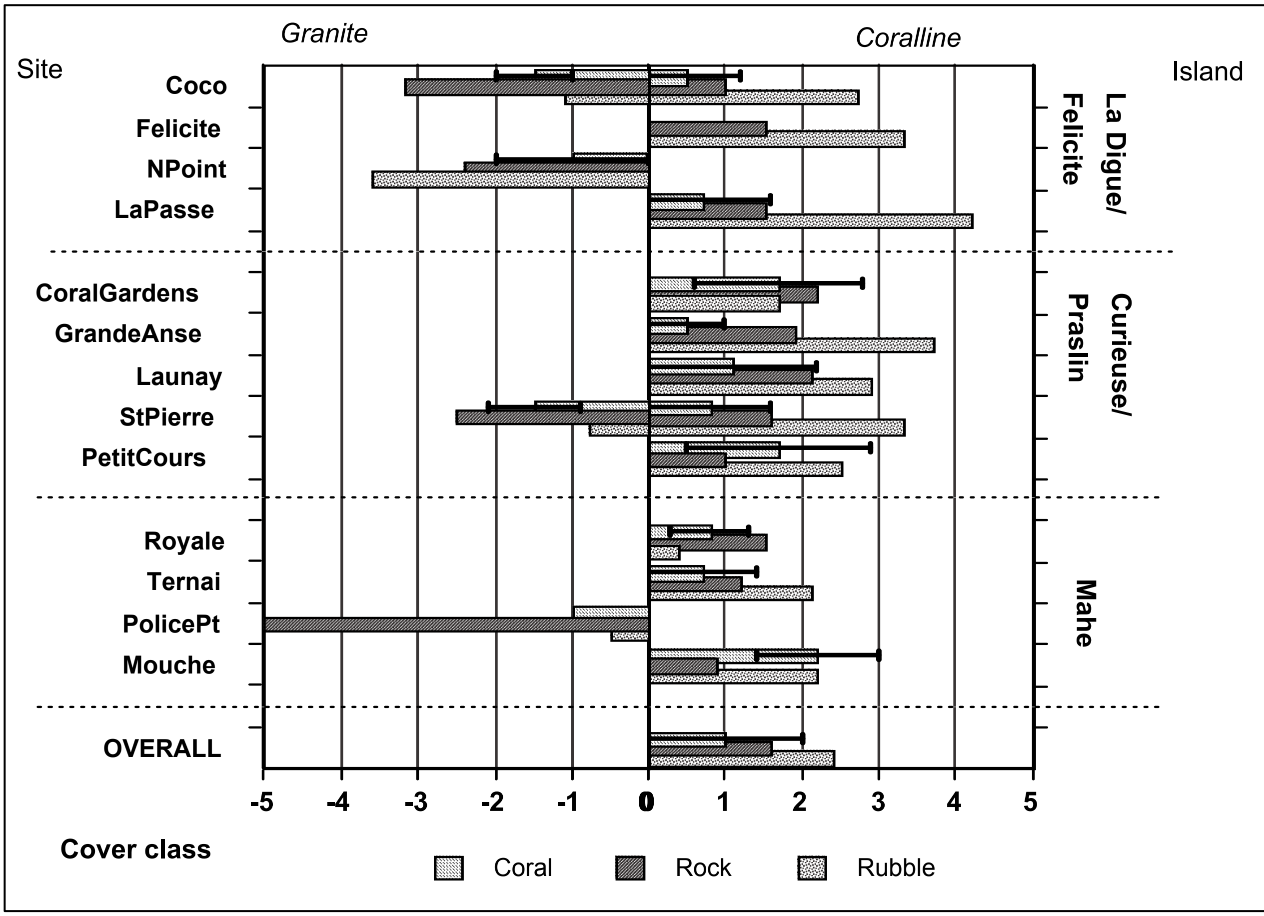

Figure 8. Benthic cover status at study sites on Mahé, Praslin and La Digue, separated by granitic or coralline substrate type.

Damage to Seagrass Beds

Damage to seagrass beds in the Seychelles was low, with only one definite case of damage recorded at Baie Ternay Marine Park (above). Suspension of sediment and erosion of the reef channel resulted in the burial and smothering of the shallow seagrass area between the reef crest and beach inside the bay. Some of the seagrass areas appeared to be recovering as the excess sediment is being removed by normal tidal and wave action, exposing smothered seagrasses (though some still living) and dead pen shells. Mortality of pen shells (*Pinna* sp.) living in the seagrass beds was high, with many of the shells now exposed 1-2 cm above the substrate. This may indicate a minimum depth of newly deposited sand, and (unsuccessful) attempts by the bivalves to burrow upwards to avoid smothering. At the boundary between seagrass beds and the channel, undercutting of the seagrass bed and exposure of roots occurred.

Marine Turtles

The impact of the tsunami on nesting sea turtles in the Seychelles seems to have been relatively minor and what impact there was appears to have been restricted to the inner islands. No obvious damage to nesting beaches was reported from any of the following sites in the outer islands (pers. comm. Jeanne Mortimer): Aldabra (Terence Mahoune), Farquhar atoll (Antonio "Mazarin" Constance), and D'Arros/St. Joseph (Jean-Claude Camille; pers. obs., J.A. Mortimer). Bird Island reported "large tides" but no apparent damage to any monitored turtle nests (Margaret Norah). Aride Island reported two nests destroyed by the tsunami (Dylan Evans). Within the Marine Parks, no apparent damage was reported on the beaches of Ste. Anne Island (Jude Bijoux), but at Curieuse nests were lost at Anse Cimitiere but not at the most important nesting beach Grand Anse (Alain Cedras). At Curieuse, erosion at Grande Anse is the norm at this time of year, but the problem appears to have been exacerbated by the tsunami. At Intendence beach on Mahe no nest damage was recorded (Anders Dimblad).

DISCUSSION

Two major patterns in coral reef damage were noted, controlled by the geographic location of each island and exposure direction of each site, and reef substrate. The northern islands clustered around Praslin (including Curieuse, La Digue, Felicite and the rocks of Isle Coco and St. Pierre) showed very high levels of damage (approaching 100%) on carbonate reef substrates. By contrast, sites around Mahe showed much lower levels of impact. The limited damage on Mahe is due to the shelter provided by the outer northern islands, and energy dissipation of the tsunami traveling over the greater distance of shallow water from the outer edge of the banks to Mahe.

Granitic reefs suffered less damage than reefs with a calcium carbonate substrate (Fig. 8). Granitic surfaces were either immovable as they form the bedrock of the islands, or in the case of boulders and rocks, are too dense and of a compact shape to be displaced by the force of the tsunami. Even on carbonate rock surfaces that were consolidated and firm, attached corals showed little breakage and mechanical damage or overturning. However the majority of true 'coral reef' sites in the granitic islands have a reef framework that is loosely consolidated due to mortality during the 1998 El Niño and subsequent bioerosion. This reef matrix was not robust enough to resist the tsunami waves, either from direct impact of the force of water, or movement of rubble and rocks. In these areas significant reef rubble was moved by the wave and consequently associated live coral colonies were also displaced and damaged. We documented > 50% of substrate damage and >25% of direct damage to corals in northern and eastern-facing carbonate framework sites), <10% damage in shallow carbonate substrate sites in central, western and southern locations, and < 1% damage on all granitic substrate sites. Given the importance of coral reefs to the economy and social structure of the Seychelles (e.g. all the damaged northern sites are prime tourist locations for the country) this provides a strong threat to the country and requires action for mitigation.

An important correlation between coral reef location (coastal geomorphology) and shoreline damage was noted. Most damage to shorelines occurred where fringing reefs and bays with extensive coral development occur – e.g. Anse Petit Cours (Praslin), the causeway (Curieuse), Anse Royale (Mahe) and Anse la Mouche (Mahe). At these locations, development immediately above the high tide line was made possible by the protection offered by fringing reefs. However the reefs offered only limited protection from a wave the size of the tsunami, and maximum damage occurred where reef channels cut in closest to land (the causeway at Curieuse, Anse Royale, Anse la Mouche). Thus the vulnerability of the low coastal plains to wave damage was clearly shown by the tsunami. While fringing coral reefs protect these shorelines during regular conditions, their protection was limited during this extreme event.

Along with the high vulnerability of coral reefs in the northern islands, the Curieuse Marine Park suffered damage to its infrastructure (UNEP 2005). The wall protecting the mangrove forest and artificial lagoon was damaged, which will expose the high-diversity mangrove stand to erosion during the southeast monsoon. Additionally, infrastructure of the MPA was damaged, including boat engines, electrical equipment and physical facilities on land.

Tsunami damage to coral reefs in the Seychelles was severe on the northern carbonate-framework reefs, but minor elsewhere. These damages, occurring while reefs were still recovering from 80-90% mortality of corals during 1998, point to a critical vulnerability of the coral reefs of the Seychelles. The El Niño in 1998 created extensive rubble fields from death and breakage of the fast growing branching corals (*Acropora* and *Pocillopora*) that dominated the shallow waters of Seychelles reefs (Jennings et al. 2000). At the time of the tsunami, the primary reef carbonate frameworks in the granitic islands were relatively weak physical structures, consisting of attached and loose calcium carbonate pieces of varying sizes. These may become strongly consolidated by coralline algae growth over 5-10 years under good conditions (e.g. observation from Baie Ternay). The chemical and biological consolidation into a rigid reef framework, such as that found on some fringing reef sites (e.g. Anse Royale) may take hundreds to thousands of years. Only 6 years after the bleaching, the loosely consolidated reef frameworks were not able to resist the force of the tsunami, resulting in severe movement of rubble and breakage.

In the short to medium term, any mitigation activities will have to deal with the problem of loose reef frameworks and the long time needed for reef matrix consolidation, in order to promote coral reef recovery and growth. In the medium to long term, damage from the tsunami should be considered in the context of Seychelles as a Small Island Developing State. As such, it has a particular vulnerability to shocks and threats due to its small size, from natural disasters to economic and global political influences. While damage from the tsunami was not catastrophic to coral reefs, it significantly worsened the catastrophic impact of coral bleaching 6 years previously, with impacts focused on the most vulnerable, and most valuable, coral reef areas. On these reefs, the tsunami set back biological recovery of corals by 6 years. Because of the extensive physical damage to the reef matrices, however, the set back to overall reef recovery may be much longer than that.

The interaction of these two types of threats in the medium to long term will be particularly important for the Seychelles – physical exposure to extreme waves events, and their increasing severity due to climate change – rising sea level, northwards migration of the cyclone belt in the southern Indian Ocean, and increasing severity and frequency of major storms. While the occurrence of another tsunami cannot be predicted, the increasing severity of the threat from waves to the Seychelles is clear. Broad principles reflecting the importance of coral reefs to Seychelles were used to develop recommendations for mitigation:

I. Improve capacity for assessment of coastal health and vulnerability to waves and storms, using on bathymetry, coastal topography and coral reef status;
II. Improve watershed management that minimizes downstream and marine impacts of water use and treatment, to maximize the recovery potential of coral reefs impacted from multiple threats including eutrophication, overfishing and coral bleaching;
III. Integrate ICZM and Marine Protected Area management frameworks covering all of Seychelles' coastal and EEZ waters, recognizing the coastal protection benefits of healthy coral reef ecosystems.

As part of the UNEP assessment mission, a number of short to long term recommendations were made to respond to the tsunami damage. Briefly, these included:

1. Mitigation of tsunami damage and enhancement of coral reef recovery - rehabilitation and restoration technologies for coral reefs are in their infancy, but studies should be initiated to address the key factors of substrate stability, water quality improvements to enhance coral survival and enhancement of natural recruitment and survival of small corals.
2. Assess and replace lost infrastructure of Curieuse Island Marine Park, in particular to protect the mangrove forest.
3. Development of coral reef and environmental monitoring capacity at SCMRT-MPA and strengthening of the Seychelles Coral Reef Network to ensure complementarity among

monitoring programmes in the Seychelles.

4. Development of a shoreline vulnerability model and planning capacity.

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CORDIO Status Report 2008

Part 4 – Biological Research

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

The Effects of Habitat on Coral Resistance and Resilience to Bleaching

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ABSTRACT

This study examines the bleaching responses of scleractinian corals at four sites in Kenya (Kanamai, Vipingo, Mombasa Marine Park and Nyali) representing two distinct lagoon habitats (relatively shallow and relatively deep). Bleaching responses were monitored for the general coral community and zooxanthella densities and chlorophyll levels were monitored for target species (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*) during a non-bleaching year (2006) and a year of mild bleaching (2007). The objective of this study is to determine whether corals in different habitats display varying resistance and resilience to bleaching stress and to indicate which environmental characteristics are responsible for the variation in response. Considerable differences in bleaching responses between shallower and deeper lagoon sites were observed, with shallower sites Kanamai and Vipingo exhibiting much lower bleaching and paling incidence than deeper sites Nyali and Mombasa Marine Park. These shallower lagoons display much more fluctuating thermal and light environments than the deeper sites, with higher maximums, lower minimums, higher standard deviations and higher diel variation. These results suggest that corals in the shallower lagoons have acclimatized and/or adapted to the fluctuating environmental conditions they endure on a daily basis and have become more resistant to bleaching stress. Furthermore, in deeper sites that did exhibit significant bleaching (Mombasa Marine Park and Nyali), it was found that coral recovery occurred more quickly in the protected area compared to the non-protected area.

INTRODUCTION

Climatic changes are causing increased frequency of coral bleaching events worldwide. Coral bleaching events are usually associated with above-average water temperatures and high irradiance levels that cause the disruption of the obligate symbiosis between corals and micro-algal zooxanthellae. The zooxanthellae are expelled and the coral is left in a weakened state that can eventually lead to mortality of colonies and even a phase shift from a coral-dominated to an algal-dominated reef and a subsequent loss of biodiversity.

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

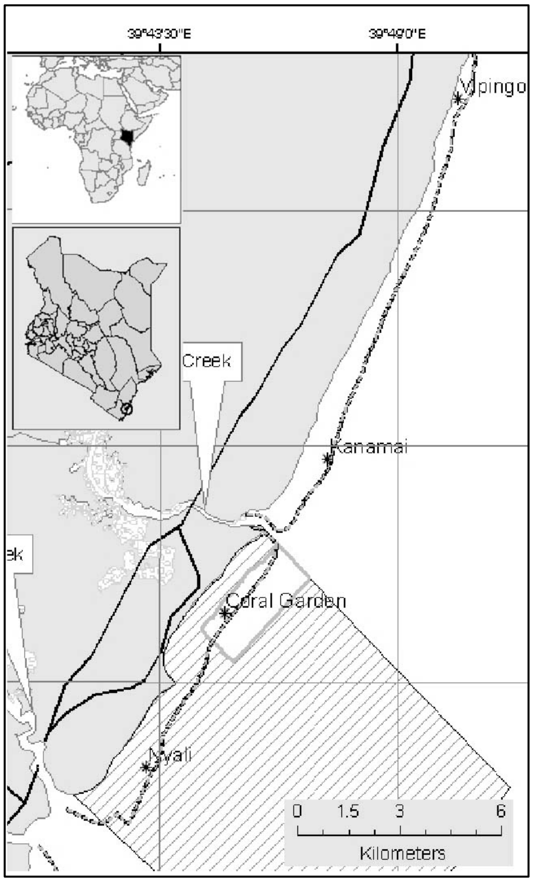


Figure 1. Map of study sites.

However, it is possible for corals to either resist conditions that cause coral bleaching or to recover from bleaching events (resilience). Resistance can be defined as the ability of an ecosystem or individual to withstand disturbance without undergoing a phase shift or losing neither structure nor function (Odum, 1989). Resilience can be defined as the ability of a system or an individual to absorb or recover from disturbance and change, while maintaining its functions (Carpenter et al, 2001). Several ecological and environmental factors can affect a coral reef's resistance and resilience to bleaching events. These include the coral reef's community species composition, herbivory levels, zooxanthellae population, temperature and irradiance history, connectivity to other reefs, water movement, and shading or screening properties (Grimsditch and Salm, 2006; Hoegh-Guldberg, 1999; West and Salm, 2003).

Furthermore, it has been shown that it is possible for colonies to acclimatize to increased temperatures and high irradiance levels so that they are able to resist bleaching events when they occur. Acclimatization can be defined as the ability of an organism to undergo phenotypic changes in response to stress in the natural environment that result in the readjustment of the organism's tolerance levels to that stress (Coles and Brown, 2003). Threshold temperatures that induce coral bleaching-related mortality vary worldwide (from 27°C in Easter Island; Wellington et al, 2001, to 36°C in the Arabian Gulf; Riegl, 1999) according to the maximum water temperatures that are normal in the area, implying a capacity of corals and/or zooxanthellae to survive higher temperatures for a certain period of time. Furthermore, corals that are regularly exposed to stressful environmental conditions have been shown to acclimatize and exhibit physiological tolerance to elevated temperatures and UV-radiation that exceed normal thresholds (Brown et al, 2000; Brown et al, 2002a; Brown et al, 2002b, Coles and Brown, 2003).

In order to combat the worst effects of climate change and to conserve this valuable ecosystem, it is important to determine which factors affect coral reef bleaching resistance and resilience and to apply this knowledge in management plans. Although bleaching events cannot be prevented by managers, by implementing appropriate management responses it is possible to help a coral reef recover from bleaching and to mitigate the worst effects.

This study examines the bleaching responses of corals at four sites (Nyali, Mombasa Marine Park, Kanamai and Vipingo, Fig. 1) representing two distinct lagoonal habitats on the Kenyan coast (deeper and shallow lagoons). The sites were characterized using environmental parameters such as depth, water flow, light and temperature. Bleaching responses were monitored for the general coral community and zooxanthellae densities and chlorophyll levels were monitored for target species (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*) during a non-bleaching year (2006) and a mild bleaching year (2007). The objective of this study is thus to determine whether corals in different habitats display different bleaching responses (i.e. resistance and resilience) and to suggest which environmental characteristics are responsible for the variation in response.

MATERIALS AND METHODS

Five large and healthy coral colonies for each target species (*Pocillopora damicornis*, *Porites cylindrica* and *Porites lutea*) were mapped at two shallow lagoons (Kanamai and Vipingo, 0.4m depth and 0.6m at low tide respectively) and two deeper lagoons (Mombasa Marine Park and Nyali, 1.4m and 1.8m depth at low tide respectively) along the Kenyan coast (Fig. 1). Target species were chosen according to general abundance and bleaching susceptibility, with one highly susceptible (*Pocillopora damicornis*), one moderate (*Porites cylindrica*) and one tolerant (*Porites lutea*) target species. Coral size class and line intercept transect data were also collected for two fixed 25x2m transects at each site.

The bleaching season in Kenya occurs during the late northeast monsoon from mid March when doldrum conditions become most intense to late April when the first storms of the southeast monsoon induce cooling of surface waters. In the two years of the study, sampling began before bleaching during the northeast monsoon (February and early March), continued during bleaching season of the northeast monsoon (late March and April) and finished during the recovery period of the southeast monsoon (May, June and July).

Coral fragments were collected from the mapped colonies using a chisel. The fragments were transported to the laboratory submerged in seawater in small plastic bottles and were held in an aerated seawater tank. Coral tissue was removed from the skeleton using a water jet. Seawater was then added to the tissue to make up a practical volume, usually 500 ml. The tissue slurry was homogenised and 1.0 ml of homogenate was loaded into a Sedgwick-Rafter chamber. Using a compound binocular microscope and a magnification of x400, the number of zooxanthellae in 10 random quadrats was recorded. The counting chamber was then reloaded and another 10 random quadrats were counted. The area of the coral skeleton was measured using the foil method; the area/weight ratio of aluminium foil was determined and coral skeletons were then wrapped in this foil. The foil was then trimmed to fit the skeleton area and weighed. Using the weight of the trimmed foil and the area/weight ration for the foil, the skeleton area could be determined.

To measure chlorophyll *a* levels, a known volume of the sample was filtered through a GF/F filter paper and the filtrate was dissolved in 10ml of 90% acetone. It was then centrifuged for 10 minutes at 2000rpm and the chlorophyll absorbance was read using a spectrophotometer.

If it was observed, bleaching incidence was recorded in the water using a random swim method. This consists of noting the size class, genus and bleached/pale/dead percentages of each bleached colony in 20 haphazard $2m^2$ areas at each site.

Water temperature was monitored using underwater temperature loggers that were left at each site during the entire duration of the study. Light was monitored using a light meter for only 24-hour periods on the same day at each site to avoid theft and overgrowth of the light meter. Water flow was measured using a clod card method (McClanahan et al, 2005). Plaster-of-Paris clod cards were made in an ice-cube tray, dried and weighed before being deployed in the field in small net bags that were tied to the substrate. They were collected 24 hours later, dried and weighed again in order to determine how much had dissolved.

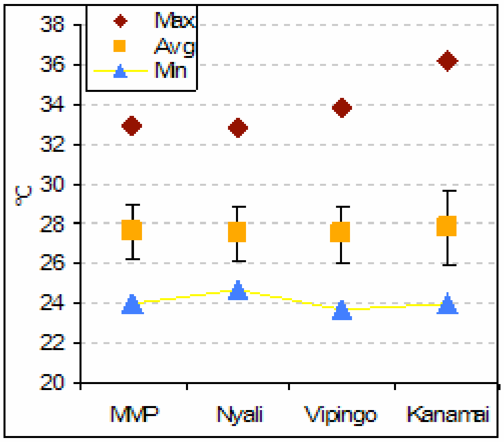


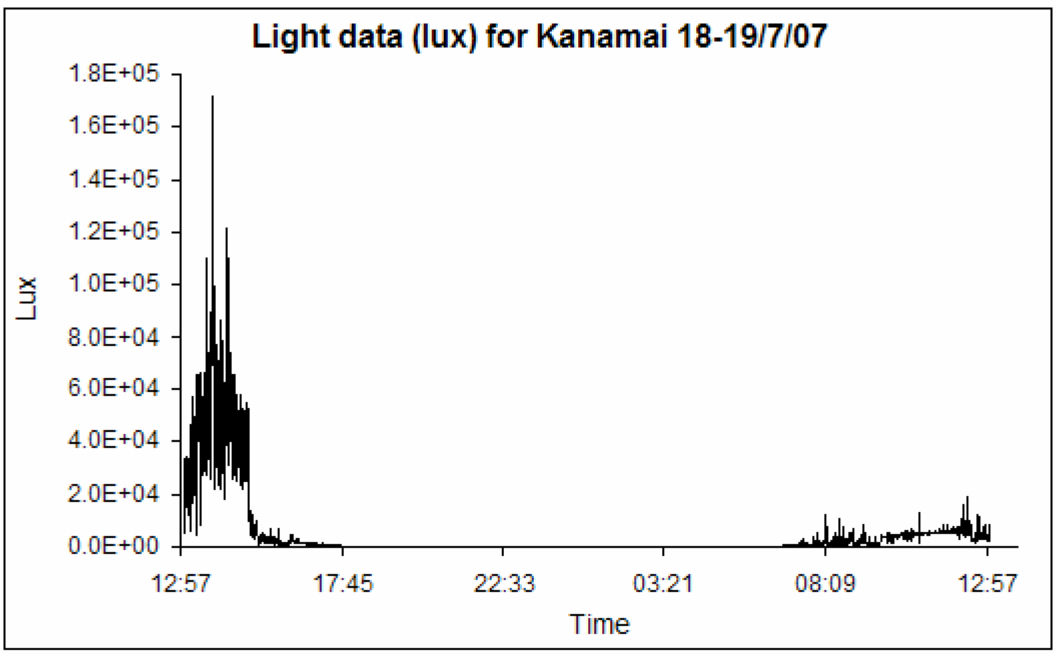
Figure 2. Average (±standard deviation), maximum and minimum water temperatures during study period.

RESULTS

Temperature

The shallow lagoons Kanamai and Vipingo displayed the most extreme temperature conditions, with higher standard deviations (±1.9°C and ±1.5°C respectively), higher maximum temperatures (36.2°C and 33.8°C respectively), lower minimum temperatures (24.0°C and 23.7°C respectively) and bigger differences between diurnal and nocturnal temperatures (+0.9°C and +0.4°C respectively) than the deeper lagoons. Between the two, Kanamai displayed the more extreme fluctuations, as well as the highest average temperature overall (27.8°C) (Fig. 2).

The deeper lagoons of MMP and Nyali displayed less pronounced temperature variations with lower standard deviations (both ±1.4°C) as well as smaller



Site	Average	Standard deviation	Max
Kanamai	4,913	14,315	170,846
Vipingo	4,758	10,489	110,223
MMP	518	879	5,167
Nyali	n/a	n/a	n/a

Figure 3. Light levels during a 24-hour period (18-19 July 2007) at Kanamai. Light data for each site during the same period is summarized and tabulated below the graph. All data is in Lux.

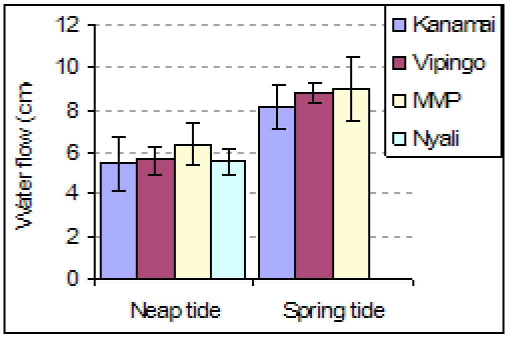


Figure 4. Average water flow (cm/s) at sites for neap and spring tides over a 24-hour period. Unfortunately, data for Nyali spring tide is unavailable due to technical difficulties.

maximum-minimum (+8.9°C and +8.1°C respectively) and diurnal-nocturnal (both +0.2°C) differences than the shallower lagoons. However, the deeper lagoons displayed bigger temperature increases from the 2006 to 2007 northeast monsoon bleaching seasons, with a +0.9°C increase in Nyali and a +0.8°C increase in MMP compared to a +0.7°C increase in both Kanamai and Vipingo.

Light

As expected, the shallow lagoons Kanamai and Vipingo also displayed more extreme light regimes than the deeper lagoon MMP. Unfortunately, light data for Nyali was not available due to technical problems. Kanamai (4913±14,315 lux) and Vipingo (4758±10,489 lux) both displayed much higher average light levels, higher standard deviations and higher maxima (70,846 lux and 110,223 lux respectively) than MMP (average of 518±879 lux, maximum of 5167 lux) (Fig. 3). Although light data is unavailable for Nyali, it can be assumed that the light regime is similar (with perhaps even lower averages) to MMP due to the depth and sediment levels of the site.

Water Flow

There was no clear trend between water flow at deeper and shallower lagoons. MMP consistently displayed the highest average water flow during both neap (6.4 cm/s) and spring tide cycles (9.0 cm/s). Kanamai (5.4 cm/s) displayed similar water flow to Nyali (5.5 cm/s) and Vipingo (5.6 cm/s) during neap tide and, although unfortunately data for spring tide at Nyali is unavailable, it appears that MMP stands out as the site displaying highest water flow. Overall, Kanamai displayed the lowest water flow during both neap and spring tides (8.1 cm/s) (Fig. 4).

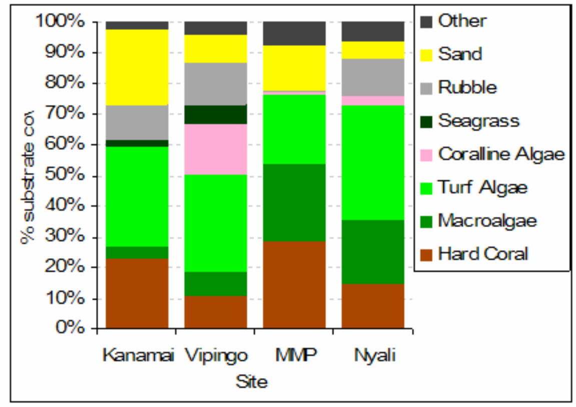


Figure 5. Substrate cover (%) at study sites.

Substrate Cover

MMP and Kanamai displayed higher hard coral cover (28.4% and 23.0% respectively) while Nyali and Vipingo displayed lower hard coral cover (14.7% and 10.6% respectively), showing no trend with depth. Macroalgal cover was higher in deeper sites MMP (25.5%) and Nyali (21.0%) than in shallower sites Vipingo (8.3%) and Kanamai (3.7%) (Fig. 5).

Coral Cover

All sites are dominated by massive and branching *Porites* colonies. 90.5% of MMP, 80.3% of Kanamai, 59.9% of Nyali and 42.2% of Vipingo coral cover was massive and branching *Porites.* Vipingo (10.2%) and Nyali (8.3%) displayed the highest relative coral cover of the more bleaching-susceptible genera *Acropora* and *Pocillopora*. *Acropora* and *Pocillopora* only accounted for 3.7% of Kanamai's coral cover and 0.7% of MMP's coral cover (Fig. 6).

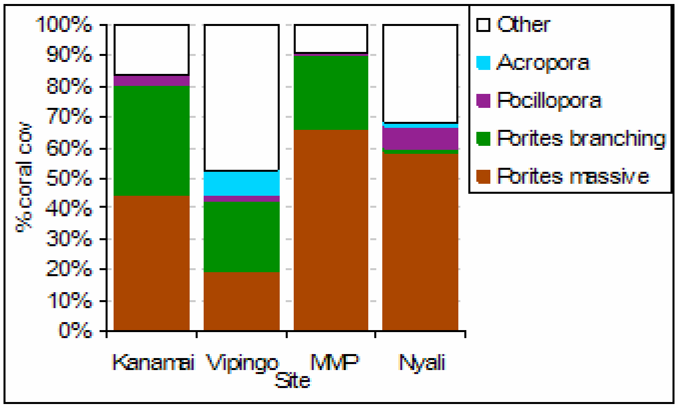


Figure 6. Percentage of coral area covered by each genus.

Bleaching and Mortality Incidence

Bleaching was first observed during late April of 2007. The shallow lagoons Kanamai and Vipingo exhibited lower levels of combined paling, bleaching and mortality (4.4% and 6.3% of total coral area respectively) than the deeper lagoons Nyali and MMP (35.1% and 26.9% of total coral area respectively). During the recovery period, MMP still exhibited relatively high bleaching incidence (9.8%) but low mortality (0.9%). Nyali exhibited the highest mortality (11.7%) and also relatively high bleaching (4.5%). In July, mortality increased to 13.1% in Nyali and 2% in MMP, but bleaching incidence in MMP decreased to 6.0%, indicating recovery (Fig. 7). Overall, *Pocillopora* and *Porites* accounted for the highest proportion of bleached colonies, but differed greatly in their mortality rates. In MMP, Nyali and Vipingo, *Pocillopora* accounted for 37%, 47.1% and 33.3% of bleached colonies respectively. In Kanamai, MMP and Nyali, *Porites* accounted for 47.2%, 28.3% and 13.8% of bleached colonies respectively (Fig. 8). However, during the recovery period of June and July, *Porites* experienced low bleaching-related mortality while *Pocillopora* experienced high mortality. *Porites* colonies only experienced mortality in Vipingo, where they accounted for 12.5% of total bleaching-related

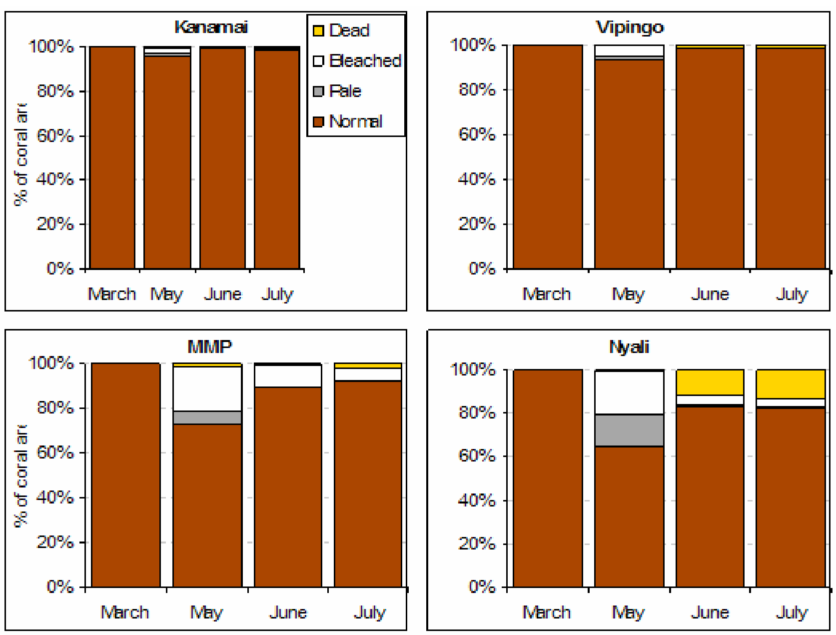


Figure 7. Bleaching, paling and mortality incidence during 2007.

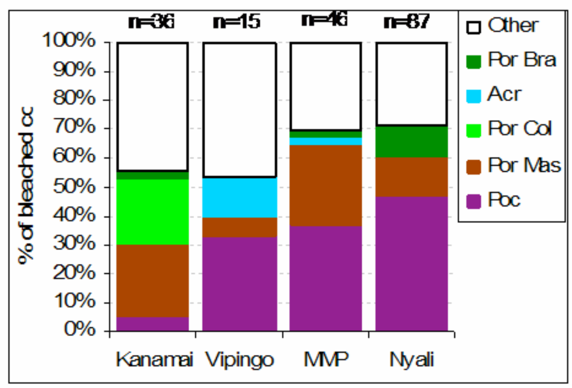


Figure 8. Proportion of bleached corals by genera.

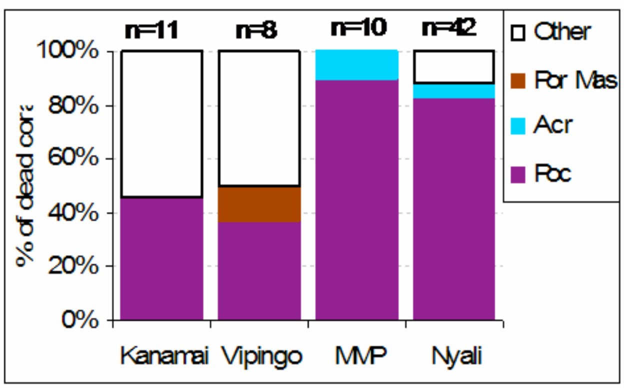


Figure 9. Proportion of corals exhibiting bleaching-related mortality by genera.

mortality, whereas *Pocillopora* accounted for the highest proportion of bleaching-related mortality in all sites (from 37.5% in Vipingo to 90% in MMP; Fig. 9). Furthermore, of the three species only *Pocillopora damicornis* suffered significant mortality in both 2006 (50% overall mortality) and 2007 (47% overall mortality) with colonies in Kanamai experiencing the lowest mortality rate in both years.

Zooxanthellae Densities

Average zooxanthellae densities for marked colonies (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*) were higher for all species at all sites in

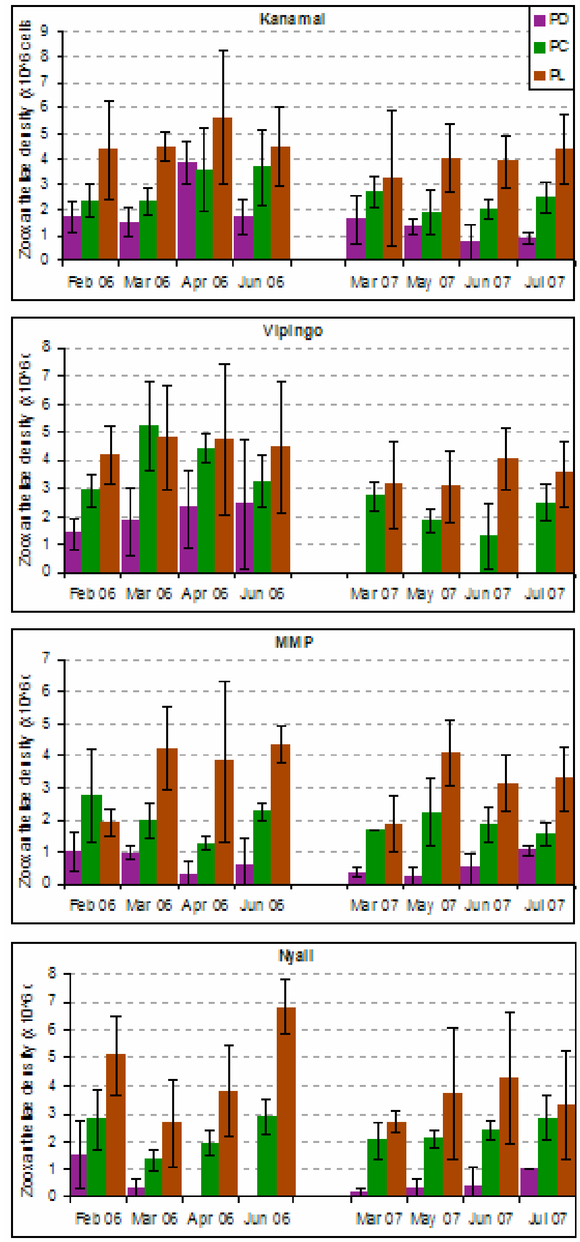
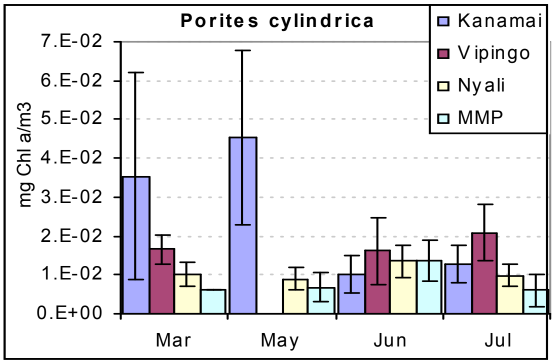
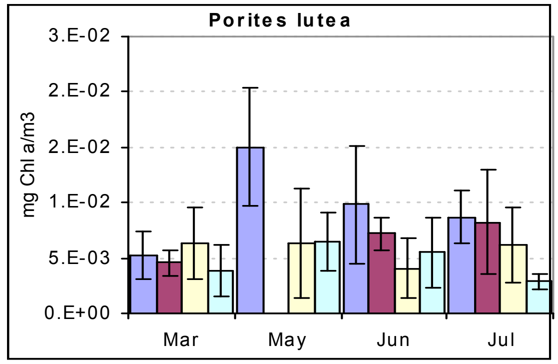


Figure 10. Average zooxanthellae densities for mapped corals (*Pocillopora damicornis*, *Porites cylindrica* and *Porites lutea*) during 2006 and 2007.

2006 than in 2007. Average zooxanthellae densities were also higher in shallower sites Kanamai and





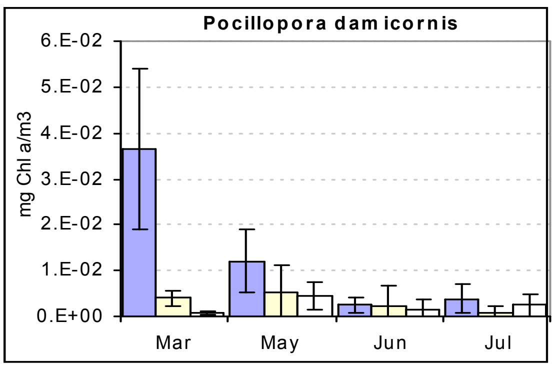


Figure 11. Average mg chlorophyll *a* per m^3 for mapped corals (*Porites cylindrica*, *Porites lutea* and *Pocillopora damicornis*) during 2007.

Vipingo that in deeper sites MMP and Nyali for all species. In general, Kanamai exhibited the highest average zooxanthellae densities while MMP displayed the lowest. *Porites lutea* colonies exhibited the highest zooxanthellae densities while *Pocillopora damicornis* displayed the lowest densities, with *Porites cylindrica* in between the two (Fig. 10).

In 2006, colonies in MMP, Nyali and Kanamai displayed similar zooxanthellae density trends in most species with decreases in the warm months of February and March, and recovery in the following months as temperature decreased. Colonies in Vipingo, on the other hand, exhibited increasing densities for all species during February and March followed by decreases from April to June. In 2007, average zooxanthellae densities in *Pocillopora damicornis* remained very low ($<1x10^6$ cells cm^{-2}) in all sites with recovering densities in July. *Porites lutea* and *Porites cylindrica* colonies showed a general increasing trend in average zooxanthellae densities from March to July (Fig. 10).

Chlorophyll *a* Levels

Chlorophyll *a* concentrations were generally higher at shallower sites Kanamai and Vipingo than at deeper sites Nyali and MMP, and Kanamai exhibited by far the highest chlorophyll *a* concentrations while MMP exhibited the lowest. *Porites cylindrica* consistently exhibited the highest chlorophyll *a* concentrations at all sites, while *Pocillopora damicornis* consistently displayed the lowest concentrations, with *Porites lutea* in between the two (Fig. 11).

Chlorophyll *a* concentrations in *Pocillopora damicornis* colonies generally decreased progressively at all sites from March to July as colonies bleached and failed to recover. *Porites lutea* and *Porites cylindrica* colonies in the shallow site Kanamai displayed peaks during March and then decreasing concentrations to July. In MMP and Nyali, the concentration peaks for these two species were not as pronounced and generally occurred in May or June (Fig. 11).

DISCUSSION AND CONCLUSION

Considerable differences in bleaching responses during 2007 between shallow and deeper lagoonal sites were observed, with shallower sites Kanamai and Vipingo exhibiting much lower bleaching and paling incidence than deeper sites Nyali and MMP in both haphazard sampling and marked *Pocillopora damicornis* colonies. These results suggest that corals in the shallower lagoons have acclimatized to the more extreme environmental conditions they endure on a daily basis and have become more resistant to thermal stress than corals in the deeper lagoons.

Shallow sites Kanamai and Vipingo displayed more extreme temperature and light regimes than deeper sites Nyali and MMP with higher maxima, lower minima, larger standard deviations and larger diel variations. The smaller volumes of water in the shallower lagoons probably explain the difference in temperature and light regimes; shallower lagoons absorb but also lose heat more quickly and attenuate less light than in the deeper lagoons.

Moreover, differences in temperature and light regimes could explain differences in bleaching responses between similar-depth sites. Kanamai is a shallower site than Vipingo, displaying higher average temperatures, standard deviation in temperatures, difference between maximum and minimum temperature, diel temperature variation, maximum light level and standard deviation in light levels. This may explain why Kanamai also displayed lower bleaching incidence and bleaching-related mortality than Vipingo. Similarly, MMP is a shallower site than Nyali, displaying higher average temperatures and difference between maximum and minimum temperature. Nyali experienced increased warming during the 2007 northeast monsoon bleaching period (+0.9°C to 2006) compared to MMP (+0.8°C to 2006). These factors could explain why Nyali exhibited higher bleaching incidence than MMP.

On the other hand, water flow did not correlate well with depth and bleaching incidence, and although corals in Nyali suffered much higher bleaching incidence than Kanamai and Vipingo, all these sites displayed very similar water flow velocities. It therefore appears that light and temperature histories were more influential than water flow in determining the bleaching responses of corals.

Moreover, average zooxanthellae densities and chlorophyll *a* concentrations are higher in Kanamai and Vipingo than in Nyali and MMP, with highest densities in Kanamai. Studies in the region have shown that corals with higher zooxanthellae densities are more resistant to bleaching (Grimsditch et al, 2007), a hypothesis that is further confirmed by these results. In addition, *Porites lutea* displayed the highest densities and was the most tolerant to bleaching, while *Pocillopora damicornis* exhibited the lowest densities and was the most susceptible to bleaching. Zooxanthellae population dynamics could thus also partly explain bleaching responses at different sites.

Interestingly, species that suffered less bleaching (*Porites lutea* and *Porites cylindrica*) did not exhibited decreases in chlorophyll *a* concentrations through time, and actually exhibited increases in chlorophyll *a* during bleaching and recovery months in some cases. However, *Pocillopora damicornis*, which was more susceptible to bleaching, displayed decreasing chlorophyll *a* concentrations with time, indicating that bleaching events cause disruptions in pigments as well as symbionts.

The genus most affected by bleaching at Nyali, MMP and Vipingo was *Pocillopora*, and it accounted for most of the bleaching-related mortality in all sites. *Porites* also made up significant proportions of bleached corals in MMP, Nyali and Kanamai. However, *Porites* colonies hardly exhibited any bleaching-related mortality, showing that although this genus does bleach and pale it is tolerant to bleaching. Despite their susceptibility to bleaching, *Acropora* corals form a very small proportion of bleached corals in most sites because they are scarce, except for in Vipingo where they form a larger proportion of the total coral are and subsequently also a larger proportion of bleached corals.

All sites were dominated by massive and branching *Porites* corals, discounting the possibility that large variations in coral community compositions determined bleaching responses. Bleaching-susceptible genera such as *Pocillopora* and *Acropora* did not necessarily form a larger proportion of the coral population in sites most affected by bleaching. The highest area percentage covered by these genera occurs in Vipingo, which is a shallow site exhibiting low bleaching incidence. However, differences in community composition could partially explain varying bleaching responses between similar-depth sites. Nyali exhibited higher bleaching incidence than MMP and also a higher proportion of area covered by bleaching-susceptible genera. The same applies to Vipingo compared to Kanamai.

During the recovery period, colonies in Nyali displayed higher mortality than those in MMP, while a higher proportion of corals in MMP remained bleached but did not die. It thus seems that colonies in Nyali were being overgrown by algae more quickly than those in MMP, which remained in a bleached state longer. This could be due to the protected status of MMP and the possibility that herbivory levels are higher than in Nyali. In fact, populations of important herbivores such as parrotfish and surgeonfish have been shown to be significantly higher in protected areas than in non-protected areas along the East African coast (McClanahan and Arthur, 2001).

In conclusion, the data from this study show that during the 2007 bleaching season, corals in the shallow lagoons of Kanamai and Vipingo were more resistant to bleaching stress than corals in the deeper lagoons of MMP and Nyali, probably due to a history of higher light and temperature extremes and variation at the shallower sites. Interesting differences were also found between the deeper lagoons at Nyali and MMP – on the one hand MMP reefs experience slightly larger diel variation in temperature, and on the other they experienced less warming in 2007. Whether this acclimatization is due to short-term phenotypic changes or due to a longer-term process of adaptation through natural selection is a question that could be further researched. *Pocillopora* was the genus most susceptible to bleaching-related mortality, especially at Nyali, and *Porites* branching, massive and columnar all displayed high tolerance to bleaching. Among all these patterns of bleaching susceptibility, it is not clear whether the acclimatization is host-based or symbiont-based, and monitoring of the zooxanthellae clades in corals at these sites could help in answering this question. Finally, bleached corals in MMP suffered lower levels of mortality than in Nyali, possibly associated with higher rates of herbivory due to MMP's protected status. While herbivory is often related to resilience of reefs and the influence of herbivores assisting recovery by coral recruits, this result suggests herbivory may also mediate interactions between algae and bleached corals, and assist in the survival of bleached corals.

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Spawning Patterns of *Acropora* Species in the Mombasa Lagoon in Kenya

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keywords: coral, sexual reproduction, spawning, equatorial reefs

ABSTRACT

Seventeen species of *Acropora* were studied in the Mombasa lagoon in Kenya from 2004-2005 to determine the timing and frequency of spawning, and the level of synchrony within and among different species. Spawning in this genus occurred over an extended 7 month period from October-April, with the majority of marked colonies (77%) releasing gametes between January-March in the northeast monsoon. Individual species were capable of split-spawning over 2-4 lunar months, and the length of spawning varied between species. Spawning occurred over a range of lunar phases, but predominantly in the 2 weeks following the full moon. It is evident that *Acropora* species in Kenya display a greater degree of spawning asynchrony compared to similar assemblages in other parts of the world.

INTRODUCTION

Sexual reproduction of scleractinian corals has been fairly well documented in the Pacific, Atlantic and the Red Sea and studies have revealed a wide variety of reproductive patterns among species and geographic locations (reviewed by Harrison & Wallace 1990). Mass coral spawning events that occur annually on the central Great Barrier Reef (GBR) (Harrison et al. 1984; Babcock et al. 1986) contrast markedly with corals in the northern Red Sea, where spawning occurs in different seasons, months or at different lunar phases despite a high degree of synchrony within individual species (Shlesinger & Loya 1985; Shlesinger et al. 1998).

Only a few detailed studies have been done on coral reproduction in the Western Indian Ocean (WIO). *Pocillopora verrucosa* was found to be a simultaneous hermaphrodite that spawned gametes annually between March and April in the Maldives (Sier & Olive 1994) and around the new moon in January in South Africa (Kruger & Schleyer 1998). Synchronised spawning was also recorded in six soft coral species in South Africa (Schleyer et al. 1997), and an unusual form of asexual reproduction was described in *Goniopora stokesi* at Aldabra Atoll in the Seychelles (Rosen & Taylor 1969).

Some unpublished data and *in situ* observations of spawning are also known in the region. Daytime spawning was observed in more than 100 individuals of *Fungia danai* between 09:00-10:00 hrs in February 2006 (5 days after full moon) in the Chagos Archipelago (Mangubhai et al. 2007). Individuals appeared to be males, releasing a cloud of sperm in short repeated bursts lasting for a few seconds, creating a distinct cloud along the reef. Spawning slicks were observed in March 1997 on Ari Atoll in the Maldives (Loch et al. 2002), and *Acropora* species were observed spawning in October 1994 on Chumbe Island reef in Tanzania (Franklin et al. 1998) and during full moon in November 1998 in the lagoon of Albion in Mauritius (R. Moothien Pillay, pers. comm.). A short study at Misali Island in Tanzania undertaken from December 2002-March 2003 found mature gametes present in 84% of *A. tenuis* and 7% of *A. valida* samples in February, 1-2 days prior to the full moon (A. Pharoah, unpubl. data).

Given the paucity of available information on coral reproduction in the WIO, a study was undertaken in 2003-2005 to provide data on the timing and patterns of scleractinian coral reproduction on Kenyan reefs. Results on the broad patterns in the timing of spawning of faviid and *Acropora* species in the first year were published in Mangubhai & Harrison (2006). This paper presents data on spawning patterns in *Acropora* species from the second study year, where the timing of spawning was narrowed to a finer level, and examines the level of synchrony within and among different species.

METHODS

A total of 209 colonies, comprising of 17 species, were marked and sampled at Kijembe and Mamba Reefs in the Mombasa lagoon (4º4'S, 39º43'E) over a 9-month period from September 2004–May 2005. A single branch measuring 5-10 cm was removed from marked colonies during each collection period, and the timing and frequency of collections was based on spawning periods recorded in the previous year for individual *Acropora* species (Mangubhai & Harrison 2006).

Reproductive condition of oocytes was assessed in the field as follows: 'mature' if oocytes were pigmented (Fig.1), 'immature' if oocytes were smaller and pale or white, .and 'empty' if oocytes were too small to view with the naked eye (Oliver et al. 1988; Mangubhai & Harrison 2006). In the laboratory, tissue samples were

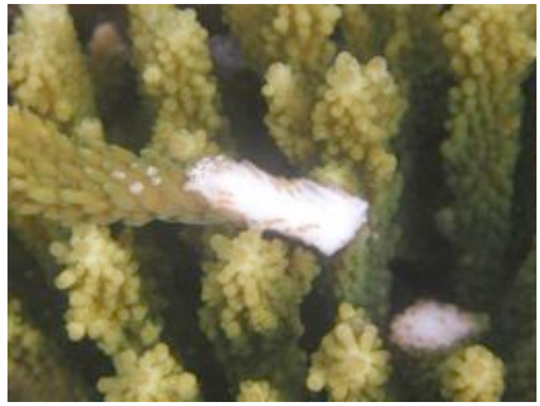

Figure 1. Mature pigmented ('pink') gametes visible in coral polyps in the field in Acropora valida.

fixed in 10% formalin in seawater, decalcified in weak HCl (0.5-5%) over a 2-3 week period and then preserved in 70% ethanol. Decalcified branch samples were placed on a dark-coloured petri dish and five polyps were randomly selected from the centre of the branch and removed under a dissecting microscope, and the presence or absence of gametes was recorded. Spawning was inferred from the disappearance of mature gametes between sampling periods, and the absence of brooded planulae or embryos.

Branches of 9 species (*Acropora* sp.1, *A. divaricata, A. humilis, A. mossambica, A. samoensis, A. secale, A. sordiensis, A. tenuis* and *A. valida*) were monitored in separate aquaria for 3-4 days from December 2004–March 2005. Coral branches were examined every half hour from 18:00 (just prior to sunset) to 23:00 hrs or until spawning ceased, using a torch covered with red cellophane to avoid causing stress to the corals which may cause colonies to release oocytes prematurely (P. Harrison, pers. comm.). Information was recorded on the timing of 'setting', (i.e. when the egg-sperm bundles are formed and then held in the oral cavity prior to release), the onset and duration of spawning and the method of gamete release. Where spawning in aquaria occurred, field samples were collected from the same colony the next day to confirm spawning in the field.

Table 1. The colours of eggs observed in reproductively mature *Acropora* species. n = number of colonies sampled. Colours: w = white, o = orange, p = pink, c = cerise.

Species	n	Colour
Acropora sp.1	17	o, p, w
A. digitifera	3	o
A. divaricata	33	o, p, w
A. gemmifera	5	p
A. humilis	17	o, p, w
A. kosurini	1	o, p
A. lutkeni	2	o, p
A. mossambica	23	o, p, w
A. nana	3	p
A. nasuta	6	o, w
A. samoensis	6	o, p, w
A. secale	9	o, p, w
A. sordiensis	20	o, p, w
A. subulata	12	o, p, w, c
A. tenuis	20	p, c
A. valida	25	o, p, w

Figure 2. Arrangement of mature oocytes (o) and spermaries (s) on mesenteries in a polyp of *Acropora valida*.

RESULTS

Reproductive Pattern

All *Acropora* species studied in Kenya were simultaneous hermaphrodites, with both mature oocytes and spermaries observed together in polyps prior to gamete release (Fig. 2).

Each polyp had eight gravid mesenteries with mature spermaries (two large and two small pairs) and oocytes (two long and two short strings) that develop on separate mesenteries, and this pattern was consistent in all polyps of *Acropora* species studied. Oocytes were generally oval though some became irregular in shape depending on their pawning was not observed directly in the field, observations of spawning in aquaria of 7 species of *Acropora* and the disappearance of mature oocytes and spermaries from consecutive samples taken a few days to a few weeks apart, indicates that these species are broadcast spawners. Furthermore, no planulae were recorded in any of the >1000 tissue samples examined.

Spawning

Mature pigmented oocytes were observed in the field on average 2-3 weeks prior to spawning, though in some colonies mature oocytes were observed for 4-6 weeks prior to spawning. Pink and orange were the most common oocyte colour observed at maturity, though not all oocytes within a colony became pigmented prior to spawning (Table 1). Cerise-coloured oocytes were less common and were only recorded in *A. tenuis* and *A. subulata*. Mature white or pale oocytes were recorded in 11 (64.7%) of the 17 species, and in 28 (13.4%) of the 209 colonies studied. Oocyte colour was generally inconsistent among different colonies within species, and therefore did not provide a useful tool for identifying morphologically similar species.

Spawning in *Acropora* species was asynchronous, and extended over 7 months from October–April, with the majority of colonies (77%) releasing gametes between the summer months of January–March in the northeast monsoon (Fig. 3). The main spawning

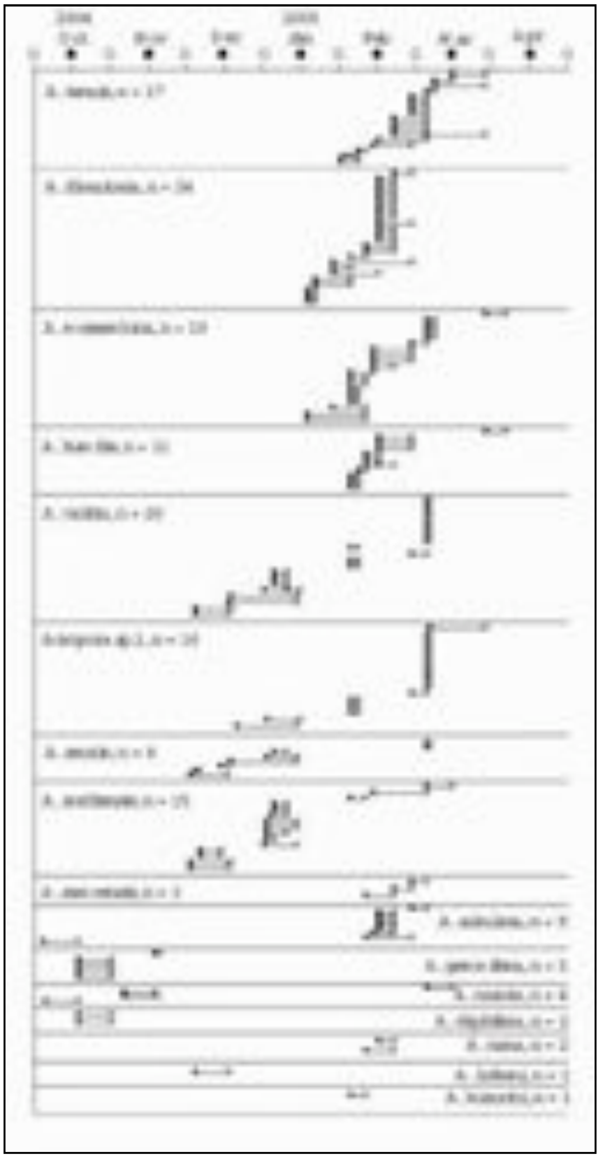

Figure 3: Reproductive periods for marked colonies of *Acropora* species at Kijembe and Mamba Reefs, Mombasa Marine National Reserve, from 2004-2005. Each row represents a spawning record for a single colony. •—o = the period between the last sample date when gametes were present (closed circle) and the subsequent sample date when gametes were absent (open circle), •—•—o = the closed circles in the middle represent the date when some of the gametes had disappeared, indicating partial spawning occurred. o= full moon, •= new moon.

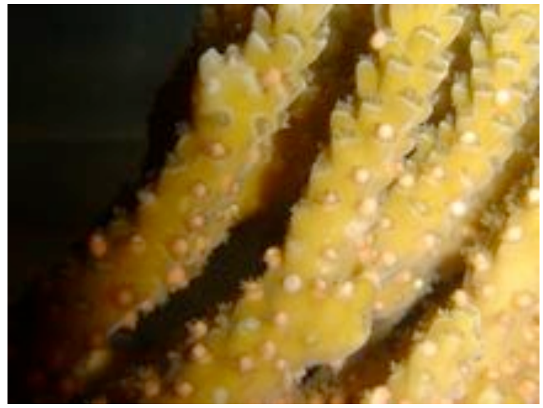

Figure 4. 'Setting' and spawning of mature gametes in *Acropora tenuis*.

occurred in February with 42% of colonies, comprising 11 species, releasing gametes in this lunar month. In species represented by >5 colonies spawning was split over 2-4 months. Partial spawning in individual colonies was less common in *Acropora* compared to *faviid* species (unpubl. data), and was recorded in 1 *A. humilis,* 1 *A. valida* and 2 *A. tenuis* colonies (Fig. 3).

The length of the spawning period varied between species, with spawning occurring for shorter periods of 2 months in *A. subulata, A. divaricata* and *A. humilis* and longer periods of 4 months in *A. valida, A. sordiensis* and *A. mossambica* (Fig. 3). In species represented by ≥ 10 colonies, the main spawning period was in January, February or March, when 43-80% (mean = 51%) of the population of each species released gametes. No species had their main spawning period in the inter-monsoonal month of April, prior to the onset of the southeast monsoon season.

Data showing the lunar phases over which coral spawning occurred, for those colonies with spawning periods inferred from samples taken over 3 days or less, are shown in Table 2. Spawning in *Acropora* species in Kenya occurred over a range of lunar phases, but predominantly in the 3rd and 4th lunar quarters, that is, in the 2 weeks following full moon (Table 2). While *A. tenuis* spawned mainly in the 3rd and 4th lunar quarters, a small number of colonies spawned in the 1st/2nd quarter. *Acropora divaricata* and *A. subulata*

Table 2. The lunar phase when the last sample was observed (lunar day - mature) and the subsequent sample when gametes were absent (lunar day - absent) from coral colonies containing mature gametes. Data are shown for colonies with spawning periods inferred from samples taken over 3 days or less. Lunar days are divided into four lunar quarters: 1st = 0-7, 2nd = 8-14; 3rd = 15-21, 4th = 22-29, where lunar day 0 = new moon and lunar day 15 = full moon.

Species	n	Lunar Day		Lunar quarter
		Mature	Absent	
A. tenuis	1	18	21	3rd
	1	24	27	4th
	1	21	24	4th
A. valida	8	21	22	3rd
	2	21	24	4th
Acropora sp.1	9	21	22	3rd
	3	21	24	4th
A. secale	1	19	21	3rd
	2	21	22	3rd
	1	29	2	4th/1st
A. sordiensis	1	17	20	3rd
A. mossambica	6	21	24	4th
	4	21	24	4th
A. divaricata	3	4	7	1st
A. humilis	3	21	24	4th
	1	24	27	4th
A. gemmifera	1	3	5	1st

Figure 5. Spawned gametes of *Acropora valida.* Note the lighter pink areas are where sperm clouds are breaking up from the oocyte-sperm bundle.

spawned predominantly in the 1st lunar quarter, around new moon.

Coral spawning was observed in 6 of the 9 *Acropora* species held in aquaria (Fig. 4). Three of the branches held in aquaria released gametes on the same night as the colonies in the field from which they were removed, and 7 branches released gametes in aquaria 1-2 weeks earlier than their corresponding colonies in the field (Table 3). In most branches, the setting of egg-sperm bundles under the oral cavity commenced between 19:10-19:45 hrs, with spawning commencing between 21:13-21:56 hrs. *Acropora tenuis* commenced setting around sunset, and spawned between 19:02-19:17 hrs. In *Acropora* sp.1 and *A. valida* setting

Table 3: The timing of setting and spawning in branches collected from marked colonies and held in aquaria between January–March 2005. Type: natural = spawning confirmed for the same night in colonies in the field; premature = branches in aquaria released gametes, but colonies in the field still had mature gametes; '–': no samples were taken in the field to confirm spawning.

Species	Date	Lunar day	Type	Start setting	End setting	Start spawn	End spawn
A. sordiensis	5-Jan-05	24	-	19:30	20:54	21:13	21:27
A. divaricata	6-Jan-05	25	premature	19:36	21:09	21:25	21:35
	6-Jan-05	25	premature	19:37	21:09	21:25	21:35
	7-Jan-05	26	-	19:30	21:16	21:22	21:40
	10-Jan-05	0	premature	19:35	20:43	21:24	21:33
	11-Jan-05	1	premature	17:47	21:08	21:35	21:38
	12-Jan-05	2	premature	19:20	21:00	21:28	21:35
	17-Jan-05	7	-				21:30
	18-Jan-05	8	-		20:30	21:20	21:30
	19-Jan-05	9	-	19:39	21:19	21:30	21:30
A. tenuis	21-Jan-05	11	premature	17:45	18:50	19:02	19:17
A. humilis	27-Jan-05	17	premature	19:45	22:00	20:04	20:14
	29-Jan-05	19	-	20:17	21:27	21:56	22:03
Acropora sp.1	2-Mar-05	21	natural	19:10	20:38	20:55	21:05
	2-Mar-05	21	natural	19:10	20:38	21:00	21:19
A. valida	2-Mar-05	21	natural	19:10	20:38	20:55	21:05

commenced at 19:10 hrs, and spawning occurred between 20:55-21:00 hrs. Compact positively buoyant egg-sperm bundles were extruded slowly through the mouth (Type I spawning behaviour, Babcock et al. 1986), and floated immediately to the water surface where water movement generated by the airstone caused the bundles to slowly break apart, separating individual oocytes and sperm clouds (Fig. 5). All egg-sperm bundles were released rapidly from the branches, within 15-19 minutes of the commencement of spawning. Similar patterns of gamete released were recorded in *A. sordiensis, A. divaricata, A. tenuis* and *A. humilis*.

DISCUSSION

The 17 *Acropora* species studied in the Mombasa lagoon in 2004-2005 were simultaneous hermaphrodites and broadcast spawners. This sexual pattern and mode of reproduction and development predominate in *Acropora* (subgenus *Acropora*), and are consistent with studies from other regions (reviewed by Harrison and Wallace 1990).

In Kenya, *Acropora* species spawned over a 7-month period between October–April and interspecific spawning synchrony was less synchronous in *Acropora* species compared to faviids (Mangubhai

& Harrison 2006), a pattern which is found on both equatorial (Oliver et al. 1988) and higher-latitude reefs (Hayashibara et al. 1993) in some locations. The spawning pattern emerging for *Acropora* species in lagoonal reefs in Kenya is one of asynchrony, and contrasts markedly with the central GBR and western Australia where high intra- and inter-specific spawning synchrony results in an annual mass spawning event where many species spawn over one or a few nights after full moon periods in the October/November (late spring/early summer) and March (summer), respectively (Harrison et al. 1984; Babcock et al. 1986, 1994). The results from this study also contrast with studies from Japan, Palau and Singapore, which display more synchronised multispecific spawning of *Acropora* assemblages (Hayashibara et al. 1993; Penland et al. 2004; Guest et al. 2005).

The spawning patterns recorded in Kenya share similarities with *Acropora* species on subtropical reefs in the Solitary Islands, Australia, where spawning was staggered among species and among colonies within some species, and occurred over 2-5 months from December to April, and over a range of lunar phases (Wilson & Harrison 2003). It was suggested that highly variable sea surface temperatures in the Solitary Islands, particularly during gamete maturation, may explain the extended and asynchronous spawning pattern observed in this location (Wilson & Harrison 2003). Sea surface temperatures in Kenya are generally less variable during maturation, but are more variable during the peak spawning period from January–April, with differences of 2.5ºC recorded (see Fig. 5 in Mangubhai & Harrison 2006). The variability in sea surface temperatures is likely to be a result of the shallow depth of the lagoon, which makes it susceptible to temperature fluctuations associated with cloud cover and prevailing wind conditions. However, temperature variability in Kenya during peak spawning periods are still less than those at the Solitary Islands where 6-8.5 ºC differences can occur during the peak spawning period from December-March (A. Scott, pers. comm.).

The spawning patterns recorded in Kenya also share some similarities with scleractinian corals in the northern Gulf of Eilat in the Red Sea, which exhibit 'temporal reproductive isolation', where spawning is separated in time (seasons, months and lunar phases) for different species (Shlesinger & Loya 1985; Shlesinger et al. 1998). There are, however, a number of notable differences between the two regions. Firstly, in Kenya a smaller percentage of corals (~51%) participate in the main spawning month compared to the Red Sea (90-100%, Shlesinger et al. 1998), which means that intraspecific spawning is more asynchronous in Kenya. Secondly, *Acropora* species in Kenya may spawn in the month(s) immediately preceding and/or following the main spawning event, so that gamete release can occur over 2-5 consecutive lunar months in individual species. Broadcast spawning species in the Red Sea release gametes over 1 or 2 consecutive months (Shlesinger & Loya 1985; Shlesinger et al. 1998). Thirdly, in the Red Sea, species that spawn in the same lunar month will spawn in different lunar quarters from each other, which reduces the overlap between spawning species (see Table 1 and Fig. 1, in Shlesinger & Loya 1985). In Kenya, there is overlap between species during all lunar quarters, and colonies within some species may spawn over >1 lunar quarter. However, it is important to note that spawning times have only been described in 6 (Shlesinger and Loya 1985; Shlesinger et al. 1998) of the approximately 42 known species of *Acropora* in the Red Sea (Wallace 1999), and therefore there is a high probability that there would be overlap in spawning between some species in different lunar quarters. It is evident that Kenyan *Acropora* species display a greater degree of spawning asynchrony than in other regions. The level of reproductive plasticity recorded in this genus (cf. faviids), such as that recorded by this study, may explain the highly polymorphic nature of *Acropora* species, with high rates of hybridisation recorded between both similar and in some cases dissimilar morphological forms (Willis et al. 1997), their success in colonising reefs, and their dominance in most tropical reef habitats (Wallace 1999).

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Spatial and Temporal Variation in Coral Recruitment and Mortality in Coastal Kenya

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ABSTRACT

Measuring recruitment patterns and mortality of corals is important for understanding mechanisms that regulate their populations and mediate species coexistence. However, there is limited data on coral recruitment dynamics in Eastern Africa and much of the WIO. We studied spatial and temporal patterns of coral recruitment and mortality in four lagoonal reefs in Kenya. The objectives of the study were to compare coral recruit densities and juvenile mortality between sites, months, seasons and years. Twelve 1m ^{2} permanent quadrats were sampled for the variables at each site on a monthly basis from February 2006 to June 2007. Recruit density in the protected Mombasa Marine Park was significantly higher (7.45 recruits/m^2) than the other sites that are not protected. Recruit density was higher in SEM (Southeast Monsoon) than in NEM (Northeast Monsoon) seasons in both years with 2006 having higher recruitment than 2007. A total of 16 genera were recorded with Mombasa Marine Park having the highest number of genera (13) while a non protected site Kanamai had a significantly lower density (3.52 recruits/m^2) with a low genera number (8). Other non-protected sites (Nyali and Vipingo) had intermediate recruit densities. Dominating genera were *Favia, Porites, Favites, Pocillopora* and *Pavona* in their order of overall abundance. Coral genera exhibited site specific abundance and mortality rates with *Pocillopora* having high abundance in Nyali (3.46 recruits/m^2) and high mortality rate in Vipingo (85%). Benthic cover was dominated by Hard coral, turf algae, sand and rubble in all the sites. There was significant variation in seawater temperature levels with Kanamai recording the highest mean temperature (27.83^{0}C), temperature range (12.27) and also recorded the highest maximum temperature (36.23^{0}C). These findings suggest that there is spatial and temporal variation in recruit density, genera richness and survival of coral genera. Results also indicate that area protection and sea-water temperature influence recruitment between habitats but benthic substrate characteristics influence recruitment within a habitat.

INTRODUCTION

Coral recruitment can operationally be defined as the initial sighting of recently settled juveniles in the adult habitat (Caley *et al.,* 1996). Successful recruitment is

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

critical for the survival of a coral population. Measuring recruitment patterns and mortality of corals is of fundamental importance for understanding the mechanisms that regulate their populations and mediate species coexistence (Underwood and Fairweather 1989).

Recruitment in corals has been extensively studied, usually within the first weeks or months after initial settlement from the plankton (reviewed by Harrison and Wallace 1990), demonstrating considerable temporal variation between seasons and years, and spatial variation between sites (e.g., Birkeland 1977, Rogers *et al.,* 1984, Wallace 1985a, b; Babcock 1988, Harriott and Fisk 1988). Spatial and temporal variation in recruitment has been shown to be an important component in the population dynamics of corals (Warner and Chesson, 1985). Differences in coral recruitment rates between and within sites has been measured in several sites in Kenya; (Obura *et al.,* 2005, Maghubhai *et al.,* in review) and Tanzania (Muhando 2002) and has shown that seasonal variation in recruitment rates differ among taxa of corals, though a variety of locations show the general pattern of highest recruitment in the warmest season. Seasonality in recruitment has also been reported in the U.S Virgin Islands (Dustan 1998), Great Barrier Reef (Wallace and Bull 1982, Harriot 1992, Harriot and Fisk 1988) Okinawa (Sakai and Yamazato 1984) the northern Gulf of Mexico (Bagget and Bright 1985) and Hawaii (Fitzhardinge 1985). In all cases, most recruitment occurred in the spring and summer months, following the major spawning season. However, the interaction between recruitment and management regimes is little understood.

Settlement rates and taxonomic composition may be expected to vary spatially due to variations in geographic availability of larvae, prevailing hydrographic conditions and physical characteristics of sites. Most studies examining more than one site show significant differences in recruitment between sites, but replicated time-series show that many of these patterns are complicated by temporal variations (Baggett and Bright 1985, Wallace 1985). Taxonomic differences in recruitment patterns have also been

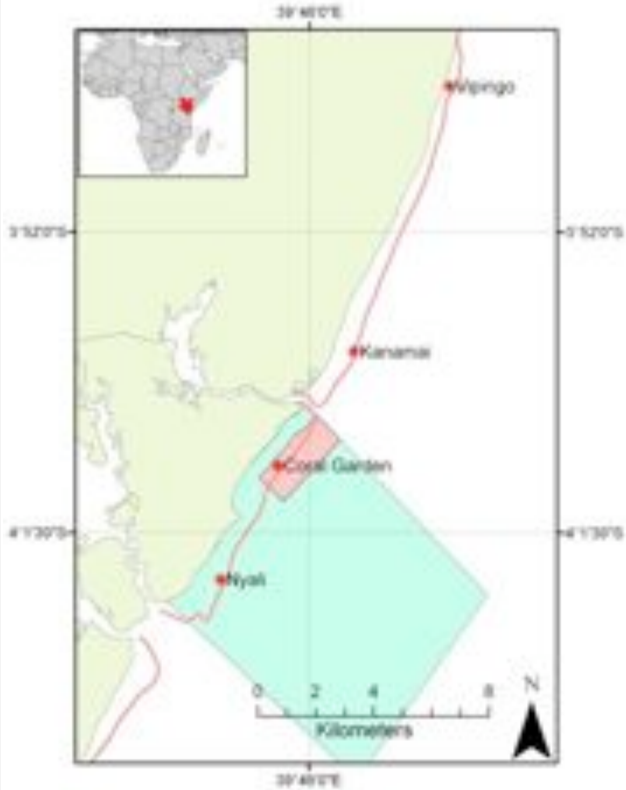

Figure 1. A map showing the location of the study.

found at the scale of individual reefs (Harriott and Fisk 1988). Some corals respond to specific settlement cues (Morse et al. 1988), which is likely to contribute to spatial variation in abundance. Similarly, preemption or overgrowth by established corals and algae is an important mechanism that can cause spatial variation in recruitment (e.g., Birkeland 1977, Sammarco 1980, and Hughes 1985). Studies of coral recruitment in the Caribbean have found variable rates of recruitment between species (Rogers *et al.,* 1984 and Smith 1992, 1997) with large frame-building species showing low recruitment rates.

This study aimed at determining the spatial and temporal variation of genera recruitment and survival in the Kenyan coast. We asked 3 questions (1) whether there was site variability in coral recruitment and mortality rate (2) whether there was monthly, seasonal and yearly variability in recruitment and mortality rate, and (3) whether area protection, temperature and coral cover area influenced coral recruitment and mortality rates.

MATERIALS AND METHODS

Study Area

The study area encompasses four reef sites; Mombasa Marine Park (MMP), Nyali, Vipingo and Kanamai on the North coast of Kenya (Fig. 1). MMP is characterized by water temperature range of 25-31°C throughout the year with stable salinity levels and moderately high nutrient level from terrestrial runoff and ground water. It has a reef height of 1.09m and the amplitude from neap tide to spring tide varies from 1.5 to 4m. This site experiences occasional water exchanges with the oceanic waters during high and low tides due to a small depression that forms a small channel through the reef crest. This site is protected from all extractive uses including fishing but is a primary site for glass bottom boat and snorkeling trips among tourists. Nyali resembles the MMP but traditional fishing is allowed. Kanamai and Vipingo are unprotected shallow sites characterized by extensive fishing and intensive exploitation of corals, shells and other marine organisms for commercial purposes. Their reef heights are 1.4 and 1.45m, respectively. All four sites are patch reefs within the shallow lagoon (0-7 m depth) that is formed by a 200 km fringing reef that extends from Shimoni (near the border with Tanzania) to Malindi.

Sampling Design

Two replicate stations were used at each site. The distance between stations ranged from 200m to 5m. A line transecs of 25m long was used to permanently mark the area to be sampled at each station. Three 1m^2 permanent quadrats were sequentially located on each side of the line transect. The quadrats were randomly placed using a system of random numbers. Placement of the quadrats was such that they excluded at least 50% of coral cover, sand or other substrates that may inhibit settlement. Nails were driven into to the reef substrate at the corners of each square to delimit the quadrat area. A 1 m^2 PVC quadrat was used to help mark the quadrats for sampling (Fig. 2). Each station was then sampled once a month for a period of 16months.

Sampling for Recruits

Recruits were defined as corals that are less than 10cm in diameter. During the initial sampling, the number of recruits was recorded for each quadrat and recruits identified to genus level. The position of each recruit was recorded on an underwater paper for the purpose of sampling the same individual on subsequent sampling. The maximum diameter and the maximum perpendicular to that diameter of each recruit colony was measured to the nearest 1mm using a plastic caliper, from which the area of each coral was calculated. During subsequent sampling, new recruits (individuals not observed in the previous sampling) were recorded. Individuals observed in previous sampling period but not observed in immediate sampling period were considered to have died. Recruits that were overgrown with algae were also considered as dead.

The substrate characteristics at each station was described by characterizing the percentage intersection rate of the substrate type (e.g. hard coral, sand, rubble, algal turf, coralline algae, *Halimeda*, macroalgae, soft coral, sponge and zoanthids) along a 10m line transect. Seawater temperature was monitored throughout the study period using temperature loggers placed at each of the four sites.

Data Analysis

Monthly recruit density was derived from the number of recruits per 1m^2. Monthly mortality rate was derived from the number of dead recruits per 1m^2 per and was quantified as a percentage decrease. To determine site, monthly and yearly variations in recruit density and mortality rates t-tests were used.

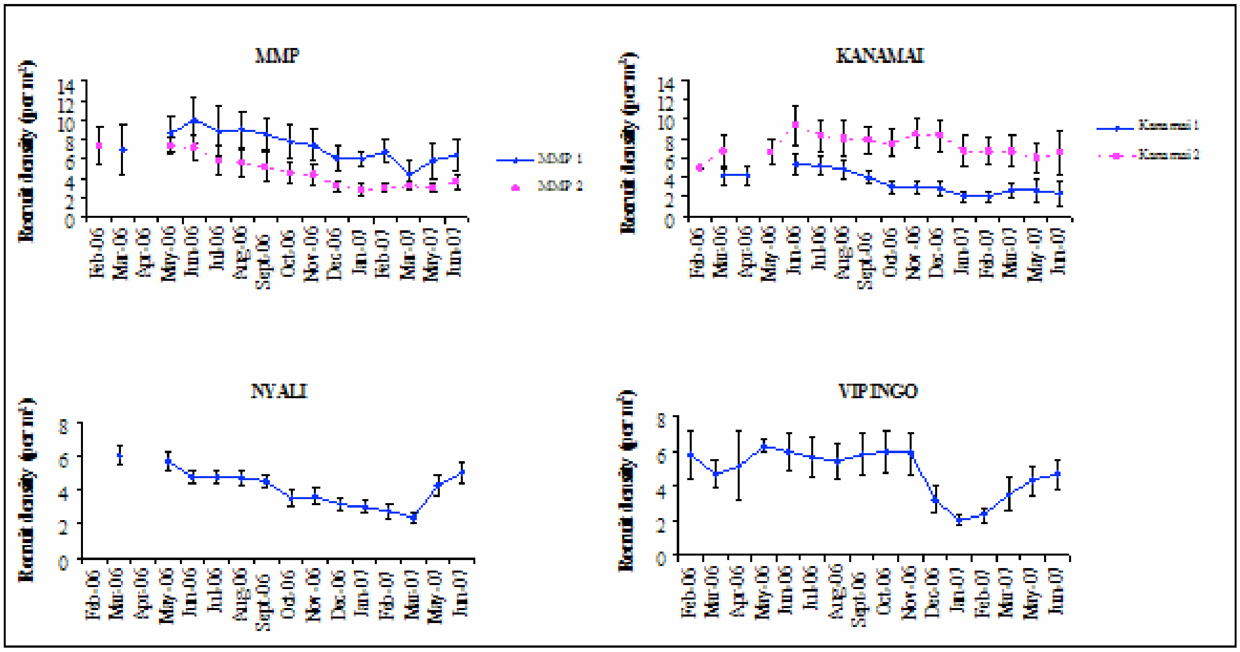

Figure 2. Abundance of recruits per 1m^2 for the period from February 2006 to June 2007 (mean and standard deviation). Individual sites shown within MMP/Kanamai due to significant differences between them.

RESULTS

Recruit Density

There was a significant difference in recruit density within MMP and Kanamai while stations within Nyali and Vipingo did not vary significantly. Mean recruit density varied from 3.51 ± 2.14 (Kanamai 1) to a maximum of 7.45 ± 4.09 (MMP 1) as shown in Table 1.

The highest number of recruits recorded in a single quadrat was 20 in MMP 1. Monthly recruit densities varied significantly in Kanamai 1, MMP 2 and Nyali whereas the other sites did not have any significant variation in monthly recruit densities. Highest monthly recruit density occurred in Nyali in March 2006 (6.00 ± 1.23) and the lowest in Kanamai 1 in Jun 2007 (2.3 ± 2.31, Fig. 2). Southeast Monsoon and Northeast Monsoon seasons varied in their recruit densities with SEM 2006 recording the highest density (6.14 ± 3.48) and lowest density was in NEM 2007 (3.51 ± 2.52, Fig. 3). Both NEM and SEM showed high recruit densities in the year 2006 and low densities in year 2007.

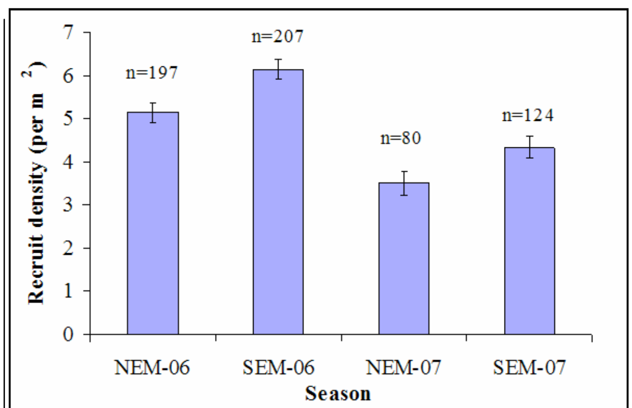

Figure 3. Abundance of recruits (mean and standard error) for the two major seasons (SEM and NEM) in the year 2006 and 2007.

Table 1. Mean, standard deviation, maximum and minimum of recruit density (no. per m^2) and the overall mortality rate of coral recruits in 2006 and 2007. There were no significant differences between replicate sites at Nyali and Vipingo, so data for each reef were pooled.

	Kanamai 1	Kanamai 2	MMP 1	MMP 2	Nyali	Vipingo
Mean	3.52	7.37	7.45	4.81	4.03	4.85
N	77.00	81.00	69.00	72.00	152.00	157.00
StdDev	2.13	3.63	4.09	2.81	1.70	3.47
SE	0.24	0.40	0.49	0.33	0.14	0.28
Max	8.00	17.00	20.00	13.00	10.00	16.00
Min	1.00	2.00	1.00	1.00	1.00	1.00
Mortality (m^{-2})	1.42	0.41	0.67	3.53	4.23	3.51

Table 2. Genus composition at each site and their overall abundance.

Genera	Mombasa	Nyali	Kanamai	Vipingo	Total
Favia	x	x	x	x	20%
Porites	x	x	x	x	19%
Favites	x	x	x	x	19%
Pocillopora	x	x	x	x	13%
Pavona	x	x	x	x	8%
Platygyra	x	x	x		6%
Galaxea	x	x	x		3%
Acropora	x	x			3%
Acanthastrea	x				2%
Montipora	x			x	1%
Astreopora	x	x			1%
Cyphastrea	x	x			1%
Fungia		x	x		1%
Hydnophora	x				1%
Echinopora		x			0%
Alveopora				x	0%

Genera Abundance and Mortality Rate

A total of 16 genera was recorded in all the sites. MMP recorded the highest number of genera (13, Table 2) while Vipingo showed the lowest number of genera (7) and the other sites showed intermediate numbers of genera. Recruitment was dominated by *Favia* (20%), *Porites* (19%) and *Favites* (19%) whereas *Pocillopora* and *Pavona* occurred in all sites but had very low abundance (13% and 8% respectively, Fig. 4). Abundance of other genera was very low with majority having ≤ 2% abundance and was grouped together as others.

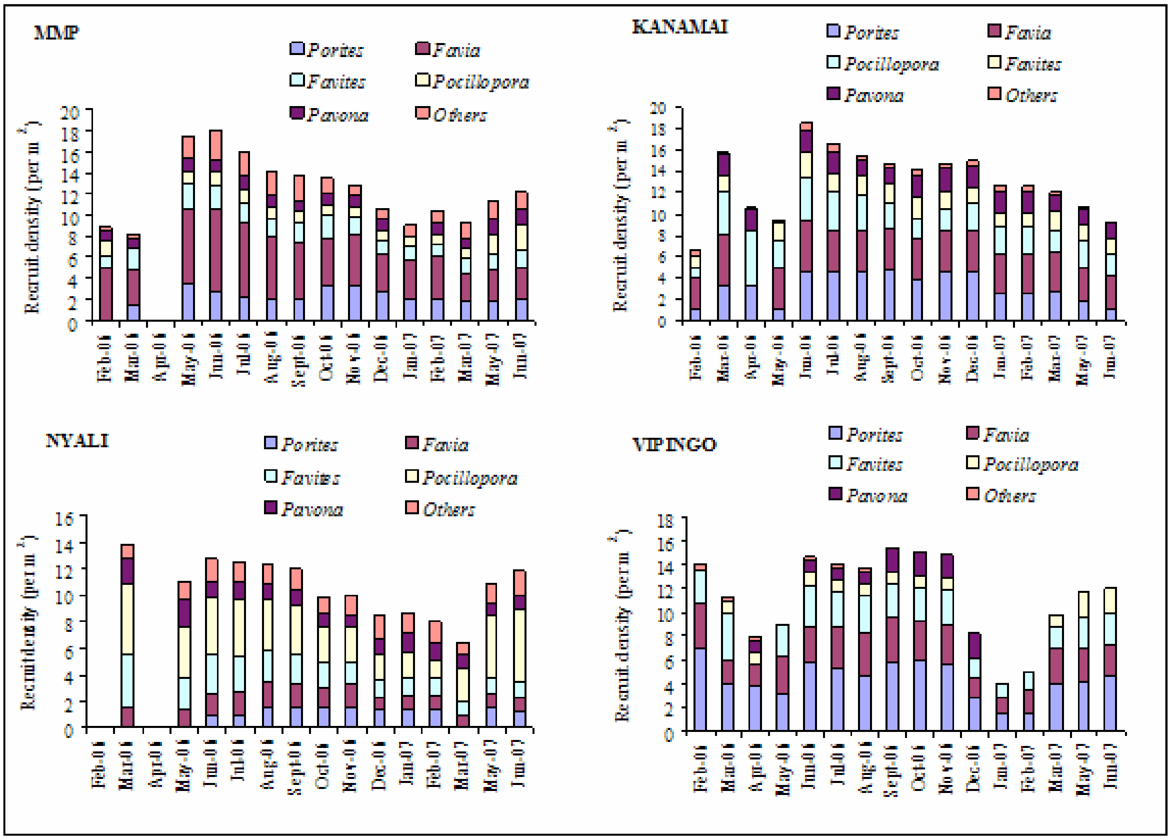

Figure 4. Composition of recruits population in the four sites from February 2006 to June 2007.

Table 3. Overall mean and standard deviation, maximum, minimum and range of sea-water temperature in four sites in Kenya in 2006 and 2007.

Site	MMP	Nyali	Vipingo	Kanamai
Mean	27.57	27.50	27.47	27.83
StDev	1.40	1.41	1.45	1.92
Max	32.90	32.79	33.84	36.23
Min	24.03	24.65	23.74	23.95
Range	8.87	8.14	10.10	12.27

Favia was more abundant in Kanamai and MMP, *Porites* in Vipingo and *Pocillopora* in Nyali. There was monthly variation in the abundance of *Favia* and *Favites* with both having highest recruit densities in June 2006 (5.79 and 2.67 respectively), but *Pocillopora* and *Porites* did not have significant monthly variation in recruit densities. Genera also showed varying mortality rates between sites with *Porites* and *Favites* showing low mortality rates in Vipingo (38% and 50% respectively) and high mortality rates in Nyali (Fig. 5). *Pocillopora* recorded low mortality in Nyali (43%) and high mortality in Vipingo (85%).

Habitat Characteristics

Surveys on benthic cover reported high percentage cover of hard coral in Kanamai 1 (28%, Fig. 6), coralline algae and turf algae in MMP 2 (15%, 36% respectively) and macro algae in Nyali 2 (24%). Temperature varied significantly between sites with Kanamai having the highest mean temperature, 27.8 ºC (Table 3).

Maximum temperature occurred in Kanamai (36.2 ºC) and this site recorded the highest range in temperature over the entire study period (12.3 ºC, Fig. 7), while the lowest range in temperature occurred in Nyali (8.1 ºC).

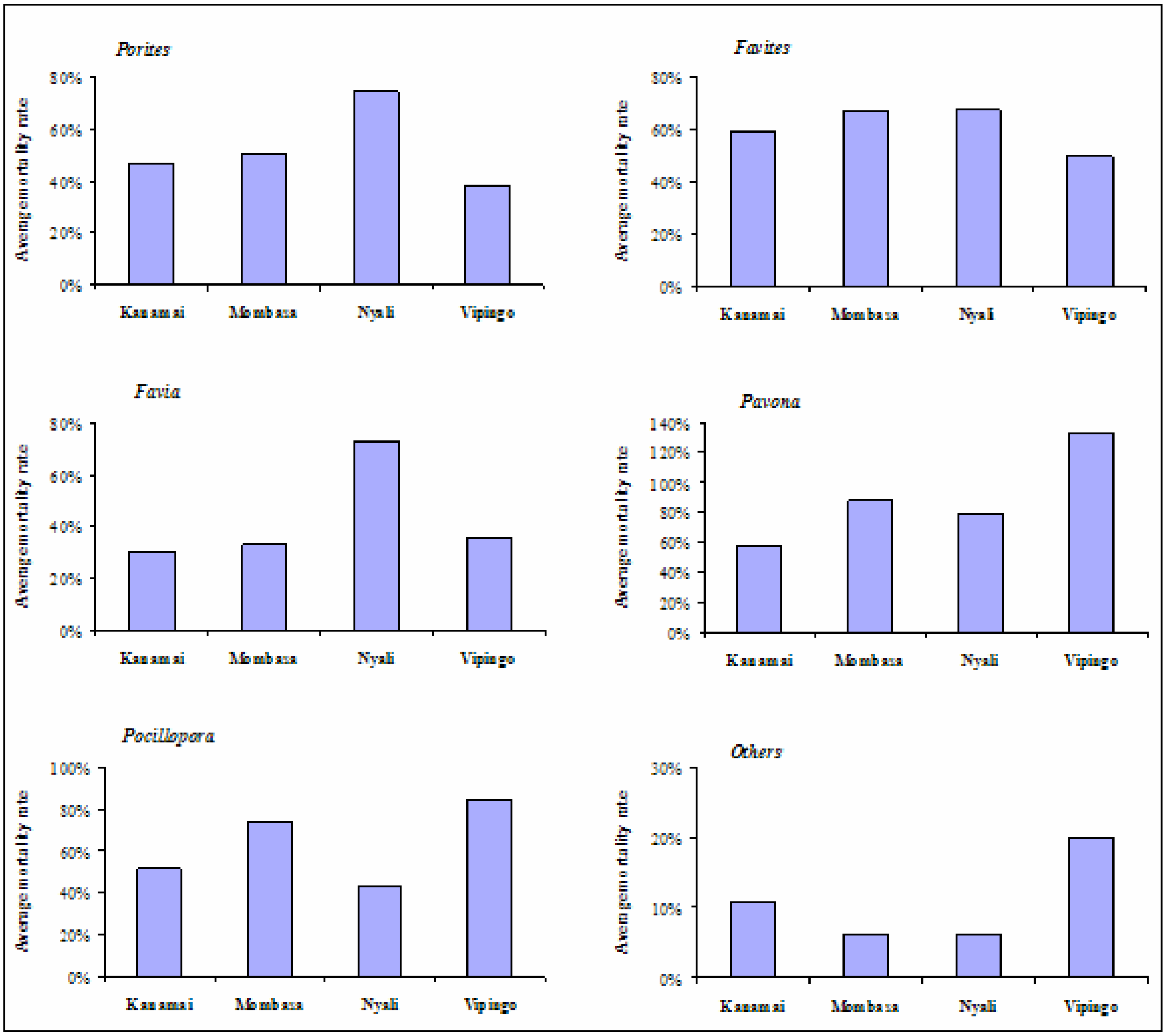

Figure 5. Site specific mortality (%) of common genera in the four reefs. Mortality was calculated as the total number of recruits that died divided by the total number of recruits for each genus.

DISCUSSION

The pattern exhibited in this study was of significant variability across sites, seasons and years. Within this pattern, Mombasa Marine Park (MMP) showed higher abundances compared to the other sites. Recruitment was high in the SEM season and the year 2006 recorded the highest recruitment. In addition, MMP recorded the highest number of genera and generally, *Favia*, *Porites*, *Favites*, *Pocillopra* and *Pavona* were the dominating genera. Substrate characteristics showed site specific abundances with hard coral having a higher percentage cover in station 1 of MMP (28%, Table 2). Kanamai recorded the highest temperature

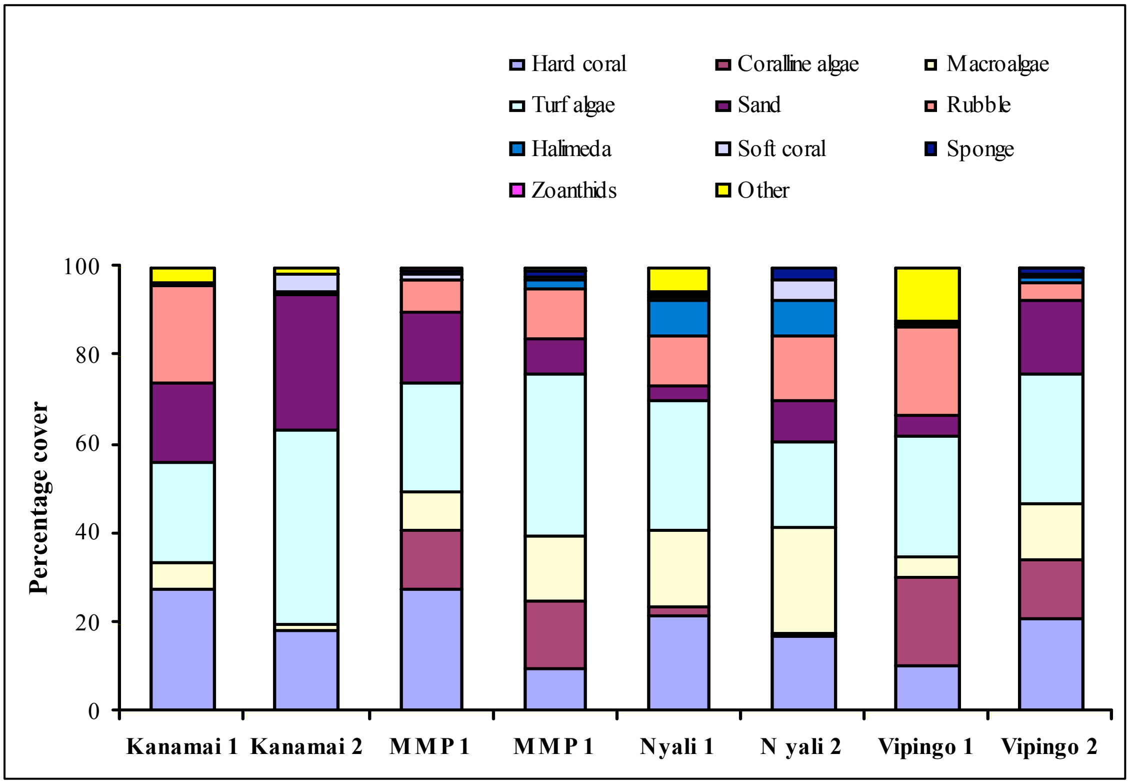

Figure 6. Benthic cover at all the stations.

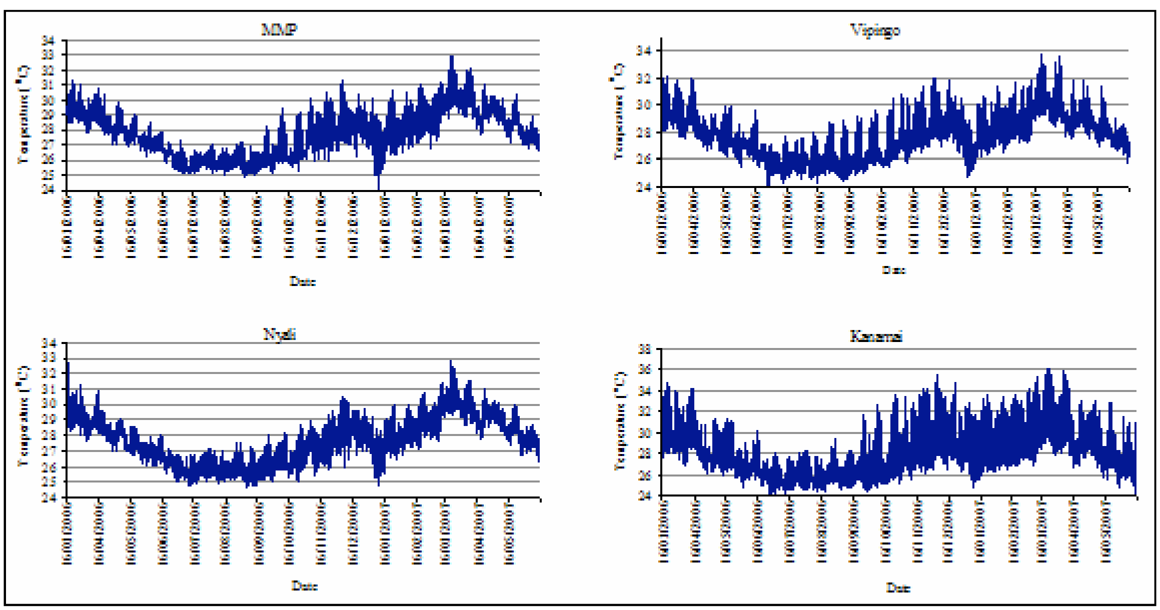

Figure 7. Hourly seawater temperature (^{0}C) on coral reefs in MMP, Kanamai, Nyali and Vipingo from March 2006 to June 2007.

levels and the broadest range between maximum and minimum temperatures (Table 3).

A number of factors co-occurred at the site with the highest recruit density, in the MMP. This site had the highest coral cover, which has been shown to be correlated with production of larvae (Miller et al., 2000), though it is not known to what extent study sites may be self-seeding. Additionally the greater structural complexity provided by high cover of varying coral morphologies, as found in MMP, contributes to greater juvenile survival. MMP is also located near a channel which brings a strong current flow. This provides for greater exposure to coral larvae from the reef front, and the strong current flow makes the water more aerated and substrate surfaces cleaner hence more conductive to settlement and post-settlement survival (Obura *et al.,* 2005). Temperature range was low in MMP compared to that in Kanamai and Vipingo which is favourable for recruit survival (Shepherd *et al.,* 2002). Similar results of high recruitment in MMP were found in Obura *et al.,* 2005 and Tamalander, 2002.

Variation in recruitment within the MMP can be associated with the differences in coral cover. However, the site in Kanamai with the highest coral cover area recorded the lowest recruitment. This implies that apart from coral cover area; there are other factors that influence recruit density and also recruitment is patchy. In this case, the high temperature variation between MMP and Kanamai could be a possible factor that contributed to the variations in recruitment. This shows that coral cover can determine recruit densities within habitats but other broader scale factors such as temperature variation may be strong determinants of recruit densities between different habitats.

Results on recruit density between Nyali and MMP contrast those recorded on settlement tiles where Nyali recorded high settlement density (Mangubhai *et al.,* 2007). Spat abundance is linked to larval availability and dispersal whereas the density of juvenile corals within an area reflects post-settlement mortality (Clark, 2002). This shows that there are many larvae that settle in Nyali but only a few make it to the visible juvenile stage. The high mortality rates recorded in this site (Table 1) explain this variability. However, a synchronized study on settlement plates and artificial substrate is recommended to make strong conclusions. The influence of mortality rates on recruit density is also experienced within Kanamai and MMP whereby the stations with high mortality rate recorded low recruit densities (Table 1).

Monthly variability in recruit density was observed in some stations only, with Nyali recording the highest monthly recruit density in March 2006 and Kanamai recording the lowest density in June 2007. The month of March is associated with calm and clear conditions. The month of June is a rainy season with high sedimentation, macroalgal dominance due to input of nutrients from terrestrial runoff and physical disturbance from waves make the substrate conditions less favorable for recruitment and may cause increased mortality of recruits. At a broader scale, the SEM season had high recruit density compared to NEM season in both the year 2006 and 2007. Studies on settlement plates in the East African region have shown a general pattern of high recruitment during the warmest months and low recruitment in the cool months (Maghubhai *et al.,* in press; Obura *et al.,* 2005; Muhando, 2002 and Nzali *et al.,* 1998). Results of this study recorded high recruitment during the cool months and this is explained by the fact that there is a time laps before visible juveniles are observed in the natural substratum.

MMP and Nyali had a higher number of genera compared to Kanamai and Vipingo (Table 2). This reflects differences in both temperature conditions and protection between the sites. MMP and Nyali experience lower absolute and range in temperature, which in general are more favorable for survival of coral recruits. In addition, MMP is protected and Nyali has limited protection while Vipingo and Kanamai are not protected, which may also result in higher coral diversity at the former. The abundance of coral genera varied with *Porites* being more abundant in Vipingo and MMP, while *Pocillopora* was more abundant in Nyali, similar to findings of McClanahan and Maina (2003) and (Mangubhai *et al.*, 2007).

In conclusion, protection level and sea-water temperature may be influencing coral recruitment at these study sites. However, variation of recruitment within a habitat may be mainly influenced by substrate characteristics. Further studies on temporal variation of benthic substrate characteristics are recommended to determine how the seasonal dynamics in benthic cover affect seasonal variability in recruit densities.

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High Zooxanthellae Densities and Turnover Correlate with Low Bleaching Tolerance in Kenyan Corals

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When a coral bleaches, the obligate symbiosis between the coral polyp and the micro-algal zooxanthellae is disrupted and the zooxanthellae are expelled from the polyp. Although a bleached coral does not necessarily die, it is more vulnerable to disease, algal overgrowth, bioerosion and eventually mortality. Mass bleaching and mortality events in the last decade have prompted increased research into zooxanthellae, and it is possible that zooxanthellae population strategies affect a coral's tolerance to bleaching stress.

Variation in zooxanthellae density and mitotic index was studied in eleven species of scleractinian coral (*Acropora* sp., *Echinopora gemmacea, Favia* sp., *Galaxea fascicularis, Hydnophora microconos, Montipora aequituberculata, Pavona decussata, Pocillopora damicornis, Pocillopora eydouxi Porites cylindrica* and *Porites lutea*) from the Mombasa Marine Park, from 1998 and 2006. This data was compiled with average and standard deviations of monthly SSTs and radiation levels in a Canonical Correlation Analysis (Fig. 1).

The Canonical axes shows that zooxanthellae density and mitotic index are nearly orthogonal, ie. independent from one another, and neither align very strongly with any of the environment axes. Of the coral species, *Pocillopora damicornis* and *Pocillopora eydouxi* display the lowest zooxanthellae densities and the highest mitotic indices. By contrast, *Galaxea fascicularis, Porites cylindrica* and *Porites lutea* display the highest zooxanthellae densities but low mitotic indices. Looking at Canonical axis 1, which aligns with zooxanthellae density, species at the low end (*Pocillopora* spp, *Acropora* spp.) tend to be more susceptible to bleaching, and those to the right end (*Porites* spp) more resistant. Species clustered near the center of the distribution with intermediate zooxanthellae densities and mitotic indices tend to have intermediate responses to bleaching. Highest mitotic indices are shown by *Pocillopora*, among the most susceptible of corals to bleaching.

Our results broadly agree with Stimson et al.'s (2002) findings of an inverse correlation between bleaching susceptibility and zooxanthellae density, and the conclusion that species with high densities and low mitotic indices (low zooxanthellae turnover) are more tolerant to bleaching, while species with low densities

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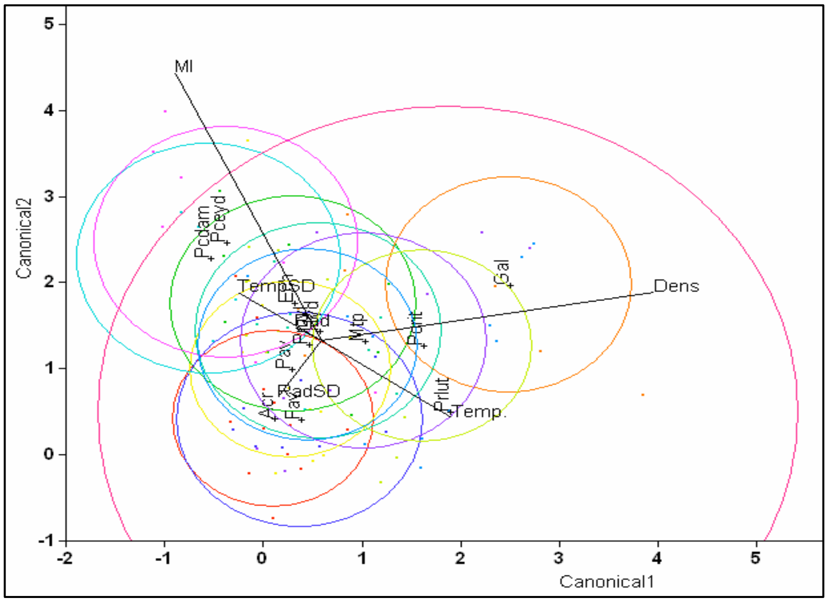

Figure 1. Canonical Correlation Analysis between monthly zooxanthellae density, mitotic index, temperature, standard deviation of temperature, radiation and standard deviation of radiation. Den = Density, MI = Mitotic index, Rad = Radiation, Rad SD = Standard deviation of radiation, Temp = Water temperature, Temp SD = Standard deviation of water temperature. Species names abbreviated. Biplot rays have been lengthened by a factor of three for clarity.

and high mitotic indices (high zooxanthellae turnover) are more susceptible. This apparent relationship between bleaching tolerance and zooxanthellae density may be explained by several hypotheses:

-higher densities of zooxanthellae could lead to higher self-shading and thus protection from light stress (Warner et al., 1999);

-higher zooxanthellae densities could mean higher concentrations of UV-absorbing compounds such as mycosporine-like amino acids (MAAs);

-higher zooxanthellae densities correlate with higher amounts of coral tissue per square centimeter of corallum surface, and coral tissue depth protects zooxanthellae from light stress (Hoegh-Guldberg, 1999);

-finally, turnover rates and zooxanthellae regulation may simply mean that high biomass/low turnover species bleaching slowly, while low biomass/high turnover species bleaching more rapidly, simple as a result of the turnover dynamics.

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Zooxanthellae Densities are Highest in Summer Months in Equatorial Corals in Kenya

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Tropical reef-building corals contain micro-algae known as zooxanthellae (*Symbiodinium* sp.) within their tissue with which they exist in an obligate symbiosis. Zooxanthellae are crucial to coral polyps because they provide them with photosynthates, energy, oxygen and pigmentation.

Several studies from around the world have observed that zooxanthellae population densities can undergo marked seasonal fluctuations. Research in Israel (Shenkar et al., 2006) Thailand (Brown et al., 1999), Mauritius (Fagoonnee et al., 1999), the Bahamas (Fitt et al., 2000; Warner et al., 2002) and Hawaii (Stimson, 1997) has shown that zooxanthellae population densities are highest during colder months and lowest during warmer months, with intermediate densities in between. These fluctuations have mostly been explained in terms of temperature and solar irradiance that affect the zooxanthellae's capacity to photosynthesise (Brown et al., 1999; Fitt et al., 2000; Shenkar et al., 2006; Stimson, 1997; Warner et al., 2002). However, these studies were conducted at higher latitude sites where seasonal environmental parameters are more variable and the difference between summer and winter conditions is more marked than at sites closer to the equator.

CORDIO collected zooxanthellae density and mitotic index data for eleven species of scleractinian coral (*Acropora* sp., *Echinopora gemmacea, Favia* sp., *Galaxea fascicularis, Hydnophora microconos, Montipora aequituberculata, Pavona decussata, Pocillopora damicornis, Pocillopora eydouxi Porites cylindrica* and *Porites lutea*) in the Mombasa Marine Park from 1998 to 2006. Four main seasons are distinguished for analysis, the northeast monsoon (16 December – 15 March), the late northeast monsoon (16 March – 30 April), the southeast monsoon (1 May – 31 October), and the transitional period (1 November – 15 December). The late northeast monsoon and the transitional period are doldrum periods when warming of surface waters is most intense between the two winds. Temperatures (Fig. 1) and radiation levels (Fig. 2) are lowest during the southeast monsoon and highest during the late northeast monsoon.

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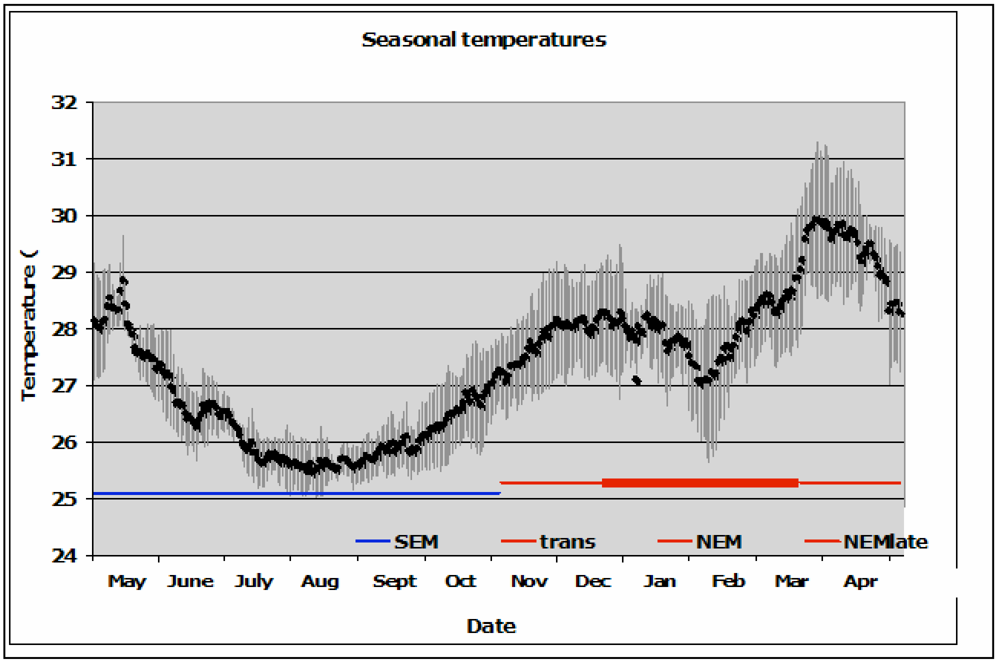

Figure 1. Temperature data for the Mombasa Marine Park showing daily means and standard deviation for 1999-2005. Horizontal bars show seasons described in the text.

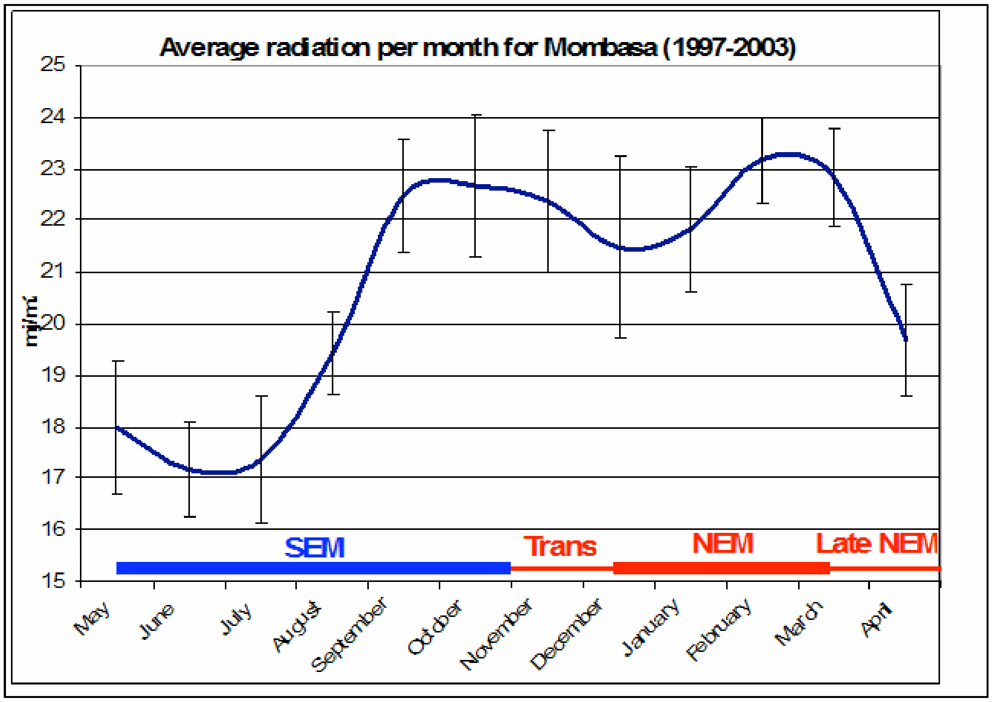

Figure 2. Radiation data for Mombasa showing monthly means and standard deviation for 1997-2003. Horizontal bars show seasons described in the text. Data courtesy of Mombasa Meteorological Office.

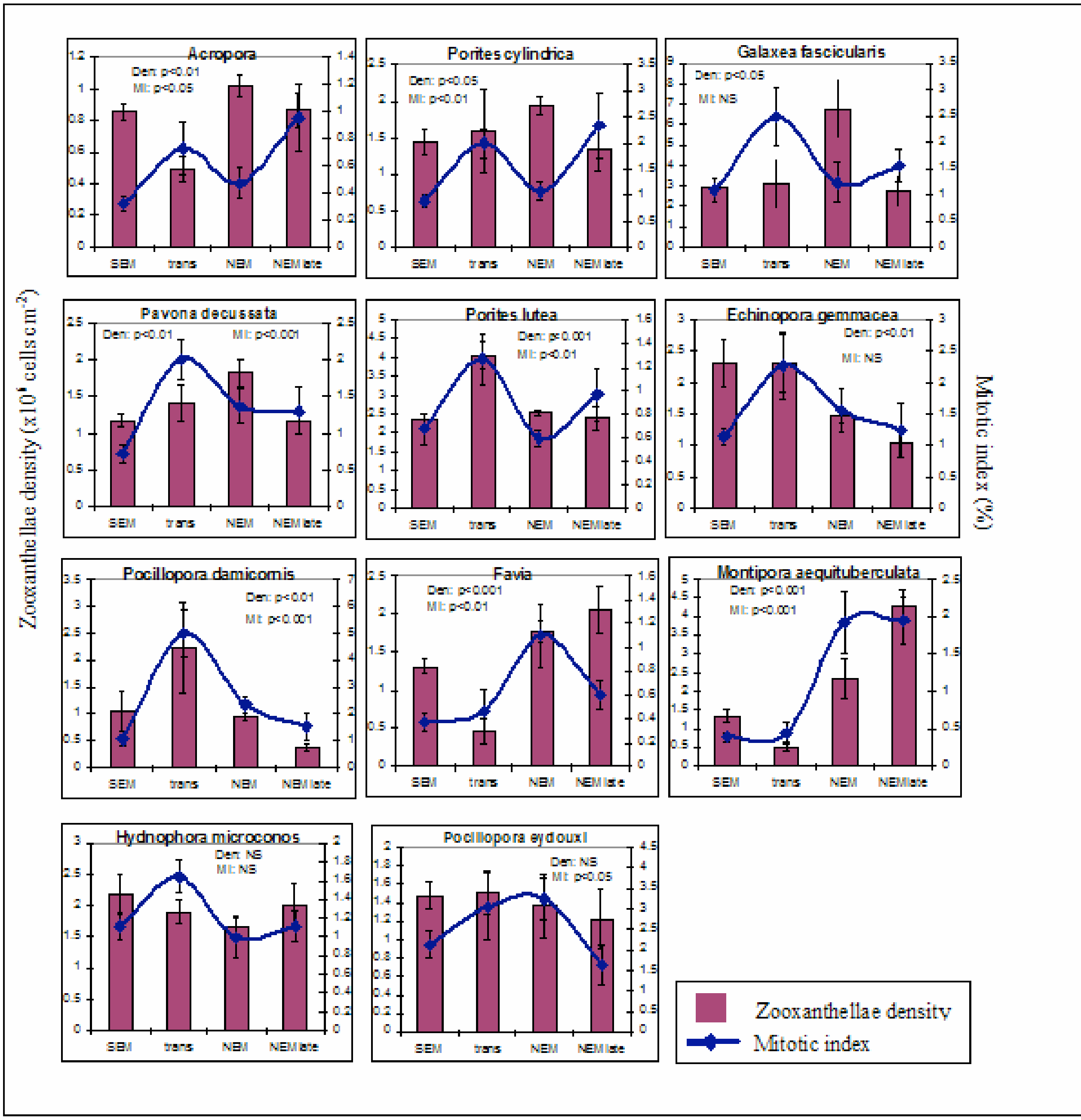

Figure 3. Average seasonal zooxanthellae densities and mitotic indices for all species. SEM = Southeast monsoon. Trans = Transitional period between monsoons. NEM = Northeast monsoon. NEMlate = Late Northeast monsoon. ANOVA values are also shown to illustrate significant differences between seasons. Den = Zooxanthellae density. MI = Mitotic index.

Although different zooxanthellae densities in different species peaked in different months, all species displayed highest densities at some point during the overall northeast monsoon season (1^{st} November to 30^{th} April) and most displayed highest mitotic indices during the transitional period directly preceding the Northeast monsoon (1^{st} November to 15^{th} December) (Fig 3). The higher densities found during the northeast monsoon (when temperatures and radiation levels are higher) are surprising as they are contrary to trends found at higher latitudes. It is possible that at higher latitudes seasonal variability of temperature and light is so great that it dictates zooxanthellae density fluctuations, while corals closer to equator may be less influenced by seasonal variability of temperature and light, and other factors may have a greater influence on population dynamics.

This study thus highlights the degree of variability in zooxanthellae population dynamics there may be among coral species and between sites at widely different geographic locations.

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A Description of *Acropora* sp. 1 in the Mombasa Lagoon in Kenya – A New Species or a Potential Hybrid?

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INTRODUCTION

Acropora species are taxonomically complex because they are highly polymorphic and have the potential to cross-fertilize and form hybrids that may be competent to settle, undergo metamorphosis and survive for up to 3.5 years (Willis et al. 1997). In Kenya *A. valida*, *A. secale* and *A. lutkeni* are, at times, remarkably similar in the field and can be difficult to separate. Mangubhai & Harrison (2006) highlighted the difficulties in separating *A. valida* from *A. secale* in the Mombasa lagoon due to the presence of a large number of immediate 'morphs' with characteristics of both species. In 2004 skeletons were collected of *A. valida*, *A. secale*, *A. lutkeni* and any corals showing characteristics of these 3 species for comparison to specimens at the Museum of Tropical Queensland in Australia. *Acropora valida* and *A. secale* from the Mombasa lagoon were found to be generally more sturdy (i.e. thicker and longer branches), while *A. lutkeni* was less sturdy and radial corallites were more 'organised' compared to specimens from other parts of the Western Indian Ocean and the Asia-Pacific region.

A fourth putative 'species' was identified, *Acropora* sp.1, which has tentatively been placed in the *Acropora nasuta* group (Wallace 1999) because it appears to share skeletal characteristics with all 3 species. Field and skeletal characteristics are provided below. The potential for *Acropora* sp.1 to be a more 'extreme' form of *A. secale* or *A. valida* or a more 'conservative' form of *A. lutkeni* cannot be overlooked, and there is also the possibility that hybridisation may be occurring between the different species. Detailed morphometric and genetic studies, and the further narrowing of spawning times, may resolve the taxonomic status of this putative 'species' at a later date.

Field: Colonies are mostly brown with brown or cream axial corallites (Fig. 1a-b). Towards the base of branches radial corallites become white giving them a scale-like appearance. Branches are rarely tapering, with branch thickness mostly made up by the radial corallites. However, these skeletal characters also occur in a small number of *A. valida*, *A. secale* and in *A. lutkeni*, making field identification of *Acropora* sp.1 difficult.

Skeleton: Colonies are corymbose or caespito-corymbose with a central or side attachment, with branches of 12-22 mm diameter and up to 140 mm in length. Axial corallites outer diameter ranges from 2.3-3.0 mm and inner diameter from 0.6-1.0 mm. Radial corallites are touching and are a mixture of sizes with fairly thick walls. The branch tip (10-20 mm) has tubular radial corallites with round to nariform openings, sometimes alternating with smaller sub-immersed corallites so that it bears a strong

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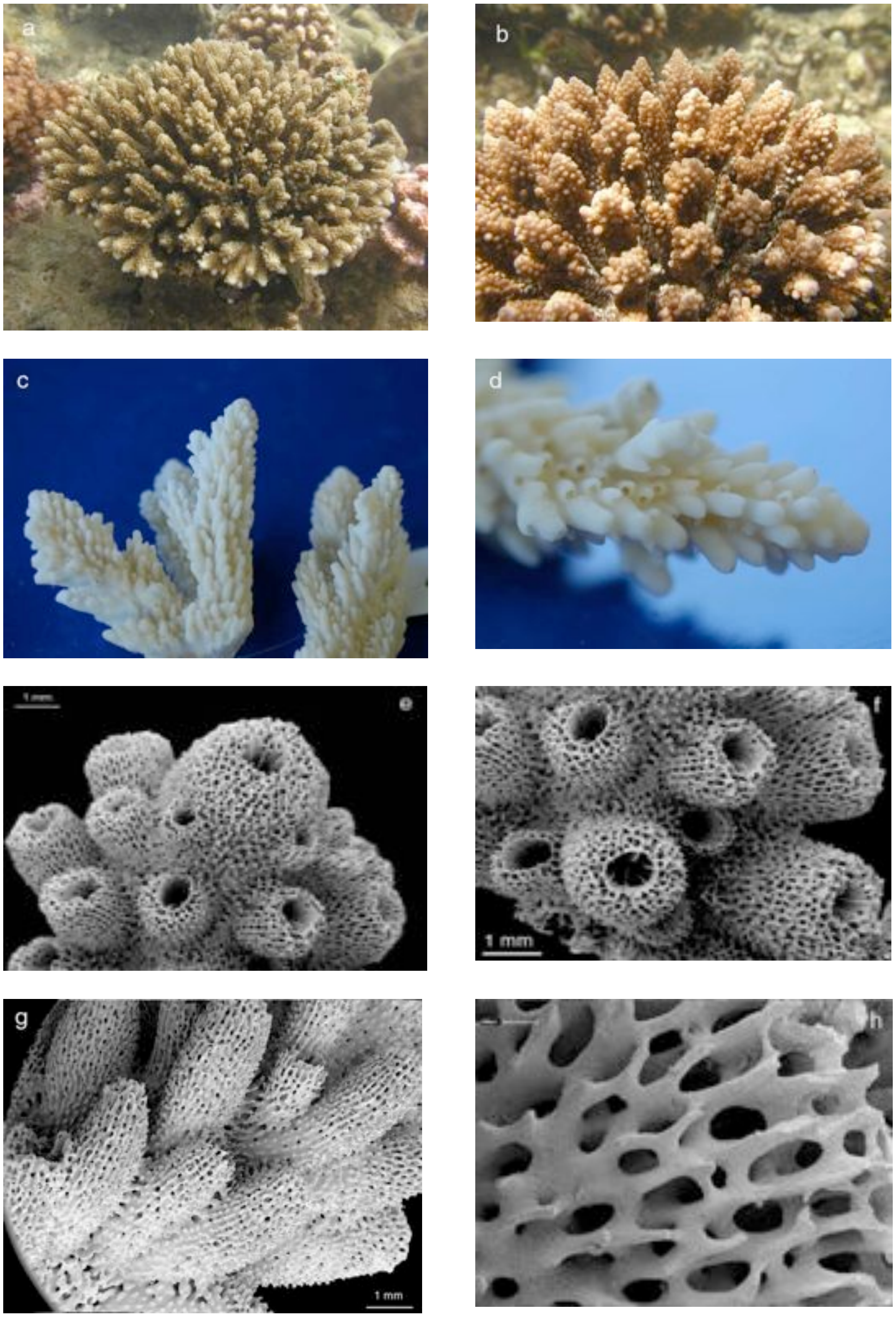

Figure 1: *Acropora* sp.1. Live colony (a-b), portion of colony (c-d); electron micrograph showing axial and radial corallites (e-g) and coenosteum on radial corallites (h).

resemblance to *A. secale*. However, below about 20 mm, radial corallites can become strongly appressed so that the remaining portion of the branch more closely resembles *A. valida*. The presence of secondary sub-branches and long tubular radial corallites of different lengths gives the branches a sturdy robust appearance that resembles *A. lutkeni*.

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The Lallie Didham Coral and Shell Collection, at CORDIO East Africa

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The scleractinian coral fauna of the East African mainland coast has had little formal systematic study. H.J. Hamilton, at the University of Dar es Salaam in the 1970s completed a Masters degree focusing on the coral fauna of Dar es Salaam and nearby areas of Tanzania and Kenya (Hamilton 1975, Hamilton and Brakel 1984). Since then, field surveys for coral diversity have been conducted at many sites but until high quality *in situ* identification resources with global coverage were released after the turn of this century (Veron 2000, Wallace 2001), species identification was severely hampered. In a regional compilation, Sheppard (2002) reported from the literature coral species numbers of 112 for Kenya and Tanzania combined, compared to recorded numbers of 270+ and predicted numbers over 300 (see Obura, 2007). As a result of this under-representation, the East African coast has featured as a lower-diversity subregion within the overall Indo-Pacific province (Veron 2000).

At present coral collections are held at the University of Dar es Salaam in the Faculty of Aquatic Science and Technology, and in the National Museums of Kenya, in Nairobi. The Lallie Didham coral and shell collection will add a further reference collection to be based in Mombasa, Kenya, to improve training in coral taxonomy and identification, and as a reference for the updated diversity of corals in the region.

Lallie Didham was born in 1929 in London, England, and moved to East Africa in 1952. Living in Malindi since 1960 adjacent to Casuarina Point, she was instrumental in helping the then Wildlife Conservation and Management Department in selecting the Malindi and Watamu reefs as Africa's first Marine Protected Areas, gazetted in 1968. Following that, Lallie was appointed an Honorary Warden, and maintained her support to the Malindi Warden throughout her life. Living by the reefs in Malindi, Lallie developed a passion for snorkeling and diving, which she pursued actively until 2002 with dive trips up and down the Kenya coast, and across the globe. With this passion came an interest in corals and shells, which she started to collect in the 1960s, recognizing the value of keeping voucher specimens, especially of rare and unusual species from limited localities. Lallie's collecting contributed to many leading collections around the world, and she passed specimens to the collections of the Museum of Natural History (London), Museum of Tropical Queensland (Australia) and the Australian Institute of Marine Science, among others, to the leading coral taxonomists in the world.

With her sad passing in 2001, Lallie's coral and shell collection has been loaned by her family under the care of CORDIO East Africa, to be curated and displayed for education and research. The coral collection was sorted and catalogued at CORDIO by Rose Machuku from Moi University, and Laurence Defrise, from Belgium. The collection numbers some

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Photo 1: Lallie Didham, at home in Malindi (right) and out snorkeling with KWS Warden Janet Kaleha and coxswain Heri (above left).

Table 1. Family composition of the Lallie Didham coral collection.

Family	Specimens
Acroporidae	69
Agariciidae	54
Caryophyllidae	1
Dendrophyllidae	48
Euphyllidae	12
Faviidae	144
Fungiidae	140
Helioporidae	4
Meandrinidae	3
Merulinidae	27
Milleporidae	5
Mussidae	28
Oculinidae	12
Pectiniidae	38
Pocilloporidae	36
Poritidae	49
Siderastreidae	47
Trachyphyllidae	12
Tubiporidae	1
Grand Total	730

Figure 1. Part of the Lallie Didham coral collection, on display at CORDIO East Africa, Mombasa.

730 specimens in 19 families and 64 genera. Cataloguing of specimens to the species level is in progress. The geographic range of specimens is not fully documented, but is known to extend along the whole coast of Kenya, with a small number of specimens likely from northern Tanzania. The shell collection has been grouped by family and photographed, and a malacologist will be sought to conduct further work on it.

In the long term CORDIO will seek a partnership with the National Museums of Kenya and Kenya Wildlife Service for the collection to form the heart of the national reference collections for corals and shells. In this capacity it will be open to the public for viewing, and to Kenyan students to teach them about corals and coral reefs, and train new generations of biologists and taxonomists.

ACKNOLWEDGEMENTS

We would like to acknowledge the family of Lallie Didham, for loaning the collection.

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Resilience-Integrating Science and Management in Coral Reefs Relevant to Climate Change

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ABSTRACT

Climate change will inevitably continue to cause degradation of coral reefs over coming decades (Hughes et al. 2003). The amount of damage depends on not only the rate and extent of change, but also on the ability of coral reefs to cope with change. Many MPA managers are asking, "What can we do about a large-scale issue such as climate change?" Resilience is the ability of a system to absorb or recover from disturbance while maintaining its functions and services. Natural coral reef resilience is being undermined by anthropogenic stresses such as degraded water quality, unsustainable and destructive fishing, and coastal development. These local pressures act in synergy with climate change to functionally reduce the resilience of the system, undermining its ability to cope with climate change. It becomes critical then for scientists and managers to determine the range of threats affecting the ecosystem to manage its ability to cope with climate change. While science has clearly documented the effects of climate change on coral reefs, climate-conscious strategies for managing them are only just emerging (Marshall and Schuttenberg 2006). At the MPA scale, the primary approach is to reduce other stressors and to boost the resilience of the reef.

Resilience assessments provide a comprehensive overview of threats, as well as of the state of the system. With this information in hand, a manager can make sound decisions. For example, fishing may be closed for different herbivorous fish groups during or after a bleaching event to minimize algal competition with recovering corals. Or the manager may press for more stringent control of pollution or runoff to minimize stress to corals during bleaching events. Conducting resilience surveys before an MPA is zoned can also help identify critical sites and refugia from different threats.

The IUCN Climate Change and Coral Reefs Working Group (CCCR) was created with support from the MacArthur Foundation to bring together leading coral reef practitioners to expedite the development of management tools and strategies that boost coral reef resilience. This paper outlines the methodology developed by the CCCR for assessing the

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resilience of coral reef sites to climate change (IUCN 2008). The paper focuses on one of the six components of the overall method, a suite of semi-quantitative 'resilience indicators' that are estimated on a 5-point scale.

An Operational Framework for Assessing Resilience

Coral reef resilience to climate change is determined by a range of oceanographic, environmental, ecological and anthropogenic factors (Grimsdith and Salm 2006). West and Salm (2003) and Obura (2005) provide a framework that relates these to thermal protection, thermal resistance, thermal tolerance and recovery potential. To operationalize these factors and variables for monitoring and management they can be distinguished by whether they are ecological, environmental (physical), or anthropogenic in origin, and by whether their primary influence is on the sensitivity of corals to thermal stress (protection, resistance and tolerance) or recovery ability following coral mortality, or both of these. Sensitivity is a combination of resistance (ability to experience exposure without bleaching) and tolerance (ability to survive once bleached); recovery potential is the capacity within the system following coral mortality for new corals to colonize and survive, thereby returning the reef to a coral-dominated state. Together, sensitivity and recovery potential determine the resilience of coral communities to rising sea temperatures.

The first step in practical application of resilience principles is to define resilience in operational terms: resilience of *what* to *what*? The IUCN methodology translates general resilience principles into a suite of variables that can be measured or estimated, on the resilience of corals and coral reefs to thermal stress. These can be used to derive an index for comparing the relative resilience of different coral reef areas. This operational definition for coral reef resilience provides the framework for selecting variables that can be measured, and for developing a semi-quantitative index of resilience.

The IUCN Methodology, Resilience Indicators and the 5-point Scale

The distinguishing features of the methodology compared to standard coral reef monitoring protocols are in more detailed measurements of coral population data (size classes, recruitment, condition etc), a functional group approach to fish surveys focusing on herbivores, and estimation of a variety of resilience indicators selected to quantify the main factors that affect reef resilience. Here we describe the resilience factors and semi-quantitative indicators quantified in the methodology.

Data collection on the resilience indicators is grouped by factors that affect resilience of a site to climate change. For example, screening and shading is a factor that affects the degree of bleaching of a coral (West and Salm 2003, Obura 2005), and can be estimated by multiple variables including turbidity, exposure to river plumes, reef slope, etc. With sufficient time, resources and expertise the quantification of these factors could be done through detailed quantitative measurements (e.g. turbidity readings throughout the year), however this is impractical for rapid assessment thus an estimation approach is used, based on a semi-quantitative 5-point scale that the observer must estimate based on conditions at the time of field surveys and general and published knowledge about the site or region.

The 5-point scale was selected to facilitate estimation of minimum (1), maximum (5) and moderate (3) levels for each indicator for the region of application, and intermediate levels of low (2) and high (4). In general scaling is done such that 1 designates low/poor/negative conditions for corals and 5 high/good/positive conditions. Where an indicator can be quantified directly (e.g. visibility in meters, slope in degrees) it is estimated directly, and converted to a 5–point scale during analysis.

Because the indicator scaling is semi-quantitative, observers must be fully comfortable with the rationale behind the scaling, and have a broad knowledge of local conditions. A criterion table containing a detailed description of each level of the 5-point scale for each indicator is included in the manual for the method, and must be reviewed and customized for each region/area of application. For example the location in a region with maximum wave energy should define the maximum (5) on the scale for wave energy; in one region this might be a reef front that experiences 2 m wind-waves during storms, in another region this might be a reef front that experiences 4 m ocean swells during its winter season. Scaling for between-region comparisons will be dealt with later, based on the levels set in each region's definition table.

Toward a Resilience Index

Resilience, even in its simplified operational form, is a multi-dimensional property of a system. By incorporating this complexity, resilience has emerged as a key concept for understanding and managing highly dynamic and interconnected systems such as coral reefs. Yet, for resilience to be useful in many applied settings it must be able to be represented on a single dimension. This enables decisions about the relative resilience of different parts of the system to be made, and facilitates the use of resilience in practical planning and policy decisions. For example, an assessment of the relative resilience of different reefs or reef sites within a planning area can help managers decide how to prioritize investment of limited management resources. With knowledge of the location of naturally resilient sites, or of reefs that have low resilience due to human activities (such as exposure to poor water quality), managers can strategize their efforts to optimize resilience outcomes.

A simple resilience index can be derived from the multiple variables that are known to contribute to system resilience. Appropriately standardized (to generate a rating of 1 to 5, for example), such an index will enable managers to assess the relative resilience of different reefs. Further, by examining the values of the underlying resilience factors and variables, managers can delve into the basis for the resilience rating of any particular reef. This can be especially useful when multiple reefs have the same resilience rating, but for different reasons. Understanding the basis for a resilience rating can help managers decide whether action might be effective in restoring or maintaining the resilience of a site.

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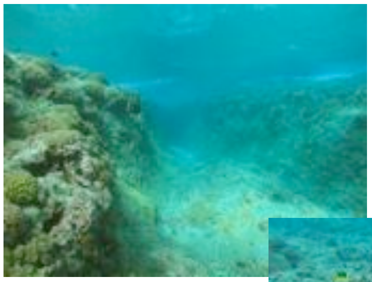
RESILIENCE FACTORS & INDICATORS

a) Physical factors

Temperature	Primary stressor for bleaching related to climate change	Spot measurements with a thermometer allow basic comparisons among sites, but ideally need long term in situ records, and satellite data to infer differences among sites.
Depth	Basic zonation variable for coral reef and community structure, and for attenuation of temperature, light and other variables	In situ measurement, usually samples done in standard depth zones for analysis. Tidal variation important to be factored out, particularly where range > 2 m.
Radiation	Primary stressor for high-light bleaching and during doldrum conditions.	Basic measurement with light loggers (eg. Hobo) possible, or better with light meter. Usually not possible, or can be done at a few locations to ground-truth visibility and depth factors.
Visibility	Proxy for turbidity and attenuation of light levels at a site, a primary and synergistic stressor with temperature.	Horizontal visibility at the sampling depth, or improved with use of secchi disc (though not possible in shallow water). Where possible suspended particulates/turbidity can be measured.



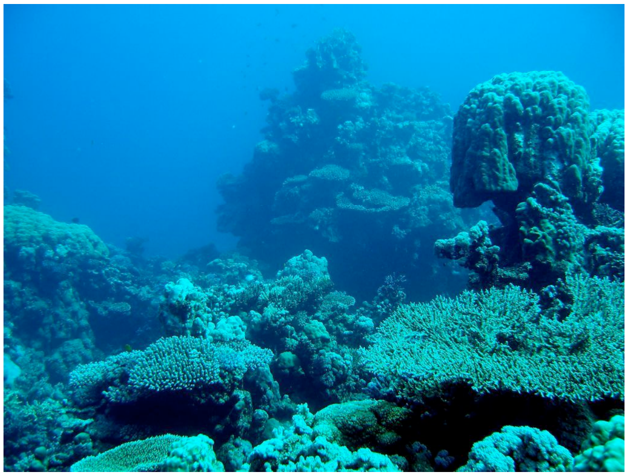
Temperature and light are two of the dominant factors that control coral growth and reef distribution from local to global scales, and both decrease with depth. They are also the primary variables involved in mass coral bleaching related to climate change, where increased temperatures and light levels during calm periods result in severe stress and bleaching. Physical measurements of both should be known for the study area over an annual cycle, such as by installing temperature loggers at key sites, and making light measurements during key seasons. These will help interpret the one-off estimates of temperature and light made during field surveys using the variables above.

Photos top to bottom: Coral reef depth zones on an outer atoll slope, showing influence of wave energy and light attenuation: surge zone impacted by high wave energy (0-5 m), shallow platform with high coral cover (5-15 m), reef edge above dropoff into deep water (15-20 m), and deep fore reef slope (25 m) showing coral plates determined by low light penetration.

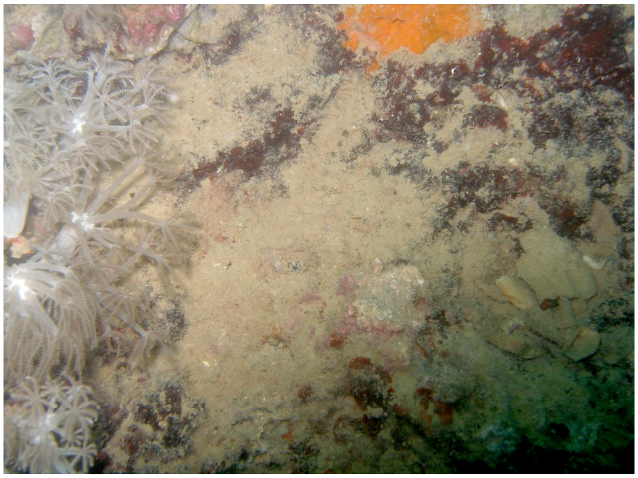
b) Substrate and reef morphology factors

Sediment layer texture	Sediment grain size and sorting affects benthic organisms.	Estimation on 5 point scale, from large-size/carbonate sand grains at one end (good) to fine silty sediment with high terrigenous content at the bad end.
Sediment layer depth	Depth of sediment layers on hard substrata, particularly in association with algal filaments/ turf.	Estimation on 5 point scale, from no sediment on hard substrata to drifts of sediment and/or entrapment of sediment in algal filaments/ turf that inhibit settlement.
Topographic complexity – micro	The surface roughness and small-crevice space on reefs affects recruitment of corals.	Estimation on 5 point scale of surface roughness on < 10 cm scale, from smooth to complex 3-D spaces allowing light penetration but shelter from predators and sedimentation (e.g. in complex branching frameworks)
Topographic complexity – macro	The large scale structure of a reef, providing habitats for large and higher-trophic level mobile organisms (e.g. fish)	Estimation on 5 point scale of structure on a 1-10 m scale, from a flat pavement to complex 3-D reef slopes with spur/ grooves, pillars, caves and large internal reef spaces.

Recruitment and growth of corals, and therefore recovery and resilience, are affected by the topographic complexity and substrate quality of a reef. Topographic complexity is important as it determines the amount of space available for fauna and flora to attach to, the types and numbers of micro-habitats and shelter provided for different reef residents, and the complexity of interaction between substratum and the water column. At the small scale (micro-topography) small crevices provide important habitats for coral recruits to grow. At the large scale (macro-topography) physical structures such as spurs, grooves, pillars and caves provides habitats for larger organisms crucial to resilience, such as herbivorous fish. Sediment quality and quantity strongly affect the survival of benthic organisms, and in particular settlement larvae to the benthos and their subsequent recovery. Sediment that is fine and of terrigenous origin (silt) is a stronger inhibitor than coarse sediment of calcareous origin, both for physical reasons and because it contains higher levels of organic matter and microbial community detrimental to corals.



A reef with complex micro- and macro-topography has the capacity for high recruitment and survival of young corals and provision of shelter for many other organisms. Photo credits to David Obura, unless indicated otherwise.



Fine terrigenous sediment on a reef surface inhibits coral larval settlement and survival.

c) Cooling and flushing factors

Currents	Currents cause vertical mixing that may reduce surface temperatures, and can reduce coral stress by reducing boundary layer effects on coral metabolism.	Estimation on 5 point scale, informed by local knowledge and/or by 'typical' expectations of particular reef structures such as linear reef fronts, channels, etc.
Waves (Exposure)	Wave energy causes vertical mixing, can reduce boundary layer effects on coral metabolism and increases oxygenation of water, enhancing coral metabolism. Exposure to weather events is expressed as wave energy to corals.	Estimation on 5 point scale, from minimum waves on sheltered/leeward reefs to maximum waves on reef crests. Increasing depth reduces the influence of wave energy, so is quantified under 'depth' not in this indicator. Exposure and wave energy are related, so one may be sufficient for estimation.
Deep water	Proximity to deep water enables mixing with cold water by upwelling and waves, currents and exposure.	Estimation on 5 point scale, from immediate proximity at a vertical wall, to distant. Alternatively, distance to a deep contour (30/50 m) may be measured from charts.
Depth of reef base	The depth of the base of a reef slope affects the potential for mixing of deep cool waters.	Actual depth of base of main reef slope. Along with "deep water" gives an indication of potential for upwelling/ mixing of cooler water.

Exposure to very warm surface waters is the primary cause of coral bleaching, where both the degree of warming (>1°C above normal during the summer months) and the duration of warming accumulate stress in the coral. These factors result in cooling of sea water temperatures by causing or facilitating mixing of deep cooler waters into the warmer surface layers. Currents mix the water column, especialy when they are variable, such as tidal currents, and when interacting with a complex bottom structure., Breaking waves result in mixing within the wave/surge zone. Proximity of the coral community to deep water (e.g. the 50 m contour line), or a deep reef base facilitate mixing of deeper water.

Breaking waves cause water mixing, reducing the temperature of the warm surface layer.

Proximity to deep water and a deep reef slope enhance vertical mixing of cool deeper waters up into the shallows, by currents, tides, internal waves and surface waves.

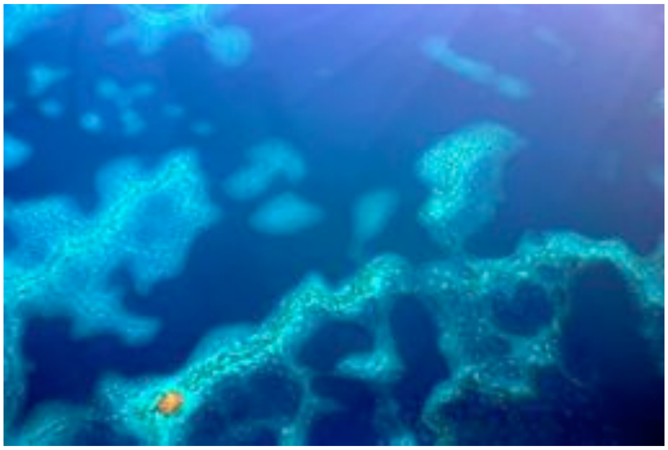
d) Acclimatization/extreme condition factors

Low tide exposure	Shallow corals exposed to the air at low tide experience frequent stress, and may be more resistant to thermal stress.	Estimation on 5 point scale, relevant only to very shallow corals.
Ponding/ pooling	Restricted bodies of water heat up more due to less mixing and greater residence times, and also enhance metabolic stress.	Estimation on 5 point scale, maximum for enclosed shallow bodies of water
Survival of past bleaching event	Corals that have bleached in the past but not died may be acclimatized to bleaching conditions, and have higher tolerance for repeated bleaching events	Estimation on 5 point scale, based on time since, and scale of, bleaching event.

Acclimatisation is the learned adjustment to new conditions by an organism, i.e. phenotypic change in an organism due to stress that results in readjustment of the organism's tolerance levels, and its continued survival. Corals that are regularly exposed to extreme or highly fluctuating environmental conditions, such as on reef flats or in shallow lagoons that are subject to intense solar radiation and high fluctuations in temperature, have acclimatised to survive in these environments. This is thought to give the corals some protection from high temperatures that cause bleaching and mortality in deeper corals less accustomed to high variability, even though they may display high levels of background stress due to the fluctuating conditions. This assessment method estimates the degree to which corals are exposed to the air during low tide or are found in restricted pools or bodies of water that heat due to solar insolation. Furthermore, corals on reefs which have previously been exposed to bleaching conditions and survived may be more resistant during future bleaching events.

An *Acropora* colony that survived a past bleaching event may have enhanced resistance for the next one.

Corals exposed at low tide and isolated in shallow pools may acclimatise to wide fluctuations in environmental conditions, enhancing resistance to bleaching. Photo: Andrew Porter.



Ponding of water is enhanced by enclosed bays and reticulate reef systems, inducing high temperature fluctuations.

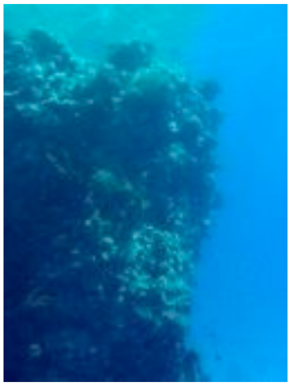
e) Shading and screening factors

Compass direction/ Aspect	The aspect of a reef slope affects the angle of incidence of the sun on the reef surface, and therefore radiation per area of reef/colony surface.	Compass direction of the reef slope. The 5 point scale will be determined based on compass direction and latitude, during analysis.
Slope	The angle of a reef slope affects the angle of incidence of the sun.	Estimated slope angle, in degrees. The 5 point scale will be determined based on the range of values, during analysis.
Physical shading	Shading of corals by reef slopes, pillars or above-water features (hills/cliffs/ rocks) can protect corals from stress.	Estimation on 5 point scale, with the maximum for full shading at noon.
Canopy corals	Shading of understory corals by canopy corals (tables, staghorn, plates, etc) can protect them from stress.	Estimation on 5 point scale, with the maximum for cover by canopy corals.
Visibility	Proxy for turbidity and attenuation of light levels at a site, a primary and synergistic stressor with temperature.	Horizontal visibility at the sampling depth, or improved with use of secchi disc (though not possible in shallow water). Where possible suspended particulates/turbidity can be measured.

Exposure to high levels of solar radiation, both ultraviolet (UV, 280-400 nm) and Photosynthetically Active Radiation (PAR, 400-700 nm), also results in coral bleaching, and strongly exacerbates bleaching due to high sea water temperatures. Physical features that provide shade, for example cliffs or overhead rocks and corals, or conditions that reduce water transparency and solar radiation, for example light scattering by turbidity or absorption by chromophoric dissolved organic matter, can protect corals from bleaching. The temporal/seasonal dynamics of variable factors that reduce light levels, such as turbidity or cloud cover, must be assessed carefully compared to those that are provided by permanent physical features, such as shading. Thus visibility at the time of surveys is used as a proxy for turbidity, but it must be further assessed in terms of seasonal variation and reliability during bleaching events. Areas that are reliably protected from solar radiation can provide crucial refugia for corals that re-seed surrounding reefs after bleaching events.

Coloured dissolved organic matter in low-visibility waters screen corals from UV and PAR, and river plumes during the warm season may even protect corals from bleaching.

Shading by overhanging structures can protect corals from bleaching. The macro-topography these structures offer also provide habitats for fish. Photo: Thomas Jundt.



Shading by steep slopes and walls, particularly if they point away from the mid-day soon during the local summer, shade corals from high light stress.

f) Coral population factors

Bleaching	Current levels of coral bleaching.	Percentage of corals bleached.
Mortality-recent	Current levels of coral mortality.	Percentage of corals showing partial/full mortality.
Mortality-old	Levels of mortality from the past.	Degree of historic mortality evidenced by appearance of dead coral skeletons. Directly quantified, or as 5 point scale depending on ease of estimation.
Recovery-old	Levels of recovery from the past mortality events.	Degree of recovery from old mortality, appearance of dead coral skeletons and regrowth/recolonization of corals since then, and knowledge on past mortality. Directly quantified, or as 5 point scale depending on ease of estimation.
Disease	Levels of coral disease	Percentage of corals showing disease conditions.
Recruitment	Recruitment of new corals is necessary for population recovery and injection of genetic variability.	Estimated number and genus of recruits/new corals < 2-3 cm, per m2 of substrate.
Fragmentation	Asexual reproduction by fragmentation is an important strategy of propagation for many corals.	Estimated contribution of fragmentation in generating new colonies, and primary genera affected. 5 point scale based on evidence for partial mortality/ fragmentation producing significant number of small to mid-sized corals (e.g. 5 – 20 cm)
Dominant size classes	The dominant size classes, by area, indicate the maturity and ecological stage of a community.	Estimation of dominance in the coral community by size class and genus of coral, indicating successional stage of the community.
Largest corals	The largest corals at a site indicate how long conditions have been suitable at the site, and the degree of environmental stability/ community persistence	The size in meters, and genus/species of the three largest colonies at the site.

The state of a coral population is indicated by these factors, including aspects related to current stress and mortality, past mortality, recovery from past mortality, recruitment of young corals and what age/size group of corals dominates the population. Together with indicators of diversity and the dominant genera, these can give an indication of whether the population has already suffered impacts from bleaching, and potential resistance to future bleaching. These indicators provide indicators of coral health against which to assess the other indicators of resilience.



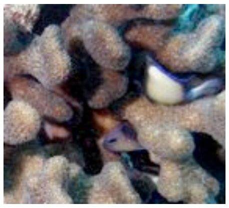


Photos from left to right: Extensive stands of large corals indicate stable conditions for the assemblage, low levels of past disturbance for those species and dominance by large colonies. Abundant small to mid-sized corals indicate high levels of recruitment and growth, and possible recovery from a relatively recent disturbance event, such as mass bleaching. A coral juvenile, having survived settlement and recruitment phases. Disease levels may increase with seawater warming and as stress levels in corals increase, making them less resistant to disease attack. Bleaching of corals can range from pale to fully white, and may affect only parts of a colony.

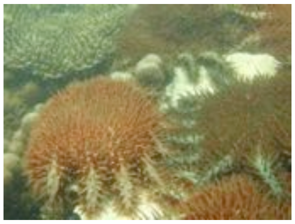
g) Coral associates

Obligate feeders	The abundance and diversity of obligate coral feeders are indicative of the health of coral colonies and complexity of interactions at a site.	Estimation on 5 point scale, from absent to high abundance/ diversity.
Branching residents	The abundance and diversity of fish and invertebrate residents in branching coral colonies are indicative of the health of coral colonies and complexity of interactions at a site.	Estimation on 5 point scale, from absent to high abundance/ diversity.
Competitors	The abundance and diversity of coral competitors are indicative of inhibiting factors to coral growth and recovery.	Estimation on 5 point scale, from absent to high abundance/ diversity
Bioeroders – external (urchins, nonfish)	The abundance and diversity of nonfish exernal bioeroders are indicative of inhibiting factors to coral growth and recovery	From transect/ quadrat counts or by estimation on 5 point scale, from absent to high abundance/ diversity.
Bioeroders – internal (sponges, worms, etc)	The abundance and diversity of internal bioeroders are indicative of inhibiting factors to coral growth and recovery	Estimation on 5 point scale, from absent to high abundance/ diversity
Corallivores (negative impact)	The abundance and diversity of corallivores (eg. COTs, Drupella) are indicative of additional mortality to coral colonies.	From transect/ quadrat counts or by estimation on 5 point scale, from absent to high abundance/ diversity.

Corals are afected by a broad variety of positive and negative interactions with other species. Obligate coral feeders (e.g. some butteflyfish) and residents in branching corals can be used as indicators of the health of corals and their ability to support dependent species. The presence of 'negative' associates can indicate levels of stress experienced by corals defending themselves against e.g. competitors or predators, and also of ecological/ environmental conditions that might favour the competitors over corals, e.g. of high-nutrient conditions promoting competing sponges or internal bioeroders. While there are many positive and negative associates of corals, the ones identified for estimation in this assessment method should be well known and relevant to the study area.







Photos from left to right: Species resident in branching corals can give an indicator of the health and maturity of the coral community. Competitive interactions, such as with encrusting sponges and microbial mats indicate conditions suitable for competitors, and that corals are experiencing stress from these interactions. Boring organisms on coral skeletons may cause some stress to corals when at high densities. Coral predators such as the crown of thorns seaster (*Acanthaster planci*) can cause significant damage to coral communities.

h) Connectivity factors

Capacity for self-seeding (autochthony)	Recruitment of new corals appears to be more strongly driven by self-seeding than previously thought.	Based on literature, proxy indicators – reef/island size, strength/linearity of currents, presence of eddies.
Capacity for external seeding (allochthony) – small scale	Larval density decreases with distance from healthy source reefs, thus inter-reef distances important for allochthonous larval seeding.	Distance from nearest healthy reef/system, on 10 km scale.
Capacity for external seeding (allochthony) – large scale	Larval density decreases with distance from the source, thus distances between major reef tracts important for allochthonous larval seeding.	Distance from nearest reef system/ complexity of regional reef biome (in 100s of km)
Suitability of currents in maintaining connectivity among reefs	Locations within direct current flows will have enhanced capacity for external seeding of larvae, current systems maximizing flow among reefs and locations will maximize connectivity among sites.	Estimate degree of connection (cross-flow) vs. upstream/downstream flow).
Natural larval dispersal barrier	Natural dispersal barriers reduce the degree of external seeding of larvae	Distance to and size of nearest natural dispersal barrier.

Recovery of a coral community after mass mortality is strongly influenced by the supply of larvae from reproductive adult populations, i.e. connectivity between reefs. Further, since stressed corals may not produce larvae for over a year, and since susceptible species may be completely eliminated from a reef by bleaching, the recovery of a bleached reef may be initially dependent on coral larvae from neighbouring reefs. Reefs are therefore more resilient to disturbances such as bleaching if they are well connected to healthy '*source*' reefs or '*refugia*' by ocean currents that provide larvae to replenish the degraded reef. The availability of larvae is related to the proximity to healthy reefs and oceanographic features such as currents, eddies, and their interaction with bathymetric and topographic features such as bays and inlets. Localised hydrodynamic features that prolong water residence times increase the likelihood of settlement. Dispersal barriers prevent transport of larvae to downstream reefs and may be natural (for example river discharges) or anthropogenic (for example pollution sources or enhanced river outflows). In addition to these connectivity factors, recruitment success and post-recruitment survival of juvenile corals is affected by the quality and stability of the substrate and other factors such as coralline algae, herbivore grazing and sedimentation. Understanding connectivity patterns is essential to designing successful Marine Protected Area networks.

An *Acropora* recruit is likely seeded from a different reef, as the larvae of broadcast-spawning species spend some weeks in the water column feeding and growing.

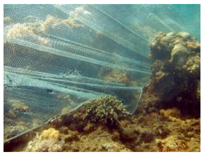
The geomorphology of the coastline and adjacent reef systems, together with the direction and strength of currents, determine the capacity for source-sink relationships between reefs. In general, complex reef systems have higher levels of connectivity due to complex currents among them.

Dispersal barriers may be physical, such as land- or open ocean barriers that prevent connectivity between reef systems, or due to environmental barriers such as large estuarine or river systems that create unsuitable conditions in the water column and on the bottom for coral survival and growth.

i) Anthropogenic factors

Nutrient input	Nutrient enhancement or eutrophication alters many reef processes, enhancing algal and microbial growth, and metabolically stressing corals.	Estimate effect of anthropogenically derived nutrients on site, from zero to extreme.
Pollution (chemical)	Chemical pollution causes metabolic stress to reef organisms, either causing mortality, or reducing their ability to withstand other stresses	Estimate effect of anthropogenic pollutants on site, from zero to extreme. Distance to pollution sources can be an alternative.
Pollution (solid)	Solid wastes foul the substrate and may make it unsuitable for coral recruitment and growth.	Presence of solid waste on site and/or distance to sources.
Turbidity/ Sedimentation	Anthropogenically enhanced turbidity and sedimentation in general negatively affects corals, though see shading/screening factor.	Estimate effect of anthropogenic factors on turbidity/sedimentation at site
Physical damage	Physical damage to the site or to corals results in mortality and/or inhibits recovery.	Estimate effect of physical damage on site
Fishing pressure	Overfishing causes reef degradation by changing trophic web structures, altering top-down ecological controls and leading to phase shifts.	Estimate effect of fishing by observation underwater and/or using catch monitoring data, local knowledge and other sources.
Destructive fishing	Destructive fishing causes physical damage to the site, and/or alters fish population dynamics.	Estimate destructive fishing by observation underwater and/or using catch monitoring data, local knowledge and other sources
Dispersal barriers	Anthropogenic factors that enhance natural barriers or create new barriers to external seeding of larvae	Distance to and degree of nearest anthropogenic dispersal barrier and/or enhancement of natural barriers.
MPA or other management	Management that reduces any of the above anthropogenic stressors enhances the natural ability of corals and reefs to resist bleaching and to recover.	Estimate effectiveness of management actions from none to high (as an additional factor to the reduced level of the stressors above).

Anthropogenic activities affect many ecological processes on coral reefs, and corals chronically affected by anthropogenic impacts must expend energy on resisting stress and therefore have a lower resilience to other disasters such as bleaching. Stressed corals bleach more easily, produce fewer larvae and grow more slowly, and this reduces recovery rates. This assessment method focuses on anthropogenic nutrient input, pollution, sedimentation, physical damage, fishing pressure and destructive fishing; and provides an estimation of how each of these stresses reduces natural resilience by degrading specific ecological processes. For example, over-fishing of herbivorous fish depletes the system of this key functional group and allows macro-algae to outcompete corals after a bleaching event. Effective management at the source of key anthropogenic stressors, for example through Marine Protected Areas or fisheries management that maintains populations of herbivores, can help promote recovery and thereby support the ability of corals and reefs to resist and recover from bleaching impacts.



Photos from left to right: Anthropogenic impacts on coral reefs are diverse and have led to the degradation of may reef systems worldwide. Fishing, even by small-scale commercial fishers can significantly damage reefs due to human population growth and increasing demand for marine products. Photo credit: Monica Zavagli. Examples of direct damage to coral reefs includes bottom-damage by nets and overfishing of juveniles, destruction of reef structures by dynamite and anchor damage from boats of all types. Development in coral reef areas, particularly for mining or industry, can result in high levels of pollution that reduce the resilience of reef communities. High density urban populations and over-developed coastlines can result in high levels of sewage pollution to coral reef waters, causing coral mortality and a switch to more nutrient-tolerant communities.

CORDIO Status Report 2008

Part 5 – Fish Spawning Aggregations

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 IndianOcean)/Sida-SAREC. Mombasa. http//:www.cordioea.org

Reef Fish Spawning Aggregations in the Western Indian Ocean: Current Knowledge and Implications for Management

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keywords: spawning aggregations; local ecological knowledge; verification; periodicity; habitat, management implications

ABSTRACT

Studies of reef fish spawning aggregations are new to the Western Indian Ocean compared to other regions. This paper reviews the current state of knowledge of spawning aggregations in the region and assesses their implications for fisheries management and conservation. Fisher knowledge has identified more than 30 species of reef fish that aggregate to spawn, mainly belonging to the families Lutjanidae, Serranidae, Lethrinidae and Siganidae. Verification has been achieved for 25 spawning aggregations from 7 species, including five and six aggregations of *Epinephelus fuscoguttatus* and *Siganus sutor*, respectively. Reef fishes commonly spawn within the northeast (November-April) and inter-tropical monsoon periods. Serranid aggregation sites include reef passes, channels, reef slopes and pinnacles, while *Siganus sutor* spawns on patch reefs and granitic reefs. The status of spawning aggregations is poorly known and evidence of aggregation collapses are currently confined to Seychelles. Few spawning aggregations are protected in the region and their applicability to new approaches of managing for resilience will not be realised without considerable efforts in research and advocacy. The management of spawning aggregations through marine protected areas does not constitute a solution for fisheries management and must be viewed as complementary to tools such as catch and effort controls.

INTRODUCTION

In the Western Indian Ocean (WIO) scientific information on artisanal fisheries is insufficient and management regimes require substantial improvement (van der Elst *et al.*, 2005). In areas of East Africa, overfishing may constitute the most important local threat to coral reefs (McClanahan *et al.*, 2000). Combined with the impacts of coral bleaching, coastal pollution, development and other direct and indirect causes (Samoilys & Church, 2004; Obura, 2005;

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 IndianOcean/Sida-SAREC. Mombasa. http//:www.cordioea.org

Payet, 2005), problems in the region often appear intractable. Marine protected areas (MPAs) or reserves are increasingly viewed as a solution to a global fish crisis (Gell & Roberts, 2003; Halpern 2003). While the functioning of MPAs for conservation objectives is not in doubt, improving their use for fisheries management requires filling significant scientific gaps in their application and design (Sale *et al.*, 2005).

In the context of coral reef degradation, concepts of managing for system resilience highlight the need for networks of MPAs (Obura, 2005, Schubert *et al.*, 2006). The protection of reef fish spawning sites as sources of seed is central to marine reserve network models (Sala *et al.*, 2002). However, this approach has progressed little as an applied conservation or reef fisheries management tool, even where scientific knowledge of aggregation sites is extensive. With few spawning aggregations effectively managed in no-take reserves (Sadovy & Domeier, 2005), let alone as part of networks, this element of managing for resilience lags far behind that of biodiversity and coral conservation (e.g. TNC, 2004, Grimsditch & Salm, 2006). Reef fishes are highly diverse in terms of their reproductive strategies and patterns (Sadovy, 1996) but spawning in aggregations at specific times and locations is common to several families of reef fishes (Domeier & Colin, 1997).

Dedicated initiatives to locate and study spawning aggregations in the WIO began in 2003 with a three-year programme in Seychelles to locate and verify sites reported by fishers (Robinson *et al.*, 2004; Robinson *et al.*, 2007). This was followed by an IUCN-led initiative to document local ecological knowledge of aggregations in Kenya, Mozambique and Tanzania and, later, to verify sites in Kenya (Samoilys *et al.*, 2006; Samoilys *et al.*, in prep). A more localised and fishery specific research project which also studied spawning aggregations was recently completed in southern Kenya (Kimani, in prep.). Fisher knowledge on fish spawning behaviour is often detailed (Johannes, 1981; Samoilys & Squire, 1994). Locating aggregations from fisher knowledge often remains a difficult task depending on the availability and quality of fisher information and other data on periodicity and sites. Due to the fact that reef fish may aggregate for purposes other than reproduction, it is necessary to verify spawning and aggregation formation using spawning indicators, such as behavioural observations of spawning and surveys that demonstrate increase in abundance coupled with hydrated ovaries. Methodological approaches for this field have emerged in the last decade (Colin *et al.*, 2003; Pet *et al.*, 2006) and have formed the basis for much of the work in the WIO to date.

This paper reviews the current state of knowledge on reef fish spawning aggregations in the WIO region. The information presented largely draws on the three aforementioned projects in Seychelles, Kenya and Tanzania, but also draws on information from other countries and constitutes the first synthesis of its kind for the region.

FISHER KNOWLEDGE OF SPAWNING AGGREGATIONS

The documentation of fisher knowledge on reproductive behaviour is widely recommended as a first step to locating spawning aggregations (Johannes, 1981; Samoilys & Squire, 1994; Colin *et al.*, 2003). However, fishers' knowledge is also difficult information to analyse in order to distinguish reliable data on spawning aggregations (Daw, 2004). In summarising fishers' information from the WIO (Table 1), some or all of the following criteria were met (Robinson *et al.,* 2004, Samoilys *et al.,* 2006):

i. descriptive information on spawning aggregation behaviour of species conforms to typical spawning behaviour such as courtship, territorial displays of males, release of gametes;
ii. fish were seen with fully ripe gonads (hydrated ovaries);
iii. information on species reported by >1 fisher;
iv. information on location reported by >1 fisher.

Slightly more species have been reported to form spawning aggregations in Kenya compared to Seychelles, while the lack of reports from Tanzania is probably due to less research on this topic. The

Table 1. Species reported by fishers to form spawning aggregations in three countries of the WIO region (Robinson, *et al.,* 2004; Samoilys, *et al*., 2006; Kimani, in prep.; Samoilys, *et al*., in prep.).

Family	Species	Kenya	Seychelles	Tanzania
Acanthuridae	*Acanthurus mata*	√		
	Naso brevirostris	√		
Carangidae	*Carangoides gymnostethus*		√	
	C. fulvoguttatus		√	
	Selar crumenophthalmus		√	
Haemulidae	*Plectorhinchus flavomaculatus*	√		
	P. gaterinus	√		
	P. schotaf	√		
Lethrinidae	*Lethrinus crocineus*		√	
	L. harak	√		
	L. nebulosus		√	
	L. obsoletus	√		
	L. xanthochilus	√		
Lutjanidae	*Aprion virescens*		√	
	Lutjanus argentimaculatus	√		
	L. bohar	√	√	
	L. ehrenbergi	√		
	L. fulviflamma [1]	√		
	L. gibbus	√		
	L. quinquelineatus	√		
	L. rivulatus	√		
	L. sanguineus	√	√	
	L. sebae	√	√	√
Serranidae	*Cephalopholis miniata*	√		
	Epinephelus fuscoguttatus	√	√	
	E. lanceolatus [2]			√
	E. multinotatus [3]		√	
	E. polyphekadion	√	√	
	Plectropomus laevis		√	
	P. punctatus	√	√	
Scaridae	*Scarus rubroviolaceous*		√	
	Leptoscarus vaigiensis	√		
Siganidae	*S. argenteus*		√	
	S. sutor	√	√	√
Sphyraenidae	*Sphyraena jello*		√	
Mullidae	*Mulloidichthys vanicolensis*	√		

[1]: *Note:* L. fulviflamma *incorrectly reported as* L. kasmira *in Samoilys et al., 2006.*
[2]: *Information on* E. lanceolatus *provided by N. Jiddawi, Institute of Marine Sciences, Zanzibar.*
[3]:*The same Creole name is often used for* Epinephelus multinotatus *and* E. flavocaeruleus*, leading to uncertainty in fisher reports (Robinson et al., 2007).*

rabbitfish *Siganus sutor*, a regional endemic and an important target species of reef fisheries, is well known as an aggregating species in all three countries. At the family level, the most species reported to form aggregations belong to the family Lutjanidae, followed by the Serranidae, the Lethrinidae and the Siganidae. Fisher observations of Carangidae spawning aggregations have largely been confined to Seychelles, where these species are important components of the artisanal catch.

Spawning in large aggregations is common to serranids (Domeier & Colin, 1997; Sadovy, 1996). Knowledge of reproductive behaviour is widespread in Seychelles, where at least five serranids and several key spawning sites have been consistently identified by fishers (Robinson *et al.*, 2004). In contrast, knowledge in Kenya and Tanzania appears more fragmentary (Samoilys *et al.*, 2006). Unlike the Seychelles where serranids are a target species of the artisanal fishery (Grandcourt, 2005), observations of fish catches and long-term data from catch monitoring systems suggest that serranids are unimportant to the Kenyan (see Waweru *et al.*, this report; McClanahan *et al.*, 1999; Kaunda-Arara *et al.*, 2003) and Tanzanian (Anderson, 2004; Wells *et al.*, 2007; Samoilys *et al.*, in press a) reef fisheries (but see below). It is therefore not surprising that fishers' information on their spawning aggregations is scant in East Africa. *E. polyphekadion* aggregations were known to fishers in northern Kenya and northern Tanzania (Samoilys *et al.,* 2006), however verification has only been obtained for *E. fuscoguttatus* spawning sites from southern Kenya, where large catches of this species with hydrated ovaries have also been observed (M.S. pers. obs.). Key informants and patriarchal fishers have proved invaluable in efforts to locate aggregations in the region.

VERIFIED SPAWNING AGGREGATIONS

A total of 25 spawning aggregations have been verified from seven species (Table 2). In Seychelles, 12 aggregations at 7 sites belonging to 4 species have been verified. *E. polyphekadion* and *E. fuscoguttatus* aggregations overlap spatially and temporally at three of the sites and are joined by *P. punctatus* at two sites. Multispecies sites are common amongst serranids, with *E. polyphekadion, E. fuscoguttatus* and *Plectropomus areolatus* commonly sharing sites in the Pacific (Sadovy, 2005). *P. punctatus*, being endemic to the WIO, replaces *P. areolatus* in this region. Since numerous families have been observed to spawn in close association with these serranids, their spawning sites may be considered key sites in reef systems (Johannes *et al.*, 1999; Russell, 2001) and their protection may therefore be justified on grounds of biodiversity conservation in addition to fisheries management.

Aggregations of *E. fuscoguttatus* have been verified at two sites in Kenya through observations of behaviour and colour changes consistent with spawning in this species (Johannes *et al.*, 1999; Rhodes & Sadovy, 2002; Robinson *et al.*, 2007), and an increase in densities of fish at the two sites. These sites are also examples of multispecies sites, where spawning behaviour has been verified for several other species, using indirect behavioural signs (Table 2). Possible evidence that fishers have targeted *E. fuscoguttatus* aggregations was found at Msambweni, southern Kenya; fish with hydrated ovaries were observed in large catches of this species (M.S. pers. obs). Fishers also reported spawning behaviour at the sites of capture (P.K pers. obs.). Note that this information was not obtained through the structured fisher interviews in the area (Kimani, in prep.), highlighting the importance of including macroscopic staging of gonads during catch monitoring. Hydrated gonads are easily identified as the eggs spill out from the abdomen in a characteristic manner, from which the term "running ripe" was derived.

Peak aggregation abundances vary greatly within and between species and sites. For example, *E. fuscoguttatus* abundances vary from less than 100 (in sites in Kenya and Seychelles) to more than 1000 fish (at sites in Seychelles). For the serranids, *E. polyphekadion* formed the largest aggregations, with numbers at one site peaking at over 2000 fish (Robinson *et al.*, in prep). No aggregations have been properly monitored in Kenya and therefore comparable data are not available. Aggregations of *Mulloidichthys vanicolensis* typically consisted of between 10 and 15 pairs (Samoilys *et al.*, in prep; Robinson *et al.*, 2007). The largest reef fish spawning aggregations verified in the WIO to date belong to *S.*

Table 2. Spawning aggregations verified in Seychelles and Kenya through a) direct or indirect observations of aggregative spawning and/or b) increases in abundance (Robinson *et al*., 2007; Samoilys *et al*., in prep.; Kimani, in prep.).

Country	Site	Species	Spawning[1]		Abundance[2]
			Direct	Indirect	
Seychelles	S1	*Epinephelus polyphekadion*	Yes	Yes	**Yes**
	S1	*Epinephelus fuscoguttatus*	Yes	Yes	**Yes**
	S1	*Plectropomus punctatus*	Yes	No	Yes
	S2	*Epinephelus polyphekadion*	Yes	Yes	No
	S2	*Epinephelus fuscoguttatus*	No	Yes	No
	S2	*Plectropomus punctatus*	Yes	No	No
	S3	*Epinephelus polyphekadion*	No	Yes	**Yes**
	S3	*Epinephelus fuscoguttatus*	No	Yes	**Yes**
	S4	*Plectropomus punctatus*	Yes	Yes	No
	S5	*Epinephelus polyphekadion*	No	Yes	**Yes**
	S6	*Siganus sutor*	Yes	Yes	Yes
	S7	*Siganus sutor*	Yes	No	No
Kenya	K1	*Epinephelus fuscoguttatus*	No	Yes	Yes
	K1	*Mulloidichthys vanicolensis*	No	Yes	No
	K1	*Acanthurus mata*	No	Yes	No
	K1	*Naso brevirostris*	No	Yes	No
	K2	*Epinephelus fuscoguttatus*	No	Yes	Yes
	K2	*Mulloidichthys vanicolensis*	No	Yes	No
	K3	*Mulloidichthys vanicolensis*	No	Yes	No
	K4	*Naso brevirostris*	No	Yes	No
	K5	*Epinephelus fuscoguttatus*	No	Yes	No
	K6	*Siganus sutor*	Yes	Yes	No
	K7	*Siganus sutor*	Yes	Yes	No
	K8	*Siganus sutor*	Yes	Yes	No
	K9	*Siganus sutor*	Yes	Yes	No

[1]: Direct signs of spawning include observations of gamete release or hydrated ovaries. Indirect signs include patterns in gonado-somatic index, colour changes and territorial/courtship behaviour associated with spawning, and observations of gravid females.
[2]: Text in bold indicates where increase in abundances has been determined quantitatively in both aggregating and non-aggregating periods. Otherwise, estimates are qualitative and/or lacking non-aggregation observations.

sutor, with more than 5000 fish aggregating at each of the two verified sites in Seychelles (Robinson *et al*., 2007).

The serranid aggregations verified in Seychelles conformed to the transient type often associated with these species (Domeier & Colin, 1997). Transient aggregations, which are common to the Serranidae, are usually short lived, are often large, comprising hundreds to tens of thousands (Smith, 1972; Samoilys & Squire, 1994) of individuals, and participating fish may migrate considerable distances to and from the site (Bolden, 2000). Resident aggregations typically do not involve large distance migrations, form more regularly and occur close to or within the areas of residence for participating fish. Resident aggregations are common to the surgeonfishes (Acanthuridae) and some parrotfishes (Scaridae) (Domeier & Colin, 1997; Cornish, 2005). However, not all species conform to these two types, as seen in *Plectropomus leopardus* (Samoilys, 1997).

Aggregations formed by siganids, namely *S. canaliculatus*, have been characterised as belonging to the transient type (Domeier & Colin, 1997). *S. sutor* aggregations appear to conform to this definition. Four *S. sutor* aggregations have been verified in the Msambweni area in Kenya, and there are indications that another seven sites identified by fishers could also be spawning sites. Fishers have described *S. sutor* migrations to the sites within a spawning period that often lasts from 7 to 12 days (Kimani, in prep); a similar duration was observed in Seychelles (Robinson *et al.*, 2007).

Few spawning aggregations have been verified in the WIO region compared to the western Pacific and tropical western Atlantic/Caribbean regions (Cornish, 2005). At the time of writing, a search of the online database of the Society for Conservation of Reef Fish Aggregations (www.scrfa.org) revealed that only two WIO aggregations (*E. fuscoguttatus* and *E. polyphekadion*, from Seychelles) have been reported. An *E. polyphekadion* aggregation from the Chagos archipelago and a *Plectropomus areolatus* aggregation from Maldives are also reported. The region remains inadequately represented compared to others where reports number in the hundreds. This situation most likely reflects a lack of research in the WIO rather than a rarity of occurrence (Cornish, 2005) since many species known to aggregate are common to the region and the reproductive strategy appears stable within species. The number of spawning aggregations that have been verified in the region during the past few years through the studies reviewed here suggests that more are likely to be documented if targeted research can be maintained.

AGGREGATION SITE GEOMORPHOLOGY AND HABITATS

Spawning aggregations often form in reef passes and channels, on reef promontories, shelves and drop-offs, and on patch and pinnacle reefs (Sadovy, 1996; Samoilys, 1997; Johannes *et al.*, 1999; Russell 2001), though this information still remains largely anecdotal (Colin *et al.*, 2003). The significance of site selection is still not fully understood (see Claydon, 2004). Reef passes or reef slopes close to major channels are common spawning sites for serranids in Seychelles, which are shallow (< 20 m) and defined by strong tidal currents. The serranid sites verified in Kenya are similar, being spurs on outer reef slopes. *S. sutor* aggregation sites may be more varied in terms of geomorphology and habitat. In Msambweni, Kenya, patch reefs inside the fringing reef lagoon are common spawning habitats for the verified spawning aggregations of *S. sutor.* These sites are characterised by generally high coral cover interspersed with coral rubble. Both *S. sutor* sites verified in Seychelles are granitic reefs on shallow bank habitats beyond the base of (carbonate) fringing reef slopes. Fishers in Seychelles also report that *S. sutor* and *S. argenteus* spawn on carbonate reefs, although this has not been verified. The degree of association with coral habitat appears stronger amongst serranids than siganids (Robinson *et al.*, 2007).

Habitat degradation caused by destructive fishing practices, pollution and coastal development are considered threats to spawning aggregations (Sadovy & Domeier, 2005). Although the relationship between habitat variables such as rugosity and aggregation abundances is not well defined, habitat appears important for certain species (Beets & Friedlander, 1998). For example, *E. polyphekadion, E. fuscoguttatus*, *P. leopardus* and *P. areolatus* aggregate at coral dominated sites where territories are defended by males and refugia are occupied by large numbers of females (Samoilys & Squire, 1994; Johannes *et al*., 1999), which may indicate a degree of reliance on habitat complexity for spawning success. The impact of coral bleaching on spawning aggregations remains unstudied but may become more significant in a changing climate. In terms of acute stresses, habitat destruction resulting from coastal development may be important on local scales. For example, land reclamation has lead to the disappearance of *Epinephelus ongus* aggregations and the collapse of their fishery in Seychelles (Robinson *et al*., 2007).

PERIODICITY OF SPAWNING AND AGGREGATION FORMATION

Many reef fishes exhibit peaks of spawning activity nested within protracted spawning seasons (Munro *et al*., 1973; Sadovy, 1996). This pattern may be pronounced in the WIO due to the monsoon system (Nzioka, 1979; Kulmiye *et al*., 2002). Detailed information is available for very few species (Table 3). *S. sutor* spawning appears to peak within two periods in Kenya and Seychelles. While Ntiba & Jaccarini (1990) did not recognise a protracted season, recent studies indicate that spawning probably occurs across much of the northeast (NE) monsoon (Table 3). Spawning periodicity has not been described for many serranids in the WIO but appears to be concentrated in the NE monsoon. Species that form transient aggregations often spawn within a narrow season (Sadovy, 1996; Claydon, 2004), which appears to be the case for *E. fuscoguttatus* and *E. polyphekadion* in Seychelles where the seasons are typically 2-3 months long (Robinson *et al*., 2007). In Kenya, observations of *E. fuscoguttatus* aggregations vary from February to May, but more research is needed to determine the exact timing. The majority of other reef fish for which data exist also appear to spawn in the NE monsoon, including acanthurids and mullids (Table 3). Exceptions to this pattern include some siganids and lutjanids which spawn in the southeast monsoon (Robinson *et al*., 2004; Robinson *et al*., 2007; Samoilys *et al*., in prep).

AGGREGATION STATUS AND FISHERIES

Owing to their predictability in time and space, transient spawning aggregations are highly vulnerable to overexploitation (Johannes *et al*., 1999; Sala *et al*., 2001). Moreover, much of the annual reproductive output of participating fish may occur in a single aggregation (Shapiro *et al*., 1993; Samoilys, 1997), rendering populations of these species highly vulnerable to targeted aggregation fishing (Sadovy & Eklund, 1999; Sadovy & Domeier, 2005). The status of spawning aggregations, transient and resident, is poorly known in the WIO region. Fisheries-independent monitoring programmes are being developed for sites in Seychelles but are too recent to assess status. In the absence of scientific information, local knowledge indicates that several serranid aggregations have been depleted or have collapsed (Robinson *et al*., 2004), both in areas close to centres of population (*Epinephelus ongus*) and on the outer banks of the Mahé Plateau (e.g. *Epinephelus multinotatus* and/or *Epinephelus flavocaeruleus*) (Robinson *et al*., 2007). Fisher knowledge of spawning aggregations in Kenya indicates that while the phenomenon has been widely observed, few have understood its significance as an important source of seed and fisheries recruitment, and no assessment of the status of spawning aggregations has been done.

Reef fisheries are generally considered overexploited in the WIO (McClanahan *et al*., 1999; Kaunda-Arara *et al*., 2003; FAO, 2006). For families characterised by the formation of transient aggregations in particular, aggregation fishing may be contributing to this situation. Where landings data exist and are disaggregated by family, it is apparent that fisheries targeting serranids are significant (Fig. 1). Given the large reported catches of serranids in Mauritius and Tanzania, aggregations may have been targeted, especially where species such as *E. polyphekadion* and *E. fuscoguttatus* are important constituents of the catch. It should be noted, however, that the relatively large serranid catches reported to FAO by Tanzania does not concur with the findings

Table 3. Comparison of spawning and aggregation periodicity for species known to form spawning aggregations. Information on some species is separated for different sites within the country. Spawning season information is from a) fishers' knowledge, b) reproductive biology studies. Aggregation periods and lunar information are from research involving direct observation or gonad analyses. Lunar periods: NM = new moon, FM = full moon, Qtr = Quarter. Seasons in the WIO: NE monsoon (light trade winds) = Nov-Apr; SE Trades (strong trade winds) = Jun-Aug; inter-monsoon = May, Sep/Oct.

Species	Country	Spawning season: fishers	Spawning season: research	Aggregation: research	Lunar period: research	Reference(s)
S. sutor	Kenya		Jan-Feb, May-Jun			Ntiba & Jaccarini (1990)
	Seychelles	Oct-May	Sep-May	Oct, Nov	FM	Robinson et al. (2004; 2007)
	Kenya	Apr-Sep				Samoilys et al. (in prep.)
	Kenya	Nov-Apr, Jun-Aug		Nov-Mar	FM	Kimani, P. (in prep)
E. fuscoguttatus	Kenya, Tanzania		Nov-Jan			Nzioka (1979)
	Seychelles	Nov-Jan	Dec-Feb	Dec-Feb	NM	Robinson et al. (2004; 2007)
	Seychelles	Nov-Dec		Feb	NM	Robinson et al. (2004; 2007)
	Kenya			Feb		Kimani, P. (in prep)
	Kenya			Apr, May	3rd Qtr, NM	Samoilys et al. (in prep)
E. polyphekadion	Seychelles	Nov-Jan	Dec-Feb	Dec-Feb	NM	Robinson et al. (2007)
	Seychelles			Mar, Apr		Robinson et al. (2007)
P. punctatus	Seychelles			Dec, Jan	NM	Robinson et al. (2007)
	Seychelles			Feb	1st Qtr	Robinson et al. (2007)
M. vanicolensis	Kenya			Apr	FM	Samoilys et al. (in prep)
A. mata	Kenya			May	3rd Qtr	Samoilys et al. (in prep)
N. brevirostris	Kenya			Apr	1st Qtr - FM	Samoilys et al. (in prep)

of localised studies on artisanal fisheries, which indicate that this group are not particularly important constituents of the catch (McClanahan *et al.*, 1999; Samoilys *et al.*, in press a). This finding suggests that commercial rather than artisanal fisheries predominantly target serranids. In heavily exploited reef areas, sparse fisher knowledge relating to these phenomena may be because of low abundances or collapse of aggregations (Samoilys *et al.*, 2006).

Siganids are key target species of trap, line and net fisheries in the region (Anderson, 2004; Samoilys *et al.,* in press a) and aggregations are clearly known to

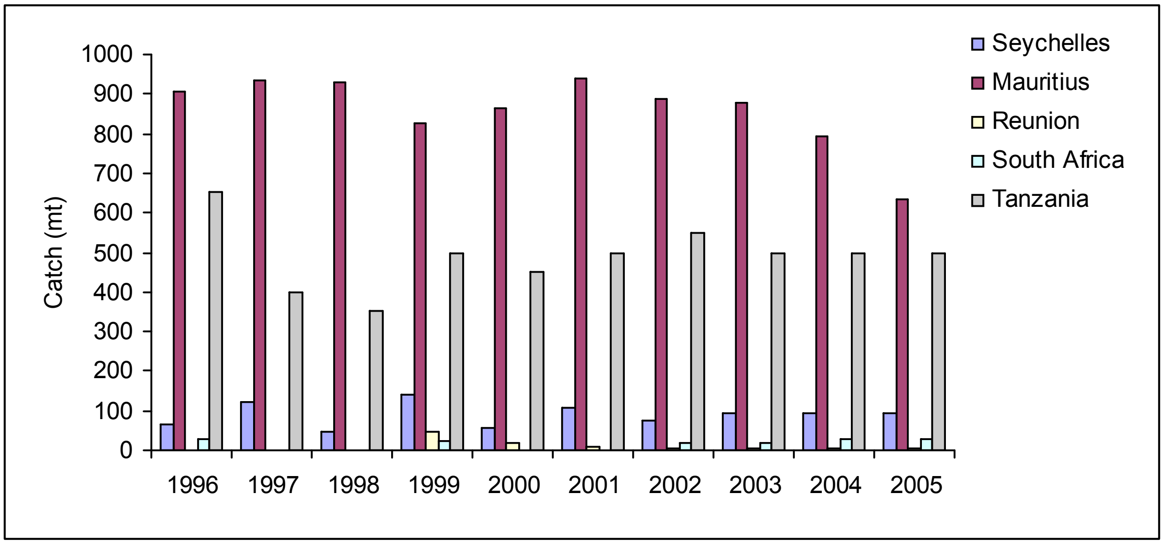

Figure 1. Reported catches of groupers (Serranidae) in the Western Indian Ocean (Source: FAO FISHSTAT Plus).

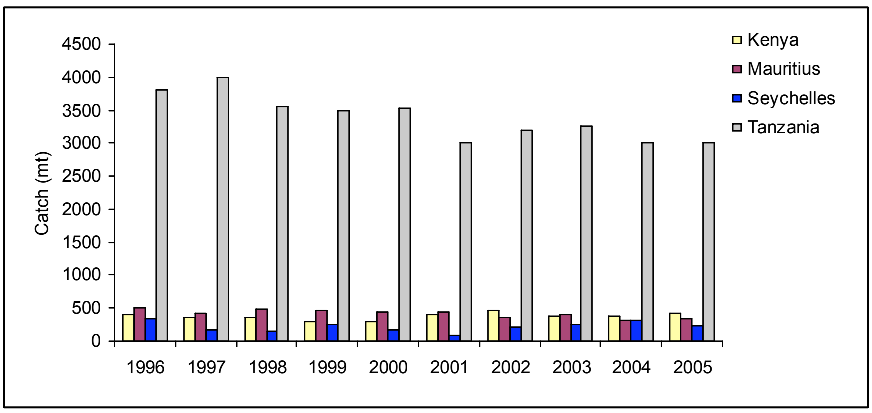

Figure 2. Reported catches of rabbitfish (Siganidae) in the western Indian Ocean (Source: FAO FISHSTAT Plus).

fishers and exploited (Kimani, in prep; Robinson *et al.*, 2004; Robinson *et al.*, 2007; Samoilys *et al.*, 2006). Since Tanzanian fishers are aware that *S. sutor* spawns in transient aggregations, it is possible that aggregation fishing contributes to the large catches reported for this family in Tanzania (Fig. 2). Independent long-term monitoring since 1998 in Tanga, Tanzania, has shown a 5-6 fold decline in herbivore densities since 2003 which is attributed to the trap fishery that targets siganids (Samoilys *et al.*, in press a, b).

In the Msambweni area of Kenya, four well known *S. sutor* spawning sites have been targeted by local fishers for generations, with anecdotal evidence indicating that the present day patriarch fishers began fishing the aggregations in the 1960s. Large catches of *S. sutor*, often close to 1 tonne, have been landed by ring-net fishers during a single fishing event (Fig. 3). While these catch data were recorded at the neighbouring landing site of Gazi, fishers ostensibly fished in Msambweni waters and are known to target the four prominent spawning sites located there

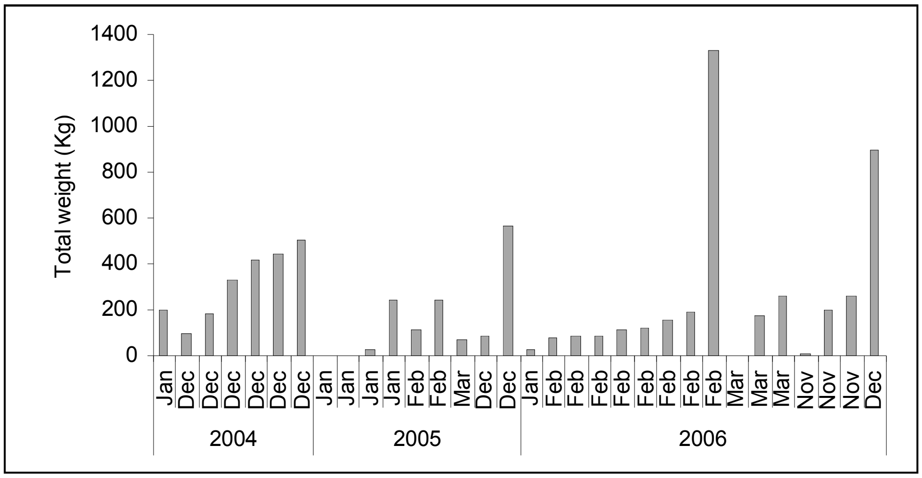

Figure 3. An extract of catch records of *Siganus sutor* from the Gazi fish landing site, Southern Kenya, showing magnitude of total daily catches by ring-net gear. Often, only between one and two ring-net boats operate in the area (Source: CORDIO East Africa).

(Kimani, in prep). A three month catch monitoring system at the Mkunguni landing site of Msambweni indicated that light artisanal gears like basket traps and fishing lines averaged up to 8 kg/fisher/day when fishing a *S. sutor* aggregation. Effort in the trap fishery is high (average 10 traps/fisher) and catches of up to 500 kg have been landed over a single lunar spawning period. In spite of the high levels of catch and effort, reports on the status of the fishery are contradictory, with many fishers reporting stable aggregation catches and others reporting a decline. By comparison, *S. sutor* has been heavily exploited, including its aggregations, for close to 100 years in Seychelles (Hornell, 1927), yet stocks have not collapsed, possibly due to the fact that only nearshore populations are targeted

MANAGEMENT IMPLICATIONS

Fisheries management in the region is largely focused on industrial fisheries. Few artisanal fisheries have clearly defined harvesting strategies or management plans including controls on inputs and outputs. Overexploited coastal fisheries and ecosystem impacts of fishing are widespread (De Young, 2006). Consequently, the arguments for MPAs are well supported on both conservation and fisheries management grounds. For MPAs to complement fisheries management objectives, however, a greater emphasis on the protection of vulnerable life history stages is urgently required. MPAs are rarely designed to incorporate spawning aggregation sites and nursery habitats although some may have inadvertently received protection (e.g. in Seychelles). In Kenya, spawning aggregations were not considered in the design of MPAs. The early studies reported here have made some progress towards identifying spawning sites but much work remains in terms of verifying and studying the dynamics of aggregations.

A wide range of management tools for spawning aggregations could be considered depending on local circumstances. Appropriate responses to aggregation fisheries will likely differ between species, site, fishery and country. In Maldives, serranids form the basis of an economically important export-driven live reef food fishery (LRFF) (Sattar & Adam, 2005). This fishery is now considered heavily overexploited (Adam, 2006) and trade measures such as export restrictions or bans may be appropriate to limit effort. Seychelles recently prohibited the LRFF, in part to protect spawning aggregations (Aumeeruddy & Robinson, 2006). In many countries, the reliance on species that aggregate to spawn for food security may dominate management objectives, as exemplified by the siganids. In this case, gear restrictions, temporary area or seasonal closures and rights-based management approaches may be more appropriate than the formation of MPAs, and certainly more acceptable from political and socio-economic perspectives. However, these measures may only work if traditional and local compliance systems are in place. From a fisheries management perspective, the choice of tool to manage spawning aggregations should be part of a suite of measures to manage the overall fishery, which is relevant to both governmental and community-based regimes. A much greater emphasis on, and support for, research will be required in the region if spawning aggregation protection is to be part of regional fisheries management and conservation toolboxes.

Plans for a wider regional research and management programme on spawning aggregations are at an advanced stage. Studies will focus on further verification of reported aggregation sites. This will be followed by efforts to define the spatial and temporal dynamics of aggregations at key sites in order to provide information for management. In addition to research, components of the programme will focus on closed area design and application, reserve networking and awareness raising activities within fisheries and conservation management domains.

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Reef Fish Spawning Aggregations in South Asia and the Andaman Sea: Preliminary Findings from Local Knowledge

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INTRODUCTION

Reef Fish Spawning Aggregations (FSA) are a phenomenon where reef fish species gather in large numbers at a specific time and site to spawn (for definitions see Domeier and Colin 1997). For coral reef fishes these sites are consistent over years. Spawning aggregations can be critical in the life cycle of the fishes that use this reproductive strategy. In particular, for those species that travel relatively large distances to aggregation sites and gather for a short period to spawn each year (termed "transient" spawning aggregations, Domeier and Colin 1997), such aggregations can represent 100 percent of the species' reproductive output.

Fish may migrate over very large distances (10s of km) to an aggregation site, as exemplified by the Nassau grouper in the Caribbean (Bolden 2000). In addition, the pelagic fertilised eggs and larvae from such aggregations may travel far before settling out of the plankton to mature. Thus a single spawning aggregation may have an impact on fish populations over an area spanning several hundred kilometres. If these aggregations break down, for example through persistent fishing of the aggregations, the species' population can decline dramatically to critically unsustainable levels (Sadovy 1999). Since many species from several families of reef fish spawn in aggregations careful management of this phenomenon is critical if the health of fish populations and hence

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

the entire coral reef ecosystem is to be maintained (Sadovy and Domeier 2005). Accordingly, reef fish spawning aggregations are a central component to the coral reef resilience concept, as synthesised in *The Nature Conservancy's Reef Resilience (R2) Toolkit* (Domeier et al 2002, R2 2004). This Toolkit addresses methods for minimising stress to coral reefs in order to maximise their ability to resist or recover from coral bleaching caused by climate change (e.g. Obura 2005).

The character of spawning aggregations leaves them highly vulnerable to over exploitation, and there are many examples where fishing has drastically reduced spawning aggregations (e.g. Sala et al 2001, Aguilar-Perera 2006). In view of this, the 3rd IUCN World Conservation Congress adopted Recommendation 3.100 on "Reef-fish spawning aggregations" (IUCN 2004). The recommendation expresses the concern of IUCN's 1,072 member institutions about the increasing exploitation of reef-fish spawning aggregations in various parts of the world, and about the dramatic ecological and socio-economic effects that such exploitation can lead to. It further urges governments to establish sustainable management programmes for sustaining and protecting reef fish and their spawning aggregations, and also requests a number of organisations to take action to promote and facilitate the conservation and management of fish spawning aggregations, by raising awareness of the long term ecological, economic and societal values of spawning aggregations. The importance of this recommendation was further emphasised by the International Coral Reef Initiative (ICRI 2006).

Reef fish spawning aggregations have been described and/or documented in many locations, including the Caribbean (Sadovy 1999, Bolden 2000), South Pacific (Sadovy 2004), Micronesia (Johannes et al 1999), Australia (Samoilys 1997), the Seychelles (Robinson et al 2004), and East Africa (Samoilys et al 2006, Robinson et al, 2007). Studies have indicated some similarities between spawning aggregations. For example, aggregating fish tend to be of large species from the Serranidae, Lutjanidae, Siganidae, Labridae, Scaridae. The timing and behaviour of aggregations and the physical characteristics of the sites vary (Claydon 2004) and there is still much that we do not know or understand about this critical phenomenon (Domeier et al 2002).

Guidelines on the study of reef fish spawning aggregations have been prepared by Colin et al. (2003). However, it appears very little research has been focused on spawning aggregations in South Asia and the Andaman Sea, and while spawning aggregations are known to occur there seems to be little but anecdotal evidence available beyond some detailed work in Lamu atoll in the Maldives (Sluka 2001a,b,c). There is also little information available on the implications of reef fish reproductive biology for overall reef health as well as reef resource dependent human societies. Consequently, spawning aggregations have frequently not been considered in most aspects of coral reef and fisheries management in South Asia and the Andaman Sea.

Interview Survey in South Asia and the Andaman Sea

A project has been initiated by IUCN and CORDIO in collaboration with national and local institutions, aimed at gathering some of the first data on spawning aggregations in the South Asia and Andaman Sea region, with a view to providing information that can support further research on reef fish population dynamics and reef resilience, as well as strengthen management of coral reefs and reef resources.

The objectives of the study are to a) determine which reef fish species form spawning aggregations; b) determine the specific sites of aggregation formation; c) determine the seasonal patterns in spawning aggregations by species; d) determine the level of awareness of spawning aggregations and status of stocks of those species among fishers; e) sensitise fishers and marine resource personnel in south asia on reef fish spawning aggregations and their implications to conservation and sustainable fisheries; and f) provide recommendations for the protection and management of sites of spawning aggregations.

The study is being carried out through interview surveys with fishers, who often are aware of and are fishing spawning aggregations (Johannes 1981), following the guidelines by Colin et al (2003). The survey covers most of the key coral reef areas in the region, including Lakshadweep, Gulf of Mannar and Andaman and Nicobar Islands in India, the Thailand Andaman Sea coast, reef areas in the West and South of Sri Lanka, Aceh in Indonesia, and the Maldives. The interview surveys were initiated around the region between March and August 2007, and are still ongoing (September 2007).

Preliminary Findings

Based on discussions with fishers on the northern Sumatra islands of *Weh and Aceh, Indonesia,* as well as ecological assessments in the area, three potential spawning habitats for Giant Trevally (*Caranx ignobilis*) have been identified. A detailed survey of fishers knowledge gained from household and field surveys is currently in progress to identify biological and resource use characteristics of these areas and further potential spawning aggregation sites in the region.

In the *Maldives* surveys have been carried out at Vaavu and Baa Atolls. Fishermen on Vaavu are aware of reef fish spawning aggregations and have identified sites and times for groupers (*Epinephelus fuscoguttatus, Plectropomus areolatus and P. pessuliferus*). One island in the atoll has an established grouper fishery that targets spawning aggregations on a regular basis. However, reportedly the fishing pressure on these sites has decreased over the years. Preliminary results from islands in Baa atoll indicate most fishermen either do not know about spawning aggregations or are hesitant to provide information. However, this does not include results from some of the islands with a local reef fishery. Field verification and characterisation of some of the sites has been planned.

Interviews in the Union Territory of *Lakshadweep, India*, conducted in some depth on Minicoy and Agatti islands and opportunistically at Kavaratti and Kadmath islands, indicate limited knowledge of reef fish spawning aggregations. The phenomenon of spawning aggregations is known and has been observed in some tuna baitfish (a number of species are used for tuna bait, including *Spratelloides gracilis, S. delicatulus*, and *Encrasicholina heteroloba*, as well as some Caesionidae, Apogonidae, Pomacentridae etc.), but fishers in the area had never heard of or seen reef fish spawning aggregations in larger fish such as groupers and snappers. However, many seemed to know the spawning seasons of pelagic species. This is reflective of the relatively low commercial importance of reef fish in the islands, where the hook and line tuna fishery is the main export earner. The reefs in the archipelago do exhibit many of the characteristics associated with reef fish spawning aggregations elsewhere, and further field surveys as well as more intense interview surveys are underway. In view of the concerns with respect to a growing export fishery targeting high value reef fish, knowledge and management of potential reef fish spawning aggregations is viewed as a high priority.

In the North Andaman region of the *Andaman and Nicobar Islands, India,* a first preliminary survey provided indications of spawning aggregations including several grouper spawning aggregations (largely *Plectropomus* spp.) in South Andaman. These aggregations are apparently fished for the lucrative export trade to South East Asia.

Surveys of nine villages in the *Gulf of Mannar, India* have reported no spawning aggregations in the shallow (0.5-3m) reef areas around the near shore islands. However, four possible fish spawning aggregations have been identified in areas further off shore, 5-10 miles out and at depths between 10 and 20m, with opinions of species, timings, including lunar phase shared among several fishers from different villages. Species reported included primarily the Lethrinidae, but also Siganidae, Lutjanidae, and Scaridae. The area is heavily fished with gillnets and hook and line, and higher catches are reported at the times of aggregation.

Interviews with 190 small-scale fishers in the southern part of *Phuket Island* and *Bulon Island,* *Thailand* provided some evidence of fish aggregations, although none of the respondents specifically mentioned spawning as a reason for fish aggregating, with some considering feeding the primary reason and others unable to provide an explanation. Sites were characterised as isolated underwater rock-outcrops or rock pinnacles on sandy bottom, and some located in channels between islands. Species observed aggregating included trevally (Carangidae) as well as certain serranids (*Epinephelus coioides* and *E. lanceolatus*), lethrinids (*Lethrinus lentjan*), and scombrids (*Rastralliger brachysoma* and *R. kanagurta*).

DISCUSSION

While several potential reef fish spawning aggregation sites have been identified through this study, the results are preliminary and unverified, and thus indicative only. It is clear that although many fishers are not immediately aware of spawning aggregations, others possess at least some knowledge of spawning areas, species and times. Further, as has been found in many other parts of the world, it appears that many aggregations are targeted by fishers in the area. The results are encouraging in the sense that they indicate functional spawning aggregations can still be found in the region.

In view of the intense fishing pressure in many parts of the region, particularly over the past two decades, it is expected that some aggregations have been diminished. As this trend is likely to continue, accurate and reliable information as well increased awareness among managers and policy makers of reef fish spawning aggregations, their ecological significance and vulnerability, are needed in order to design and implement suitable management responses.

Detailed and final results from the surveys will be published in national reports as well as a regional synthesis intended for presentation at the 11th International Coral Reef Symposium in 2008. Information on exact locations and timings of fish spawning aggregations will not be published in the public domain, but will be reported to the Society for the Conservation of Reef Fish Aggregations (SCRFA) database.

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Part 6 – Artisanal Fisheries Research

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The Small-scale Reef Fishery at Phuket Island, Thailand Andaman Sea Coast

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ABSTRACT

Questionnaires were used to collect general socioeconomic information on local fishing communities in the southern part of Phuket Island, Thailand. The majority of household representatives interviewed in target communities were strongly fishery dependent, having been fishing for their entire working careers (76%), or being primarily fishermen also engaging in other supplemental livelihoods (13%). Important small-scale fishing practices included fish trap, hook-and-line, dive-fishing, and gill net fisheries; the former two being the most common. Fishing grounds were not always strongly restricted to coral reef areas, and varied depending on the types of fishing gear used. Monitoring of catches from hook-and-line and trap fisheries of selected individual fishers was carried out to estimate fishing effort and yield. Catch rates of hook-and-line fishing for each individual boat-trip (usually spending 1-2 days with 2-4 persons per trip) ranged between 8.7 and 155 kg, with an average weight of 38.8 kg/trip. Trap-fishing yielded 10-92 kg for each individual boat trip (usually taking 7-8 traps left in the sea for 7-15 days) with an average weight of 31.1 kg/trip. Because catch monitoring was carried out during the south west monsoon season, it is assumed that fishing effort and catch were relatively low. However, a minimum estimate of annual fishing yield was extrapolated for the area. Based on data from the present study, fishing yields from the southern part of Phuket for hook-and-line and trap fisheries collectively were in the range of 515-772 metric tons per annum.

INTRODUCTION

Fishing is a common reef-use pattern among local communities on the Andaman Sea coast of Thailand. The livelihoods of indigenous people in particular (including 3 ethnic groups, Moken, Moklen and Urak Lawoi, collectively referred to as 'sea gypsies'), are traditionally completely dependent upon reef resources. However, over the recent past their fishing opportunities have been greatly limited due to several constraints such as expansion of proclaimed protected areas (i.e. marine parks, marine sanctuaries) and tourist areas, legal restrictions on fishing equipment and species caught, degradation of marine resources, and rising cost of fuel and fishing equipment (Arunotai et al., 2006, Arunothai this volume). There are 13 Marine National Parks along the Andaman Sea coast of Thailand, covering a variety of marine and coastal habitats. Most notably, almost all major coral reefs are located in marine parks. In the southern part of Phuket, the area encompassing Hi, Lon, and Aeo Islands and the south-east tip of Phuket Island was proclaimed a sanctuary in 1969. In 1992, Phuket Province was designated as an environmental protection area, and fishing of ornamental fishes was totally banned. Dynamite and cyanide fishing have been prohibited since 1985, and "muro-ami" dive-in net fishing has been banned since 1997.

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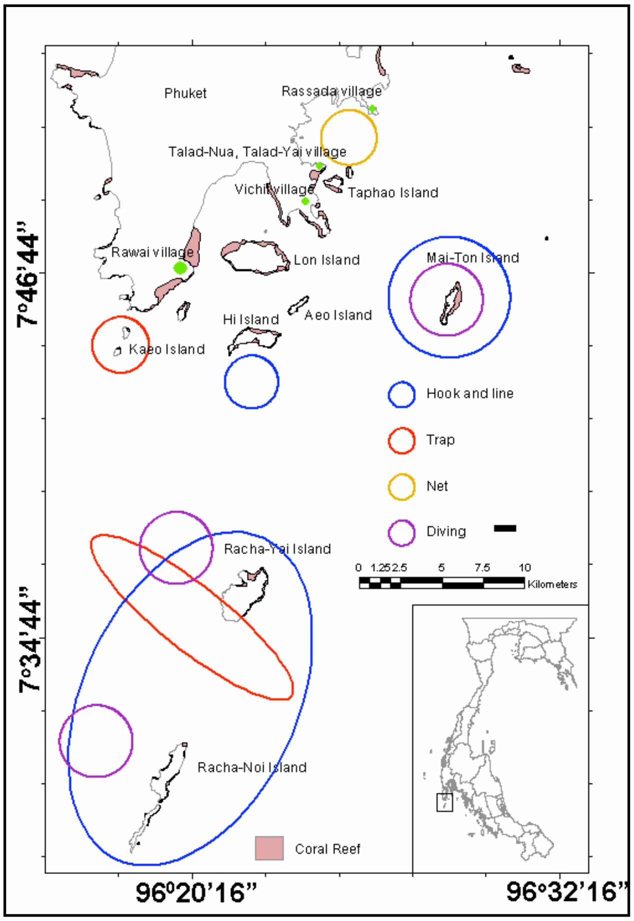

Figure 1. Fishing grounds of the small-scale reef fisheries in the southern part of Phuket Island.

While poverty and hardships are common in local fishing communities, there are significant gaps in knowledge about the socio-economic situation of local and/or indigenous fishing communities. Similarly, information on the magnitude of reef fisheries is either insufficient or lacking completely. This study was carried out to compile information on the small-scale reef fishery and to determine the dependence of these communities on reef fisheries.

SCOPE AND METHODS

Project activities included a questionnaire survey, informal discussion with key informants, and recording catch data in 5 local fishing communities in the southern part of Phuket Island: Rasada, Talad Nua, Talad Yai, Vichit, and Rawai sub-districts (Fig. 1). Through interviews household members were asked about their personal background (e.g. age, education, occupation and income) and more specifically about their fishing activity (e.g. type of fishing boats, fishing gears, fishing grounds, and species targeted). In addition, monitoring of catches from hook-and-line and trap fishing among selected individual fishers was carried out between July and December 2006. Data sheets were distributed to a number of fishers to record total catch, species composition, and the value of the catch obtained from each boat trip. Data sheets were retrieved once a week. As keeping this kind of record of fishing operations was unfamiliar to many fishermen, particularly among the indigenous community, data sheets were filled and returned somewhat inconsistently. Three to five trap fishers and 7-10 hook-and-line fishers cooperated well in provision of data.

RESULTS AND DISCUSSION

Socioeconomic Data

A total of 63 interview responses were obtained from local fishermen in the 5 sub-districts surveyed, of which 62 were men. The age of respondents ranged between 23 and 74 years, with an average of 47, while education backgrounds were mostly at primary school level, with 38 % attaining 4th grade and 33% 6th, followed by junior high school (6%) and high school (5%). Eighteen percent of respondents were illiterate, primarily from the 'sea gypsy' communities at Rawai and Rassada sub-districts. It should be noted that there has been much improvement in education level among young people in these fishing communities as they are increasingly encouraged to study. About 76 percent of the interviewees were relying solely on fishing for an occupation, 13% were primarily fishermen that also engaged in other kinds of supplemental occupations, and the remaining 11%

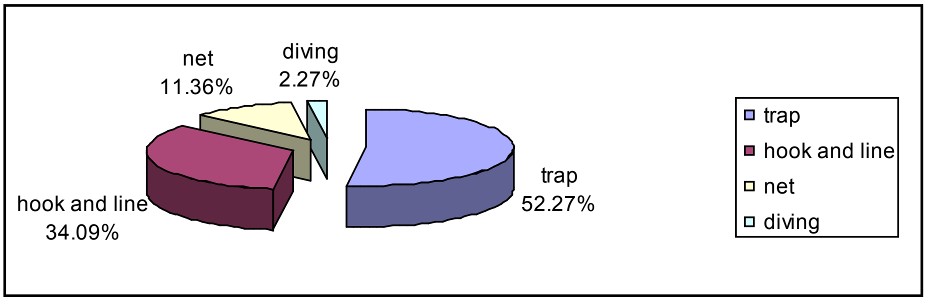

Figure 2. Fishing gears used in the small-scale reef fishery in the southern part of Phuket, based on data on number of fishers using each gear.

fish as a supplement to other primary livelihoods they are engaged in, such as working on tour-boats, as handicraft makers, and gardeners. The yearly income ranged from 12,000 to 228,000 Baht, with an average of about 65,000 Baht (~ $US 1,625). Based on findings and opinions and concerns expressed among respondents, it is clear that the majority of households in these communities depend greatly on fishing, both as the main source of income and as food for household consumption.

Fisheries Characteristics

The survey carried out shows the small-scale fishery in southern Phuket relies primarily on long-tail motorized boats and simple gear to collect nearshore species. The fishing boats ranged in size from 9 to 12 m long and were equipped with 5.5-18.5 hp engines. Fishers use just one (68%) or a combination (32%) of fishing gears. Trap and hook-and-line were among the most common fishing practices (Fig. 2). Fishers from different villages seemed to have a preference to certain types of fishing gear. Hook-and-line was primarily used by local fishers from Talad Yai and Talad Nua sub-districts. Indigenous villagers of both Rawai and Rassada sub-districts used trap as primary fishing gear. Local fishers from Vichit sub-district commonly used both trap and hook-and-line. Shrimp trammel nets and fish gill nets were also used as secondary fishing gears among Rassada's fishers. Dive fishing, incorporating hand-collecting together with a spear was restricted mainly to indigenous fishers from Rawai sub-district. "Hookah" diving, the use of a compressor on a boat with a long air hose connected to a diving mask, has facilitated deeper and longer dives. Most trap-fishers from Rawai also use diving to place and fix traps on the sea floor, as well as for recovering the traps. In the case of large and heavy traps, fishers do not haul up the traps on the boat, but rather dive down and scoop fish out of the traps with hand nets.

Among these four main types of fishing activities, dive-fishing had the most direct connection to or closest proximity to coral reef habitats. Divers, usually 4-7 on daily trips, collect shells (both ornamental and edible species), spiny lobsters and fishes at depths ranging from <10 m to 40 m. This fishing practice was restricted to the calm season, approximately from December to May, and carried out both during the day and night (around new moon phases). Catches varied greatly, ranging from 5 to 100 kg per trip.

Trap fishing was also generally linked to coral reefs. Typically, fishers do not place their traps directly on coral reefs, but rather in the shallow fore reef zone (to about 20 m). Sandy to muddy-sand bottoms, or deep rocky areas (as deep as 80 m) are preferred for deploying the traps. Indigenous fishers were found to be skillful in spotting "underwater fish paths" in the channels around islands where they regularly placed their traps. Trap fishing is operated both in the dry season, with calm sea conditions, and the rougher wet season. Catches comprised mostly reef-associated fishes, with catch size varying greatly depending on number and size of traps deployed. A minimal operating effort of less than 10 small traps (dimensions 1.5-2 x 2-3 x 3-4 m) yielded a few to a hundred kilogram of fish at every retrieval cycle of 7-

10 days, while higher operating effort of 10-15 traps of larger size (2.5 x 4 x 5 m), or 30-50 traps of 2 x 3 x 4 m, yielded a few hundreds up to a thousand kilograms at every retrieval cycle of 10-20 days. In general, each boat trip commonly involved 4-8 fishers working 7-8 traps.

Hook-and-line fishing was found to be spatially widespread and covering a variety of habitats, including the pelagic, bare sandy bottoms, heterogeneous-substrate bottoms, coral reefs, or rocky areas. Fishers usually use still lines with 1-5 hooks with fish-baits, or 4-6 hooks with artificial lures depending on target fish species and habitats. The former technique is used to target demersal or bottom dwelling fishes, while the latter is suitable for pelagic fishes. The relative distances to reef habitats varied greatly from 10 m up to 5 km away (Fig. 2), with a range of operating depths of 10-80 m. Boat trips, commonly lasting 1-2 days and involving 3-4 fishers, are led by a boat master who locates fishing spots by experience. Fishing sites are changed without uniform patterns. Catch size ranged between a few and 50 kg per boat trip.

Shrimp trammel nets and fish gill nets were found not to be used in coral reef areas. Fishers deployed their nets above bare and flat seabed at depths of 1-20 m. Each daily boat trip involves 2-4 men, and the yield varies between 10-100 kg of target species.

Catch Monitoring of Selected Fisheries

Participatory monitoring of catches in the hook-and-line and trap fisheries provided reasonable estimates of fishing yield and effort. At least 50 species in 20 families of fishes were recorded. Catch using hand-line ranged between 8.7 and 155 kg for each individual boat-trip, with an average value of 38.8 kg/boat-trip (usually spending 1-2 days with 2-4 persons per trip). The lowest average catch was measured in October (Fig. 3) when the fishery came to an almost complete stop due to intense and prolonged rough sea conditions. Based on occurrence and relative importance in biomass of fish groups in the catches reported by fishers, the major target species of the hook-and-line fishery includes emperors, groupers, trevallies, snappers and threadfin breams (Table 1).

Trap-fishing (commonly using 7-8 traps left in the

Table 1. Occurrence (%) and biomass contribution in the pooled catch (%) of target fish families reported by fishermen deploying hook-and-line (68 records) and trap fishing (33 records).

Fish family	Common name	Hook-and-line		Trap	
		% occurrence	% biomass	% occurrence	% biomass
Serranidae	Groupers	49.4	20.3	90.9	26.2
Lethrinidae	Emperors	88.2	27.8	39.4	6.7
Lutjanidae	Snappers	55.9	6.5	69.7	13.6
Carangidae	Jacks and Trevallies	45.6	17.4	54.5	22.2
Nemipteridae	Threadfin breams	29.4	10.5	–	–
Scombridae	Tunas and Mackerels	23.5	4.9	3.0	1.0
Haemulidae	Grunts and Sweetlips	8.8	1.4	21.2	7.5
Sphyraenidae	Barracudas	7.4	1.0	3.0	0.3
Dasyatidae	Stingrays	5.9	3.4	6.1	0.7
Rachycentridae	Cobia	5.9	2.0	3.0	0.7
Scaridae	Parrotfishes	–	–	12.1	2.4
Siganidae	Rabbitfishes	–	–	9.1	7.3
Balistidae	Triggerfishes	–	–	3.0	5.8
Caesionidae	Fusiliers	–	–	3.0	3.6
Acanthuridae	Surgeonfishes	–	–	3.0	1.2
Polynemidae	Threadfins	–	–	3.0	0.4

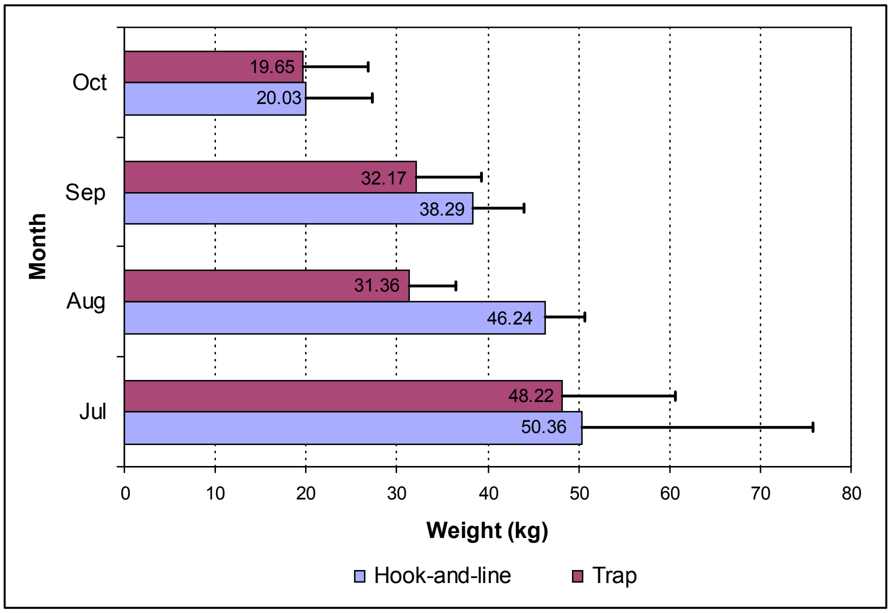

Figure 3. Monthly average (+ standard deviation) yield (kg/boat-trip) for each type of fishing gear.

sea for 7-15 days) yielded 10-92 kg, with an average weight of 31.1 kg/boat-trip, with the lowest catch observed in October (Fig. 3). Major target species included groupers, trevallies, snappers, emperors and sweetlips (Table 1). A number of other typical reef fishes were caught exclusively using traps, such as parrotfishes, rabbitfishes, fusiliers and surgeonfishes.

Since this catch monitoring program was carried out during the strong south west monsoon season, the fishing effort in terms of number of operating boats or fishing intensity, as well as fishing yield, is expected to be comparatively low. However, the data obtained can, with some extrapolation be used as a basis for estimating the minimum annual fishery yield of the area. As presented in Table 2, the ranges of annual yields for hook-and-line and trap fisheries were approximately 410-615 metric tons, and 105-157 metric tons respectively. Trap fishing seemed to target

Table 2. Estimated annual yields for hook-and-line and trap fisheries in southern part of Phuket Island, extrapolated from data reported by fishers. (Total annual effort C = A x B x 12 (months in a year); Total annual yield E = C x D).

Parameter	Hook-and-line	Trap
A) Total number of fishing boats	110	140
B) Frequency of fishing (trips/boat/month)	8-12	2-3
C) Total annual effort (boat-trips/year)	10,560-15,840	3,360-5,040
D) Average catch (kg/boat-trip)	38.8	31.1
E) Total annual yield (kg/year)	409,728-614,590	104,496-156,744

more reef-associated fishes than using hook-and-line, and provides an indication of the direct contribution of coral reef resources to local fishing communities.

DISCUSSION AND RECOMMENDATIONS

At present, although the small-scale fisheries of local communities in southern Phuket have faced several constraints (restrictions on area, equipment, and species, increase in fishing cost, and degradation of marine resources) that place limitations on their fishing livelihoods, the majority of the household members are still engaged in fisheries. There is also a general perception about advantages of fishery occupation in supporting income and subsistence (Arunotai et al., 2006). This study shows that at least a number of small-scale fishing practices in the area, i.e. dive-fishing, traps and hook-and-line, are to some extent directly dependent upon coral reef resources. In view of this it would be worthwhile to collect more specific socio-economic information regarding the dependence of local fishers on coral reefs, including e.g. economic benefits, welfare and ethic values, as well as community perceptions and attitudes toward reef management. This can include ownership and social responsibility of local communities with respect to their reef resources, and can be a basis for pushing forward management interventions. Other studies in the area have stressed the importance of community involvement for the success of coral reef management (Panchiyaphum, 2007).

This study provides information that can contribute to strengthening an ongoing government program on establishment of marine and coastal resources conservation volunteer groups. Such conservation volunteer groups have been established among stakeholders of common interest or similar occupations (e.g., long-tail boat operator groups, dive-tour together with individual diver groups, and local fisher groups), since 1992 up to the present. Networking of established conservation groups has proved to be a significant success in supporting management. Through workshops and discussion among these stakeholder groups, reef-use conflict (e.g. reef fishery vs. diving tourism) has been resolved by building understanding and agreement among groups. For example, in the past, indigenous fishers in Rawai village were engaged in illegal fishing, particularly catching ornamental reef fishes using cyanide. The established indigenous-fisher group has proved important in eliminating illegal fishing in the community through generating collective will. Official records since 1997 indicate that arrests due to illegal fishing for and/or trading in ornamental fishes in Phuket have markedly decreased in recent years, from about 5 cases per year before 2000, 2-3 cases per year during 2000-2006, and none on record this year (Satapoomin unpubl.). It also appears that while strict law enforcement has contributed to this, strengthening dialogue and understanding between officers and local fisher group as partners in conservation of marine resources has been a stronger force, and proved successful in diminishing illegal fishing in the area (P. Panchiyaphum, pers. comm.). This further stresses the importance of co-management in marine resource conservation.

With limitations of the data acquired from this preliminary study, it is not possible to draw conclusion pertaining to the crucial questions of the sustainability of the reef fishery in Phuket. Results from this study, however, can serve as a reference point for further studies and for quantifying future changes in local fisheries. Further detailed studies are needed to assess the impacts of reef fisheries on coral reefs. This could include developing an observation-based sampling strategy for certain types of reef-associated fisheries, such as dive-fishing and trap-fishing, which could provide more precise information regarding fishing effort and yield. Intra- and inter-seasonal variation in the fishery should also be studied in more detail, as well as basic data particularly on fishing-pressure parameters and maximum sustainable yield of individual target species following research protocols established elsewhere (e.g., Laroche et al., 1997; Kulbicki et al., 2000; Labrosse et al., 2000;

Letourneur et al., 2000). This information will be useful for further development of fisheries management and conservation in the area.

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The Artisanal Reef Fishery on Agatti Island, Union Territory of Lakshadweep, India

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keywords: Artisanal / subsistence fishery, coral reef, participatory fish catch monitoring, fishing gear, gear selectivity, fisheries management

ABSTRACT

The main features and characteristics of the subsistence reef fishery in Agatti island, Union Territory of Lakshadweep, India, are described based on information obtained through participatory fish catch monitoring over one and a half years in 2006-7. The overall catch per unit effort (CPUE) recorded was 1.66±0.07 kg per person per day (± standard error of the mean), based on data from 3030 fishing events. Considerable variation in CPUE was observed in particular between gears, but also between landing zones and to some extent time of year. The total annual catch from the reef fishery was estimated at over 56 metric tons, harvested from a lagoon area of 12 km^2. Almost half of this total catch is obtained from the 2% of the catches larger than 20kg, much of it using the more indiscriminate gears available on the island such as large-scale dragnets (local name bala fadal). While the data does not support conclusive statements on the sustainability of the fishery it is clear that the importance of the reef fishery for the local population as a source of household income and food remains high, and growth in exploitation seems likely in view of the demographic structure of the island as well as a developing reef fishery for export markets. Some recommendations are provided with respect to the management challenge this poses.

INTRODUCTION

Agatti island is the westernmost island in the Indian Union Territory (UT) of Lakshadweep, located at 10º 51' N and 72º E (Dept. of Planning and Statistics 2000). The island has an area of 2.7 km^2, and is surrounded by 12 km^2 of lagoon and 14.4 km^2 of reef flat (Bahuguna and Nayak 1994), lying in a roughly north to south direction. The lagoon surrounding the island is wider and deeper on the western than on the eastern side (Fig. 1). The local population of 7072 (Dept of Planning and Statistics, 2002) resides in the wider northern section of the island (see also Hoon et al. 2002, Hoon and Tamelander 2005). The traditional fishing and land rights of Agatti islanders

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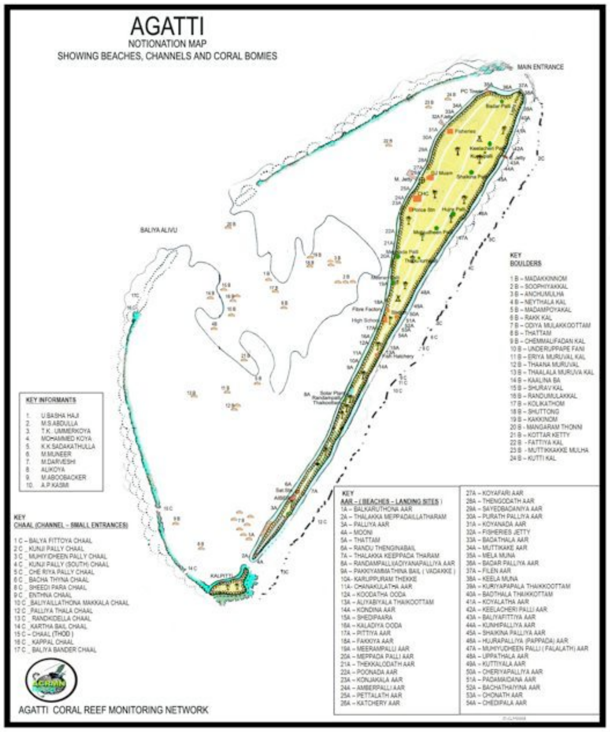

Figure 1. Map of Agatti island and the surrounding lagoon, with important fishing and landing sites. The map has been prepared through consultation with fishers and elders on the island.

also include the Bangaram lagoon, which encompasses the small islands Bangaram, Tinnakara and Parelli's, and a sunken reef Perumal Par (Hoon 2002).

Previous studies conducted on Agatti have described the island and its territories in terms of demography, socio-economic status of the islanders, as well as their use of the coral reef resources and fishing methods (Dept. of Fisheries 1990, Hoon et al. 2002, Hoon 2003, Hoon et al. 2005, Hoon and Tamlander 2005). The islanders remain highly dependent on natural resources. The main income for Agatti is the hook-and-line tuna fishery, a major export industry. The tuna landings in Agatti are the highest in Lakshadweep and consisted of 30% to 38% of the entire tuna catch of Lakshadweep (Dept of Planning and Statistics 2002). However, at the household-level the reliance on the reef fishery and gleaning for protein and income is high. Twenty percent of the households on Agatti report reef fishery and gleaning as their main occupation, and 90% of the protein intake of the poor households comes from reef fishing and gleaning (Hoon 2003). Further, sand, rubble and coral boulders remain important construction materials (e.g. Hoon 2003 and Hoon and Tamelander 2005). Tourism is a growing industry, with resorts catering for both domestic and international tourists established on Agatti and Bangaram. A further resort is planned on Tinnakara, and a second air carrier started daily flights to Agatti in April 2007.

The high reliance on natural resources in combination with the high density of the island population places significant strain on the local environment and, together with natural perturbations and global climate change, poses a significant management challenge. However, as has been noted previously, formal management and gathering of resource use data has focused on larger scale and commercially more significant activities, such as the export-oriented pole-and-line tuna fishery, while little attention has been paid to subsistence and small scale activities that nevertheless are of immense importance for the local population (e.g. Hoon and Tamelander 2005). This has left a gap in the environmental and resource management of Agatti, but also a divide between local populations and the knowledge they possess on the one hand, and management authorities on the other.

There is considerable uncertainty regarding the sustainability of resource use in Agatti, as well as apparent inconsistencies between opinions voiced and trends observed. The many conflicting views and opinions on status and trends of the availability of reef resources and utilization patterns means there is an obvious risk for increased conflict over resource use and access. In the absence of quantitative data, past studies have estimated reef resource use based on numbers of resource users and estimated catch size and composition according to fisher/gleaner perceptions, rather than on actual harvest data (e.g. Hoon and Tamelander 2005).

To address this a participatory study was initiated to quantify and characterize in greater detail the artisanal reef fishery and other reef resource use on Agatti island. Results from one and a half years of catch monitoring of the reef fishery are presented herein, and recommendations made with respect to management implications of the findings as well as further needs for quantitative study of the reef fishery.

MATERIAL AND METHODS

Data collection was carried out through a community based monitoring programme, building on the existing resource use monitoring team on the island described by Hoon and Tamelander (2005).

A new catch monitoring protocol was developed and introduced through a consultative process with the monitoring team, consisting of data recorders (women and men from the island fishing community) as well as a data manager. A workshop was also organized to train the monitoring team, including a number of local fishers.

The sampling protocol builds on low-intensity sampling throughout the year, with catches recorded for 10 continuous days, 6 times a year. The data recorders focus on one landing zone each (although they can cover multiple zones when the need arises) (Fig. 2).

For each catch the following variables were recorded: date; name of data recorder; landing zone; name of fisher; number of fishers; cloud cover (clear, cloudy, rain); wind conditions (low, medium, high); approximate start and end times for fishing operation; fishing activity/gear used; mesh size (if net is used); boat type (if boat is used); fishing site (one to three sites visited in order of importance); total number of fish caught; number of species in the catch; total weight of the catch. Further, for each species in the catch the following was recorded: number of fish, estimated size range and average size in cm; and average weight per fish. An ID number was automatically assigned to each catch event.

Local terminology has been used as much as possible, to ensure the methods and data are more

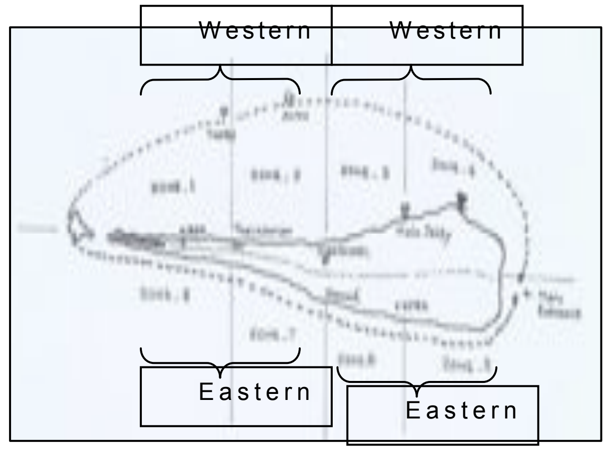

Figure 2. Landing zones on Agatti island (from Hoon and Tamelander 2005).

accessible to the local population, and to better utilize their knowledge of their environment. Consequently fish species are recorded using local names. A total of 113 distinct local taxa have been identified through the catch monitoring. Some of these refer to individual species, while others include two or more species, an entire fish family, and in some cases, fish from different families. A definition list was created grouping local taxa under 40 ‘family groups’, building on scientific definitions, however also taking into consideration how species are defined locally, which is influenced by food and commercial value of the fish as well as how it is caught (Table 1). Results presented in this paper are summarized based on these family groups.

Fishing activities or gears used are also recorded in local terminology. The gears are briefly characterized in Table 2. More detailed descriptions and characterizations can be found e.g. in Hoon and Tamelander 2005.

Although on occasion caught in the reef fishery, incidental catches of tuna have been excluded from this analysis as they are largely pelagic, the main target of a semi-industrialized fishery, and catches are recorded through Fisheries Department data. However, pelagic fish that are frequently found in reef areas and caught through reef fishing operations have been included, such as seer, dorado and mackerels.

Table 1. Reef fish. Local names and taxonomic definition (sharks, rays and tuna as well as two unverified local names not included).

Fish group	Local taxa	Fish group	Local taxa
angelfish	shabadu kallam	milkfish	ilimeen, kuruthola, manabalkody
baitfish	bella chala, bodhi, chala, manja chala , pacha chala, rahiya	mojarra	furachi
barracudas	kolas	morays	malanji
billfish	kudirameen, ola meen	mullets	thidira
box fish	thomp	parrotfish	chandi, feesom
butterfly fish	fakikadiya	pufferfish	chemaniyam
damselfish	kally, kurichil, lattom, mamban, thukiyam	rabbitfish	oram
dorado	habnoose, shaameen	sea chubs	funji, kalkuratty, poonchi
emperor	auran metty, fallam metty, fonthom metty, kannam metty, kilukkom, kulakkathi, manjam, metty, pulli metty	seerfish	ayakura
flying fish	farava	snapper	chemmali, fulariyam, karim karavalli, phuleriyum
fusiliers	baichala	sole	lammam
garfish	keram, oola	squirrel and soldierfish	kallaalam, kankaduvam, pherunganny
goatfish	kalmanakam, manakkam	stone fish	pehchan
gobies	mandiyam	surgeonfish	barifad, fala, karukkam, naithala, nilalam, varipad
grouper	arkolichammmam, chammam, pulli chammam	sweetlips	kotha
halfbeak	mural	threadfin	mookam
jacks and trevallies	cheemkanni, fankuluval, faradam kuluval, fiyada, keri machan, kulluval, madathala	triggerfish	falli, karatty
lizardfish	balaka	wrasse	balala, njaala, thokka
mackerel	bangada		

The island has been divided into four main landing zones (for a discussion see Hoon and Tamelander 2005) that represent an overall aggregate of fishing sites within each zone (Fig 1 and 2).

Results presented here are based on a total of 3030 fish catches recorded during one and a half years between September 2005 and May 2007. Results are presented as total catch and catch per unit effort (CPUE) expressed as kg fish caught per man-day by gear, landing zone, and month. Based on monitoring data on the average daily fishing effort by gear, estimates of total annual catch have been made. Most commonly caught species, gear selectivity and size of the fish caught have been calculated based on species composition of the catches.

RESULTS

Gear Use

Gear use around the island is largely determined by hydrography and how the gear is operated, as well as

Table 2. Fishing activities/gears used on Agatti.

Local Name	Description
bala adiyal	Shore seine, used mainly in the western lagoon
bala attal	Purse seine, used inside the lagoons around the island
bala fadal	Large drag net involving 15-30 people, operated in both eastern and western lagoons
bala idal	Gillnet set in the lagoon
cast net	Small mesh castnet used mainly from the shore and frequently opportunistically, around the island
hand line	Baited hook and line, used opportunistically around the island, frequently from boats during transport or in association with other fishing activities
kalmoodal	"Boulder trap" – a net set around a coral boulder which is then agitated using rods to drive out fish. Not commonly used
kurakkal	Light and spear or sword. Not commonly used, only practised in shallow water
rod and line	Baited hook and line, used opportunistically around the island and mainly from the shore
shal kakal	Gillnet set in reef channels, used mainly during the monsoon and at spring tide. Not commonly used

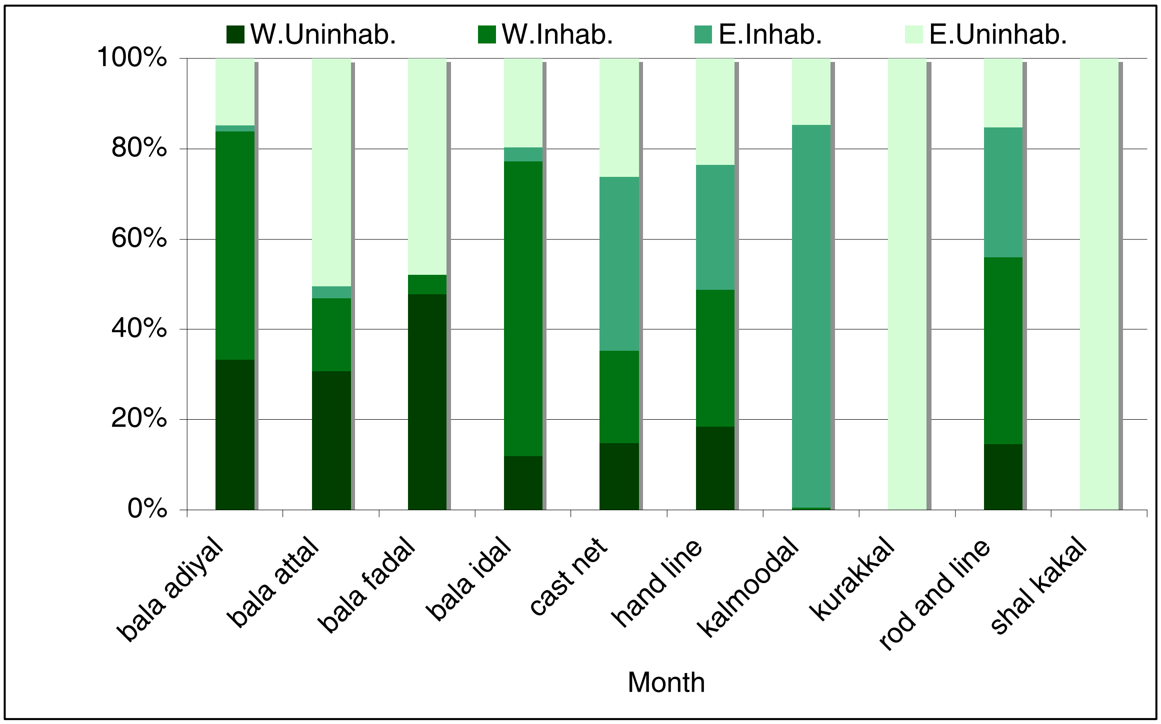

Figure 3. Gear use by fishing/landing zone expressed as % of total number of recorded fishing operations in each zone.

by habitat and availability of target species. Purse and dragnet operations such as bala attal and bala fadal are carried out mainly in the uninhabited section due to ease of operations – there are fewer boats, and less traffic and disturbance. The simpler gears operated mainly by one person are used on an opportunistic

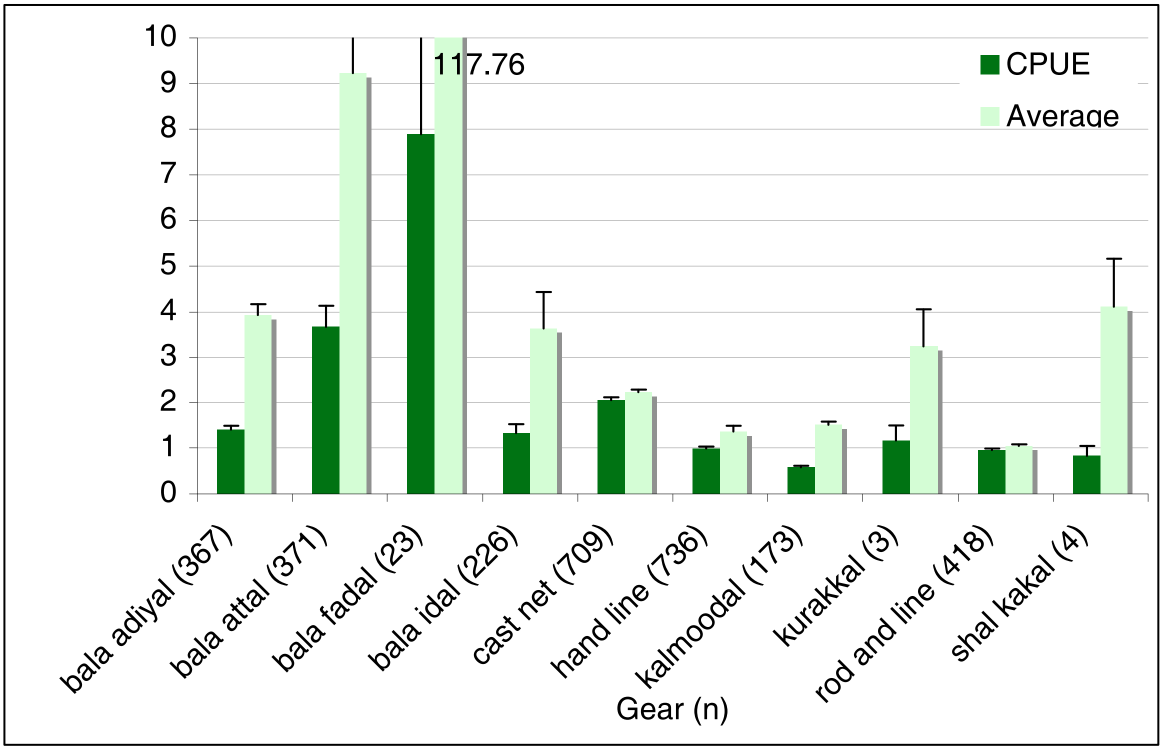

Figure 4. Catch per unit effort (CPUE) and average catch per operation by gear (number of records in brackets). The error bars indicate standard error of the mean (SEM).

basis both from shore and small crafts, rather evenly in the zones around the island. This includes cast nets, hand lines and rod and line (Fig. 3).

Bala adiyal and bala idal, shore seines and bottom set gillnets, are used primarily in the western lagoon. The bala adiyal nets can be walked out from the beach, which has a suitable profile, and areas of coral boulders can be avoided. Bala idal is used significantly more in the inhabited section of the island to allow easy and quick access to check for fish (this compares well with Hoon and Tamelander 2005). Suitable reef channels for shal kakal occur mainly on the eastern reef.

Bala fadal (large drag net) has traditionally been used only in the broad western lagoon, where the operation commonly involves two boats and up to 30 people. A change in activities noted since 2004 is that a modified form of bala fadal has been introduced in the eastern lagoon, whereby 8-15 team members walk out nets to enclose around ½ km of the lagoon and then drag it to the shore. Bala fadal is used almost exclusively in the uninhabited part of the island.

The 'traditional' fishing methods kalmoodal and kurakkal (trapping fish over boulders and spearing fish at night using a torch) are practiced only in the shallow eastern lagoon, which is accessible on foot even at high tide – the water depth remains less than 2 m. These methods are mainly used for recreation. This is reflected in the low sample size, as operations are relatively rare.

CPUE

The overall Catch Per Unit Effort (CPUE) recorded, expressed as catch in kg per person per day, was 1.66±0.07 (average from 3030 fishing events ± standard error of the mean).

CPUE varied considerably between fishing gears, and was notably higher for bala fadal and bala attal

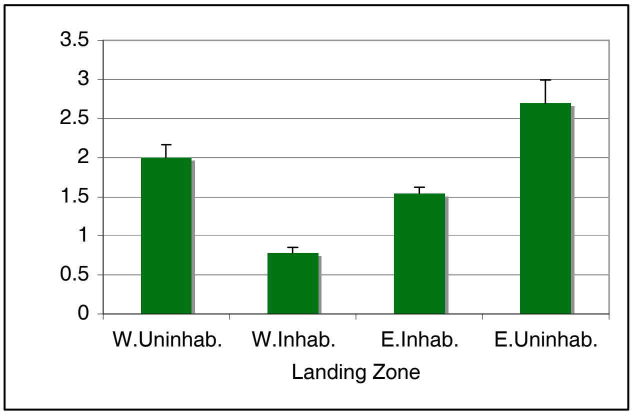

Figure 5a. Average CPUE (±standard error of the mean) by landing zone.

(Fig 4). Due to the nature of these gears – drag net and purse seine - they require several people for their operation but also ensure a lot of fish is caught. The standard error of the mean (SEM) illustrates a higher variability in catch size especially in bala fadal and to some extent bala attal (the sample size is sufficiently large). The large SEM in bala fadal is due to the considerable difference in operation (see comment above), catch and CPUE between the two bala fadal varieties. The larger operations in the western lagoon yielded higher total catches as well as CPUE, was 11.25±4.53 based on 12 recorded operations, compared with 4.21±1.60 based on 11 recorded operation in the eastern lagoon (Fig.s 4 and 5). All but one operation took place in the uninhabited section of the island.

The overall CPUE varies somewhat between landing zones; most notably the CPUE is low in the inhabited section of the western lagoon – less than half of that in the uninhabited section of the western lagoon, and less than a third of that in the uninhabited section of the eastern lagoon. This is due to lower CPUE than in the uninhabited section for e.g. bala adiyal, idal and fadal, as well as cast net, hand line and rod and line, and perhaps more significantly, lower CPUE than in the eastern lagoon for bala adiyal, bala idal, cast net, hand line and rod and line (Fig. 5).

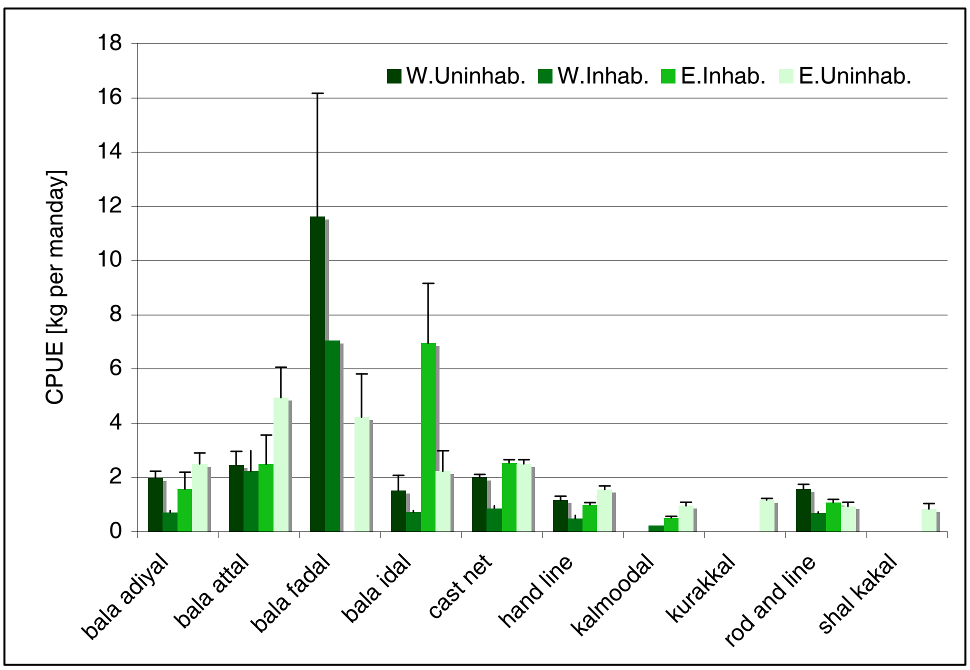

Figure 5b. Average CPUE (±standard error of the mean) by gear and zone.

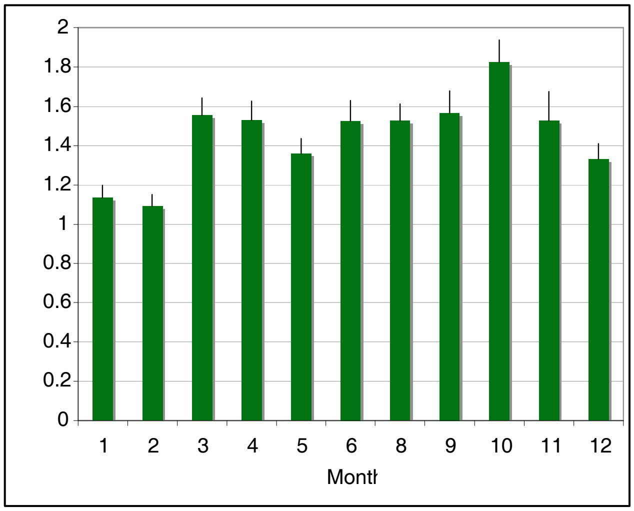

Figure 6. Average CPUE by month (±standard error of the mean).

CPUE also varied over time (Fig. 6), with average CPUE of around 1.55 kg per person per day in March and April, June to September and in November. It was notably lower between December and February and in May, and somewhat higher in October.

Total Catch

Using the CPUE obtained from the catch data and estimates of gear use frequency, the total annual reef fishery catch in Agatti has been estimated at 56 metric tonnes (Table 3). Bala attal and bala fadal catches together constitute over 50% of the estimated total, with bala attal catches of over 16 tonnes making up 29% of the total catch. Other gears with a significant proportion of the total catch, bala adiyal, cast net, hand line, bala idal and rod and line, range between 10.3% of the total for bala idal and 5.5% for rod and line. Kamoodal, kurakkal and shal kakal catches together make up less than 3% of the total catch.

Catch Weights

To compare the relative contribution of catches of different size toward the total weight of fish caught, individual catches recorded were divided into nine classes based on catch weight (<0.5kg; 0.5-1kg; 1-5kg; 5-10kg; 10-20kg; 20-50kg; 50-100kg; 100-500kg and >500kg). Over 90% of the catches were smaller than 5kg, and together constitute just over a third of the total catch recorded. Fifty one percent of all catches recorded fall within the 1-5 kg category, making up

Table 3. Total catch by gear. Average CPUE and average number of fishers involved in gear operations are based on catch data records, number of fishing events per year is estimated based on census data. The estimated total annual catch in kg is calculated based on CPUE and gear use data. The error margin of the estimated total annual catch is calculated based on the standard error of the mean in CPUE and number of people operating gears.

Gear	Avg CPUE	Avg # people	# of Events	Total catch	Error Margin
bala adiyal	1.40	2.64	1560	5,779.47	462.16
bala attal	3.67	2.37	1872	16,306.89	2,183.16
bala fadal	7.89	15.29	100	12,056.28	3,879.77
bala idal	1.32	2.38	1248	3,941.45	671.31
cast net	2.06	1.03	2496	5,300.45	155.86
hand line	0.99	1.09	4680	5,063.10	289.91
kalmoodal	0.58	3.06	624	1,102.96	154.30
kurakkal	1.17	3.00	104	364.00	104.69
rod and line	0.95	1.03	3120	3,074.42	161.96
shal kakal	0.83	5.15	20	85.36	60.87
TOTAL	1.70	2.08	15824	55,955.54	3,129.23

Table 4. Fish taxa occurring in more than 20 catches (number of recorded catches; average catch per fishing event in kg; total weight recorded in the catch monitoring data in kg; and estimated annual total weight caught in kg).

Species	Count	Avg Catch Weight	Tot Weight Recorded	Est. Annual Total
Jacks/Trevallies	2057	1.16	2,386.01	12,756.9
Garfish	110	17.81	1,959.08	10,474.3
Goatfish	980	1.49	1,463.10	7,822.5
Surgeonfish	556	1.47	817.43	4,370.4
Emperor	779	0.98	766.22	4,096.6
Mojarra	751	0.85	635.79	3,399.3
Halfbeak	159	2.26	360.01	1,924.8
Grouper	467	0.67	314.01	1,678.9
Snapper	387	0.67	260.60	1,393.3
Baitfish	34	3.92	133.35	713.0
Parrotfish	169	0.79	133.11	711.7
Threadfin	253	0.50	125.66	671.8
Triggerfish	95	1.31	124.01	663.0
Fusiliers	34	3.48	118.43	633.2
Mackerel	58	1.98	114.59	612.6
Wrasse	120	0.95	113.61	607.4
Sea Chubs	79	1.40	110.51	590.8
Squirrel/Soldierfish	171	0.37	63.14	337.6
Damselfish	24	1.53	36.65	195.9
Barracudas	60	0.55	32.77	175.2
Rabbitfish	19	0.58	10.94	58.5
Lizardfish	28	0.36	10.21	54.6

30% of the total catch. By comparison, 35 catches over 50kg, constituting only 1.2% of the total number of catches, make up 42.4 % of the total catch by weight. Catches over 20kg constitute 1.9% of the total number of catches, but make up 48.3% of the total catch by weight.

Species Caught and Gear Selectivity

An analysis of the fish catch composition (Table 4) shows that five families (or species groups), jacks and trevallies, garfish, goatfish, surgeonfish and emperor made up over 70% of the estimated total annual catch. Jacks and trevallies occurred in almost 30% of all catches. The average catch weight is particularly high in garfish, halfbeaks and baitfish, largely due to the fact that they frequently form large schools that can be trapped using various nets. Garfish in particular exhibits a much higher average catch due to occasional catches of 50kg to over 300kg. Based on reports from fishermen it is assumed these are regular occurrences. As illustrated in Table 5, three to five species groups usually constitute more than 70% of the catch.

DISCUSSION

CPUE

The CPUE for cast net recorded in the catch data was higher than what fishers have reported through interviews (see Hoon and Tamelander 2005). This is to some extent a function of the nature of the fishery

Table 5. Gear selectivity. Species groups constituting more than 5% of the total catch weight, by gear (selected gears).

Species	bala adiyal	bala attal	bala fadal	bala idal	cast net	hand line	rod-line
Jacks/Trevallies	30.7	18.7	8.2	10.6	43.1	13.6	71
Garfish		44.4		35.3			
Goatfish	21.6	19.1		13.1	19.7		
Emperor	6		20.9	6.4		16.7	
Surgeonfish			34		6.6		
Grouper						18.8	11
Mojarra	10.2	5.7			13.1		
Snapper						19.1	
Billfish				12.8		5.7	
Halfbeak	8.4		5				
Seerfish						13.2	
Triggerfish			6.1				
Mackerel	5.3						
Other	17.9	12.1	25.7	21.8	17.5	13	18

and the fish catch sampling strategy. Castnet is an opportunistic gear and may be used on a whim. If fish are being caught the fisher may continue until content with the catch, whereas many times when catches are small or none at all the activity is not continued for long, and not always reported as a "fishing activity". The effect is that the catch monitoring method may overestimate the CPUE for castnet somewhat.

The difference in CPUE and total catch per event in the gears mainly operated by one person, such as cast net, hand line and rod and line, can be explained by the fact that the activities at times are carried out by two people together, and catches may at such times be pooled. This is the case especially for hand line, which is often used from boats in connection with netting operations.

The differences in CPUE between the landing zones reflects the intense pressure on the western inhabited section of the island – the proximity to human populations makes fishery access easy, and the lower CPUE may reflect resource depletion due to over fishing. However, it is also likely that environmental degradation contributes to resource depletion. The inhabited section of the western lagoon contains two busy jetties, a coir processing plant, and receives a large part of the sewage seepage from the island community, which are likely to affect fish habitat and communities.

The island is subject to monsoonal weather patterns, with a 'fair season' between November and March, a 'rough season' between May and September, and 'transition seasons' in October and April. The CPUE variations over time reflect this seasonality to some extent. The reef and lagoon fishery is more intense during the rough season, when the weather is unsuitable for hook-and-line tuna fishing. During the fair season, when more fishers spend more time in the hook-and-line tuna fishery, the CPUE of the reef fishery is lower. May, being the month with generally the roughest sea conditions, showed a somewhat lower CPUE than during the remainder of the rough season. The high CPUE in October was due to large catches using bala attal and bala adiyal. It is unclear if and how fish behaviour in response to temperature and weather patterns factors in.

The low number of records of kurakkal and shal kakal show the gears are rarely used, and further conclusions regarding these gears based on the data gathered are speculative and must be made with caution.

Total Catch

The total annual catch, estimated at 56 metric tonnes between 2006 May 2007, is lower than the 100 tonnes estimated and reported by Hoon and Tamlander, 2005. In part this reflects inconsistencies in the bala idal catch, which was reported to be almost 10 times higher in 2003-2004. Other significant differences were found in the estimated total catch of bala fadal and bala attal, which showed larger total catches than previously reported, due to a higher frequency of use and higher CPUE using bala fadal, and a higher CPUE using bala attal. Bala adiyal showed a much smaller catch than previously reported, the differences primarily due to lower CPUE and use-frequency.

While some of these differences are due to differences in monitoring methods (estimates through fisher interviews compared with quantitative catch monitoring), it is clear that it also reflects changes in fishing on the island and is possibly indicative of changes in the environment. For example, a new type of bala fadal operation has been introduced, and data on daily fishing effort (unpublished) indicate a decline in fishing operations in the recent couple of years. Further, through consultations and awareness workshops organized on the island fishers have indicated that fish catch is declining and fish composition in the catch is changing.

The method presented herein can be particularly valuable for tracking trends in the fishery CPUE and total catch if carried out continuously or at least at regular intervals. It can also complement perception data on catches and gear use gathered using Participatory Rapid Assessments (PRA).

Catch Composition, Gear Selectivity and Catch Size

Catch composition and gear selectivity indicate that the fishing methods used are somewhat selective. However, many species groups are made up of different local taxa: emperors contains 9 different local taxa, jacks and trevallies 7, snappers 4, groupers 3, and goatfishes 2 respectively (see Table 1), and a single catch may contain several different species of from each group. However, a closer look at individual catches shows that average number of species within each species group per catch event is relatively low. The species groups most commonly represented by more than one species in individual catches are jacks and trevallies, emperors and surgeonfish, and to a slightly lesser extent groupers and goatfish. The average number of species per species group and catch is under 1.5 for all species groups.

In spite of the preference for specific fish and the fact that fishing gears are developed and used with this in mind, it is also obvious that the quantity of fish caught matters, which leads to a situation where some of the more popular gears are optimized for a large catch rather than catch exclusivity. The number of species groups that each constitute less than 5% of the total catch by weight for a given gear, and perhaps more importantly, their combined weight as a % of the total catch, give an indication of how selective a fishing gear is. Using these criteria the least selective gears appear to be bala adiyal and bala fadal; 26 different species groups and 37 local taxa were recorded in bala adiyal operations, with 20 different species groups constituting 17.9% of the total catch. In bala fadal, where the total number of species groups and local taxa recorded are lower (23 and 35 respectively), the 'bycatch', 18 different species groups, makes up over one quarter of all catch. Also in bala idal over one fifth of the catch is made up of minor species groups. This mirrors statements by local fishers that many of the nets are designed and used with catch quantity rather than specificity in mind.

By contrast, over 80% of bala attal catches are made up of only three species groups – garfish, goatfish and jacks and trevallies – and the minor constituents of the catch, although rather diverse at 20 species groups, make up only 12.1% by weight. While cast net has the highest number of species caught with any gear (38 local taxa) jacks and trevallies, goatfish and mojarras make up over 75% of the total catch by weight. Hand line seems to have a broader spectrum of target species, but a lower bycatch. Six fish groups constitute 87% of the catch, the remainder is made up of only 13 species groups. It is noteworthy that the results presented herein differ somewhat from what was reported by Hoon et al 2002. This supports the perception among fishers that catch composition has gradually changed over the past five years.

Similar to many other small-scale subsistence reef fisheries there is very little discarded bycatch in the Agatti reef fishery. Although certain species are preferred there are uses for almost all species.

One striking feature of the reef fishery on Agatti is the proportion of the total reef fish landing caught in a comparatively low number of large catches. It is worth noting that the large catches are landed using the more indiscriminate and possibly more destructive fishing techniques, notably bala fadal. There is a need study in more detail how the different fishing gears impact the resource and the health of the ecosystem, as well as the socioeconomic and cultural aspects of their use, as this will have bearing on management decisions regarding the reef fishery. However, it does seem clear that regulations on the unselective and potentially destructive bala fadal would be more feasible to institute and have a larger impact than attempts to regulate minor gears that according to the data presented here are less likely to deplete the fishery resource and would appear less likely damage the ecosystem.

Fishing Sites vs Landing Zones

When fish catch is recorded fishers note down sites visited, 1-3 sites in descending order by quantity of fish caught at each site (subjective ranking by the fisher). In all, over 70 fishing sites have been recorded in the catch data, including coral boulders, reef channels and specific spots on the shore (many of these are indicated on the map in Figure 1). However, this number is approximate as sites have not been checked for duplicate names/synonyms, and they have been georeferenced only to some extent. It is clear though, that sites can have rather different spatial definitions, some referring to a coral boulder or even one side of the coral boulder, an area of only a few square meters, whereas others are more broad, such as "the bar area", which denotes the outer reef crest and slope around the island. It is clear that the gear used also has implications for the definition of a fishing "site". Thus in this study catch has been reported by four landing zones rather than actual fishing sites. Since a large part of the catch is landed in the zone nearest and most convenient with respect to the fishing site, the landing zones provide an acceptable approximation of catch by site cluster. Hoon and Tamelander (2005) provide a justification for this approach, in the absence of site-specific analysis of catch. However, it should be noted that catch from especially boat-operated gears may be landed where the boats are usually moored (primarily the western inhabited zone) rather than in the closest zone, which may affect the accuracy of the fishing intensity data presented. The overall patterns are believed to be correct, however.

Local and Scientific Taxonomy

While many local names for fish match scientific fish species, and some local fish group names seem to largely match scientific families, analysis of catch data presents a number of obstacles in relation to terminology and taxonomy. Most notably, the local names used are not systematic with respect to scientific/taxonomic level – some fish are described only by a family-level name, others by very species-specific ones or even referring to juveniles of a certain species. This reflects the relative importance of specific species to islanders and their lives, as well as the local understanding of functional categories.

An example of this is the much greater taxonomic detail in local names referring to baitfish than other small fishes, due to the importance of the tuna hook-and-line fishery that uses large quantities of baitfish and distinguishes between species. It is important to note, however, the baitfish group includes fusiliers as well as damselfish and possibly also e.g. small serranids, gobies and blennies. The species presented as damselfish in this study are thus damselfish that are not used as tuna bait. Similarly, several of the main target food fish species are classified in detail, e.g.

jacks and trevallies and emperors. Lack of taxonomic detail is observed with respect to fish species that obviously occur around the island but do not constitute important or preferred catch, such as rabbit fish, for which only two local names were encountered.

A further issue is that local terminology is not always used consistently, and a fish, for which a local name that refers to a single species may exist, may be recorded using the name of the fish group to which it belongs. For example, a white-blotch rock cod may be recorded simply as a grouper, i.e. 'chammam' (the family-based species groups used in this study), or using the more specific 'pulli chammam'. Some local names also lack clear distinctions or have overlaps, e.g. in relation to emperors and snappers, where several local names refer to specific species and others may refer to groups that include both emperor and snapper species.

While the local taxonomy approach taken in this study might create a 'bias' for some species or species groups, it is reflective of local conditions. The benefit of using local terminology, making the data collection as well as results more immediately locally applicable, by far outweighs the disadvantages, many of which can be dealt with.

On the whole the level at which local names have been aggregated is considered appropriate for the purposes of this study – to characterize the reef fishery in much greater detail than has been done to date, and quantify the fishing effort and fish catch. The accuracy of the taxonomic system used is viewed as sufficient (after all, more often than not local taxonomy does match the scientific) to also make statements regarding the relative importance of major food fish families and the total harvest. One development that could be useful in this regard would be to ensure species are always recorded to species level, or at least lowest possible taxonomic level. However it must be recognized that the local terminology is rather flexible in nature and varies even from person to person (for example, 262 different names and/or spellings of names occur in the catch data, which correspond to 113 distinct local names), and many fish lack species names. Another approach could be to analyse catch based on a combination of taxonomic and trophic groups. For either of these to be feasible highly detailed and currently not available information on local taxonomy is needed.

Sustainability of the Fishery

It has been reported that the reef fishery in the Lakshadweep decreased in response to the introduction in the 1970s of the tuna hook-and-line fishery (Arthur 2005), and further speculated that this may have contributed to a greater capacity of the reefs of the area to recover from the devastating mass bleaching in 1998 (Arthur 2007, Arthur 2000). However, there are indications of an increased reef fishery for local consumption, and perhaps more worryingly, for export to South East Asia, targeting high value fish such as groupers and snappers. This poses a management challenge as it can be an opportunity for sustained income or lead to temporary but high profits and a rapid decline and collapse in key fish populations (Murty 2002), as has been seen around the region. Management and conservation of the fisheries resource of Agatti must be formulated and implemented in a way that sees to the needs of the many people who depend on reef resources for protein and subsistence. This requires the involvement of local stakeholders as well as Fisheries department and non-governmental organisations, but the task is complex in the context of a rapidly changing global economic and social environment.

While CPUE analysis can yield an abundance of information about a fishery, including changes and trends over time, there is some doubt with regards to whether CPUE in itself can provide adequate information on changes in fishery resource status or provide indications of resource degradation early enough for management responses to be timely and meaningful. Because fishers are skilled and actively seek out places where fish are likely to be found it is possible fish population decline will not be seen as a significant change in CPUE until populations are near total collapse. Thus CPUE trends over time should not be used alone, but rather complemented by other surveys, importantly resource status surveys, which for reef fish can be carried out with relative ease using standard fish under water visual census methods (e.g. English et al. 1998).

Such resource and environmental status surveys have been initiated on Agatti. Members of the local community were trained in modified and somewhat simplified fish UVC and benthic assessment techniques, focusing on indicator species, resource species and important fishing areas identified by fishers. Early results are promising, with e.g. good correlation between (primarily corallivorous) butterfly fish and coral cover observed. However, additional training and field practice are needed for results to be sufficiently reliable. If allowed to continue the ecological survey data will provide an important complement to fish catch and other resource use data in the formulation and implementation of reef resource management.

Resource Conflict

Hoon and Tamelander (2005) reported little resource use conflict on Agatti island, except a divide between formal management authorities and local resource users, a situation that continues unchanged. However, should reef health and fish populations deteriorate, as a result of natural perturbations, due to increase in fishing for local consumption, or due to an uncontrolled expansion of the lucrative export oriented fishery for high value reef fish – perhaps the most worrying prospect at this time – the situation of relatively moderate resource use conflict is likely to change. A proactive management approach needs to be taken to address this in a way that ensures fair resource access and sees to local needs both in terms of conservation and development.

It is also notable that there has been a lot of speculation among local fishers regarding a high abundance and density of green turtles in the Western lagoon of Agatti, in particular in the inhabited section. The turtles are frequently cited as a cause for damaged fishing gear, and there are many reports of nets being torn, especially close to the shore and more so in the inhabited section of the lagoon. In addition turtles are often blamed for reduced catches not only through loss of gear but also altering the environment and reducing fish stocks. Preliminary results from a survey of the occurrence of green turtle in the western lagoon seems to corroborate some of the observations made by local fishers. The turtle densities are significantly higher in the area where local fishers experience the highest frequency of damage to their fishing gear (unpubl., surveys by NCF, CARESS and CORDIO in December 2005). While this does not provide evidence of negative impact of turtles on the fishery resource, it clearly reflects that there is some cause for the situation to be viewed as a conflict by the local fishing community.

There is also, as noted by Hoon and Tamelander 2005, a potential for conflict in relation to the reef resource uses that are technically illegal or regulated, but carried out without controls, such as the harvest of building materials, ornamental fish and other scheduled species (Lakshadweep Gazzette 2001a,b). Harvesting of sand, rubble and coral boulders for construction, as well as octopus and seashell collection, has been monitored as part of the fish catch monitoring programme, but results are not included herein and will be presented separately.

Catch Monitoring and Estimates from Fisher Interviews

The fish catch monitoring method presented herein can if carried out continuously or at regular intervals be particularly valuable for tracking trends in the fishery, and it is expected to provide more accurate estimates on CPUE and total catch than estimates based on interviews and perceptions. However, it is clear that the perceptions of fishers provide valuable, usually highly accurate information that can complement quantitative catch monitoring. This has also been observed during turtle and sea grass mapping surveys of the Agatti western lagoon where perceptions of turtle and sea grass distribution among islanders mirror maps created based on scientific survey data. This validates Participatory Rapid Assessment (PRA) as a quick and fairly accurate technique for obtaining data where none exists and where skills and funding are not available to carry out lengthy and time consuming scientific studies.

RECOMMENDATIONS

In view of the results presented herein, as well as other reports and surveys from the area (including e.g. Arthur 2000, 2005, 2007, and Hoon and Tamelander 2005), the following recommendations are made. Although made specifically with respect to Agatti, most recommendations apply to other islands in the Lakshadweep as well.

A more proactive approach to engaging local populations and resource users in formulating and implementing management policies for the area, and ensuring that this is based on best available scientific findings, is needed from management authorities;

The information available on state of the environment and resource use in the area needs to be synthesized in an appropriate format for supporting management decisions, and data gaps need to be filled through additional surveys and regular monitoring, most notably with respect to resource status and environmental health;

The sustainability of the current fishing effort needs to be determined through sufficient reef health and fish population monitoring, in combination with resource use and socioeconomic monitoring. Management responses e.g. gear restrictions and spatial or temporal closures need to be considered. The idea of a community managed no-take zone has been floated in Agatti and has been well received by fishers;

Importantly, there is a need to pay particular attention to regulation and precautionary management of the export fishery, especially concerning vulnerable and easily over exploited species such as groupers, bumphead parrotfish and napoleon wrasse. This includes setting regulations, establishing quotas, and carrying out enforcement through patrols as well as control of export;

It is also important to note that while there is a regulatory framework on natural resource use it is frequently not enforced coherently and consistently – some laws are broken on a daily basis, others never. A new approach with clearer and more consistent policies as well as and more public engagement is required;

The management interventions recommended should also include an increased focus on development of alternative or supplemental livelihoods for the people of Agatti and the Lakshadweep as a whole, to reduce natural resource dependence and stress on natural resources, and to diversify the local economy and making it more resilient to change.

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Increasing Catch in an Over-exploited Reef Fishery: Diani-Chale, Kenya, from 1998 to 2006

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ABSTRACT

Artisanal fisheries are an important economic activity of the coastal communities in Kenya. In this paper fish landing data collected through participatory monitoring from seven sites was analysed to determine trends in catch per unit effort (CPUE) in the artisanal catch for the period 1998-2006 in the Diani-Chale area. The catch from a subsample of fishermen was recorded at the landing site level on two days each week. Results indicate a general increase in catches over the period with annual average minimum in 1999 (3.1 kg/fisher/trip) and maximum in 2006 (6.2 kg/fisher/trip). Catch varied significantly through the year with a monthly minimum of 3 kg/man/trip in June and a maximum of 5 kg/man/trip in March. A total of 64 fish families were recorded whereby Siganidae, Scaridae, Lethrinidae, Scombridae, Sphyraenidae, Lutjanidae and Acanthuridae accounted for 77% of the total catch. Landed fish catches showed a high degree of temporal and spatial variation, and is also likely affected by many factors, including monsoon seasonality, habitat health, fishing gear, fishing pressure, fishers' preferences, and choice of fishing site among others.

INTRODUCTION

Coral reef fisheries provide income, food security and employment to a large number of people throughout the tropical and subtropical seas. Along the Kenyan coast, marine fishery resources have remained underutilized despite efforts to stimulate the fishing industry and maximize fish catches. Nonetheless, along with the expansion of the fishery, it is required that catches remain at sustainable levels. The coastal artisanal fisheries mainly comprises of the brackish water fisheries with fishing limited to creeks, estuaries and inshore waters of less than 40 m depth. The latter constitutes the Kenyan south coast fishery characterised by small traditional non-motorized canoes with a few semi-industrial fleets.

Inshore and brackish water artisanal fisheries contributes about 90% of marine fish landings which accounts for less than 5% of total declared national fish landings (Obura 2001, GoK, 2004). Marine fishery in Kenya supports about 10,000 fishermen, half of whom operate in Southern Coast (Ochiewo 2004) and approximately 600 fishers in Diani-Chale (Malleret-King *et al* 2003). During the dry and relatively calm season (Northeast monsoon-November

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

to April), the small traditional vessels mainly operate within the inshore coral reef areas and inside the estuaries and creeks whereas the few motorized canoes fish in the open sea. The rainy season with storms extends from May to October (Southeast monsoon-SEM). These rough sea conditions restrict fishing operations of canoe fishermen from the open sea resulting in a high fishing effort at the shallow coral reef waters during the period.

The increasing fishing pressure on near shore waters has resulted in overexploitation and extensive degradation of coral reef ecosystems as in the case of Diani-Chale which remains among the heavily exploited reefs (McClanahan 1995, McClanahan *et al.,* 1997, Obura *et* 2002), while off shore resources remain largely untapped.

The Diani-Chale, arstisanal fishery has experienced a decline in diversity and abundance and there are indications that some species are overexploited well beyond maximum sustainable yield - MSY (McClanahan, 1992) and require prompt management measures. Intense fishing, including of trigger fish (Balistidae) has resulted in an increase of sea urchin populations increasing competition with herbivorous fish (McClanahan and Shaffir 1990; McClanahan and Muthiga 1998). During the 1995-1999 period an overall decline in catches was reported (McClanahan and Mangi 2001) but since then catch rates and abundance of predominant fish groups appear to have been stable, with minor variation among gear types (Obura 2001, Kanyange and Obura, 2003).

The artisanal fishery of Diani-Chale is multi-species and multi-gear, employing traditional dugout canoes propelled by either poles or sails. The gears used include basket traps, handlines, spear guns, gill nets and cast nets among others. Even with the existing fisheries management measures, there has been unregulated gear use although elders and fisher folks have in the past played a big role in eliminating use of destructive gears such as beach seines from some fish landing sites (McClanahan and Mangi 2001). The gears target different species and fishers have preference for certain fish and fishing sites with most-

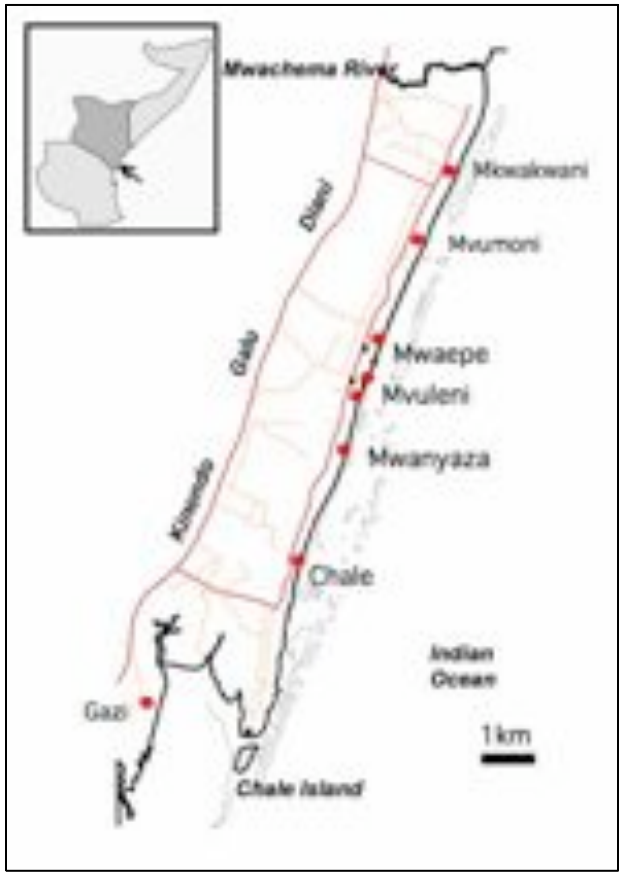

Figure 1. Map of the Diani-Chale reef area, showing the landing sites.

visited sites having the highest catch rates. Fishermen work individually or in pairs and at times in small groups and fishing is characterized by low catches hence poor incomes and living conditions.

To manage fisheries, information about fishers, catch and effort, fish stocks, fish processing and trade is vital. Such information forms the basis for policy choices, management plans and evaluations, and has to be sufficient, of good quality and up-to-date. The magnitude, spatial and temporal distribution of fishery resources (catch records and catch per unit effort) is required to give indications of effort, biomass and potential yield to enable evaluation of long-term cyclic variations.

It has become increasingly important to actively involve local communities in resource management from research or monitoring stage to formulating management policies. In Diani-Chale efforts have been made to increase the fishers' involvement in monitoring of fishery resources and the environment (Obura 2001, Obura et al. 2001, Obura et al 2002). The participatory monitoring program initiated in 1998 aimed at (1) introducing a community based monitoring program to track trends in resource use and condition benefit management agencies simultaneously; (2) engaging the fisher groups, community institutions and other stakeholders in resource management; and (3) use the monitoring programme as a tool for education and capacity building among fishers.

The findings of the participatory data collection process from seven fish landing stations for the period 1998-2006, were used to provide a better insight into the importance of the Diani-Chale fisheries. The study evaluates the level of exploitation of the artisanal fishery in Diani-Chale and Gazi fishing grounds highlighting seasonality and fluctuations in catch landings focusing on: catch rates (CPUE kg/man/trip), composition of landed stocks, and fishing strategies used. Overall, the report gives an overview of a typical artisanal fisheries catch profile of Kenyan reef fisheries at the same time demonstrating the fishers' capability to monitor the fishery. The data discussed will be useful in making management decisions for sustainable artisanal fisheries and will also add to the existing knowledge of the artisanal reef fisheries of Diani-Chale and Diani marine reserve.

MATERIALS AND METHODS

Study Site

Diani-Chale area is located 30 km south of Mombasa in Kwale District (Fig. 1). Data is analyzed from 1998 to 2006 from seven artisanal fish landing stations namely; Mwaepe, Mvuleni, Mwanyaza, and Chale, and from 2004 to 2006 from Gazi, Mkwakwani and Mvumoni. All the landing sites except Gazi are located within a continuous fringing reef system with a reef crest about 0.5 to 1.5 km from the shoreline sheltering sea grass beds in the lagoon with a maximum depth of 5-6 m. Gazi is in a bay covering some 18km^2 but is sheltered from strong waves by the Chale peninsula and island to the east and a fringing coral reef to the south. With a fisher density of about 15-20 fishers/km^2 in a 30-40 km^2 area (Alidina, 2005) Diani-Chale coral reefs are characterized by low coral cover, low fish abundance and high abundance of sea urchins (McClanahan *et al* 1994*,* McClanahan & Obura, 1995).

Catch Monitoring

The daily catch of individual fishermen was monitored twice per week at each fish landing site by a trained fisherman. Units of measurement were discussed and selected in community meetings and tailored to meet fishermen's local knowledge, practices and needs of the catch assessment systems (Obura 2001). Recorded data included: name of the captain, number of crew, gear used, vessel or means of transport, fishing site, total catch (kg- estimated wet weight using a spring balance) and catch composition (taxa and number of fish). Focusing on representation among the main gear types, emphasis was always placed on adequately surveying the different gear types used, with a separate census exercise undertaken to enable extrapolation from catch per fisher to total catches (see Tuda et al, 2007). The results of the monitoring work were shared on a regular basis in the presence of fisherfolks, community leaders, fishery resource managers and other stakeholders with the fishery trends shown and discussed openly in community meetings.

Data Analysis

The data were analyzed to estimate daily, monthly, seasonal and yearly averages of the catch per fisher, catch per gear and landing site and composition of the landed catch. The catch per unit effort (CPUE) was based on the weight of fish caught during a fishing trip or day (kg/man/trip). All data were tested for

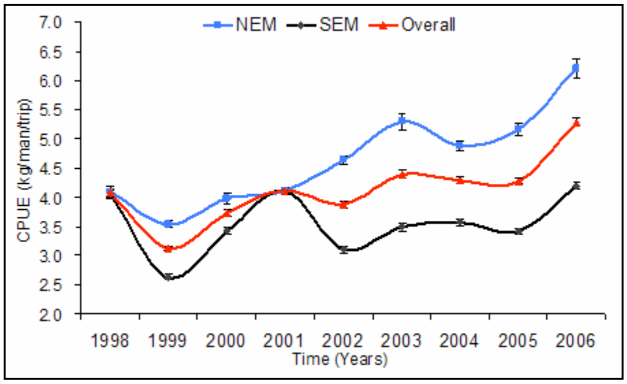

Figure 2. Annual and seasonal trends of CPUE (kg/man/trip) in Diani-Chale from 1998-2006; error bars indicate standard error of the means.

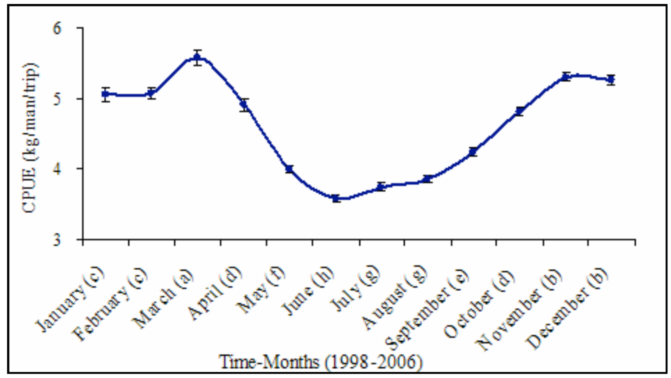

Figure 3. Monthly variations in catch per unit effort (CPUE) in Diani-Chale, error bars indicate standard error of the means while letters in brackets indicate post hoc results. Months with the same letter were not significantly different from each other.

normality using a KSL test. Since the data was not normally distributed even after several transformations, non-parametric Wilcoxon and Kruskal-Wallis tests were used.

RESULTS

Catch per Unit Effort (CPUE)

The estimated annual and seasonal CPUE for all gears from 1998 to 2006 ranged from 2.6 kg/man/trip to 4.2 kg/man/trip during SEM and between 3.5 kg/man/trip to 6.2 kg/man/trip during the NEM with the minimum recorded during 1999 and the maximum in 2006 (Fig. 2). Following a decline from 1998 to 1999, annual catch showed a steady increase from 2000 to 2006. Including the 1998 points, a linear regression slope of 0.165 (r^2 = 0.5834) was obtained, giving an overall increase of 165 g per fisher per year.

The CPUE in Diani- Chale was significantly higher during the NEM as compared to the SEM (Wilcoxon, Z=-35.87, p<0.0001). Similarly, significant differences in CPUE among years was noted except for 1998/2001 and 2004/2005 (Kruskal-Wallis c= 1033.69, p<0.0001). Within an annual cycle, catch rates were minimum in June and during the SEM (May – August, 3 to 3.7 kg/man/day) and maximum in March and during the NEM (3.7 to 5 kg/man/trip) with the differences among months being significant (Kruskall-Wallis c=1825.21, P<0.05, Fig. 3).

Annual mean catch rate was lowest in 1999 at Mwaepe (1.5 kg/man/trip) and highest in 2004 at Gazi (6.4 kg/man/trip, Fig. 4). However there was considerable variation in CPUE between years at each landing site and each year between landing sites (Table 1). For all years combined, catch rates differed significantly between landing sites (Kruskall-Wallis c=1033.69, P<0.05) except for Chale and Mkwakwani ,while for all sites combined there were significant differences over the years (P<0.0001, Kruskall-Wallis c-3735.15) except in 2004/2005 and 1998/2001. An upward trend in CPUE was recorded from five out of seven landing sites with Mvuleni recording the steepest trend (Table 1). Gazi and Mvumoni showed a gradual declining trend from 2004 while Mwaepe, Mwanyaza and Chale recorded slightly increasing trends with a peak CPUE in 2006.

Fishing Gear

Traditional fishing gears dominate the Diani-Chale fishery (Table 2), with some being modified with new materials and/or adoption of new designs from other communities. In this dataset, the main contributors to the total catch in the area were bunduki and malema with 22% and 19% respectively, while amongst the least important are mkondzo, kimia kigumi , kimia chachacha, juya, shomo, nyavu ya kutega and zonga which scored less than 2% (Table 2). The contribution of gears to the total catch fluctuates over time (Fig. 5). Juya, beach seines, were banned in Diani since 2000 as they are illegal gear and destructive. However they are common in Gazi and are among the top gears used by number of fishers.

Catch rates for the gears ranged from a minimum of 1.7 kg/man/trip for kimia kigumi to 9.4 kg/man/trip for kimia and ring net (Table 2). Jarife (6.2 kg/man/trip), bunduki (4.7 kg/man/trip) and malema (4.2 kg/man/trip) recorded relatively higher catches as compared to other gears (< 2.7 kg/ man/trip). An increase in CPUE over the years was observed from the majority of gears (Table 2). The fastest increases recorded (Table 2) are for gears with few data points, to these high rates of rise are not realistic. For gears sampled from 1998-2006, the rise in catch was between 0.13-0.53 kg/fisher/year on the high side (jarife, bunduki, mshipi, juya, shomo, kimia kigumi) and 0.03-0.08 kg/fisher/year on the low side (malema, mkuki, nyavu and mshipi).

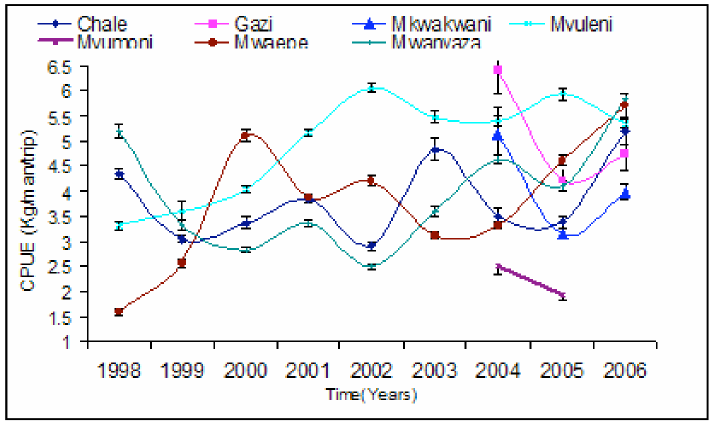

Figure 4. Annual variations in catch per unit effort (CPUE) by fish landing site in Diani-Chale, error bars indicate standard error of the means.

Gear use varies considerably between landing sites. The four commonest gears in the fishery are malema, bunduki, nyavu and mshipi as they are widespread and used at almost all landing sites (Table 2). Some gears are only used at specific landing sites; kimia kigumi,

Table 1. Annual catch per unit effort (CPUE, (kg/man/trip) by fish landing site in Diani-Chale, 1998-2006 (means, ± standard deviation) and annual increase for longer-term sites given by linear regression of catch on year for each landing site. Kruskal-Wallis (KW) nonparametric ANOVA for differences in CPUE between landing sites: * p < 0.01, ** p < 0.001, *** p < 0.0001.

Year	Chale	Gazi	Mkwak-wani	Mvuleni	Mvu-moni	Mwaepe	Mwan-yaza	All sites	KW
1998	4.3±4.3			3.3 ±2.4		1.6 ±1.2	5.2±2.6	4.1±3.8	**
1999	3.0±3.0			3.6 ±5.6		2.6 ±2.2	3.3±2.7	3.1±3.6	***
2000	3.4±5.3			4.0 ±2.0		5.1 ±3.4	2.8±1.5	3.7±4.1	***
2001	3.8±4.0			5.2 ±2.6		3.9 ±1.6	3.4±2.1	4.1±3.1	***
2002	2.9±3.6			6.1 ±3.1		4.2 ±3.4	2.5±1.8	3.9±3.5	***
2003	4.8±9.1			5.5 ±3.9		3.1 ±2.0	3.6±2.9	4.4±5.9	***
2004	3.5±4.7	6.4±8.7	5.1±3.6	5.4 ±3.5	2.5±1.9	3.3 ±2.1	4.6±2.9	4.3±4.2	***
2005	3.4±3.8	4.2±9.5	3.1±2.6	5.9 ±4.2	1.9±1.4	4.6 ±3.8	4.1±3.0	4.3±5.2	***
2006	5.2±7.7	4.7±9.4	4.0±4.4	5.4 ±2.9		5.7 ±8.7	5.8±3.3	5.3±6.9	***
All years	3.7±5.2	4.7±9.4	3.5±3.4	5.1 ±3.6	2.1±1.6	4.0 ±4.2	3.9±2.8	4.1±4.7	***
c-Value	489.92	81.27	21.99	1098.88	11.13	1645.45	1493.15	1033.69	
P-Value	0.0001	0.0001	0.0001	0.0001	0.0008	0.0001	0.0001	0.0001	
Regression slope (r^2)	0.100 (0.118)			0.307 (0.668)		0.300 (0.411)	0.1433 (0.127)	0.165 (0.583)	

Table 2. Catch performance of fishing gear used at the study sites in Diani-Chale from 1998-2006. CPUE measured in kg/fisher/day and regression slope (i.e. change in catch) in kg/fisher/year. Percentage of total catch contributed by the gear. Kruskal-Wallis (KW) nonparametric ANOVA for differences in CPUE for each gear between landing sites: * p < 0.01, ** p < 0.001, *** p < 0.0001. + - gears recorded over 2004-6 giving only 3 points for regression.

Gear type		Catch statistics			KW	Long term trend	
Local name	English Name	CPUE	sd	%	*p*	*Slope*	*r2*
Kimia+	Cast net	9.4	21.5	11	***	-1.426	0.0660
Ring net	Ring net	9.4	15.9	9	-	1.747	0.8410
K. chachacha+	Cast net	6.9	21.0		***	1.465	0.8812
Jarife	Shark nets	6.2	11.1	11	-	0.527	0.2450
Bunduki	Spear gun	4.7	3.4	22	***	0.210	0.6132
Mshipi	Hand line (hook and line)	4.2	5.3	14	***	0.273	0.7340
Malema	Basket traps	3.7	2.8	19	***	0.082	0.1969
Mkondzo/ mkuki	Spear	3.3	1.9		***	0.053	0.2020
Nyavu	Gill net	3.3	4.6	14	***	0.035	0.0110
Juya+	Beach seine net	3.0	3.3		-	0.399	0.2670
Nyavu ya kutega	Bottom set net	2.8	2.7		**		
Shomo	Harpoon	2.6	1.9		**	0.171	0.6650
Kimia kigumi+	Beach seine net	1.7	1.9		-	0.132	0.9750
Zonga		1.5	1.7		*		
Uzio	Stake traps						

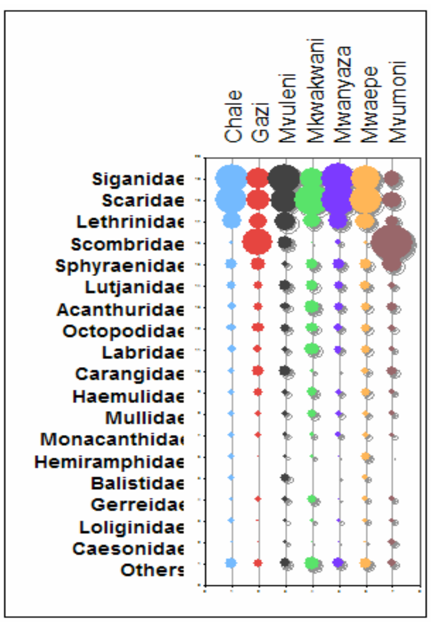

Figure 5. The major fish families harvested in Diani-Chale and the percentage catch composition by landing site. Families contributing less than 1% are summed as "others". Circles are scaled by area, largest circle = 43% (Scombridae, Mvumoni).

kimia chachacha, and ring nets were only recorded in Gazi, juya from Chale and zonga was recorded from Gazi and Chale. In Gazi, ringnets, mshipi and jarife recorded the highest catch rates. Mwanyaza recorded peaks in the use of jarife (17 kg/man/trip) and nyavu (8 kg/man/day) while Mvuleni recorded maximum CPUE from bunduki (6 kg/man/trip) and nyavu ya kutega (7.3 kg/man/trip). Variation in catch rates from malema, bunduki and mkondzo between landing sites was slight.

Catch Composition

A total of 1,106,749 individual fishes from 64 families were recorded from all landing sites over the 7 year period (Table 3). By abundance the Siganidae and Scaridae dp,omated at 25.5 and 24.9% respectively, followed by Lethrinidae (10.2%), Scombridae (5.2%), Sphyraenidae, Lutjanidae and Acanthuridae. Altogether, these families accounted for 77% of the total catch. The was primarily typical reef fishes although reef associated and pelagic piscivores such as Scombridae, Sphyraenidae, Octopodidae and

Table 3. Catch composition by fish family and landing site.

Species group	Habitat	Catch composition (%total catch) per landing site							
		Chale	Gazi	Mvuleni	Mkwak-wani	Mwan-yaza	Mwaepe	Mvu-moni	OVER-ALL
Siganidae	Reef	28.1	15.1	28.7	15.8	29.8	23.6	8.7	25.5
Scaridae	Reef	27.4	15.4	20.0	29.5	31.0	26.8	9.3	24.9
Lethrinidae	Reef	10.5	8.7	11.5	8.3	10.4	9.9	5.4	10.2
Scombridae	Pelagic	0.8	24.0	6.9	0.1	1.1	0.7	43.9	5.2
Sphyraenidae	Reef associated	5.3	7.4	1.5	5.0	4.9	4.5	9.4	4.5
Lutjanidae	Reef	3.2	3.4	4.6	4.0	3.3	3.8	2.3	3.6
Acanthuridae	Reef	2.4	3.1	2.6	6.9	3.2	3.1	3.4	3.0
Octopodidae	Reef associated	2.6	4.2	2.8	4.1	2.5	3.1	2.0	2.9
Labridae	Reef	2.3	2.4	2.1	6.1	2.5	3.0	1.2	2.5
Carangidae	Reef associated	1.6	4.0	4.4	0.8	0.5	2.2	3.4	2.4
Haemulidae	Reef	2.0	2.8	1.6	3.7	2.0	3.0	1.5	2.2
Mullidae	Reef	1.9	2.1	1.8	2.9	1.8	2.1	1.3	1.9
Monacanthidae	Reef	1.6	1.6	1.4	1.2	1.5	1.8	1.0	1.6
Hemiramphi-dae	Pelagic	1.6	0.1	0.6	0.9	0.2	3.4	0.1	1.3
Balistidae	Reef	1.6	0.0	2.5	0.0	0.4	1.3	-	1.3
Gerreidae	Coastal	0.6	1.9	1.6	2.8	0.3	1.1	1.2	1.1
Loliginidae	Reef associated	1.5	0.5	0.6	0.8	0.8	1.2	1.3	1.0
Caesonidae	Reef	0.5	0.3	1.0	0.1	0.2	0.5	2.3	0.6
Others		4.4	3.2	3.8	6.9	3.7	5.0	2.4	4.2
# of families	-	60	55	57	53	58	60	47	64
Total # of individuals		270,422	100,732	227,534	33,201	202,338	247,280	25,241	1,106,749

Hemiramphidae (1.3%) formed a substantial portion. Many families were rare and grouped into "others", accounting for 4.2% of the total catch. There were slight differences between the composition of catch between landing sites (Fig. 5). The families Scombridae and Sphyraenidae dominated the catches landed at Mvumoni (43.9% and 9.4%) and Gazi (24% and 7.4%) while other landing sites landed typical reef fishes. Mwanyaza recorded the highest percentage of Siganids (29.8%) and Scarids (31%).

Catch composition varied by fishing gear (Fig. 6). Siganidae dominated jarife, juya, zonga, mkondzo, malema, ring net and speargun catches (41%-26%) whereas Scaridae was the leading catch in juya, zonga and malema (34%-26%). Kigumi and nyavu ya kutega catches were dominated by Scombridae (44% and 41% respectively) while mkondzo and shomo were dominated by Sphyraenidae (22.6% and 14.2% respectively). Carangidae accounted for 42% of the kimia chachacha catch. The percentage composition for dominant fish families for various gears showed some slight variation over the monitoring period.

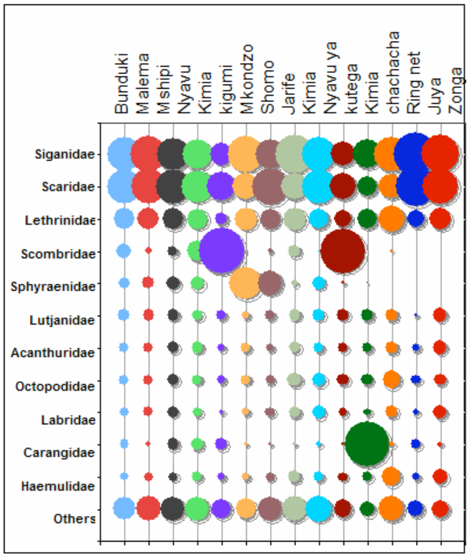

Figure 6. Percentage composition of most abundant fish families harvested by fishing gear in Diani-Chale. Families with less than 2% summed as "others". Circles are scaled by area, largest circle = 45% (Scombridae, kigumi).

DISCUSSIONS

Overall Catch per Unit Effort (CPUE) Trends

The yearly CPUE (kg/man/trip) in Diani-Chale shows an increasing trend from 3.1 kg/man/trip in 1999 to 6.2 kg/man/trip in 2006 (Fig. 1), due to a broad increase in catch rates among almost all gears in the fishery (Table 2). This increase is corroborated by independent data over the same period and is in contrast to declining trends recorded from 1995-1999 where habitat degradation and excessive effort were held responsible for catch declines (McClanahan and Mangi 2001). The lowest catch rate in 1999 falls in the year after the 1998 coral bleaching and mortality event in which shallowest portions of Diani reef suffered 60-80% mortality (DO, unpublished data). Reef recovery has occurred from about 2000 to the present (pers. obs.), and the banning of beach seines from most of the Diani landing sites may have contributed to the recovery of the fishery (McClanahan and Mangi 2001). Interestingly Mvuleni, Mwanyaza and Mwaepe landing sites have shown the strongest signs of improvement, and are the three sites that most aggressively expelled beach seines.

However beach seines are not totally removed from the reef as fishers can only stop others from landing fish at their beach, but traditionally have few powers to control activities in the water. Thus beach seine crews have continued to operate from Kinondo Mgwani landing site, which has refused to allow monitoring since 1997 and Mkwakwani, which refused monitoring up until 2004. Additionally, beach seine teams operating from Gazi share fishing grounds with those from Chale landing site, around Chale Island.

The higher catch rates in the NEM (<6.2 kg/man/trip) over the SEM (<4.2 kg/man/trip) are likely due to calm weather conditions, the rough weather during the SEM reducing fishing effort during this season (Obura 2002). Seasonal to monthly differences were documented in the composition of the catch and it may be that fish migrations, decreased density and activity due to a deeper thermocline in the SEM (Obura 2001b) and different seasonal reproduction patterns for both pelagic and demersal fish (Okera 1974, Kaunda-Arara and Ntiba 1997, and Kulmiye et al. 2002) may influence catch rates in the different seasons.

Mvuleni, Gazi and Mwaepe have above-average CPUE (Table 1). Differences in CPUE between landing sites could be associated with the extent and condition of the reef and lagoon, fishing effort, withdrawal of destructive gear and nearby commercial markets (Obura 2001, McClanahan *et al* 1996). The high catch for Mwaepe is surprising, as it is adjacent to the most degraded reef studied in Kenya (McClanahan and Muthiga 1998 and McClanahan *et al* 1997) and is reported to have recorded extremely low catches. The reef south of Mwaepe is less degraded however, and Mwaepe is located at the main break in the Diani fringing reef, which often has aggregations of schooling fish in it (e.g. chubs, DO pers. obs.).

Occasional catches from the channel and outer reef increase the mean catch rate considerably. Likewise Gazi has open access to a more extensive bay system, and this attracts migrant fishers from Vanga and Pemba (Tanzania) who use motorized boats and ring nets during the NEM (Ochiewo 2004, CORDIO unpublished data), contributing to high catches there. Also in Gazi, extensive mangrove systems may increase the biomass of fish locally through export of detritus and nutrients and provision of refugia and/or food that increase the survivorship of the juveniles (Mumby *et al* 2003, Ogaden 1997,Laegdsgaard and Johnson 1997).

The four most common gears in the fishery: malema, bunduki, nyavu and mshipi are widespread and used at almost all landing sites thus their contribution to the total catches is high while others such as kimia kigumi, kimia chachacha, and ring net were only recorded in Gazi (Table 3 and Fig. 4). This confers with earlier work where they were found to contribute between 16-31% to the recorded landings. This explains why contribution of ring net to the overall catches is lower. The decline in the contribution of bunduki and juya over time could be associated to change in gear use (Fig. 5).

Among gears, bunduki and malema were most commonly recorded and the main contributors to the total catch with 22% and 19% of landings respectively. Interestingly data collection from bunduki fishers declined gradually from 31% in 2002 to 18% in 2006. Bunduki was declared illegal in 2001 and sensitivity from the young fishermen who normally use it, and conflict with their elders and those in authority (e.g. supporting monitoring for management) is likely to have led to this decline. By contrast, the overall numbers of fishers using bunduki did not change over this time (Tuda et al., 2007).

Catch per Unit Effort by Fishing Gear

Among the main gears used, two are illegal in Kenya - spearguns (bunduki) and beach seines (juya). In 1995-6 bunduki and juya contributed 38% and 39% to the total catches respectively at Diani (McClanahan *et al* 1996). The use of beach seines has dropped as a result of exclusion, close to zero within Diani sites, but at about 12% of overall catch including Gazi (Tuda et al., 2007). Within this dataset, the proportion of bunduki dropped from 31% in 2002 to 18% in 2006. A full census indicates that bunduki are the most common gear in Diani-Chale, being used by 30% of the fishers, and contributing 33% of the total catch (Tuda et al., 2007). The decline in bunduki catch being recorded here is likely due to stigmatization of the fishers after the gear was banned in 2001, and their increasing unwillingness to participate in monitoring.

The fishing techniques and gears have changed with time , which is likely to continue given the increasing demand for fish and marine products.. Acquisation of modern fishing vessels at Mvuleni and Mwaepe landing sites may have contributed to the shift in gear use enabling fishermen to extend their fishing range. However, local knowlegde about the fish behaviour, seasonal variation and periodicity remains important in adoption of newer methods.

The overall average CPUE for different fishing gears in Diani-Chale and Gazi bay varied widely with lowest and highest catches recorded for kimia kigumi (1.7±1.9 kg/man/trip) and kimia and ring net (9.4 ± 2.5 kg/man/trip) respectively (Table 3). The most popular gears, malema, mshipi, nyavu and bunduki, had relatively moderate to low CPUE of 2-5 kg/man/trip.

Catch Composition

The total number of fish families (64) recorded during the present study is greater than those recorded previously in the same sites. Thirty seven families were landed from seagrass, sand and coral habitats (McClanahan and Mangi 2004), 40 families from seagrass and un-vegetated areas were sampled by experimental beach seine fishing in Gazi bay (De Troch *et al* 1996), and 50 families were reported from the same bay (Kimani *et al* 1996). The scale of sampling in this study – twice weekly at all major landing sites for almost 10 years is likely the reason for the higher diversity reported here. This is also in opposition with the common criticism that participatory monitoring does not sample diversity as well as scientific/technical monitoring (see Obura et al. 2002, Muhando 2007).

The dominance of low trophic level families and relative absence of top predators confirms over fishing and 'fishing down the food chain'. Top predators are often the preferred fish and slow to recover as they grow slowly and mature late. The families Siganidae, Scaridae and Lethrinidae accounted for 60.6% of the landings, dominating all landing sites except in Gazi and Mkwakawani where family deeper and net-based fishing (ring nets, etc) target Scombridae (Fig. 5). This corroborates earlier studies which reported dominance of sea grass and coral reef-associated species with small number of species contributing largely to the total captures (McClanahan and Mangi 2004). Rabbitfish dominate catches from heavily exploited reefs while small Lethrinids dominate catches from moderately exploited reefs. Studies done at the fished Mpunguti Marine Reserve and unfished Kisite Marine Park showed Lethrinids as the dominant family for 37% from each protection area and generally higher fish biomass in unfished reefs as compared to fished ones (Samoilys 1988, McClanahan and Mutere 1994, Watson 1996). With the same three families dominating most gear catches, there are likely to be high levels of competition, and therefore conflict, among different gear users.

CONCLUSIONS

Overall catch per unit effort (CPUE, kg/man/trip) in Diani-Chale appears to be increasing from a low of 3.1±3.6 kg/man/trip in 1999 to 5.3±6.9 kg/man/trip in 2006, with higher catches during the NEM than SEM. There are significant differences in monthly CPUE with catches ranging from 3.07±2.79 kg/man/trip in June to 5.07±6.47 kg/man/trip in March. The upward trend in CPUE was recorded from five out of seven landing sites with Mvuleni recording the steepest trend while Gazi and Mvumoni showed a gradual declining trend from 2004 to 2006. Within these overall patterns, catch rates are characterized by high variability, as catch is affected by local site characteristics, gear use patterns, seasonal and other patterns in fish abundance and factors that affect catchability.

Kimia and ring nets recorded the highest catch rates (9.4 kg/man/trip) while juya, nyavu ya kutega, mkondzo and kimia kigumi and juya recorded the lowest (<3 kg/man/trip). The fish catch of Diani-Chale shows a high level of dominance by the Siganidae, Scaridae and Lethrinidae which together with Scombridae, Sphyraenidae, Lutjanidae and Acanthuridae, account for 77% of the total catches.

Improvement of Diani-Chale fishery may entail retiring and phasing out destructive fishing gear classes (gear shift), change in fishers perception and behaviour about fishery management, improving technology and increasing incentives to limit habitat damage besides development of alternative livelihood activities.

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Estimating Total Fishing Effort over Tidal to Annual Periods in the Diani-Chale-Gazi Reef Fishery in Kenya

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ABSTRACT

The Diani-Chale area of the southern Kenya coast has been the subject of considerable fisheries research and management for over 2 decades, however a detailed estimate of fishing effort is not yet available. A seasonal census of fishers and activity patterns was held from 2003 to 2006, to capture variability by tide, lunar phase and season in fishing effort by all local gear types. The confluence of religious and lunar/tidal calendars results in a very strong cyclical pattern in fishing, with low tides during the full moon spring phase in the northeast monsoon being the preferred time for fishing and half moon neap phase in the southeast monsoon the least preferred. On average, daily fishing effort was 27.3±8.9 to 42.3±6.6 fishers at each landing site, in the SEM and NEM, respectively. Over a full year this exerts a pressure of 85,551 fisher-days in Diani-Gazi. The total fisher population is estimated at 570 fishers, and the total annual catch, based on gear-specific catch rates is estimated at 403 tonnes. Both spearguns and beach seines are illegal gears in Kenya but between them they support 37% of fishers in the NEM and 57% in the SEM in the study area. Spearguns alone account for 33% of the total fishery. Based on their importance and current knowledge on impacts of these gears it is recommended that beach seine regulation be strengthened and rationalized, but that the social importance and limited evidence for damaging effects of spearguns will require softer regulations to reduce their prevalence but not eliminate them totally. Extrapolated to the national level, recognizing many limitations in doing this, these results from Diani-Gazi suggest the national artisanal fishery employs almost 23,000 fishers catching over 16,000 tonnes of fish annually. Both figures are 2-3 times higher than officially reported levels of 10,000 fishers and 5-7,000 tonnes/year, respectively.

INTRODUCTION

The Diani-Chale of the southern Kenya coast area has suffered intense reef degradation for decades (Khamala 1971), evident through lower abundance of finfish and coral cover, increased numbers of sea urchins and increased turf algae cover (McClanahan and Muthiga 1987, Obura, 2001), nonetheless the area supports one of the oldest artisanal fishing communities in Kenya (McClanahan et al., 1997). Nevertheless, a precise estimate of the number of fishers in the area is not yet available.

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

Table 1. Fishing gear used in the study sites.

Local name	English Name	Description.
Bunduki	Speargun	Locally made using wooden or metal tube shafts, with steel harpoon powered by rubber/inner tube strips. Illegal.
Mkuki	Spear	Metallic rod (steel) sharpened at one end, may have a wooden handle or not, mostly targeting octopus and rays. Traditional.
Shomo	Harpoon	Wooden Harpoon without metallic tips mostly targeting octopus. Traditional.
Malema	Basket traps	Wooden strips woven in hexagonal patterns with an entry point for the fish, with pieces of rocks attached to weigh the trap down. Traditional.
Uzio	Stake traps	Intertidal traps and fences (used without boat). Traditional.
Mshipi	Hand line (hook and line)	Hook and line, made of steel hooks and nylon monofilament, uses bait. Modified traditional.
Nyavu	Gill net	General term for fishing nets, made of nylon, but of various mesh sizes and used differently. Modified traditional.
Jarife	Bottom set net	Net with large mesh size targeting large fish such as sharks, mesh size range of 5 cm to 12 cm Usually set offshore.
Nyavu ya kutega	Bottom set net	Used similar to *jarife*, smaller mesh size ranges from 1.5-2.5 cm..Set in channels along the path of fish.
Cha cha cha	Cast net	Large net with fine mesh sizes of < 3cm, targeting sardines and sprats. The net is set in the middle of two nets of different mesh size, held on either side by two moving vessels.
Juya/kimia kigumi	Beach seine net	Large robust net, with small mesh size and fine-mesh cod end. Illegal as damages habitat, juveniles populations and bycatch. Requires large group of fishers to operate. Introduced gear.
	Ring net	Large seine nets, medium mesh from 5-9 cm, set in a circle, originally in deep water for fish shoaling at the surface. Two sets of ropes on the top and bottom, pulled by the fishers from a boat. Requires large group of fishers to operate. Introduced gear.

Kenya's Fisheries Department estimates that there are about 10,000 fishers directly engaged in fish production along the Kenyan coast (SOC 2008), however local level numbers are not known. The national estimate is derived from the number of licenses issued for fishers and boats registered at the different landing sites. However there are a number of problems with these methods. First, compliance is low, particularly for the registration of fishers. Second, an average of two or three fishers per traditional fishing vessel at the coast is used, however some vessels carry over 12-15 fishers (un-powered) or over 20 (powered). Also, the bulk of fishers neither have nor use vessels, particularly speargun fishers who swim and those who glean on the reefs and in shallow water. In addition, some people fish as a part time activity and likely to excluded in such counts.

Kenya's artisanal fishery includes a wide range of gear types (Table 1), the selection of which involves many historical and preference factors for individual fishermen (Glaesel, 1997), and these change with environment, social and economic pressures over time (Ochiewo, 2004). Further, fishing activity changes according to tidal and seasonal cycles as water depth, daylight and the monsoon seasons affect accessibility of different fishing grounds for different vessels and gears.

Participatory monitoring and research activities have been carried out from 1997 to the present in Diani-Chale, supported by CORDIO (Obura et al.

2002, Alidina, 2005). More broadly, the area has been the focus of community involvement in co-management of marine resources following many years of lack of any formal management since the area residents resisted the establishment of an MPA in 1994 by the Kenya Wildlife Service (Rubens 1996, Obura et al 2001, Alidina, 2004). A problem with fishery management in Diani-Chale has been the lack of a total effort estimate, i.e., knowing how many active fishers use the reef from one day to the next, and over relevant cycles such as the tidal, lunar and seasonal cycles and in a calendar year.

To address this issue, a seasonal census of fishers and activity patterns was held from 2003 to 2006, the results of which are reported here. The specific objectives of the study were to estimate the fisher population at the selected the landing sites, and determine if fishing activity follows temporal patterns related to the tides and seasons.

METHODOLOGY

The census was initiated in 2003 at four primary landing sites, Mwaepe, Mvuleni, Mwanyaza, and Chale, and by 2006 included measurements at the other three main landing sites in Diani-Chale: Mkwakwani, Mvumoni and Gazi (Fig. 1, Table 2). Data was collected during the two main monsoon seasons that determine the degree of fishing activity. The northeast monsoon (NEM), or *kaskazi*, from November to March, is characterized by gentler winds from the northeast and sunny, dry conditions making fishing easy. By contrast the southeast monsoon (SEM), or *kusi*, from April to October, is dominated by strong winds off the ocean from the southeast, with rough seawater conditions and frequent rain, making fishing difficult. Additionally, Kenya has a strong semi-diurnal tide (Tobisson et al., 1998), with two cycles in a 25 hour period and a strong cycling between neap and spring tides twice during a lunar phase (Fig. 2). The timing of the high tides and low tides over the lunar cycle is stable such that the peak of the morning high tide on the first day of the new or

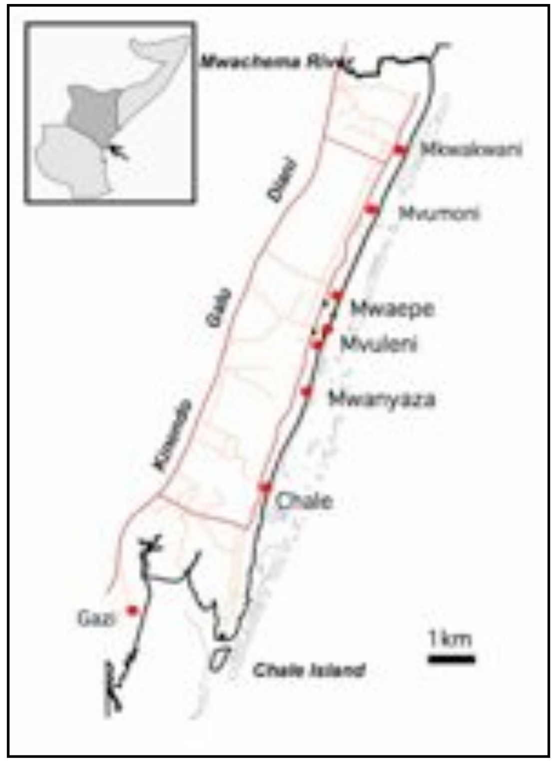

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Figure 1. Map of the Diani-Chale area showing the fish landing sites sampled in this census.

Table 2. Number of years and seasons sampled at the main sites, 2003-6 and at the Additional sites less frequently.

Year	Season	Long term sites				Short term sites		
		Chale	Mvuleni	Mwaepe	Mwany.	Gazi	Mkwakw.	Mvumoni
2003	SEM	X	X	X	X			
2003-4	NEM	X	X	X	X			
2004	SEM	X	X	X	X			
2004-5	NEM	X	X	X	X	X	X	X
2005	SEM	X	X	X	X	X	X	X
2005-6	NEM	X	X	X	X	X	X	
2006	SEM	X						

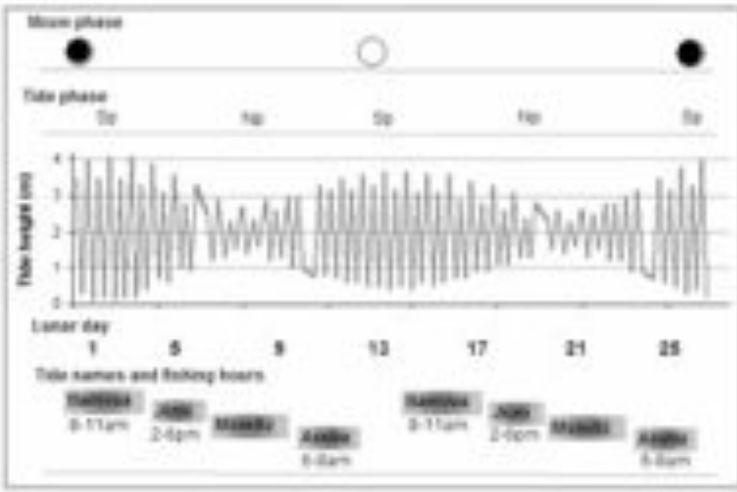


Figure 2. Lunar and tide calender for artisanal fishery in Diani-Chale. Moon phase, tidal phase (spring/neap), tide height (m), lunar day, local names for tides (see text for details) and optimum fishing times.

moon occurs at about 2 am ±30 min throughout the year (Jiddawi et al. 2002).

Sampling was conducted during a full lunar period at the peak of each season. Eight sampling days were chosen to fall on the spring and neap phases of the tidal cycle in each lunar month (e.g. days 2/3, 7/8, 15/16 and 22/23). On each day, data was collected for a full 12 working hours. Data recorded included: the actual time that each fisher or fishing unit set out to go fishing, the type of vessel used, the fishing gears used, and the total of captain and crew for each fishing unit. In addition, the name of the captain was recorded. For accurate recording the data collector was strategically placed at the landing site to record even those fishers who do not directly use the landing site when going in to fish, a common behavior among the spear gun fishers who do not have anchored vessels at the site. Depending on the time spent by fishers in the sea, the data collector also recorded the time each of the fishers returned.

Extrapolations from numbers of fishers to total catch for the Diani-Chale fishery used catch per fisher estimates from Maina et al. (2008).

RESULTS

The Moon, Tides and Fishing Activity

Islam is the main religion among fishers in Diani-Chale hence much emphasis is put on the Islamic calendar, and the lunar month (Fig. 2). This lasts approximately 29 days based on observation of the moon phase. The first time that the thin waxing crescent moon is visible after new moon (low in the evening sky just after sunset) marks the beginning of the month, and is designated day 1. The lunar month ends on days 28-30, depending on sighting of the moon. In practice, the dependence of the Islamic month on observation of the moon is affected by variability in local conditions (weather, presence of mountains, etc.), and this results in some disagreement on the precise day of the month. This can vary across countries, and also among religious leaders. At the study site, the sighting of the moon and days of the Islamic month are coordinated by radio broadcast Zanzibar, Tanzania, daily.

Local terminology is used in describing the tidal phase relative to the moon (Fig. 2): the days of the large spring tides bracketing the new or full moon are referred to as *bamvua*, which generally lasts for 3-4 days around the full moon from days 29- 3 and 15-18 of the Islamic calendar. Following these days, the tidal range decreases until a week later during neap tide when the range is smallest. This is known as *msindizo* and falls between days 8-10 and 21-23. The period associated with receding springs (*bamvua*) towards neaps (*msindizo*) is referred to as *maji ya jioni* as the good tides for fishing occur in the late afternoon (*jioni*) and occurs between days 5-7 and 18-20. The period as neap tides build back up into spring tides is called *maji ya asubuhi* as the good tides for fishing occur in the early morning (*asubuhi*) and occurs from days 11-13 and 24-27. *Msindizo* means to rest and during this period the malema (basket trap) fishers don't fish as the late low tide in the afternoon limits

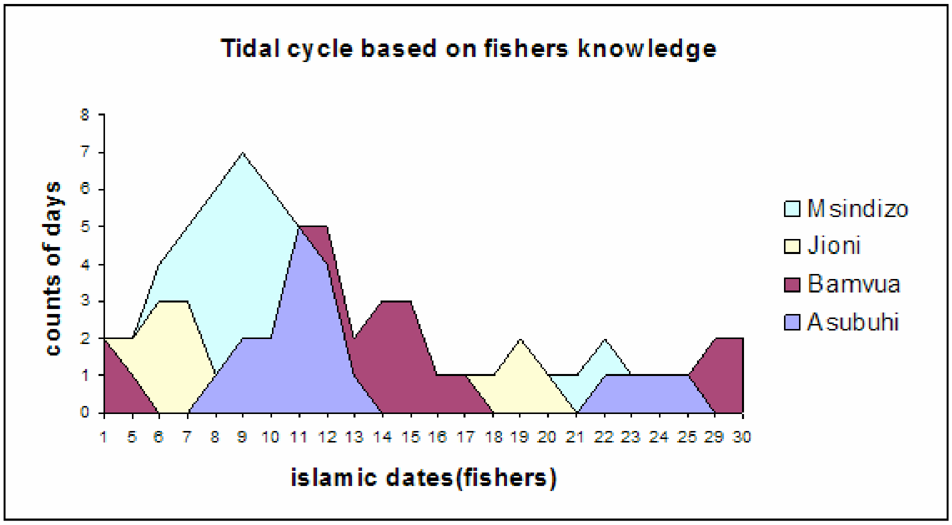


Figure 3. Reporting by fishers of the phases of the tidal cycle based on Islamic/lunar day over the study period from 2003 to 2006.

them from setting their traps as a result of darkness. Additionally, there is a lore that traps should be set with the opening facing east and the baited side on the west, so that as the sun sets it illuminates the bait attracts the fish into the trap. But with the late low tide in *msindizo* it is dark shortly after setting the traps, and the fish are unable to see the bait, reducing the catch.

Of relevance here, data recorded over multiple lunar cycles and years results in overlap of some of the named phases (Fig. 3). Additionally, variation and overlaps in the actual day that have been reported by the fishers, are attributed by fishers to the morphology of the landing sites. For example, one fisher stated that the tides vary slightly from one end of the 10 km study site to the other (i.e. from Diani to Chale/Gazi); Diani has a shallow lagoon compared to Gazi and Chale, hence the tide recedes faster at the former. As a result the tide may be perceived as *asubuhi* in Chale but as *bamvua* in Mwaepe.

Fishing Effort

The main landing sites, Chale, Mvuleni, Mwaepe and Mwanyaza were sampled each season from the SEM 2003 (July) to NEM of 2005-6 (December-February), while the additional sites were sampled once in the NEM of 2003-4 and in NEM and SEM in 2005-6. On average, the number of fishers censused each day during the NEM (36-42) was higher than the SEM (26-27, Fig. 4), and with slightly lower variation during the NEM. The number of fishers varied greatly across the landing sites. Gazi had by far the highest number (Fig. 5) with over 100 per day during the NEM decreasing to less than 80 during the SEM, with

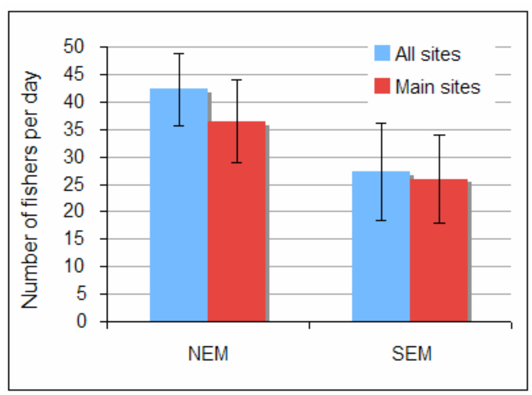


Figure 4. Number of fishers per lunar day by season at all landing sites, 2003 – 2006.

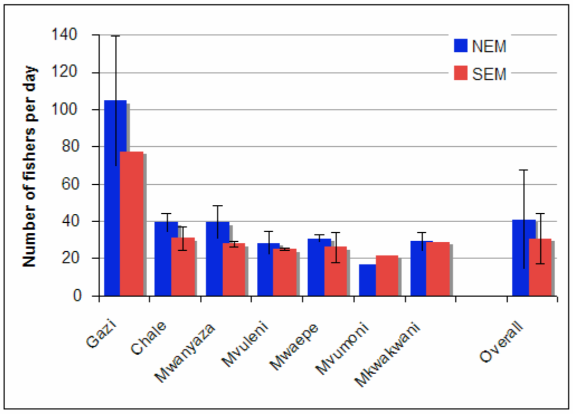


Figure 5. Number of fishers per day by season for each landing site in Diani-Chale.

wide error bars (the SEM was only sampled in one year, so no error bar shown). All other sites had more or less similar numbers, though the number decreased from Chale in the south (35-40 per day) to Mvumoni and Mkwakwani in the north (15-30 per day).

The number of fishers varied with the lunar and tidal cycles (Fig. 6). During the NEM however, variation was less, with almost no cyclical trend observable for fishers at all sites over the lunar phase (Fig. 6a), and only a small degree of variation over the tidal phase (Fig. 6b) showing slightly more during days 4-6 and slightly less during days 10-12, corresponding to *bamvua* and *msindizo* periods respectively. At the main sites the variation is more pronounced, with a distinct increase in fishers during the spring tides after the full moon (lunar days 15-18) and less during both neap tides (*msindizo*) on lunar days 8-11 and 22-26, and tidal days 8-10. Variation in fishers per day is more pronounced during the SEM particularly for the neap tide/msindizo days preceding the new moon around lunar days 20-24. At the main sites during the NEM, the slight increase in fisher activity during the spring tides (*bamvua*, tidal days 2-4, lunar days 2-4 and 15-18) is clearly shown.

From 2003 to 2006 there was no consistent trend in number of fishers per day at the landing sites. Overall, numbers stayed approximately the same (Fig. 7). Notably, there was neither an increase nor a decrease in fishing effort over the 3 years of the census (DSIC – stable fishery). Chale and Mwaepe

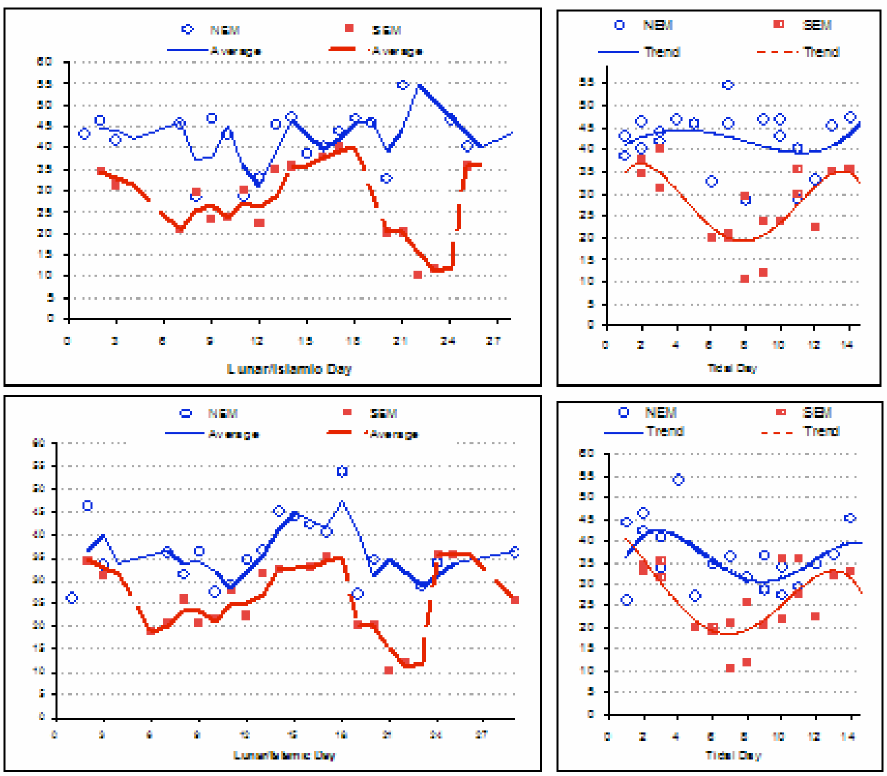


Figure 6. Numbers of fishers per day in each season, by lunar and tidal day. Top row – all sites, bottom row, main sites with continuous record, 2003-6. Left – plot of number of fishers by lunar/Islamic day. The trend lines are 3-point moving averages for each season. Right – plot of number of fishers by tidal day. The trend lines are 4th-order polynomials.

showed declines in numbers of fishers during the SEM while Mwanyaza and Mvuleni showed declines during the NEM.

Based on the number of fishers per lunar day, the total number of man-fishing-days per season and year can be calculated (Table 3). With an average of 42.25 and 27.30 fishers per day during the NEM and SEM respectively, we estimate that 1,225 and 792 fishers are active per lunar month, and 6,379 and 5,842 in each season. Using a global mean of 3.8 kg/fisher/day catch from the same dataset (Obura et al. 2002), these correspond to 24,240 kg and 22,201 kg of fish caught in the NEM and SEM respectively, and an annual catch for the Diani-Chale reef system of 46,442 kg.

The above numbers give the average daily fishing effort. However fishers don't fish every day, and we calculated a possible maximum number of fishers

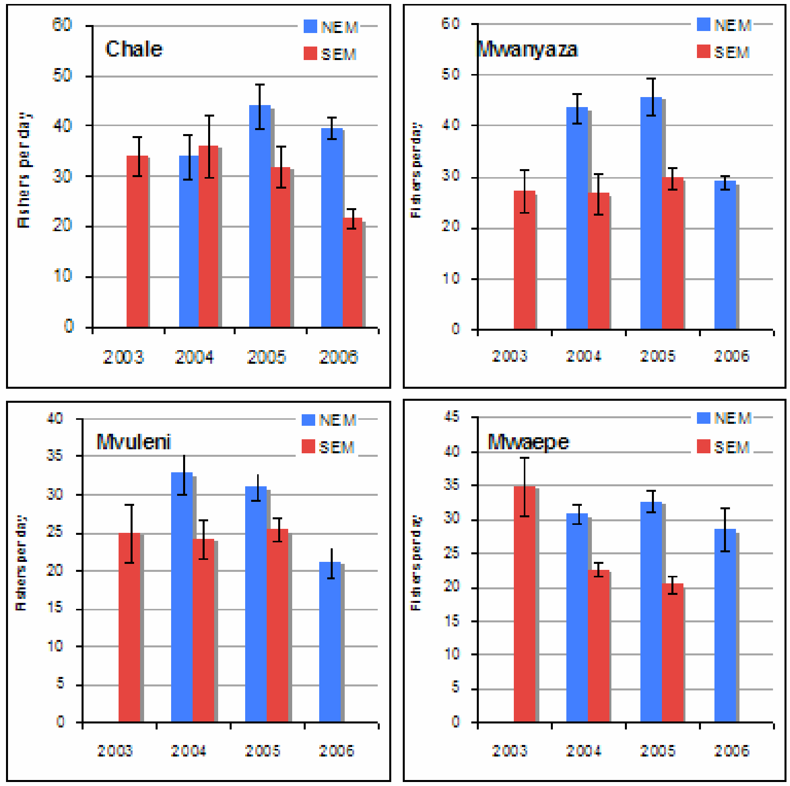


Figure 7. Change in average number of fishers per day during the NEM and SEM from 2003 to 2006 at the four main landing sites in Diani-Chale.

as follows: for each captain's name, the maximum crew size was taken and added together to estimate a total number of fishers. Table 4 shows the numbers estimated by landing site and year. Overall, the numbers suggest a population of approximately 570 fishers in the Diani-Chale area. With 36.4-42.2 active fishers on average at each of the seven landing sites in the two seasons (Fig. 4), and therefore 252 – 294 fishers overall across the study sites, 45-52% of all potential fishers are active on any given day.

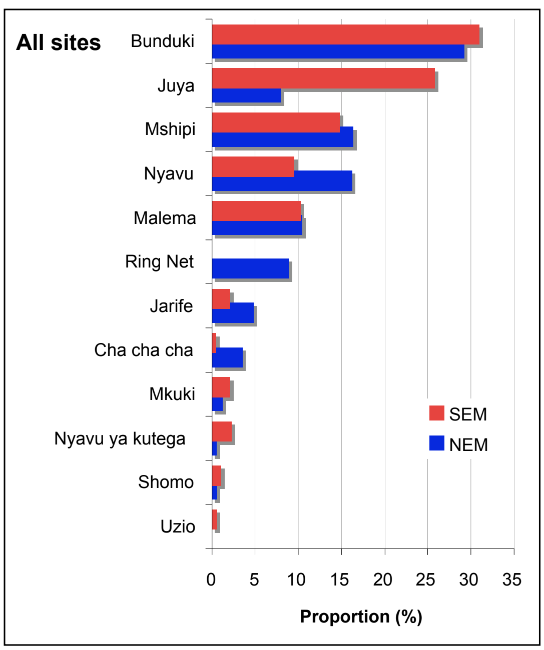
Gear Use

Spearguns were the most common gear used in both seasons, by 84 and 74 fishers in the NEM and SEM, respectively (Table 5) corresponding to > 30% of fishers among all sites combined, and slightly more in the main sites (Fig. 8). Beach seines, or juya, were the next most common gear (10-25%) due to their heavy use in Gazi particularly during the SEM (61 fishers per day). Next most common in use were the traditional gears hook and line (*mshipi*), gill nets (*nyavu*) and basket traps (*malema*), at 10-15% of fishers overall. Beach seines and ring nets at Gazi, and bottom set nets (*jarife*) at all sites showed strong seasonal differences in use. Ring nets and set nets are used outside the reef, so use is restricted to the calm NEM. Use of beach seines at Gazi is strongly seasonal, and predominant in the SEM when their use in shallows close to shore may favour them over other gears that need to be used in deeper waters, and due to a local regulation at the landing site restricting their use in the NEM in order to minimize conflict with others gears. Gill nets in Gazi were much more common during the NEM, and fishers may trade off between the two depending on the season.

Based on catch rates for each of the gear types

	Per landing site		Diani-Chale area	
	NEM	SEM	NEM	SEM
Number of fishers per day				
Mean	42.2	27.3	296	191
Standard deviation	6.6	8.9	46	62
Standard error of mean	2.3	3.0	16	21
Number of fisher-days per lunar phase				
# days	29	29		
Total fishing days	1,225	792	8,576	5,542
1 se range	68	86	473	604
Upper 95%	1,090	619	7,630	4,335
Lower 95%	1,360	964	9,522	6,749
Number of fisher-days per season				
Total (season)	6,379	5,842	44,654	40,897
1 se range	352	636	2,463	4,454
Total (annual)	12,222		85,551	
Estimated total catch				
Average catch per fisher	4.4			
Total (season)	28,068	25,707	196,476	179,948
Total (annual)		53,775		376,423

Table 3. Total fishing effort by lunar month and season for the average landing site and for the Diani-Chale areas as a whole (7 landing sites). NEM/SEM season transitions have been assigned as 1 April and 1 November, with 151 and 214 days in each season, respectively. Average catch per fisher for 2003-6 obtained from Maina et al., 2007.



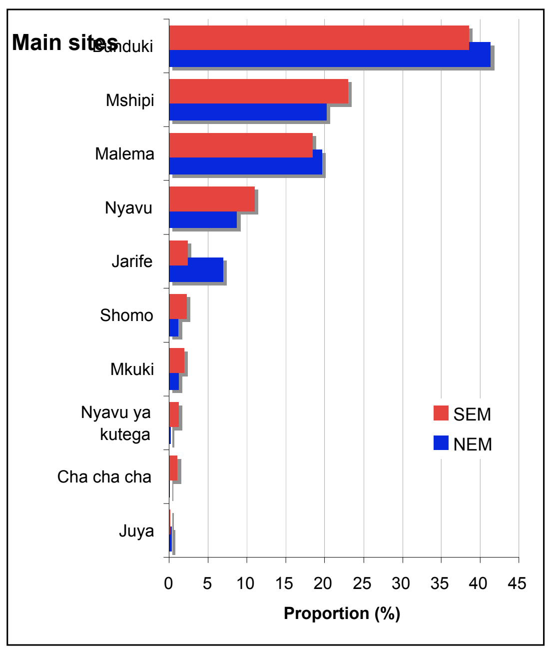


Figure 8. Proportions of different gear types used in the NEM and SEM, at all sites (left) and for the main study sites (right).

Table 4. Estimate of total number of fishers by landing site.

	2003	2004	2005	2006	Average
Chale	135	179	88	113	129
Gazi		220	155	67	147
Mkwakwani		94	67	46	69
Mvuleni	84	156	69	84	98
Mvumoni		38	35		37
Mwaepe	109	123	52	81	91
Mwanyaza	78	127	54	62	80
All		**810**	**466**		**571**

Table 5. Average daily number of fishermen using each gear at all the landing sites, by season.

	Chale		Mvuleni		Mwaepe		Mwanyaza	
Gear	NEM	SEM	NEM	SEM	NEM	SEM	NEM	SEM
Bunduki	18.3	14.3	9.1	7.4	8.8	8.5	20.6	12.5
Juya	0.0	0.2	0.5	0.0				
Mshipi	2.7	1.5	7.6	7.3	9.8	9.1	7.7	7.6
Nyavu	2.9	4.8	3.8	3.9	2.6	1.2	2.6	2.3
Malema	6.3	5.9	6.2	3.3	6.8	6.9	7.7	4.3
Ring Nt								
Jarife	6.9	1.2	0.5	0.4	2.0	0.4	0.1	0.6
Cha	0.0	0.1	0.0	1.1			0.2	0.0
Mkuki	0.4	0.7	0.4	0.5	0.5	0.6	0.3	0.4
Ny kut.			0.2	1.1	0.0	0.2	0.1	0.0
Shomo	1.7	2.5						
Uzio								
Total	39.1	31.2	28.3	24.9	30.6	27.0	39.3	27.7

Table 5 continued.

	Gazi		Mkwakwani		Mvumoni		Total	
Gear cont.	NEM	SEM	NEM	SEM	NEM	SEM	NEM	SEM
Bunduki	5.0	5.1	11.3	10.8	11.3	15.5	84.3	74.1
Juya	22.5	61.5					23.0	61.7
Mshipi	10.1	2.0	6.7	4.6	2.6	3.1	47.2	35.2
Nyavu	25.3	0.0	8.2	7.4	1.5	3.1	46.8	22.7
Malema	0.1	0.0	3.2	4.1			30.2	24.5
Ring Nt	25.6	0.0					25.6	0.0
Jarife	4.4	2.5					13.9	5.1
Cha	10.0	0.0					10.2	1.2
Mkuki	0.0	1.0	0.3	2.0	1.6	0.0	3.6	5.1
Ny kut.	1.3	4.1					1.6	5.5
Shomo							1.7	2.5
Uzio	0.1	1.4					0.1	1.4
Total cont.	104.4	77.6	29.5	28.9	17.0	21.8	288.2	239.1

Table 6. Estimated total catch by gear for the Diani-Chale artisanal fishery for northeast and southeast monsoons, annual total and proportion of total catch by gear. Estimates based on numbers from Table 3 and CPUE from Waweru et al., this volume). * uzio CPUE not estimated in Waweru et al., 2008, so is assigned the mean rate.

Gear	CPUE (kg/man/trip)	Number of fishers daily		Total catch (kg)			% total
		NEM	SEM	NEM	SEM	Annual	
Bunduki	4.7	84.3	74.1	59,809	74,548	134,358	33%
Mshipi	4.2	47.2	35.2	29,903	31,679	61,582	15%
Juya	3	23.0	61.7	10,419	39,590	50,009	12%
Nyavu	3.3	46.8	22.7	23,331	16,024	39,355	10%
Ring Net	9.4	25.6	0.0	36,372	-	36,372	9%
Malema	3.7	30.2	24.5	16,879	19,435	36,314	9%
Jarife	6.2	13.9	5.1	13,043	6,776	19,819	5%
Cha cha cha	6.9	10.2	1.2	10,593	1,746	12,339	3%
Mkuki	3.3	3.6	5.1	1,801	3,633	5,434	1%
Nyavu ya kutega	2.8	1.6	5.5	678	3,280	3,958	1%
Shomo	2.6	1.7	2.5	649	1,406	2,055	1%
Uzio*	4.1	0.1	1.4	77	1,206	1,284	0%
Overall				203,554	199,325	402,879	

(Maina et al., 2008) the total contribution of each gear to the area fishery can be calculated (Table 6). Using individual gear CPUE the total catch estimated (402,879 kg) varies from the blanket estimate in Table 3 (376,423 kg). The high usage and CPUE of bunduki makes it the largest contributor to catch in the area, providing 33% of all fish caught in Diani-Chale and Gazi. Hook and line fishing contributes the next highest proportion of catch, at 15%. Beach seines (juya), because of their low CPUE, prohibition from most of Diani-Chale area and seasonally restricted use in Gazi, contribute 12% of all catch, in third place.

DISCUSSION

The combination of religious and lunar/tidal calendars results in a very strong cyclical pattern in fishing (Fig. 2), and the monsoon seasons strongly influence the amount of fishing during the year (Figs. 4, 5). Access to the sea is restricted by strong wind and waves, so fishing activity is lower during the southeast monsoon (SEM). Nevertheless, the fringing reef structure of the Diani-Chale coastline results in lagoon waters being sheltered from ocean waves for 4-6 hours during low tide each day so some access to the sea and to intertidal exposed reef flats is possible under almost any conditions, and fishing during the SEM is only slightly below levels in the NEM. At the short-term sights of Mvumoni and Mkwakwani there was no difference in fishing between seasons, and the former even showed higher fishing activity in the SEM. Gazi bay is a more open and exposed system than the fringing reef at Diani-Chale, and a larger increase in fishing during the NEM is clearly seen (Fig. 5).

During both seasons cyclical fishing activity by tidal and lunar phase was recorded (Fig. 6) however this was much less so during the NEM than during the SEM. Lower fishing activity during ‘msindizo’, or neap tides, was reported by fishers as being due to low tide falling in the late afternoon. During neap tides the lagoons are more exposed to ocean conditions as the higher low tide height results in the reef crest not being fully exposed – and during the SEM rougher conditions are experienced in the lagoon. Thus rougher conditions in the SEM appear to accentuate the lunar pattern of less fishing activity during neaps/ msindizo. It was interesting though, that while the lunar/tidal cycle in fishing activity was strong at the long-term sites (Diani-Chale) in the NEM, it was weaker with all sites considered (Fig. 6). This breakdown in the cycle may be dominated by fishing activity at Gazi, which is known for a larger proportion of migrant fishers, and for young men (who may be inexperienced) joining fishing crews as casual labour, for beach seines and ring nets. They may be less tied to traditions of fishing by the lunar and Islamic calendar, and the gears they operate, particularly ring nets (which may be used floating or on the bottom) in the NEM may be less dependent on tidal cycles that affect water depth and the use of bottom-dependent gears.

This study estimates a total population of 570 fishers operating in the 7 landing sites in Diani and Gazi, with daily numbers averaging 27.3±8.9 to 42.2±6.6 fishers per site, in the SEM and NEM, respectively. These fishers exert a pressure of 85,551 fisher-days per year in Diani-Gazi (Table 3). Using the mean CPUE for the area (Maina et al. 2008) we estimate a total catch of 376,423 kg of fish from the reef system, though using a more accurate method based on gear-specific CPUE, the total catch is 10% higher, at 402,879 kg (Table 6). A number of factors in the census method used tend to under-estimate the number of fishers each day. These include the activity of night-time fishers, who are common, avoidance of data collectors by fishers using illegal gears and fishers uncomfortable with research and monitoring for various reasons, and fishers operating from locations other than the 7 landing sites. Additionally, some of the landing sites, such as Mwanyaza, extend over several hundred meters of beach, and fishers may be missed. Factors that lead to over-estimating effort generally do not apply to the counting of fishers, but may occur in weighing and reporting of catch such as rounding up errors, related to pride in reporting high numbers. The method used to arrive at the total number of 570 fishers in the area may result in over-estimation, as the same individuals may be double-counted on different days if they fish with different captains, and some captains may work as crew on some days. However this does not affect the daily counts and total catch estimates.

Non-fishing activities and opportunities may influence fishing patterns noted here. The sites showing the least difference between NEM and SEM fishing effort, or a reversal of the expected pattern of less fishing during the SEM, are Mvuleni, Mwaepe, Mvumoni and Mkwakwani. These are the northern sites in the area (Fig. 1) and the most closely associated with the tourism industry in Diani. Gazi, Chale and Mwanyaza are all more isolated from tourism. The high season for tourism falls mainly in the NEM in December-March, and many fishers may either be employed in other tourism-related work, or opt to take tourists to the reef as this earns more than fishing, thus decreasing fishing effort.

Overwhelmingly the most important gear in the Diani-Chale fishery is the speargun (bunduki), operated by 30% of all fishers and catching 33% of all fish caught. The next dominant gears are far behind, with hook and line and beach seines more or less equal at about 15% of fishers using them and 12-15% of total catch. Fishers depend on speargunss and hook-and-line almost equally throughout the year, but beach seine use is highly seasonal, supporting 25% of fishers during the SEM (predominantly in Gazi, when other options are limited) but only 10% in the NEM. Both speargunss and beach seines are illegal gears in Kenya. Their combined importance in the artisanal fishery, supporting 37% of fishers in the NEM and 57% in the SEM, poses significant challenges for rational management. Both are gears of last resort in that they require minimal investment and experience of the fisher (Obura et al. 2002). Their greater use during the SEM when traditional gears are harder to operate, requiring more experience, emphasizes their importance as a last-resort source of income and protein.

The damaging effects of beach seines on fish populations has been amply demonstrated due to their high juvenile and by-catch rates (McClanahan, 2005), and the destructive effects of their use on corals and seagrass beds is clear from trampling by the operators to snagging and breakage when the nets are dragged. Less emphasized but increasingly apparent is their destructive impact on social structures. Welcomed early on because of their large overall catches and employment of local youth (Obura et al. 2002), they soon deplete fish populations locally and out compete other gears (McClanahan, 2004). The low per-fisher catch rate of beach seines (Table 6, Maina et al. 2008) does not appear to deter fishers from using it. This may be because the low individual catch is masked by the large overall catch, or individuals accept this trade-off as they do not have to invest in gear or preparation of their own. In some areas beach seine captains are exclusively outsiders, and ownership of the gear and boats is by the captains or non-fishing entrepreneurs (CORDIO/FAO, in prep). Thus from being independent fishers owning and operating their own traditional gear, and earning both cash and protein for home consumption, fishers become day-labourers. In the most extreme cases beach seine crews may carry home only their share of sales, without a share of low-grade fish which traditionally may be the main source of household protein (CORDIO/FAO, in prep).

Spearguns were banned by decree due to claims from fishing elders that they are destructive. However scientific evidence for this has not been shown, and the conflict between speargunners and other fishers is reminiscent of age-class and other social conflicts rather than fishing effects (Obura et al. 2002). The value of spearguns as an entry-level gear for inexperienced young fishers is clear. Because of this the social costs of their being illegal are potentially high, as strict enforcement would deprive one third of all Diani-Gazi fishers of their livelihood. The inconsistency in tolerating an illegal gear can be highly damaging to rational management, particularly at this time when authority and responsibility are being delegated to Beach Management Units, and fishers will have to face the multiple dilemmas of tolerating infringements or enforcing the law on their colleagues and relatives. Conflict among fishers, whether by age-class, social standing, origin or other internal division will most likely be aggravated by this dilemma resulting in worsening, not improved, fisheries management.

Based on the numbers of fishers dependent on the illegal gears, and the degree of evidence supporting those designations, we recommend:

- Strengthen efforts to enforce and rationalize beach seine regulation and enforcement. This will remove a destructive gear from both fishery and social perspectives, affecting about 17% of total fishing effort by either encouraging alternatives to remove this effort, re-assigning the effort to non-destructive and less conflictual gears, and/or redesigning the gear and its use to be less destructive;
- Rescind the ban on spearguns but devise alternative management options, through the BMUs. This will affect one third of all fishers. For example, by restricting spearguns to entry-level fishers (e.g. less than five years) and/or by zonation of fishing sites or times, the total effort by spearguns may progressively be reduced and that of other gears increased. Achieving this will require technical improvements to other gears that have lower catch rates than spearguns (Table 6) as well as establishment of formal training courses to attract fishers away from spearguns, perhaps through the Fisheries Department, BMUs or both. Additionally, focused investment and promotion of alternatives to fishing are required.

Scaling up these results to the national level can be done through a simple extrapolation of these results, assuming the area, landing sites and BMUs are representative of those nationally. Three of the landing sites reported here are formally gazetted by the Fisheries Department as BMUs. The fisheries Frame Survey of 2006 (GOK 2006) reported 31 landing sites in Kwale District, which was 26.9% of the total of 115 coastal landing sites. Thus from numbers reported here for Diani-Gazi (570 fishers and 403 tonnes annual catch) we estimate the Kwale District totals to be 5,890 fishers and 4,164 tonnes/yr, and the national totals to be 21,900 fishers and 15,481 tonnes per year, respectively. The number of fishers is over twice the Frame Survey results of 2,986 (Kwale) and 10,154 (national), and the total catch is double the level reported for 2005 of 7,605 tonnes (GOK 2005). Differences in methodology may account for some of the discrepancy. However considering that this study does not include the higher-productivity catch estimates of offshore fisheries common on the northern coast (e.g. tuna trolling and large bottom nets, jarife) and included in Fisheries statistics, the under-estimation of national marine catch and its socio-economic importance may be more than indicated. A detailed census of fishing effort as done here, combined with accurate catch per effort records and local frame surveys should be carried out at a more representative selection of landing sites to achieve a more accurate estimate of these parameters.

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Assessment of Fisherfolk Organizations and Beach Management Units (BMU) in the Management of Fishery Resources in Diani-Chale, Southern Kenya

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keywords: Beach Management Unit Regulations (BMU), Fisher Folk, Fisher Groups, Artisanal Fisheries Management in Kenya, Fisheries Co-management

ABSTRACT

The Diani Chale fishery at the Kenyan coast is facing intense pressure of over-exploitation by communities living along the coastline. Fishing is the main source of livelihood to many families and unregulated exploitation of the resource would impact negatively on thousands of families. The Fisheries Department has the mandate to manage fisheries resources; however the convectional top-down approach in implementing government policies has not succeeded in regulating coral reef fisheries and preventing overexploitation. Consequently, the government has designated Beach Management Units (BMUs) as a mechanism to involve fishers in co-management of fisheries, requiring fishers at a landing site to take on many management roles. The study examines the ability of existing fisher groups and organizations in areas of group membership, election of officials, financial resources and accountability to determine how well prepared fishers are to function as BMUs. Groups were found to have very low levels of transparency and accountability, and mismatched priorities between officials and members. Though fishers see themselves as poor and look to external agencies to provide funding, 82% of the resources the groups utilize come from internal sources and suggest much greater levels of independence than they recognize. The gaps between the expectations in the BMU regulations and the capacity of fisher folk are highlighted and some of the capacity building needs and recommendations for implementing BMU regulations in Diani-Chale are provided.

INTRODUCTION

The Kenyan coastline is rich in marine resources and biodiversity. Many communities depend on the marine and coastal environment and its associated resources for their livelihood. Marine fishing directly and indirectly employs approximately 20,000 people (Tunje, 2002), and provides monetary incomes to

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

Table 1: Objectives for group formation.

Ranking	Objectives	No. of times mentioned by		Total
		Members	Officials	
1	Development/Self Reliance	10	10	20
2	Advocacy/Fisher Rights	3	9	12
3	Equipment Purchase	5	6	11
4	Fishers Welfare	5	5	10
5	Conservation/Sanitation	0	3	3
6	Market Fish	0	2	2
7	Revenue Collection	2	0	2
8	Conflict Resolution	1	0	1

about 70% of the coastal communities in Kenya (Malleret & King, 1996). In many tropical regions high population, influx of immigrants, poverty and unemployment have exerted pressure on coastal resources including fisheries. Management of artisanal fisheries under these conditions is challenging as resource users have few alternatives to enable them to ease pressure on resources. Co-management is an important tool in empowering resource users to better manage their resources.

In Kenya the government has drafted legislation to establish Beach Management Units (BMU) as the basis for co-management of fisheries, for marine and inland fisheries to broaden stakeholder participation in fisheries management. Formally, the BMU is envisaged to consist of three main components: an Assembly, an Executive Committee and Sub-Committees. The BMU, through its by-laws, shall provide for the establishment of Sub-Committees depending on the need. The Executive Committee shall elect its ordinary members to head each Sub-Committee while the Assembly shall elect members to serve in the Sub-Committees. The Membership of the Beach Management Unit would be subject to meeting certain regulations.

The main objective of the Beach Management Unit is to strengthen the management of the fish-landing stations, fisheries resources and the aquatic environment (DFRE/ILM 2003). It is also expected to support the sustainable development of the fisheries sector, ensure the achievement of high quality standards of fish and fishery products and prevent or reduce user conflicts. According to the regulations, each BMU shall have jurisdiction over a beach, the geographical area that constitutes a fish-landing station. An official of the Fisheries Department shall designate a co-management area for each BMU in which the BMU shall undertake fisheries management activities jointly with the Department of Fisheries.

The official of the Fisheries Department shall then draft a Co-Management Plan for that co-management Area in consultation with the Beach Management Unit. The Co-Management Plan shall specify fisheries management measures that the BMU shall undertake to ensure sustainable use of the resource in their area of jurisdiction. In the case of a fishery or areas in which members of more than one BMU utilize the resource, the official of the Fisheries Department shall designate a joint co-management area.

The Beach Management Unit Regulations empower the BMUs to levy fees and other charges against its members and other users of the beach for the services that it provides, to raise income in order to meet its day-to-day expenditures. The levies would

Figure 1: Map of Diani-Chale area showing the location of landing sites included in this study.

Table 2. Names and acronyms of fisher groups, year of registration, last election and the number of elections held.

Acronym	Group name	Registration	Last Election	Elections held
GFSHG	Gazi Fishermen Self-Help group	2002	2002	1
GBMC	Gazi Beach Management Committee	2004	2005	1
MFSHG	Mwaepe Fishermen Self-Help group	1997	2003	1
MVFSHG	Mvuleni Fishermen Self-Help group	2003	2003	1
MZFSHG	Mwanyaza Fishermen Self-Help group	2004	2004	1
CFSHG	Chale Fishermen Self-Help group	1997	2004	1
SCFSHG	South Coast Fishermen Self Help group	2003	2006	1
MKFSHG	Mkwakwani Fishermen Self-Help group	2006	2006	1

come from fishing vessels, fish traders and other facilities provided by the BMU. BMUs may also receive donations from the government, private persons and NGOs. The BMU would be expected to meet its own expenses from the funds generated. This includes the expenses incurred in the daily operations and payment of the employees as stated in its by-laws.

This study attempts to review and understand the status of local fisher groups in Diani Chale in relation to group composition, representation and leadership, to assess their capacity and readiness to adopt and undertake functions detailed in the BMU regulations. The study will identify some of the opportunities and constraints that exist concerning the implementation of BMUs and conclude by with suggestions on capacity necessary to meet the responsibility being delegated to the fishers by the government.

METHODS

The study focuses on 6 landing sites of Diani Chale area of Kwale District that stretches from the Mwachema river to Gazi Bay in the south (Alidina 2004): Mkwakwani (Trade winds), Mwaepe, Mvuleni and Mwanyaza in Diani location, and Chale and Gazi in Kinondo location (Fig. 1). A total of 8 fisher organizations were studied (Table 1), 5 from Diani and 3 from Kinondo. Three officials and five group members from each organization were sampled and interviewed separately in order for the respondents to speak with confidence and for the officials not to dominate responding to the questions.

A structured questionnaire was developed and administered to the groups capturing the following key areas:

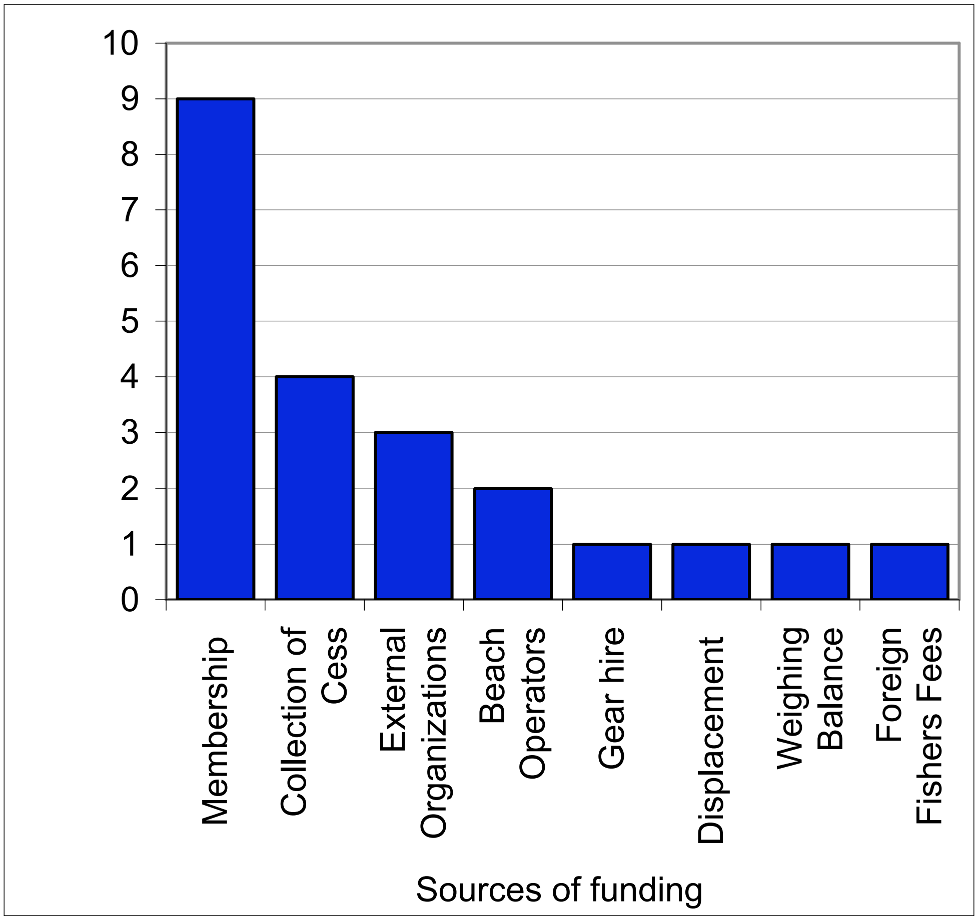

Figure 2. Sources of funding for fisher groups. Notes: Membership - fees/monthly contribution within the group; Displacement – remuneration for moving off previous site; Vessel Hire - paid by researchers and tourists for use of group vessel.

- Objectives for the group formation
- Group administration, election and meeting patterns
- Membership fee structure, Other charges and accountability
- Funding for the fisher groups
- Total annual income
- Expenditures for the fisher groups
- Resource management and Conservation

Secondary data sources largely consisted of literature from CORDIO East Africa (Organizational Capacity Assessment Report for MFSHG and CFSHG), PACT-Kenya (Capacity Building in the Environment Sector) (OCA) and the Fisheries Department, Mombasa (FD). Data was augmented by personal interaction with the groups, observation on resource use practices during field visits and engaging fishers through informal discussions.

RESULTS

The main objective for the formation of fisher groups

Table 3. Group membership fee structure, landing charges and accountability (amounts in Kenya shillings).

Groups	No of members	Membership fees	Monthly subscriptions	Cess (Ksh/kg)	Financial Reporting Officials	Members
GFSHG	60	500	50	2.00	Yes	No
GBMC	9	100	n/a	n/a	Yes	No
CFSHG	60	3000	n/a	5.00	Yes	No
MZFSHG	30	50	50	n/a	Yes	No
MVFSHG	33	200	30	1/3 part	Yes	No
MFSHG	36	100	50	n/a	Yes	No
S/CFSHG	100	200	n/a	n/a	Yes	Yes
MKFSHG	50	n/a	50	n/a	Yes	Yes

in Diani Chale was initiation of development projects to improve their living standard and achieve self-reliance (Table 2). Advocacy for fisher rights, equipment/gear purchase and fishers welfare were mentioned as additional objectives. Revenue collection and conflict resolution were stated as objectives by members, but not by officials. Conversely, conservation/sanitation and marketing of fish was an important objective for group officials but not to the membership.

Fisher groups in Diani Chale had from 9-100 members (Table 1). Elections were only done once when groups were initially formed but not thereafter. Some officials retained leadership for 3-7 years and there was frequently collusion of family members serving as officials. In addition, group by-laws were not followed by the leadership or members.

The main sources of funding among the fisher groups were membership fees (both a joining fee and monthly subscriptions), collection of cess, donations from external organizations, contributions from beach operators, and charges on use of their weighing balance (Fig. 2). Hiring out of fishing vessels, levies from foreign fishers and remuneration for moving off the previous site were among the least mentioned sources of income among the groups.

Membership fees varied (Table 3) with Mwanyaza charging as low as KSh 50/- and Chale as high as KSh 3000/- (i.e. from U$ 0.60 to U$ 40), but average around KSh 400. Chale Fishermens Self-Help group started with a joining fee of KSh 100 but increased this to KSh 3,000. Those groups that charge cess on fish traded, collected from KSh 2 - 5 per kg (e.g. Gazi and Chale, respectively). The group in Mvuleni owns a motorized boat and divides its catch into three parts: one part is split among the fishers, the second is sold and goes towards boat maintenance and the third is deposited in the group's bank account. Overall, internal sources of funding comprised 82 % of all responses (18 out of 22) with external sources comprising 18%.

The total annual income reported by the fisher groups in Diani Chale (Fig. 3) ranged from KShs 10,000-60,000 per year. MVSHG group reported the

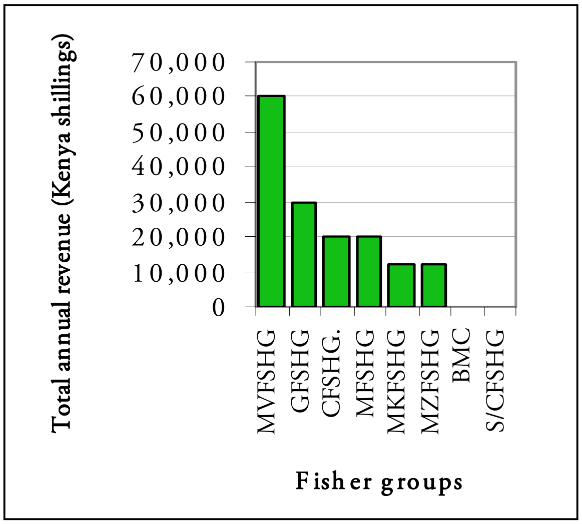

Figure 3 Total annual income for the fisher group in Diani-Chale.

highest level of income followed by GFSHG at KShs 30,000. CFSHG and MFSHG had the same amount of income at Kshs 20,000, while MKSHG (Trade Winds) and MZSHG had slightly above Kshs 10,000 each. GBMC and SCFSHG did not report their earnings.

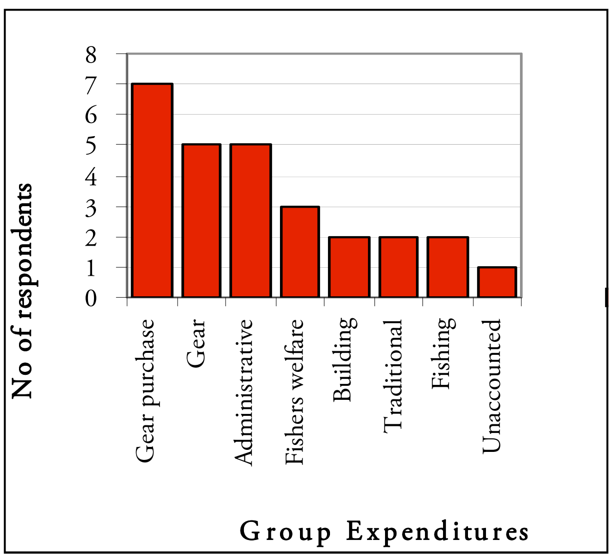

Figure 4. Areas of expenditure among fisher groups.

Fisher groups spent their income primarily on gear purchase and maintenance, administrative functions and fisher's welfare (Fig. 4). Construction and maintenance of buildings at the landing sites, traditional sacrifices and fishing expenses were also mentioned. Some funds were reported by groups members to be spent on 'unexplained circumstances'.

Fisher groups in Diani Chale lacked financial discipline and management. The membership and officials gave conflicting responses about financial reporting. It is only in two groups (SCFSHG and

MFSHG) where both the officials and members agreed that reports were ever tabled. Although the officials from all the groups claimed tabling their financial reports, members from six fisher groups denied ever receiving them. None of the groups have prepared audit reports. The activities of fisher groups were reported very differently from one landing site to another (Fig. 5). General landing site hygiene was mentioned by all groups except Mwaepe, Mwanyaza, and South Coast Fisher Group.

Chale, Mkwakwani, Mvuleni and Mwanyaza are involved in regulating the operations of traders at their landing sites by deciding which traders buy their catch. Fisher groups like Mvuleni, Mwanyaza and GBMC have managed to control the use of illegal fishing gears. Four fisher groups, Mwaepe, Mkwakwani, Mwanyaza and South Coast Fisher Group have not been involved in any role in the management and conservation of resources. Mkwakwani fisher group is the only group in Diani Chale that has managed to control invasion by external fishers using destructive beach seines into their fishing zones.

DISCUSSION AND CONCLUSIONS

In Diani-Chale fishers form groups to improve their standard of living, earnings and fishing capacity. Members focus on revenue collection to support their livelihoods, gear purchase and fishers welfare. However, officials tend to focus on resource

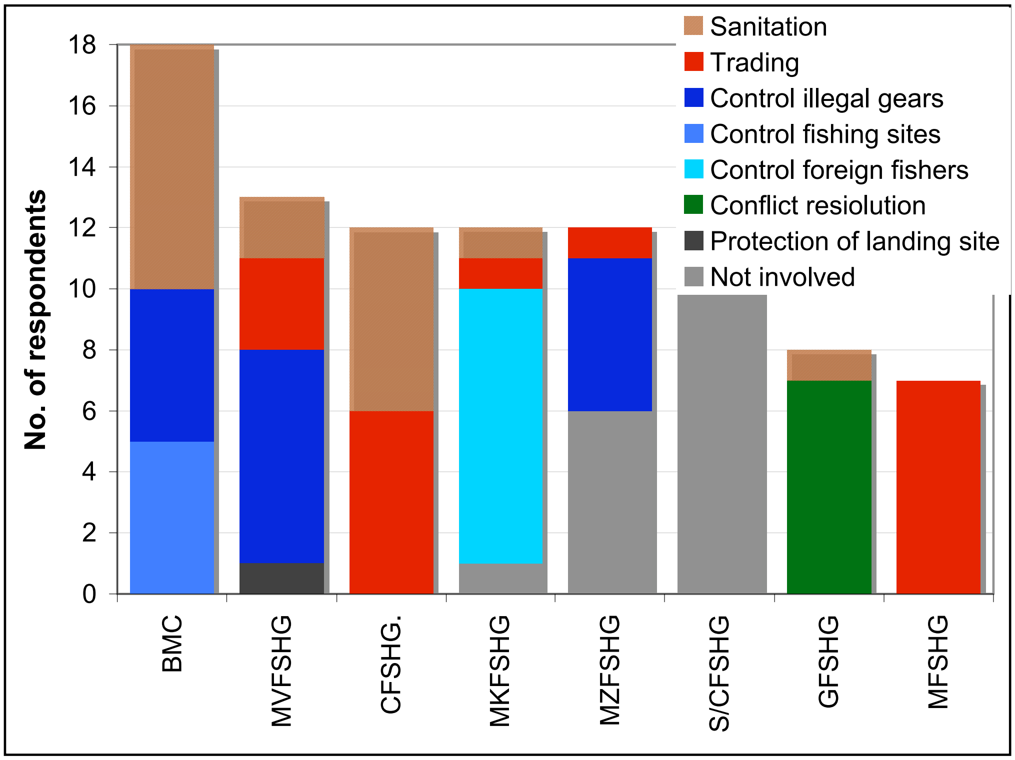

Figure 5 Activities of fisher groups relevant to resource management and conservation.

management, conservation and marketing. However no single group has managed to initiate a development project to raise incomes on its own. Putting development agenda as a priority among some groups could have been influenced by the perception that coming together as a group would attract donor funds; however many such groups disintegrate soon after they realize such funding is not forthcoming (Mulwa 2002) The South Coast Fishermen Self-Help group and Gazi Beach Management Committee existed on paper but during surveys were not found to be functional.

The primary sources of income for the groups are internally generated: membership, cess and other fees accounts for 82% of their income. Thus the fisher groups are primarily self-funded, in contrast to their perceptions that they are not able to undertake any activities unless funded externally. There is high variability in total income reported by the respondents; it is unclear how accurate the amounts reported are since officials from some groups avoided questions related to finances while in others they are likely to have under-reported their earnings fearing loss of support they already enjoy.

The expenditures of the groups primarily related to direct fishing costs that include gear purchase and maintenance, administrative functions, fisher's welfare, building of the bandas and maintenance, traditional sacrifices and other miscellaneous costs. No groups reported any excess funds available for major savings or investment, or that could be used to support broader co-management activities anticipated for BMUs. Further, the groups do not operate revolving fund schemes through which members have the opportunity to save or access loans through the group structure, an activity common to other community-based groups.

Importantly, the groups lacked honesty,

transparency and accountability; few financial reports are tabled to the members, leading to continuous suspicion and conflict. Elections are held irregularly with some groups retaining the same leaders up to 7 years in office. This situation contributes to, or is a product of some infighting and lack of trust among group members. Further, some landing sites have several fisher groups established, some of which are confrontational and in conflict with each other, showing several levels of conflict among fishers at a landing site that obstruct open and accountable action.

The expectations and requirements of setting up and running an operational Beach Management Unit are quite demanding. From our analysis most landing site institutions are nowhere near the required level in terms of their human capacity, skills and experience to undertake tasks such as conflict resolution and management of resources. It is therefore important that during establishment of BMUs the Fisheries Department should ensure there is adequate preparation, capacity building and technical support provided to fishers. Two of the most important areas are:

1. Lack of trust and open-ness within and between groups is a significant barrier to transparent and accountable activities at the group and landing site (BMU) levels. For example, fisher groups do not conduct revolving fund schemes, as the lack of trust within groups undermines each individual's confidence that their savings will be safe and can be used when needed. Training and assistance in democratic and equitable organization of the groups is critically important to future BMU success.

2. Although the groups have shown the ability to generate funds locally, the high dependence on membership fees and other forms of local funding both discourages the involvement of many fishers in the groups and constrains how much the groups can achieve. BMUs will need additional sources of funding to support their new responsibilities, including a regular financial disbursement from the central government in recognition of the responsibilities devolved from government.

Implementation of BMUs should be conducted on a case by case basis and should consider previous interventions at the landing sites and why they may have failed. Some landing sites have several fisher groups established, some of which are confrontational and in conflict with each other. Many such fisher groups have assumed responsibilities of managing landing site activities and have assumed some Beach Management functions. Other local institutions may also be relevant, such as the Diani-Chale Management Trust (DCMT) in the study area, which was established in 2001. With a coastal area management focus, it has been attempting to establish an over-arching fisheries/reef management role for some years, though with limited success. Establishing new BMUs in Diani-Chale must build on these groups and institutions and gain their support rather then isolating them and imposing new structures that may be rejected. Among other problems, these pre-existing groups might compete for revenue with the Beach Management Units. Already in Diani Chale the DCMT considers Beach Management Units in the area as competitors, a conflict that must be resolved to avoid further conflict and competition.

Finally, as with most other issues that relate to fisher landing sites in Kenya, land tenure is a major constraint. The majority of the designated landing sites are on private land, therefore their existence is threatened and future occupancy is not guaranteed. This has been an issue that has preoccupied fisher's minds and has discouraged management or development interventions in Diani-Chale – without security of land tenure no permanent structures can be built at the landing sites.

ACKNOWLEDGEMENTS

We would like to thank the fishers and fisher groups of Diani-Chale for the ten years of work we have conducted with them, and hope this analysis can contribute to improved management of their fisheries. Hussein Alidina played a leading role in setting up this study and discussions over the results.

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Development of a Web-based Geographic Information System as a Decision Tool to Support Fisheries Science and Management: A Case Study of Diani-Chale, Kenya

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ABSTRACT

By treating many spatial components simultaneously GIS technologies provide opportunities to integrate and use large amounts of information in simple visual graphics to assist in managing natural resources. A spatial perspective can be useful in a fisheries context to suggest prospective management measures to resource managers. Here we present artisanal fishery data in a novel GIS-enabled format. Data was collected through a participatory monitoring programme in the Diani-Chale area of southern Kenya from 1997 to 2007. Analyses were conducted to provide spatial and temporal statistics on fishing sites, total catches, catch per unit effort (CPUE), catch composition and benthic attributes. Data was organized in ArcGIS and uploaded using HTML scripting onto a web based Internet Map Service (IMS) platform, ESRI's ArcIMS. This enables a user to view the GIS through a standard internet/web browser or ESRI client application, such as ArcGIS or ArcExplorer/ArcReader. Users are able to query, search, pan, zoom and identify any geospatial data layers for display. With the database installed on a personal computer, users can also add data layers and annotate their version to suit their purposes. The database is provided on an accompanying CD-ROM as well as on an 'esite' on CORDIO's website (www.cordioea.org). The interactive provision of spatial datasets is being done to promote information sharing among marine resource scientists and managers and to test emerging technologies in assisting accurate and informed decision-making.

INTRODUCTION

The Diani-Chale area is located 25 km south of Mombasa in Kwale District, along the southern Kenya coast (Fig. 1, 4031' S and 39050' E), and extends from the Tiwi river in the north to Chale island and Gazi bay in the south (Slim & Gwada, 1993). The area represents one of the most degraded coral reef systems in East Africa (McClanahan & Obura, 1995) and is characterized by high fishing effort, high levels of conflict among fishers and other coastal resource users and relatively poor enforcement (Alidina 2005).

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

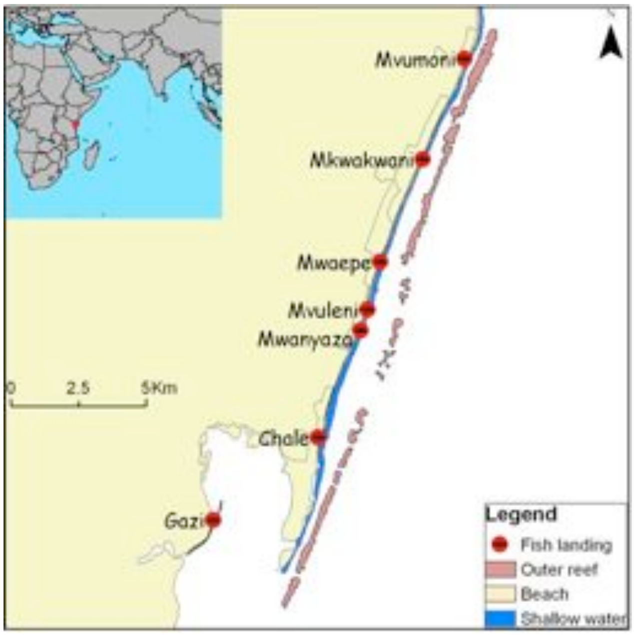

Figure 1. The general location of Diani-Chale area on the South Coast of Kenya and fishing/landing sites.

The development of a local system of resource management in Diani-Chale is an evolving process and is of interest to a number of organizations active in the area.

The Diani-Chale area on the south coast of Kenya has been the focus of much of the participatory monitoring work undertaken by CORDIO East Africa (Obura et al. 2002). The efforts of CORDIO East Africa have focused on the use of participatory monitoring and research approaches as a strategy to create awareness among fishers and engage them to be more involved in resource management (Obura 2001; Obura et al, 2002).

This paper describes a web based geographic information system that can be used as a decision support tool for fisheries analysis and management. The application emphasizes the dynamic presentation of geographic information, which enhances the power of visual data communication, increases user interactivity, and improves the usefulness and value of spatial data.

The Technology

The tremendous growth in Internet use has resulted in an increased demand for the delivery of geographic data, maps, and applications over the Internet. Through ESRI's ArcIMS, organizations can author maps and geo-referenced datasets centrally and publish them to a Web site of their own creation, complete with map navigation and query tools regardless of the scale or complexity of their needs. Web-based GIS puts an "atlas" of information into the hands of the client – quickly, cost-effectively, and in a way that is open for growth and change. Web GIS uses three predefined templates – an HTML viewer and two Java viewers; the HTML viewer offers wide browser support and does not rely on Java applets but can use only a single Image MapService. Java viewers provide enhanced functionality and support feature streaming technology. With a Web GIS, one can:

- Publish and access documents and URLs based on map features.
- Create "views" of all or part of the geographic area of interest and its various features.
- Change the look of and label selected map features to emphasize their display.
- Quickly generate a hard copy map.
- Integrate with PowerPoint for map publishing and presentation.
- Integrate with Excel for sophisticated tabular processing and output.
- Link associated tabular data to a map layer's features without having to know anything about the database, its structure or how to connect to it.

THE DIANI-CHALE SPATIAL DATABASE

To demonstrate the interactive online GIS concept, a web GIS of the Diani-Chale participatory monitoring programme of CORDIO was assembled, to help support fisheries analysis and management.

Data Acquisition

In order to provide a comprehensive Web GIS Database, topographic map layers at a scale of 1:50,000 from the Survey of Kenya were obtained and overlayed with a LandSat7 +ETM image (from 22 January 2000).The LandSat7 image was geometrically corrected to the topographic map of the Kenya coastline. A supervised image classification was done with the application of the nearest neighbour resampling method. Classification of pixels with similar spectral characteristics representing various habitat classes was carried out using the cluster module (Richards, 1993) to produce beach and intertidal layers. Point data of fishing sites in the reef area were collected through participatory mapping and later converted into polygons to approximately represent fishing grounds.

Digital processing for the work was performed using Erdas Imagine 8.6 for image processing and Arc GIS 9.1 for GIS work and display (ESRI 1996) Attribute data for all the map layers was added interactively at the time of initial data capture in the field and tested for attribute code consistency, topology errors and attribute field definition correctness. All map layers were projected to the same co-ordinate system (Transverse Mercator WGS 1984 Zone 37s).

Implementation of Diani-Chale eSite

A number of software packages were customized to implement the eSite. ESRI's Internet Map Server (ArcIMS) package was chosen as it provides a high level of functionality for spatial analyses and creates innovative tools to allow users to import georeferenced data, make spatial selections, perform spatial analyses and output the results for further analysis. ArcIMS is part of ESRI's ArcGIS line of Geographic Information System (GIS) software products and can be installed on a range of different World Wide Web (web) servers. ActiveX Connector was used to develop a custom client application using Visual Basic and Active Server Pages (ASP) scripting language to deliver data and information. ASP, a form of server-side scripting, allows the programmer to use JavaScript or Visual Basic Script (VBScript) to generate custom HyperText Markup Language (HTML or web pages) on-the-fly, and to perform some basic scripting functions such as data checking and database integration and hence build solutions and deploy them to users without requiring the presence of ArcGIS Desktop applications (ArcMap, ArcCatalog, ArcToolbox).

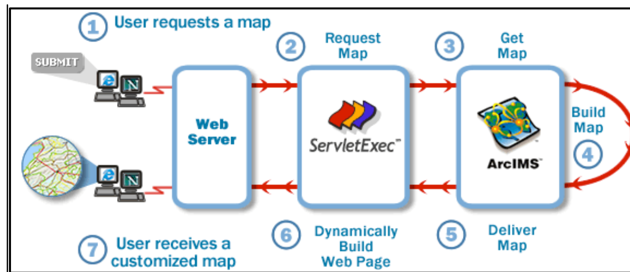

Figure 2. The transaction process of Web GIS. The user sends requests and the web server handles and sends responses.

ArcIMS gives a choice of two different map viewers, the HTML viewer and the Java Viewer. The HTML viewer is simpler and requires a smaller download for the client (User's browser), but it cannot perform some of the advanced functionality available through ArcIMS. The Java Viewer is a highly customizable interface capable of the full functionality of ArcIMS, including feature and metadata services, but requires uploading a larger java applet (program) to the client. For the Diani-Chale esite, the advanced features of the Java Viewer were not needed, and the customization features and wide browser support available in HTML viewer were sufficient.

Web GIS uses hypertext transfer protocol (HTTP), the rules for transferring information over the Web. A web server handles requests from a client using HTTP and uses a servlet engine to send a response. (Fig. 2).

Overview of the Interface

When an atlas is opened its default topic is loaded and the information associated with that topic is displayed in six windows

1. The Map Layers Window lists all the topic's map layers. By turning a map layer on and off, you can see the various relationships and information in the map view. "Possible Active Layers" are green and have an asterisk (*) in front of them. These layers can be made active by clicking on them. When they are active, one can select features, identify features, and find features on that map layer.
2. The Tips Window provides useful tips on using the system.
3. The Topics Views Window lists the atlas' topics along with any views the user creates. These dictate what information in the atlas is available for use. A 'Topic' is a group of map layers, data sets, and documents that are always shown when a user launches Dynamic Maps or logs onto the web site. Topics focus the users' attention on an item or area of interest while providing information that is tailored to meet specific needs.
4. The Related Information Window lists the map layers that have related information, and lists the name of the related information object. Clicking on the object's name will launch the object and will make its associated map layer active.

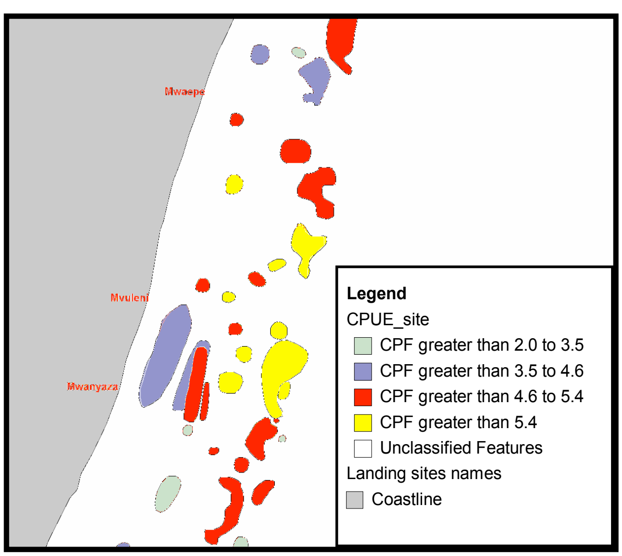

Figure 3. Spatial distribution of CPUE within selected fishing sites.

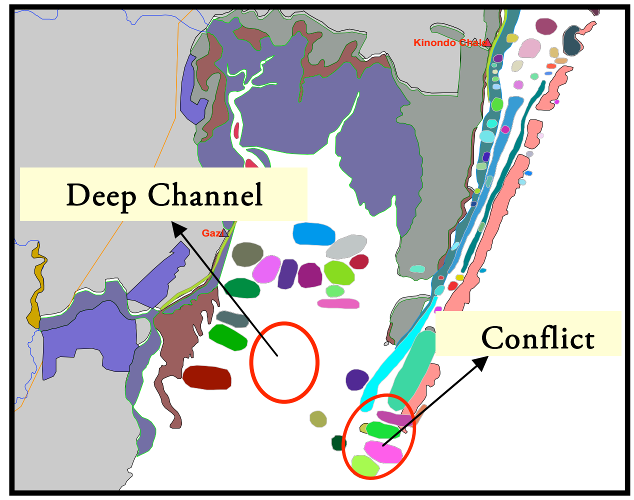

Figure 4. Spatial distribution of fishing sites within Gazi bay and possible conflict with adjacent fish landing sites.

5. The Spreadsheet Window provides the interface between the tabular data and the map layer, and shows the fields and values for the records in a data table or query. The records in the Spreadsheet are linked with their relative map features.
6. Tabular data window: This window lists the tabular datasets and any queries generated . Clicking on a dataset will launch it in the spreadsheet and will make its associated map layer visible.

INITIAL RESULTS

Using the Diani-Chale spatial database, we wanted to view fish catch for different fishing sites. Sites were classified into six classes from the lowest to highest catch per unit effort (CPUE) in kg/trip/fisher (Fig. 3). The resulting map shows that most of the fishing sites have CPUE greater than 4 kg/trip/fisher, and that higher-catch sites are grouped near the outer reef with

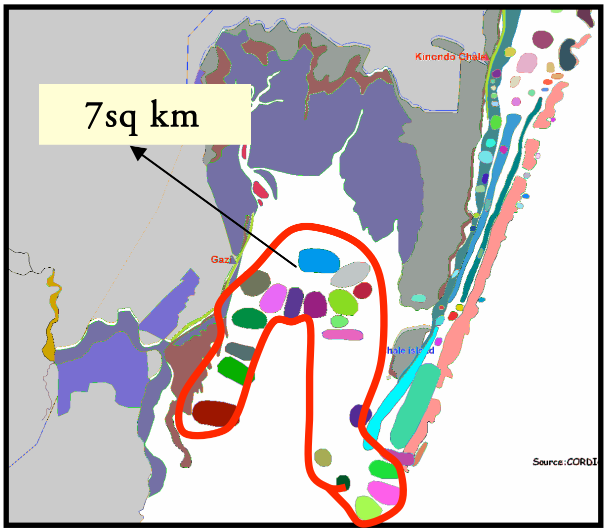

Figure 5: The approximate area of Gazi fishing zone (7 sq km).

lower catches in the central lagoon areas and close to the beach.

Another view was created to show the spatial distribution of fishing sites within Gazi bay (Fig. 4). The fishing sites cluster around the edges of the bay, the fishermen avoiding fishing in the deep center of the bay. It also shows an overlap of fishing zones between Gazi and Chale fishermen, which leads to some conflict between them (Obura et al. 2001).

The spatial analysis functionality of the esite was used to determine approximate area of the Gazi fishing zone (Fig. 5). This was measured using the customised tool for area calculation and produced an approximate area of 7 km^2. It is interesting to note that named fishing sites do not cover 100% of the sea area – large zones between named sites are apparently not used, or at least not specifically named by local fishers.

DISCUSSION

Web GIS can be used as a tool in the policy-making toolbox. A marine resource advisory committee could use a mapping website to share its advice with the public. As an online tool, it can reach a larger group through libraries and other public access areas. Maps and other interactive or multi-media educational materials are easily included in online materials. As a CD-based platform it can also be easily disseminated to locations with poor internet access.

Negotiated rule making is used when stakeholders have strong and opposing opinions. Preparing information on an esite and visualization of diverse values would enhance stakeholder understanding of the issues. A GIS analysis tool could focus disagreements over the consequences of certain positions, by immediately showing the effects of various actions.

Prior to public meetings and hearings, access to online maps would make information available before the event, allowing stakeholders to be better prepared for discussions. The same maps that are shown online could also be shown at the meeting or hearing, where a visual representation of data allows for greater understanding and more effective communication.

On its own, the interactive mapping component offers the most possibilities for augmentation of existing public participation mechanisms. As a tool for data sharing, communication, and education of stakeholders, it could be incorporated into many existing processes.

Limitations

In designing and building the Diani-Chale esite and application, a number of limitations have become apparent:

User interface

Designing a simple, yet powerful user interface for the esite was a challenge. For an official implementation of esite, a skilled web interface designer should be consulted to design the interfaces of the interactive esite. The educational goals of the site will determine the content of the web pages, while the expected audience will determine the design and complexity of the mapping site. Brevity and clarity should be a priority, with simplicity for novices and adequate detail for expert users. The issues addressed should be well explained, along with the mechanisms used in the application.

Cost

The software used for the site includes a number of expensive packages from ESRI. It was possible to do this at CORDIO East Africa because of a grant of a site license, but this would pose a serious problem for an agency with a limited budget.

CONCLUSION

The Diani-Chale esite showed that an online interactive GIS tool can be used as a decision-support tool to support fisheries science and management. Acting as an educational tool, a decision-making tool, or the basis for a new public participation process, this new tool can enhance existing techniques. Through improved inclusion of science and engaging visual display of data and decision criteria, Web GIS can bring decision making processes into the world of the Internet. It has the potential to improve communication with and education of stakeholders, and to build capacity among stakeholders for participation in the decision-making process.

Despite limitations, particularly in data availability, Web GIS can streamline the public participation process for conservation and management of marine resources. It can encourage the development of a dynamic, communitarian process in which all stakeholder values are taken into account, and which enhances the quality and fairness of the decisions produced through public participation.

ACKNOWLEDGEMENTS

Special thanks goes to Hussein Alidina for his professional advice and direction in the project. Thanks are due to fishers who assisted in data collection and CORDIO East Africa staff for their invaluable support. We acknowledge financial assistance from ESRI in the form of a site license for GIS software packages and Sida/SAREC support to CORDIO East Africa in support of research and ICT capacity.

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CORDIO Status Report 2008

Part 7 – Socio-economics and Livelihoods

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

Flip - Flop: Recycling for Social and Environmental Regeneration

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The Flipflop concept started in 1997 on the north coast of Kenya, in the Kiunga Marine National Reserve, in a project of the World Wide Fund for Nature (WWF) and Kenya Wildlife Service working with local communities to secure the future of the area's people, habitats and species by promoting sustainable and responsible interaction with the environment. Here the local women, young men and children started to collect this washed up rubbish from as far a field as Japan, Indonesia, Malaysia and China to make toys, fishing buoys and cushion stuffing.

The story started when a health worker was looking for ways to improve the diet of the local people, but villagers had little money. As she walked the beaches, deserted except for washed up flip-flops, she suddenly saw this free resource for the creative women and youth of the area to earn an income. They began by chopping up the flip-flops to fill cushions, with children playing with the discarded off-cuts, turning them into boats and planes. From this a small toy industry was born that has matured into a cottage industry supplying beautiful and diverse products such as beads, key rings and animal sculptures … and now fashion and household accessories. It is hard to believe that a simple flip-flop can be transformed from environmentally damaging waste into eye-catching glamour using only human creativity.

Learning from successful craft industries in Eastern Africa, UniquEco was born, a 'socially-responsible entrepreneurship' to produce and market products that have a social and ecological mark. UniquEco primarily works with recycled flipflops from the beaches of East Africa, and has expanded to recycle discarded and unwanted plastic bags, inner-tubing, canvas, garden mesh and aluminium, the 'flip-flop equivalents' in Nairobi's busy towns.

In developing this concept, UniquEco has learnt many valuable lessons about sustainable conservation and how to make it work for local people dependent on the environment:

- -people better understand the concept of business than aid as it has a direct cause and effect experience;
- -people's skill base and creativity are broadened and fostered through direct action;
- -training and outside ideas complement local skills in areas such as product perfection, packaging and design;
- -a separate marketing platform is critical to long-term success.

UniquEco now has a central workshop in Nairobi and also works with groups located in informal settlements in crowded city centres such as with special needs children in Nairobi's Kibera.

Families now have money to spend on education, healthcare and house-building, and women are earning an income, helping to redress gender inequalities. We hope that the 'Flipflop' wheel continues to whirl – that of cleaning up the world's litter and providing opportunities to some of the poorest communities and individuals to improve their lives and the environment on which they depend

Photography by Etienne and Lucy Oliff, Wildlife and Educational Documentaries

Additional and Alternative Occupations for the Urak Lawoi Sea Nomads of Phuket, Thailand

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ABSTRACT

There is only very limited knowledge of alternative or supplemental livelihood or income diversification projects implemented in Thailand focusing on marine dependent indigenous communities. This study focuses on extracting lessons learned from past livelihood projects in three Urak Lawoi indigenous communities in Phuket Province, Thailand – Sapam, Laem Tukkae, and Rawai villages. The major occupation of the villagers in the three communities is small-scale fisheries. Although it involves hardship and uncertainty, it is preferred by many, especially men over 30 years of age, as it is self-employed, and yields a considerable sum of money on "lucky" days. However, the main challenge for the Urak Lawoi nowadays is that fishing is increasingly limited due to increasing fishing restrictions (protected areas, species and equipment restrictions, etc.), rising cost of equipment and diesel oil, and degrading marine resources, and there are occupational hazards. Further, fishers' income fluctuates, and there is a risk of getting trapped in a debt cycle.

Numerous projects focusing on providing alternative or supplemental livelihood opportunities and training for the Urak Lawoi have been carried out over the years. However, most of these projects and activities have been fruitless because many were short-term activities; the trainings were done with little market support; those who worked with the communities did not know the strengths and weaknesses or limitations of the villagers; and there exists a deeply-root bias against the Urak Lawoi. There has also been a lack of coordination and collaboration among different agencies and organizations working with the Urak Lawoi. Priority interventions for community development and livelihoods improvement should include increasing effort in understanding and appreciating special characteristics of the Urak Lawoi communities, coordinating and integrating work among different agencies and organizations, providing small-scale long-term alternative occupational activities while promoting markets for Urak Lawoi food and crafts, and creating innovative methods in working with the communities.

INTRODUCTION

The Urak Lawoi or the former sea nomads of the Andaman Sea have lived by and from the sea for a long time and are particularly dependent on coastal and coral reef resources. Traditionally they collected sea produce, including different species of shellfish, sea cucumbers, lobsters, etc. However, they have

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gradually transformed from marine hunter-gatherers to artisan fishermen and have adopted more sophisticated gears like boat engines, large fish traps, fishnets, and diving with air supply from compressors or hookah. This requires more investment, which has led to indebtedness to middlemen or entrepreneurs. It also puts them into a stronger competition with local Thai fishers. The two differences between Urak Lawoi fishers and local Thai fishers are that the former are more engaged in hunting and gathering (shooting fish and collecting shellfish and other sea animals) and they are the only group in Thailand who use hookah for professional deep-water fisheries.

Ensuring sustainable socio-economic wellbeing while protecting the culture of the Urak Lawoi communities is very important, and there have been attempts, both by the state and private agencies, to provide different forms of support for supplemental or alternative livelihoods. Unfortunately these experiences were rarely documented or published, let alone evaluated. This survey was conducted to review alternative livelihood activities or projects conducted by individuals, the private sector, government and non-government agencies, to assess success or failure of such activities and compile these as guidelines to aid and support further livelihoods initiatives.

The Urak Lawoi

Coastal areas and islands in the Andaman Sea have been the home to "sea gypsies" or "sea people" (Chao Lay in Thai language) for many centuries. In Thailand, there are 3 ethnic groups of sea people – the Moken (population about 800), the Moklen (population about 3,500), and the Urak Lawoi (population about 5,500). The three groups are Austronesian language speakers, but their culture and traditions vary in detail. The Moken live on islands in Ranong and Phang-nga Provinces and although they have became more settled within the past 10 years, traditional hunting-gathering activities and major rituals are kept relatively intact. The Moklen have long settled along the coastal areas in Phang-nga and Phuket Provinces, they have adopted Thai language and culture and their occupations are diverse, ranging from mangrove foragers and strand collectors to wage workers and pararubber plantation owners. The Urak Lawoi are the most populous group of sea people, they have settled in large communities on islands and coastal areas in Phuket, Krabi, and Satun Provinces.

The Urak Lawoi are an ethnic group who have their own unique language and culture. The Urak Lawoi are skillful swimmers, divers, navigators, and gatherers. The name which they call themselves also reflects the identity and ties with the sea and marine resources ("Urak" means people and "Lawoi" means sea). In the old days, they traveled and moved frequently especially when there was an epidemic or many deaths in the community. Nowadays the Urak Lawoi have adopted a sedentary life.

Although the Urak Lawoi are old-time residents along the Andaman Sea shore, they were not accepted or welcome by the local people. In the past the term "Chao Lay" was used as a derogatory term in several parts of southwestern Thailand especially Phuket. "Chao Lay" connotes negative characteristics like dirtiness, uneducated, wasteful spending, etc and stems from a lack of understanding of their traditional culture and lifestyle. This is derived from deeply rooted ethnocentric attitudes, which are constructed out of stereotyping and creating "other-ness". The Urak Lawoi have admirable characteristics like modesty, honesty, and willingness to do laborious work, but these are rarely acknowledged by the larger society. The Urak Lawoi's physical appearance and preference is singled out and looked down upon without considering the whole cultural and environmental context (Narumon 2003).

Most of the Urak Lawoi are embarrassed by this "negative label" of "Chao Lay", and they often feel inferior to the local people. As a consequence, they have been exploited by many, especially entrepreneurs. Phuket tourism promotion and development has resulted in the expansion of businesses and industry, such as real estate and land development, and beachside land has gained a dramatically higher value and become a desirable "property". The Urak Lawoi have found that the land on which their forefathers subsisted and made a settlement has been claimed, and they have been deprived of land rights and entitlement.

Traditionally, the Urak Lawoi were marine hunter-gatherers. They dived for sea cucumber, shellfishes and other sea animals to consume and to trade. Traditional extraction of marine resources requires the use of indigenous knowledge from navigation and tool making to identifying habitats and characteristics of each animal. Raw materials for building the boat and house, for tools, medicine, and firewood are found in the coastal forest. So the Urak Lawoi were knowledgeable about the forest as much as the sea.

Boats are very important for the Urak Lawoi because it is both a vehicle and tool for fisheries. Traditional boats called "prahu" were used to travel to different islands by oar or sail. More recently, they have adopted "hua thong" or local-style fishing boat with outboard motor or long-tailed engine. However, the detailed features of traditional boats are still vivid in the mind of elderly men and several of them make traditional boats in miniature form.

In the past, during the dry season, the Urak Lawoi traveled to different islands by boat. This traveling or "bagad" might last from 1-3 days to several months depending on island distance, weather, and the yield of their catch. During the bagad, the Urak Lawoi built small huts or lean-tos on the beach as their temporary home. Generally, the entire family traveled together to bagad sites which provided natural protection against winds and waves, and with fresh water source (Wongbusarakum 2002). During the rainy season, the Urak Lawoi lived in a larger settlement. They foraged in the forest frequently and some groups even grew wild rice, such as on Lanta Island. They used human labor instead of draft animals.

The Urak Lawoi semi-nomadic lifestyle was an immediate return system, meaning that they consumed whatever they caught or gathered almost right away. There was no need to preserve or stockpile the food since they could depend on this day-to-day subsistence. While Urak Lawoi men went out to sea for their daily or weekly round, the women helped with near shore fishing and collecting shellfish, including cooking and processing food (Wongbusarakum 2002). This division of labor became even stronger after the Urak Lawoi became more sedentary. Now only men go out to sea while women wait at home, doing their house chores and taking care of the younger family members.

At present, the Urak Lawoi no longer organize a bagad. Those who go out to sea are adult men and the fishing round is for commercial sale as well as for household consumption. Instead of using their bare hands, harpoon, hook and line, the Urak Lawoi now use larger motorized boats with diverse and sophisticated equipment. One of the important equipment is hookah - a compressor with a long air hose connected to a diving mask. This enables them to dive deeper and longer. Nevertheless, it poses a great risk for divers and several men suffer from the bends, or decompression sickness.

The Urak Lawoi also increasingly depend on entrepreneurs or middlemen for their fishing occupation. In the past, these middlemen were the Chinese or Chinese-Thai who lived in or nearby the Urak Lawoi communities. Later, a few Urak Lawoi have saved up enough to become the middlemen themselves. However, the majority do not earn enough capital to buy their own boat, motor, and fishing equipment all at once. They need to borrow the money or get the equipment in advance, then pay back in installments or deduct from their fisheries earning. Furthermore, many Urak Lawoi need to borrow for their daily household expenditure. Several middlemen who supply gear as well as market the fish caught by the Urak Lawoi also open grocery shops so that money paid to the Urak Lawoi for marine catch comes back to them through the sale of daily necessities.

Some Urak Lawoi in a few communities have enough land to cultivate vegetables, coconuts, cashew nuts, and fruit trees. However, most communities have limited land, and are often squeezed or encroached by private ownership. The three Urak

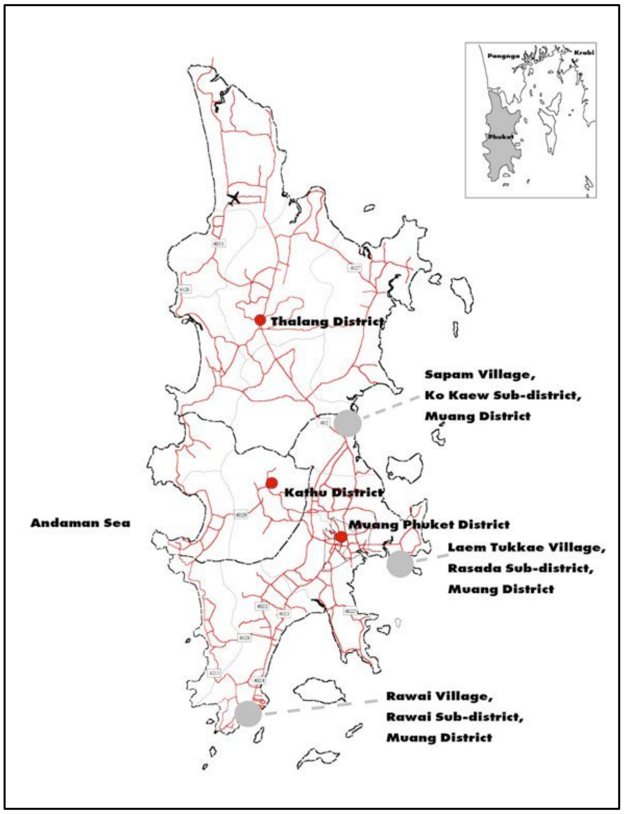

Figure 1. Map showing the island of Phuket and the three Urak Lawoi communities included in this project.

Lawoi communities in Phuket do not have enough land to do any small-scale cultivation. In addition, the communities become more crowded and dense because of population growth. In addition to fisheries and cultivation in certain cases, some Urak Lawoi also go out to find wage labor work like clearing land, harvesting coconut, construction work, etc. In the communities which are located in tourism areas, the Urak Lawoi have more chance to work in hotels or resorts – women work as maids, kitchen helpers, and dish washers, and men work as security guards or engaged in marine tourism businesses like working on boats. These jobs bring steadier income (if they are salary-based) and pose lesser health risk compare to fisheries work. Nevertheless, many Urak Lawoi still prefer fisheries because they have the knowledge and skills and are self-employed.

STUDY AREA AND METHODS

This survey focused on the three Urak Lawoi communities in Phuket Province (Fig. 1):

Sapam Village, Ko Kaew Sub-district, Muang District. Sapam Village consists of 226 Urak Lawoi living in 48 households (Data from Asian Resource Foundation 2006). The village is located on a mud flat with stilted houses connected by concrete walkways. There is a small canal by the village where boats are moored. This village used to be more open and spacious, but now the surrounding land falls under private ownership and the area is more populated. The Urak Lawoi in Sapam earn their livelihood through fisheries. The mud flat has abundant shellfish, so the main occupation is collecting and selling cockles and other shellfish. Nowadays, several sections of the mud flat are enclosed for raising cockles, so the open area where the Urak Lawoi can forage is even more limited. Besides, the area where the village sacred shrine is situated is encroached by a concrete structure, leaving only a small space for the shrine.

Laem Tukkae Village, on Sireh island, Rasada Sub-district, Muang District. There are 1,316 Urak Lawoi in 190 households in Laem Tukkae Village, with 666 males and 650 females (data from the District Office, 2005). Over 100 years ago, there was no community on Sireh Island other than the Urak Lawoi community. In 1983 private ownership of Laem Tukkae land was claimed. Some Urak Lawoi informants stated that they were asked to give their signature or fingerprint to "accept electricity", but were not aware of the details of the agreement. Later on, they were asked to pay rent for their occupancy. The Urak Lawoi filed a complaint to the Provincial Office, but the issue has not been resolved. The Phuket Provincial Office attempted to identify a new plot of land for Urak Lawoi settlement, but it was located in the inner part of Sireh Island, so the villagers refused to move. The Urak Lawoi in Laem Tukkae usually earn their livelihood through fisheries, mainly by fish trapping and collecting/extracting rock oysters.

Rawai Village, Rawai Sub-district, Muang District. The Urak Lawoi have made their residence here over 100 years, but the lands are under private ownership of local Thai persons. As a result, the Urak Lawoi residents are deprived of decent facilities, they cannot refurbish or extend their houses. Of all the Urak Lawoi communities in Thailand, this village is the most densely populated. There are also shrimp farms, a small fish-packing factory, and shell-processing factory (washing, polishing, and supplying seashells for local shops and export) in the village. On the western side, there is a Moken community. There are 1,200 people in the village in 201 households, 595 males and 605 females (surveyed by Aporn Ukrit in 2003). The Urak Lawoi and the Moken in Rawai engage in fisheries, fish sale, working on speedboats, working for tour companies, hotels and resorts, and wage other labor. The fact that the village is located right on the main road to several tourist attractions makes it an "open" community. Tourists and local people often come the village to buy fresh seafood and ornamental shells at the stalls in front of the village.

Reports, theses, and papers, as well as web-based information about alternative occupation development for the Urak Lawoi communities in Phuket undertaken by individuals, organizations or state agencies were reviewed. Most of the information on such activities appeared only after the tsunami in 2004.

Field surveys were also conducted. These consisted of interviewing representatives of over 10 state and local administrative offices or agencies, as well as Urak Lawoi from the target communities. Over 90 Urak Lawoi males and females from 3 villages were interviewed on occupation, experiences of additional or alternative occupation training, attitudes towards fisheries and the change of occupation, and aspiration for the younger generations. 30 Urak Lawoi were requested to give an in-depth interview on their past experiences in earning a livelihood, occupational training received, attitudes towards fisheries and changing occupations, and aspirations for their family and younger generations. Ten of these were with Urak Lawoi who are or have been engaged in non-fisheries occupations.

A community meeting was also held to discuss preliminary findings and receive comments and generate recommendations from Urak Lawoi representatives, individuals and agencies who engaged in developing livelihood options for the Urak Lawoi.

RESULTS AND DISCUSSION

Advantages of Fishing

Urak Lawoi hunting-gathering and fisheries are quite distinctive in that they are diverse in terms of methods, fishing and foraging grounds, labor, length, and market. The research team found that most Urak Lawoi villagers especially males over 30 years of age have preference for fishing because it is the only livelihood they have a distinctive advantage in being good at. They felt that they did not have any qualification or useful skills to compete in the job market. The strengths or advantages stated for fishing are:

- Self-employment: Fishing hours depend on the tides, the weather, and the Urak Lawoi themselves. Fishers do not have a boss or supervisor, so work depends on one's own free will. In addition, the co-workers are those whom one already knows very well - family members, kin, friends - so there is rarely competition or conflict at work.
- Good income: Fishers can earn a good income. A lucky day may yield 1,000 baht (approx. U$ 50) or more. Many Urak Lawoi men said they tried wage labor and salary work, but the money earned is not enough, as jobs are primarily menial tasks. For them, although the income from fisheries is irregular, it is generally better than other occupations.
- Already have the skills: Fisheries is the occupation handed down for generations. The Urak Lawoi have all the skills needed for fisheries, passed down from parents to children, so the Urak Lawoi learn to become expert divers and fishers.
- No need for job applications: Most Urak Lawoi feel that they get limited educational attainment so they

do not have qualifications to apply for jobs other than manual labor. They do not need to apply and compete to fish.

- Fishing can be done all year round and is subsistence in nature: Although fisheries are quite seasonal, most Urak Lawoi stated that it can be carried out all year round, with some shift in areas and methods, for example, shrimp netting can be done during the rainy season and silver sillago netting ("sand fish", literal translation from Thai) can be done during the dry season. Furthermore, fisheries is a fall-back occupation, e.g. after the tsunami when other jobs declined, several Urak Lawoi came back to fisheries to earn their livelihood, especially when supported by aid and development organizations and foundations with boats, engines and fishing equipment. Last but not least, fishing is also a subsistence activity, meaning that the Urak Lawoi can keep some of the catch (usually with the lowest market value) for their household consumption. This allows some money to be saved as they do not have to buy fresh food in the market.

Disadvantages of Fishing

There are also disadvantages to fishing. At present, fishers face more and more limitations, and fisheries rules and regulations seem to pose the greatest threat for the Urak Lawoi, followed by the rise in the cost of fishing, the degradation of marine resources, middlemen and the risk of being trapped in a debt cycle, uncertainty in catch and income, and health risks/occupational hazards.

Sanctuaries or Protected Areas

These have been designated and expanded. The Urak Lawoi often said that in the old days they could make an easy living from the sea and could travel and anchor anywhere they liked. Nowadays their foraging grounds are very limited because many areas have become marine sanctuaries or protected areas, and as such tourist havens that do not allow fishing. These areas are likely to be further expanded in the future. Apart from state designated areas and tourist areas, some local communities have started to declare their own protected areas as well, like Yao Island where local villagers prevent the Urak Lawoi from collecting oysters and threaten that if the Urak Lawoi continue to collect there, they will call the Sub-district Administrative Organization staff to arrest them. As the Urak Lawoi know little about laws, when they are threatened with jail they give up claiming their rights (Lertchai 2003). Many resorts drive the Urak Lawoi away from waters around them even though the waters are not formally protected (Sirirat 2006). With all these factors, they can no longer access many areas where their forefather roamed freely

The Urak Lawoi have increasingly been restrained and deterred by these and other rules and regulations, and increased enforcement by the government through patrols. Arrests have become more frequent, often including confiscation of the boat, motor, air compressor (for hookah), and other property. Additionally, they may also be forced to pay a penalty fee or fine, and other expenses.

The Urak Lawoi also face occasional tampering with their fish traps in ordinary fishing grounds like Kiew Island, Dok Mai Island, and Kai Island, e.g. by misinformed or ignorant recreational divers trying to strengthen conservation. In some cases the Urak Lawoi have been unable to stop such damage as their boats are slower, and because they are peaceful people they tend to avoid confrontation. The Urak Lawoi have also been accused of using dynamite and cyanide fishing so are seen in a very negative light by tourists and divers. When giant clams were stolen from protected area, the Urak Lawoi became an immediate scapegoat even though the real theft might have been from some other community.

Rising Cost of Fishing

The cost of fishing boats, engines, fishing equipment, and diesel oil has been on the rise. Currently, a long-tail boat with engine, second hand and in good condition, is around 70,000 baht (approx. U$ 1,800), 26 rolls of shrimp nets and 23 rolls of fishnets cost 30,000 baht (approx. U$ 750). The cost of a fish trap

Photo captions: a) Collecting polychaetes for fish bait, Sireh village (© Tamelander); b) Making fish trap, Rawai village. Traps made are getting larger and larger (© Tamelander); c) Sorting fish catch, Rawai village (© Tamelander); d) Seafood vendor, Rawai village (© Narumon); e) Extracting rock oyster meat, Sireh village (© Narumon); f) Extended family having a meal, Rawai village. Home-cooked food made from local marine catch and vegetables grown is household garden patches is important for the Urak Lawoi (© Tamelander); g) Traditional singing and dancing troupe from Sireh (© Narumon); h) Selling seashells, Rawai Beach (© Narumon).

is around 5,000 baht (U$ 125), or 2,000 baht (U$ 50) for a smaller one, and each trap lasts an average of 3-4 months. Nowadays the Urak Lawoi have to build a larger number of larger sized fish traps in order to obtain the same amount of fish. Further, while traditionally using simple tools and equipment made by themselves, the Urak Lawoi nowadays have to buy material, including building materials, as there is no open forest for them to cut wood and bamboo to make their fish traps.

Degradation of Marine Resources

Most of the Urak Lawoi agree that marine resources are declining. In earlier days they could catch more fish in less time, and within a short distance from their village. Nowadays they have to go further, but the catch is less. Even rock oysters become smaller in size and are more difficult to find compare to ten years ago. The advantage is that nowadays seafood is much more expensive than in the past, and many Urak Lawoi prefer present days when seafood fetch higher price though fishers are facing more hardship. The Urak Lawoi think that resource degradation is caused by large commercial trawlers, such as double trawlers, which catch both large and small marine animals. In addition, the coastal environment is increasingly polluted due to discharge from the shore, from shrimp farms, and oil spills. After the tsunami, the number of fishing boats has also increased so the Urak Lawoi need to fish at a greater distance from the shore, and much more money has to be spent on diesel oil.

The Entrepreneurial System and Debt Cycle

In the past, the Urak Lawoi usually worked with middlemen or entrepreneurs, because these were the mediators between the community and the outside world. This remains the case today, but increasingly the Urak Lawoi depend on the middlemen in times of need, particularly when money is needed e.g. to purchase equipment, when they get arrested or have to pay a fine, and when they are sick. The money advanced is paid back, with interest, out of the earnings from fishing. This situation is similar to other fishing communities, but the Urak Lawoi are in many ways more disadvantaged and thus more exploited. Therefore, although fishing can earn a relatively high income, the threat of a debt cycle is strong.

Uncertainty and Irregular Income

Catch varies with weather, season, and other factors, and the rainy season poses a problem for fisheries. This results in irregular income. For many Urak Lawoi, however, this irregularity and uncertainty is not the major problem. They can always work on shore, mending fishnets, building fish traps, and collecting shellfish at low tide. In other words, they can spend their time with the maintenance of their equipment and they can depend on fall-back resources (shellfish and other sea animals) from strand areas. Some Urak Lawoi assert that the yield during rainy season is actually better than in the dry season.

Occupational Hazards

Fisheries has its own occupational risk due to the weather and sea conditions. For the Urak Lawoi, there is an additional risk from diving due to the use of hookah. In the three communities, there are Urak Lawoi men who suffer from the bends - some are paralyzed, or have lost their agility and strength, and some have died.

Due to the above-mentioned limitations and disadvantages of fishing, some Urak Lawoi find it necessary to have additional or alternative occupation, and some see the value in supporting their children's education to earn enough qualification for other work. For many Urak Lawoi, however, the advantages of fisheries outweigh the limitations.

Past Support to the Urak Lawoi

Several agencies and organizations have extended livelihood support to Urak Lawoi communities, but data on these efforts were very difficult to find. At the government office levels, it is not a tradition to keep written or documentary records on activities done at the village level. Furthermore, the rotation and shifting of office staff and officers made it even more difficult to trace those activities. At the community level, some Urak Lawoi villagers could remember the activities but they rarely remembered the names of government offices, private agencies, or non-governmental organizations, except those with long-term staff. Most of the information about livelihood support available is from after the tsunami in 2004. Livelihood support for Urak Lawoi men has included boat motor repair, and making miniature boats as souvenirs for tourists, and for women making batiks, handicrafts from local materials, embroidering, sewing, cooking and baking.

Support to fisheries livelihoods has focused on sustainable fisheries like adjusting or shifting fishing equipment and mariculture support. Mariculture is quite suitable for the Urak Lawoi due to their existing maritime skill. Nevertheless, it has some requirements and limitations - It offers a delayed return compare to fishing occupation; Capital investment is required for cages, larvae or seeds, feed, etc.; Official permission is needed for certain cage culture or farm enclosure; and regular attention is needed against disease, theft, etc. In the past, the Urak Lawoi were not interested in mariculture because fishing and collecting activities yielded satisfactory catch, and brought immediate return, compared to the difficulties and delayed returns of mariculture. However, after mariculture has become a success elsewhere and fisheries become more difficult, some Urak Lawoi turn their interest to mariculture and some even invest their own money in small mariculture activities.

Several Urak Lawoi men suggested that artificial reefs should be developed increasingly to provide more fishing sites and to enable the villagers to deploy their fish nets and fish traps without having to encroach on protected areas. In addition, such artificial reefs can deter push-net boats and large trawlers from near-shore fishing. Governmental organizations like the Department of Marine and Coastal Resources and Department of Fisheries, provincial offices, and even local communities have already participated in creating artificial reefs in several parts of the Andaman Sea and the Gulf of Thailand.

The main obstacles in working with the Urak Lawoi communities 10-20 years ago were language and cultural differences, extreme conservative attitudes, and limitations of formal education. More recently, between two and ten years ago, the main obstacle was that livelihood development did not quite fulfill the villagers' needs and expectations. Most recently, during the past 2 years, the main obstacle has been that many organizations come in to work with the communities during post-tsunami period, but with various conditions and demands and with little coordination. Many villagers have taken this opportunity to become passive recipients of help, which makes the community development work even more difficult.

Overall, occupational support for the Urak Lawoi extended by various agencies and organizations has largely not yielded satisfactory results – the villagers did not cooperate well, their interest was short-lived, the knowledge and skills were not practical or not applied and materialized into sustainable occupation, the villagers did not have capital nor necessary tools, and there were problems with demand for products or market access. In spite of some effort, the Urak Lawoi remain dependent on marine resources. In analyzing lessons learned from the past occupational support projects, several external and internal factors were identified that impede project success (Table 1). Due to lack of systematic documentation, inefficient assessment and evaluation, limited lessons learnt analysis and sharing, and the fact that interventions were primarily short-term, most past activities have fallen short of villagers' expectation as they could not become a real "alternative" for the Urak Lawoi.

RECOMMENDATIONS

In reviewing the history of support to the Urak Lawoi, we identified two sets of recommendations to guide future interventions. The first set of recommendations addresses the approach and type of assistance, the second identifies livelihood opportunities with greater likelihood of success.

Table 1. Factors obstructing the success of occupational support project.

Factor	Issue	Detail of issue
External factors— agencies and organizations providing support	Activity –Time	Activity or project is too short
	Activity –Type	Activity does not respond to the real need for or marketability of the product or service
	Staff	Staff have little experience with working with such a special community, they do not understand villagers, culture and needs sufficiently. One is not able to adapt or find innovative way to work with the communit
	Work and indicators	Work and indicators are rigid in nature. y
	Target group	There is no specification of target group
	Coordination	Too many agencies or organizations, some with different conditions, too little coordination
	Attitude	Ethnocentrism is deeply rooted and reflected in peoples attitudes and behavior
Internal factors – Urak Lawoi and their community	Lack of interest in supplementary occupation	Attitude and system of thinking about fisheries
		Villagers need immediate or short-term return
	Planning for the future	Lack of planning or vision of the future, traditionally a 'day-to-day' economy
	Group-oriented and self-organization	Lack of self-organization
		Lack of trust and confidence

Approach and Type of Assistance

- Serious attempts must be made to understand and appreciate special characteristics of Urak Lawoi communities, and getting rid of ethnocentric bias and stereotyped images. Community workers need to understand the community through insiders' views, which have been shaped by being treated as inferior and exploited by many. Positive attitudes towards the community need to be built and affirmed. It should be recognized that not all the individuals in the community are the same and not all of them are "anti-development". Government offices also need to overcome the social and ethnic bias, and should act as a role model for the local people. For example, if there is a strong bias against food made by the Urak Lawoi, then government offices could overthrow the bias by ordering the food for meetings or banquets. They should also disseminate more accurate information about the Urak Lawoi and create a more balanced image of the communities.
- Coordination among agencies/organizations and integration of work is necessary. The need for coordination has been raised repeatedly, but it is hardly accomplished because coordination and information exchange requires more time and effort than ordinary "reactive" work. Furthermore, it depends on the support of policy -level officials staff and up to the attitude and personality of the staff as well.
- There is a need for better dialogue and communication. Misunderstanding and bias between the Urak Lawoi and divers or diving companies can be transformed into opportunities for the Urak Lawoi with better communication and effective coordination. The Urak Lawoi are knowledgeable and skillful sea people, but they

lack self-confidence and tourism related skills. With the right approach the people who occasionally have been labeled as marine resource destroyers will turn into partner in conservation and promote the sustainable use of resources.

- Long-term and full-cycle projects are needed that respond to the needs of the community, make use of know-how, materials and equipment, and ensure market access. Occupational support should be carried out by staff well acquainted with Urak Lawoi communities, their strengths and limitations, and should give consideration to "income" and "market" possibility. Occasional and piecemeal support in various forms should be dissuaded. Agencies/organizations providing short and fruitless occasional training courses have generally lost their credibility in the eyes of the villagers.
- Innovation and flexibility in livelihood development work is needed, including regular evaluations and assessments and analyzing lessons learned. Projects with rigid work plans and inflexible budgets are neither realistic nor suitable for working with Urak Lawoi communities. Non-governmental organizations have many times been more successful in working with Urak Lawoi communities than government offices, because while the government offices have to work with many communities, non-government organizations can focus their work on specific communities and even tailor their work to suit each community. In addition, government offices have to follow bureaucratic procedures, so they cannot be flexible or innovative in their work style. Some projects or activities are determined from the top down, and sometimes this has made it difficult for operational level officers, who are not required, requested or allowed to think and work in a reformative or revolutionary way. This leads to a lack of innovation and prevents adaptive approaches.

Alternative Occupations

From the survey on occupational support for the Urak Lawoi, the research team found that possible additional and alternative occupation support could focus on handicrafts, tourism-related work, and mariculture. While these are activities that have been attempted before, they should be approached with the above recommendations in mind to avoid limitations and past mistakes. Particular attention should be made to innovation and flexibility (avoiding rigid work plans and budgets, and allowing for adjustment and readjustment), continued commitment (long-term support to the point of success), and dialogue (horizontal communication, sharing experiences and lessons learned).

Handicrafts

This is self-employed and suitable for work at home, so for women, this work will not interrupt house chores or taking care of children. Making miniature prahu is a success story in terms of skill and product output, and it is a suitable occupation for elderly men and men with disabilities, but it is problematic in terms of marketability. It is unfortunate that at a world-renown tourist destination such as Phuket, locally-made indigenous handicrafts do not have access to the large and hugely profitable souvenir market.

The problem of marketing can be alleviated if there is a strong coordination between communities, government offices, and business organizations. There should also be a small outlet at the communities. In November, 2006, empty stalls in front of Laem Tukkae were renovated and opened to sell souvenirs made of shells. This will help with product marketability, but it will require good public relations and skill development support in order to sustain the handicraft occupation. Specific recommendations include:

- identifying and assuring more market channels, identifying enabling measures for more access into the Phuket souvenir market;
- developing more attractive product designs and more product diversification, and skill improvement

training and workshops for small groups;

- developing attractive package designs for value adding purposes, like paper boxes for existing crafts, e.g., miniature boats;
- providing a revolving fund for production by individuals or small groups.

Tourism-related Work

For the Urak Lawoi communities, there are two ways of promoting livelihood development in tourism-related work: training and facilitating employment in the tourism sector; and promoting tourism in and around Urak Lawoi communities.

Training and Employment Opportunities, Sea Tourism

Some Urak Lawoi are already engaged in tourism occupations. Moreover, tourist places are expanding nearby the villages, including a spa resort near the Rawai community and a hotel resort near the Laem Tukkae community. This can be an opportunity for the Urak Lawoi if there is adequate preparation and proper management. The Urak Lawoi are familiar with the marine environment, and this is advantageous for marine tourism work. Recommendations for occupational support are as follows:

- providing knowledge or skill training such as communication skills, foreign language skills, and water safety;
- supporting applications for certificates or licenses for career advancement;
- preparing a list of Urak Lawoi who have passed a training courses and show serious attention toward an apprenticeship opportunity;
- providing an opportunity for apprenticeship or "learning by doing" under supervision. This requires cooperation with and support from tourist businesses. Work output should be evaluated regularly and additional support (advice, training, etc.) given when needed.

Promoting Tourism in and Around the Communities

The "sea gypsy villages" of Rawai and Laem Tukkae are already on several tourist maps distributed in Phuket, and the name "sea gypsy" is an attraction in itself. Several agencies/organizations have already suggested tourism promotion in and around the communities, and some even have plans for such support. Sea-based tourism, handicrafts and cultural tours are possibilities for income earning from tourism. Promoting villagers' participation in tourism work opens up an opportunity for additional and alternative occupations. Tourists will have a chance to learn and understand more about the Urak Lawoi's way of life and their hardship. Tourists can have an adventure with the Urak Lawoi: fishing, collecting polychaetes, cracking oyster shells, etc. Income can also be obtained from other products such as seashell accessories and pandanus crafts, and services such as tour guides, shuttle and charter boats, etc. With proper management, tourism can benefit the Urak Lawoi and make them proud of their language, culture, and identity as sea people. The recommendations for promoting tourism in and around the communities are as follows:

- setting up a community tourism plan with community participation, designated tourist areas, attractive sites in and around the communities, developing community-based tourism activities such as organizing a nature-culture or ethnobotany trail;
- collecting information about their way of life to set up a culture and nature interpretive program, including printing media such as pamphlet, booklet, poster, map, culture-nature interpretive guides, etc.;
- training local guides and developing tourist service skills, and developing guidelines or codes of conduct for tourists so that they show respect and courtesy towards local beliefs and customs;
- preparing systematic management of tourist services in the community such as setting up a tour boat cooperative group, setting up a boat

queue, setting up water safety rules such as providing life jackets, planning for tourist income distribution and sharing within the communities;

- promoting community-based tourism, following up on output, analyzing lessons learned to improve tourism activities in the future. Identifying measures to prevent cultural commoditization and negative impacts on the communities.

Mariculture

As indicated before, there are both pros and cons with mariculture, one major challenge being the delayed return on investment. However, some Urak Lawoi have changed their attitudes towards fishing and have even tried their hand on lobster keeping/raising. Therefore, mariculture can be introduced by starting with those who have some experience or have shown interest in such an activity. Training and apprenticeship in some mariculture farms is recommended as the Urak Lawoi trainees can be exposed to samples of best practices in mariculture activities. During the first phase, other supplementary occupation should be provided so that mariculture keepers can earn some income while waiting for a return from mariculture.

Apart from additional and alternative occupational support, it is necessary to focus on peoples' quality of life. Recommendations for community development related to livelihood support are to encourage savings and future planning, to build awareness and participation in natural conservation, to promote educational development, and to enhance community rights. In Urak Lawoi communities there are disadvantaged individuals and families who need extra help to enable them to be independent. This group includes people with disabilities, widows and widowers, elder people, orphans, etc.

It should be emphasized, however, that support for additional and alternative occupations does not aim to divert the Urak Lawoi entirely away from fishing occupations, but rather to build their capabilities and to enhance their opportunities for alternative occupations.

As mentioned earlier, the Urak Lawoi have been transformed from hunter-gatherers to traditional and modern fishermen within the last 30-40 years. Now they are dependent on boat motors and modern fishing equipment. As a result, more investment is needed and many Urak Lawoi are indebted to entrepreneurs. Their traditional lifestyle is gradually fading. Yet there are still a few Urak Lawoi who remain hunter-gatherers and use traditional methods of fishing. Like the Moken, the adept sea nomads, these Urak Lawoi are sea people who know how to make and use simple equipment and methods. The simpler the method is, the more skill and knowledge hunters and gatherers must have. If we talk about cultural rights, then this way of life as hunter-gatherers should be appreciated, respected, protected, and promoted. That means sustainable hunting and gathering should be accepted and possible allowed to some extent even in designated protected areas. Therefore, it is proposed that in addition to promoting additional and alternative occupation, the protection and promotion of the traditional hunting-gathering livelihood should also be carried out . Not only would that be beneficial to the natural resources and environment, but it will also encourage the cultural pride and identity of indigenous people like the Urak Lawoi.

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The Coral Reefs and Livelihoods Initiative (CORALI) - Building an Improved Approach to Livelihood Enhancement and Diversification with Coral Reef Users in South Asia and the Andaman Sea

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INTRODUCTION

Diversification of economic activities, at the household and community levels, away from a high dependence on the exploitation of natural resources, is gradually being recognised by many governments and development specialists as a path leading to greater economic growth, as well as an indicator of it. In terms of poverty reduction, diversification is seen both as a coping strategy of the poor to deal with increasing uncertainty in rural areas as a result of natural resource degradation, increasing competition and the encroachment of global influences; and as a development strategy for enabling the poor to graduate out of poverty (IMM *et al.* 2005).

In addition, government agencies and NGOs concerned with the conservation of natural resources are beginning to recognise the potential of livelihood diversification as a mechanism to encourage people to move away from the harmful exploitation and degradation of those resources. Indeed, ensuring adequate and effective support to livelihoods development remains one of the main challenges to coral reef conservation. The process of generating viable and sustainable livelihood strategies – for whatever reason - is not straightforward for the people whose livelihoods may need to change, nor for agencies that try to assist them. It is a challenge that requires both an understanding of the complexity of livelihood change and also an approach that can address this complexity in a systematic way.

This paper provides a brief overview of the Coral Reef and Livelihoods Initiative (CORALI) and then describes the evolution of knowledge about the complexity of livelihood change that has underpinned the development of an approach to supporting Sustainable Livelihood Enhancement and Diversification (SLED). The paper then describes the research process that has been designed to further develop a SLED approach and presents some of 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

Box 1: Principles for Identifying Opportunities for Sustainable Livelihood Enhancement and Diversification (SLED)	
Opportunities for Sustainable Livelihood Enhancement and Diversification should: -Relate to the needs and aspirations of the poor; -Build on strengths; -Be viable (from economic, institutional and cultural perspective); -Be appropriate for the number of people concerned; -Have acceptable (to the poor) levels of risk; -Not increase vulnerability;	-Be in harmony with existing household livelihood strategies; -Be complementary to the strategies of other people in the community; -Conform with national policies and legislation; -Enhance the independence of the poor; -Ensure the rights of the poor; -Ideally enhance the innovative capacity, vision and adaptability of the poor.

early findings from this process. Finally, a working draft of the SLED approach is illustrated and described.

Coral Reefs and Livelihoods Initiative (CORALI)

CORALI[1] has been designed to address the challenge of "*how to better support livelihood development as a key part of a more holistic approach to coral reef conservation*". CORALI is funded to operate between 2006 and 2007. It incorporates three elements: a) the development of a regional skills and knowledge network; b) the development of an improved approach to socio-economic monitoring; and c) the further development of a participatory approach to SLED in coral reef dependent communities.

Understanding Livelihoods and Livelihood Change

Over the past two decades a significant body of research knowledge relating to poverty and people's livelihoods has been produced. The research leading to this knowledge has important implications for the challenge of supporting livelihood change in coral reef dependent communities. Four key areas of research are outlined below:

1. Understanding the relationships between coastal policies and poor people's livelihoods:

Research in coastal communities of India, Sri Lanka and Bangladesh[2] analysed changes in the livelihoods of the poor and how the poor and development agencies have responded to those changes (IMM 2003a). This research in particular emphasised how the ability of poor people to respond to change was restricted, because:

- Poor people often do not have a *voice* in policy and management decision-making processes, they are therefore not able to shape the "enabling" environment to support their own needs. Development agencies often find it difficult, time consuming and expensive to talk with poor people and in many cases the poor people themselves lack the confidence, ability or opportunities to participate in detailed planning processes.
- Poor people are often restricted in the options that they have for changing their livelihoods. This lack of *choice* can be a result of: the lack of livelihood assets at their disposal; weak or limited service provision from governments, civil society or the

[1]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.

[2]The Sustainable Coastal Livelihoods (SCL) research project was implemented by IMM Ltd. between 2000 and 2003 and was funded by the Department for International Development (DFID).

private sector; the social trends and influences that affect the environment in which they live and work; and their vulnerability to new changes. As a result the livelihood strategies that poor people adopt will often be largely pre-determined by their circumstances.

- The impacts on poverty of service delivery initiatives is highly dependent on the *capacity* of different groups of people to take up those services. Those able to access new services, or take advantage of the changing circumstances they create, can benefit from them; but those who, for whatever reason, lack the capacity to adapt often either miss out on potential benefits or, in some cases, actually become worse off.

An important output of this research was the development of an initial framework for supporting Sustainable Livelihood Enhancement and Diversification (SLED) that started to systematically address the complexity of livelihood change. A key part of this framework was a series of principles for identifying opportunities for helping poor people to enhance or diversify their livelihoods (shown in Box 1).

2 Learning about the impacts of change in the post-harvest fisheries sector on poor people.

Research into changes affecting poor people in the post-harvest fisheries sector in India[3] documented the consequences that the changes had for different stakeholder groups (IMM 2003b). The research found that:

- The changes in the sector (fish supply, distribution of fish, processing, marketing and consumption), while driven by similar forces across the country, affected different groups of people in different ways. Understanding how different groups are able to cope with change is a key part in helping them to deal with change positively.

3 Understanding the complex relationships between people and reefs:

Research designed to assess the wider value of coral reefs to vulnerable coastal communities in South Asia and East Africa[4] - using a livelihoods approach - generated important insights into the complexity of the relationships between poor people and reefs (see Whittingham *et al.* 2003), these included:

- The ecosystem services provided by coral reefs are diverse and include: supporting services to wider ecosystems (e.g. fish breeding grounds); provisioning services (e.g. nutrition and building materials); regulating services (e.g. coastal protection); and cultural services (e.g. recreation, spiritual and education).
- The stakeholders who affect and benefit from the ecosystem services from coral reefs are diverse. They include both groups who have a direct relationship with coral reefs (such as reef fishers, fish processors, reef managers, fish consumers, hoteliers, international tourists, and people living in coastal communities who receive shoreline protection) and those who indirectly affect the reef (such as coastal industries, farmers, foresters). Together with the sheer diversity of stakeholder groups the heterogeneity that exists within each sub-group of stakeholders (e.g. income status, race, gender, education, access to information, culture and beliefs) adds to the complexity of any coral reef management challenge.
- Coral reef ecosystems can be a keystone resource that is available at times when land-based opportunities are few (e.g. in the agricultural low season). When calculated in financial terms this benefit may not amount to much, however at a local-level, reefs may be of vital importance in terms of local livelihood strategies, reducing vulnerability to change and enhancing food security.
- Well-meaning policies and management strategies aimed at conserving threatened reefs and halting

[3] The research project "Changing Fish Utilisation and its Impact on Poverty in India" was implemented by IMM Ltd. between 2000 and 2002 and was funded by DFID.
[4] The Reef Livelihoods Assessment (RLA) project was implemented by IMM Ltd between 2001 and 2002 and was funded by DFID.

Box 2: Characteristics of a SLED approach	
-Needs a systematic approach that recognises and responds to complexity of people's lives rather than using predetermined strategies. -Should help people to consider livelihood enhancement, diversification and alternatives. -Needs to be addressed at macro, micro and meso-levels simultaneously – linking into wider development efforts. -Requires a multi-disciplinary approach.	-Should build on the strengths of the poor. -Needs to address the different factors that affect the ability of people to take up livelihood change. -Needs to be mainstreamed and appropriate institutions need to be built and supported over a long period of time. -Needs to be done in a participatory way if the needs of all different stakeholders are to be catered for.

reef degradation are often having an adverse impact on poor people, particularly where the poor have been excluded from decision-making processes.

4. Understanding the factors that help or inhibit livelihood change:

In research which studied livelihood diversification in coastal communities in Cambodia (IMM *et al.* 2005) the Sustainable Livelihoods Framework was used to categorise and describe the factors which support or inhibit livelihood change[5]. These included:

- Factors relating to income diversification, for example: access to credit, improving market linkages, vocational skills, and identifying new income generating opportunities.
- Factors relating to wider livelihood strategies, for example; access to health care, informal networks, confidence, social and cultural norms, and property rights.

Livelihood research in general, has confirmed the need to "incorporate all the different factors which affect the ability of people to identify, take up and sustain livelihood changes. These factors need to be understood and responded to systematically in ways that recognise and respond to the complexities of poor people's lives rather than using predetermined strategies" (Campbell *et al.* 2006). An approach is required that can provide both people and service providers with the opportunities to develop their capacity, build confidence and ultimately to forge better relationships that will facilitate sustainable livelihoods for the people. Some of the key characteristics of such an approach are described in Box 2.

Constructing a Basic Approach for Supporting Sustainable Livelihood Enhancement and Diversification

In bringing the lessons of past livelihoods research projects together a basic approach was built to provide guidance for development practitioners whose task it is to assist people to enhance and diversify their livelihoods. The approach is designed to identify the key elements of best practice that should be addressed in the process of assisting livelihood change and includes three broad sets of activities:

1. *Discovery* – Learning with reef-dependent people and service providers about where they are now and how they got there. Understanding the changing relationships that people have with natural resources. Helping people to appreciate their strengths and potential for development.
2. *Direction* – Helping reef-dependent people and service providers to analyse themselves and the opportunities in the world around them, in order to make informed choices about the desirability, feasibility and profitability of livelihood change. Working with people to build visions for livelihood change and developing strategies with people to achieve those visions.

[5]The research aimed at "Understanding the Factors that Support or Inhibit Livelihood Diversification in Coastal Cambodia" was implemented by IMM Ltd in 2005 and funded by DFID.

3. *Doing* – Working with reef-dependent people to develop their capacity to change and to develop the relationships, provide the information and support to help them make that change.

While this basic approach for SLED has a firm footing in research and global experience, in order to develop it into an accepted approach for facilitating livelihood change, it needs to be fully tested at a local level, to: a) provide more detailed field-level processes and tools; b) generate evidence to confirm the validity and generalizability of the approach; and c) provide evidence to inform and influence managers and policy makers concerning its effectiveness as a management approach.

METHODS

CORALI has adopted a people-centred and poverty-focused approach to working with people who depend on coral reef resources for a key part of their livelihoods. An objective of CORALI is to provide the evidence and tools that can take the SLED approach from its research base into an effective and accepted field-level approach. To do this an action research[6] process has been designed to take lessons from past experiences (global and regional) and use the local knowledge and field-experiences of partners in the region to further develop and field-test the SLED approach. The two central components of the research process are outlined below:

1. Reviews of Experiences with Livelihood Diversification:

A wealth of experience with livelihood development initiatives exists globally and within South Asia. In many cases that experience lies in a multitude of initiatives across many sectors. The reviews focused on the lessons learnt from those initiatives that were united by their challenge to answer the basic question of *"how to understand and respond successfully to the need for livelihood change"*. Understanding the factors that have contributed to the success or failure of these initiatives is a key part of the SLED development process. This activity consisted of two complementary parts:

a. *A Review of Global Experiences with Livelihood Diversification* (Campbell in press). The review of global experiences with livelihood diversification considered the challenge from four perspectives: rural community development; livelihood change as a tool to address conflicts between livelihoods and aquatic resource sustainability; promoting entrepreneurship and success in enterprise formation; and corporate enterprise staff development and growth. Drawing from these experiences the review, distilled the key lessons for the process of supporting livelihood change, described a number of key stages for a SLED approach and developed a series of principles for SLED.

b. *South Asia Regional Overview of Experiences with Livelihood Diversification* (Sriskanthan in press). The review of livelihood enhancement and diversification interventions in coastal communities in South Asia (with supplementary examples from South East Asia) examined the successes and failures experienced by these initiatives. The review used analytical methods based on the Sustainable Livelihoods Framework, focusing on common themes, problems and lessons learned, and provided a discussion of their implications for livelihood enhancement and diversification in reef dependent communities in South Asia.

The findings from the reviews were fed into the process of further developing the SLED approach at the SLED development workshops (see below).

2. Pilot Testing the SLED Approach in the Field:

The process of pilot-testing the SLED approach is

[6] *Action research has been defined as activities or interventions intended to achieve tangible development goals while at the same time increasing our understanding of how those goals can be achieved (Moris and Copestake 1993).*

Table 1. SLED development - Field-sites and Research Partners.

Country	Pilot Site	Research Partner	Pilot Site Communities
India	Andaman Islands	The Andaman and Nicobar Environmental Team (ANET)	Karen tribal communities in eight villages.
		Karen Youth Association	
	Gulf of Mannar	Suganthi Devadason Marine Research Institute (SDMRI)	Five villages in the Gulf of Mannar area.
		People's Action for Development (PAD)	
	Lakshadweep Islands	Centre for Action Research on Environment, Science and Society (CARESS)	Integrating the activity into livelihoods work being carried out with communities in Minicoy and reef related socioeconomic monitoring work being carried out in Agatti.
Sri Lanka	Bar Reef	Coastal Resource Management Project (CRMP), Ministry of Fisheries and Aquatic Resources	Two communities that have direct links to the reef ecosystems of Bar Reef Marine Sanctuary.
Maldives	Baa Atoll	Atoll Ecosystem-Based Conservation of Globally Significant Biological Diversity In the Maldives' Baa Atoll Project (AEC Project) / Ministry Of Environment, Energy And Water, Maldives	Community in Eydhafushi, who are the major resource users of Dhigaliha MPA.
		Foundation of Eydhafushi Youth Linkage (FEYLI)	
Indonesia	Weh Island, Aceh	Wildlife Conservation Society - Indonesia	Communities around the no-take MPA Taman Wisata Pulau Weh Sabang.
		Yayasan PUGAR (Centre for People's Movement and Advocacy)	

being undertaken at six sites across South Asia and the Andaman Sea (table 1 gives a list of sites and project partners).

Over the course of ten months the field-teams will meet for a series of three SLED development workshops during which the teams reflect on past experiences and then define their activities for the pilot fieldwork. This process is summarised as follows:

Completed Research Elements (January 2007 – July 2007)

- SLED Development Workshop 1 – Introducing the SLED approach and building the framework and activity plan for site level implementation.
- Fieldwork Phase 1 – Raising awareness about the SLED approach; understanding the distribution of ecosystem services; building relationships with the community; gaining an understanding of livelihoods and livelihood diversity; and identifying community representative groups and service providers in communities.
- SLED Development Workshop 2 – Reviewing the fieldwork process and outputs; considering the

findings of the global overview of experiences; and developing the activity plan for the second phase of field testing.

Ongoing and Future Research Elements (August 2007 – January 2008)

- Fieldwork Phase 2 – The field-teams will implement the second phase of the SLED Approach which will include: scoping opportunities; building visions with groups and communities; community mobilisation; identifying opportunities for supporting sustainable livelihood improvement activities; and building linkages.
- SLED Development Workshop 3 – The final of the SLED development workshops will allow the field-teams to reflect on the overall SLED approach; develop training and guidance materials for the first two phases and plan micro projects aimed at facilitating livelihood change in the communities.
- Implement SLED Initiatives – Pilot teams will be funded to: implement micro-projects that will support livelihood change in the communities where they are working; and link into broader development processes that can provide continued support.

To support the development and implementation of the SLED approach, CORALI is building a regional network of development practitioners who are working with people in coastal communities to enable them to adopt more sustainable and beneficial livelihood strategies. The exchange of information, experiences, and best practice between organisations is facilitated by project staff and supported by a web site (www.coraliweb.org). As the SLED approach further develops, evidence to inform and influence policy and facilitate the linkages between the development practitioners and the environmental managers and policy makers will be produced.

RESULTS

This section synthesizes some of the lessons learnt from the two key research components of the SLED development process: the literature reviews of practical experiences with facilitating livelihood change, and the first phase of pilot fieldwork. A working draft of the SLED approach is also presented to illustrate how these experiences and lessons are being forged into a field-level approach.

Approaches to Livelihood Diversification: A Review of Global Experiences

A desk review of global experiences with implementing livelihood diversification processes (Campbell *in press*) demonstrated that in many communities livelihood diversification is a common strategy (Gordon, 1999 and IMM *et al.,* 2005) and some might even say it is the norm (Barrett and Reardon, 2000). However, there are many situations in society where people's livelihoods need to change and there have been many different initiatives designed to facilitate this. Whilst different approaches have been developed under different circumstances, most of them are fundamentally trying to achieve the same thing. They are helping to understand livelihood change needs, defining potential change options and facilitating the change process. Some of the key elements of best-practice, for the process of supporting livelihood change, include:

Understanding how people's livelihoods have evolved:

People and their livelihoods are not a static situation that has come from nowhere, they and their livelihoods have evolved over time and those life experiences can be strong predictors of their vocational preference (Smart 1989). For example, many young people follow their parents or their communities traditional values systems and strategies for living. It is therefore important to understand why people have developed to where they are if we are to understand where they are likely to end up and how we can facilitate change.

Box 3: Key Stages in Supporting Livelihood Enhancement and Diversification

1. Understanding the stakeholder groups and individuals.
2. Understanding peoples livelihoods and how they connect with wider society and the reef system.
3. Understanding which facets of these livelihoods mean the most to different people.
4. Developing a shared understanding of external change and its likely effect on livelihoods.
5. Understanding peoples aspirations and visions.
6. Understanding the opportunities for change.
7. Understanding the viability of potential options especially the market demand for the goods and services from opportunities.
8. Defining the obstacles to achieving visions.
9. Defining the principles and process of livelihood change.
10. Planning the livelihood change process.
11. Fostering a sense of community leadership, ownership and partnership for change.
12. Facilitating an enabling environment for livelihood change.
13. Facilitating the livelihood change.
14. Continuing livelihood development.
15. Monitoring and consolidating the livelihood change process.

Understanding what helps people to decide to change:

The motivation to decide to change a livelihood strategy, for example away from one which is damaging the reef to one which is more sustainable, is a complex process. Some people see an opportunity to change their livelihoods and are drawn by it, others are pushed by circumstances. In the case of the *Jambi Kiwa*[7] initiative in Ecuador, it was a combination of the push of marginalisation and the pull of market opportunity that drove the women to establish a cooperative for medicinal and aromatic plants.

Building a consensus for change:

Whilst managers of MPAs or other coastal management areas may have identified the need to reduce pressure on the resources the aim to conserve may not be recognised by the resource users. For example, intensive and unsustainable aquatic resource use in the short-term to fund children's education may be seen, by fishermen, as a perfectly rational long-term livelihood strategy. Therefore, a key part of any change process must be to have identified a shared understanding of the need for change.

Sharing a vision of the future:

As important as recognising the need for change is the need to define where the change process will be heading. Corporate change processes are very much concerned with defining clear change goals. In an Asia Development Bank (ADB) livelihoods development project on the Tonle Sap, Cambodia, designed to reduce fishing and other environmental pressures on the lake, Appreciative Inquiry was used as a tool to develop visions, based on strengths and past success, of where livelihood change might lead. Developing and sharing a vision of where a community wants to evolve to helps provide community cohesion in the change process.

Understanding the options for change:

Often people do not change because they see no prospects for change. Even when their livelihoods are criminalised they may find it difficult to find

[7]For more information on the Jamba Kiwa initiative see: www.jambikiwa.org

alternatives. Part of the motivation for using "menu approaches" is to provide lists of options for people and this can be useful as one part of a more systematic approach. Good examples of tools which help people to vision ideas beyond their normal scope of operations include the book "Save Na Mekim" (The Melanesian Council of Churches, 1982) which illustrated different rural livelihood activities, gave instructions on how to take them up, illustrated key stages or outputs, and discussed the benefits.

Building innovative capacity and continuing livelihood development:

Research into coastal livelihoods in Cambodia (IMM 2005) demonstrated that providing people with a new livelihood opportunity overcomes an existing problem but does not necessarily give them the capacity to innovate to face future challenges. Building skills to help individuals and communities to innovate in the face of future changes in their environment is key to long-term survival and growth.

Raising awareness in government and NGOs and facilitating support:

Livelihood change requires both short-term support for the change process but also long-term support for continuing livelihood development. Civil society organisations often play a key role in this process but they cannot work alone. Haggblade *et al.* (2002) recognised both the importance of the role of government and NGOs in supporting livelihood diversification and the weaknesses in the support. In many cases support for enterprise development falls between ministries and departments and gets missed out of programmes. Specialist agencies, such as those dealing with the coast or with reefs, rarely have the skills to address livelihood issues. Raising awareness amongst government and NGO workers about the needs for livelihood change and the roles that they can play is an important facet of success.

Building a stronger enabling environment:

In the absence of a supportive institutional environment emerging livelihood strategies will find it difficult to survive and thrive. The Arab Regional Centre for Entrepreneurship and Investment Training (ARCEIT)[8] project recognised the complexity of factors which support or inhibit livelihood change which affect different stakeholder groups in different ways. ARCEIT has taken a multi-pronged approach: supporting schools, providing counselling, conducting research, running technical training, providing credit and promoting the debate about entrepreneurship. Helping to build this enabling environment is essential to both the early survival of new enterprises and livelihood change, and to their long-term growth and profitability.

While none of the individual experiences analysed by the review demonstrated a clear way forward, collectively they began to provide a roadmap which may be adapted for the purpose of facilitating livelihood change in reef dependent communities. In summary form, Box 3 sets out a series of key stages for supporting livelihood enhancement and diversification.

South Asia Regional Overview of Experiences with Livelihood Diversification

Rural development responses to issues of coastal livelihood security in South Asia have typically focused on income generation and livelihood diversification initiatives targeted at poor, resource dependent communities. The challenge for development practitioners is to develop an understanding of the underlying factors at the local level that contribute to the success and failure of these initiatives, and how these lessons can be incorporated into future project design and process management.

The South Asia review (Sriskanthan in press) analysed a range of livelihood enhancement and diversification project reports and reviews from across the region in order to pinpoint the factors that

[8] *For further information on ARCEIT see http://www.arceit.org*

contributed to their successes and failures. It was found that these could be expressed under three broad categories: (1) Project feasibility, design and process; (2) Necessary livelihood assets; and (3) Influencing factors. The key findings from the review are discussed in more detail below.

1. Project feasibility, design and process

This refers to the basic principles and thinking underpinning the design and implementation of livelihood enhancement and diversification interventions. This stage of project development contains some crucial steps that can be separated into three thematic areas:

(i) Project feasibility – Ensuring the basic economic, cultural and social feasibility of an activity through market analysis and community consultation is a basic necessity for any proposed project. Many projects still fail to invest in this, opting to take the "menu of options" approach to selecting livelihoods activities, which often leads to inappropriate or untenable activities being promoted.

(ii) Project design – The recurring themes related to project design included ensuring full community participation in the design process to foster ownership, as well as to fully understand and reflect community priorities; the development of strong monitoring systems to track and understand progress; and the need to build in project features that support the future sustainability of actions beyond limited project-budget lifetimes. Projects that embraced these principles of project design were more successful in the long run and experienced sustained results.

(iii) Project process – Some of the main tenets of a good process were found to be ensuring a participatory approach and emphasising community mobilisation. Many projects expressed the need to link into broader development and government processes, which feeds into the concern of improving future sustainability. Managing community expectations in order to maintain interest and motivation was also seen as important.

2. Necessary livelihood assets

The success of an activity is related to how well the intervention recognises and incorporates the development of important livelihood assets. This includes investing in human and social assets such as building relevant skills, as well as recognising existing assets (such as current education and experience) in order to introduce activities that are appropriate to these. The development of social networks was seen to be crucial and the role of community groups, such as self-help groups and CBOs, was highlighted as one of the key factors that fostered success. The need to provide adequate and accessible credit facilities was expressed by many of the projects reviewed. Sometimes, even if a project provides credit facilities these may not be appropriate for the needs of poorer stakeholders. For example, an ADB micro-credit project targeting fishing communities in the south and west of Sri Lanka opted to use existing credit institutes to disburse larger-scale loans which many of the project participants had insufficient collateral to qualify for. The project would have been more successful if it had invested in supporting smaller-scale, grassroots credit facilities that would have been more accessible to poorer members of the community (Perera, 2004). In addition to this, supporting the development of or access to more general physical assets, such as schools and health clinics, appeared to be very influential in a number of cases.

3. Influencing factors

There are a wide range of external influencing factors that have a significant effect on the livelihoods of coastal communities. Numerous examples from the literature surveyed cited the strong impact of social, cultural and political factors, and projects have to incorporate these realities into their approach. In many of the prevailing cultures across South Asia, social divisions are strictly observed and this has huge ramifications in terms of livelihood options. One

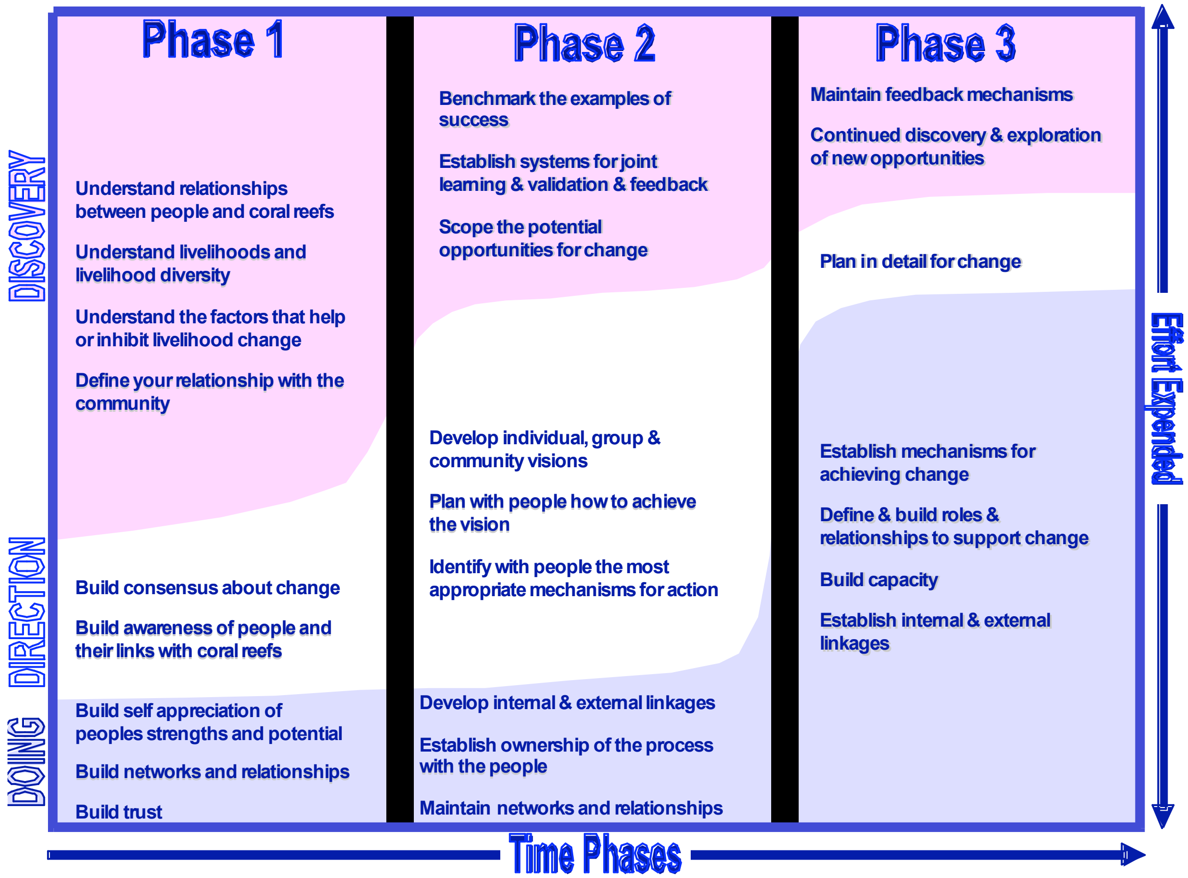

Figure 1. A working draft of the SLED approach.

study of livelihood diversification in Andhra Pradesh found that caste and political patronage were the two most influential factors that determined an individual's opportunities for diversification and improved material well-being (Farrington *et al.* 2002). Cases surveyed under this review reflected elements of this. For example, the perception that certain livelihood activities are appropriate only to individuals of a low social status was seen to hinder the uptake of supported activities in a coir rope making project in Sri Lanka (Perera, 2004). Cultural barriers to assuming non-traditional livelihood activities were also evident, and there is a need to recognise the links between livelihoods and identity. Political interference was found to be responsible for inappropriate participant selection in a number of the cases studied under this review, supporting the notion that patronage from influential groups can have a huge bearing on people's options. Positive influences included the involvement of the private sector, the presence of strong, well functioning NGOs and CBOs, strong government support, and access to markets. Inadequate or poorly enforced legislation and policies that fail to create disincentives to abandon destructive or unsustainable activities can undermine efforts to encourage alternatives. Other issues to consider are natural, political or economic shocks that can have a far reaching impact on social and economic systems.

Box 4: Understanding factors that help or inhibit livelihood change – the stigma of communicable disease

Minicoy island has a history of segregating people with incurable illnesses. In the past people who had small pox were housed in Viringlii island (also known as small pox island on old maps), while people with leprosy were made to live on the northern end of the island which is even today known as Kodi – leper. Discussions with self-help group members on Minicoy revealed that communicable illness still is a common cause for dismissing a member from a group. Today HIV/AIDS affected people in Minicoy feel restricted because no one wants them on their team or to use their services.

An interview with an HIV positive man revealed that he faces discrimination. He is well educated and wants to pursue a career, but no one will employ him. He still hasn't lost heart and is seeking help from the island administration to support him and others like him with some livelihood options. He is currently planning to set up an internet café – a venture that he can pursue alone. In his case, while the illness inhibits him from working for other people, his family connections and social status ensure that he can get the best help available, both in terms of ongoing health treatment and support to establish a business alone.
(CARESS 2007)

SLED Fieldwork Experiences

Findings from the first phase of fieldwork were presented at the second SLED workshop in June 2007. During this phase the field-teams undertook the activities for the first phase of the SLED process (Fig. 1), which included using a range of qualitative investigative methods to build up their understanding of people's livelihoods and the diversity of livelihoods in the pilot communities. Once such method, involved the collection of stories from members of the community as a way of exploring the evolution of people's livelihoods and the factors that had helped or inhibited them in the process of change. An example of a story is given in Box 4, and a series of pictures from the fieldwork are shown in plates 1-4. (Full fieldwork reports are available on www.coraliweb.org). Some of the broad conclusions and lessons learned from the fieldwork are outlined below:

- The common point of reference for communities when they are providing information on the nature of their livelihoods to development agencies has traditionally been to emphasise what they don't have, what they don't do and what they need. The field-teams noted that the approach of focusing on people's strengths and potential – as advocated in SLED – is a far more proactive and inspiring starting point for initiating livelihood change;
- Working with and communicating with the very poor poses difficult challenges and the field teams emphasised the need to invest time in engaging with very poor groups. The field-teams recognised the need to use innovative facilitation methods and show patience and understanding if they are to support very poor people to appreciate their strengths and potential and build their confidence to engage in the SLED process;
- Income should not be the sole consideration when identifying opportunities for income generation. Although it is a useful indicator that can assist the field teams to understand people's economic incentives for change on a limited level, it can also detract from the fact that people's decision making and livelihood strategies are based on far broader considerations;
- Individuals who have the potential to lead the SLED process in the community may not be those who hold the formal positions of authority or power. Development initiatives have traditionally focused on strengthening the

Plates, clockwise from top left: ¨ Laaji, building his own house: Appreciating what people have and what people can do is a key part of the first phase of SLED. *Credit: Saw John (*Karen Youth Association); ¨ Cultural activities can be a great way of building confidence and relationships. *Credit: Rajendra Prasad (PAD);* ¨ Using participatory tools can be an effective way of working with groups of people. *Credit: Rajendra Prasad (PAD)****;*** ¨ Rebuilding a Livelihoods framework with the field-team in preparation for the SLED fieldwork is an effective way of preparing the field workers for their task of learning about livelihoods. *Credit: Abdulla Mohamed Didi.*

formal institutions and positions within communities. However, the field-teams recognised that people who have had success in their lives or who are very motivated and enthusiastic for change may also be very powerful advocates for the SLED process;

- By working with individuals, groups and then, ultimately, the broader community, the field-teams found that it was possible to achieve consensus between groups and the community as a whole. This type of consensus over the need for change and the direction of that change will be a key driving force behind people's ownership and commitment to the SLED process.

A full analysis of the fieldwork experiences and their implications for the SLED approach is included in the report of the CORALI-SLED development workshop 2 (Cattermoul *et al.* 2007).

A Working SLED Approach

The SLED approach that has emerged from the past livelihoods research experiences and the CORALI process is people-centred. This may sound obvious, but many development activities in the past have tended to focus on technologies, resources, sectors, institutions, production, markets or particular sets of issues in such a way that the "people" involved have often been forgotten. By contrast, the SLED approach places people firmly at the centre of attention. It insists that all development must begin by: a) looking at people – as individuals, households, groups and communities; b) by understanding their capacities and potential (and not just their problems); and c) by working as partners to achieve common goals.

The approach builds on the three areas of SLED activities (Discovery, Direction and Doing), each of which has been broken down into a series of fieldwork components. The components are placed in a framework that demonstrates the stage of a project where they would be initiated (Fig. 1).

The three main SLED activity groups (Discovery, Direction and Doing) feature throughout the SLED process. For example, at the early stages of SLED the field teams will focus mostly on discovery activities such as building up their understanding of the relationships that different groups of people have with the coral reef. However, the process of doing this should help those people to analyse how changes in the reef have affected their livelihoods – and so may contribute to their appreciation of the need for change in their livelihoods. Likewise, fieldwork that is conducted effectively should help the team to build up their relationships with the community and involving other service providers and government authorities will begin to build the lines of communication and support that will be required to enable the process of livelihood change.

The process of building this framework is iterative and as lessons emerge from the second stage of SLED fieldwork (implemented between July and October 2007) the framework will be amended. A set of principles for implementing SLED and a series of guidance documents for development practitioners will also be developed as part of CORALI.

RECOMMENDATIONS

The process of implementing SLED involves a long-term commitment to community development. The first two phases of the process constitute the work that is required to initiate livelihood change in the short-term. Under CORALI it has been feasible to work with certain groups in the communities through these two phases, and this process is producing supportive evidence and valuable lessons relating to the positive impacts of the SLED approach. The third phase of the SLED approach is concerned with providing the services that will support livelihood change in the long-term. While the field-teams will have an opportunity to initiate a series of micro-projects to support livelihood change these will clearly not be sufficient either in scale or longevity to provide the scope of support services that will be required to facilitate long-term livelihood change. Throughout the second phase of field-testing the teams are working to develop linkages with wider development processes so that they may be able to extend their work on SLED both within the communities where they have been established and beyond the ten months of CORALI funding. For example, the SLED work that has been undertaken in Sri Lanka will be linked into the work programme of the ongoing ADB Coastal Resource Management Project.

The SLED approach has evolved over the course of the last five years and will continue to evolve as the experiences with implementing it build up. It is important that this process is supported by a long-term initiative, such as CORALI, that can both: facilitate the transfer of skills and knowledge relating to the application of the approach; and continue to inform and influence policy-makers on the value and potential of the SLED approach as a tool for supporting livelihood development as key part of a more holistic approach to coral reef conservation.

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The Role of Alternate Livelihoods and Awareness Creation in Coral Reef Conservation in the Gulf of Mannar, Southeastern India

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ABSTRACT

Growing coastal populations, destructive fishing activities, increasing use of modern fishing crafts and gears and coastal development have already caused considerable damage to a significant part of the coral reef areas in the Gulf of Mannar. It is clear that this to a large extent has been caused by a lack of awareness about the fragility of natural ecosystems among local communities, as well as a shortage of livelihood options. This must be addressed as a central issue in conservation and management initiatives. Activities focusing on viable alternative and additional livelihood options, such as aquaculture, value-addition, exploitation of previously under-utilized resources, and related awareness raising and education were implemented in villages along the Gulf of Mannar coast. Methods and impact are briefly presented and reviewed herein.

Figure 1. Fisher family.

INTRODUCTION

Coral reefs are an important economic resource world wide, but are now suffering from widespread decline due to over-exploitation and damage inflicted by 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

growing populations that utilize them (Pearson, 1981; Connell, 1997; Jackson, 1997). The Gulf of Mannar (GoM), one of the four major reef ecosystems in India, is no exception. Ever-increasing populations and economic and industrial growth adds pressure on coastal resources (Meenakumari, 2005). Over 50,000 people depend on the fishery resources of this reef area for food and livelihood (Patterson et al., 2007), and consequently large areas of reefs in the Gulf of Mannar are disturbed (e.g. Patterson et al., 2007; Patterson Edward et al, this volume). The main challenge the fishery now faces is to balance the needs for resource conservation with the needs of local people, for long-term sustainable management of the ecosystem (Shanthini et al., 2002). It is also clear that resource users, who have a great stake in sustaining their resource base, must be actively involved in this process (Pomeroy et al., 1996).

To address this SDMRI has carried out various pilot activities, research and training programmes, in collaboration with and supported by the Government of India, the Government of Tamil Nadu and the Coastal Ocean Research and Development in the Indian Ocean (CORDIO) programme. The aims of these activities have been manifold, including creation of awareness among stakeholders about the value of corals and associated resources and need for conservation; capacity building on viable alternate livelihood options among natural resource dependent coastal people in order to reduce the pressure on the ecosystem; sustainable utilization of natural resources; encouraging community-based conservation mechanism; and promoting effective but friendly enforcement strategies through education and training. This paper describes some of the approaches used and synthesizes key results and lessons learned from five years of community-based awareness creation and livelihoods enhancement.

Throughout, much focus was placed on women in fishing communities, particularly through Self Help Groups (SHGs). The SHGs, established in all coastal villages, play a major role in generation and wise use of financial resources. In Indian culture, women play an important role in maintaining the home and family, and it is believed that women are reliable and more likely to pay back borrowed funds, making it easier to sustain microfinance programmes with their involvement. In view of this the Government also encourages SHGs in order to promote development among women. SHGs encourage and help women to save money, enabling them to use available funds for development or particular needs. SHGs lend money to members, e.g. to help households purchase fishing materials and other equipment that can increase household income, for family functions and children's education. This way people can avoid borrowing from moneylenders at high interest rates, which has been found to be one reason for the continued low economic status of households in the area. Each SHG consists of a president, secretary, treasurer and 17 members. The number of groups per village varies depending on the population of the village. A coordinator meets all SHGs in each village once per month, to assess progress and coordinate activities.

Education and Awareness Creation

The lack of knowledge among fisher folk about coastal ecosystems, their ecology and productivity, makes them insensitive to the fragile balance in the ecosystem, and unknowingly they are using destructive fishing methods to save time and effort (Patterson et al., 2002). A survey conducted during 2001 studying the knowledge among fisher folk about the ecological significance of coral reefs, found that awareness was very poor. Twenty nine percent of the men and only 3.1% of the women on the Tuticorin coast were aware of the ecological importance of corals for providing products and services (Patterson et al, 2002). To address this, a series of awareness programmes, were conducted, primarily targeting fisher women in view of their comparatively low awareness, but also since they are in a position to influence both active male fishers and children within their households. Several local-level training programmes and workshops were conducted, providing basic but up-to-date information about resources and ecosystem status and trends, identification particularly of economically important or threatened species, community based conservation, coral reef conservation rules and regulations, as well as enforcement mechanisms. The process also served to exchange ideas and experiences among the stakeholders, particularly on traditional management systems, their success and shortcomings. The awareness programmes were particularly targeted towards families that were involved actively in removing live and dead corals from the islands for burning lime and for construction materials, covering topics such as the ill effects of coral quarrying, the loss of habitat for many fin and shellfishes, as well as erosion and the loss of natural barriers that can protect from waves and natural disasters.

A survey in 2004 indicated there was considerable improvement in the awareness level among the fisher folk (Patterson et al., 2005), and in the aftermath of the 2004 Indian Ocean Tsunami there was a tremendous change in peoples' attitudes. Most people felt that coral reefs saved coastal communities from the tsunami, villagers on the Tuticorin coast voluntarily stopped coral mining and dynamite fishing completely stopped in Thirespuram village. In the Gulf of Mannar, women in fishing communities turned out to be the most effective educators of working male family members, e.g. in promoting fishing methods that do not cause damage to the environment. They are also able to inform a larger constituency through Self Help Groups about conservation and resource management that can sustain livelihoods for future generations. It was also clear that carrying out educational and awareness activities in the local language increases the impact and success rate. Further, it was found that although India has all the necessary rules and regulations for protecting coral reef ecosystems, in most cases the primary stakeholders, i.e. villagers and natural resource users, as well as to some extent the implementing authorities, were not fully aware of these. Most importantly greater awareness among the coastal population is needed, as well as greater participation in the formulation and implementation of such

Figure 2. Vermi-compost training.

regulations. Environmental education should be a life-long process for all sections of the population (Vijaya et al., 2005).

Alternate Livelihood Schemes

In view of the high dependence on coral reef resources in the Gulf of Mannar, the concept of livelihood enhancement becomes very important for resource management and conservation of biodiversity. It seems clear that in a context such as that of the Gulf of Mannar, conservation programmes can be successful only if they also address the plight of the local populations, assisting them to develop suitable and viable alternate or supplemental livelihoods.

Through implementation of livelihood pilot projects on the Tuticorin and Vembar coasts of the Gulf of Mannar, SDMRI seeks to train and empower women (through SHGs) and men to earn additional income while reducing dependence on reef resources. This promotes conservation and sustainable resource use while actually increasing household income and enhancing socio-economic status. Experience has shown that e.g. crab and lobster fattening, development of value added products, cephalopod culture, and vermi-compositing are some of the alternate livelihood schemes that are viable (Patterson, 2003; Patterson et al., 2005; DST Project Report, 2006). These are described in more detail below.

Crab and lobster fattening

Among crustaceans, the crabs and lobsters are particularly valuable resources supporting an important fishery in the Gulf of Mannar. The daily catch of this fishery includes molted crabs (e.g. mud crab, *Scylla serrata* and blue swimming crab, *Portunus pelagicus*) as well as molted and under-sized lobsters (*Panulirus homarus. P. polyphagus and P. versicolor).* Molted crustaceans have recently shed their carapace, and the new carapace remains very soft. These are locally called "water crabs" or "water lobsters", and as they do not fetch a high price in the market are usually discarded or sold for a low price. Culturing these crabs and lobsters until the carapace hardens and a normal market value can be obtained is called fattening. Crabs and lobsters are landed throughout the year in the Gulf of Mannar, including a lot of molted individuals, on average 7-10% of mud and blue swimming crabs and 8-10% of lobsters.

Fattening of the mud crab takes 21 to 24 days, while the swimming crabs' carapace hardens within 7 to 9 days. For lobsters the process takes about 25-30 days. Growing out under-sized lobsters requires 3-4 months. The crab and lobster fattening utilizes catch that would otherwise have been discarded dead, and provides an additional income of between Rs.1000 to 1500 per person involved per month. Under-sized lobster constitutes about 2-4% of the total catch. Though it is not a good practice to collect under-sized lobster, these are caught during regular fishing with small meshed gears, and fattening was suggested to increase their value. At the same time fisher folk were advised not to collect juvenile lobster and informed about the pitfalls and implications for the sustainability of the fishery.

SDMRI trained over 300 fisher women and men in crab and lobster fattening in Tuticorin and Pudukottai Districts respectively. The District Administration provided all infrastructure and facilities for the fattening unit for women SHGs in Tuticorin District. Similarly, in Pudukottai District, the District Administration provided financial assistance to women SHGs to set up fattening units. As it is relatively simple, many of those trained remain actively involved in this venture, and crab and lobster fattening is increasingly common and considered a viable alternate livelihood that can provide additional income for fishers. Based on the successes in Gulf of Mannar, other coastal areas in Tamil Nadu, including Pudukottai District, have also implemented similar fattening schemes.

Value addition of under-utilized marine resources, e.g. gastropods

The Gulf of Mannar has numerous mollusk resource species, and gastropods such as *Chicoreus ramosus*, *Pleuroploca trapezium*, *Lambis lambis etc.*, have traditionally been harvested for the beautiful shell and expensive operculum. Nowadays, skin diving for mollusks has reduced considerably, and most of the landings are by-catch from the finfish and shellfish fisheries, and shells are mainly used for ornamental purposes and in the lime industry. Although delicious and rich in nutrients, utilization of gastropod meat has been very limited, mainly due to conservative food habits among coastal dwellers and lack of knowledge of the potential of gastropods as a food source. Consequently enormous quantities of potentially valuable, protein-rich mollusk meat was earlier discarded or sold for a low price. In order to make use of this available resource, value addition was suggested, whereby additional income to fisher households is generated by increasing the value of harvested mollusks through processing.

Through SHGs, fisher women were trained in the development of several value added products, such as pickles, soup powder, chutney powder, smoked products and wafers. Over 250 fisher women have been trained so far. Meat of gastropods is now regularly consumed by villagers, and fisher women can earn a minimum of Rs.1000 per month by selling the processed products in their villages and at local markets. The activity has been highly successful in utilizing an available by-catch that would otherwise have been discarded for improving nutrition and income.

Figure 3. Shore seine - catch.

Cephalopod culture

At all fish landing centers in the Gulf of Mannar, cephalopod eggs are found in the by-catch throughout the year, indicating that the cephalopods breed continually. Two species of cephalopod eggs are common, namely the big fin squid (*Sepioteuthis lessoniana)*, and Pharaoh's cuttlefish (*Sepia pharaonis),* while eggs of the spineless cuttlefish (*Sepiella inermis)* are less commonly found although they occur in small quantities. Large quantities of eggs from trawl nets are discarded without any use on a daily basis. To find ways to utilize this potential but wasted resource, SDMRI through a Govt. of India research project, standardized techniques for culturing cephalopod eggs collected from trawl nets to juvenile and adult stages.

The cephalopod culturing trial involved simple technology and included the following steps: collection and identification of eggs, transportation, incubation, embryonic (intracapsular) development, maintenance of the hatchlings and juveniles and adults, feeding, behavioral and growth studies and disease management. Eggs were collected from fishermen or where they had been abandoned on the shore and immediately transported to the culture lab in a container with continuously aerated seawater. The eggs were carefully acclimatized to the lab water temperature for about 1 hour, after which they were rinsed with filtered seawater in order to remove any adhered dirt. The eggs were then dipped in a mild solution of Oxytetracycline antibiotic (2 mg / 500 ml) for a couple of minutes, and egg capsules were removed from the clusters using clean scissors, in order to prevent infections or microbial growth on the egg stalks, which are tied together during the time of egg laying. During incubation eggs were kept in perforated plastic baskets in one cubic meter seawater tanks, with an 80% daily water exchange. The bottom and sides of the tanks were scrubbed daily and any accumulated dirt was siphoned out. Eggs were turned once per day to prevent fungal infection, and eggs with dead embryos were discarded. Detailed culture techniques, including infrastructure, feed, and problems are explained in the DST Project Report (2006).

Growth of embryos over time was observed. The incubation period was found to be different for the three cephalopod species: 21±2 days *in S. pharaonis*, 15±2 days *in S. inermis* and 17±2 days in *S. lessoniana.* Cephalopods grow very fast and as a result they require large quantities of feed, initially live feed and later dead fish. Prior to undertaking large-scale culture, feed availability must be thoroughly investigated. Without sufficient feeding the animals can show cannibalistic behavior. Some cephalopods, mainly squids, show schooling within about 20 days after hatching. If separated from the school their behavior becomes erratic, and so cephalopods should be raised in groups rather than individually. Similarly, keeping cephalopods in small tanks appears to stress the animals. During mating, male cephalopods may engage in mock battles for access to females, which damages their epithelium leading to mortality. At such times, the males and females could be segregated. As cephalopods are in high demand particularly for the export market, cephalopod culture could be a viable additional income-generating activity for local people. In the domestic market, *S. pharaonis* fetch a market price of Rs. 100/kg, while *S. lessoniana* Rs. 110/kg. and *S. inermis* Rs. 20-40/kg. Cephalopod culturing techniques have been disseminated to local fisher folk

Figure 4. Vermi-compost pit in the backyard of fisher women.

in order start small-scale cephalopod cultures using discarded eggs from the by-catch, and SDMRI has trained 19 local fisher folk on a trial-basis. While this can provide an opportunity to utilize a so-far wasted resource in a useful manner to increase income, it could also extend to replenishment of natural stock and supporting management and conservation. However, further pilot trials are needed before the activity can be scaled up.

Vermi-composting

The role of earthworms in the breakdown of organic debris and in the soil turnover process was first highlighted by Darwin (1881). Vermi-composting is a simple and eco-friendly method of converting diverse biodegradable wastes from e.g. household and livestock into biofertilizer using earthworms. The vermin-compost contains all major and micro nutrients, humus and organic matter, which are essential for plant growth and soil health, making it highly useful for soil enrichment. The process does not require sophisticated instruments and involves relatively little work, and it can provide additional income to rural women, unemployed youth and school children (Balamurugan and Patterson, 2005).

A pit approximately 1m deep is dug in the soil and a 5 cm layer of broken bricks or pebbles are spread at the bottom, covered by a thick layer of sand as this helps drain excess water. A layer of soil is spread on top of the sand, moisturized, and inoculated with locally collected earthworms. Small lumps of cow dung are placed over the soil and covered with bio wastes such as dry leaves. The pit is then filled with alternating layers of cow dung and bio waste, and water added until the pit is moist throughout, but not wet. The pit is kept covered with coconut or palmyrah leaves to prevent birds from feeding on the worms. Once per week the content of the pit is turned for uniform conversion. As the compost is getting ready the content turns into a soft, spongy, sweet smelling, dark brown compost. The appearance of juvenile earthworms by this time is a healthy sign. After 60 days no additional water is added, which compels the worms to move into the vermi bed, which facilitates harvesting of the compost without damage to the worms. The harvested compost is placed as a heap on solid ground and in the shade, facilitating any worms still present in the compost to move to the lower layer from where they can be recovered and transferred to a new composting pit.

SDMRI has trained over 300 fisher women from coastal villages in Tuticorin coast in vermi-composting, many of whom are keeping composts in their backyards and generating additional income through selling the product locally. A vermin-composting pit owner earns about Rs. 1500 to 2000 per crop.

DISCUSSION AND CONCLUSION

Realizing the importance of the reef ecosystem of the Gulf of Mannar, the Government of Tamil Nadu (GoTN) created a Marine National Park covering the 21 islands in the area in the 1980s. The Government of India (GoI) declared the Indian part of Gulf of Mannar a "Marine Biosphere Reserve" in 1989, covering an area of 10,500 km^2 between Rameswaram and Kanyakumari. Awareness about the importance of managing coral reefs and reef resources and conservation became broader among all sectors and stakeholders in India after the 1998 global coral bleaching event, largely as a result of a number of international and national initiatives such as Global Coral Reef Monitoring Network (GCRMN), Coastal Ocean Research and Development in the Indian Ocean (CORDIO), Global Environment Facility-United Nations Development Programme (GEF-UNDP) and Indian Coral Reef Monitoring Network. Further, activities carried out through the CORDIO network since 2002, such as reef monitoring, restoration, capacity building among reef dependent fisher folk, creation of alternative livelihoods and awareness initiatives, as well as programmes by the Union Ministry of Environment and Forests, have greatly contributed to knowledge about the area and an understanding of how to address the issues and threats it is facing (Patterson, 2003; Chellaram and Patterson, 2005; Mathews and Patterson, 2005; Patterson, et al., 2005; Wilhelmsson et al., 2005; Patterson, 2005; Patterson et al., 2005; Patterson and Samuel, 2005; Patterson et al., 2006; Mathews and Patterson, 2006; Chellaram et al., 2006; Patterson et al, 2006; Patterson et al., 2007). The 2004 Indian Ocean tsunami made people more aware of the importance of islands and reefs, and the fisher folk along the Gulf of Mannar voluntarily came forward to end coral mining. Further, the Gulf of Mannar Biosphere Reserve Trust, formed by the GoTN to implement the GEF-UNDP project "Conservation and sustainable use of Gulf of Mannar Biosphere Reserve's coastal biodiversity", has taken the initiative to undertake job oriented trainings targeting fisher youth from the area, in order to facilitate diversification of income generating activities and take pressure off reefs and the fishery resource.

However, in spite of these efforts the Gulf of Mannar is still under considerable stress. Destructive resource utilization practices are proving difficult to stop completely due to the high dependence of a large number of poor coastal people on reef resources for their livelihood. In addition, businesses such as the lime industry particularly on the Tuticorin coast have exploited the situation of high poverty among fisher folk by using them for illegal coral mining activities to obtain raw materials. Population growth, low literacy level and crowded fishing grounds continue to pose a threat to the reef resources, and fishing remains the only traditional profession recognized by and familiar to many poor fishermen.

Dealing with this situation requires long-term, broad and diverse efforts, including continued development of viable alternate livelihood options along with awareness creation and environmental education, which can gradually create a change. It is also essential that fisher women are encouraged to take a lead role in generating household income, thereby reducing the pressure by the predominantly male fishers on the marine environment. This requires increasing the literacy levels among women in fishing households, as well as providing e.g. vocational training, which is currently being addressed by SDMRI.

It must be noted that, in spite of many steps taken by the Government and other organizations in providing alternate livelihoods, the schemes mostly fail because activities or plans are not appropriate and require engagement and commitment in the long-term, beyond the scope of most interventions. In most cases, funding is available only for training fisher folk, but not for supporting start-up activities on a large scale. Many of the schemes also prove not to be viable as there is a mismatch between the skills and desires of the people, the activities being promoted, and market forces. In order to be able to change opinions and attitudes as well as traditional ways of living among poor fisher folk, sufficient technical and financial support is required.

Through programmes supported by CORDIO and the Government of India, SDMRI has successfully developed and implemented a number of alternate livelihood options on a pilot-scale, such as crab and lobster fattening, development of value added products from under utilized marine resources and using hygienic post harvest techniques to enhance quality, and vermi-composting. The schemes are successful because the products have good market demand and there is a tie-up between producers and markets, and because facilitation, monitoring, support and technical advice for the activities has been sufficient over time. Importantly, the buy-in and support from district administrations has greatly increased sustainability and scaling-up of the activities, including e.g. the spread of crab and lobster fattening to other parts of the Tamil Nadu coastline after successful piloting in Tuticorin.

It is important to note that any alternate livelihood scheme should be based on local resources and a clear need, and underpinned by sound technical, financial, and market knowledge. Agencies involved in livelihoods enhancement activities should consider these aspects for greater sustainability and greater employment and food security benefits to local populations in the longer term. When implemented well livelihoods enhancement can constitute an essential part of conservation and management of marine resources.

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Human Dimensions of Madagascar's Marine Protected Areas

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ABSTRACT

We conducted a socio-economic assessment in thirteen communities within or adjacent to Madagascar's Marine Protected Areas (MPAs); Nosy Atafana MPA in the Mananara Nord biosphere reserve; Tampolo, Tanjona, and Masoala MPAs in the Masoala National Park, and the recently designated Sahamalaza MPA. Socio-economic information was gathered using several techniques, including household surveys, resource user key informant interviews, community leader key informant interviews, and oral histories. Communities varied considerably in regards to their dependence on marine resources. Communities in the Masoala and Tanjona marine parks had a relatively high dependence on fishing and gleaning (particularly for octopus and sea cucumber). Communities in Sahamalaza had moderate dependence on marine resources and Sahasoa, near Nosy Atafana, had a relatively low dependence. We found that fishing effort in several of our study sites was comparable to moderately exploited sites in Kenya (Cinner and McClanahan, 2006). However, it will be necessary to examine fishing effort relative to the size of fishing ground to have a better overall impression of fishing pressure across the study sites. Strategies to improve management in Madagascar's marine parks may include: (1) presenting consistent and transparent socioeconomic and ecological monitoring to communities to clearly demonstrate the effects of conservation on community livelihoods; (2) forming cross-scale linkages between national, provincial, and local governance institutions to promote resilience to social and ecological disturbances.

INTRODUCTION

Madagascar's high levels of endemic flora and fauna have made the island a key conservation priority site (Myers et al. 2000). In 2003, the Malagasy President announced that Madagascar would create a six million hectare network of terrestrial and marine reserves, effectively tripling the area under protection (Duffy 2006). Yet, there has been little effort to understand the human dimensions of this proposed conservation initiative, particularly in the marine context.

As conservation theory and practice moves away from excluding resource users to creating partnerships with them, it is becoming increasingly clear that conservation is as much about understanding people as it is about understanding ecological processes (Cinner

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et al., 2007). Many conservation projects fail to achieve either biological or social goals because they do not adequately understand, address, and incorporate the socioeconomic needs and concerns of stakeholders (Christie et al. 2003, Christie 2004, Cinner et al. 2007). Here we investigate some key socioeconomic conditions in Madagascar's marine protected areas (MPAs). We examine the intensity and type of resource use, occupational multiplicity, population, settlement pattern, and market influences.

METHODS

We selected villages within or adjacent to Madagascar's national marine reserves at sites in the northeast (Nosy Atafana MPA in the Mananara Nord biosphere reserve and Tampolo, Tanjona, and Masoala MPAs in the Masoala National Park) and northwest (recently designated Sahamalaza MPA). Villages were chosen to encompass a range of geographical, social, and economic conditions which included population size, development, history/length of settlement, and dependence on marine resources. To gather information within villages, a combination of systematic household surveys (for example, surveying every second or third household), semi-structured interviews with key informants (community leaders and resource users), recording of oral histories, and participant observations. A total of 264 household surveys were collected and analyzed.

Sampling of households within villages was based on a systematic sample design (see Henry, 1990; de Vaus, 1991). In very small communities (<30 households), a whole haul census was generally attempted (but never achieved because of long term absence of specific residents). A household was defined as people living together and sharing meals. Variance from the systematic sample was assumed to be equal to the estimated variance based on a simple random sample (Scheaffer et al., 1996). The number of surveys per park ranged from 43-70. The number of surveys per community (within each park) ranged from 7-44 (Table 1), depending largely on the population of the village, and the available time per site (this was influenced by factors such as weather, the availability and frequency of transportation to certain sites, and budget requirements).

Figure 1. Conducting a household survey in Ankitsoko.

The head of the household was interviewed with a structured survey form by a trained research assistant (Fig. 1). If the head of the household was not available, the household was revisited later. If the head of the household was still not available, another adult from the household was interviewed.

Dependence on fishing was determined by having respondents list all the occupations the household engaged in for food or money. Respondents were then asked to rank these activities in order of importance. Those who regularly engaged in fishing estimated the percentage of their fish catch sold or bartered.

RESULTS

Population and Settlement Pattern

Human population size can affect the pressure placed on reef resources and influence the types of interventions required to manage them. Population and settlement pattern were examined as indicators of potential pressure on reef ecosystems. The villages were relatively small, many of which had populations of less than 100 (Table 2). Sahasoa was the largest village studied. A mean of 4.5 people per household

Table 1. MPAs, study communities and number of surveys conducted.

MPA and Community	Number of surveys	Number of fishers surveyed	Proportion of fishers, %
Masoala MPA	***53***	***26***	***49***
Ambinambe	7	7	100
Ankitsoko	18	3	17
Ambodilaitry	28	16	57
Tanjona MPA	***54***	***46***	***85***
Tanjona	13	9	69
Ifaho	13	12	92
Andomboko	9	9	100
Ankarandava	10	9	90
Antsabobe	9	7	78
Tampola MPA	***43***	***19***	***44***
Ambodiforaha	17	6	35
Marofototra	26	13	50
Nosy Atafana MPA	***44***	***15***	***34***
Sahasoa	44	15	34
Sahamalaza MPA	***70***	***38***	***54***
Antranonkira	9	4	44
Nosy Berafia	40	19	48
Nosy Valiha	21	15	71
All sites	**264**	**144**	**55**

was recorded for all the study sites. There was considerable variation in household size within parks. For example, at Tanjona, household size ranged from 2.8 in Antsabobe to 5.7 in Ankarandava. At Cap Masoala, there were 3 people per household in Ankitsoko and 4.3 in Ambinambe. Antsobobe, Ankarandava, and Andomboko were the smallest villages studied, each were relatively dispersed and had less than 15 households (Table 2). Nosy Berafia and Nosy Valiha had several sub-village settlements dispersed around the islands. For the purposes of this study, we combined these hamlets into a single study site (i.e. village) for each island.

Livelihoods

Occupational categories reported included fishing, selling marine products, agriculture, tourism, salaried employment[1], and the informal sector[2]. Most study

[1] The category "salaried employment" includes salary positions such as secretarial work, teaching, security, etc. Salary jobs in the tourism sector (i.e. hotel security) are considered in the tourism category.

[2] The category "informal sector" can include participation in informal markets, such as selling food or clothes from a kiosk, casual work, etc.

Table 2. Population and settlement pattern of study sites (aggregations at the park level in bold and specific villages within each park are indented).

Indicator	Average people per household	Number of households	Population size	Settlement pattern
Cap Masoala	**3.5**	**88**	**308*[1]**	
Ambinambe	4.3	12	51	C, N
Ankitsoko	3.0	25	75	I, N
Ambodilaitry	3.5	51	180	C, D
Tanjona	**4.8**	**66**	**316**	
Tanjona	5.5	16	87	C, D
Ifaho	3.4	19	64.	C, D
Andomboko	4.7	11	51	C, D
Ankarandava	5.7	10	57	C, D
Antsabobe	2.8	10	27	C, D
Tampolo	**5.1**	**56**	**286**	
Ambodiforaha	4.7	20	94	C, N
Marofototra	5.4	36	193	C, N
Nosy Atafana	**5.4**	**244**	**1314***	
Sahasoa	5.4	244	1314	C, N
Sahamalaza	**4.4**	**133**	**585***	
Antranonkira	4.8	18	86	C, N
Nosy Berafia	4.5	70	311	C, D
Nosy Valiha	4.3	45	192	C, D

D = Dispersed settlements that were spread out and contained distinct sub-villages that were geographically separated.
N = Nucleated settlements were communities that were relatively contiguous.
C = Coastal (the majority of houses or town center are located <500 meters from the coast).
I =Inland (the majority of houses are >500 meters from the coast).
*Only includes estimates of study sites- There were more villages in the parks that we were not able to survey, thus these are underestimates of the true populations dependent on the parks.
[1] The population estimate for the entire Masoala park (including Cap Masoala, Tanjona, and Tampolo) are 1,361, suggesting that there may be an additional 451 residents in the Cap Masoala park (Grandcourt et al. 1999).

sites were relatively similar in the occupational diversity (Table 3), but the most rural and remote site (Sahamalaza) had considerably fewer occupations per household (Table 3).

The agricultural and cash crop sectors had the broadest participation, with over 92% of respondents being involved. Slash and burn practices for both agriculture and cattle (to provide green grass shoots after the burn) were widespread and potentially are a concern for both terrestrial and nearshore marine environments (see Kull 2000). In Sahamalaza, the terrestrial environment appeared to be particularly

Table 3. Occupational Multiplicity per household (+ 95% CI).

MPA Study site	Average number of different occupations	±
Cap Masoala	3.1	0.1
Tampolo	3.0	0.1
Tanjona	3.2	0.1
Nosy Atafana	3.2	0.3
Sahamalaza	2.2	0.1

degraded and terrestrial conservation will be an important component of long-term coastal zone conservation. As the terrestrial environment becomes increasingly degraded, it is expected that there will be increasing pressure on marine environments. In the Mananara and Masoala peninsula regions, a high primary dependence on cash crops (particularly vanilla) and secondary dependence on fishing suggest that fluctuations in international prices of cash crops could have repercussions on the use of marine resources. For example, in Marofototra, community leaders explained how the drop in vanilla prices has led to an increased reliance on fishery resources.

Fifty four percent of all respondents were engaged in traditional fisheries. The highest participation was at Tanjona, where 98% of households were involved in the fishery and 87% considered fishing a primary occupation. Participation in the fishery was relatively low in Nosy Atafana, where less than 36% of households were involved and only 7% ranked fishing as a primary occupation. Many of those who participated in the fishery considered it their most important occupation, particularly at Cap Masoala, Sahamalaza, and Tanjona. This suggests that fisheries management regulations in these areas will have a direct impact on a high proportion of peoples'

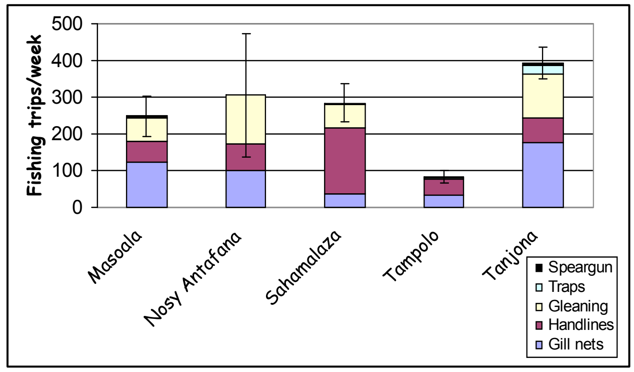

Figure 2. Estimated number of fishing trips per week per community and associated gear type (+ 95% CI).

livelihoods. Gleaning at all sites was less important than fishing, but did comprise a significant livelihood activity with the exception of Tampolo. Gleaning activities generally focused on octopus and sea cucumbers.

The salaried employment sector, and "other" sector (which included remittances, traditional healing arts, etc.) made up 3% and 9%, respectively. Tourism is an important economic activity in parts of coastal Madagascar. However, only 1% of respondents were involved in the sector informally as porters or local guides.

Fishing and Markets

Fishing effort

To determine the intensity of fishing effort in the communities, respondents were asked the average number of trips per week that they and other members of their family participate in for each gear type. Figure 2 examines total fishing effort across the parks[3]. These estimates do not include the areas of the parks that we were unable to survey and are an underestimate for Cap Masoala, Sahamalaza, and Nosy Atafana. Tanjona exhibited the highest overall fishing pressure, and Tampolo exhibited the lowest. Gill nets were the

[3]It should be noted that when respondents used more than one gear type in a trip, they were considered separate trips if at least one gear was "passive" (e.g. traps which are set and returned to after some time). However, when multiple gears were used, but more than one gear was "active" (e.g. a seine net or handline), they were considered partial trips (depending on how many gears were used).

Figure 3. Fish trap construction in Tanjona.

most frequently used gear, followed by handlines, gleaning, traps, and spearguns. Gleaning consisted of collecting octopus and sea cucumbers from intertidal or shallow subtiddal reef flats. Spears were frequently used in octopus collection. Traps were constructed out of local materials and generally had mesh gauge of approximately 3 inches (Fig. 3).

Market influences

At the sites examined, fish marketing was entirely by small-scale traders for local consumption (Fig. 4). Very few respondents reported being involved in buying and selling fish or marine products. The exception to this is involvement in the sea cucumber industry, particularly in Sahamalaza and Tampolo (Masoala peninsula). In contrast to Kenya, where small-scale traders bought fish at landing sites, did some processing (scaling, gutting, and possibly cooking), and either sold fish in local open air markets or transported fish to urban centers (i.e., Mombasa or Malindi) for sale in retail fish shops, fish marketing in Madagascar was done primarily by the fishers and their family. Poor transportation and low fish prices meant that many communities were not heavily integrated into provincial or national markets. There were no medium-scale (i.e. traders with freezers or refrigerated storage capacity) or large scale (i.e. traders with exporting facilities) fish sales or processing at any of the sites assessed in this study.

Figure 4. Regional fish market (in Maroantsetra).

CONCLUSIONS & RECOMMENDATIONS

Although there appeared to be considerable variation in socioeconomic conditions between the communities examined, this was less so than in similar studies conducted in Kenya, Papua New Guinea, and Indonesia (Cinner et al, 2006, 2007; Cinner et al 2005, McClanahan et al 2006). This was mainly due to the establishment of the marine parks in remote and rural areas of Madagascar, compared to urban and peri-urban areas such as Malindi and Mombasa MPAs in Kenya and Bunaken MPA in Indonesia. Our study sites were all small (<250 households), remote sites with little access to infrastructure, services, or markets. However, there was considerable variation in peoples' dependence on marine resources. Some areas, such as Sahasoa village (near Nosy Atafana MPA), had low dependence on fishing, while residents in and adjacent to Tanjona MPA had extremely high dependence on fishing.

Despite the small human population size and remoteness of the study sites, fishing intensity at some sites was high (approximately 400 trips/week) and comparable with the intensity encountered in the smaller study sites in Kenya (Cinner and McClanahan, 2006). Gill nets were the most frequently used gear in the study sites, which may pose a considerable threat to reef resources through both direct damage to corals and their species and body length selectivity (McClanahan & Mangi, 2004; Cinner & McClanahan, 2006).

In the Sahamalaza region, pressure on marine resources is currently moderate and dispersed over a very large area. However this pressure may increase significantly as terrestrial habitats become increasingly degraded and unusable for agricultural purposes. Consequently, it will be crucial to develop integrated management of the terrestrial environment outside of designated park areas, particularly in the islands and peninsular regions where deforestation and subsequent erosion is severe. This will require considerable reforestation efforts and livestock management initiatives. One of the main issues in the islands region is that people do not have ownership of the land and their insecure tenure may promote practices that favor short-term gain at the expense of long-term sustainability.

There are multiple natural and social disturbances that may threaten coral reefs in Madagascar. For example, there have been six major cyclones in the 2006-7 season alone (Reuters 2007). Preliminary results of ecological surveys suggest that reefs in the region were adversely affected by the natural disasters (S. Harding pers. comm.). Coral reefs in Madagascar are also highly susceptible to social events that may alter marine resource use patterns. For example, due to the high dependence on cash crops such as vanilla, marine resource use is dependent on external (i.e. international) economic factors such as price fluctuations. Many respondents described changes in marine resource use after the drop in vanilla prices in 2003 (which decreased to 1/10 the value). One respondent noted "after the drop in vanilla prices, many people are now fishing". There is a need to develop management regimes that will promote resilience to both social and ecological disturbance events. While the decentralization associated with the 'transfer de gestion' policies may help to improve the adaptive nature of management systems in Madagascar, resilience to social and ecological events will require that conservation organizations devote considerable attention to strengthening the social networks that promote social capital and ensure cross-scale interaction with local, provincial, and national institutions.

One of the goals of this research project was to establish and expand monitoring at the sites. As part of the establishment of regular socioeconomic monitoring, it will be very important to provide feedback to the communities in terms of results and outcomes of both the socioeconomic and ecological monitoring. Socioeconomic monitoring every 3-5 years (or sooner if there is a large event such as a cyclone or dramatic fluctuation in the price of cash crops) will be important. Understandably, respondents in several communities expressed considerable frustration that the results of previous studies were not shared with them.

ACKNOWLEDGMENTS

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Socioeconomic Monitoring Initiative for Velondriake Community Managed Protected Area, Madagascar

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INTRODUCTION

The marine conservation NGO Blue Ventures has been working with local communities in the region of Andavadoaka, southwest Madagascar, since 2003. Its aim is to protect the biological diversity, sustainability and productivity of the region's coral reefs and related habitats, while improving the quality of life of the local coastal communities that depends almost entirely on local marine and coastal resources for subsistence and income. Following the results of a pilot marine no take zone launched three years ago adjacent to the remote fishing village of Andavadoaka, Blue Ventures and partner organisations, the University of Toliara's Institut Halieutique et des Sciences Marines (IHSM) and WCS-Madagascar, are currently working with 23 neighbouring villages towards the development of a network of community-run marine, coastal and terrestrial protected areas in the Andavadoaka region.

The network, named the Velondriake Community Managed Protected Area (VCMPA), spans over 700-square kilometres, incorporating coral reefs, lagoons, mangroves, beaches, sea grass beds and baobab forest, and is managed by a series of regional committees and subcommittees comprised of representatives of all villages within the protected area. The VCMPA is an wholly locally-managed and locally-driven initiative, with access to and resource use rights within the protected area governed by local community laws known as *Dina*. A number of special use zones have been designated within the VCMPA envelope, including temporary and permanent marine and terrestrial no take zones (NTZs).

Supplementing the benefits of the protected areas, project leaders are working with local communities to develop and launch sustainable livelihoods – including eco-tourism and mariculture businesses – that are aimed at providing future financial alternatives to overexploitation of natural resources. Specially managed zones for pilot ecotourism and mariculture developments are contained within the VCMPA.

Between May and June 2006 Blue Ventures conducted a preliminary socioeconomic assessment in Andavadoaka and two neighbouring villages in the region, Ampasilava and Lamboara, by implementing the SocMon WIO guidelines, with generous technical and financial support from CORDIO East Africa. The following objectives were identified for this study:

- To understand socioeconomic changes, and its drivers, within the communities;
- To identify and monitor the distribution of benefits of conservation activities in the community and MPA network;
- To understand communities' perceptions and attitudes of management initiatives already put in place and the impacts of these measures on the communities;
- To evaluate the socioeconomic impact of

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Plate 1. A Key informant interview in progress-Velonriake.

Plate 2. Drawing up boundaries for the Velondriake community managed protected area.

introduced management activities;

- To disseminate the monitoring results to increase awareness in government and policy circles of the socioeconomic aspects of artisan fishers, and their vulnerability;
- To train local staff and VCMPA committee members to continue the socioeconomic monitoring.

The socioeconomic assessment provided an overview of the area including the stakeholders, demographics, infrastructure, business development and community profiles, identifying threats and problems facing traditional coastal livelihoods in the region. Marine activities affecting coastal and marine resources were also monitored to establish a reference against which future changes in use patterns could be observed, in particular those resulting from environmental management and conservation activities. The socioeconomic assessment also included data collection on awareness of rules and regulations, as well as community attitudes and perceptions on marine resource conditions and marine management initiatives. The SocMon study, the first of its kind in Madagascar, was initiated using a combination of research methods including questionnaires, key informants (Plate 1) and focus group interviews based on the SocMon WIO guidelines. Prior to monitoring on-site training was conducted, covering field data collection, interview techniques, database use, data analysis and dissemination. This study was completed just after initiation of pilot marine no take zone trials, adjacent to the three survey villages, which led to the establishment of the broader VCMPA a short time afterwards (Plate 2).

Following expansion of regional environmental management and conservation efforts to include 23 villages within the VCMPA initiative, the first round of SocMon sites was expanded to include a broader representative sample of the varying ethnicities and marine and coastal resource users affected by the VCMPA. Logistical constraints prevented surveying in all 23 communities (Fig. 1), however all villages within the VCMPA were visited to introduce the objectives of the SocMon work prior to commencing data collection. Ten villages (Ambalorao, Ampasimara, Andrananombala, Ankindranoke, Ankintanbagna, Antsatsamoroy, Befandefa, Bevato, Nosy Ve and Tampolove) were selected to represent varying levels of a number of criteria including: population size, fishery or agricultural activities, infrastructure, ethnicity, presence of an administrative centre, and geographical location, in order to produce a balanced sample from all the villages. The expanded SocMon survey was undertaken between May and August 2007.

The monitoring team consisted of multilingual staff of both local Malagasy and international research staff. Modifications were made to the questionnaire and focus group interviews to account for the nature of the newly implemented

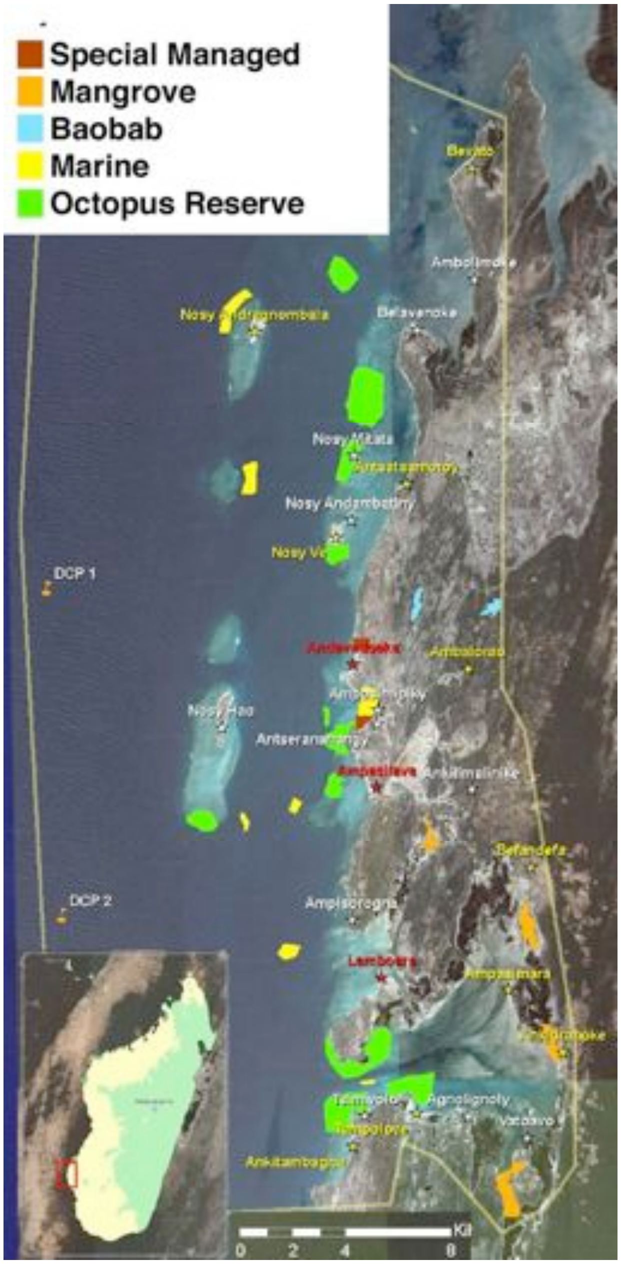

Figure 1. Map of Velondriake network of marine and coastal protected areas and villages. Villages in red participated in the first SocMon survey (2006), and in yellow added for the second SocMon survey (2007). Difference classes of protected areas are shown: special managed, mangrove, baobab forest, marine and octopus reserve.

VCMPA, in order to investigate local communities' understanding of and support for its establishment. As with the first round of surveying, a combination of data collection techniques was found to be most effective, with household surveys being reinforced through focus group and key informant interviews.

Dissemination of Results

A summary of the first round of monitoring was presented to the Velondriake management committee, regional sub-committees, and three villages surveyed prior to the commencement of the second expanded study. Upon completion, the final reports of both rounds of surveying will be distributed to local and regional government and VCMPA management committees, with the intention of providing communities, VCMPA managers and partners with information to better understand key socioeconomic and environmental issues in the region, as well as highlight priority areas for improved management of marine and coastal resources.

At a national level the implementation of socio-economic monitoring is critical to increase government understanding of the problems facing the resource-dependent Vezo people of the southwest coastal region. Few marine protected areas are currently in place in Madagascar, and the establishment of a regional community-run marine and coastal conservation initiative such as the VCMPA is unprecedented.

Feedback

To make the SocMon guidelines applicable to Madagascar, the team translated the field forms into French and again into Vezo language. It is necessary to adapt the guidelines for site specific needs such as translating into Malagasy to assist in explaining the objectives of the project among local communities. This would also be useful to assist in the expansion of the Malagasy SocMon programme to other regions within Madagascar, and to facilitate the training of new site teams.

Socioeconomic Monitoring Initiative at Rivière Banane, Rodrigues

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In response to the recent decline in fish stocks in Rodrigues, 4 marine reserves were proclaimed in the northern lagoon in April 2007. Although biological monitoring has been on-going since 2002, there was an urgent need for socio-economic monitoring to be carried out to complement this research. The main objectives of this study were therefore to formalise and add to existing knowledge on fisheries and fishers attitudes and to establish baselines for future monitoring and evaluation. SocMon surveys were undertaken at the village of Rivière Banane, in the north-east of Rodrigues, during May – July 2006 and February 2007 using a combination of household surveys, key informant and focus group interviews.

Plate 1. A motorised fishing boat at Rivière Banane.

Plate 2. Preparing a corn harvest at Rivière Banane.

The surveys indicate that fishing (Plate 1) and planting (Plate 2) are the most important occupations in Rivière Banane, undertaken by 22% and 28% of respondents, respectively, however the majority of the community are unemployed. The community is young, with 50% aged less than 30 years and the majority have received less than 9 years of schooling. The community is Catholic with the majority of respondents speaking only Creole. Households have an

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Plate 3. SocMon feedback session at Rivière Banane.

average size of 4 persons and most respondents own their houses, have an average of 4 rooms and all have access to piped water and mains electricity. Fishing is the primary source of income for 30% of households, however only 13% of respondents own their own boats, and of these only 20% have an engine. (Plate 3) Coastal and marine activities carried out in the area are: fishing for octopus using harpoons, fishing for fish using basket traps and lines, planting fruit and vegetables, raising livestock and tourist snorkelling trips. Marine products have a low – medium value and all are sold locally, as well as being used for own consumption. Three formal community organisations were highlighted, however the majority of respondents feel that they have no involvement in coastal management decisions. Respondents highlight illegal fishing, pollution, coastal flooding and soil erosion as threats to the health of coastal resources, with the solutions being better enforcement of fishing regulations and cleaning the beaches and rivers. Major problems facing the community are poor roads/lack of public transport, lack of water and invasive plants. Respondents understand the non-use value of the coastal resources, with the majority wanting future generations to enjoy coral reefs and agreeing that fishing should be restricted in certain areas.

The results therefore highlight that fishing is important to the Rivière Banane community and the development of a no-take marine reserve in the region will have an important financial impact on a number of households. The young community suggests that the development of an alternative livelihood and re-training programme may be more suitable than a Voluntary Retirement Scheme as a means of reducing fisher numbers. Illegal fishing is seen as the main threat to the coastal resources in Rivière Banane and this is particularly relevant to the development of the new marine reserve, with better enforcement needed. The study also highlights the need for greater involvement of the fishing community in future coastal management issues in order for the management plan to be successful.

Coastal Communities Adaptation and Resiliency to Vulnerability: An Analysis of Livelihood Activities in Kenya

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ABSTRACT

A socio-economic monitoring pilot project was initiated in Eastern Africa in 2002. The goal was to develop a regional socio-economic monitoring process that contributes to improving coastal and fisheries resource management.. Findings for the Diani-Chale area in Kenya are analyzed here, focusing on community livelihood strategies for three villages studied. On average, there were 5 people per household, 1.9 of whom were actively involved in providing food or income. The most important livelihood activities at the household level were small business, farming, tourism, formal employment and casual employment, fishing, sea related tourism, fish trading and other coastal related activities such as mangrove harvesting in decreasing order. Sea-based livelihood activities were undertaken by 33% households. Extractive marine and coastal activities included fishing, mangrove harvesting and crab collection. Non-extractive activities included boat operators, beach operators, diving operators and fish traders. Fishing was the second most common livelihood activity for households in Diani-Chale (32%), while fisheries accounted for 39% of all natural resources dependent activities.

INTRODUCTION

It is acknowledged worldwide and increasingly in the WIO region that for decision makers to make decisions that will improve resource management, they need a better understanding of the people who live from coastal and marine resources. The socio-economic context in which coastal communities live changes constantly, monitoring is thus an essential tool if management is to be effective in the long run. Existing knowledge must be updated so decision makers can react and adapt to new situations. Although socioeconomic assessments are often carried out in WIO, monitoring is only at its infancy; the socio-economic monitoring pilot project (SEMPP) was the first in the Western Indian Ocean.

The aim of SEMPP was to initiate socio-economic monitoring in pilot sites. Three socio-economic aspects were identified as most important for management by sites and within the region: occupational structure, local resource use patterns, and stakeholders' perceptions and relations. Results presented here relate only to one of these, occupational structure of the communities, focused on what communities do for a living or their livelihood strategies. Following the pilot testing at Diani-Chale

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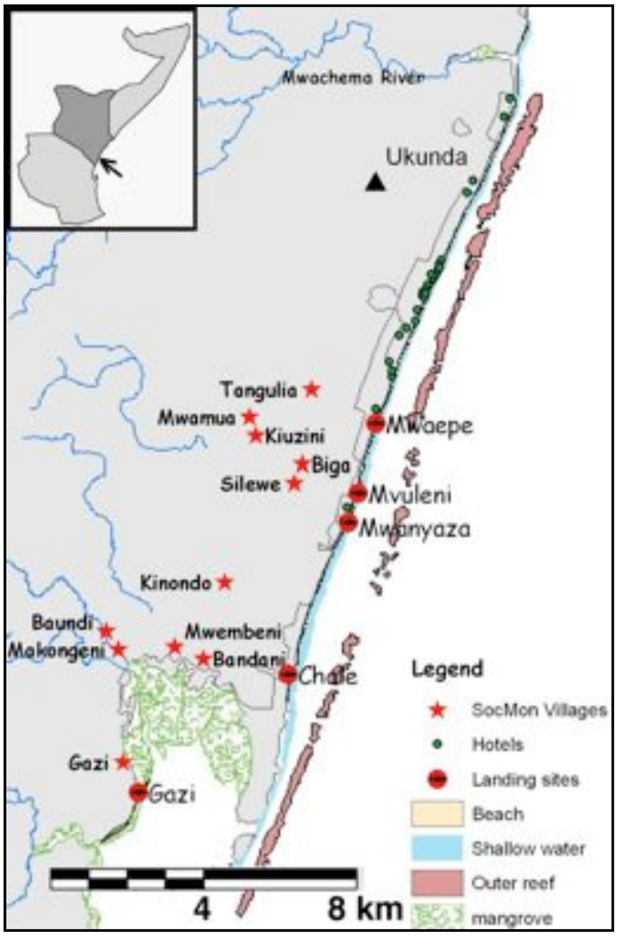

Figure 1. Map of the Kinondo-Chale reef area from Rivers Mwachema to Gazi showing the approximate locations of the villages of Gazi, Biga and the three sub-villages of Chale i.e. Kinondo, Bandani and Makongeni.

and Msambweni in Kenya, monitoring was initiated at Mtwara (Mnazi Bay Ruvuma Estuary Marine Park) and Tanga coastal zone in Tanzania, following which the full SocMon regional programme, SocMon WIO, was started in 2005.

METHODOLOGY

The Diani-Chale area is in Kinondo location, of Msambweni Division, Kwale District, approximately 25km south of Mombasa town from the Mwachema River in the north to Gazi Bay in the south. Nine villages were studied during the first round of monitoring., after which three representative villages were selected for ongoing monitoring, Biga, Chale and Gazi (Fig. 1). Chale is made up of 3 sub-villages, Makongeni, Bandani and Kinondo. The area boasts extensive beach based tourism, hotels and other related infrastructure that form a significant part of the local economy. Fishing is the most important activity done by the local community. Coral reefs and other coastal resources in Diani-Chale are considered to be heavily exploited or deteriorating. Competing use of coral reefs and coastal areas including near-shore waters between various resource users often results in conflict among various stakeholders, most notably between the tourism industry and the local community. An attempt by the government to establish marine protected area management was rejected by the community. Current management efforts have shifted focus to community-based management with designation of the area as the Diani-Chale Management Area (ICAM, 2002) and involvement of stakeholders in a participatory management process.

The monitoring project included a long preparation stage during which local leaders and committees were informed about the need for socio-economic monitoring and their support solicited. Field assistants (young men and women) from the community were trained as enumerators to carry out the monitoring in collaboration with project staff. Local community involvement in the socio-economic monitoring is essential for the sustainability of the process. Information was collected using Kiswahili language, which is widely spoken on the Kenyan coast and occasionally the local Digo language where better communication was required.

Data collection was by key informant interviews as well as focus groups. In both cases, informants were carefully selected to be from the village where the monitoring was being carried out, and with age and gender balance among informants. Key informants were asked to systematically list all households in their

Table 1. Number of households and their inhabitants in 3 Diani- Chale villages.

Village	Number of households	Total number of Inhabitants	Inhabitants per household (mean)	Income earners per household (mean)
Biga	102	578	5.70	1.5
Chale	197	1068	5.40	2.3
Gazi	165	817	5.00	1.7
Overall	464	2463	5.37	1.8

village following a mental transect through the village. The communities' occupational structure was determined through information they provided for each household, including number of household members, number of household members contributing to the households' income or food and list of activities carried out by the household for food and for income.

Data presented here is grouped at the site level (Diani-Chale) and village level (3 villages). Occupations were grouped into three categories for analysis; general occupations, natural resource based occupations and marine resource based occupations.

RESULTS

The three villages in the study area had a total of 464 households with 2463 people (Table 1). On average Biga had the highest number of inhabitants per household, 5.7 followed by Chale and Gazi 5.4 and 5.0 respectively. Chale had the highest number of active persons per household 2.3, followed by Gazi and Biga, which had 1.7 and 1.5 respectively. Most households involved in multiple livelihood activities in Diani-Chale were in Chale village. A total of 292 households in Diani-Chale area were involved in multiple livelihood activities 167 of which were in Chale representing 84.8% of the village while in Gazi and Biga, the proportion was 47.3 and 46.1% respectively (Fig. 2).

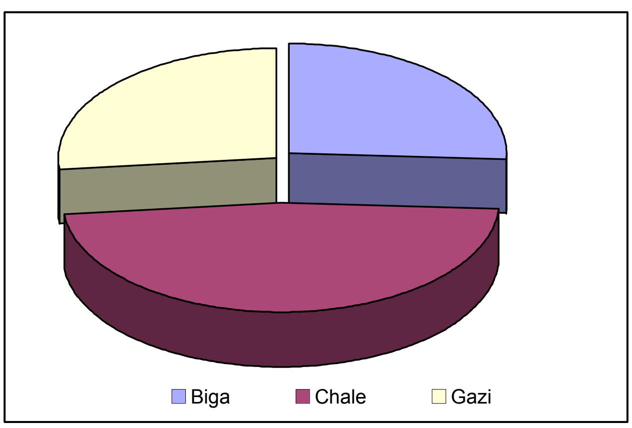

Figure 2. Households involvement in multiple l ivelihood activities in Diani-Chale.

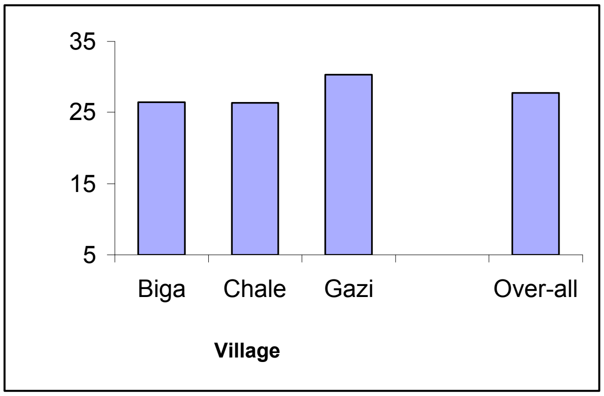

Figure 3. Proportions of Female Headed Households in Diani-Chale Area.

Females headed about 27.8% households in Diani-Chale area. The highest proportion of female-headed households were in Gazi (30.3%) while Biga and Chale were similar with about 26.5% (Fig. 3)

Thirteen broad classes of occupations were recorded during the surveys (Table 2). The largest proportion of households in the three villages, 60% depended on small business opportunities and other forms of self-employment for their livelihoods (Fig. 4). These include the sale and making of mats, food vendors, charcoal sellers. Over 30% were involved in fishing and 20% of households were also involved in

Table 2. Livelihood activities recorded in Diani-Chale.

Main Category	Groups included under category
Fishing	All fishing methods,
Fish trade	Fresh fish trader-local fish, Fresh fish trader-non local fish, Fried Fish Trade,
Fisheries	Fishing, Fish trade, Shell-Collector,
All sea	Fishing, Fisheries, Self sea tour, Employed- sea, Mangrove use.
Self sea tour	Beach-Operator, Beach-Boy, Beach-Operator, Sea Tourism,
Emp sea	Employed in Sea Tourism,
All tour	Self employed in sea tourism, Employed in sea tourism,
All emp	Employed, Employed in sea tourism,
Self bus	Small-Business, Medium-Business, Sale and making of mats, Food vendors, Charcoal sellers.
Farming	Small scale farming, Large scale farming, Farm Trader,
Others	Traditional doctor, Artisans, Casual emloyees,
Mangrove use	Mangrove Cutter, Mangrove seller,
Natural resource dependent	All sea, Farming

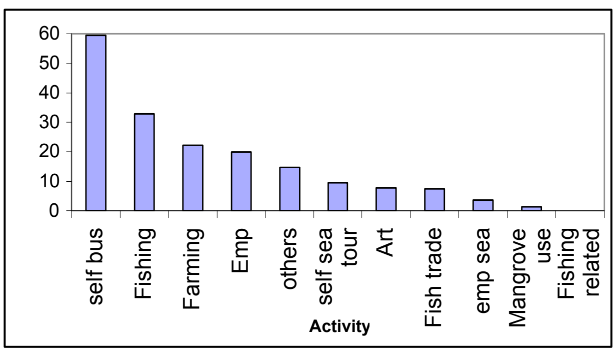

Figure 4. General occupations in Diani-Chale at site level (see Table 1 for explanation of occupation abbreviations).

farming. About 19% of households relied on various forms of paid employment including casual employment. The rest of activities were undertaken by less than 10% of households, such as fish trading, 7.3%, sea and coastal related tourism activities such as boat operators, dive assistants, coxswains and beach operators were undertaken in 9.5 % of the households.

Small businesses or self-employment was the most common livelihood activity in all three villages (Fig. 5), supporting 36% of households in Biga, 44 % in Gazi and 84% in Chale where it was more than twice the proportion supported of any other activities. Fishing was the second most important activity for households in Biga supporting about 33% households, while it ranked third in Chale 33.5% and in Gazi, 31% after farming and employment respectively. Self-employment in sea tourism ranked third in Biga village where it supported more than 23% of households compared to the other 2 villages. Self-employment activities in tourism include boat operators and beach operators.

A minimal number of households were dependent on self-employed sea tourism in Chale and Gazi villages, 8.6% and 1.8% respectively. Similarly employment in sea related tourism activities such as dive assistants, coxswains was below 10% in all three villages, Chale was highest with 6.1%, while Biga and Gazi villages had less than 2%.

Non-sea related tourism activities such as employment in beach hotels were only encountered in about 2% of the households in Biga, non in Gazi and an insignificant percentage in Chale. Farming supported 38.6% of the households in Chale, the highest proportion among the 3 villages, even slightly

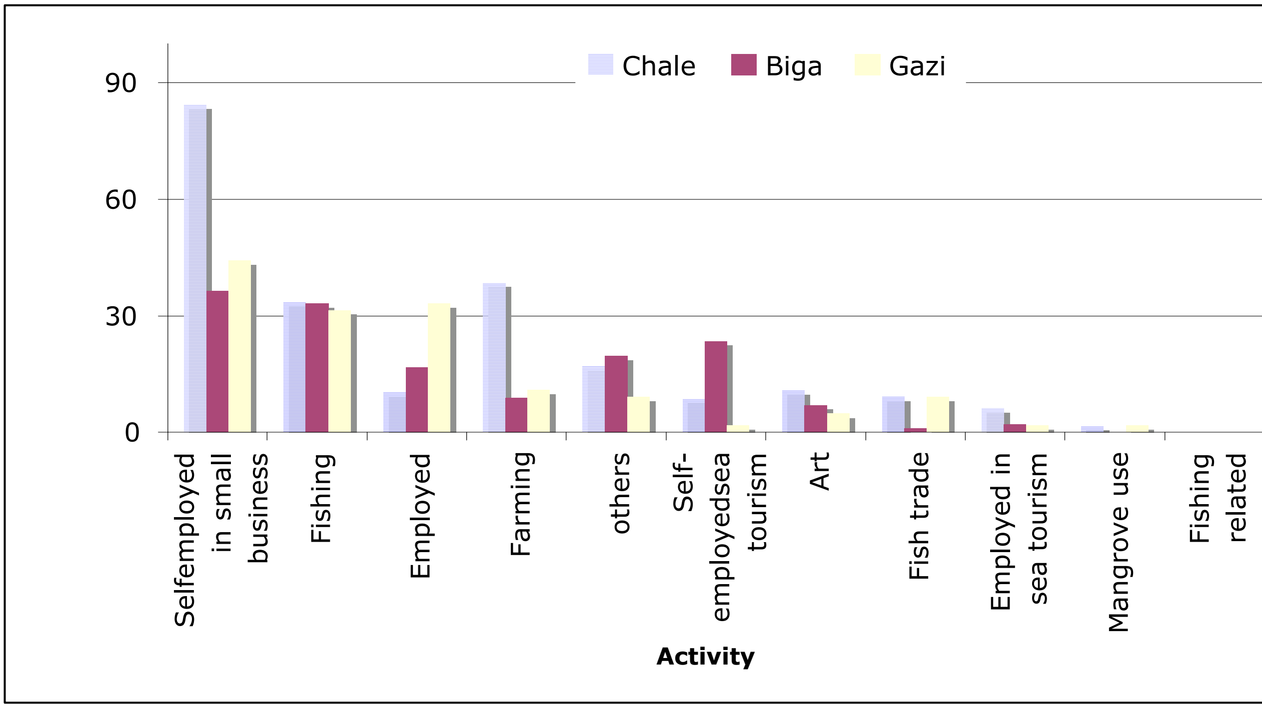

Figure 5. General Occupations in Diani Chale at Village level.

exceeding fishing in the village. In Biga and Gazi villages, farming supported much less than 11% of the households. Gazi was the only village with a high proportion of households (above 33%) in either formal employment or casual employment. Less than 17% of the households in Biga and Chale depended on formal and casual employment. The same proportion of households in Gazi and Chale, 9.1% villages, undertook fish trade and much less in Biga, 1%.

Considering only those livelihood activities that depended on natural resources in Diani-Chale area, fisheries were the most important activity (39% of all households) followed by farming (22%) and tourism activities (13%) while households depended on mangrove were only 1.3%. At the village level, fisheries were the most important activity, supporting > 34% of households, in all villages. Farming was second most important in Chale (38%) but ranked third in Biga at only 12%. Tourism was ranked second in Biga at 25.5 % while it was third in Chale (14.7%) and very low in importance in Gazi (1.4%), a

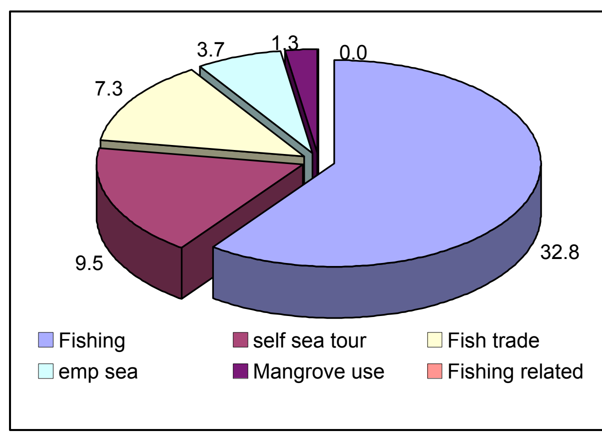

Figure 6. Marine resource based activities at site level.

proportion that was lower than mangrove use.

Among marine-based occupations in the Diani-Chale area, fishing was the most important supporting 32.8% households (Fig. 6). Self employed sea based tourism activities and fish trading were 2nd and 3rd most important although each supported less than 10% of the households, the two combined supported much fewer households compared to fishing alone.

At the village level fishing was followed closely by self employed sea tourism in Biga (23%) while in Chale, only about 9% of the households depended on self employed sea tourism, a proportion equal to fish trade, 9%. Biga was the only village where self-employed sea tourism contributed towards the livelihoods of such a high proportion of household. Fish trading ranked 2nd in Chale where it supported just over 9% of households. Among Gazi households, fish trade supported about 8% where it was second most important among the marine activities, the rest including mangrove use supported less than 3% of the households each. Chale had the highest dependence on employment in sea-based tourism (6%) a proportion three times that of Biga village. On the contrary dependence on self-employed sea tourism activities was ranked highest in Biga among the three villages.

DISCUSSION

This monitoring exercise considered all activities that contribute food or income at the household level. Thus it includes activities that are often excluded during regular censuses, such as home-based and household enterprises such as the making of mats, vending food and vegetables, and farming for food. Such activities are often classified as unpaid family work yet they contribute significantly to the household economy and can be developed further to improve livelihoods. Further, women undertake much of this work, their contribution in the economy is very under-reported in regular censuses. This is more so considering that females headed up to 28.2% of households in Diani-Chale. The Kwale District Development Plan of 1997-2001, shows the district has high rates of unemployment. The percentage of economically active population in wage employment in Kwale district is 19.8% (CBS, 1999). 63.8% of the unpaid workers were females and 33.3% of women workers engaged in unpaid family work (CBS, 1999).

The average household size is 5.3 in Kwale district, with 34.8% of households headed by females (CBS 1999). These figures were very similar to those obtained for Diani Chale area during from this monitoring where the average household size was 5.4 (Table 1) and 27.8% households were female-headed (Fig. 3). Gazi village had more female-headed households in the area, a pointer to their active involvement in livelihood activities . In this study the importance of an activity as a source of livelihood was considered according to how many households undertake it rather than how much income it generates. This is because some activities are less formal in nature and are meant to directly provide food to the household rather than bring income. Consequently activities carried out by women were fairly addressed.

Livelihoods in the Diani-Chale area were largely dependent on natural resources available within the area e.g. fishing and fish trading activities and farming. The close proximity of the sea has greatly influenced the activities the community undertakes (King, 2000). Fishing was the single most widely undertaken marine related activity in this area followed by fish trading. Chale and Gazi villages had the largest proportion of fish traders (Fig. 3).

Close proximity of the 3 Diani-Chale villages to tourism activities is expected to provide income opportunities for the communities (Kwale District Development plan 1997-2001). This expectation was true for Biga village, which is located closest to the active tourist beaches of the Diani-Chale area. However, monitoring shows that whereas informal tourism activities (i.e. boat operating, beach operators and dive operators) accounted for activities in more than 23% of households, formal employment in tourism was depended upon by less than 2% of the households (Fig. 5). This latter figure is a very small proportion for an area with many hotels. Previous studies indicate that one of the causes for the disappointment of the local community about the presence of tourism in the area is the lack of benefits for the community (Rubens, 1996). Tourism development has not directly benefited this community in the form of formal employment opportunities. This may be an indicator of the lack of vocational skills, required to work in this sector at the local level. While this low level of formal employment is partially compensated for in the informal sector, resentment is felt in the local community.

Gazi village had a higher proportion of households dependent on employment, at 33% than the other villages, at about 20%. The population of Gazi has more people who have immigrated from outside the Diani-Chale area. By contrast, Chale villagers had a higher dependence on farming (33.5%), considerably higher than for Gazi and Biga villages and slightly above fishing in the same village. This is attributable to availability of large areas of undeveloped land that is easily converted to farmland. However, farming in the area is severely affected by the presence of many wild pigs and primates from the adjacent sacred "Kaya Kinondo ", which raid crops.

CONCLUSIONS

Households in Diani-Chale have diverse livelihood options by having household members involved in multiple activities. This helps to subsidize fisheries, and may be a response to the decline in fisheries in the area. The most important of options to fishing were farming and tourism in Chale, beach tourism in Biga, and employment in Gazi. All 3 villages were actively involved in small business enterprises. Fisheries were the most important marine based livelihood option in Diani-Chale, hence fisheries management is critical to sustainability of livelihoods in the area. A more holistic approach to fisheries management over the current sectoral approach is needed for the area, particularly considering the other livelihood activities that households already undertake. Promoting other marine based activities but which have been under-utilized to date will maximise community benefits, including for example sustainable mangrove utilization for Gazi village, and more active involvement in formal sea tourism activities in Biga. Management should also focus on promoting other highly ranked sources of livelihoods such as small businesses the community undertakes, to make them more profitable.

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In the Face of Poverty Mangrove Wetlands are Lifelines: Viability Indicators in Silvofishery Initiatives along the Kenyan Coast Assessing Polyculture of Milkfish *(Chanos chanos)* and Mullets *(Mugil mugil)*

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ABSTRACT

Milkfish (*Chanos chanos*) have been grown in polyculture with mullets (*Mugil cephalus*) in marine coastal ponds to increase productivity by more efficiently utilizing ecological resources within an aquatic environment and reduction of risks. Little attempts have been made to culture the two together in East Africa. The study was aimed at identifying the growth rate of milkfish and mullets during the wet (long rains) and dry seasons (short rains) in Kenya; assess variability in pond water quality during peak spring and neap tides; and, assess milkfish and mullet fingerling occurrence over the year. The culture was done in three earthen ponds (each 0.018ha) constructed in the sandy flat behind the mangrove forest, in Kwetu and Majaoni, Mtwapa creek, and Makongeni, Gazi bay. The first culture cycle was July –December 2005 (dry-short rains) and second culture cycle being March-August 2006 (wet-long rains). Stocking was done at 4 fish/m^2 and a polyculture ratio of 5 milkfish: 1 mullet with an organic manure fertilization (poultry manure) of 25kg in sacks floated on the pond and replaced after every three weeks. Fish sampling was done once every month. Basic water quality parameters (temperature and oxygen) were measured twice a week while other water parameters and nutrient analysis were done four times during the experimental period at peak neap and spring tides. Milkfish and mullet fingerling collection was done for six days in a month during spring tide using a "mosquito-mesh" seine net and push net along the mangrove channels where the water remains stagnant at low tide and during the incoming water. One way ANOVA indicated that milkfish growth rate was significantly lower in wet (0.52 ± 0.18 g/day) than dry (1.21 ± 1.0 g/day) seasons ($P<0.001$), and similarly for mullet between wet and dry (0.15 ± 0.04 vs. 0.29 ± 0.15 g/day, $p<0.05$). Pond water temperature varied between 27.1±1.3 to 31.2±2.1°C (morning and

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

evening respectively) during dry season and 25.7±1.2 to 28.2±1.9oC in the wet season. Fingerling availability in 2005 - 2006 was analysed with repeated ANOVA and indicated significant difference in milkfish ($P<0.001$) and mullet ($P<0.001$) abundance between months; the occurrence of the two fish species also differed significantly at $P<0.001$.

INTRODUCTION

Fish farming accounts for more than one-quarter of the total fish directly consumed by humans, using about 220 finfish and shellfish species (Naylor et al., 2000). Tilapia, milkfish, catfish, carps and marine molluscs contribute 80 % of the global aquaculture output amounting to 29 million tonnes in 1997 (Naylor et al., 2000). Ninety percent of the world's aquaculture is undertaken in Asia, with China producing two – thirds of the world total while Europe, North America and Japan, which produce only 10% consume the bulk of the seafood traded internationally (Naylor et al., 2000).

Milkfish aquaculture has a long history in Nauru (Pacific Ocean) where fry were caught in the surf and transferred to brackish water Ponds Island's interior which caused mortality of most fry but a large number survived (Spennemann, 2002). Schuster (1960) reported that milkfish have been recorded in the Red Sea, the Aden Gulf, the California Gulf, and off the coast of East Africa. Milkfish culture can be traced back about 700 years in Indonesia (Ronquillo, 1975), and at least 400 years in Philippines (Ling, 1977). At present milkfish occurs near continental shelves and around oceanic islands throughout the tropical indo-pacific. Mullets (*Mugil cephalus*) are temperate and tropical euryhaline (Tucker and John, 1998).

Chanos chanos belongs to a monotypic gonorynchiform family and is most closely related to the freshwater Ostariophysi (Bagarinao, 1994). Milkfish populations show high genetic variation but low genetic divergence, similar to other commercially important teleosts. The natural life history of milkfish is one of continual migration. Adults are relatively large (to 1.5 m or 15 kg), long-lived (to 15 years), pelagic and schooling. They spawn offshore near coral reefs or small islands. The eggs, embryos and larvae are pelagic and relatively larger than those of most marine species. Larvae ≥10mm long and 2-3 weeks old move inshore via a combination of passive advection and active migration. Passing shore waters and surf zones, they settle in shallow-water depositional habitats such as mangrove swamps and coral lagoons, where they spend a few months as juveniles. A fishery on inshore larvae supports the centuries-old aquaculture of milkfish in Southeast Asia. The mullet (*Mugil cephalus*) is under family mugilidae which are schooling, very omnivorous and eat detritus and a wide range of organic material. The suitable temperatures for spawning range between 23 to 28°C while suitable salinity ranges are 17 to 36 ppt (Tucker and John, 1998). In Florida the mullets spawn offshore and larvae start drifting to shallow coastal areas while adults are found in the shallow coastal and estuaries. *Mugil cephalus* are extremely active omnivores and almost constantly swimming and feeding over wide areas.

The development of mariculture in Africa has experienced several setbacks including high cost of labour per unit output (Christensen, 1995); lack of documentation on possible impacts to the environment; appropriate technology; facilities, infrastructure and government policies. Despite that, the demand for marine fisheries production is increasing with the expansion of tourism and increase in human population (Anon, 1997).

Milkfish have been grown in polyculture with mullets in marine coastal ponds (Joseph, 1982). The underlying goal of polyculture involves increasing productivity by more efficiently utilizing ecological resources within an aquatic environment inclusive reduction of the risks i.e. mullets are especially susceptible to ectoparasites and scale loss (during handling) leading to vibriosis (Tucker and John, 1998) . This type of aquaculture is attempted by stocking species with different feeding habits and different habitat preferences (Lutz, 2003). Synergism is often seen in polyculture systems where some species perform better in presence of other species.

From the biological, environmental and economic sustainability points of view, it is now becoming clear that it is more advantageous to farm herbivorous rather than carnivorous fish because of the lower amount of fish meal required as well as conversion efficiency (Mmochi et al., 2002). However despite the debates on the issue, farming of herbivorous finfish and filter feeders has a better chance of solving the world's food problems and protecting the environment.

The success of milkfish as a cultured food fish species may be attributed to its ability to tolerate extremes of environmental conditions; temperature, salinity, dissolved oxygen, ammonia, nitrite, crowding and starvation. Low temperatures (23°C) decrease survival, activity, food intake, and growth and development of milkfish while high temperatures (up to 33°C) have the opposite effect (Villaluz and Unggui, 1983). Milkfish tend to show signs of hypoxia at 1.4mg/l while 50% mortality occurs around 0.1 to 0.4 mg/l at 31 to 34°C (Gerochi et al., 1978). Tolerance limits to salinity vary with age (Duenas and Young, 1983) with larger fish being more efficient at handling osmotic stress than smaller ones (Ferraris et al., 1983). Milkfish can tolerate high ammonia levels of 21 to 20ppm, far above the normal values (around 1ppm) recorded in ponds (Jumalon, 1979; Cruz, 1981). Gill damage due to ammonia is reversible ten days after exposure in ammonia-free water. The juvenile can also tolerate high levels of nitrite- 675ppm (Almendras, 1987), thus eliminating ammonia and nitrite toxicity as main factors of mass kills in milkfish ponds.

In consideration of the above attributes, and research studies in Kenya and Tanzania, this research came up with a silvofisheries (polyculture of milkfish and mullets) program to look at innovations on community mariculture which can be easily adoptable; cheap; accessible; sustainable and of less environmental impacts to the environment. The water supply to the earthen culture ponds depended on the tidal cycle of seawater with no artificial aeration or water input. Several water quality parameters were monitored and assessed regularly during spring and neap tides. The objectives of this study were: to monitor the variations of the main water quality parameters in the culture pond at spring and neap and relate them to fish production; to monitor growth rate and yield of milkfish and mullets during the rainy and dry seasons; to assess if there is any seasonal variability in milkfish and mullets fingerling abundance.

METHODS

Study Site, Pond Design and Preparation

The study was carried out in three replicate ponds in three sites along the Kenyan coast: Kwetu Training Centre - Mtwapa creek, Majaoni youth group-Mtwapa creek and Makongeni Baraka conservation group-Gazi bay (Fig. 1). Three replicate ponds of 0.018ha were used for the trials – one from each site. Waste pipes with elbows were place at the gate sites for filling in water and draining of ponds while other waste pipes with screens were placed on the dykes relatively higher as overflows during high spring tides and occasionally during heavy rain floods (Fig. 2). Pond design and preparation took place from February to May 2005 and for the second phase, January to February 2006. After completion of pond construction, ponds were cured through drying and water flushing in preparation for stocking. One week prior to stocking, water was let into the pond through screens at the gate and overflow pipes.

Water Quality and Fertilization

Water temperature, pH, salinity and dissolved oxygen were taken in situ. While water samples were collected for chl-a, BOD, Ammonia, Nitrites, Phosphates, calcium, particulate organic matter and total suspended matter in the laboratory. Water samples were taken at 3 points a long a transect in each of the culture ponds and mixed to get a sub-sample for laboratory analysis. The parameters that were measured in the field involved measuring at three points along a transect to obtain an average. Water quality status is quite eminent in aquaculture ponds.

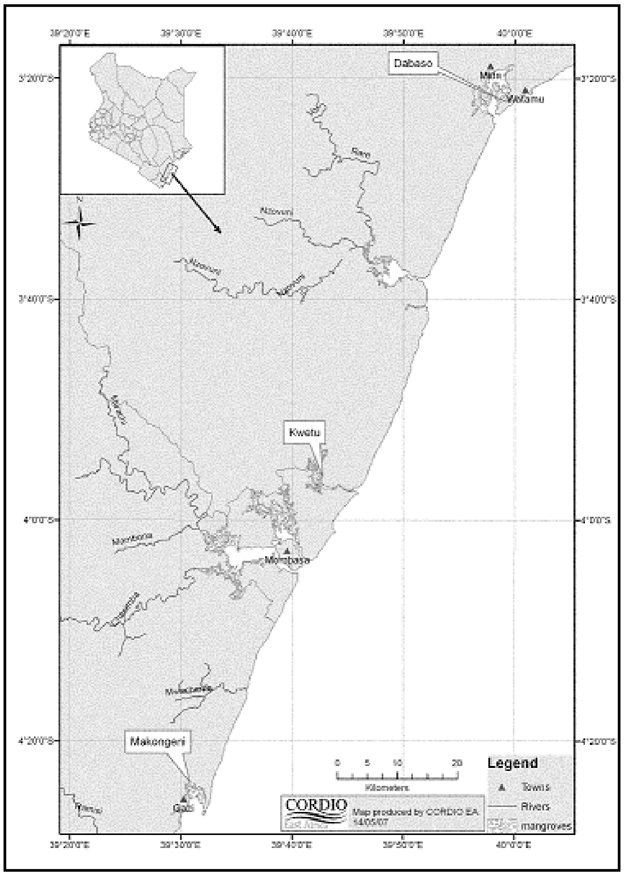

Figure 1. Map of Kenya coast showing the study sites where polyculture trials were carried out (Mtwapa creek and Gazi bay).

Figure 2. A pond at Majaoni showing stand pipe for draining the pond and overflow pipes to relieve the pond of extra water at spring high tides and increase water exchange in the culture ponds.

Temperature of the pond was monitored on a daily basis (morning; 0800 hours to 0930hours and evening; 1400hours to 1600hours) for a period of seven months in the first culture cycle-2005 and five months in the second culture cycle-2006. Dissolved Oxygen and Biological Oxygen Demand were measured three times during the experimental period in the morning and evening while other parameters were measured twice at spring and neap tides in the course of the field experiment. Costly water quality parameters were minimized since the results were targeted to help the local people who may not have the equipment and technology/know-how to use them. Whenever any stress was observed on the fish; sensitive water quality parameters (Dissolved oxygen) were assessed to ascertain if they were within the tolerance levels.

The culture facility (pond) was designed to allow in water at high spring tide to enrich the pond with planktonic materials and nutrients from the ocean water to develop the required lablab (benthic algal mat) for milkfish and mullets. During neap tide, four sacks of chicken manure weighing 25kgs each were floating in the pond to release nutrients for primary productivity in the pond and production of the benthic algal mat. The manure could also act as direct food for milkfish and mullets which were the target species under culture. No application of artificial fertilizer was made and manuring was reduced to three week intervals to reduce input of excess nutrients into the ocean.

Pond Stocking and Fish Sampling

Fish fingerling collection took place for a period of 2 months (April – June 2005) for the first cycle and March - April 2006 for the second cycle due to unavailability of the seeds. The culture period was programmed to be between six and seven months in the two trials. During the first cycle, a total of 692 milkfish and 124 mullets were stocked per pond with similar stocking in the second cycle. Milkfish and mullet fingerlings of between 2-8cm total length with an average weight of 5-9g/fish were selected for

Table 1. Average water quality parameters as recorded in the ponds at spring and neap tides and average quality of the open sea

Water quality parameters	Pond water		Surrounding Ocean
	Neap tides	Spring tides	
Chlorophyll-a (µg/l)	0.925±0.740	1.733±0.580	0.75±0.32
Calcium (mg/l)	0.019±0.020	0.0347±0.010	0.015±0.01
Total suspended matter(g/l)	0.0367±0.004	0.0398±0.004	0.0456±0.13
Particulate organic matter(g/l)	0.0335±0.004	0.0366±0.003	0.0426±0.06
Dissolved oxygen(mg/l)	5.75±2.530	6.592±3.580	5.25±2.36
BOD (MgO_2/l)	0.7587±0.367	0.9622±0.693	0.2±0.34
Salinity (ppt)	27.382±0.120	34.667±3.270	32.58±0.11
pH	8.0783±0.065	7.445±0.022	7.52±0.12
Ammonia-N (mg/l)	1.243±0.780	0.5311±0.086	0.214±0.02
Phosphate (mg/l)	1.718±0.140	0.0382±0.008	0.153±0.04
Nitrite-N (mg/l)	0.0723±0.034	0.0196±0.003	0.017±0.21

stocking. However, a number of other fish entered in with the tide as eggs through the screens but were removed with hook and line and at sampling.

Sampling was limited to two times during the capture period. This was mainly due to inadequate techniques of capturing milkfish and mullets, lack of efficient sampling tools, and the fear to cause frequent discomfort to the fish as a result of very muddy bottom. The proportion of sampling in terms of numbers could not be obtained since few fish were able to be caught at any one time and constant movements in the waters could not be made due increased turbidity with each movement.

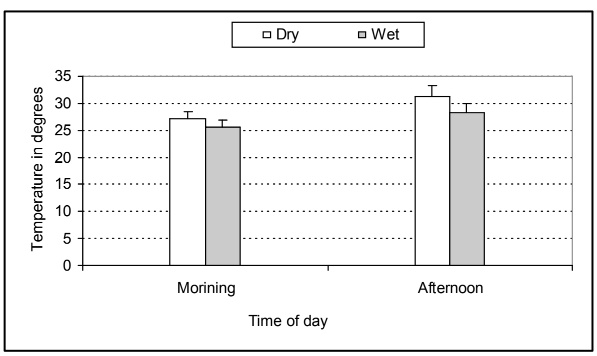

Figure 3. Temperature variations in the culture ponds during wet and dry seasons in the three replicate pond sites along the coast of Kenya.

Harvesting

Harvesting was done after 7 months in the first cycle and 5 months in the second cycle. The whole pond was drained of all the water in order to allow for effective harvesting to take place. All the harvested fish were grouped into their respective species (milkfish and mullets) then separated into sizes and measured for both total length and wet weight (Fig. 3). Harvested fish were then sold to the local people at a reasonable price to create awareness on the potential for fish culture and mangrove conservation.

RESULTS

Pond Water Quality

A survey of the physical chemical parameters was done in the sea water around the replicate culture ponds to assess if there were any significant difference between pond water and open sea water quality in sites and tides. No significant differences in open water quality were observed in the 3 replicate ponds ($p = 0.478$). Table 1 gives a summary of average water quality

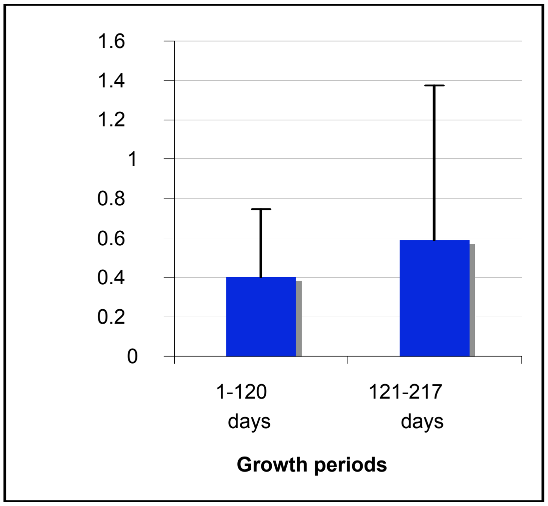

Figure 4. Growth trend of milkfish in an earthen pond during the wet season over a period of 217 days.

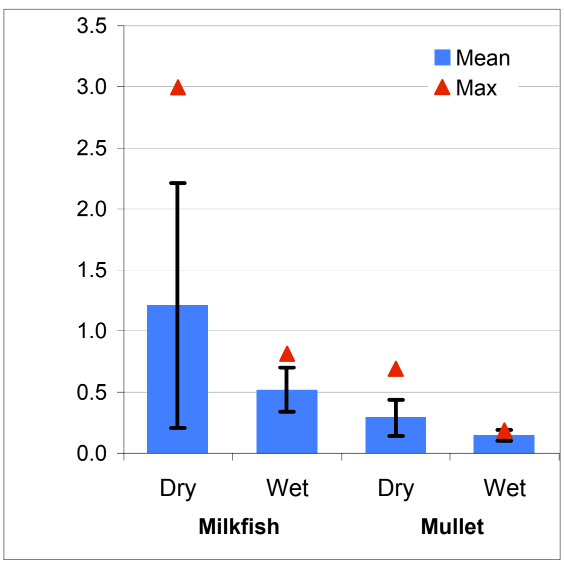

Figure 5. Growth rate (g/day) of milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) during different growing season (wet and dry) along the coast of Kenya.

Table 2. Harvesting size (mean, standard deviation and maximum, in grams) of milkfish and mullet per culture cycle during the period 2005-2006.

Season	Parameter	Milkfish	Mullet
Wet	m ± sd (g)	81.3 ± 28.1	28.7 ± 6.9
	max (g)	117.8	30.4
Dry	m ± sd (g)	262.5 ± 218.1	62.9 ± 31.9
	max (g)	650.5	150.2

parameters recorded in the ponds (neap and spring tides) and sea.

Wet months indicated lower mean temperatures compared to dry months however not significantly different ($p = 0.078$). One way ANOVA indicated significantly lower morning temperatures in the pond water compared to the afternoon ($p = 0.05$) (Fig. 3). Pond water was generally neutral at neap tide pH 7.4 equivalent to that of the open sea pH 7.5 while it became more alkaline at spring tide pH 8.1.

On average, dissolved oxygen was reasonably high ranging between 5.8-6.6mg/l in neap and spring tides (Table 1). ANOVA results showed that salinity of water was significantly higher at spring tides (34.7ppt) compared to neap tides (27.4ppt) ($p = 0.05$).

Chlorophyll-a was highly influenced by spring tides in the pond increasing to almost double that recorded in the neap tides a concept justifying the importance of water exchange in the culture ponds and the dependence on the natural productivity of the mangrove system. Low levels of suspended organic matter and particulate organic matter were recorded in the pond systems, which lead to the low BOD recorded in the ponds (Table 1).

Fish Growth Rate and Harvesting Size

Milkfish growth was consistent over the study, averaging 0.4 g/day in the first 120 days and almost 0.6 g/day from 121-217 days (Fig. 4). However variation in growth rate among individuals was very high: of the 7 individuals sampled, 2 fish with starting

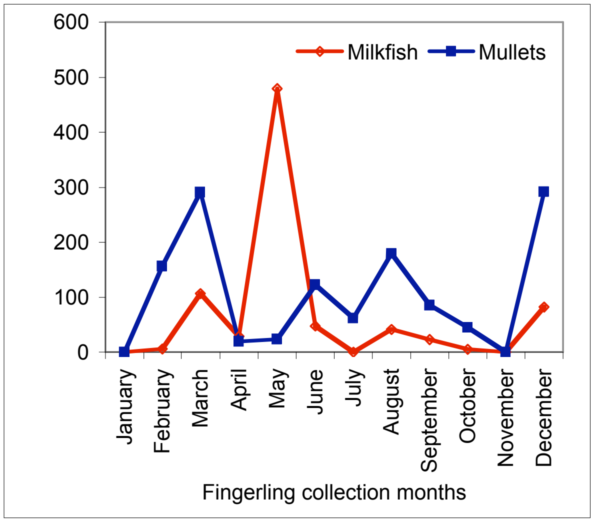

Figure 6. Number of milkfish and mullet fingerling collected from 2005-2006.

weights of 24.8 and 25.3g grew to 80 and 370g, respectively, over 217 days, while 5 fish from 2.8 – 5.4g initial weight grew to 34 – 115.3g over the same period.

Both milkfish and mullet fish were observed to be active during mid afternoon in hot sunny days. The average growth rate for mullet fish was comparatively lower than milkfish ($p = 0.05$). The dry season provided the highest significant growth rate for both milkfish (1.21g/day) and mullets (0.29g/day) compared to the wet season ($p = 0.05$) (Fig. 5). The average weight of milkfish harvested during the dry season differed significantly from that of wet season ($p = 0.05$) however, with a higher standard variation in the dry season (Table 2). The same trend was recorded for mullets but with relatively small standard deviations between the individual fish weights. The maximum weight attained by the both milkfish and mullets varied in the wet and dry seasons.

Fingerling Occurrence

The survey made for two years (2005-2006) indicated that milkfish occurrence could be only reliable twice in a year between March and June with a peak being recorded in May. A relatively small collection peak was found in December. Hardly any fingerling collection for milkfish could be made in January and February while a few were collected between July and October (Fig. 6). Mullet fish fingerling abundance was observed to be more abundant throughout the year with limited occurrence between April and June and in November. The abundance of the milkfish and mullet fingerlings varied between and within sites with no significant difference ($p = .089$).

DISCUSSION

Culture Species and Fingerling Capture Strategy

Milkfish *(Chanos chanos)* and mullet *(Mugil cephalus)* were targeted for culture in this trial due to their tolerance to a wide range of water quality factors, simplicity of feeding habits and adaptability to crowding. The ability for crowding helps to capture many species at a small point unlike the territorial ones (Rice and Devera, 1998). In small scale aquaculture, culture of species that are tolerant to a wide range of water quality factors help to reduce culture expenses; implying that it is best to select species that are tolerant to fluctuations and extremes of water quality like milkfish and mullets (Swift, 1985).

All the seed stocked were readily obtained from the wild through seining but not from hatcheries. Even in South East Asia where hatchery technology has been developed (Lee and Liao, 1985), most of the culture of this species is based on collection of larval and juvenile fish from a capture fishery (Villaluz, 1986). Mosquito nets being cheap and available locally were used to seine milkfish and mullet fingerlings along the mangrove channels both at low and high tides during spring tides. Occasionally the milkfish and mullet fingerlings were found in the pools of water within the intertidal area at low tide and scooped with hand nets for stocking.

Water Quality

Conversion of wetlands into aquaculture ponds has resulted in increase of nutrients and organic wastes, leading to general deterioration of water quality (Mmochi et al., 2002). The water quality problem is associated with both physical and chemical factors such as high or low dissolved oxygen, high concentration of nitrogenous compounds (ammonia-N and nitrate-N) and high levels of hydrogen sulphide.

Temperature and Salinity

Milkfish do not inhabit areas of the Pacific Ocean influenced by cold currents but they do occur in seas affected by warm ocean currents. Their distribution coincides with coral reef areas where the water is warm (more than 20°C), clear and shallow (FAO, 1987).

Temperature was not observed to be a problem in the milkfish and mullet culture ponds since it varied from 24°C to 33°C during wet and dry seasons. It was significantly higher during the dry season (27.1°C - 31.2°C) compared to wet season (25.7°C -28.2oC). Therefore temperature was not a limiting factor to growth as argued by Roberts (1964). Based on the argument by Rice (2003) that warm water fish species grow best between 25 and 32°C, the recorded water temperature in this study was appropriate for fish growth.

Higher salinity influences solubility of oxygen in water, resulting in decreased dissolved oxygen saturation in the water. Fish get adapted to specific salinity regimes and become stressed when there are rapid changes (Rice, 2003). In the current study salinity was significantly high at spring (mean 34.7ppt) compared to neap tides (mean 27.4ppt). This was a clear indication of the tolerance needed for the culture species for effective culture process. The recorded salinity level falls within the range of salinity in the marine environment and was not expected to cause any stress in growth of cultured fish and mainly tolerant species like milkfish and mullets (Lee and Liao, 1985). However, it has been pointed out that a salinity difference of only 5mg/l (ppt) can be lethal to some fish (Boyd, 1990; Rice, 2003). This might have been the cause of the fish kill that occurred in the present study two days after heavy rains during wet season that reduced salinity significantly to 25ppt.

pH and Chlorophyll-a

Most fish can survive normally in a pH range of 6.5 to 8.7 (Rice, 2003) while extremes of pH can be directly harmful to the fish or increase the toxicity of a number of naturally occurring ions or metabolic wastes such as ammonia. In the current study, pH levels were within the fish culture levels (7.0 to 8.5) while increasing as the day matures. There was a clear difference in pH between neap (8.07) and spring (7.44) with higher values being recorded at neap in the mornings and afternoons. There was a general increasing pH from morning to evening which is associated to photosynthesis during the day that used up carbon dioxide thus facilitating the release of carbonate ions from calcium carbonate (Boyd, 1992), but the levels were okay for milkfish culture. The levels compared well with the values found in the mangrove channels (7.52) where no fish were being cultured however, the afternoon pH was comparatively low compared with the ones recorded by Mirera (2000) in the Tilapia ponds where artificial fertilizers were used. Waters that are in the range of pH 6.7 to 8.0 at day break and 9.0 to 10.0 by late afternoon are considered the best for fish production.

Chlorophyll-a, is an indicator of primary productivity in the pond. High chlorophyll-a, indicate good primary productivity in the ponds to warrant high fish production. Mean values at neap were lower (0.93 µg/l) than spring (1.73 µg/l). The recorded results in these research study were higher compared to those by Mirera (2000) at Sagana in his studies of phosphorus fertilization where a high correlation was observed between fish standing crop and chl-a. Consequently, they were much lower than those recorded by Boyd (1992) at Auburn University. Measurement of chlorophyll-a levels in water within the mangrove channel (0.75 µg/l), revealed that the pond had higher levels and hence likely to be more productive.

Dissolved Oxygen

Dissolved oxygen is one of the critical parameters of concern with any kind of aquaculture system, therefore calling for proper monitoring of its dynamics in small scale pond aquaculture where aerators are not applicable. Dissolved oxygen levels in this study were between 5.75 and 6.59mg/l which did not have any significant difference with the surrounding sea water. However, mortalities (fish kill) were observed following two days of rainfall in the Kwetu and Majaoni ponds during the wet season that was associated to stratification of water forcing fish to gulp for air on the surface in the early morning which was hardly enough (less than 0.9mg/l) due to still air (Rice, 2003). Dissolved oxygen (DO) levels were relatively high in the pond in the early morning of spring high tide (2.85 -4.1mg/l) and afternoon (7.5-8.3 mg/l). The neap tide dissolved oxygen variation was between 3.25 -3.75mg/l in the morning and 8.6 – 11.15mg/l in the afternoon. While the morning values were similar to those obtained by Mirera (2000) in his phosphorus experiments, afternoon values were far much lower in the current study which explains the difference of artificial and organic fertilization.

More dissolved oxygen was recorded in the ponds during spring tides than at neap tides which could be a result of temperature, salinity, chlorophyll-a and atmospheric pressure (Batiuk, 2002). According to Boyd (1990) and Rice (2003), an artisanal fish pond should have sufficient oxygen levels to support fish all the way to the bottom. However, fish selected for culture in artisanal ponds should be tolerant to low dissolved oxygen a case which was observed for milkfish and mullets in the current study.

Nitrite and Ammonia-N

The level of nitrite (toxic component of nitrogen) in the culture ponds was relatively low (0.0196 - 0.0723mg/l) compared to what is expected in aquaculture ponds. This can be associated to the fact that no feeding was used during this experiments which could have increased the amount of nitrogen in the water (Darborow et al., 1997). Significantly higher nitrite levels were recorded in neap tides compared to spring tides possibly because of reduction in water level by evaporation or higher amount of organic matter in the system due to higher lablab accumulation and decomposition (Neori et al., 1989; Hall et al., 1992). The nitrite levels were also well controlled within limits since there was no much variation in pH which is a contributory factor to their increase.

Total Ammonia Nitrogen (TAN) is composed of toxic (unionized) ammonia-NH3 and non-toxic (ionized) ammonia-NH+4 but only a fraction of the TAN is in the toxic form. Dangerous short term levels of toxic un-ionized ammonia which are capable of killing fish over a few days start at about 0.6mg/l. The total ammonia nitrogen (TAN) recorded in this study were ranging between 0.53 – 1.24mg/l far below the individual toxic component of un-ionized ammonia (0.5 -2.0mg/l). However, there were significant differences in ammonia nitrogen between spring and neap tides indicating the importance of water exchange in a pond systems to help in pond self regulation. The amount of ammonia excreted by fish varies with the amount of feed put into the pond, increasing as feed rate increases. Ammonia also enters the pond from bacterial decomposition of organic matter such as uneaten feed or dead algae and aquatic plants (Darborow et al., 1997) which could have been the main contributory factors in this study since no feed was used.

Phosphates and Calcium

Phosphates were observed to be significantly higher during the neap tides (1.72 mg/l) compared to spring tides (0.038 mg/l). This was associated to the dilution effect of water from the open ocean at spring tides while higher neap tide values could be a result of phytoplankton breakdown and release of phosphates from the sediments (Welch, 1980). The available phosphate levels were above the required values for earthen culture ponds 0.001-0.05ppm (Knud-Hansen, 1998). Hence an indication that soluble reactive phosphorus was not limiting in the pond. Meaning that nitrogen was well utilized in these ponds due to availability of phosphorus, since nitrogen full use may be hindered by deficit of phosphorus.

Calcium concentration in the pond was similar both at spring (0.035mg/l) and neap (0.019mg/l) tide. The difference could be associated to water replenishment in the pond during spring high tides leading to increase in calcium.

Total Suspended Solids and Particulate Organic Matter

Total suspended matter and particulate organic matter are important factors in limiting primary productivity in the culture ponds if their level is too high. The two parameters were noted to be low and of less consequence in the fish culture trials. The values were observed to be low at both spring and neap tides (0.03 to 0.05). Higher levels of total suspended matter was during spring signifying the particles coming in with tidal water and uplift of settled materials at the bottom of the pond due to falling of tidal water from inlet pipes. The result indicated low impact of these factors on primary productivity in the pond, hence, less likely impact on fish yield.

Dynamics of Fish Growth

Milkfish take food mainly from the substrate. They ingest the surface layer of the substrate together with the associated micro-and meio-fauna (Blaber, 1980). Pond reared milkfish feed mainly on either lablab (a complex mat of blue green algae, diatoms and associated invertebrates) or lumut (mainly filamentous green algae). The study observed that milkfish and mullet growth rates were significantly higher during the dry season compared to wet season. This observation is supported by Guanzon et al (2004) who found out that production of milkfish was higher during the dry season. Growth rates of milkfish were positively correlated with temperature and salinity, while net production rates were positively correlated with temperature and rainfall, but were inversely correlated with dissolved oxygen.

The higher growth rate of milkfish and mullets in the dry season is due to abundance of lablab which is the main feed item. It has been observed elsewhere that Lablab is equivalent to the benthic algae (FAO, 1987) and leads to high milkfish production compared to the other methods (Lumut and plankton). Lumut (filamentous green algae especially *Enteromorpha* sp. and *Chaetomorpha* sp) yields are below 400kg/ha, while lablab method yields average 1000 to 2000kg/ha possibly why the milkfish growth in the present study was high in the dry season with abundant lablab unlike in the rain season with abundant lumut. During the rainy season, lablab disintegrates and lumut and/or plankton becomes part of the main natural food base and yet their support to faster fish growth is limited (Banno, 1980).

It was observed that milkfish intensified feeding during mid-afternoon in a hot sunny day when lablab started peeling off the pond bottom to float fostering active surface feeding by fish. The observation was also echoed by Kumagai et al., (1985) and Chiu et al., (1986) “Feeding activity peaks at midday and in the afternoon when dissolved oxygen, water temperature and digestive enzyme activity are highest”.

Studies carried in Asia suggest that harvesting of milkfish is done usually when the fish have reached an average of 300 to 800 g body weight. While pond yields have reportedly ranged from 50 to 500 kg/ha/year (Bardach et al., 1972). The present study harvested milkfish at an average of 82g during the wet season and 263g in the dry season with some of the fish having individual weight of up to 650g concurring well with studies recorded by Mwaluma (2003). Mullets were harvested at a relatively lower average weight of 29g and 63g during wet and dry season respectively. There was a generally uniform growth of milkfish during the wet season suggesting that feed availability and water quality parameters impacted all fish sizes equally.

Fingerlings Occurrence

The spawning cycle of milkfish has been observed to be seasonal and varies with localities. Based on the annual occurrence patterns of milkfish fry, the breeding season of milkfish has been described to be long near the equator and becomes progressively shorter with a single peak at higher latitudes in the northern hemisphere (Kumagai, 1984). Kenya being near the equator, the present survey indicated that milkfish occurrence could be only reliable twice in a year between March and June with a peak in May and a relatively small peak in December while mullet fish occurrence was throughout the year with limited occurrence between April and June when milkfish abundance is expected to be highest. Observations in the Philippines indicate that, milkfish fry occur practically throughout the year with the peak season being April-July and October-November (Villaluz, 1986) while Indonesia has two milkfish fry seasons: April-June and September – December (Chong et al., 1984) that ties well with observations made in the current study. The observations on milkfish fingering occurrence along the coast of Kenya is also supported with records of FAO (FAO, 1987).

Both milkfish and mullet fingerlings in this study were collected during periods of spring high tides. The fish were seined with push nests in the mangrove channel water pools at low tide. In Philippines, milkfish were observed to enter a mangrove lagoon fortnightly with the high tides of spring tide periods where they grow into juveniles before leaving the area with the high tides (Kumagai et al., 1985). The observations also concur with those of Kumagai, (1987) that fry were collected during the new and/or full moon period because intense spawning occurs during the quarter moon period however; total fry catch showed annual fluctuations due to such factors as climate and fishing efforts.

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CORDIO Status Report 2008

Part 8 – Education and Awareness

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

Teacher Training for Education on Marine Resources Conservation in Thailand

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INTRODUCTION

The coastal environment and natural resources along the Thailand coasts, including mangroves, coral reefs, sea grass beds, and beaches, are heavily used for a number of human activities such as tourism, industrial and infrastructural development, fisheries and aquaculture to name a few. Coastal zone development has largely been carried out in a haphazard way, creating a negative impact on the environment as well as on coastal communities, causing habitat degradation, pollution and conflict over resource use, all of which have broader social implications. There is an urgent need to conserve the coastal resources and address the issue of effective coastal zone planning and management.

One of the main underlying causes of inappropriate coastal land and sea use is an inadequate knowledge of coastal resources and sustainable use by the general public and the administrators of coastal communities. Teachers are a valuable human resource in transferring knowledge and creating awareness on environmental issues and sustainable use of natural resources to younger generations as well as communities. Providing access to knowledge through local schoolteachers is considered an essential path to implanting knowledge in society for the long term.

Periodic training of teachers on environmental issues has been carried out in the past by various government and nongovernment agencies. However, often teachers have received some additional knowledge on the subject matter, but not effective teaching tools to be used. Since teachers have many responsibilities through their regular work at schools, most do not have time to set up or update their own teaching curriculum with any regularity, and only some innovative teachers can apply new knowledge for their own use. Thus most past efforts on teacher training have only partially succeeded in providing improved knowledge to the younger generations.

The objectives of this project were to develop teaching manuals for teachers, to be used in school as a key component of teaching activities, and provide training activities in order to improve the teaching and learning process. The expected outcome is to increase awareness and a sense of ownership of marine and coastal resources among children in coastal communities of the Andaman Sea.

Activities covered development of curricula and teaching manuals on coastal and marine resources and

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Figure 1. The development of teaching manuals and training activities.

their management for primary school (year 4-6) and secondary school levels (year 7-9), and conducting training workshops for teachers at both levels. Figure 1 shows some photos from the development of teaching manuals and training activities.

Development of Curricula and Teaching Manuals

A working group was established for the preparation of curricula and teaching manuals on coastal resources and management, comprising lecturers on marine environment and education from Phuket Rajabhat University (PRU) as well as a number of experienced and innovative teachers in Phuket District. A series of meetings and workshops were held to source input, define outline and formats, and draft manuals. The materials were carefully reviewed by an advisory committee that included the educational supervisor of Phuket, an expert on coastal resources, and senior lectures from PRU, to ensure that the manuals were factually correct and contained up to date information, and in agreement with the Ministry of Education's basic education curriculum. The manuals were finalized through extensive consultation with teachers.

The teaching manuals on coastal resources and management for primary school and secondary school level comprise 6 volumes: 1. Coastal environment; 2. Coral reefs; 3. Mangroves; 4. Sea grass beds; 5. Sandy beaches and rocky shores; and 6. Beach forest. The manuals contain a wealth of information on each subject matter, and provide guidance on identifying questions, finding and evaluating information, report

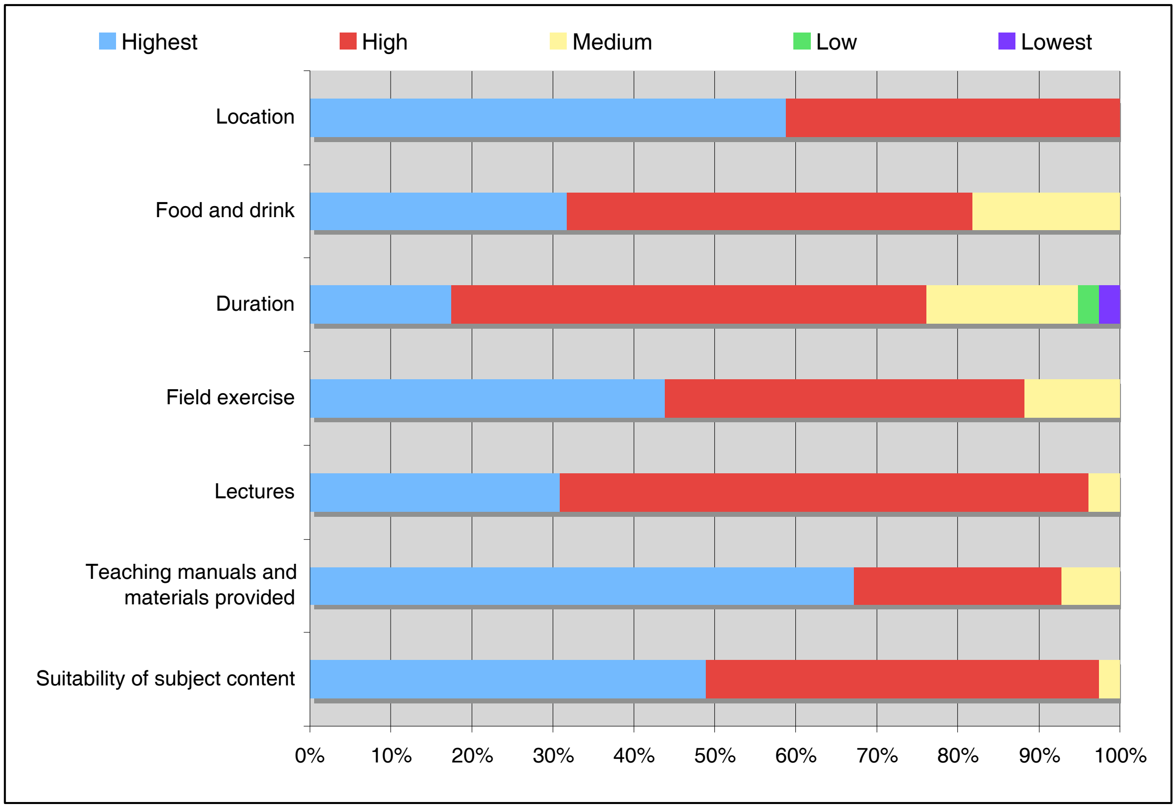

Figure 2. Results of assessment of satisfaction with the teacher training workshops (evaluation results pooled for the two workshops).

presentation, how to subsequently apply knowledge, and suggestions for further inquiry in related subjects. In addition, they include information on the teaching and learning process, sources of additional information, and a section on evaluation and assessment with tools and criteria provided.

By emphasizing students as the learning center (Darling, 1994, Brandes, 1992) the manual for primary school level seeks to promote a dynamic and participatory learning environment. The aim is to create awareness and a capability of learning starting with simple knowledge that relates to the students' living environment. The manual for secondary school level emphasizes processes by which students create their learning activities through an inquiry cycle, using subjects relevant to their surrounding environment (Fennimore, 1995, Lang, 1995). The teaching manuals comply with Ministry of Education directives and formats.

Training Workshops for Teachers

Two teacher-training workshops were held; for primary school level from 17-20 October 2006 and for secondary school level 20-23 November 2006. About 40 teachers from schools in Phuket and Phang-nga provinces attended each workshop. The workshops comprised lectures, field exercises and activities identified in the teaching manuals. Group discussions and exchange of information and opinions were included. Assessment on the satisfaction of the outcome of the workshops is shown in Figure 2. The level of satisfaction with the training was high, with over

80% of the participants rating all items assessed in the "highest" and "high" level of satisfaction categories, with the exception of the duration of the training which some felt was too short ("highest" and "high" ratings were over 75%, though). Most importantly there was a general agreement among participants that the subject content of the manuals was appropriate.

CONCLUSION AND DISCUSSION

The results from the course and material assessment as well as comments received through group discussions with teachers indicate that the teaching manuals are suitable for coastal resources in the area and welcomed by teachers. The manuals can be used in real classes as everyday guidance as well as for special projects and initiatives, they are suitable for the class levels that they target and especially useful in how they stimulate the students' learning abilities. They also are appropriate in view of the basic education standard set by the Thai Ministry of Education. All teachers participating in the training workshops agreed to use the manuals in their teaching activities.

It is recommended that further training workshops are carried out, and also extended to include teachers in other provinces along the coast of the Andaman Sea. With more input and feedback from teachers, improvement and expansion of the teaching manuals can be carried out to cover all subjects on coastal and marine areas. Materials targeting students that link in with teaching materials may also be produced.

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An Education and Awareness Program on Coral Reefs in the Andaman and Nicobar Islands

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INTRODUCTION

The coral reefs around the Andaman and Nicobar Islands have been the main source of livelihood for the islanders over many years. Traditional experience and wisdom passed down over generations, in combination with restricted entry into Tribal Reserves, ensured that fishing practices remained traditional and sustainable over long periods of time.

However, the earthquake and tsunami in 2004 were followed by abrupt displacement of local communities, succeeded by economic, material and social intervention in several parts of the Andaman and almost all of the Nicobar Islands. This disruption in the pattern of life of the population has led away from traditional practices. Changes in coastal topography, temporary changes in distribution of resources, shift of dwellings from the coast and scarcity of equipment to access open waters have made communities fish in inland creeks, even during fish breeding seasons. Protracted stay in transit camps, monetary aid and free food and aid rations, much needed in the aftermath of the tsunami, have also built up inertia among displaced communities to resume traditional ways of life.

To increase our understanding of these changes and to seek possible solutions, an awareness and education program was carried out in association with coral reef surveys.

AWARENESS PROGRAM

Living with local communities during coral reef surveys enabled us to design and carry out awareness campaigns addressing local priorities and needs. The overall focus was sustainable fishing practices and the principal threats to coastal resources, and changes in distribution of resources. In the Andaman Islands, where reefs are still recovering from the damage sustained, particular emphasis was placed on minimizing threats such as sedimentation and pollution from effluents. As the submergence of reefs actually led to the depletion of resources in the Nicobar Islands, the focus was on optimizing the chances for resource revival and seeking alternatives.

Seventeen villages in the Nicobar Islands were visited, and over 2500 villagers participated in awareness events. Often village elders interpreted the event in the local language, and participation of Village Captains, Priests, Heads of Tribal Councils and entire families in these sessions facilitated an extended percolation of the message in the region. Video material was used extensively for the education and awareness program. This included footage

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

obtained during our surveys of the islands, as well as some clippings from films such as the BBC documentary Blue Planet. Film clips showcased the biodiversity of reefs, ecological processes, resource dynamics, as well as threats, impacts and their implications. In 8 villages electrical power was not available and the awareness program focused on interaction and discussion with communities, aided by pictures and illustrations on marine biodiversity. Finally, in 3 villages in the Andaman Islands, experiences were also shared with officials of the Department of Environment and Forests (from Forest Rangers to the Principal Chief Conservator of Forests), and Officers of the Andaman And Nicobar Administration in Port Blair

OBSERVATIONS AND INFERENCES

The experience of living among the island community was enriching, allowing us to learn first-hand about the culture, hospitality, sensitivity and innate curiosity of the villagers. It also made possible a two-way exchange of information and knowledge, which is essential to bring about a synthesis of traditional wisdom and scientific understanding that can support development in these communities, with minimum intervention in lives and culture while ensuring sustainability. However, this requires a long time of continuous contact and dialogue. It is clear, though, that the type of informal educational interactions organized under this program can facilitate this, and will help in bridging the gap between the youth and the traditions of older generations, especially in the current context of changed ecological and socio-economic conditions.

In addition to educational and awareness activities the program made some interesting observations. Traditional fishing practices in the Nicobar Islands previously included a traditional tenure system, governing ownership and use rights of territorial waters of even a single house or a large hamlet adjacent to the sea. It appears this system has been eroded, and post-tsunami resource consumption patterns and emerging fishing practices need to be studied and documented in order to identify the true extent of the impacts of the tsunami and earthquake as well as mitigate negative implications.

In the Andamans, it was observed that many reconstruction activities were being carried out in a rather haphazard way, often without consideration to environmental impact. This includes e.g. utilization of sand from beaches, which could alter beach profiles and stabilization processes after the major perturbation. Further, construction of seawalls and barriers to prevent seawater inundation of specific areas is also preventing tidal movement, which may cause seawater inundation elsewhere, in areas that were not inundated by the tsunami. Cutting wood and vegetation on hills may also have an adverse impact on the reefs due to increased sedimentation during monsoons. It is unfortunate this should still continue as it has long been known to be among the major threats to reefs in the area.

Marine Environmental Education in Kenya

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ABSTRACT

Environmental education (EE) and awareness are important tools in conservation and sustainable development. EE is a process through which information, skills and experiences are shared to empower target groups with knowledge that is translated into positive attitudes and values about the environment and hence an ability to make prudent decisions with regard to the conservation and sustainable use of natural resources. A teachers' training program in EE has been established in Mombasa, starting in 2003, with assistance from ProZim, a Swiss NGO, CORDIO (Coastal Oceans Research and Development Indian Ocean) and other donors. Since 2003, 41 teachers from 28 (13 urban and 15 rural) schools have been trained. Minor differences have been observed between rural and urban school teachers while ranking importance of EE topics. For example, in 2005, methods of transferring EE received the same ranking from both rural and urban teachers; ecology topics received a higher ranking from rural teachers while environmental management topics were ranked higher by urban teachers. This report highlights similarities and differences in ranking importance of EE topics, with possible reasons as well as challenges faced by the teachers in transferring EE.

INTRODUCTION

The Teacher Training concept is adapted in Kenya to meet the Kenyan marine and coastal resource conservation and management needs through partnership with the Mombasa Municipal Education Office and other institutional stakeholders.

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

In Kenya, the primary school curriculum is generally devoid of EE, despite the reliance of people on natural resources for food and livelihood security. The teachers' training program in EE helps to fill this gap by training primary school teachers on aspects of EE ranging from marine and terrestrial ecosystems to methodologies for effective EE knowledge transfer. The training program is carried out through a week-long seminar for 10-15 teachers comprising lectures, discussions, excursions, practical activities and project planning. Case studies for the program are drawn from Haller Park, Mombasa Marine Park and previous year school projects. After the training, teachers implement projects of choice with students through relevant clubs, incorporate EE examples during class lessons and mentor another teacher prior to certification. In addition, follow-up is conducted after the training by linking to learner programs such as "Schools to the Sea" program which offers practical learning opportunities.

The "Schools to the Sea" program promotes greater marine ecology awareness focusing on mangroves, sea grass and corals. It is the result of a collaboration involving CORDIO, ACTS (Assist a Child to School), Buccaneer Diving and Voyager Hotel with funding from Project AWARE and CORDIO. The program targets schools closest to Mombasa Marine Park and has given opportunity to more than 300 pupils and 25 teachers from 9 schools to appreciate the magnificence of the ocean since its commencement in 2006. "Schools to the Sea" is conducted through structured lessons incorporating indoor and outdoor activity including discussions, lectures, art and poetry expression and a component that comprises of guided excursions.

The 2006 Teachers Training Seminar in Environmental Education was the fourth since inception in 2003. Thirteen teachers from 13 primary schools in 4 districts attended, bringing the total number of teachers trained since 2003 to 41. Two environmental education officers and a turtle conservation group member have also attended the seminar in 2004 and 2005 while 3 teachers have

attended the full seminar twice and several have returned to attend some sessions to share their experiences. In the first two years facilitators participated from a supporting Swiss NGO while in the last two years guest facilitators from local institutions have handled technical topics. This has been useful in adapting to local needs and developing a support base for the program.

The aim of the seminars is to build the capacity of teachers to become responsible natural resource users who have an impact on pupils, fellow teachers and the local environment. The objectives are:

1. To increase the environmental capacity of those teachers to pass relevant and correct knowledge and experience to their pupils;
2. To expose the teachers to different methodologies that are effective for EE knowledge transfer;
3. To provide a forum for teachers to interact.

METHODS

English is the main language of communication. Topics in environmental education (EE) theory are initially covered followed by ecology, transfer methodologies and environmental management. EE theory includes introduction to the environment, evolution of EE and case studies from other countries. Ecology topics covered are Haller Park, corals, sea

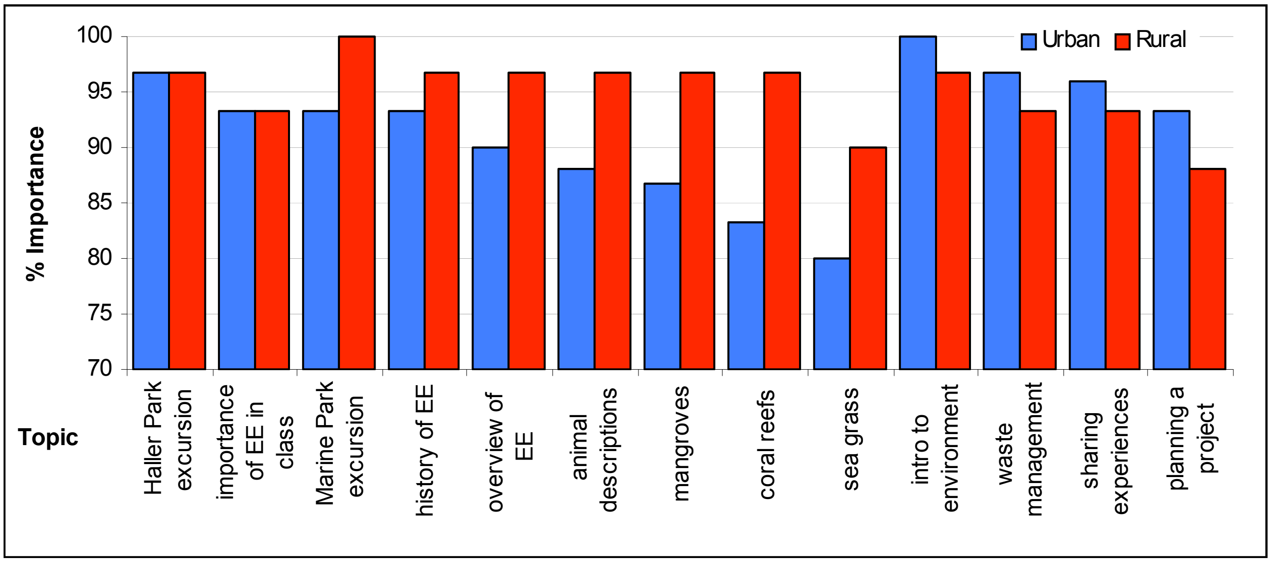

Figure 1. Importance of topics as ranked in 2005.

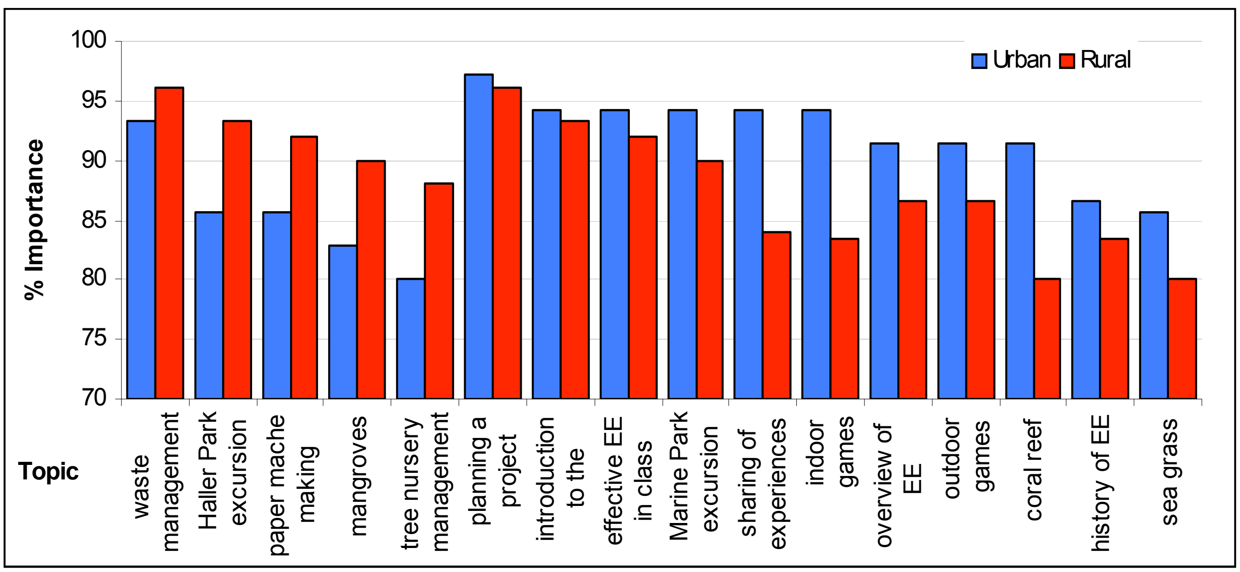

Figure 2. Importance of topics as ranked in 2006.

grass and mangroves. Transfer methodologies shared are indoor and outdoor games, excursions and teacher/pupil project. Environmental management topics covered are tree planting, tree nurseries, waste and pollution as well as recycling opportunities such as paper maché making.

EE theory is led by a facilitator who encourages the participants to be at ease for the transfer methodologies and environmental management topics which are carried out through group sessions, discussions and presentations. Ecology topics are led by technical experts in each particular field.

A pre-seminar questionnaire is used at the start of the seminar to determine the level of exposure participants have in environmental matters and a post seminar questionnaire handed back on the last day summarizes the participants' perceptions on all aspects of the seminar. Daily evaluations are used to determine relevance, level of importance and get suggestions for improvement regarding different topics and how they were covered on each day. Follow-up projects commence in the subsequent school term, in collaboration with partner organizations where possible.

Questionnaires and daily evaluations have been used since 2003 although results and discussion in this paper on relevance of topics ranking is based on 2005 and 2006.

RESULTS

Of the 41 teachers trained since 2003, 51% were male and 49% female, while 59% were from rural schools and 41% urban. The first seminar had fewer participants, but since then a relatively consistent gender and rural/urban balance has been maintained.

In 2005, out of 13 topics, 2 topics received similar ranking from participants, 7 were ranked more important by rural teachers and the remaining 4 were ranked more important by urban teachers (Fig. 1). Similar ranking was given to the excursion in Haller Park and to the importance of using EE in class. Rural teachers gave a greater importance to (in descending order)- Marine Park excursion, history of EE, overview of EE, animal descriptions, mangroves, coral reefs and sea grass. Urban teachers gave a greater importance to (in descending order)- introduction to the environment, waste management, sharing experiences and planning a project.

In 2006, out of 16 topics, 11 were ranked more important by urban teachers and 5 as more important by rural teachers (Fig. 2.) Rural teachers ranked (in descending order)–waste management, excursion to Haller Park, paper mache making, mangroves and tree nursery management. Urban teachers prioritized importance (in descending order) as planning a project, introduction to the environment, effective EE in class, excursion to Marine Park, sharing experiences, indoor games, overview of EE, outdoor games, coral reefs, history of EE and sea grass.

DISCUSSION

In 2005 rural teachers ranked theory topics such as history and overview of EE and ecology topics such as mangroves, corals and sea grass as more important while urban teachers ranked environmental management topics such waste management as being of higher priority. This changed in 2006, with rural teachers ranking environmental management topics like waste management, paper mache making and nursery management higher than their urban counterparts who gave greater priority to EE transfer methods like effective EE in class, sharing experiences as well as indoor and outdoor games.

This difference could be attributed to the characteristics of participating teachers. In 2005, most of the rural teachers attending had existing clubs in their schools and ongoing environmental projects whereas their urban counterparts did not have any environmental interventions in their schools. The rural teachers were thus more interested in deeper understanding of the history of EE and comparison with other areas and ecology topics. Urban teachers in attendance were at the time more interested in intervening in their schools to provide solutions to challenges such as waste management.

In 2006, participating rural teachers had clubs in their schools but no ongoing projects; thus explaining their interest in potential projects. Most urban teachers attending had been involved in the "Schools to the Sea" program (which incorporates learning, guided excursions and student expression through art work) and were keen to improve on EE transfer skills; thus explaining their interest in those topics. Due to their involvement in the "Schools to the Sea" program, these teachers had received more exposure to ecology topics.

In 2005, the Haller Park excursion received similar ranking from both rural and urban teachers unlike the Marine Park excursion which was more prioritized by rural teachers potentially because both categories of teachers had some awareness of the terrestrial ecosystem, while the marine ecosystem was more familiar to rural teachers, many of whom live and work in villages with fishing communities. At the same time, both categories recognized the importance of effective EE transfer through the classrooms and accorded the topic similar ranking.

The similarities and variations in ranking of importance shows the relationship between basic information and how the level of awareness further impacts on the desire to learn more and intervene in providing solutions to local environmental challenges.

The challenges highlighted by the teachers in transferring EE were similar among rural and urban teachers. These include inadequate knowledge concerning environmental matters such as ecology, background and history of EE; options for interventions, and more significantly how to effectively transfer the EE knowledge acquired using the limited time and financial resources available to them. Both categories of teachers were concerned about inadequacy of resources for practical activities such as excursions and project materials, for example acquiring seedlings and necessary implements in the case of tree planting.

Another concern raised by the teachers was the limited time available for extra curricula activities especially in schools where there is greater emphasis on academic performance. This concern is linked to that of inadequate support from the school administration and fellow teachers as a result of the perceived secondary importance of extra curricula activities. All teachers agreed that support from the school administration plays a key role in alleviating the other challenges including limited knowledge, time and fellow teachers support. It is thus important to make school administrators aware of environmental challenges and the significant role they play in supporting their teachers and students in solving environmental challenges.

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Coastal Oceans Research and Development in the Indian Ocean: Status Report 2008

The Coastal Oceans Research and Development in the Indian Ocean (CORDIO) programme was initiated in 1999 as a direct response to the El Niño caused mass bleaching and mortality of corals in the Indian Ocean in 1998, focusing initially on Eastern Africa, Western Indian Ocean islands and South Asia. Since the Indian Ocean tsunami in 2004 the programme also covers the Andaman Sea. The objectives of CORDIO are to sustain research on coastal and ocean ecosystems relevant to conserving and sustaining ecosystem function, goods and services; to strengthen social and economic assessment and research for integrated coastal management processes to improve the livelihoods and well-being of coastal populations; to improve policies and the use of scientific and technical information in local to national and regional policy; for better networking and integration of science, management and policy; and, finally, to build necessary capacity for meet these objectives.

This is the fifth in the series of CORDIO Status Reports following ones published in 1999, 2000, 2002 and 2005. This publication reflects the evolution of the CORDIO programme in response to progressing threats from climate change as well as human activities. In all, the report includes 48 articles in sections covering overviews and regional summaries, reports on status, tsunami impact, biological research, fish spawning aggregations, artisanal fisheries, socioeconomics and livelihoods, and information and awareness.

We hope the publication will give the reader a sense of the immense scope of change that ecosystems and people are facing, and the urgent need to respond from local to global levels to assist positive responses and take steps to constrain and minimize the rate of climate change.

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