Recent advances in coastal ecology: studies from Kenya

Hoorweg, J.C.; Muthiga, N.

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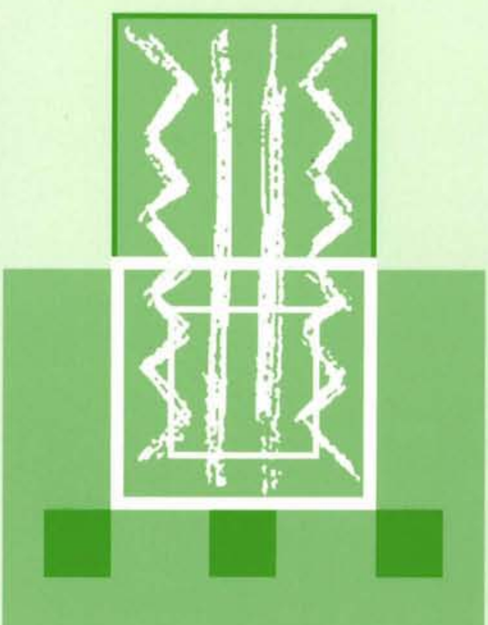

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Nyawira Muthiga (eds.)

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List of Acronyms and Abbreviations

ASC	African Studies Centre
ASF	Arabuko Sokoke Forest
CBO	Community Based Organisation
CDA	Coast Development Authority
CERS	Coast Environment Research Station
CFCU	Coastal Forest Conservation Unit
CORDIO	Coral Reef Degradation in the Indian Ocean
CRCP	Coral Reef Conservation Project
DC	District Commissioner
DO	District Officer
DoF	Department of Fisheries
DVM	Dorsal Ventral Measurement
EAWLS	East African Wildlife Society
EEC	European Economic Community
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organisation
FD	Forestry Department
FO	Fisheries Officer
ICIPE	International Centre of Insect Physiology and Ecology
ICZM	Integrated Coastal Zone Management
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Union for the Conservation of Nature
KANU	Kenya African National Union
KEFRI	Kenya Forestry Research Institute
KMFRI	Kenya Marine and Fisheries Research Institute
KWS	Kenya Wildlife Service
MFR	Marine Fisheries Reserve
MNP	Marine National Park
MNR	Marine National Reserve
MOP	Mother of Pearl
MP	Member of Parliament

MPA	Marine Protected Area
MSY	Maximum Sustainable Yield
NES	National Environment Secretariat
NGO	Non-Government Organisation
NMK	National Museums of Kenya
NOAA	National Oceanic and Atmospheric Administration
NTZ	No Take Zones
PC	Provincial Commissioner
SFO	Senior Fisheries Officer
TADECO	Tana Delta Conservation Organisation
TARDA	Tana and Athi Rivers Development Authority
TDEAP	Tana Delta Environmental Awareness Programme
TDWSC	Tana Delta Wetlands Steering Committee
TED	Turtle Exclusion Device
TEZ	Trawl Exclusion Zone
UNEP	United Nations Environment Program
UNESCO	United Nations Education, Social and Cultural Organisation
WWF	World Wide Fund for Nature

Acknowledgements

In November 1999, the Kenya Wildlife Service (KWS) and the Coast Environment Research Station of Moi University (CERS) organised a second conference on the ecology of the Kenya Coast to present an overview of recent research devoted to the coastal environment. Presentations included papers from the staff of local research institutes as well as summaries of PhD and MSc research. A number of contributions from the proceedings have been selected to form the basis of this monograph. Some of the papers were rewritten, others were comprehensively edited to bring them up-to-date, a process that took considerable time.

The editors wish to mention the institutions that kindly supported the exercise from the very beginning, namely, KWS, Moi University and the Netherlands Embassy. Our thanks go to Mr A. Kaka, Assistant Director of KWS, and Dr W. Yabann, Dean of the School of Environmental Studies at Moi University, for their support. Thanks also go to the Netherlands Embassy and the Agricultural Counsellor, Ir. H. van Asperen, for the grant that allowed the conference to take place and the later process of rewriting and editing the manuscript. The African Studies Centre in Leiden and its director, Dr G. Hesseling, graciously provided additional financial support when it was needed.

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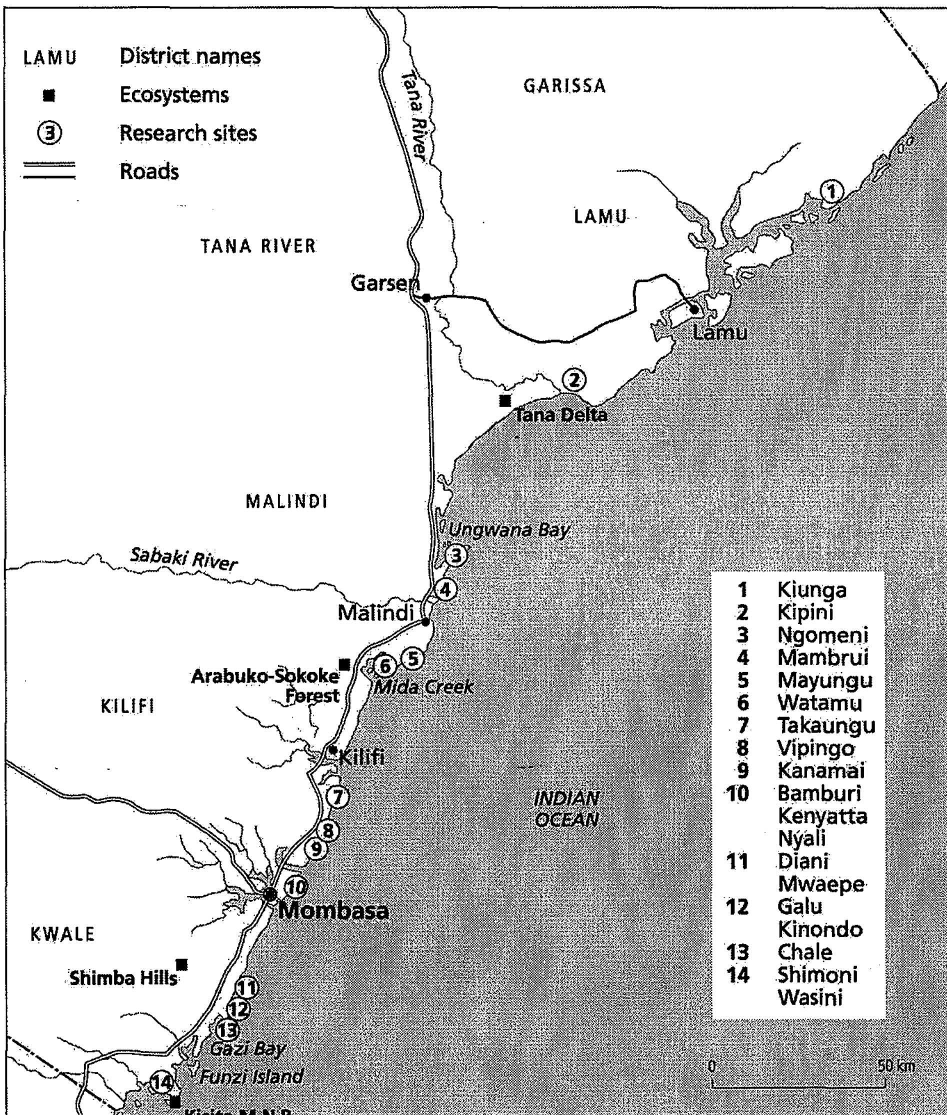
Preface

Map 1 *Kenya Coast with location of research sites*



Introduction

Jan Hoorweg[1] & Nyawira Muthiga[2]

The coastal plain and uplands are separated from the rest of Kenya by an extended shrub zone. The coastal habitats include estuaries and creeks, sandy shores and sand dunes, caves, rocky shores, mangrove swamps, seagrass beds and coral reefs (Frazier 1993). The seasons are governed by the trade winds and correspond to the hot north-east *(kaskazi)* and cool south-east *(kusi)* monsoon. The coastal strip has a lush vegetation but further inland rainfall decreases, soil fertility is poor and scrub vegetation predominates (Foeken 2000). The region has six marine protected areas and land refuges that serve to protect the rich biodiversity of plants and animals. The terrestrial fauna ranges from rare insects and endemic birds to monitor lizards and forest elephants while the marine waters harbour many species of tropical reef fish as well as sharks, sailfish, sea turtles and the last specimens of the endangered dugong (Wamukoya *et al.* 1996).

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In many African countries, the capital is situated on the coast with the resulting pressures of population and industry on the environment. This is not the case in Kenya, although the coastal region now has a population of more than 2 million[3] and has become a major tourist destination. The existence of many coastal ecosystems is threatened, often by combinations of factors (Tole 2000). The Sabaki estuary is experiencing the effects of upstream deforestation and industrial pollution, the coral reefs are suffering from bleaching caused by a rise in seawater temperatures and from destructive fishing practices while mangrove forests are being negatively affected by land reclamation and commercial logging.

The Kenya Coast can be divided in two parts that differ markedly in geology, vegetation and human settlement.[4] North of the Sabaki estuary, the landscape is generally flat, dry, with scrub vegetation and it is thinly populated. South of the estuary, it is hilly with more rainfall and it is more densely populated. Most of the economic and tourist activities are concentrated on the southern coast where the pressure on the environment is greatest and most of the destruction of natural resources occurs.

To protect the fragile coastal ecosystems, knowledge is needed about the state of the natural resources and the impact of human activities. This is the subject of coastal ecology i.e. the study of coastal ecosystems in a wider sense. Although the study of coastal ecology is a relative newcomer a proliferation of studies has occurred in recent years. Several textbooks on the East African Coast have been published in the last few years. The existing coastal ecosystems are described in McClanahan & Young (1996) and a taxonomic guide of plants and animal species was compiled by Richmond (1997). An Atlas of the Kenyan Coast was published by UNEP (1998) and the coral reefs of the Indian Ocean are treated in McClanahan, Sheppard & Obura (2000). The culture, history and economy of coastal society are reviewed in Hoorweg, Foeken & Obudho (2000a).[5]

Local research organisations include the Kenya Marine and Fisheries Research Institute (KMFRI), the Kenya Wildlife Service (KWS), the Coral Reef Conservation Project (CRCP),

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3 Figures for the coastal districts (Kwale, Kilifi, Malindi, Mombasa, Lamu and Tana District below Garsen) roughly an area extending 100 km inland. At the time of Independence in 1963 the population was less than 750,000 (Morgan & Shaffer 1966).

4 This division should not be confused with common parlance which speaks of the south coast (Mombasa to Vanga) and the north coast (Mombasa to Malindi).

5 Richmond (1997) and Hoorweg *et al.* (2000) contain comprehensive bibliographies, with more than a thousand titles each.

the Coast Environment Research Station of Moi University (CERS) and the regional centres of the national research institutes for agriculture and forestry (Hoorweg 1996).

Following an earlier collection of studies (Hoorweg 1998), the present monograph offers a review of recent environmental research on the Kenya Coast to show the wide variation in subject matter and type of research that exists. Study locations extend from Kiunga in the north to Kisite in the south (Map 1: p.2). The main subject areas consist of the following:

- coral reefs & beaches
- erosion & pollution
- marine fisheries
- mangroves
- biodiversity
- community participation.

Coral Reefs, Intertidal and Littoral Communities

Reefs and beaches are bearing the brunt of ecological pressures on coastal ecosystems. Many plant and animal communities are suffering degradation as a result of the siltation of the main rivers, rises in sea-water temperatures, pollution by unprocessed sewage, damage from tourist activities and destructive fishing practices.

The coral reefs along the Indian Ocean coast are found in Tanzania, Mozambique, Madagascar and Kenya and mostly consist of fringing reefs and patch reefs (McClanahan *et al.* 2000). A fringing reef follows the southern Kenyan coast over a distance of 200 km, the longest continuous reef of its kind in the world (McClanahan & Obura 1996). Reefs are important to the coastal environment as they provide protection from erosion, contribute to the formation of sandy beaches and sheltered harbours, and offer nursery grounds for countless marine life forms. Coral reefs, however, are sensitive to environmental changes and respond differently to levels of environmental stress.

Coral bleaching (the whitening of corals) is a response to temperature rise and in the worst cases can lead to the death of a reef. *Mdodo (2)* [6] studied the effects of the 1997-98 El

6 Cross-references to other chapters are given by name of (first) author and chapter number in italics.

Niño which resulted in a 2-3^0 rise in temperature of the coastal waters over a three-month period. This caused mass bleaching along the Kenyan Coast with over 90% of the corals in three study sites affected. Results from later studies (McClanahan, Muthiga & Mangi 2001) indicate high mortality rates with some reefs losing 70-80% of their hard coral population. *McClanahan (1)* reports on a series of studies along the coast to restore degenerated reefs by the physical removal of sea urchins and fleshy algae, and the transplantation of corals. Removing sea urchins resulted in increases in coral cover and fish biomass but there was a large difference between the results of small-scale trials and large-scale manipulations. Fish populations generally responded positively to reductions in fleshy algae, with the exception of certain fish species. The experience with coral transplants was generally positive although growth was slow. The important finding of these studies is that restoration is possible and that it is dependent on external factors such as weather conditions, and a concomitant reduction in fishing intensity is nearly always required.

Sewage pollution and nutrification also affect coastal communities. *Mwayuli (4)* studied the species diversity, abundance and composition of macro algae in relation to water quality as measured by water temperature, salinity, nutrients and faecal coliforms. Elevated nutrient and coliform levels resulted in an increased macro algae cover dominated by fewer species – not a healthy development. *Muthama (3)* examined seagrasses in shallow coastal waters. Seagrasses cover bare sand or mud-bottoms, serve as a habitat for many small invertebrates as well as a nursery, breeding and feeding ground for numerous fish species. The findings confirmed that seabeds with vegetation had a higher faunal abundance than non-vegetated beds and that mixed seagrass beds offered greater habitat diversity.

Epibenthic bivalves are molluscs with a hinged double shell found primarily on seagrass and reef-flat zones that have a commercial as well as a conservation value. Bivalve abundance and species composition, distribution and diversity were studied by *Boera (5)*. The distribution of bivalve communities was dependent on type of substrate, tidal range and wave activity while human activities posed a severe threat because the presence of people and their movements result in shell closure and reduced activity of the bivalves. Trampling on the fragile shells caused the greatest amount of destruction.

SEDIMENTS, EROSION AND POLLUTION

Two large river systems originate in the Kenyan highlands and flow into the Indian Ocean. The Tana River and the Sabaki River[7] drain most of eastern Kenya with the rivers nearly meeting at the outlets to the ocean. Upriver, below Mount Kenya, the Tana River has been dammed to generate hydroelectric power and its further course continues through thinly populated lands. Plans exist for more dams but there are fears that the waterflow will be severely affected. For most of its course, the Sabaki River flows through densely populated lands and experiences the effects of upstream deforestation and sedimentation as well as pollution by agricultural and industrial waste.

Two studies are concerned with the hydrology and sedimentology of the Sabaki River. *Abuodha (6)* reports on the hydrological conditions of the Sabaki River channel and the suspended and bedload sediments being transported into the Indian Ocean. *Munyao (7)* focuses on the nature and composition of sediments and the manner of deposition. The discharge increased manifold with the long rains in the highlands in April-June and deposition was dependent on the prevailing trade winds. Sandy sediments did tend to stay near the outlet while the muddy fluvial plume drifted far out to sea depending on wind and current conditions affecting large areas of the coast. The sand component is responsible for the beach accretion and the formation of large dunes that have occurred between Malindi and Mambrui over the past 40 years.

While beaches near the Sabaki estuary grow wider, erosion is a concern further south. *Mwakumanya (8)* studied the shoreline's retreat near Mombasa where waves and currents erode unconsolidated shoreline materials and deposit the sediments on beaches elsewhere. The shoreline retreat was relatively rapid at around 20 cm/month. Shoreline composition, beach slope and wave characteristics contributed most to shoreline instability. Human activities aggravate the retreat and the problem is most serious in areas with many tourist developments. Erosion results in damage to local fishing grounds but may also destroy buildings erected close to the shore. Erosion-control structures rarely achieve more than diverting the problem to adjacent areas.

Discharge of waste is an additional hazard threatening coastal ecosystems. The collection and disposal of solid waste is the responsibility of the respective municipalities and county

7 Known upstream by the names of Galana River and Athi River.

councils which, at best, provide unreliable services. Effluents are generally disposed of in pits, septic tanks or reach the ocean untreated. Most of the solid waste comes from the urban centre of Mombasa with its one million inhabitants and also from the tourist hotels scattered along the beaches north and south of Mombasa. Tourism places high demands on the local infrastructure such as transport, electricity and water supplies and tourists also generate much larger amounts of waste per capita than the local population.

Maende (9) writes on solid waste management in Mombasa District, having surveyed waste generation, waste handling, transportation, storage and disposal in educational institutions, supermarkets, hospitals, hotels, restaurants, markets, recreational parks and industries. The main disposal methods were roadside dumping, private incineration and dumping at the municipal site in Kibarani (recently moved to Mwakiringe), although there was a general lack of records and estimates difficult to make. Many shortcomings are noted such as unhygienic handling methods, outdated equipment, infrequent collection, an absence of refuse containers and toxic emissions from incinerators. *Muthini (10)* provides information on the amounts of waste generated by beach hotels, its composition and seasonal variations. Waste generation was estimated at 1.9 kg/visitor/day and hotels can produce 150-300 tons/year depending on the number of guests they have. Hotels did tend to make their own arrangements for transporting waste to garbage dumps but even the official dumpsites are often poorly situated. Some hotels had started with waste separation and source reduction, recycling, re-use and composting practices but they need to develop more linkages with waste dealers, pig farmers and recycling firms as outlets. Both authors emphasise the need for improvements in municipal and private waste collection services to reduce health risks and improve the quality of the environment.

Marine Fisheries

The main forms of marine exploitation are the commercial and artisanal fisheries. The catch consists of demersal (bottom) fish, pelagic (surface) fish, sharks and rays, crustaceans, squid and gamefish (Aloo 2000). Other resources are sea cucumbers and molluscs. For oceanographic reasons the potential catch in Kenyan marine waters is lower than in other East African countries while the actual catch, estimated at 7-8,000 tons/year, is near its maximum sustainable yield (McClanahan 1996: 54). The coastal waters are the territory of an estimated

5-10,000 artisanal fishermen who are highly dependent on the in-shore fish populations. Attempts to manage reef conditions by physical 'gardening' were already mentioned but there is also growing attention to the role of artisanal fishers in resource conservation.

The effects of restrictions on fishing areas and fishing gear were studied by *Mangi (11)* who compared five locations. All sites showed a significant decline in annual catches over the five-year period of study which confirms that the potential of Kenyan near-shore fishery is being nearly fully exploited. The presence of a marine park appears to increase the fish stock in the adjacent reserves where the catches of the artisanal fishermen were higher than elsewhere. Similarly, catches were better in areas where beach seines were effectively excluded. These management changes did increase the total catch but also had the effect of attracting more fishermen. Maximising catches and at the same time protecting ecosystems requires a delicate balance.

The fisheries management interventions above originated from outside agencies. In general, the artisanal fishermen are not conservation minded. Traditional conservation practices reportedly still exist among fishermen in the Galu sublocation (McClanahan *et al.* 1996) but there was little sign of marine conservation among fishermen in Kilifi and Lamu with the exception of certain practices relating to personal safety, hygiene and fish handling *(Tunje 12)*. The choice of fishing method was mainly decided by the fisherman's previous training and experience with the prospect of high catches in mind. Willingness to participate in programmes of marine conservation depended foremost on the perceived benefits for the fishermen, notably improvements in monetary income. Still, certain situations may yet push the local population into action. Examples are the local populations in Galu and Uyombo who confronted the fishermen from Pemba known for their destructive fishing practices. On the other hand, the fishermen in Diani were against the start of a local marine reserve and managed to block its establishment.

King (14) analysed how this latter issue had evolved in the local communities around Diani and compared it with conflicts about the use of beach seine nets and ownership threats to a fish landing site. Social network analysis showed that during the initial phases of these conflicts a status quo was usually maintained between the low-level actors involved, including the chief and the resource management organisations such as KWS. However, in the end, local politicians and senior members of the administration became involved, inevitably introducing their own agendas and interests. The author recommends that resource management organisations should act as facilitators of local initiatives, at the same time using their corporate network and influence to involve key members of the wider community.

The good news is that marine parks not only benefit fish stocks but also benefit local populations and lead to improvements in socio-economic conditions and food security. *Malleret-King (13)* reports that households around Kisite Marine National Park did benefit in two ways. Firstly, those fishing near the protected reefs were found to be more food secure than fishermen elsewhere, and secondly, the nearer households were to the park and tour operators, the more they managed to draw a livelihood from tourist activities.

Commercial fish landings consist of the sport-fishing industry, a fleet of some five Kenyan-registered trawlers and the distant-water fleets in international waters. The sport fishermen are mainly based in Watamu and Malindi, cater for the top end of the tourist market and concentrate on tuna and billfish (Kimani & Moragwa 2000). Little is known about the distant-water fleets operating outside the 200-mile exclusion zone. The trawlers mainly operate in Ungwana Bay, Malindi Shallows and near Kipini, and bring in 200-250 tons of prawns in a good year (UNEP 1998). *Fulanda (15)* reports on the environmental impact of trawling. The trawler catch consisted of 14% prawns and 14% (demersal) fish with a commercial value. The remainder (72%) consisted evenly of juveniles, non-commercial fish and debris and this by-catch was generally discarded. The destruction of juveniles is only one way in which the trawlers pose a threat to the marine environment. The trawl nets damage the benthic habitats as a matter of course. Ships are barred from trawling an in-shore zone of five nautical miles but they reportedly violate this exclusion zone frequently, with resulting damage to the artisanal fishing grounds and the gears of the local fishermen.

A less-known form of marine exploitation is the harvesting of marine snails and molluscs. The black-lip pearl oyster is collected for its shell (mother of pearl) and until recently a profitable oyster-shell fishery existed on the Kenyan Coast but now appears to be on the decline. Exact figures about the quantities gathered are hard to obtain. *Kimani (16)* interviewed some shell collectors and shell exporters and analysed oyster samples. The black-lip oyster was found from Malindi to Shimoni but they were most abundant far south. The densities were highest in sheltered backwaters with seagrasses, corals and rock bottoms and comparable to elsewhere in the Indian Ocean. The oysters on the Kenyan Coast appeared to be smaller in size but the large majority were sexually mature and there are no signs that the population is endangered.

MANGROVES

Mangrove forests have an important place in the ecology of coastal habitats, protecting the land from erosion and offering shelter and breeding grounds for many life forms. Along the East African Coast, nine species of mangrove trees are found. The most extensive stands occur in Tanzania and Mozambique with a total area estimated at 2,340 km^2 (Ruwa 1996: 117). Kenya accounts for 53,000 ha according to an often quoted estimate, with more than half of the area in Lamu District (Doute *et al.* 1981).[8] By all accounts, mangroves on the southern coast have suffered a loss of area and also decreases in the density and maturity of mangrove stands. This degradation has occurred because of land reclamation (for salt ponds and tourist facilities) and increased exploitation of mangrove trees (as building materials and firewood). Three contributions cover the exploitation of the resource, mangrove rehabilitation and infestation by natural enemies respectively.

Mbuvi (17) gives figures by district of mangrove production for the period 1990-96. Lamu had the highest production and the lowest internal demand, hence most of the poles were traded in Mombasa. The resource has been overexploited judging by the absence of large poles currently on the market, the import of quality poles from Tanzania and the erosion evident in many mangrove swamps. Effective management of the mangrove forests in the Kiunga and Mida areas was hampered by the overlap in responsibilities and the low level of co-operation between the Forest Department and KWS.

Kamau (18) is interested in the possibilities for rehabilitation of mangrove stands and more particularly the presence or absence of trace metals. Concentrations were measured in locations having suffered different kinds of degradation. Overharvested mangrove stands and aquaculture ponds were lowest in trace metals, particularly zinc and cadmium. For future rehabilitation, however, salinity levels may be equally important or pose even greater limitations.

Sonneratia alba is a pioneer mangrove tree that holds back waves and currents and creates conditions for other mangroves to establish themselves. Die-back of this tree was reported in 1999 as a result of infestations by two natural enemies that have appeared on the scene. The two species of borers, a beetle (*Bottegia spinipennis*) and a moth (*Salagena*

8 There is uncertainty about the accuracy of this estimate for Lamu which may be too low (Ferguson 1996).

obsolescens), are formally described by *Gordon (19)* with a review of their ecological niches and life histories. Both species have been identified in Africa before but it is unclear whether they are recent invaders or are indigenous to the Kenya Coast. It is possible that the two species had recently shifted to this new host, although they do not seem to have any natural enemies. The moth is likely to be the greater threat since it poses a danger to fruit trees, including the cashew tree.

BIODIVERSITY

This section deals with a mixed number of subjects namely forest flora, elephant herds, cereal stem borers and damsel fish respectively to illustrate the diverse nature of coastal issues. Of the extensive coastal forests that once existed along the Indian Ocean, only an estimated 3,000 km^2 remain (Burgess *et al.* 1996). Everywhere, the forests are threatened by the clearing of land for agriculture and mining, logging for timber and the cutting of saplings for fuel. Kenya still has an estimated 800 km^2, consisting of the forest reserves in the Shimba Hills and Arabuko-Sokoke together with remaining smaller patches (UNEP 1998). 'Kaya' is the local name for patches of lowland forest – very diverse in nature and with a high conservation value with many rare plants – that have been preserved because of their cultural significance for the local population. Over 60 such patches have been identified ranging from 5 to 400 ha in size with half of them retaining their cultural function. *Luke (20)* presents a review of the work of the Coastal Forest Conservation Unit (CFCU), in particular the ongoing botanical research and efforts to gazette the kayas as national monuments.

The Shimba Hills and Arabuko-Sokoke Forest are the last remaining elephant habitats on the southern coast. *Litoroh (21)* writes about the situation in the Shimba Hills National Reserve with an estimated 700 elephants, at the time, in an area of 240 km^2 and numbers increasing.[9] Both ecosystems are under pressure from surrounding communities that have a great need for land. The confinement of many elephants in a small area, such as the Shimba Hills, has resulted in habitat degradation and frequent human-elephant conflicts, poaching and intrusion by man versus farm raids by elephants. Countermeasures have included fencing

9 The estimate for Arabuko Sokoke is 50-70 (bush) elephants in an area of 420 km^2 although only an area of 43km^2 is gazetted as a national reserve (UNEP 1998).

which permanently confines the animals to the park and the opening of an additional refuge (Mwaluganje Elephant Sanctuary). Other options include translocation and fertility regulation but experience has shown that translocated animals return over long distances and that it takes decades for fertility regulation to provide results.

Another example of the manipulation of animal populations is the attempt to control insect pests through natural enemies. The dominant maize borer in East Africa (*Chilo partellus*) came from Asia early in the 20th century. In 1993, a co-evolved enemy was purposely introduced (*Cotesia flavipes*) which, by now, is to be found all over southern Kenya and northern Tanzania. *Otieno-Ayayo (22)* reports on field experiments into the factors that facilitate or hinder the spread of this parasitoid. Dispersion was related to topography, precipitation and natural barriers (water masses, forests) but also showed interaction with agricultural practices such as slash-and-burn cultivation and chemical spraying.

An altogether different topic is that of the negative side-effects of current (protozoan) antibiotics and growing resistance to these medicines. Certain plant and animal tissues have antiprotozoan quantities and *Dzeba (23)* examined extracts of three local organisms, namely (the gills of) the damsel fish (*Abudefduf sexfasciatus*), a species of marine algae (*Lyngbya majuscula*) and a species of seagrass (*Thallassodendron ciliatum*). The fish extracts appeared to offer the greatest potential and showed the strongest effect with little toxicity.

Community Participation

There is a growing realisation that participation by local communities is essential for the conservation of natural resources and that participation to a large extent determines success. This is certainly the case on the Kenya Coast where the population has easy access to most of the terrain. The last section of the book is concerned with co-management of natural resources usually a combination of non-governmental agencies and local communities. Two surveys examine the role of coastal communities in the exploitation and conservation of natural resources near two major ecosystems, the Tana Delta and the Arabuko-Sokoke Forest. Both papers discuss attempts to involve local populations in the sustainable exploitation of coastal forests and mangroves respectively.

The Tana River flows into a wide delta with important wetlands that occupy at least 50 km of coastline, so far, ignored by commercial agriculture and major industrial or tourist development. The educational level of the local population is low (Eisemon 2000). In the past decade a start has been made with land adjudication and questions need to be addressed as to how to develop the delta without damaging the fragile environment. A steering committee and a community-awareness programme for the Tana Delta Wetlands have been set up. *Becha (24)*, in his contribution, describes the major stakeholders such as government institutions, non-government organisations, elders, community-based organisations and various types of resource users. Land accessibility and land ownership were at the top of the list of issues that emerged from interviews with these groups, followed by human-wildlife conflict, resource depletion, resource conflicts, river water volumes, insecurity, law enforcement and poorinfrastructure.

The forest reserve of Arabuko-Sokoke is the largest remaining block of coastal forest on the Indian Ocean coast, about 400 km^2 in size. The forest is under continuous threat from commercial logging and encroachment by smallholder farmers from adjacent communities. Long-standing efforts continue to conserve the forest because of its biodiversity, including endemic and endangered species, and to save the remaining stands of indigenous trees. Involvement of local communities has taken different forms notably the commercial exploitation of forest products and income-generating activities outside the forest. The first strategy, the commercial exploitation of forest products includes bee keeping and butterfly rearing. The *Kipepeo* (Butterfly) Project was initiated in 1993 and has been fairly successful in providing an income for some members of the local communities. According to surveys in 1993 and 1997, gathering wild butterflies for commercial breeding activities had a negligible effect on the natural butterfly population (*Ayiemba 26*). The second strategy aims at poverty alleviation through income-generating activities. *Mwendwa (25)* reports on the possibilities for agro-forestry in four villages near the forest. Inquiries were made among the inhabitants on existing soil types and soil fertility as well as the village organisations that can serve as future channels of information. The assumption in both strategies is that the income benefits will strengthen local support for conservation but this premise remains largely untested so far. Moreover, the adjacent communities are not the only groups that have an eye on the forest's resources.

Rasowo (27) reviews the Fisheries Department's experience with pond shrimp culture in Ngomeni. This project required considerable mangrove clearance but was of limited commercial success. Reasons for the lack of success were the choice of shrimps and the manner of pond construction, both working to the disadvantage of local inhabitants. Silvofisheries offer an alternative because it combines mangrove cultivation and fish production. A pilot project in Kwale District is underway in a location that was previously ravaged by commercial mangrove cutters and where attempts are now being made to involve the local population in a combination of mangrove reforestation and fisheries initiatives.

In all, this monograph contains 27 contributions differing widely in scope. Subjects range from coral reef restoration to butterfly breeding, from river sediments to Kaya forests, and from marine fisheries to elephant management. The analytical power of the research varies greatly: there are reviews of years of work such as that on the restoration of coral reefs but also thesis research that is more modest in scope. Study locations extend from Kiunga in the north to Kisite in the south but most studies concentrate on the southern coast where the pressure on the environment is greatest (Map 1: p.2). There are indeed many signs of degradation and examples of ecosystems that are threatened: coral reefs, mangrove forests and kayas are all cases in point.

The coastal environment is under pressure because of naturally occurring processes, the escalating subsistence needs of the local population and the increasing economic exploitation of natural resources. The coastal region is economically disadvantaged compared with the centre of the country (Meilink 2000) and economic growth opportunities must be explored. At the same time, concerns exist about unfettered development and the environmental implications for coastal ecosystems. The case for a regional development policy focusing on agriculture, tourism and port services has been argued (Hoorweg, Foeken & Obudho 2000b) but each development scenario has environmental consequences and inherent dangers.

Development policies must take into account the fragile nature of the coastal ecosystems. Coastal protection and conservation requires the combined efforts of the many parties involved – government agencies, NGOs, local communities, commercial enterprises and the research community. Integrated coastal zone management (ICZM) is a way of bringing together the different parties to ensure the sustainable use of coastal resources and to protect the quality of life for the local population and future generations (Clark 1996). ICZM is in its infancy in Kenya (UNEP 2000) and research has an important role to play in this process but publications are usually widely scattered. This monograph presents an overview of the range of study activities that exist. The research varies from descriptive studies and studies that provide benchmark information for later evaluation purposes to studies that are management oriented and aim at active intervention to protect or restore ecosystems. Whether signalling where and when environmental degradation is occurring or experimenting with promising interventions, all the studies have a contribution to make in protecting our cherished coastal riches.

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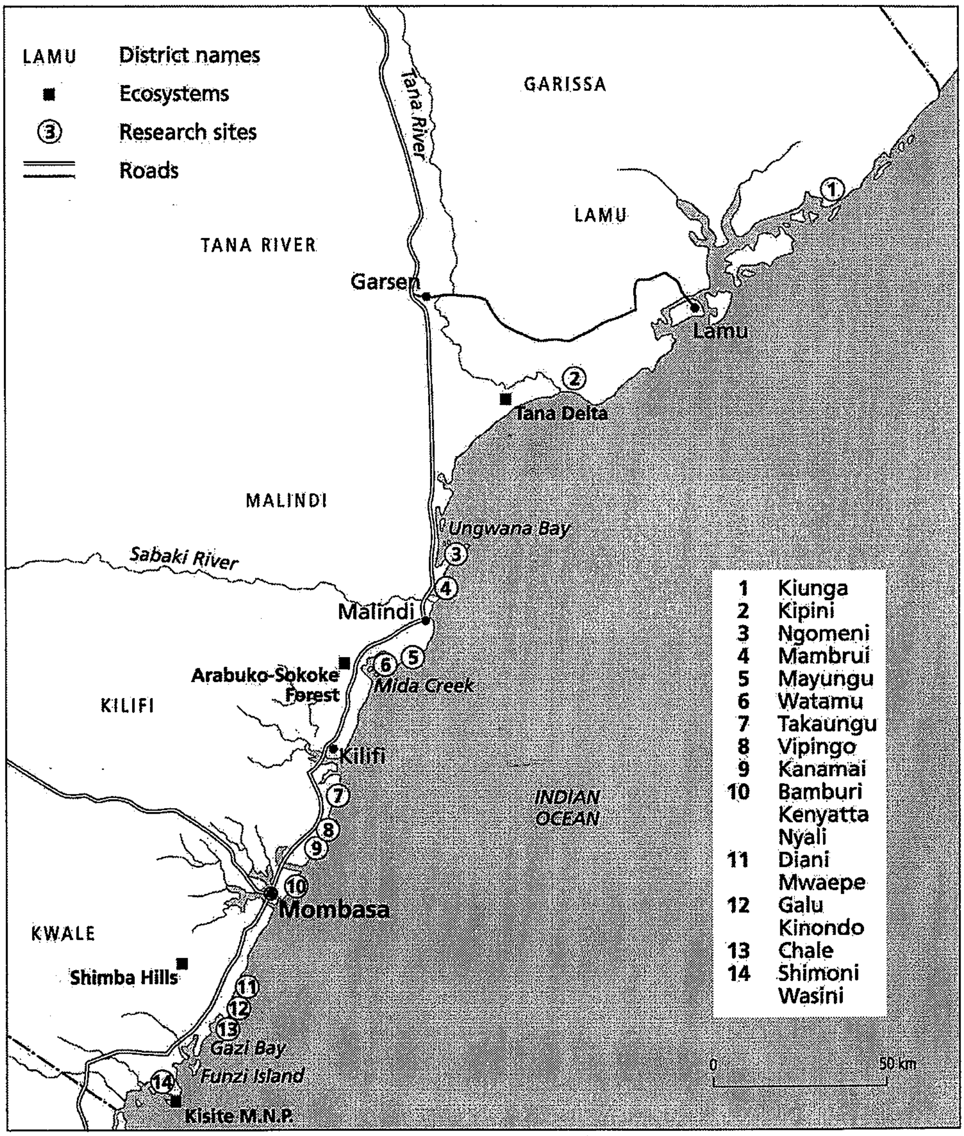
Coral Reefs, Intertidal and Littoral Communities

Map 1 *Kenya Coast with location of research sites*



1

Disturbance, Recovery and Restoration of Kenyan Coral Reefs

T.R. McClanahan[1]

ABSTRACT

Evidence for the degradation of Kenyan coral reefs is abundant but the means to restore and manage them is less well understood. Degradation studies show that there are often two terminal states of coral reefs: one where the reef is dominated by large fleshy algae and the second by abundant sea urchins. Summaries of studies are presented where sea urchins and fleshy algae were reduced in order to determine the effect of algal and sea urchin dominance on coral reefs as well as the effect of elimination of fishing on one coral reef. Studies indicate that reducing coral reef plant and animal pests work best if done in areas where fishing is reduced. Reduction of fishing in one coral reef produced a number of predicted changes in the reefs, including increased fish and coral cover and reduced sea urchin and algal turf abundance. There are few options to restoring reefs that will not require reduced fishing effort. Many reefs presently have low coral cover due to the coral bleaching and mortality in March 1998, so there is a need to increase coral reef restoration activities.

INTRODUCTION

There are some emerging patterns to the ecological organisation of coral reef ecosystems to various disturbances or stresses. For example, environmental stresses can often increase the dominance of species that have unique survival characteristics under unusual conditions like

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reduced dissolved oxygen or low light penetration, or high population growth in the absence of less stress-tolerant predators. Human disturbances to reefs and coastal watersheds is often a combination of resource removal or fishing, which influences predation, and nutrification and sedimentation of coastal waters which influences production and competition of benthic species. In some cases, such as Marine Protected Areas (MPA's), resource removal is absent or greatly reduced and the other two factors plus tourist and global factors such as global warming, exotics and diseases are the major concerns of management.

Kenya is fortunate to have the most and oldest nonextractive MPA's in the Western Indian Ocean (Salm & Ngoile 1998; McClanahan 2000) and this has been critical in developing and testing models of reef degradation (McClanahan 1995, 2000). There are various possible outcomes to degradation dependent on the factors that have caused the environmental changes. A simple conceptualisation of reef degradation is that there are a number of degraded states to coral reefs, these include dominance by sea urchins, brown fleshy algae, green filamentous and fleshy algae or reefs dominated by turf algae but few corals or coralline algae. Nutrification, coral bleaching, overfishing and diseases are the main forcing factors suggested to influence the state of the reef.

The terminal degraded states that may be amenable to restoration include the erect fleshy algal state, the sea urchin 'barren', and, turf algal state. The erect algal state might be restorable by the physical removal of algae or through an increase in herbivory, through reduced fishing of herbivores (i.e. parrotfish, surgeonfish and rabbitfish) or by adding unfished herbivores such as sea urchins, or some combination of the three. The sea urchin barren might be restored by reduced fishing on sea urchin predators, such as *Balistapus undulatus*, or, again, by the physical removal of sea urchins or the two factors in combination. The turf algal state might be restorable through coral transplantation, but if sediments, warm water or diseases persist, this technique may not have a long-lasting effect. Many of the above manipulations have been done in and out of Kenya's MPA's and the outcome of these studies will be discussed below along with the potential for reef restoration after the devastating 1998 El Niño event.

Sea Urchin Reductions

Large-Scale vs. Small-Scale Manipulations

Method. Sea urchin manipulations were done on two different scales in order in order to determine if ecological experimentation on a small-scale produced different results when applied at the larger scale of whole-reef sections. In particular, the concern was that the observed increase in fish was largely attributable to immigration of fish into the small plots once algae and associated resources increased. Sea urchin reductions done on a larger scale could, however, dilute the effect of this immigration and potentially result in greater increases in algae and a greater loss of hard coral. Therefore, this larger spatial and temporal scale study was initiated to test the above possibilities. Consequently, with the assistance of the park authorities and local fishermen sea urchins were reduced in two such sites of about 100m x 100m and we followed the changes in the ecology of these sites for nearly three years. The outcomes of this study are compared with the results of the shorter and small-scale study. Study sites were located in Vipingo, Diani and Mombasa Marine National Park (Map 1: p.20).

Results. Sea urchins in the experimental reduction sites were originally estimated before reduction at 30.2±10.4 (= s.d.) per 10 m^2 or 4736.5±523.5 kg/ha in the manipulation sites and 23.4±3.2 per 10 m^2 or 2375.1±136.9 kg/ha in the reference sites. They were reduced to 11.5±7.8 per 10 m^2 or 1335.5±801.0 kg/ha and slowly recovered to 21.7±2.8 per 10 m^2 or 2405.0±210.1 kg/ha at the end of the three years, being the same as the reference sites at that point (Appendix 1.1: p.33).

The largest change was an increase of 500 to 790% in fleshy algae, mostly *Sargassum*. In both manipulated sites fleshy algae increased from <5% cover to 25% cover during the first 200 days but eventually decreased to the level of the reference sites, in one site after 300 days and the other after 900 days (Appendix 1.1). Hard coral cover remained the same in the reference sites (36 vs. 38%) but increased from 28 to 46% in the manipulated sites. Coral cover did not, however, increase in the manipulated sites until after 300 days and was slower to recover in the site where fleshy algae persisted the longest.

Comparison of the above large-scale with the small-scale manipulations (McClanahan, Nugues & Mwachireya 1994; McClanahan *et al.* 1996) suggests that the scale of the sea urchin manipulation does not greatly affect the qualitative but that it does affect the quantitative outcome of the experiment. Increases in fish abundance were qualitatively similar for both scales in that butterflyfish, parrotfish, scavengers, wrasses and total fish abundance increased in both experiments (Table 1.1). There was, however, always a greater increase in fish in the small compared to the large-scale manipulations for all the above groups with the exception of the butterflyfish. Surgeonfish and the 'others' group were less predictable based on the manipulations and scale. In addition, herbivory by sea urchins went down more on the small than the large scale and herbivory attributable to finfish showed the opposite pattern. Benthic cover shows similar increases in fleshy algae with the small-scale but a greater loss of algal turf at the large-scale manipulation. This is largely attributable to the increase in hard coral cover in the large-scale experiment but a decrease in the small-scale experiment. The difference in hard coral is largely attributable to the different lengths of time of the small- and large-scale manipulations. As mentioned above, hard coral cover did not increase in either the small- or large-scale manipulations until after around 200 days (Table 1.1; see also McClanahan *et al.* 1996).

Table 1.1
Changes in fish wet weight, herbivory and substrate cover in large (10,000 sq.m) and small (2,500 sq.m) sea urchin reduction plots*

	SMALL-SCALE MANIPULATION	LARGE-SCALE MANIPULATION
Fish Wet Weight (kg/ha)		
Butterflyfish	2.80	2.97
Parrotfish	148.00	42.66
Scavengers	38.70	12.66
Surgeonfish	11.10	– 5.19
Wrasses	21.50	6.44
Others	115.60	– 14.76
Total	345.80	39.35
Herbivory (% change)		
Sea Urchins	– 89.20	– 26.25
Finfish	145.70	5.35
Substrate (% change)		
Algal turf	– 5.10	– 19.25
Calcareous algae	0.02	0.45
Coralline algae	– 0.10	0.82
Fleshy algae	9.10	10.23
Hard coral	– 3.60	10.27
Seagrass	– 0.60	0.84
Soft Coral	–0 .30	– 1.22

* Numbers are differences between the means at pre- and post-removal periods.

Conclusion. This study supports a number of the findings of previous sea urchin reduction studies in that sea urchins maintain low fleshy algae abundance (Sammarco 1982; Hay & Taylor 1985; Foster 1987; Hughes, Reed & Boyle 1987; Carpenter 1990a; McClanahan *et* *al.* 1996) and, in some cases, appear to be suppressing the abundance of other fish groups (Hay & Taylor 1985; Carpenter 1990b; Robertson 1991; McClanahan *et al.* 1994, 1996). Our studies are unique in showing that the suppression of fish was not restricted to herbivorous fish but also seems to suppress butterflyfish and scavengerous wrasses, snappers and emperors. Shared plant food resources are not the only basis for competition between sea urchins and other fishes. The response of herbivorous surgeonfishes in this and our previous sea urchin manipulations were weak compared to some of the above non-herbivorous groups. Consequently, it is likely that diffuse competition is as strong as direct competition in the studied coral reef food web (Menge 1995).

The relationship between sea urchin grazing and coral abundance is complex as sea urchins can reduce coral competitors, such as fleshy algae, but can also reduce corals themselves through intense grazing (Sammarco 1980, 1982). In addition, high sea urchin abundance is frequently associated with heavy fishing (Hay 1984; McClanahan & Shafir 1990) and destructive fishing methods, such as drag nets, can also reduce coral cover, making it difficult to distinguish the direct (i.e. drag nets) and indirect (i.e. a high abundance of sea urchins) effects of fishing on coral cover (McClanahan & Mutere 1994; McClanahan *et al.* 1996). In addition, storms and scouring can also reduce or eliminate the build up of macroalgae (McClanahan 1997) and, therefore, exposure to waves and currents can further affect the outcome of these management experiments. This and a previous study shows that fast-growing algae is quicker than coral to respond to the sea urchin reduction but that fleshy macroalgae eventually decreases and hard coral eventually increases after about 200 days. The decrease in algae may be due to an increase in herbivores – both fish and sea urchins – and a loss due to storms. I suggest that both increased herbivory and seasonal storms eventually reduced the build up of fleshy macroalgae and that this, combined with reduced sea urchin grazing, resulted in an increase in hard coral cover after 200 days.

Concerns about the role of scale on the outcome of the manipulation were partially justified in that the effectiveness of the sea urchin reduction and the response of fishes was greater on the small than large-scale manipulations. Corals respond slower than algae to changes in the grazer community, as discussed above, such that the temporal scale of observation can affect one's conclusions about the usefulness of sea urchin reductions in increasing coral abundance, short studies should predict a loss while longer term studies should predict an increase in hard coral. Further, the large-scale experiment did not manage to reduce sea urchins or herbivory by sea urchins as much as the small-scale experiments and this is largely attributable to the greater recolonization of sea urchins over the three-year compared to the one-year study. In addition, the increase in fish, herbivorous parrotfish, and finfish herbivory was lower on the large than the small scale. Small-scale manipulations have a greater potential for mobile species, like fishes, to migrate into plots and utilise recently available resources where as large-scale changes or manipulations are likely to dilute this response. It is arguable that there might be larger differences if the spatial scale of the manipulation was even greater than our large-scale experiment. At the scale of whole regions the loss of an important grazer could be qualitatively different than the moderate scale manipulation reported here, as witnessed by the loss of *Diadema antillarum* in the Caribbean (Lessios 1988).

Fleshy Algae Reductions

Sea Urchin Additions

Method. In some cases where algae are dominating reefs and fishing restrictions are in place, the addition of sea urchins may be a useful way to restore these reefs. Such a reef is found within the Watamu MNP, in an area 100m south of the coral garden (Map 1: p.20). This area has isolated rock outcrops separated by sand and seagrass. The dominant macroalgae on these outcrops were *Sargassum duplicatum* and *Halimeda opuntia*, but there were other species of *Sargassum* and *Halimeda* as well as species in the genera *Turbinaria*, *Dictyota*, *Lobophora*, *Hypnea* and *Amansia*. Between October and December 1997, four plots were selected for adding common grazing sea urchins (*Diadema setosum*, *D. savignyi* and *Echinothrix diadema*). Fishermen collected ~2000 individuals of the above three species from a local fishing ground, placing them in 15 plastic containers of 1000 litre seawater each, transporting them to the study area, and releasing them onto the experimental plots. The sites were visited daily for the first four days to return straying sea urchins and to estimate the degree of sea urchin emigration from these plots. The benthos and fish fauna in these plots were studied for ~1.5 months before and ~1.5 months after the manipulation.

Emigration of the two *Diadema* species occurred during the first two days, these were returned to the plots, and emigration was subsequently not observed. In contrast, *Echinothrix diadema* emigrated slowly but probably continuously and despite returning them to the plots they were observed emigrating until the final sampling. The abundance of these sea urchins was reduced rapidly such that they were reduced from 30 to less than 5

Table 1.2
Abundance of fish families over a 35-day period after the addition of three species of sea urchins to experimental plots in the Watamu MNP dominated by fleshy algae (kg/100 sq.m)

	DAY: – 42 Mean (SE)	DAY: 2 Mean (SE)	DAY: 24 Mean (SE)
Acanthuridae	0.49 (0.08)	5.87 (1.39)	0.48 (0.14)
Balistidae	0.00 (0.00)	2.56 (1.99)	1.16 (0.83)
Chaetodontidae	0.00 (0.00)	1.34 (1.34)	0.04 (0.04)
Labridae	0.78 (0.21)	17.70 (2.32)	1.22 (0.23)
Mullidae	0.92 (0.37)	6.67 (5.18)	1.52 (0.31)
Lutjanidae	0.01 (0.00)	10.69 (5.59)	0.33 (0.14)
Pomacanthidae	0.01 (0.01)	1.79 (1.79)	0.55 (0.18)
Pomacentridae	0.24 (0.11)	5.23 (2.48)	0.40 (0.14)
Scaridae	1.70 (0.29)	15.27 (4.42)	2.30 (0.90)
Siganidae	0.07 (0.07)	2.11 (1.56)	0.50 (0.16)
Others	1.21 (0.86)	4.40 (3.71)	2.50 (0.90)
TOTAL	5.43 (0.78)	73.62 (10.42)	11.02 (1.75)

urchins per $10m^2$ in 35 days. *Diadema setosum* showed the largest absolute losses followed by *D. savignyi* and these two species were, from observation, the preferred prey of the predators. The lesser preferred species, *E. diadema*, decreased slightly in number due to both emigration and predation.

Results. Adding sea urchins led to a large, but short-lived increase of the surgeonfish, wrasses, damselfish and all fish combined (Table 1.2). Observations suggest that large triggerfish (*Balistapus undulatus* and *Balistoides viridescens*) moved into the plots and fed on the transplanted sea urchins. Carcasses opened by the two triggerfish species were fed on by a number of other species (mostly Labridae), and many fishes, not feeding on the carcasses, were associated with mixed-species schools attracted to the feeding aggregation, For instance, parrotfish, surgeonfish and other individuals in various families seemed to be schooling with the predatory and scavenging species and were unlikely to be directly affected by the sea urchins themselves or their grazing effects, after only two days. Algae was reduced in small patches in the plots where sea urchins gathered, but due to the rapid reduction in sea urchins and inability to maintain the 'full treatment effect', benthic changes were not monitored beyond the first 1.5 months.

The sea urchin addition experiment was largely unsuccessful in this regard as two of the added *Diadema* species were quickly consumed by fish predators. Consequently, in old parks or reefs with abundant carnivores, the addition of *Diadema* is unlikely to succeed in Indian Ocean reefs, but might be useful in reefs that are fished or have a lower abundance of carnivores. The third, largest and most mobile and predator-resistant species (McClanahan 1998), *Echinothrix diadema*, has the greatest potential as an algal-reducing species in parks, but it also had greater movements and this made it difficult to manipulate and replicate experimentally on the 10m x 10m plots. It may also feed on corals, so the response to increased *E. diadema* grazing could be complex. Future experiments with *E. diadema*, on large spatial scales >100m^2, are required to test its usefulness for restoration of algal dominated reefs.

Physical Removal of Fleshy Algae

Method. An additional experiment in the same study site at Watamu reduced the erect algae using gardening shears and wire brushes. The benthos and fish fauna in these plots were studied for two months prior and one year after the manipulation. Benthic cover, fish abundance and species richness, coral transplant growth and mortality studies, were studied in the algal reduction treatment and control plots.

Results. The outcome of this study suggests a number of effects of fleshy algae on coral and fish populations. The removal of macroalgae increased coral cover measured by line transects. The majority of this change is attributable to removing the algal canopy and measuring the exposed corals and coralline algae that were originally beneath this canopy, rather than an increase in the absolute abundance of these groups. There was, despite partial recovery of algae, a continued increase in coral cover in the year that followed the removal and a reduction in coral cover in the non-manipulated controls. In addition, small coral pieces that were transplanted generally showed increased growth in the algal reduction plots compared to controls for some measures, after an initial period of adaptation, although *Acropora* grew poorly in all plots.

Fish populations generally responded positively to the algal reduction with increases in density and number of species in nearly all groups except macrophyte-feeding parrotfishes and damselfishes, and no species number increases for wrasses (Table 1.3; McClanahan *et al.* 1999). Some of these changes were expected and others not. Most herbivorous fishes feed on turf algae (Choat 1991), which is likely to be more abundant once the canopy algae is reduced. The positive response in many of the invertebrate-feeding species was unexpected as we predicted that their prey might decrease (Duffy & Hay 1991). Perhaps increased net benthic production on the algal reduction plots resulted in increased prey and therefore associated predators, and a positive association among different species of fish. Schooling activity as shown above for the sea urchin addition study could have resulted in greater numbers of non-resource limited species.

Table 1.3
Abundance of fish in the algal reduction and control plots at Watamu MNP (total fish wet weight; kg/100 sq. m)

DAYS	CONTROL Mean (SE)	EXPERIMENTAL Mean (SE)
– 69	5.65 (1.35)	6.13 (0.46)
– 2	5.79 (1.59)	7.24 (2.72)
28	4.28 (1.30)	10.93 (1.61)
69	4.18 (0.90)	6.67 (0.66)
98	5.70 (0.95)	8.49 (0.69)
162	4.77 (0.67)	11.12 (1.32)
225	6.15 (1.88)	13.16 (2.82)
308	5.72 (2.44)	11.01 (1.99)
357	4.84 (1.45)	12.42 (1.34)

CORAL TRANSPLANTS

Large corals can be broken into smaller pieces and attached to the reef substrate with cement, epoxy or wires. This method has been used in Kenya in the above algal reduction study and found that growth was slow to begin, variable, but on the whole positive. For *Acropora* transplants, increases in height and branch extension, was highly variable and consistent positive growth took more than six months to achieve. *Acropora* had the highest incidence of full and partial mortality and predation in all studied plots. Branching *Porites* showed net positive growth in height throughout, however it was also variable in the early stages. *Porites* had the lowest frequency of stress or disturbance and mortality in all treatments. Growth for *Montipora* was moderate and highest in the sea urchin addition, intermediate in the algal reduction, and least in the control treatment plots. *Porites* and

Montipora showed highest levels of stress in the algal dominated control plots due to partial mortality and overgrowth by algae. For both *Acropora* and *Porites*, competitive interactions, with algae and epiphytes such as tube worms, were most frequent in control plots, and lower in the algal reduction and sea urchin addition treatments. *Acropora* and *Montipora* both suffered more significant growth reductions as a result of stress than did *Porites*.

We abandoned this restoration experiment after March 1998 when planted and naturally occurring corals bleached and died at the end of the north-east monsoon with the 1998 El Niño warming and associated coral bleaching (Strong, Goreau & Hayes 1998, McPhaden 1999). Consequently, regional or global-level phenomenon have the potential to interfere with local restoration programs, and their potential influences on restoration goals needs to be considered before attempting restoration. Additionally, if nutrification is one factor contributing to algal dominance, continued or increasing nutrification will make restoration programs difficult. Coral transplants generally seem to grow slowly and survival is variable, consequently, transplantation has its limitations for recovery from large-scale disturbances such as the El Niño of 1998.

Conclusion

Many corals died and a number of reefs with low levels of herbivory were changed into brown fleshy algal dominated reefs after the 1998 El Niño (McClanahan, Muthiga & Mangi 2001). A number of species in the genera *Acropora*, *Pocillopora*, *Stylophora*, *Seriatopora* and *Millepora* were reduced to very low levels. There is a great need to restore corals, particularly the rare species and brown-algal dominated reefs and to compare recovery on actively restored and passively recovered reefs. A study of coral recruitment in Kenyan reefs, after the bleaching, showed low levels of recruitment ($<10/m^2$) in the marine protected areas (Dusek 2000), so there may be a special need to increase studies of transplantation and coral recruitment in the parks.

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Appendix 1.1

Population density of sea urchins (SU) and cover** of fleshy algae (FA) and hard coral (HC) by experimental conditions and time elapsed*

DAY OBSERVATION			SEA URCHINS Mean (SE)		FLESHY ALGAE Mean (SE)		HARD CORAL Mean (SE)	
SU	FA	HC	*Ref.*	*Exp.*	*Ref.*	*Exp.*	*Ref.*	*Exp.*
–68	–66	–66	24.0 (4.0)	30.0 (10.0)	5.0 (3.0)	2.0 (0.0)	36.0 (7.0)	28.0 (1.0)
–8	–	–	23.0 (1.0)	30.0 (8.0)	–	–	–	–
4	–	–	26.0 (8.0)	17.0 (4.0)	–	–	–	–
34	41	41	25.0 (3.0)	6.0 (1.0)	2.0 (0.0)	5.0 (2.0)	40.0 (6.0)	35.0 (4.0)
88	96	96	26.0 (1.0)	6.0 (1.0)	6.0 (2.0)	23.0 (3.0)	46.0 (6.0)	33.0 (3.0)
188	185	185	20.0 (7.0)	5.0 (2.0)	6.0 (1.0)	20.0 (4.0)	32.0 (6.0)	26.0 (1.0)
320	320	320	21.0 (3.0)	10.0 (1.0)	5.0 (1.0)	12.0 (11.0)	37.0 (6.0)	37.0 (7.0)
467	467	467	12.0 (3.0)	8.0 (2.0)	8.0 (5.0)	15.0 (4.0)	42.0 (6.0)	41.0 (3.0)
674	675	675	20.0 (1.0)	13.0 (3.0)	6.0 (1.0)	8.0 (4.0)	38.0 (5.0)	44.0 (2.0)
817	818	818	22.0 (5.0)	16.0 (3.0)	9.0 (5.0)	17.0 (8.0)	38.0 (5.0)	46.0 (3.0)
937	–	–	22.0 (2.0)	20.0 (5.0)	–	–	–	–
1069	–	–	21.0 (3.0)	22.0 (2.0)	–	–	–	–

* Number/10 sq. m.

** Percent (%).

2

Environmental Factors in Coral Bleaching: The 1997/98 El Niño in Kenya

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ABSTRACT

Elevated sea water temperature in March and April 1998 caused by the El Niño Southern Oscillation caused mass coral bleaching along the Kenyan coast. Over 90% bleaching and mortality was recorded in the region. Chlorophyll-a concentration ranged between 0.002–0.284 mg/cm^2 for bleached corals and 0.176–0.795 mg/cm^2 for normal corals. Zooxanthellae density ranged between $0.7x10^6$ – $5x10^6$ per cm^2 for normal corals and $0.02x10^6$ – $0.2x10^6$ per cm^2 for bleached coral (total loss of zooxanthellae and pigment was recorded in a few coral fragments).

INTRODUCTION

Coral reefs, found in most tropical regions of the world's oceans, are built primarily by hermatypic corals (Burgess 1979; Veron 1986). Each colony is made up of many individual coral animals, called polyps. Within the cells of these polyps live some tiny single-celled protists (dinoflagellates) called zooxanthellae, which synthesise organic food compounds for the polyps and impart to them the many splendid colours observed in corals (Barnes & Hughes 1988; Brown & Ogden 1993).

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Reef ecosystems are restricted geographically to tropical, warm (20-28^{0}C) clear and shallow sunlit (up to 60 m) waters. Coral reefs rank among the most biologically productive and diverse of all natural ecosystems; their high productivity stemming from efficient biological recycling, high retention of nutrients and a structure which provides habitat for a vast array of other organisms (UNEP/IUCN 1988). In Kenya, the reefs fringe the coast approximately 2 km offshore except for openings at river mouths. They have a high economic value supporting the inshore fisheries, and serve as an attraction to tourists (McClanahan 1994; McClanahan & Obura 1995). They are also of high environmental value, serving to protect the shores from erosion and contribute to formation of sandy beaches and sheltered harbours.

Coral reefs are sensitive to environmental changes and respond differently to different levels of environmental stresses. One such response is bleaching, which is the whitening of corals, resulting from the loss of symbiotic zooxanthellae and/or a reduction of the photosynthetic pigment concentrations in zooxanthellae residing within the gastrodermal tissues of the corals (Brown & Ogden 1993; Glynn 1991, 1993, 1996). The causes of small scale isolated bleaching events are thought to be changes in temperature, salinity, light, sedimentation, aerial exposure and pollution. Large scale bleaching events are caused by greenhouse warming, increased UV radiation flux, deteriorating ecosystem health, or some combination of the above factors (Brown & Suharsono 1990; Buddemeier & Fautin 1993; Glynn 1993, 1996; Dunne 1994). Almost all accounts have implicated increased sea water temperatures as a primary causative factor in the bleaching and subsequent mortality of reef corals (Brown & Ogden 1993; Fangerstrom & Rougerie 1994).

Bleaching is sometimes followed by massive coral mortality and near extinction of rare coral species and possibly serious reef degradation (Brown & Suharsono 1990; Glynn 1994). Bleaching also reduces skeletal growth (Goreau & Macfarlane 1990), delays coral recruitment (Glynn 1990) and reduces species and reef biodiversity (Glynn 1996). Recently published studies make it clear that, although bleaching is an easily recognisable phenomenon, it is difficult to quantify objectively because pigment and zooxanthellae concentrations vary seasonally, with species, sites and between years. The long-term consequences of bleaching are poorly understood and may depend on synergistic environmental factors.

Coral bleaching has been reported in East Africa in March 1987 and in 1994, over a 10-year period of observation (McClanahan 1990) and occurs annually at low levels when sea water temperatures are highest at the end of the north-east monsoon in March-April (Obura 1995). Bleaching was observed during mid-March spring low tides in both years. The 1987 bleaching was most pronounced in the raised reef site in Vipingo, Kenya (McClanahan 1990). Reports of coral bleaching in 1994 were, however, reported from Mafia Island, the northern Tanzanian coast and the whole of Kenya's Southern fringing reef (McClanahan 1997). A number of genera such as *Acropora*, *Pocillopora* and *Galaxea* lost nearly all their pigment. Most of these observations have not been well documented. Bleaching also occurs annually in Malindi in December-March, caused by sediment outflow from the Sabaki River after the short rains in November/December.

The principal aim of the study was to quantify the amount and intensity of bleaching in Kenyan corals, and to relate these to dominant environmental trends over the study period.[5] With this information we may be able to develop techniques that can be used to assess coral and reef health for conservation and management of threatened reefs. The study was part of a broader research programme at Coral Reef Conservation Project (CRCP) investigating coral bleaching and management implications and has contributed necessary data on zooxanthellae/chlorophyll dynamics in corals.

STUDY AREA

This study was carried out on reefs at Malindi Marine National Park, Mombasa Marine National Park and Kanamai, an unprotected reef (Map 1: p.20). These sites occur along the coastline of Kenya, north of Mombasa. Malindi Marine National Park was chosen in order to study coral stress caused by sediments from the Sabaki River during the wet season. Mombasa Marine National Park was chosen because of easy accessibility and nearness to the laboratory. Detailed information about this park is available at the Coral Reef Conservation Project and Kenya Marine and Fisheries Research Institute, Mombasa. Kanamai was included after coral bleaching and mortality occurred in November 1997 during the El Niño rains.

Malindi Marine Park lies in the Malindi-Watamu reef complex. The park covers 630 ha, with a land base of 5 ha at Casuarina Point (UNEP/IUCN 1988). The reef slopes drop to a depth of 20m or more in some places but many reef areas are shallow. This complex is part of the Kenyan coastal fringing reef. Within the reef complex are two unique geomorphologic features: the patch reef complex in the northern part, and the area near the inlet of Mida Creek, in the South near Watamu (Katwijk *et al*. 1993).

5 A detailed description of the study is given in the Ph.D. thesis of the first author (Mdodo 1999)

The Sabaki River exits into the Indian Ocean some 10 km north of the park. During one wet season the river discharged 5000 m^3 of water per second and during the dry season, 20 m^3 per second together with a considerable amount of sediment that affects the adjacent reefs (Katwijk *et al.* 1993). Studies by Obura (1995) indicated that sediment influx into the park from the Sabaki River causes coral bleaching as well as poor visibility thus reducing the tourist value of the area.

Mombasa Marine National Park is about 10 km^2 in size and was gazetted in 1987. Total exclusion of fishermen was effected in 1991. The existence of this park has greatly improved the status of the reef in terms of biodiversity. Bamburi beach has become a major destination for international and local tourists and has continued to grow in terms of popularity. A great deal of tourist activity is focused on the reef, particularly during low tide when tourists visit the park to view the corals.

Kanamai lies in Kilifi District about 20 km north of Mombasa. It is unprotected and has a shallow lagoon, of at least 0.4 m depth at low tide. The lagoon has been seriously over-exploited for corals, shells, fish and other marine organisms for commercial purposes.

MATERIALS AND METHODS

Transect Surveys.

Study sites were chosen at random after a preliminary survey of the study area. Observation and sample collection was carried out in the shallow back-reef lagoon (0.5-2.0 m deep at spring low tide), by diving, using a mask, fins and snorkels. Three 15m-line transects were laid at 5 m intervals parallel to the shore in the Mombasa, Kanamai and Malindi reefs. These line transects were used to record the extent of bleaching of six genera, namely massive and branching *Porites*, *Pocillopora, Acropora*, *Stylophora* and *Pavona*. These species were chosen because they are common in the three study sites and easy to identify. It was also easy to extract coral tissue for zooxanthellae and chlorophyll-a determination from these species. Sampling was done twice a month in each site. Number of bleached, partially bleached, normal and dead corals was determined together with the physico-chemical factors (temperature, salinity, and suspended sediments) at the sampling sites. Bleached corals appeared white, partially bleached ones were partly white and partly normal, while normal corals had pigment and appeared green, brown or blue. Dead corals appeared white with algae growing on the colonies.

Laboratory Sampling.
At each site, samples of coral branches from bleached and normal colonies for each species were collected at random rather than following the transects. For each species twelve fragments were sampled (six bleached fragments and six normal fragments) form different colonies and placed in plastic bags for chlorophyll analysis and zooxanthellae counts.

Temperature Measurements.
Surface and bottom temperatures were measured and recorded using a standard thermometer during sampling. KWS temperature probes attached to the substrate and recording hourly measurements were used to obtain continuous temperature data over the field work period. Water samples were taken at each site for analysis of suspended sediment.

Laboratory Measurement of Chlorophyll and Zooxanthellae Density.
Coral tissue was removed from a known surface area of the skeleton using small, forceful, intermittent jets of filtered sea water delivered rapidly by a water Pik (Johannes & Weiber 1970). Water piking was done inside a 1 litre beaker to allow for maximum tissue removal. The tissue slurry was homogenised for 3 minutes using a blender and its total volume measured. The homogenate was then made up to 150 ml by adding filtered sea water. Aliquots of the homogenate were poured into a sedgewick-rafter cell for zooxanthellae counts or filtered into 4.7 mm GF/C glass fibre filters for chlorophyll measurements. Zooxanthellae counts were made on fresh extracts. The density was determined by counting the cells in 10 fields from a sedgewick-rafter cell filled with the fresh sample. Chlorophyll was extracted and determined using spectrophotometric method as described by Parsons, Yoshiaki & Carol (1984).

Surface area of the pieces were determined using the foil method described by Muthiga (1984). Each coral piece was overlaid with a piece of aluminium foil, care being taken to avoid overlapping and folding of the foil. The foil pieces were weighed using sartorius balance and the surface area (cm^2) of each coral piece was calculated by comparison with weights of foil of known surface area.

Field and laboratory work was conducted between September 1997 and April 1998.

Results

Temperature

Elevated sea water temperature in March and April 1998 followed the El Niño Southern Oscillation (ENSO) and caused mass coral bleaching along the Kenya coast. The ENSO event had an effect on the climate of the study area and the region in general, with heavy rains starting in October 1997, continuing to July 1998. Sea water temperature in March and April had highs of over 32^{0}C at daytime low-tide. National Oceanic and Atmospheric Administration (NOAA) satellite data indicates that sea water temperature in March and April 1998 were elevated by 2-3^{0}C compared with previous years (Table 2.1). In the Mombasa MNP sea water temperatures were an average of 1.5^{0}C above values measured in the same period of 1997 (Obura 1995).

Table 2.1
Positive sea surface temperature anomalies from National Oceanic and Atmospheric Administration satellite data along the Kenya Coast recorded from October 1997 to July 1998

MONTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL
Temp. (^{0}C)	0	0	0	+ 0.25	+ 0.25	+ 2.5	+ 3.0	+ 2.0	0	0

Source: NOAA Internet web site.

Zooxanthellae Density

The density of zooxanthellae ranged between 0.7x10^6 – 4.5x10^6 per cm^2 for normal corals[6] and 0.02x10^6 – 0.2x10^6 per cm^2 for bleached corals[7] (Table 2.2). Additionally, undetectable levels of zooxanthellae and pigment was recorded in a few fragments of bleached corals.

Zooxanthellae densities showed significant differences among species ($p<0.001$), between normal and bleached fragments ($p<0.001$), but not among sites (Appendix 2.1A: p.50). *Porites lutea* and *Pavona decussata* had the highest zooxanthellae density per square centimetre while *Acropora* sp and *Stylophora pistillata* had the lowest zooxanthellae density.

6 Mean: 2.5x10^6 ± 1.2x10^6 (n=11).
7 Mean: 0.2x10^6 ± 0.02x10^6 (n=6).

Table 2.2
Mean zooxanthellae density (number per cm²) for different coral species in Kanamai, Malindi MNP and Mombasa MNP

CORAL	LOC.	NORMAL			BLEACHED			DIFF.
		N	Mean	S.E.	N	Mean	S.E.	(%)*
Acropora sp	Mld	4	945,522	211,580	16	21,963	9,190	98
Porites nigrescens	Knm	48	2,606,746	158,366	24	209,486	28,370	92
	Mld	52	2,434,616	126,315	-	-	-	-
	Msa	70	2,435,436	102,203	-	-	-	-
Pocillopora sp 1	Msa	16	2,674,386	248,872	-	-	-	-
Pocillopora sp 2	Mld	4	2,558,256	20,163	-	-	-	-
	Msa	4	724,774	72,702	-	-	-	-
Porites lutea	Mld	20	3,613,673	400,073	16	78,996	27,484	98
	Msa	12	4,463,251	357,469	8	164,972	27,399	96
Pavona decussata	Knm	24	3,676,809	358,329	8	706,941	113,414	81
Stylophora pistillata	Knm	32	1,040,249	78,444	12	123,440	32,622	88

* % Difference = the density of zooxanthellae lost in the bleached coral.

Table 2.3
Mean chlorophyll-a concentration (mg/cm²) for different coral species in Kanamai, Malindi MNP and Mombasa MNP

CORAL	LOC.	NORMAL			BLEACHED			DIFF.
		N	Mean	S.E.	N	Mean	S.E.	(%)*
Acropora sp	Mld	4	0.034	0.019	16	0.006	0.004	82
Porites nigrescens	Knm	44	0.731	0.071	20	0.101	0.029	86
	Mld	55	0.785	0.046	-	-	-	-
	Msa	84	0.789	0.066	-	-	-	-
Pocillopora sp 1	Msa	16	0.277	0.051	-	-	-	-
Pocillopora sp 2	Mld	4	0.413	0.090	-	-	-	-
	Msa	4	0.213	0.120	-	-	-	-
Porites lutea	Mld	20	0.522	0.095	16	0.025	0.010	95
	Msa	12	0.795	0.160	8	0.041	0.015	95
Pavona decussata	Knm	20	0.740	0.090	4	0.284	0.083	62
Stylophora pistillata	Knm	24	0.176	0.025	4	0.002	0.001	99

* % Difference = the amount of pigment lost in the bleached coral.

Comparison of zooxanthellae densities in *Porites lutea* (Appendix 2.1B) showed less variation among sites ($p>0.05$) than between coral condition (i.e. normal versus bleached; $p<0.001$).

Chlorophyll-A Measurements

The concentration of chlorophyll-a ranged between 0.176–0.795 mg/cm^2 for normal corals[8] and 0.002–0.284 mg/cm^2 for bleached corals[9] (Table 2.3).

Chlorophyll-a concentration showed significant difference between species ($p<0.005$) (Appendix 2.1C). *Porites nigrescens* and *Pavona decussata* had the highest chlorophyll-a concentrations while *Acropora* sp and *Stylophora pistillata* had the lowest. Chlorophyll-a concentration also showed significant difference between bleached and normal colonies ($p<0.001$).

A comparison of chlorophyll-a concentration between sites (Kanamai, Malindi MNP and Mombasa MNP) for *Porites nigrescens* did not show statistical difference ($p>0.05$; Appendix 2.1D).

Field Measurements of Bleaching in Mombasa Marine National Park

From September 1997 to February 1998, no incidences of bleaching were recorded apart from minor mortalities and partial bleaching. Extensive bleaching was first recorded in all the sites in March 1998. In Mombasa Marine National Park about 90% of the *Pocillopora sp* and *Porites lutea* and 99% *Porites nigrescens* encountered along the transect bleached. Other species of corals, soft corals and other reef organisms including foraminifers, sea anemones and molluscs, also experienced high levels of bleaching during this period.

Discussion

The El Niño Effect

El Niño, which historically referred to the warming of surface waters that occurs off South America's west coast every 3 to 7 years, is now recognised as a component of global climate phenomenon, the El Niño Southern Oscillation – ENSO (Hsieh & Ormond 1998). It had been widely predicted and forecast that 1997-1998 would be an El Niño year and that coral

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8 Mean: 0.498 ± 0.287 mg/cm^2 (n=11).

9 Mean: 0.0765 ± 0.010 mg/cm^2 (n=6).

bleaching might occur (McClanahan & Obura 1995). When the ENSO event occurred it caused heavy rains and flooding during normal dry seasons from October 1997 through April 1998, and sea warming from March 1998 in Kenya (Mdodo & Obura 1998). The ENSO-related coral bleaching was triggered by two types of stressors namely rainfall/sediments (in Malindi MNP and Kanamai) and elevated sea temperature (in all the sites).

Heavy rains cause rapid sea water dilution and sedimentation. Studies show that decreased salinity and increased sedimentation/smothering cause an overall reduction in suitability of environmental conditions for corals and many other marine organisms (Glynn 1993, 1996), and may cause bleaching (Obura 1995). Increased temperature alters the internal dynamics of corals/zooxanthellae symbiosis causing stress to the symbionts (Glynn 1996).

Field and laboratory studies have strongly supported the hypothesis that ENSO-induced sea warming was responsible for the catastrophic coral bleaching and mortality episode that occurred throughout the tropical eastern Pacific during the 1982/83 El Niño (Glynn 1990; Glynn & Colgan 1992) and other regions of the world. Glynn (1993) was able to successfully relate, with significant statistical relationships, world-wide (1980-1990) bleaching events with ENSO activities. This study has also implicated ENSO-induced sea warming as the main course of the 1997/98 coral-bleaching event.

Rainfall and Sediment Impacts

In Kanamai, localised bleaching was recorded in October 1997 during and after the El Niño rains which was likely due to sedimentation and sea water dilution in the shallow lagoon (the effect of rain was conceivably greater because it is a shallow lagoon – about 0.4m during low tide). There was a substantial drop in salinity in the Kanamai lagoon after the first five days of torrential rains and bleaching was observed then. Ruwa & Polk (1986) reported underground seepage in Kanamai where salinity is normal at high tide but can drop to 24-25 ppt during low tide. Similar observations, which support this, were made and first documented by Goreau (1964). Therefore, low salinity may have caused bleaching in Kanamai. Species mostly affected in Kanamai during the study were *Porites nigrescens*, *Pavona decussata*, *Stylophora pistillata* and *Acropora* sp.

In November 1997, bleaching was recorded in Malindi North Reef due to terrigenous sediments from the Sabaki River, an event that occurs every year (Katwijk *et al.* 1993; Obura 1995). Sediment loading in Malindi is associated with poor land management in upland areas, which has resulted in accelerated soil erosion and a tremendous increase in river sediments downstream.

Studies on the Sabaki river sediment transport and discharge is extensively reported in Obura (1995). Visibility can reduce from more than 15 m to 1 m over several weeks. McClanahan & Obura (1995) reported that river discharge from the Sabaki flows over Malindi MNP annually, from December to April, controlled by the north-east monsoon and short rains upcountry causing stress to corals.

Sediment stress in Malindi MNP is however not severe because of the high flushing rate of water caused by tidal fluctuation of 3 m twice daily. Substrate cover, coral diversity, and coral genus richness on reefs less than 2 m deep at low tide were not different from reefs with no sediment influence (McClanahan & Obura 1997). There is therefore a high possibility of adaptation to sediment stress by corals in Malindi MNP.

Temperature Effects

Seasonal temperature maxima usually occur in November and March/April (29.5-30.0^{0}C) while minima occur in June/July with 25.5^{0}C (Obura 1995). Sea water temperatures in March and April 1998 were higher by 2.5-3.0^{0}C than in previous years, rising sharply from 28^{0}C in February to 32^{0}C in March and April. The relationship of bleaching to temperature was confirmed by the timing of the mass bleaching event and the timing of the highest temperatures in March and April. It can be concluded that the mass bleaching event in Kenya in March-May 1998 was as a result of the ENSO related sea water warming. The optimum temperature for corals along the Kenya coast appears to be between 27^{0}C and 30^{0}C. As long as sea temperatures remain within this range, temperature is not a stressor for bleaching.[10]

Many tropical marine organisms, including corals, live near the upper thermal tolerance limits (Glynn 1993). It has widely been reported that small increases in sea temperature (0.5-1.5^{0}C) over several weeks will lead to coral stress, bleaching and death (Glynn & D'Croz 1990; Jokiel & Coles 1990). Since the corals were subjected to exceptionally high sea temperatures, it is clear that bleaching was as a result of this stress. Over 90% of the corals in three study sites were affected by bleaching. The 1997-98 bleaching event was reported in all major tropical oceans of the world and is thought to be the most geographically widespread ever recorded (ISRS 1998).

10 Cold-induced bleaching has not been reported in Kenya. Even during the coldest months temperatures hardly drop below 26^{0}C. Hence, it is very unlikely that low temperature-induced bleaching occurs. However, surveys should be done during the coldest months (July/August) to verify this.

Temperature effects are often accompanied by increased solar radiation (Glynn 1993). Both of these act to increase photosynthetic production within the symbiosis, which can have negative effects on both symbionts. Lesser *et al.* (1990) presented evidence that high temperature and irradiance stressors can disrupt enzyme systems in zooxanthellae that offer protection against oxygen toxicity. Another hypothesis is that higher rates of photosynthesis release active forms of oxygen (e.g. H_2O_2, HO) which, unless detoxified, damage cellular lipids, proteins and nucleic acids (Schick, Lesser & Jokiel 1996). In that case, bleaching serves to reduce photosynthetic activity that may damage both symbionts.

Variation in Bleaching between Species

Field measurements in Mombasa Marine National Park indicated high levels of bleaching in all species of corals sampled as well as other zooxanthellae-bearing organisms. A comparison between *Porites lutea* and *Porites nigrescens* indicated that the former took longer to die, and suffered less mortality. Nearly 50% of the bleached *Porites nigrescens* were dead by April while only about 10% mortality was recorded in *Porites lutea*. Generally, branching coral species have higher growth rates and are more susceptible to stress compared to massive species (Obura 1995).

There were significant differences in zooxanthellae density between species with *Porites lutea* and *Pavona decussata* recording the highest density while *Acropora* sp and *Stylophora pistillata* recorded the lowest. The difference in zooxanthellae densities between species may be attributed to many factors, one of which could be morphological differences in the structure and size of the polyps. *Porites lutea*, for example, has smaller polyps compared to *Acropora* sp and *Stylophora pistillata* and therefore more polyps per square surface area. This may probably provide more surfaces for colonisation by zooxanthellae.

There was a significant loss of chlorophyll-a after bleaching. Chlorophyll is unstable and will tend to be denatured when temperature increases beyond the optimal level (Lobban & Harrison 1994). Laboratory measurements showed significant differences in chlorophyll-a concentration between species suggesting that different species responded differently to stress. *Porites nigrescens* and *Pavona decussata* had the highest chlorophyll-a concentration while *Acropora* sp and *Stylophora pistillata* had the lowest.

Evidently there is a relationship between zooxanthellae and chlorophyll-a concentration in the coral tissue indicating that under normal conditions, the amount of chlorophyll-a is dependent on the density of zooxanthellae in the coral tissue and that bleaching is mainly due to expulsion of zooxanthellae from the coral tissue. Chlorophyll-a per zooxanthellae, which is not discussed in this paper, was higher in bleached corals as compared to normal corals (see Mdodo 1999).

Bleaching can be regarded as a physiological response to survive stress (Obura 1995): the loss of zooxanthellae is advantageous to both symbionts because it reduces metabolic activity and the costs of maintaining the symbiosis. However, if the stress persists, and zooxanthellae loss is prolonged, the coral eventually dies of the consequences of the stress. If stress is not too severe and decreases in time, the affected coral usually regains its symbiotic zooxanthellae within several weeks or a few months. The generation time of zooxanthellae varies between 4 and 74 days (Wilkerson, Kobayashi & Muscatine 1988).

Zooxanthellae and Chlorophyll in Normal and Bleached Corrals

Zooxanthellae density measurements revealed significant losses of symbiotic zoo-xanthellae in bleached corals with numbers less than 0.2×10^6 cells cm^{-2}. These values fall well below the reported range for normal, unbleached corals at 1×10^6–5×10^6 cells cm^{-2} (Drew 1972; Glynn & D'Croz, 1990; Glynn 1996).

During bleaching, zooxanthellae densities decreased 81-98% and chlorophyll concentrations 62-99%. These figures fall within the ranges reported by Glynn (1996) who gives an estimate of 60-90% loss of zooxanthellae and 50-80% loss of chlorophyll-a. Bleached corals appeared white or pale because the white calcareous skeleton becomes visible through the translucent tissues that are nearly devoid of pigmented zooxanthellae. The proportion of the loss of photosynthetic pigment to the loss of zooxanthellae was approximately 1:1, suggesting generally, that bleaching was effected by loss of zooxanthellae rather than changes in chlorophyll concentrations within the zooxanthellae.

The bleaching response was similar among coral species irrespective of site. Although spatial differences in bleaching have been suggested by Glynn (1996), this study shows no such differences possibly because the environmental parameters acting on the corals were uniform, and the geographical proximity and the uniformity of the sites. The temperature anomaly may have been so great that the stress response was uniform.

CONCLUSION

Field and laboratory studies strongly support the hypothesis that ENSO induced sea warming was responsible for the extensive coral bleaching and mortality throughout the coast of Kenya in March and April 1998. Results indicate a strong correlation between temperature and field measurements of bleaching in Mombasa Marine Park. Although no attempt was made to relate bleaching with changes in salinity and sediment levels statistically, it is very likely that the early bleaching that occurred in October 1997 in Kanamai and November 1997 in Malindi Marine Park was due to a combination of seawater dilution and sedimentation following the unusually heavy rains.

Field bleaching surveys indicated strong variation in bleaching between species. Different species exhibited markedly different patterns of bleaching and mortality, and susceptibility to environmental factors. A comparison of bleaching between *Porites lutea* and *Porites nigrescens* indicated that the former took longer to die, and suffered less mortality. Generally, branching, small, weedy or fast growing species showed less complex responses to stress, and higher levels of mortality (*Porites nigrescens*, *Acropora* sp, *Pocillopora* sp, *Stylophora pistillata*). Larger, slow growing massive species showed greater combinations of responses and low mortality (*Porites lutea*).

Laboratory determination of zooxanthellae densities and chlorophyll-a concentrations shows significant statistical differences between coral species and between normal and bleached coral fragments. There were significant differences in zooxanthellae density between species with *Porites lutea* and *Pavona decussata* recording the highest density while *Acropora* sp and *Stylophora pistillata* recorded the lowest. Laboratory measurements showed significant differences in chlorophyll-a concentration between species suggesting that different species responded differently to stress. *Porites nigrescens* and *Pavona decussata* had the highest chlorophylll-a concentration while *Acropora* sp and *Stylophora pistillata* had the lowest.

Results indicate that bleaching is mainly due to loss of zooxanthellae and chlorophyll-a. Different coral species have different tolerance to temperature-induced stress as well as different levels of zooxanthellae and chlorophyll-a in their tissues. Bleached corals had significantly lower densities of zooxanthellae and chlorophyll-a concentration compared to normal corals.

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Appendix 2.1

Results of ANOVA's of zooxanthellae densities and chlorophyll-a concentration between species, coral condition (normal and bleached) and sites (Malindi/Mombasa MNP)

A. ZOOXANTHELLAE DENSITY
($r^2 = 0.63$, N = 346).

Source of variation	*df*	*SS* (10^{12})	*MS*	*F ratio*	*Prob>F*
Species	4	71.4		19.099	< < 0.001
Coral condition	1	168		179.569	< < 0.001
Species x coral condition	4	57.6		15.409	< < 0.001
Error	336	314.5	0.94		
Total	345	1131.5	201.24		

B. ZOOXANTHELLAE DENSITY
(Porites lutea) ($r^2 = 0.73$, N = 56).

Source of variation	*df*	*SS* (10^{12})	*MS* (10^{12})	*F ratio*	*Prob>F*
Site	1	3.34	3.34	2.222	0.142
Coral condition	1	196	196	130.419	< < 0.001
Species x coral condition	1	2.32	2.32	1.546	0.219
Error	52	34.63	0.66		
Total	55	236.29	202.32		

C. CHLOROPHYLL-A CONCENTRATION
($r^2 = 0.34$, N = 335).

Source of variation	*df*	*SS*	*MS*	*F ratio*	*Prob>F*
Species	4	3.122	0.78	4.328	0.002
Coral condition	1	3.350	3.35	18.580	< < 0.001
Species x coral condition	4	1.736	0.44	2.407	0.049
Error	325	58.5	0.18		
Total	334	66.71	4.75		

D. CHLOROPHYLL-A CONCENTRATION *(Porites lutea)*
($r^2 = 0.44$, N = 56).

Source of variation	*df*	*SS*	*MS*	*F ratio*	*Prob>F*
Site	1	0.262	0.26	1.997	0.164
Coral condition	1	4.876	4.88	37.136	< < 0.001
Species x coral condition	1	0.205	0.21	1.563	0.217
Error	52	8.84	0.17		
Total	55	14.19	5.52		

3

Macrofaunal Assemblages of Littoral Seagrass Communities

C.M. Muthama & J.N. Uku[1]

ABSTRACT

A comparison of macrofauna found in vegetated seagrass areas and unvegetated areas was undertaken in Nyali Beach, Kenya. This study was aimed at establishing the importance of seagrasses to the Kenyan marine environment. Sampling was conducted during the N.E. and S.E. monsoon periods.

The trends show that the vegetated areas had a slightly higher abundance of macrofauna compared to the unvegetated areas. Furthermore, the areas with a mixed vegetation cover supported a higher number of macrofauna during the N.E. monsoon. The overall abundance of macrofauna was also found to be higher during the N.E. monsoon period. This paper discusses the importance of different seagrasses in the maintenance of coastal biodiversity.

INTRODUCTION

Seagrasses are submerged grasslike flowering plants. They are angiosperms, belonging to the monocotyledon group of plants, and are widely distributed in shallow coastal areas throughout the world. Seagrasses have submerged flowers with pollination occurring underwater. There are approximately 45 species of seagrass in the world's oceans, falling into two families and 12 genera. The family Potamogetonacea contains 9 genera and 34 species. The family Hydrocharitaceae contains 3 genera and 11 species (Phillips 1978).

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In Kenya, seagrasses are found in shallow coastal regions of estuaries, bays and reefs. As the prominent features of the intertidal zone, they extend from low water levels of neap tides to areas well beyond the reef in deep waters. Some seagrasses are exposed for considerable periods during low spring tide, while others though situated high on the shore, grow in pools and depressions where a certain amount of water is left by the receding tide (Isaac 1969).

Seagrasses serve multiple functional roles in coastal ecosystems. They superimpose a structural component on otherwise bare sand or mud-bottoms (Phillips 1978). They serve as a habitat for many small invertebrates and fish. Above all, the seagrass community contributes to fisheries productivity of the Kenyan coastal waters as they serve as nursery, breeding and feeding grounds for fish. They also function as a refuge for marine organisms by providing protection from predators. The blades of seagrass support a diverse epiphytic growth of algae which is a source of food for herbivorous marine organisms. Epiphytes contribute to the high productivity of the seagrass beds and it rivals that of many of the world's cultivated crops (Phillips 1978). World-wide, seagrasses have been used by man as food and as a source of income. The leaves of *Enhalus acoroides* (Linnaeus f.) Royale have been reported to be used for weaving mats and hats, whereas the rhizome is eaten as ***mtimbi*** by the Lamu people in Kenya (Isaac 1969; Wakibia 1995).

The faunal assemblages associated with seagrasses can be sub-divided into several functional sub-units (Orth 1987; Fortes 1990). These sub-units include: species, known as epiphytes attached to leaves and stems of the seagrasses, mobile species, known as nekton that swim over and under the leaf canopy and benthos (infauna) found within the sediment.

Many studies demonstrate that seagrass beds influence the community structure of marine invertebrates (Edgar *et al.* 1994; Orth 1987; Connolly 1994). The investigation of vegetated habitats has revealed a greater faunal species richness, abundance, biomass and productivity in vegetated areas compared to unvegetated habitats (Edgar 1990). This has been attributed to a number of factors. Generally, the high abundance of animals in vegetated sites could be due to an increase in the amount of physical structure usable as living space. There is also an increase in the number of microhabitats, sediment decomposition and stabilisation, food resources, protection from predators and lastly to the reduction of hydrodynamic forces caused by wave action.

The sedimentary character, of the substrate, has also been found to influence the taxa found in the seagrass sediments. Distribution patterns of benthic plants and animals are strongly influenced by the firmness, texture and stability of their substrate. In the case of mobile macrofauna these features govern the effectiveness of their locomotion and for non-motile species, the persistence of their attachment to the bottom. The particle size and organic content of the bottom material limit the versatility and thus the distribution of specialised feeding habitats (Sumich 1984). For example, suspension feeders require clean water to avoid clogging their filters with indigestible particles. Therefore, they are found on rocks or associated with coarse sediments. Some deposit feeders select organically rich areas for consumption to increase the nutritive value of what they eat (Sumich 1984).

Studies of macrofauna in Kenyan seagrass beds have been few (Uku 1995) hence the purpose of this study was to investigate the role that the seagrass community plays in the support of macrofaunal assemblages. It aimed at distinguishing the types of macrofauna found in sediments of different seagrass assemblages. Macrofauna cited in this study was comprised of microscopic animals, which were captured by a sieve of 0.5 mm mesh size and were not large enough to be identified by the naked eye.

Study Area

The study was conducted, during the months of January, 1997, and April, 1997, in Nyali Beach, approximately 7 km north from Mombasa Island (Map 1: p.20). Like the rest of the Kenyan coastline, the area experiences two seasonal trade wind changes known as North East (N.E.) and South East (S.E.) monsoons. The seasonality experienced along the East African coastline is a result of the shifting of the Intertropical Convergence Zone (McClanahan 1988). The N.E. monsoon occurs from October to March while the S.E. monsoon is experienced from March to October. S.E. monsoons are characterised by high cloud cover, rain, wind energy, decreased temperatures and decreased light. During the N.E. monsoons, these variables are reversed. These climatic phenomena ultimately affect physical, chemical and biological oceanographic processes (McClanahan 1988).

Sampling was conducted at the southern end of Nyali Beach, an area with limited human disturbance compared to the hotel beaches in the area. Patches of seagrass were identified randomly in the area. Different combinations of seagrass species were sampled. Mixed species compositions, single species composition (monospecific) and bare sand patches were the focus of this study. These seagrass associations were found 100m from the high water mark at the shore.

Materials and Methods

Assessment of Seagrass Biomass

In the field the shoots of the different seagrass were counted in replicate areas of 25x 25 cm. Samples of the above ground seagrass material was cropped from the 25x25 cm. The samples were carried to the laboratory where the species were identified using the identification keys by Isaac (1969). Thereafter each of the seagrass species was dried in the oven at 80^0C to a constant weight. This was the dry weight estimate of the above ground seagrass material.

Macrofauna Collection

Replicate cores of macrofauna were obtained from the sediments of each seagrass area and non-vegetated sites. A corer of diameter 3.5 cm was pushed down to a depth of 10 cm in the sediment. Due to patchness of the macrofauna in seagrass environments, two cores were obtained adjacent to each other and merged to represent one core sample. In the laboratory the animals were preserved in 10% formaldehyde before processing.

The macrofauna samples were then washed and sieved using a sieve of 0.5 mm mesh size. The samples were placed in suitable containers and stained using Rose Bengal dye then preserved with 10% formalin. The organisms were identified and counted under a dissecting microscope. The identification of the animal species was undertaken using the keys adopted from Barnes (1980) and Day (1974). The animals were classified according to families (Warwick 1988).

Sediment Analysis

Sediments were collected from each site using a core of diameter 3.5 cm to a depth of 10 cm. The sediment samples were wrapped in aluminium foil and oven dried to a constant weight at 80^0C. 100g of the sample was then weighed and dry sieved using a series of sieves and a mechanical shaker. The sediment grain size was then analysed using the Wentworth scale based on phi values and the mean sediment grain size was obtained using techniques cited in Buchanan & Kain (1971). Triplicate samples of 4 grams, from each sample, were ignited at 500^0C for 4 hours for the determination of organic matter.

Results

The Seagrass Composition of Nyali Beach During the Study Period

There were 9 species of seagrasses found in the Nyali Beach area during the study period.

These were *Halophila ovalis* (R. Brown) Hooker f., *Halophila stipulacea* (Forsskal) Asherson, *Enhalus acoroides* (Linnaeus f.) Royale and *Thalassia hemprichii* (Enhreberg) Ascherson from the family Hydrocharitaceae. The family Potamogetonaceae was represented by *Cymodocea rotundata* Ehrenberg and Hemprich ex Ascherson, *Cymodocea serrulata* (R. Brown) Ashereson and Magnus, *Halodule wrightii* Ascherson, *Syringodium isoetfolium* (Ascherson) Dandy and *Thalassodendron ciliatum* (Forsskal) den Hartog. The Nyali Beach area was dominated by mixed species associated with a few monospecific patches of *T.ciliatum, H. wrightii* and *H. ovalis*. The monospecific vegetation areas referred to in this report were areas covered by a single seagrass species whereas mixed vegetation areas were those with a variety of seagrass species growing together.

Table 3.1
Characteristics of seagrasses in Nyali Beach by site (average (s.d.))

	SPECIES	SHOOT DENSITIES*		SEAGRASS BIOMASS	
		Jan.	*Apr.*	*Jan.*	*Apr.*
Mono 1	*H. wrightii*	57 (23)	350 (99)	0.15 (0.06)	4.34 (2.57)
Mono 2	*H. ovalis*	61 (13)	84 (4.9)	0.53 (0.11)	0.97 (0.17)
Mono 3	*T. ciliatum*	22 (3.0)	47 (9.5)	16.8 (5.2)	34.9 (3.0)
Mixed 1	*C. rotundata*	28 (15)	–	1.62 (0.28)	–
	C. serrulata	–	17 (5.7)	–	2.84 (0.22)
	H. wrightii	41 (11)	23 (15)	1.05 (0.42)	0.48 (0.29)
	H. stipulacea	1 (1.2)	53 (33)	0.05 (0.00)	1.60 (0.02)
Mixed 2	*T. hemprichii*	28 (17)	10 (5.7)	1.56 (0.50)	8.00 (1.10)
	S. isoetifolium	44 (28)	61 (51)	2.58 (1.19)	5.32 (10.63)
	C. serrulata	17 (12)	5 (2.1)	5.14 (1.48)	2.66 (1.99)
Mixed 3	*E. acoroides*	11 (2.6)	7 (1.4)	18.3 (2.5)	10.7 (2.0)
	T. ciliatum	13 (14)	6.5 (0.7)	11.8 (9.8)	19.2 (7.4)

* Number of shoots/0.0625m^2

The abundance of seagrasses in the sampling sites. The monospecific seagrass with the highest biomass in January was *T. ciliatum*. The highest biomass from a mixed seagrass bed in January was that of *E. acoroides* which was associated with *T. ciliatum* in a mixed vegetation area. The biomass results reveal a general increase in the seagrass biomass from January (N.E. monsoon) to April (S.E. monsoon (Table 3.1). The bare sand areas were sampled in both January and April. These areas were surrounded by vegetation whereas others were found in pools during low tide.

Seagrass Shoot Densities in Nyali Beach

Mean shoot densities showed a substantial increase in April compared to January (Table 3.1). Some areas showed a decrease as shown by the third mixed area composed of *E. acoroides* and *T. ciliatum*. However some species, like *H. wrightii* (Mono 1), showed an increase from 57 to 350 shoots/0.0625m^2.

Composition of Macrofauna in the Unvegetated Areas (bare areas) Nyali Beach

The macrofauna from both the vegetated and bare areas were categorised into 11 groups based on their families. The categories were Polychaetae, Oligochaetae, Nematoda, Amphipoda, Tanadacea, Cumacea, Isopoda, Capepoda, Ostracoda, Sipunculida and Ophiuroidea. The animals which did not fall in any of these categories were placed under the 'Others' category.

The bare sand samples of January showed different characteristics in animal composition (Appendix 3.1: p.62). The bare sand locations were sampled, in January, and while the first one had 104±12 nematoda/core as the highest number of animals, the second bare sand area had only a few nematodes and Tanaedacea took the lead with a mean of 39±45 organisms/core. In the first bare sand sample of January, amphipods and ophiuroids were absent. The second bare sand sample showed no ophiuroidea and 'others' but all the other categories were represented.

In April, three bare sand areas were represented. In every bare sand location during this month, a single family seemed to dominate (Appendix 3.2: p.63). The first area had numerous Tanadacea while the second and third areas had a high number of oligochaetes.

All the bare sand samples of April had no Ophiuroidea. In addition to the lack of Ophiuroidea the second area also lacked Cumacea and Isopoda while all these groups including amphipoda were missing in the third area.

Macrofauna of the Vegetated Areas

The monospecific areas of *H. wrightii* and *H. ovalis* favoured the dominance of nematoda in January but this changed to oligochaetes in April (Appendix 3.1-3.2). During the N.E. monsoon (January), the monospecific area of the seagrass *H. ovalis* gave the highest single category of nematodes. There were approximately 112±50 nematodes/core.

In April (S.E. monsoon), the abundance of the specific locations reduced drastically (Appendix 3.2). Generally, the animals were less abundant in April as compared to January. This is indicated by the monospecific bed of *H. ovalis*. The highest number of nematodes from a monospecific bed of *H. ovalis* was 112±50 nematodes/core, the number in April dropped to 24±25 nematodes/core. There was still a lack of Ophiuroidea in the bare areas and throughout the sampling areas there was a reduction in the number of Cumacea in all the areas sampled.

The trends of the overall abundance of macrofauna shown in Appendix 3.1-3.2 indicate that the abundance of macrofauna was higher in January and the mixed areas had slightly more animals compared to the other sites.

Table 3.2 *Sediment characteristics of the Nyali Beach sampling areas*

	Jan. 1997		*Apr. 1997*	
	MEAN SEDIMENT GRAIN SIZE (Phi)	ORGANIC CONTENT (%)	MEAN SEDIMENT GRAIN SIZE (Phi)	ORGANIC CONTENT (%)
Mono 1*	2.31	1.46	3.02	1.80
Mono 2*	2.10	1.07	2.08	1.58
Mono 3*	1.28	1.22	2.30	1.66
Mixed 1*	2.88	2.27	2.67	2.12
Mixed 2*	2.72	2.30	2.88	2.17
Mixed 3*	2.42	1.12	2.12	1.43
Bare Sand	2.33	1.00	1.82	1.03
Bare Sand	1.78	1.27	2.87	1.44
Bare Sand			2.33	1.43

* For specification of the type(s) of seagrass species see Table 3.1.

Sediment Grain Size Characteristics

Sediments in the study area were sandy sediments with different ranges as shown in Table 3.2. Fine sand sediments were the most dominant in the January and April sampling areas. The results of the sediment grain size analysis showed that the mixed vegetation area of *C. rotundata, H. stipulacea* and *H. wrightii* had the highest value for mean grain size in January. Small phi values indicate coarse sediments whereas large phi values indicate fine sediments. The value was 2.88, the grain size characteristic of fine sand. The lowest mean grain size value for the month of January was 1.28 and this belonged to the medium sand category and was found in the monospecific area of *T. ciliatum*. Only two areas had a medium sediment grain size and they were monospecific area of *T. ciliatum* and an unvegetated area. All the other areas in January were characterised by mean sediment grain of fine sand. In the April samples the lowest mean grain size was 1.82 from an unvegetated area and had a grain type of medium sand. Apart from these two areas, all the other samples in the month of April had a grain type of fine sand.

Sediment Organic Matter Content

The results revealed that the percentage organic matter of the sediment from the bare sand area were slightly lower than the vegetated sites (Table 3.2). The percentage organic matter content of the mixed beds with 3 seagrass species were generally higher than those from the monospecific areas of *T. ciliatum*, *H. wrightii* and *H. ovalis*. The results also reveal that the total organic content of the sediment samples in April was slightly higher than in January.

DISCUSSION

The seagrasses found in the study site in Nyali Beach were typical of seagrasses found along the Kenyan coast as described by Isaac & Isaac (1968), Coppejans, Beeckman & Wit (1992), Wakibia (1995) and Uku (1995). The only species that were absent in the Nyali study area were *Zostera capensis* Setchell, *Halophila minor* (Zoll.) den Hartog and *Halodule uninervis* (Forsk.) Aschers. The absence of these species in the particular study sites chosen may not necessarily mean that they are totally absent in the rest of the Nyali Beach section and a more detailed survey may yet reveal their presence. Studies along the Kenyan coast have revealed the dominance of *Thalassodendron ciliatum* and *Thalassia hemprichii* in coastal lagoons (Isaac & Isaac 1968; Coppejans *et al.* 1992). As this study was limited to a small area of the lagoon, an indication of the dominant plant types was not possible.

The lower biomass of seagrasses in January compared to April was expected. The month of January falls during the N.E. monsoon and as observed by Isaac (1969) the density of vegetation and the variety of species is lower in the N.E. monsoon from October to mid March. This is the time of the year when the lowest spring tides are found during the day and when air temperatures are very high hence affecting plant growth in the shallow areas. In contrast, during the S.E. monsoon period (April) the lowest spring tides are at night and daytime temperatures are lower thus the vegetation is at its optimum growth. This was shown by the biomass increase of the seagrass species in April.

This study indicated only slight differences in the abundance and diversity of macrofauna in the vegetated and bare areas. Other studies have shown distinct differences between vegetated and unvegetated areas (Edgar 1990). However this was not so in this study. This could be because the bare areas chosen for this study were located close to the vegetated seagrass areas. This means that debris from the seagrass could have been carried into the bare areas hence providing detritus, which is a food source for the macrofauna.

The animals that composed the macrofauna of the seagrass beds of Nyali Beach are typical of seagrass areas along the Kenyan Coast and elsewhere in the world (Uku 1995). Of all the animal groups that were identified in the study area the group Ophiuroidea was very scarce in the bare sand areas. This group of brittle stars are typically found in rocky crevices along the Kenyan coast (personal observation). Thus their occurrence in the vegetated areas in large numbers indicates that the roots and rhizomes of the seagrass vegetation provides a crevice like environment that enable this group to inhabit the vegetated areas.

The overall macrobenthic distribution was lower in April (S.E. monsoon) and this could have been due to the effects of sand scour and general turbulence of the SE monsoon (Alongi 1990) which causes the death of the macrofauna, especially the Cumacea. This decrease in April could also be due to productive seasonality of the different animal groups and the abundance of predatory fish (Stoner 1980), though work on this aspect is yet to be undertaken.

At the start of the study, it was assumed that all seagrass vegetation types support a similar abundance of animal groups. This study shows that there were different animal groups dominating in the different seagrass areas. The numbers in the mixed areas were slightly higher, especially in January. This could be attributed to the fact that mixed seagrass beds could have more to offer in terms of habitat diversity as there are different types of roots and shoots in one area compared to monospecific areas, which have only one type of root, rhizome and leaf structure. This was true in January samples but in April the trend changed and monospecific beds seemed to have more animals. This may be explained by the general turbulence of the water during the S.E. monsoon and therefore uneven distribution of animals every given time. In January, the water is calm giving the animals an opportunity to choose habitats with the best environmental requirements.

Earlier studies on vegetated areas indicate that the above ground biomass is highly significantly related to macrofaunal abundance (Heck & Westone 1977). This was not the case in this study. In this study the presence of plant material was responsible for animal abundance although the amount of the material did not seem to matter. This can be seen in the fact that high seagrass shoot densities did not necessarily support a high number of animals and the animal numbers decreased in April in spite of an increase in shoot densities. Taylor & Lewis (1970) stated that areas with a large amount of dead plant debris is a favourable habitat for both suspension and detritus feeding organisms. Vegetated areas are likely to trap materials carried by water currents hence forming a concentration of dead plant material that attracts the animals to these areas.

The sediments in the study area were fine sand sediments indicating that the wave energy in this areas is low and that the area is protected from strong waves. This is reflected by the assemblages of seagrass species found in the area as areas of strong wave action would have coarse sediments and only one seagrass species that can withstand the wave action (Uku 1995). A study of sediments in seagrass beds conducted by Taylor & Lewis (1970) in Mahe also showed that sediments in seagrass beds on sheltered reef flats were fine.

The occurrence of slightly higher organic matter in sediments of mixed seagrass beds indicate the high fertility of these areas (Sumich 1984). High organic matter is also associated with high animal abundance because more deposit feeders will select these areas to increase the nutritive value of what they eat. This could be the reason why more animals were found in mixed vegetation areas which had a higher percentage of organic matter in their sediments.

Conclusion

This study shows that marine beds with vegetation have a higher faunal abundance than unvegetated beds. The animals (macrofauna) avoid areas with bare sand and occupy vegetated areas where they benefit by the provision of protection against water motion and predators, food from the detritus found here in the form of decaying matter and more living space provided by the roots and leaf blades. The mixed vegetation areas in Nyali Beach had a slightly higher abundance of animals while bare areas were located close to the seagrass beds and were therefore influenced by the accumulation of detritus which enable animals to be found in these bare areas.

Seasonal changes affect the plant and animal life in littoral marine beds as could be seen in this study. The seasonal changes experienced during the S.E. monsoon had a greater effect on the fauna than the increase in seagrass biomass.

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Appendix 3.1

Macrofauna assemblages in Nyali Beach in January, 1997 (N.E. monsoon)

(average number of organisms/core (s.d.); N=3 for each site)

	MONO 1*	MONO 2*	MONO 3*	MIXED 1*	MIXED 2*	MIXED 3*	BARE SAND	BARE SAND
Amphipoda	24 (26)	6 (7.8)	23 (9.6)	48 (26)	43 (6.6)	6 (4.7)	0	12 (6.1)
Copepoda	9 (8.3)	10 (3.5)	5 (8.3)	16 (5.6)	16 (11)	7 (3.8)	19 (18)	9 (10)
Cumacea	3 (1.2)	7.5 (10)	8 (4.5)	3 (3.2)	8 (4.4)	1 (0)	2 (0.6)	6 (5.0)
Isopoda	0	0	17 (5.2)	2 (2.9)	5 (2.5)	2 (2.6)	1 (1.0)	31 (16)
Nematoda	75 (49)	112 (50)	38 (15)	40 (16)	60 (23)	31 (20)	104 (12)	19 (17)
Oligochaetea	42 (14)	37 (16)	20 (3.8)	50 (18)	14 (2.1)	90 (36)	54 (47)	24 (20)
Ophiuroidea	0	0	3 (5.2)	2 (1.5)	.5 (5.6)	2 (0.6)	0	0
Ostracoda	28 (17)	29 (25)	30 (13)	58 (58)	56 (25)	13 (3.8)	15 (4.6)	10 (9.5)
Polycaetea	31 (16)	24 (19)	43 (20)	46 (1.2)	15 (1.0)	34 (14)	16 (12)	18 (14)
Sipunculida	7 (0.6)	10 (6.1)	7 (5.5)	12 (12)	8 (7.5)	25 (2.1)	6 (2.6)	4 (3.2)
Tanadacea	4 (0.6)	6 (6.1)	45 (33)	41 (11)	57 (34)	10 (7.0)	2 (1.2)	39 (45)
Others	10 (2.1)	9 (5.5)	8 (7.5)	10 (8.4)	6 (7.0)	10 (8.4)	4 (3.6)	0
Average, all samples	19.3 (25.8)	21.1 (33.1)	20.6 (18.2)	27.3 (26.6)	24.4 (24.7)	19.3 (26.2)	18.5 (32.1)	14.3 (18.2)
Total Abundance	695	758	742	984	878	694	667	515

* For specification of the type(s) of seagrass species see Table 3.1.

Appendix 3.2

Macrofauna assemblages in Nyali Beach in April, 1997 (S.E. monsoon)

(average number of organisms/core (s.d.); N=3 for each site)

	MONO 1*	MONO 2*	MONO 3*	MIXED 1*	MIXED 2*	MIXED 3*	BARE SAND	BARE SAND	BARE SAND
Amphipoda	14 (9.2)	11 (9.9)	24 (1.6)	32 (1.4)	16 (16)	4 (0)	12 (9.9)	1 (0)	0
Copepoda	4 (2.1)	14 (18)	9 (8.1)	8 (2.6)	3 (1.4)	1 (0)	7 (4.2)	2 (2.1)	7 (3.5)
Cumacea	0	0	1 (1.5)	0	0	0	1 (0.7)	0	0
Isopoda	0	1 (1.4)	2 (1.2)	0	1 (0.7)	0	25 (2.1)	0	0
Nematoda	48 (21)	24 (25)	38 (25)	22 (5.7)	49 (6.4)	70 (4.9)	31 (16)	10 (4.9)	13 (9.9)
Oligochaetea	93 (16)	42 (23)	40 (7.0)	29 (8.5)	29 (1.4)	84 (45)	36 (26)	29 (18)	29 (6.4)
Ophiuroidea	0	0	1 (1.5)	1 (0.7)	2 (1.4)	0	0	0	0
Ostracoda	15 (6.4)	27 (9.9)	32 (22)	12 (0.7)	22 (6.4)	2 (0.7)	18 (0)	3 (0)	6 (0)
Polycaetea	40 (15)	14 (2.8)	16 (14)	10 (1.4)	14 (1.4)	23 (12)	37 (28)	12 (6.4)	4 (3.5)
Sipunculida	8 (1.4)	3 (4.2)	6 (1.7)	4 (1.4)	11 (7.1)	14 (9.2)	9 (0)	3 (2.8)	3 (3.5)
Tanadecea	5 (0.7)	6 (4.9)	22 (13)	19 (7.1)	3 (2.8)	4 (4.2)	98 (1.4)	3 (2.1)	1 (0.7)
Others	28 (18)	5 (2.8)	6 (5.7)	7 (2.8)	8 (2.8)	6 (6.4)	6 (5.7)	3 (0.7)	2 (0)
Average, all samples	21.0 (27.5)	12.1 (15.0)	16.4 (16.9)	11.9 (11.0)	13.0 (14.4)	17.2 (29.3)	23.2 (27.2)	5.29 (8.99)	5.21 (8.39)
Total Abundance	504	291	591	286	312	412	557	127	125

* For specification of the type(s) of seagrass species see Table 3.1.

4

Water Quality and Species Diversity of Intertidal Macroalgae

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ABSTRACT

Spatial and temporal changes in species diversity, abundance and composition of macroalgae in the intertidal zones at Kanamai and Da Gama Point along the Kenyan north coast were studied from March to September 1999 to investigate their relationship with water quality.

A total of 63 species of macroalgae were collected, 23 belonging to Chlorophyta, 23 to Rhodophyta and 17 to Phaeophyta. There was an increase in the coliform number per 100 ml of water from 60 to >1600 and from 90 to 1600 at Kanamai and Da Gama Point respectively. Phosphate levels showed an increase from 0.56 to 1.025 and from 1.420 to 1.750 μg atoms P/litre for Kanamai and Da Gama Point respectively. Ammonia also increased from 1.350 to 1.540 and from 3.800 to 4.250 μg atom N/litre for Kanamai and Da Gama Point respectively. At Da Gama Point there was a tendency towards dominance by fewer species.

Pollution by sewage and elevated nutrient levels is evident. Kanamai is less nutrient-rich resulting in the higher species diversity, composition and evenness in distribution.

INTRODUCTION

Macroalgae are seaweeds belonging to the classes Chlorophyta, Rhodophyta and Phaeophyta commonly known as green, red and brown algae respectively. These autotrophic algal species occur between the top of the intertidal zone and the maximum depth to which ade-

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quate sunlight can penetrate. Seaweeds growing in reef intertidal zones, creeks and estuaries are highly productive, supporting nursery grounds for a variety of marine fauna most of which are of commercial fishery interest (Coppejans *et al.* 1997). Some green algae such as *Rhizoclonium* and calcareous algae such as *Halimeda* are important reef builders, forming a matrix in which sand and rubble are held fast, providing the initial substrate for coral polyps' settlement and establishment. Apart from supporting a rich biodiversity, seaweeds are of economic importance (Kumar & Singh 1979; Kiran *et al.* 1980; Mclachlan 1985). Coastal populations have long used seaweeds as a source of food (Mumford & Miura 1988). Certain brown seaweeds are being used to provide alginates (additives used to thicken food). Red algae such as *Eucheuma* are particularly rich in algal carrageenan, a thickening agent similar to gelatine, which is used in various food and medicines for example ice cream and cough mixture as well as beer, toothpaste and water-based paints (UNEP 1998). Macroalgae therefore are an important natural resource.

In Kenya seaweeds have not yet been put to any commercial or appreciable use though about 400 macroalgal species have been identified (Oyieke 1998). A number of researchers have reported on the ecology, distribution and taxonomy of algae in general along the Kenyan coast (Isaac 1967, 1968, 1971; Moorjani 1977, 1980; Oyieke & Ruwa 1986; Moorjani & Simpson 1988; Coppejans & Beeckman 1990; Coppejans, Beeckman & Wit 1992; Oyieke 1993, 1995, 1998; Oyieke & Kokwaro 1993, 1995; Uku 1997). Yarish & Wamukoya (1990) reported 30 species of seaweeds that are of potential economic importance in Kenya. According to UNEP (1998) a broad survey of Kenyan coastal waters has shown that there are no sites with significant stands of commercially important seaweeds and therefore none could be considered available for harvesting from the wild. Any exploitation of existing natural stands of commercially important seaweeds will lead to irreparable damage to primary productivity in the coastal zone and will drastically change the biotope. The naturally occurring macroalgae can be used as stock for seaweed mariculture. Yarish & Wamukoya (1990) suggested that farming of *Eucheuma* and *Gracilaria* could be developed in the Shimoni area of Kenya's south coast. Another alternative would be to find ways of using macroalgae that are washed on the beach. Furthermore the naturally occurring macroalgae have the potential for water quality monitoring, a subject that has not been studied at all in Kenya, though studies have been reported by authors elsewhere (Agadi, Bhosle & Untawale 1978; Wekwe, Othman & Khan 1989; Vymazal 1984; Engdahl *et al.* 1998).

The aim of this study was to investigate the relationship between water quality and spatial and temporal changes in species diversity, abundance and composition of the macroalgae in the intertidal zones at two sites with different pollution levels along the Kenyan coast.

STUDY AREA

The study was conducted at Kanamai and Malindi (Da Gama Point). Kanamai is situated in Kilifi District about 30 kilometres north of Mombasa, while Malindi lies further north about 128 kilometres from Mombasa (Map 1: p.20). The coastline of the areas is separated from the main body of the Indian Ocean by a fringing reef platform.

Climate and weather systems at the study sites are typical of the Kenya coast and are influenced by the Inter-Tropical Convergence Zone (ITCZ). There are two main seasons: the north-east (N.E.) monsoon from October to March and the south-east (S.E.) monsoon from March to October. The N.E. monsoon is characterised by low rainfall whereas the S.E. monsoon is wetter with higher rainfall levels between June and March. High cloud cover, rain, high wind energy, lower temperatures and less light characterise the S.E. monsoon. During the N.E. monsoon these variables are reversed. Annual rainfall ranges from 400 mm inland to more than 1000 mm in places in the narrow coastal belt from Malindi to Kilifi town (UNEP 1998). Sea surface temperatures and salinity vary with the monsoon season. Surface water salinity in Kenya coastal waters vary from a minimum of 34.5‰ to a maximum of 35.4‰ (UNEP 1998). Semi diurnal tides characterise the entire Kenyan coastline. There are two maxima (high tides) and two minima (low tides) per lunar day (24hrs 50min). The tidal range does not exceed 3.9 m. During the N.E. monsoon, the lowest tides occur during the day, whereas during the S.E. monsoon they occur at night (Isaac & Isaac 1968; Brakel, 1982).

Malindi and Kilifi Districts form the southern part of the Athi catchment area that is drained by the Sabaki. This is a perennial river flooding twice a year for periods ranging from 2 to 8 weeks resulting in destruction and serious pollution of beaches around Malindi (Kenya 1994). At this time the river also normally leaves its course and carries with it a large load of silt to the ocean with possible environmental effects on the marine benthic macroflora. Da Gama Point is only about 8 kilometres from the Sabaki estuary while Kanamai is about 100 kilometres away.

Kanamai is a beach facing a large lagoon. The edge of the coral reef where the waves break is about 1.2 kilometres from the beach. By comparison, Da Gama Point beach faces a relatively small lagoon. The distance to the edge of the coral reef is only about 0.5-0.8 kilometres. At Da Gama Point in addition to a number of nearby hotels, there is both commercial and artisanal fishing, trampling and a lot of boating and boat repairing. There is more human settlement around Da Gama Point than at Kanamai. Human impacts were therefore considered to be higher at Da Gama Point compared to Kanamai.

Materials and Method

Sampling was done monthly during daytime spring low tide from March to September 1999. Eight permanent transects were established perpendicular to the shore at a distance of 100 m from each other. Along each transect, quadrants of 0.5 m by 0.5 m, 50 m apart were studied from the shore to the edge of the deep sea. The average number of quadrants sampled per transect were 24 at Kanamai and 15 at Da Gama Point.

Macroalgae in each quadrant were collected from different substrates, identified up to species level and their percentage cover estimated. Those species that could not be identified in the field were collected in labelled plastic bags with ambient seawater and transported in a cool box for later identification in the laboratory. Identification of the macroalgae was undertaken using keys by Isaac & Isaac (1968), Jaasund (1976) and Moorjani & Simpson (1988).

Water temperature was measured using an ordinary mercury thermometer. Salinity was measured with a refractometre. pH was also measured *in situ* using a digital pH meter. Water samples collected were transported to the laboratory the same day in a cool box for nutrient analysis and coliform count.

Faecal coliform count was done using the multiple test-tube Most Probable Number (MPN) method (UNEP 1985a).

Dissolved inorganic macronutrients, ammonium, nitrates and phosphates were analysed by colorimetric methods (Parsons, Maita & Lalli 1984). The concentration of nitrate estimated in this study was a combination of nitrite and nitrate since concentrations of nitrite have been reported to be low and undetectable in the surface waters of the East African region.

The following indicators were used to quantify macroalgal diversity

(i) Algal composition;

(ii) Species richness (S);[2]

2 S = Number of species per defined area.

(iii) Simpson's Dominance Index (LL).[3]

Results

The macroalgae species composition and their overall abundance in the observed transects during the study period are listed in Appendix 4.1 (p.77). A total of 63 species of macroalgae were identified from Kanamai and Da Gama Point out of which 23 species belonged to class Chlorophyta, 23 species to Rhodophyta and 14 species to Phaeophyta. Rhodophyta and Chlorophyta therefore each contributed equally (36.5%) to the species composition. Phaeophyta contributed less with 27% of all species encountered. Of all the macroalgae encountered at Kanamai, chlorophytes comprised of 36.2%, rhodophytes 34.5% and phaeophytes 29.3%. At Da Gama Point, rhodophytes contributed the highest to the species composition with 43.2%, followed by chlorophytes, 29.5%, and phaeophytes with 27.3%.

The most abundant green algae at both locations were *Boergesenia forbesii*, *Chaetomorpha crassa* and *Dictyosphaeria cavernosa*. *Ulva* and *Enteromorpha* were the most abundant chlorophytes at Da Gama Point, while *Halimeda opuntia* occurred abundantly at Kanamai. The red algae *Amphiroa fragilissima, Gracilaria salicornia, Hypnea cornuta* and *Laurencia papillosa* occurred at both sites throughout the study period, while *Gracilaria corticata* and *Sarconema filiforme* were abundant at Da Gama Point. *Padina boergesenii* was the only brown alga occurring abundantly at both sites throughout

Table 4.1
Average species richness for various habitats at Kanamai and Da Gama Point, March to September 1999

PROFILE	KANAMAI	DA GAMA POINT
Near shore	5	10
Seagrass bed	10	7
Coral garden	7	–
Reef platform	14	11
Deep sea edge	8	7

3 $LL=\sum p_i^2$; p_i=the proportion of the i-th species of macroalgae with respect to the macroalgal percentage cover in the quadrat). Simpson's Dominance Index ranges from 0-1, where 0 represents a state of maximum evenness and 1 represents dominance by a single species.

the study period, while *Cystoseira myrica* occurred abundantly at Kanamai. The less frequently occurring chlorophytes *Caulerpa, Valonia fastigiata* and *Boodlea composita* were present at Kanamai, while the rare rhodopytes, *Haliptilon subulatum, Heterosiphonia sp,* and *Botryocladia leptopoda* were found at Da Gama Point.

Table 4.2
Average species richness by site and month, 1999

	KANAMAI			DA GAMA POINT		
	Seagrass Bed	*Coral Platform*	*Deepsea Edge*	*Seagrass Bed*	*Coral Platform*	*Deepsea Edge*
March	5	9	5	5	9	7
April	6	14	7	6	9	9
May	5	11	7	8	10	6
June	7	11	8	7	10	6
July	7	11	6	7	11	7
August	11	10	9	8	12	7
September	10	10	9	7	11	7

Zonation of algae at the Kenyan coast is evident on cliffs (Oyieke & Ruwa 1986). The surface of the lagoon beds especially at Da Gama Point is uneven and there are all sorts of sizes of pools offering a variety of microhabitats that make it difficult to recognize any particular zone. Nevertheless transects in this study were divided into near shore habitat, seagrass bed, coral garden, reef platform and deepsea edge habitats. The species richness at the near shore habitat of Kanamai was low (Table 4.1) and there was no significant change over the months in species richness. At Da Gama Point there was no significant change in species richness near the shore except in transects 7 and 8 which not only showed a high species richness but also an increase after May. At Kanamai inter-transect differences in the species richness was also observed. Transects 7 and 8 at the Royal Beach Club had the lowest species richness.[4] Otherwise at both locations there was an increase in species richness with the onset of the S.E. monsoon with the increase being most noticeable at the reef platform.

4 Transects 7 and 8 at the Royal Reserve Beach Club and Hotel are part of the path used as a common access to the reef platform. There is therefore a lot of trampling effect that could explain the low species richness (Brosnan & Crumrine 1994).

The seagrass bed, reef platform and deep-sea edge habitats had slightly higher species richness at Kanamai than at Da Gama Point (Table 4.2).[5]

The phosphate and ammonia levels in the water were low with an increase observed from May. At Kanamai average range of the phosphates was 0.56–1.025 μg atom P/litre while at Da Gama the range was 1.420–1.750 μg atom P/litre. Ammonia range was 1.350–1.540 for Kanamai and 3.800–4.250 μg atom N/litre. The level of nitrates was low and reduced with time (0.323–0.100 μg atom N/litre). Kanamai generally recorded a higher number of faecal coliforms than Da Gama Point (Table 4.3). This could be due to localised differences in lagoon size and whether the sewage disposal at the beaches is raw or has undergone some level of treatment. The muddy and muddy-sand near shore habitat at Kanamai could be allowing for a greater survival of faecal bacteria compared to the rocky habitat at Da Gama Point.

Table 4.3 *Coliform counts by month, 1999*
(MPN/100 ml of water)

	KANAMAI	DA GAMA POINT
March	60	90
April	900	130
May	>1600	900
June	>1600	900
July	>1600	1600
August	>1600	1600
September	>1600	1600

The Simpson's Dominance index range was generally medium to high, 0.38–0.73 and 0.49–0.82 for Kanamai and Da Gama Point respectively indicating that at Kanamai the species were more evenly distributed while at Da Gama Point few species tended to dominate. There was a high positive correlation between macroalgal percentage cover and the levels of nutrients and coliform number (Table 4.4) i.e. macroalgal percentage cover increased as levels of nutrients and coliformcount increased.

5 At Kanamai a stretch of coral garden occurs beyond the seagrass bed. Compared to the seagrass bed, reef platform and edge of the deep sea habitats, the species richness here is low, with the macroalgae confined largely to the rocks. This zone also showed an increase in species richness from a minimum of 4 in March to a maximum of 7 in July.

The following species at Kanamai showed a significant increase in percentage cover: *Amphiroa fragilissima, Enteromorpha ramulosa, Halimeda opuntia,* and *Hydroclathrus clathratus* while at Da Gama Point, *A. fragilissima, Ulva fasciata* and *U. reticulata* showed a significant increase in percentage cover.

The ranges in temperature, pH and salinity did not differ significantly at the two sites. Salinity was high (34.1-35.5‰), falling to minimum of 33.6‰ in May and June. The temperature ranged from a maximum of 35.2^{0}C in March to a minimum of 24.0^{0}C in May.

Table 4.4 *Correlation coefficient (r) between water quality and macroalgal variables at Kanamai (K) and Da Gama (D)*

	SITE	PO_4-P	NH_3+NH_4-N	MPN
Species richness	K	0.71	0.69	0.66
	D	0.62	0.57	0.56
% cover	K	0.85	0.84	0.79
	D	0.86	0.85	0.81

Key: PO_4-P = Orthophosphates;
NH_3+NH_4-N = Ammonium-nitrogen;
MPN = Most probable number of coliforms per 100 ml water.

Discussion

Macroalgal species diversity in the intertidal zones at Kanamai and Da Gama Point may be considered from two interrelated factors, namely the degree of dominance by a single or few species and the total number of species present. A community has high species diversity if many equally or nearly equally abundant species are present. If a community is composed of a few species or if only a few species are abundant, then species diversity is low.

Differences in species richness at the near shore habitats of the two sites are attributable to substrate; thus Da Gama Point had a high species richness at this habitat compared to Kanamai. The beach profile at Da Gama is rocky while at Kanamai it is diverse with rocky profile occurring largely at the reef platform. The higher dominance index at Da Gama Point shows the tendency of fewer species to dominate while there is more evenness of the species at Kanamai. On the whole species diversity at Kanamai was higher than at Da Gama Point.

There is evidence of coral polyps' establishment and development at the Kanamai seagrass bed adjacent to the coral gardens and also in some sections of the coral garden. This is due to the high abundance of *Halimeda opuntia* and *Amphiroa fragilissima*, which provide the initial substrate for coral polyps' settlement and establishment. *Halimeda opuntia* was noticeably absent at Da Gama Point. This is also in conformity with Brower & Zar (1977) who point out that high species diversity indicates a highly complex community due to varied species interaction. Thus population interactions involving energy transfer, predation, competition and niche apportionment are theoretically more complex and varied in a community of high species diversity.

Kenya seaweeds have been reported to exhibit marked seasonal abundance related to the S.E. and N.E. monsoon winds which bring a change in climate, hydrography and tidal patterns (Moorjani 1977; Oyieke 1998). Most species reach their greatest biomass during the period following long rains, from July to August. The increased number of coliforms and nutrients during the rainy season was due to increased surface runoff. This could be responsible for the increase in species richness and percentage cover of the macroalgae that was recorded with onset of the S.E. monsoon. However, long-term monitoring would help establish how seasonality further affects water quality and consequently species diversity.

A low number of 60 to 90 coliforms per 100 ml of water were recorded in March and April at Kanamai and Da Gama Point respectively. The number significantly went up from May to September (>1600). Kanamai on the whole recorded a higher number of coliforms compared to Da Gama Point. Da Gama Point with its smaller lagoon could be experiencing stronger waves which flush out more sewage compared to Kanamai. Near-shore environments which contain a large amount of organic material will allow for a greater survival of bacteria in the marine environment (UNEP 1985b). This could further explain the higher number of faecal coliforms at Kanamai which has muddy and muddy-sand organic substrate near shore. Da Gama has a rocky substrate. According to Environmental Protection Agency criteria, the coliform number obtained in March and April indicates normal unpolluted water. From May the number of faecal coliforms increased to the unsafe range indicating mild sewage pollution.

The amount of nutrients available in the water influences the algal flora composition. High abundance of the green macroalgae *Ulva* and *Enteromorpha* generally indicates nutrient enrichment due to run-off of agricultural fertilisers or sewage (Coppejans *et al.* 1997). It may also indicate upwelling of nutrient-rich deep water. Therefore Da Gama Point showed evidence of elevated nutrient levels with the high abundance of *Ulva* especially after May. *Enteromorpha* abundance increased at Kanamai from May to August.

CONCLUSION

Type of substrate, level of nutrients and sewage pollution in the water determine the species diversity of macroalgae in the intertidal zones at Kanamai and Da Gama Point. Elevated nutrient and coliform levels leading to increased percentage cover by fewer species results in lowered species diversity.

Species diversity at Kanamai is higher than at Da Gama. This is because the water at Kanamai is less nutrient rich. During the rainy season there is sewage pollution and increased nutrient levels evident at the two locations. This needs further investigation especially in relation to ways of sewage disposal by the institutions around Kanamai and Da Gama Point. Evidence of sewage pollution calls for attention, considering the fact that Kenya coastal waters have a large tidal range of 4 m and strong currents that flush and dilute pollutants in intertidal zones and creeks.

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Appendix 4.1

Species composition and abundance of macroalgae at Kanamai (K) and Da Gama Point (D), March-September 1999

CHLOROPHYTA	K	D
Boergesenia forbesi (Harvey) Feldman	10+	10+
Boodlea composita (Harvey) Brand	4+	–
Bryopsis penetta Lamouroux	1+	1+
Caulerpa lentillifera J. Agardh	1+	–
C. racemosa (Forskal) J.Agardh	2+	–
C. serrulata	1+	–
C. sertulariodes (S.G Gmelin) Howe	4+	–
Chaetomorpha crassa (C.Agardh). Kutzing	10+	10+
Cladophora mauritania Kutzing	3+	3+
Cladophora saviniana Borgesen	4+	5+
Cladophora sp.	1+	–
Codium geppii (Schmidt)	1+	–
Dictyosphaeria cavernosa (Forskal) Borgesen	9+	10+
Enteromorpha kylini Bliding	3+	9+
E. ramulosa (J.E. Smith) Hooker	6+	6+
Halimeda discoidea Decaisne	–	1+
H. macroloba Decaisne	1+	1+
H. opuntia (L.) Lamouroux	10+	–
Udotea indica A. Gepp & C.S Gepp	2+	–
Ulva fasciata Delile	1+	10+
U. reticulata Forskal	–	10+
U. pertusa Kjellman	5+	7+
Valonia fastigiata Harvey ex J. Agardh	2+	–
TOTAL NUMBER OF SPECIES	21	13

Legend

– absent in all transects sampled
1+ found in 1-9% of all transects sampled
2+ found in 10-19% of all transects sampled
3+ found in 20-29% of all transects sampled
4+ found in 30-39% of all transects sampled
5+ found in 40-49% of all transects sampled
6+ found in 50-59% of all transects sampled
7+ found in 60-69% of all transects sampled
8+ found in 70-79% of all transects sampled
9+ found in 80-89% of all transects sampled
10+ found in 90-100% of all transects sampled

Appendix 4.1, continued

RHODOPHYTA	K	D
Acanthophora spicifera (Vahl) Borgesen	6+	7+
Amphiroa anceps Lamouroux	1+	2+
A. fragilissima (L.) Lamouroux	10+	8+
Bostrychia tenella (Vahl) J. Agardh	1+	–
Botryocladia leptopoda (J. Agardh) Kylin	–	1+
Ceramium strictum (Kutzing) Harvey	3+	2+
Eucheuma spp	1+	1+
Gelidiella acerosa (Forskal) Feldmann & Hamel	8+	5+
Gracilaria canaliculata Sonder	4+	2+
G. corticata J. Agardh	2+	9+
G. millardetii	1+	–
G. salicornia (C. Agardh) Dawson	8+	10+
H. subulatum (Ellis & Solander) Johansen	–	3+
Heterosiphonia sp	–	1+
Hypnea cornuta (Kutzing) J. Agardh	7+	10+
H. nidifica J. Agardh	1+	4+
Jania adhaerens Lamouroux	6+	8+
Laurencia papillosa (Lamouroux) Greville	10+	9+
Polysiphonia denudata (Dillwyn) Greville ex Harvey	3+	4+
Portiera hornemannii (Lynbye) P.C Silva	1+	2+
Sarcodia montagneana (J. Hooker & Harvey) J. Agardh	1+	–
Sarconema filiforme (Sonder) Kylin	1+	10+
Spyridia filamentosa (Wulfen) Harvey	1+	–
TOTAL	20	19

Appendix 4.1, continued

PHAEOPHYTA	K	D
Cystoseira myrica (S.G Gmelin) J.Agardh	9+	4+
C. trinodes (Forskal) C. Agardh	1+	6+
Dictyota humifusa Horning, Schnetter & Coppejans	1+	1+
Hydroclathrus clathratus (C Agardh) Howe	5+	–
Padina boergesenii Allender & Kraft	7+	8+
P. boryana Thivy	2+	2+
Padina spp	3+	2+
Sargassum asperifolium (Hering & Mertens) J. Agardh	1+	3+
S. binderi Sonder	3+	6+
S. cristaefolium C.Agardh	2+	2+
S. ilicifolium (Turner) J. Agardh	1+	1+
Sargassum spp	1+	–
Stoechospermum marginatum (C. Agardh) Kutzing	3+	1+
Turbinaria conoides (J. Agardh) Kutzing	4+	–
T. decurrens Bory de Saint-Vincent	1+	–
T. ornata (Turn) J. Agardh var. serrata Jaasund	7+	4+
Turbinaria spp	5+	–
TOTAL	17	12

5

The Impact of Human Activities on Epibenthic Bivalve Communities

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ABSTRACT

A total of 17 bivalve species belonging to 13 families were collected and identified in Malindi Mombasa Marine National Parks; and Kanamai from Oct.'97 to Mar.'98. Bivalve fauna showed densities (2/m^2), and low diversity. *Modiolus auriculatus* and *Pinna muricata* were the m represented. There was a significant difference in species diversity between Malindi and Momba reef flats at $p>0.10$. Shallow lagoons had very low-density and diversity as compared to sea gras and reef flat zones. This was attributed to the high deposits of shell, coral, and sand. Swimming, goggling/scuba diving, walking/trampling and turning of rocks were identified as the main forms of human activities causing disturbance to the bivalves. Frequencies of occurrence of these activities varied in the three areas with Kanamai exhibiting the highest. Trampling had the most notable impact and was used to show the impact of human activities on the most vulnerable species.

Results show that the distribution of bivalve fauna in the protected and unprotected areas is density independent and is not only influenced by human activities and management strategy but rather by other biological and environmental factors such as substrate type, tide range and wave activity. Human activities however affect those bivalves with fragile shells such as *Pinna muricata*, through trampling resulting in injury and/or death. Presence of man affects the routine activities of the others such as *Tellina flavum, Anadara antiquata, Tridacna squamosa* and *Codakia punctata*. Therefore spreading out of human activities within the marine parks is recommended to reduce their impacts. These activities should be spread out into the reserves and unprotected areas.

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INTRODUCTION

The Kenya coast region is the single most important tourist destination in Kenya. The most important centres are Diani, Tiwi, and Shelly Beach in the South Coast; Nyali, Bamburi, Shanzu and Kikambala in the middle sector. These are within the influence of Mombasa town. North of Kilifi are Watamu, Silversands, Malindi, and a new centre in Mambrui. Approximately half of the tourists to Kenya visit the marine parks and reserves with 65% of these visiting Malindi and Mombasa Marine National Parks (McClanahan & Muthiga 1992).

Recently human activities have expanded and intensified tremendously within the Marine National Parks (MNP). Consequently important epifauna have been affected in various ways. Echinoderms, bivalves and molluscs are trampled upon and their shells broken, others are utilised as food such as the giant clam (*Tridacna squamosa*) and for their shells, while others are disturbed by the mere presence of people (*Tellina palatum* and *Anadara antiquata*). When coral boulders are overturned and not properly replaced, the epifauna have often perished (Schoorl & Visser 1991). There has also been evidence of free harvesting in the unprotected areas such as Kanamai (Kazungu 1998). This has resulted in diverse negative impacts on the species composition, abundance and distribution of bivalve epifauna in such areas.

The class Bivalvia comprises an important group of molluscs that can be used to quickly determine environment quality, due to their vulnerability and quick response to environmental stress (Castilla & Duran 1985, Brosnan & Crumrine 1994, Akberali & Trueman 1985). Unfortunately, little information is available regarding their species diversity, distribution and abundance.

This paper provides information on the species diversity, abundance and occurrence of some of the major epibenthic marine bivalves and the effect of human activities within the protected and unprotected marine areas.

The study area is located on the Kenya Coast and based in Malindi, Mombasa, and Kanamai. Malindi MNP is located south of Malindi town from Vasco da Gama Point and is 128 km north of Mombasa. Mombasa MNP is located in the Bamburi area, and extends from the entrance to the old port, English point, northwards to the entrance to Mtwapa creek, Cannon point. Kanamai is located on the north coast, forty kilometres north of Mombasa town. It lies in the unprotected zone on the coast and is exposed to intensive fishing, massive shell collecting and coral harvesting.

Full details of the study are given in Boera (2001).

Materials and Methods

Three areas were identified depending on the number of visitors received; two protected areas (Mombasa and Malindi MNP) and one unprotected area (Kanamai; Map 1: p.20). Within each area, three sites were selected; a reef flat, a reef lagoon, and a sea grass zone with each area acting as a block.

Reef flats are shallow reef tops that are exposed during most low tides and may consist of both dead and live corals. Lagoons are shallow protected areas landward of the reef flat.

Sea grass zones are the intertidal zones covered with various species of sea grasses and may or may not be covered with water; they may comprise soft mud, sand or both.

In each of the selected sites, three transects of (1x400m) were laid perpendicular to the shoreline during each visit to the sites. For each study area, a total of nine transects were laid. During this time all bivalves observed were identified and their shell lengths measured. A key by Abbott & Dance (1986) and Richmond & Rabesandratana (1997) was used as reference for identifying the bivalves.

Sampling Methods

Sampling was undertaken during daylight spring - low tides. Samples were taken from the shallow subtidal (up to 2m deep at low tide) and intertidal areas, at different times of the month for each site between Oct.'97-Mar.'98. Visual observations were conducted while walking on the reef flats, near edges; sand and mud flats (sea grass zone); and snorkelling (goggling) within the shallow lagoons. Sampling was carried out along set transects of 1x400m.

Monitoring of tourist activities was determined at the study sites monthly between Oct.'97-Mar.'98. Numbers of tourists observed carrying out different activities on the three areas were recorded and were later used to show the impact of human activities on the most vulnerable species. In addition, bivalve diversity, abundance and density were also recorded.

Data Analysis

The bivalves observed during this study were identified species level and a list of their occurrence prepared. Species diversity was assessed by Shannon-Weiner Index (Shannon & Weiner 1949) for each substrate type at each area. The Index was then used to calculate the t-statistic that was used to check for significant differences in the diversity within and between the sites. ANOVA were also carried out. Species density was calculated in numbers per m^2. Data from both the protected and unprotected areas were then analysed hierarchically to compare species diversity and richness, family composition and population densities of the bivalve species in the study area.

Human disturbance was determined from the number of tourists visiting each of the study areas. Frequencies of human activities observed taking place and of disturbance to the bivalves were recorded and presented in graphical form. These were then used to show the impact of human activities on the most vulnerable bivalve species (*Pinna muricata*).

Results

Species Composition and Abundance

A total of 17 bivalve species belonging to 13 families were observed from Oct.'97-Mar.'98. Table 5.1 shows the species observed; their family and sites of occurrence. Generally, *Modiolus auriculatus* were found abundantly occurring on the reef flat in both the protected and unprotected areas. *Chama costama, Chama brassica, Pollicipes polymerus, Trachycardium flavum, Periglypta reticulata, Pteria chinensis, Dosinia elegans, Tridacna squamosa* and *Gafrarium pectinatum* were found only in the reef flat. *P. muricata, Pinctada margaritifera* were found universally occurring in all the three substrate types in both Malindi and Mombasa MNP. *Codakia punctata, Anadara antiquata* and *Tellina palatum* were found in all reef flats and sea grass zones only. *T. flavum* was most represented in the sea grass zone of Mombasa MNP. The rest of the species did not display a consistent pattern of occurrence.

Total numbers were highest in the mud and sea grass zones and lowest in the shallow lagoons. *M. auriculatus* was most represented in this category in Malindi MNP while *P. muricata* was most represented in Mombasa MNP. *M. auriculatus, P. muricata, P. chinensis, P. polymerus, T. squamosa, Barbatia decussata, T. flavum,* and *D. elegans* were found universally in all the three ecological zones (Table 5.1). Most bivalve species occurred universally in all the substrate types in Kanamai with *G. pectinatum* present only on the reef flat while *P. chinensis, Chama* species, *P. polymerus* and *T. squamosa* were not observed in the sea grass zone. *M. auriculatus, P. chinensis, P. polymerus, T. palatum, C. brassica, B. decussata* and *G. pectinatum* were absent in the lagoon while *G. pectinatum, C. brassica, T. bicarinatum, T. flavum, A. antiquata, P. margaritifera* and *C. punctata* were present in all ecological zones. *D. elegans* was not observed in Kanamai during the entire period of study.

Table 5.1
Species, family, genus and occurrence of marine bivalves at the Kenya Coast

SPECIES	FAMILY	OCCURRENCE *
Modiolus auriculatus (Kraus)	Mitilidae	K,M,L
Pinna muricata (L)	Pinnidae	K,M,L
Codakia punctata (L)	Lucinacea	K,M,L
Anadara antiquata (L)	Arcidae	K,L,M
Pollicipes polymerus (L)	Pollicidae	M,L,K
Tellina palatum (Iredale)	Tellinidae	K,M
Pinctada magaritifera (L)	Pteridae	M,K
Chama brassica (Reeve)	Chamidae	M,K,L
Chama costama (Reeve)	Chamidae	M,K,L
Tridacna squamosa (Lamarck)	Tridacnidae	M,K,L
Trapezium bicarinatum (Schumacher)	Trapeziidae	K,M
Babatia decussata (Sowerby)	Arcidae	K,L
Gafrarium pectinatum (L)	Lucinacea	K,M
Periglypta reticulata (L)	Veneridae	K,L
Pteria chinensis (Leach)	Pteridae	K,L
Trachycardium flavum (L)	Cardiacea	K,L
Dosinia elegans (Lamarc)	Veneracea	M,L

* K=Kanamai, L=Malindi MNP, M=Mombasa MNP.

Total bivalve numbers varied between the different substrate types in Malindi MNP, with the sea grass zone recording the highest (1256) in January 1998 (Table 5.2). An ANOVA for the different substrate types showed no significant differences at $p<0.1$ among total numbers of the different species. In Mombasa MNP, values increased from 116 in Dec.'97 on the reef flat to 3446 in Jan.'98 with a gradual decline to 2540 in Mar.'98. Total numbers compared for the protected areas using Analysis of Variance (ANOVA) showed a significant difference among the reef flats at $p<0.1$. There was no significant difference among the total numbers of the other ecological zones.

In Kanamai the numbers were highest in the sea grass zone followed by the reef flat and lowest in the shallow lagoons with the highest bivalve number occurring in Nov.'97 in the sea grass zone (3903). A significant difference was observed between total bivalve numbers of the different ecological zones at $p<0.1$. A comparison between the protected and unprotected areas showed no significant difference.

Table 5.2 *Total number of bivalves on the Kenya Coast by location, Oct.'97-Mar.'98*

	MALINDI MNP			MOMBASA MNP			KANAMAI		
	Lagoon	*Reef*	*Seagrass*	*Lagoon*	*Reef*	*Seagrass*	*Lagoon*	*Reef*	*Seagrass*
Oct.	112	258	770	134	1040	209	62	720	3871
Nov.	174	320	832	221	1127	296	94	752	3903
Dec.	102	695	822	206	116	205	56	719	3785
Jan.	105	1256	772	139	3446	212	56	684	3643
Feb.	90	848	751	123	2939	489	62	731	3652
Mar.	82	641	769	121	2540	210	67	1814	3814
TOTAL	665	4018	4716	944	11208	1621	397	5420	22668

Density values ranged between 0 and 2 per m^2 with *C. costama* (0.083) and *P. polymerus* (0.0233) showing the highest density in the reef flat of Malindi and Mombasa MNP, respectively. *P. muricata* (0.45) and *T. palatum* (0.0325) had the highest densities in the sea grass zone in Malindi and Mombasa, respectively. There was no significant difference between the protected and unprotected areas.

Similarity of species abundance using the Bray and Curtis similarity index showed values ranging between 0-1.55 for the protected areas and 0-0.602 for the unprotected area, indicating a high variability between numbers in both areas. *M. auriculatus, C. punctata, P. margaritifera, C. costama, T. flavum* and *D. elegans* total numbers were relatively similar within the protected and unprotected areas. All other species numbers were significantly different in Kanamai. An ANOVA for the total numbers of each species in the three-substrate types showed a significant difference at $p<0.1$.

Comparisons made between protected and unprotected areas using the index by Sorensen (1948) showed values ranging between 47.1% and 90.9%, while those of the different ecological zones in each site ranged between 28.6% and 86.9% (Table 5.3). Species on the sea grass and reef flat zones in the protected and unprotected areas were very similar with higher percentage values (70-91%) while those of the shallow lagoons were found to be relatively different with lower percentages (47-76%).

Species Distribution

The coefficient of dispersion (CD) indicated that most species were either clumped/ contagious (>1) or uniformly/regularly (<1) distributed while only a few were randomly (1) dis-

Table 5.3
Sorensen's index for comparing species similarity within and between protected and unprotected areas at the Kenya Coast

Between sites	MALINDI MNP vs. KANAMAI	MALINDI MNP vs. M'SA MNP	MOMBASA MNP vs. KANAMAI
Reef flat	90.9	83.9	87.5
Shallow lagoons	47.1	76.2	55.6
Sea grass zone	70.0	80.0	83.3

Within sites	LAGOON vs. REEF FLAT	LAGOON vs. SEA GRASS	REEF FLAT vs. SEA GRASS
Malindi MNP	81.5	40.0	72.0
Kanamai	58.3	28.6	74.1
Mombasa MNP	71.4	86.9	69.2

tributed in both the protected and unprotected areas. *M. auriculatus* showed the highest tendency towards a clumped distribution, *P. reticulata, C. brassica, C. costama, T. squamosa, P. chinensis* and *D. elegans* showed a uniform distribution (0-0.397).

In Malindi MNP, coefficients of dispersion (CD) ranged between 0 and 6813 in the reef flat and sea grass zones thus indicating a clumped (>1) or uniform (<1) distribution, only *T. palatum* showed a random distribution (1). *P. muricata* (6813) showed the greatest tendency of a clumped distribution. Values ranged between 0 and 129 indicating contagious and regular distributions, with no random distribution for Mombasa MNP. The shallow lagoon had values ranging between 0 and 474 showing clumped and uniform distributions, with no random distribution but *P. margaritifera* (474) showed highest tendencies towards a contagious distribution. In the reef flat, values ranged between 0 and 1421 with *C. brassica* showing the only random distribution with *M. auriculatus* (1421) showing the highest tendency towards a clumped distribution.

The unprotected areas showed CD values ranging between 0 and 198.6 showing regular (uniform) and clumped (contagious) distribution in the shallow lagoon, *P. margaritifera* displaying the most notable contagious distribution while *A. uropygmelana, P. polymerus, T. palatum, C. punctata, D. elegans, T. muricatum* and *B. decussata* showed a uniform distribution. Values ranged between 0 and 6228.3 in the reef flat showing either a clumped or uniform distribution, with *P. muricata* showing a random distribution. *M. auriculatus*

(6228.3) showed the highest tendency of a clumped distribution while *P. reticulata* showed the only uniform distribution.

Table 5.4 *Shannon's diversity indices calculated for the reef flats, shallow lagoons and sea grass zones of the unprotected areas at the Kenya Coast*

AREA STATUS	AREA	SUBSTRATE TYPE		
		Lagoon	*Reef*	*Seagrass*
Protected	Malindi MNP	0.711 ± 0.3	0.6 ± 0.062	0.146 ± 0.05
	Mombasa MNP	0.734 ± 0.04	0.932 ± 0.02	0.932 ± 0.02
Unprotected	Kanamai	0.196 ± 0.122	0.122 ± 0.02	0.857 ± 0.7

Species Diversity

Species diversity was assessed by Shannon-Weiner Index (Shannon & Weiner 1949) for each substrate type at each area. The data is presented in Table 5.4 for both the protected and unprotected areas. The respective diversity figures for the shallow lagoon, reef flat, sea grass zone were 0.711, 0.6 and 0.146, for Malindi MNP while in Mombasa MNP values were 0.734, 0.932 and 0.932 respectively. In Kanamai, the unprotected area, the Shannon indices were 0.196 for shallow lagoon, 0.122 for reef zone and 0.146 for sea grass zone. A comparison between the different ecological zones in the protected and unprotected areas using ANOVA showed no significant differences for the reef and shallow lagoons. However the sea grass zone showed a significant difference at $p<0.1$. A comparison between diversity indices of the different months using ANOVA showed a notable difference within the different ecological zones in both protected areas at $p<0.1$.

Human Disturbance

Human disturbance was recorded in terms of activities observed at time of sampling, and their frequencies recorded. These have been presented in Table 5.5. Trampling was the most common activity (60%) followed by swimming (30%), goggling and diving (29%) and lastly by harvesting (8%) and turning rocks (7%). Swimming, snorkel-ling, diving, and walking were the most prominent human activities in the protected areas while walking/or trampling, harvesting and turning of rocks /or boulders were the most common activity in the unprotected area. Other activities such as harvesting and turning of rocks were totally absent in the protected areas.

Table 5.5 *Frequency of human activities at the Kenya Coast by type of activity and location* (%)

	MALINDI MNP	MOMBASA MNP	KANAMAI
Swimming	45.5	34.6	10.5
Walking/Trampling	18.2	42.3	36.8
Goggling/Diving	36.3	23.1	2.6
Harvesting	0	0	26.4
Turning Rocks/Boulders	0	0	26.3

Impacts of human activities have been related with the presence of damaged species abundance (Table 5.6). In areas where trampling was prominent *P. muricata* was the most affected, with crushed or damaged shells being highly prevalent (40% in Kanamai, 10% in Mombasa MNP and 6% in Malindi MNP). *P. muricata* has been used as measure because it manifests these effects immediately. Most species including *G. pectinatum* and *A. antiquata* responded to human presence by closing their valves and burrowing into the substrate especially in the shallow lagoon and sea grass zone where swimmers disturbed and sometimes even stood on them. In Kanamai fishermen dwell in the shallow lagoon and sea grass zones at low tide while fishing for octopuses and other fish using spear guns and turning rocks. Here the turning of rocks and boulders was also a major activity thus causing disturbance to the organisms further by causing dislodgement of some species such as *P.*

Table 5.6 *Frequency of dead bivalves due to trampling on the Kenya Coast by location, Oct.'97-Mar.'98* (%)

	MALINDI MNP			MOMBASA MNP			KANAMAI		
	Shallow lagoon	*Reef flat*	*Sea-grass*	*Shallow lagoon*	*Reef flat*	*Sea-grass*	*Shallow lagoon*	*Reef flat*	*Sea-grass*
Oct.	0	1.2	0	1.0	0.5	7.0	0	5.0	0
Nov.	0	1.0	0	0.8	0.7	0.7	0	12.0	0
Dec.	0.5	5.0	0	0	5.0	2.5	0	5.0	15.0
Jan.	0.2	7.0	0.5	1.0	4.2	2.0	5.0	7.0	21.0
Feb.	0.2	0.5	0.2	1.5	7.5	5.0	6.0	5.0	2.3
Mar.	0	0.2	0.1	0.5	5.0	0.7	4.0	2.1	3.0
TOTAL	0.9	14.9	0.8	4.8	22.9	17.9	15.0	36.1	41.3

margaritifera. Measurement of these impacts quantitatively was not possible, as these require more time and elaborate experiments.

DISCUSSION

Empirical evidence in several cases has demonstrated that reserves should harbor more diversity, higher abundance, and larger organisms (Castilla & Bustamante 1989, Hawkins & Roberts 1991) and even wholly different community structures (Castilla & Duran 1985, Moreno, Sutherland & Jara 1984). In the present study area, this was not the case because the protected and the unprotected areas had similar densities and diversities and where differences occurred among different ecological zones, they were very small. Results suggest that low density, relatively high variability in distribution and diversity typify the bivalve community. Whether these differences can be attributed to the presence of protected areas has not come out very clearly in this study because of the short period of sampling.

Species Composition and Abundance

Species richness comprises only 17 bivalve species, which form about half of the total number of bivalve species known to occur in the East African Coast (Yaninek 1978). Some common species were not observed during the study, which implies that probably a more elaborate sampling methodology is required for more detailed and complete observations. Species similarity between similar sites show variability; e.g. Mombasa, Malindi and Kanamai sea grass zones have similar substrate types and plant species, but have relatively different similarity values. This difference was consistent for other zones, although some species were consistently found on the reef flats and sea grass zones. However, some species were ubiquitous and not associated with a specific area or substrate. This could be due to differences in wave activity and nutrient availability as well as other biological factors. These results disagrees with the study's null hypothesis but agrees with studies carried out by McClanahan (1989) who found high variability in species composition among gastropods in similar reef locations.

Shallow lagoons in both the protected and unprotected areas had very low densities as compared to the reef flats and sea grass zones. This is in agreement with findings by McClanahan (1990) who found that reef lagoons had statistically different community structure with lower species richness as compared to the reef flats and reef edges. This can be attributed to the high deposits of shell and sand debris together with the flooded conditions that discourage or dislodge bivalves during or after settlement. The sea grass zone of

Kanamai had densities of *P. muricata, M. modiolus* and *A. antiquata* that were relatively higher than in the protected areas. The extensive sea grass zone exposed at spring low tide may have made observation much easier and allowed for the settlement of many more bivalves in Kanamai as compared to the protected areas. This implies further that species distribution is influenced by factors other than substrate type and the intensity of human activities.

The low densities of bivalve species regardless of the management strategy were notable during this study. McClanahan (1989) attributed the low densities to sampling, which may have been done at times or places not coincident with bivalve distribution or diurnal activity patterns, a possibility during this study. Large species such as *T. squamosa* may have a slow growth rate taking long to recover after harvesting (Villanoy, Junior & Menez 1988), especially in the protected areas where harvesting was carried out before the parks were gazetted. Among other species, densities may be naturally low for adult population because their distribution is influenced by other factors, both biological and physical, such as substrate type, ocean currents, exposure at low tide, post-settlement mortality and predation in both protected and unprotected areas. This has been shown in studies carried out by McClanahan (1990) in Malindi Marine Park.

Species Diversity

The relatively high species diversity observed in Kanamai sea grass and Mombasa reef flat zones can be attributed to a more even distribution of the species present. This is because other than the number of individuals, the Shannon's index that was used to measure diversity is also influenced by the uniformity in distribution of species (Pielou 1977). However, despite this difference in the diversity values no significant difference was observed within the shallow lagoons and the sea grass zones of the protected and unprotected areas. A significant difference between reef flats of both the protected and unprotected areas was observed at $p<0.01$ contrary to previous studies among other species. McClanahan (1990) found that among the gastropod fauna, only reef lagoons have a significantly different community structure between protected and unprotected areas while other ecological zones had similarities. Kanamai reef flat and sea grass zone are larger allowing more bivalve settlement and as a consequence had greater species richness and density as compared to the protected areas.

The high mean diversity (1.36 ± 0.05) in both protected and unprotected areas shows a wide range of species and an unequal spread of individuals across species variety and also shows an imbalance in the bivalve population in the study area. This was confirmed by the coefficients of dispersion, which indicated that most species were either uniformly distributed or clumped with only two showing a random distribution.

In Malindi, wave currents were quite strong and visibility very poor due to the large amounts of suspended sediment from the river Sabaki. This coupled with the El Nino rains, which resulted in high turbidity, and poor visibility during sampling could be the reasons for the lower numbers observed in Malindi MNP (Munyao 1998). Thus the probability that many bivalve species were missed is very high.

Human Disturbance

The most notable destructive disturbance was trampling in all the three sites. Some of the organisms that suffered included *P. muricata, A. antiquata* and *T. palatum. P. muricata* has a weak shell that is easily destroyed and the damage easily observed. Generally, human disturbances were highly noted in the heavily visited zones as compared to the lightly visited area. Studies carried out by Beauchamp & Gowing (1982) showed that foliose algae species, notably *Pelvetiopis limitata* were less abundant in heavily visited sites in California. In contrast, other species such as *A. uropygmelana, T. Palatum, T. squamosa* and *C. punctata* close their shells and cease activity as one approaches. Such species were affected by most of the human activities recorded including swimming, snorkelling/goggling and trampling. This is in agreement with Akberali & Trueman (1985) who reported that among most bivalves, shell closure is the most immediate response to any changes in their environment.

Among some species there was evidence of death through predation, as empty, clean and intact shells were found still attached to the substrate in protected areas. The probability that these shells are harvested as soon as they are predated upon was very high in Kanamai as empty shells of commercial species such as *T. squamosa* were not observed. Fishermen were seen collecting and cleaning the shells at times of low tide. Shell collection did not appear to be affecting any species in the protected areas, as shells of some species particularly *T. squamosa* were found intact and still attached to the substrate.

In the protected areas, the emphasis is more on the protection of corals and fishes as compared to other non- target organisms while there is little concern in the unprotected zones. As a consequence there is little information kept for the status of these organisms in both the protected and unprotected areas. The impact of human activities on other species such as *A. antiquata* and *M. auriculatus* has not been discussed, as these require more quantitative observations over a much longer period.

At the present level of human activity in protected areas there is not much notable damage to most marine bivalves. The frequency of trampled bivalves is quite low in Malindi MNP compared to Mombasa MNP and Kanamai, which exhibit a much higher frequency. Higher damage to *P. muricata* recorded in Kanamai could be due to lack of control of activities taking place in the marine area. Mombasa MNP has a narrow reef flat along which a parallel transect was laid and this could have affected the distribution frequency of physically damaged *P. muricata*, besides, much of the exposed reef flat is utilised at low tide. Other reasons could be due the effects of ecological zonation. *P. muricata* tend to be more abundant in the reef flat and sea grass zones as compared to the shallow lagoon. The reef flat and sea grass zone also experience more activity at low tide from fishermen and tourists and therefore manifest greater physical damage as compared to the shallow lagoon. McClanahan & Muthiga (1992) found no difference in physical damage to the coral community between shallow heavily and lightly visited sites. Their results showed that all shallow sites regardless of the number of visitors had greater physical damage, which suggested the role of other factors such as waves and currents rather than human activity. This study, however, strongly points at trampling being the most important factor in the physical damage of *P. muricata*. This is supported by studies on benthic diversity and abundance in Malindi by McClanahan (1990) conducted from 1985 to 1988 and later repeated in 1992 and 1993 which showed that protection of marine sites from multiple and interactive human influences appear to increase the resiliency of organisms to single influences. However, the net effect of trampling depends on the timing of the disturbance.

The lack of other data for comparison with this study therefore underscores the need for continued monitoring so as to yield information on the impact of human activities and the effectiveness of the protection of non-target organisms under the current management strategies. There is also a strong need to determine the visitor carrying capacity of each protected marine area.

The time for this study was too short (6 months) to make conclusive remarks and recommendations. Tentative recommendations are however, made to form a basis for future research:

- The number and size of the marine parks should be increased to include areas, which have potential as a habitat for many more species if the use of the marine area is properly managed and regulated.

- Strong emphasis on sustainable use outside marine parks and reserves should be encouraged to complement the effort in the marine protected areas.
- The current conservation measures should be maintained
- Monitoring of marine biodiversity should be continued so as to determine the visitor carrying capacity of the marine protected areas.

Conclusion

The class Bivalvia comprises an important group of molluscs that can be used to quickly determine environment quality and the impact of potential harmful impacts. Unfortunately, little information is available regarding their species diversity, distribution and abundance and the impact of human activities at the Kenya Coast. This study provides information on these aspects so as to enhance management and conservation strategies.

Species composition in the unprotected and protected areas was similar to that in the unprotected areas contrary to the null hypothesis of the study. Results show low densities, variability in species distribution and diversity despite the differences in management strategy.

The difference in the impact of human activities was not very much apparent in the protected and unprotected areas. Among all species the young dominated with the mature bivalves being very few in numbers. Intermediate stages are conspicuously few while among some species such as *A. uropygmelana, C. punctata* and *T. palatum* mature/ adults were missing.

Human activities have an impact on bivalve species diversity and distribution. Trampling had the greatest impact resulting in injury and/or death among *P. muricata* while other activities resulted in reduced bivalve activity and shell closure during periods when people are present.

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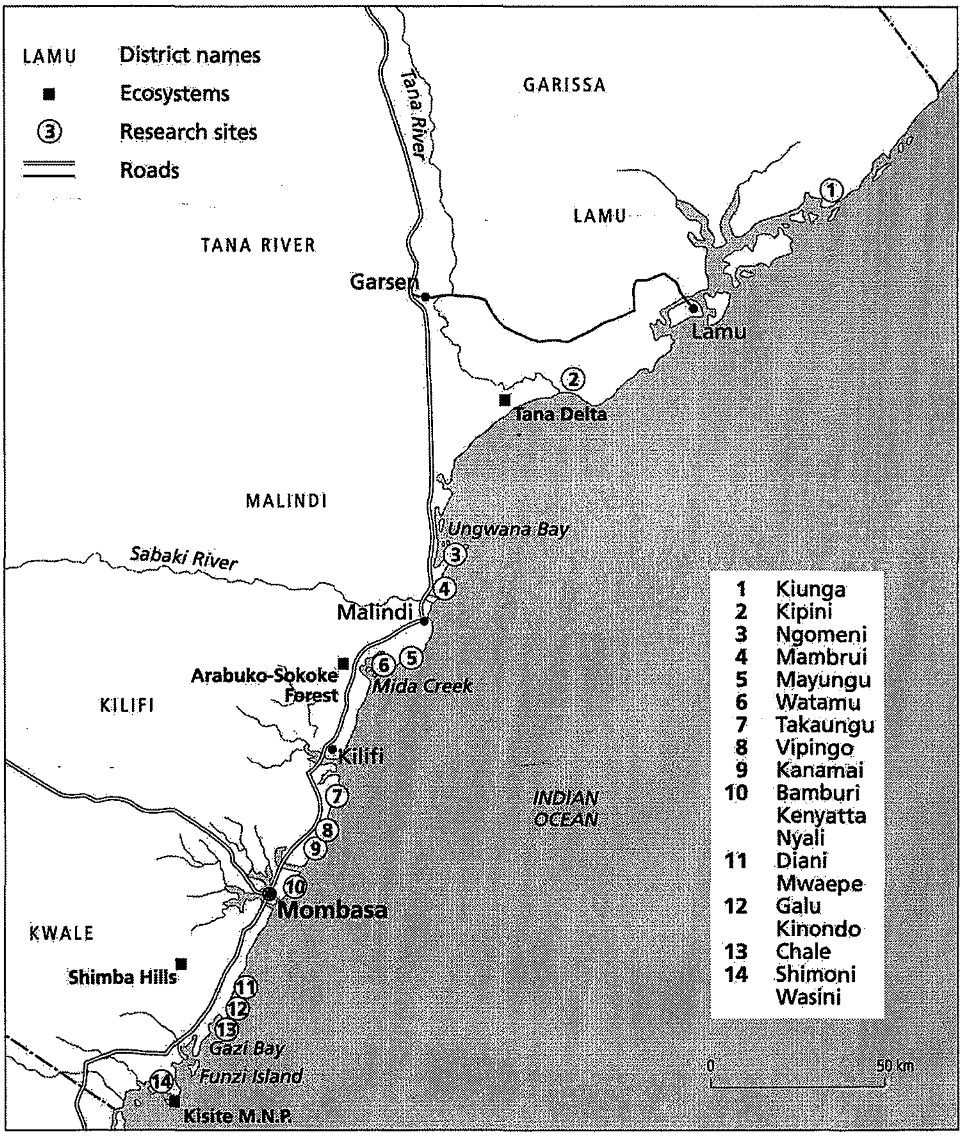
Sediments, Erosion and Pollution

Map 1 *Kenya Coast with location of research sites*



6

The Hydrology and Sediment Transport Capacity of the Sabaki River Measured at its Estuary

J.O.Z. Abuodha[1]

ABSTRACT

Data on the Sabaki River flow rates and suspended sediment concentration were analysed and used to evaluate the annual fluvial sediment input into the Indian Ocean from the Athi-Galana catchment.

The Sabaki River discharges more than 1 billion m^3 of water per year. During this investigation, the mean annual suspended sediment load was found to be $5.0X10^6$ tonnes a^{-1}. The annual bedload (sand) sediment transport is about 20% of the suspended load based on fluvial sediment transport classification of Graf (1988). The present sand budget calculations indicate that the Sabaki River bedload sand is responsible for such high rates of coastal progradation (averaging 15 m a^{-1}) experienced at Malindi Bay.

As the monsoon winds change direction seasonally, the vertical beach change data demonstrates a distinct pattern compatible with the direction of the littoral sand transport. This data suggests that the mechanism of sediment supply to the shoreface involves initial deposition of offshore bars during the Sabaki River flood events. In the period following flooding, the bar sediments are transported by wave action back into the littoral system to become a major component of the longshore drift.

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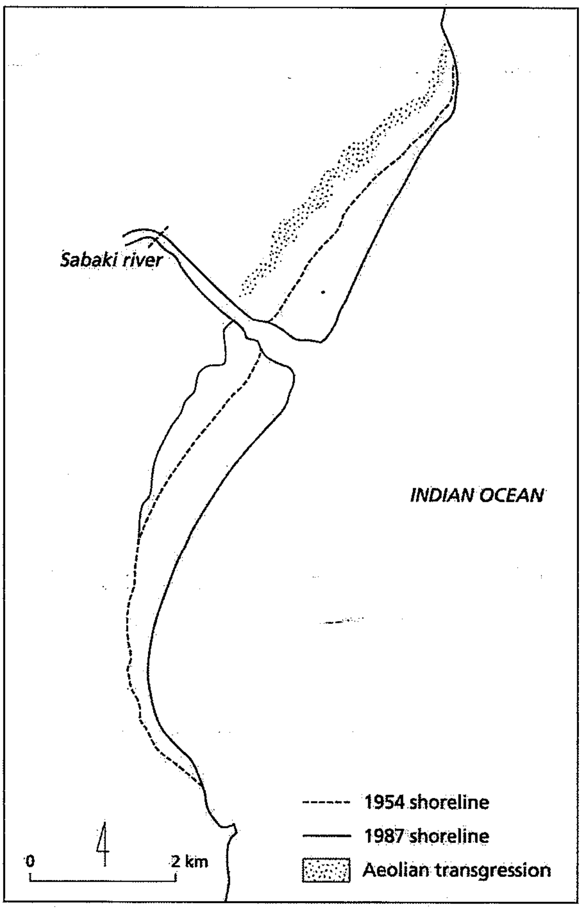
Fig. 6.1 *Shoreline positions and dunefield expansion at Malindi Bay, 1954-'87.* (Source: Aerial photographs and transgressive sand sheets).



INTRODUCTION

The Sabaki River debouches into the Indian Ocean about 5 km north of Malindi (Map 1: p.98). The headwaters of the Athi-Galana-Sabaki system drain the volcanic mountain ranges near Nairobi, the Aberdare Range as well as the Athi and Kapiti Plains. Downstream tributaries emanate from Amboseli, Chyulu Hills, Taita Hills and the northern slopes of Kilimanjaro. The lower course of the Athi River is called Galana (Giriama name) or Sabaki (Swahili name). It has a well defined alluvial plain, but lacks a delta. Instead its seaward termination consists of a filled-in estuary. The Sabaki has a length of about 600 km and a catchment area of 70,000 km^2. For most of its course the river channel meanders across the Mozambique Belt metamorphic rocks; the subsurface of its lower reaches consists of sedimentary rocks. The relatively steep gradient of approximately $3X10^{-4}$ m m^{-1} in the lower reaches of the Sabaki channel does impede extensive influx of seawater.

There is no evidence of major changes in the position of the lower reaches of Sabaki River channel since Pleistocene times and the discharge and sediment transport fluxes were probably higher in the past than at present. This is demonstrated by the presence of a series of large dune systems, dated by Oosterom (1988) as Pleistocene, flanking the modern sand sheets.

The lower reaches of the Sabaki River are incised into a 60-100 m wide channel and retain their characteristics throughout their course, at least up to the bridge. As far as the Baricho water intake, about 40 km upstream, the channel is sinuous and has a fairly uniform cross-section, typically 1-2 m deep. From the bridge seaward, the channel width gradually increases, reaching a maximum of about 1000 m at the inlet (Figure 6.1: p.100). There are signs of a minor northward channel migration seen in cross-sections taken across the river during field investigations. Comparison of sequential aerial photographs available since 1954 demonstrate that the lower 3 km of the estuary has shifted northward by about 200 m.

Recent drilling, done in July 1993, by the MOWLEM construction company to determine the foundation for a new bridge across the Sabaki also confirmed the northward migration of the river channel. Whereas the limestone formation is prominently exposed as a cliff on the north bank, the south bank consists of thick fluvial deposits; the limestone bedrock was encountered here at a depth of 36 m.

The present day beach and aeolian sand deposition is dominated by the influx of clastic sediments of terrigenous origin – quartz, mica and dark heavy minerals (Abuodha & Nyambok 1991) derived via the Sabaki River from a basin extending as far as the Aberdares and the northern slopes of Kilimanjaro. The promontory at the southern end of Malindi Bay, where the Vasco da Gama Pillar is situated, forms a divide with the southern sector of the Kenyan coast which is dominated by deposition of calcium carbonate sands weathered from the adjacent coral reef platform.

Whereas in the southern coast including Mombasa and Diani areas shoreline retrogradation is of primary environmental consideration (Abuodha 1992; Arthurton 1992), the present concern is due to rapid sediment accretion and the increased fouling and silt deposition from the Sabaki River in Malindi Bay and on the beaches at Malindi. The coast there has experienced a sustained shoreline progradation, particularly significant over the last 40 years. Structures existing near the former backshore, constructed before 1961, are presently situated at 100-200 m from the shoreline. Areas of accretion were subsequently covered with scrub and coconut palms. A seawall extending from Vasco da Gamma Pillar to the District Headquarters which previously acted as a protection to the road running parallel to the beach is now 50-150 m from the shoreline and is partly submerged under sand with a sparse cover of vegetation.

The dominant accretionary regime at Malindi during the last 40 years is a manifestation of increased flux of sediment from the Sabaki River, mainly reflecting changing agricultural practices in the catchment. The southward dispersal into Malindi Bay mainly coincides with the Sabaki River floods during the north-east monsoon. However, the dominant longshore sediment transport regime is directed northward.

At Mambrui, 5 km north-east of the mouth of the Sabaki River, the beaches are characterised by high sediment deposition rates, forming an apron which is 100-200 m wide on a fossil coral reef limestone platform. In the immediate neighbourhood of the township, the beach is flanked by sand dune complexes which may attain a maximum height of 50 m. These transgressive dunes have advanced in recent years, into the southern fringes of the township, enveloping structures near the beach including an old hospital.

The Sabaki Estuary

The Sabaki estuary extends about 12 km inland from the Malindi Bay. The estuarine boundary conditions are defined by the extent of flooding by saline water. This part of the channel experiences a tidal wave period of 12.4 hours. Applying a model similar to that used by Bell & Tomlinson (1977) for the Pangani river in Tanzania, the amplitude of the tidal wave and the resulting tidal current are found to be exactly 3.1 hours out of phase. For much of its extent, the channel is bounded northward by a 10 m cliff of coral limestone and to the south by thick fluvial deposits. The southern bank, bordering the Coast Environment Research Station of

Moi University is an area frequently flooded during spring tide, extending up to some 1 km southward of the channel and forming an intertidal zone of mangrove swamps. The channel bottom of the Sabaki River at its estuary was found to consist of clean sand; its characteristics are detailed in this paper.

The Sabaki estuary may be characterised as meso-tidal, high energy sandy environment. The inlet in front of the Sabaki is characterised by the occurrence of crescentic sand bars, spits and offshore plume; and the outflow is split into two major distributary channels. The river mouth bars are exposed during low tide and the river flow is then restricted to the two distributary channels. In addition, large submarine fans have formed which Abuodha (1989) believed to be related to the salt-wedge effect. In the morphological river mouth classification this is the friction dominated channel type of Hoekstra (1987, 1988).

Since the floods of 1961, the Sabaki has discharged large quantities of sediment into the Indian Ocean. Studies by Bird (1985), Abuodha (1989) and Arthurton (1992) have shown that due to large amounts of sand-grade sediment bedload deposited inshore, the shoreline has been fast prograding resulting in wide beaches and transgressive dune complexes present at Malindi Bay (Fig. 6.1). Prior to 1961, the beaches near Malindi were eroding with little accumulation near the river mouth. Subsequent to this period, considerable deposition has occurred at an average of $5X10^6$ m^3 a^{-1} (Delft Hydraulics 1970).

Sediment Plume

The plume is a turbid brown body of the effluent waters emanating from the river mouth especially recognisable during the wet season. Its extent seaward is however limited due its interaction with seawater and bottom friction. Qualitative description of the plume using remotely sensed data (Brakel 1984; Munyao 2000) seems to indicate a seasonal variability of the suspended load transport patterns. Such dispersion is mainly confined to the littoral zone and largely controlled by the dominant residual current flow. The extent of such plumes may reach Ungwana Bay which is about 100 km north. Obura (1996) has studied the influence of siltation emanating from the Sabaki River on coral reef development at Watamu, about 30 km south of Malindi.

Meteorological Factors

The precipitation in the Sabaki River catchment ranges from 500-1400 mm a^{-1} with an average value of about 900 mm a^{-1} (Kenya 1984). There are two rainy seasons respectively referred to as the long rains and the short rains. The first wet months are April and May with over half the annual precipitation falling between April and June, during the south-east monsoon. The second wet spell associated with the north-east monsoon occurs during October and November the total precipitation during this season being relatively small.

Tidal Effect

The tidal amplitude at Malindi, near the Sabaki River mouth is of the semi-diurnal type with a range of 2.9 m at mean spring tide and 1.0 m at mean neap tide (British Admiralty 1980), which are respectively 0.2 m and 0.1 m lower than those at Kilindini Harbour, about 120 km south. Moreover, the mean high water and the mean low water precede those of Kilindini by 5 minutes.

The tidal streams are weak, except very close inshore. As the ocean currents are comparatively strong and subject to considerable variations with the change in wind regime, the effect of the tidal streams on the overall littoral flow is negligible at more than a few kilometres offshore. In the vicinity of the river mouth, tidal currents become an important component of the general circulation, and the nearshore seasonal circulation is superimposed on the tidal regime. The lower reaches of the Sabaki River are subject to tidal influence with the resultant estuarine characteristics. In general, however, the river current causes the rate and duration of the ebb outflow to exceed those of the flood stream, especially at periods of high discharge during the rainy season.

Wave Climate and Currents

Due to the importance of waves in the general coastal circulation and dispersal of the Sabaki sediment load, it is imperative that the typical wave climate off Malindi is described. Since wave observations and statistics for this area are scanty, wave analysis is based on wave parameters observed by ships of passage (Meteorological Office 1990). The data selected from these ship observations for analysis in the present study was from a sea area bounded geographically by the shoreline to the west, latitudes $0^0$00'-$06^0$00'S and longitude $44^0$00'E. The source data from this set are annual frequency averages covering the period 1949-'89 of the following parameters: wave heights estimated to the nearest 0.5 m, wave directions given to the nearest 10^0 and wave periods in seconds. The maximum wave heights observed during the field investigations, from occasional visual observations are 4 m during the south-east monsoon and 2-3 m during the north-east monsoon. The results from ship observations based on 10329 readings taken from 1949-'89 are presented in Abuodha (1998). Analysis of ship-based wave data is presented by Turyahikayo (1987). More information on wave parameters for the Kenya coast is available in a report by Bertlin & Partners (1977).

The waves are wind generated and hence their amplitude and direction correspond to the prevailing wind regime. The wave direction/height occurrence as percentage of observations is considered synonymous with percentage of time. The strongest winds (8-14 m s^{-1}) are induced by the south-east trades (southerlies). These generate large waves and swell. During this period, April to November, the coastal zone is also subject to rare tropical storms which may exceed 15 m s^{-1}. From December to March, the dominant direction of the breaking waves is from north-east, generated by the northerlies.

The annual average wave height is 1.5 m, while the modal class accounting for more than 30% is between 1.0-1.5 m. Abuodha (1998) has also shown that 64% and 36% of the waves attain wave heights of above and below 1 m respectively. In addition, about 61% and 38% respectively break from the south-east and north-east, while the rest, less than 1% is indeterminate. The wave regime has an important influence on the coastal configuration of Malindi Bay.

The current measurement data for the nearshore area taken by Delft Hydraulics (1970) during their investigation on the Malindi Bay pollution provide a basis for the study of water circulation patterns at the mouth of the Sabaki River. More recently, elaborate measurements of current movement off the Malindi coast were undertaken by Kenya Marine & Fisheries Research Institute during the RV Ujuzi Expedition to examine the relationship between upwelling and the development of the Somali Current in this region (Anonymous, 1981). Results emanating from the RV Ujuzi Expedition are given in Johnson, Nguli & Kimani (1982) and Abuodha (1998).

The longshore current flow velocity varies between 0.2-0.4 m s^{-1}, with directions corresponding to the monsoon influence. Close to the fringing reefs or spits, there is much evidence of refraction and compression of waves and current directions are indeterminate. The tidal effect is more important in the vicinity of the river inlet where the flow funnels seaward into a tidal current. The maximum flows of tidal currents occur at low tides.

The present investigation aims at providing an inventory of the hydrological conditions of the Sabaki River channel and to relate these to the total amount of suspended and bedload sediments transported into the Indian Ocean.

METHOD

During the course of the fieldwork, from 20 April '92 to 19 June '94, measurements of river height and flow velocities were undertaken. In order to filter off the influence of tides at the estuarine point of measurement, the readings and sampling were done at low tide. The river height (d) in metres was read off a river gauge existing in the north bank under the Sabaki Bridge (Fig. 6.1) which is located about 3 km upstream from the river mouth. The actual flow velocity measurements were calculated from 10 repetitions, using a buoy attached to a 2 kg weight to minimise the influence of winds. Flow velocity was evaluated from the time it takes the buoy to move 10 m downstream.

During each visit spaced at intervals of between 7-14 days for about 2 years, two 5 litre water samples were taken from the northern and southern part of the stream for the determination of the average suspended sediment load. In order to determine the suspended sediment load the water samples were left in the laboratory for a week during which all the solids settled. The sediments were finally retrieved by decanting and filtering then air dried and weighed.[2]

Bedload transport rates were not measured in the field due to the inherent difficulty in trapping the sand moving at or near the stream bottom. Bedload transport was estimated with the knowledge of actual suspended sediment load determination for hydrological similar channels elsewhere in the world – averaging about 20%.

The shoreline progradation rates were determined from consecutive historical aerial photographs of the area taken over the years; 1954, 1969, 1977, 1984, 1987 and 1994. In order to relate short-term beach changes to the Sabaki River discharge rates, reference was made to data collected by Abuodha (2000), between Mar.'93 and Apr.'94.

In order to determine the ratio of silt-clay and sand components of the suspended load, wet-sieving analysis was carried out through a 63 μm sieve mesh on a composite sample made by mixing all the spot samples. A sand bar at mid-stream taken 100 m. upstream of the bridge and a transect across the bottom of the channel taken 3 km downstream of the bridge were sampled for granulometric analysis of the bedload sediments. The samples were collected at low tide by wading and using a cylindrical sampler. The samples are considered representative of the top 5 cm of bed material.

Large samples (larger than 100 g) were split. The samples were then washed repeatedly with distilled water to remove soluble salts, oven dried at 60^0C, and sieved at quarter-phi intervals for 10 minutes using a Retscht mechanical shaker and a nest of 10 to 15- 50X200 mm sieves. The mass frequency data was subsequently processed using a PC grain size package

2 All calculations, assumptions and formulae on sediment transport are detailed in Abuodha (2000) and Abuodha (submitted).

GAPP (Fay 1989) which calculates both moment and graphical statistical parameters (Folk & Ward 1957). The selection of sieves was from aperture ranging between 0.50-4.00 Ø and the weight held in each of these sieves was recorded.

Deeper samples are available from the cores obtained by a drilling rig during the site investigations by the MOWLEM construction company for the new Sabaki Bridge. The lithological characteristics of the deep fluvial sediments are however not included in the scope of the present research.

Results

River Flow Regime

Flow velocity values display a pattern that shows direct correlation to water depth. The results of a regression analysis for the series of observations made at the Sabaki bridge, gave a significant correlation between water depth and flow velocity at $p < 0.05$, r-value = 0.81 and $n = 74$.

The mean water flow velocities measured during the wet season of 1993-'94 ranged from 0.36 m s^{-1} to 1.34 m s^{-1}. The propagation of the tidal wave upstream towards high water does not alter the flow direction, which remains seaward. The results of this study on the daily flow velocity distribution, show that the maximum and minimum velocities occur during the low and high tides respectively. Correspondingly, the maximum discharge was realised during low tide, and at high tide the whole estuary is flooded with saline water. In the latter case, the tidal stream opposes the river current; the net effect is usually a weak seaward flow largely dependent on tides, as there is no distinct average current.

The alternating wet and dry monsoon seasons are manifested in the river discharge distribution (Fig. 6.2/Fig. 6.3: p.108), respectively showing periods of high discharge and low discharge. The overall annual water discharge for the period was about 1.2×10^9 m3 a^{-1}, measured from the area under the daily flow history curve (Fig. 6.2), which represents an average discharge of 38 m^3s^{-1}. The minimum and maximum flows during the whole period of measurement were 26 m^3s^{-1} and 229 m^3s^{-1} respectively. The average monthly wet season flow (Nov.'92-Feb.'93) was varying from 109 m3 s^{-1} to 152 m3 s^{-1}.

The flow during the dry season (Apr.-Nov.'93 and Jan.-Mar.'94) was on average less than 50 m3 s^{-1} (disregarding one anomalous value of 147 m3 s^{-1} in Apr.'93). The average monthly flow ranged from 30 m3 s^{-1} to 50 m3 s^{-1} whereas the daily freshwater discharge from the Sabaki during measurements ranged from 26 m3 s^{-1} to 50 m3 s^{-1}. It was observed during this study that the estuarine environment experiences increased incursions of saline water

Fig. 6.2 *Sabaki river discharge at low tide, April '92 to June '94.*
(Measured at the Sabaki bridge; Day 1 = Jan.1, 1992)

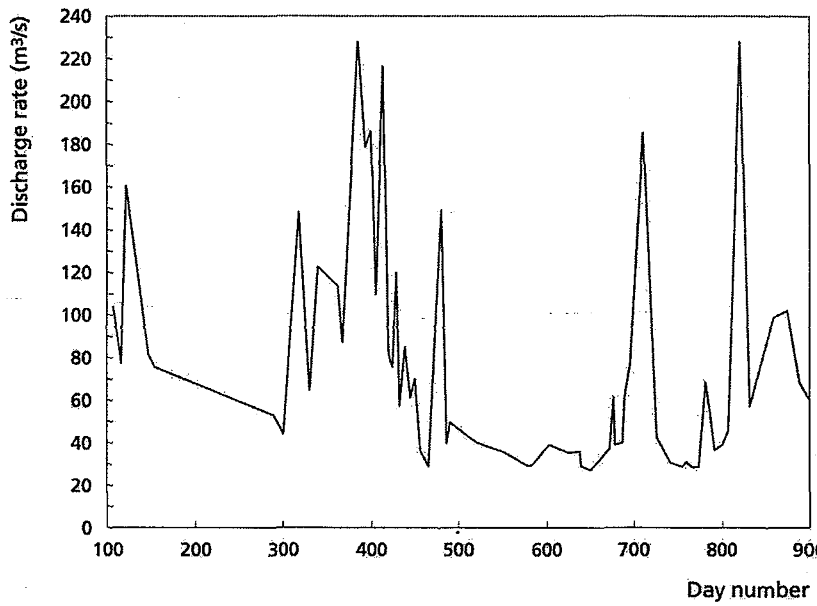
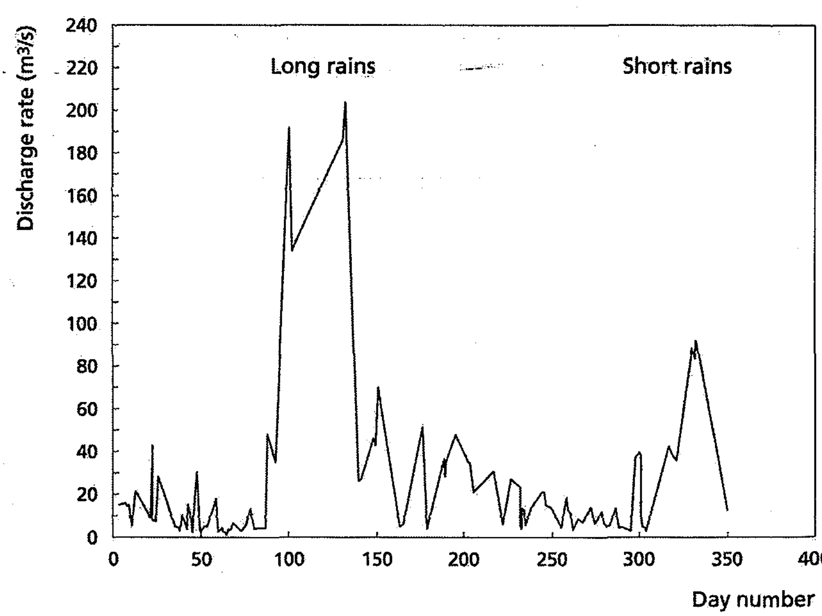


Fig. 6.3 *Sabaki river discharge by the time of year.*
(Measured at the Sabaki bridge; Combined data for 25-year period, 1961-1985; Day 1 = Jan.1; Source: Ministry of Water Development).



owing to the low discharge rates but the steep channel gradient in the downstream section of the Sabaki River mitigates the distance of penetration.

Fluvial Suspended Sediment Transport

The suspended sediment load measured varied from 0.1-7.9 kg m^{-3}, while the average was about 1.3 kg m^{-3}. Most of the suspended load is transported during the wet season (Fig. 6.4: p. 110) and the sediment concentrations may reach the above mentioned maximum value. It is estimated that 90% of the total suspended sediment input into the marine environment occurs during this period. This is considered to be due to increased erosion in the catchment area and the drainage system resulting in increased sediment delivery into the ocean. The suspended sediment concentrations of the river water in the dry season range between 0.1-0.2 kg m^{-3}. The observed sediment flux into the marine environment throughout the year is usually less than $1.6X10^5$ tonnes d^{-1} (Fig. 6.4).

Sediment Characteristics

Details of the bedload samples are given in Table 6.1. The channel bottom, sampled 3 km downstream of the bridge, consists mainly of fine-medium sand, with the mean grain size ranging from 150-250 mm, the coarser components being at the centre of the river channel and fining outwards. The sampling scheme along this cross-section was such that serial samples were collected from site 1 in the south and site 5 in the north of the channel. In general, the bedload sediments show better sorting, more negative skewness and leptokurtic kurtosis particle size distributions along transect from the southern to the northern bank. A sand bar deposit collected in the middle of the cross-section, 100 m upstream of the bridge, is the coarsest; is positively skewed and well sorted.

Table 6.1
Bedload particle size parameters according to Folk and Ward (1957)

CODE	MEAN (Ø units)	SORTING (Ø units)	SKEWNESS	KURTOSIS
SBK/5/B/1	2.18	0.35	0.23	1.31
SBK/5/D/1	2.82	0.58	0.25	1.24
SBK/5/D/2	2.31	0.54	- 0.20	1.27
SBK/5/D/3	2.63	0.23	0.18	3.17
SBK/5/D/4	2.28	0.43	- 0.39	0.85
SBK/5/D/5	2.50	0.27	- 0.62	2.29

Fig. 6.4 *Sabaki river sediment flux at low tide, April '92 to June '94.* (Measured at the Sabaki bridge; Day 1 = Jan.1, 1992).

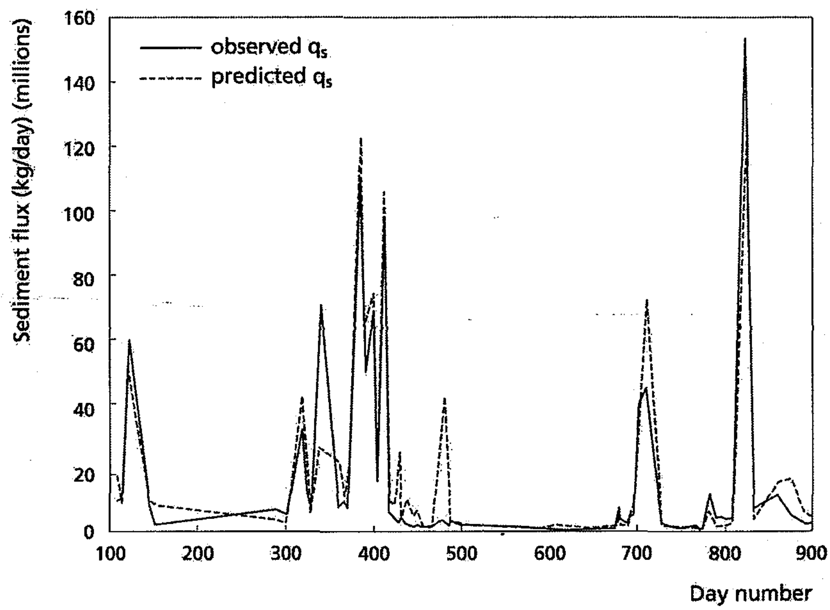
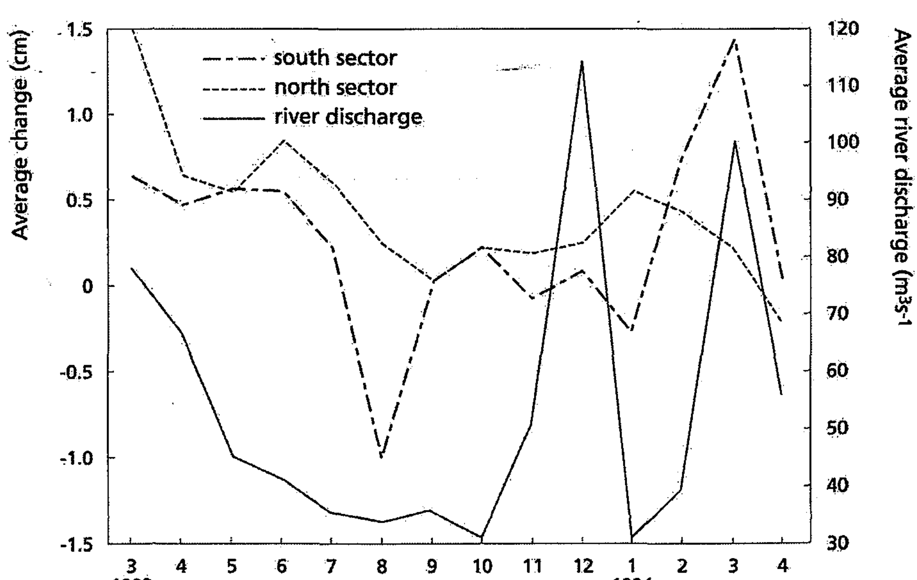


Fig. 6.5 *The average vertical beach change fot the northern and southern sector beaches of Malindi Bay and sediment discharge of Sabaki river, March '93 to April '94.*



When these samples are statistically mixed by summing up the frequency percentage in each sieve class, the resulting composite sample has a mean particle size of 227 μm and the 90th percentile is at 152 μm. Wet-sieving analysis of the suspended sediment load indicate that the sand component is less than 0.5%, the bulk of the material is of silt/clay grade.

Environmental Impacts of Sabaki Sediments: Coastal Changes, 1954 to 1994

Interpretation of a sequential series of aerial photographs for 1954, 1969, 1977, 1984, 1987 and 1994 have yielded trends of the shoreline advance during the progradation episode. The general tendency from 1954 to 1987 was a progradation of the coastline (Fig. 6.1) amounting to an average of 15 m a^{-1} in the southern sector and 13 m a^{-1} in the northern sector. The coastline progradation was at its maximum in the central part of the area, near the Sabaki River mouth. This resulted in an average seaward movement of 23 m a^{-1}. After 1987 the coastline seems to have largely stabilised, although a modest retreat of about 9 m a^{-1} near the Sabaki mouth was noted in the period 1987-'94. During the 1993-'94 period of measurement, it was observed that in the immediate south of the river mouth a shoreline retreat of about 30 m occurred due to persistent wave erosion, accelerated during windy conditions. Consequently a 0.5 m high scarp has developed here that seems to be a permanent feature of the upper shoreline. During the same period, a 20 m retreat of the shoreline was recorded in the middle of the stretch between the river mouth and Mambrui.

In the period 1954-'94 the surface area covered by aeolian sands above the local high-water-level correspondingly increased from $3.0X10^6$ m^2 to $7.2X10^6$ m^2 of which $0.7X10^6$ m^2 in the northern sector represents a landward expansion of the transgressive dunefield (Fig. 6.1). The total areal growth in the southern and northern sectors were both $2.1X10^6$ m^2.

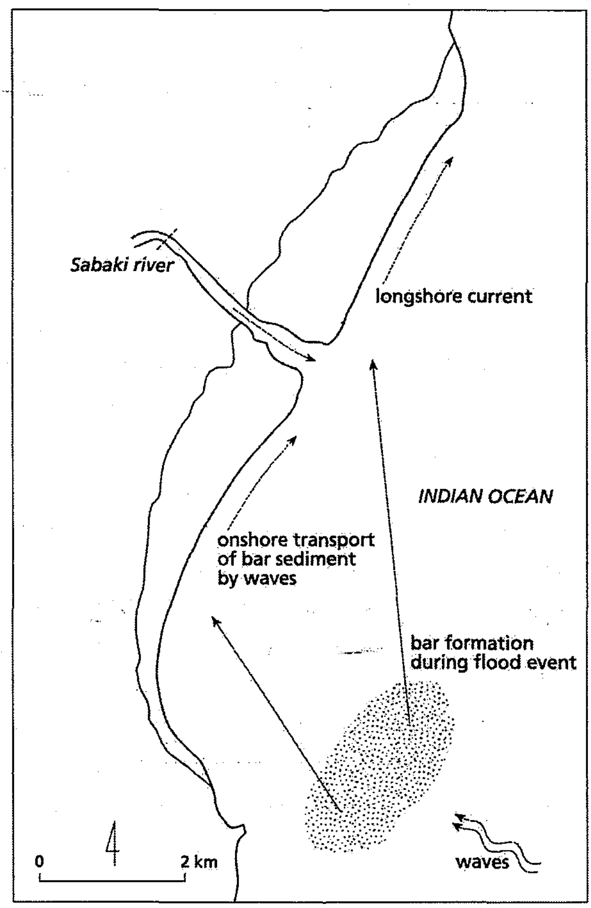
On examining the aerial photographs for 1954 we can see the landward dune ridge was intact and continuous from the Sabaki northward to Mambrui. At present the southern three quarters of this ridge has been reworked and is largely covered by mobile sand sheets. The river mouth has widened by about 200 m, mainly because of shifting experienced in the northernbank.

Discussion

Effect of Tides on Estuarine Flows

Results of this study have demonstrated the effect of tidal exchange on the discharge rate and volumes of sediments transported in suspension. During low tide the peak flow velocities are realised and the capacity of the river to transport correspondingly increases

Fig. 6.6 *Sabaki river sediment supply to the coast.*



owing to higher shear stress associated with lower water levels. During high tide when the whole estuary is flooded with seawater, the dilution effect apparently causes low concentration of suspended sediments. The results contradict the findings at the geometrically similar Porong river in Indonesia by Hoekstra (1987) and Hoekstra, Notting & Sloot (1989), where no disparities during the two alternating flow regimes were identified.

Seasonal Variations of Sabaki Discharge on Vertical Beach Change

The following two hypothesis are presented to explain the sequence of events responsible for seasonal variations of the vertical changes on the beach in the southern and northern sectors, including the effect of sediment discharge from the Sabaki River into the Indian Ocean:

- Sediment leaves the river mouth and is transported straight to the northern or southern beaches depending on the prevailing monsoon wind direction.
- Sediment is initially stored as offshore bars during the Sabaki River flooding, from where it subsequently is picked up by waves and currents and spread along the beaches in the direction of the prevailing monsoon wind system:

Results of short-term field experiments conducted between Mar.'93 and Apr.'94 support the first (general) hypothesis on the relationship between seasonally changing wind direction and sand movement originating from the river mouth at all times. This is demonstrated to some extent by Fig. 6.5 (p.110), showing that there is more build-up of sand in the north during the south-east monsoons (Apr.-Dec.'93) and the trend in transport direction is reversed during the north-east monsoons (represented by the Jan.-Mar.'94 period). For example, in the southern sector, during the south-east monsoon season, only two months recorded average erosion, and one recorded average nil change, which is in agreement with the first hypothesis.

At the onset of the south-east monsoon season in Apr.'93, substantial deposition still took place in the southern sector. This can be explained if we invoke a second hypothesis taking into consideration offshore sources, probably created by a southward drift during the north-east monsoon flooding of the Sabaki River (Fig. 6.6: p.112). Thus the offshore bars (Abuodha 1989), acting as these sources in the offshore area to the immediate north of Malindi town would be reworked and moved northward, simultaneously supplying beach-sand to both the southern and northern sectors. The average vertical change in the north is higher due to the observed continuing supply of fresh sediment (but at lower concentrations) by the Sabaki River and in addition, the southerly winds blow some sand back into the river which re-enter into the littoral system.

It was also revealed through analysis of annual frequency distribution of the average vertical beach changes in the south and north that the former showed more variability, although their modal values are the same at +0.5 cm and both curves show a small positive skewness. Although the physical meaning of this occurrence is uncertain, it is possible that this is a demonstration of the second hypothesis mentioned above.

Analysis of monthly average change as that shown in Fig. 6.5 indicates that Jul.-Aug.'93 and Jan.-Mar.'94 were the periods of greatest variation in the southern sector, which correlate with the peak of south-east and north-east monsoons, and implying that this sector was more sensitive to seasonal variations. During the monsoonal year in Sept.'93 the range of these variations seemed to have decreased to zero.

Relationship to River Discharge

During Jan. and Feb.'93, seaward of the river mouth, the river plume was moving south as far as Vasco da Gama Pillar. However, Obura (1996), during the same period, noted increased sedimentation and turbidity on the coral reefs he was investigating at the Watamu Marine National Reserve, located about 30 km south of Malindi.

In April, the effect of plume had reduced in the south, and traces of suspended sediment began to be noticed in the northern sector of the study area. During the south-east monsoon, river discharge was generally low, and the plume even though laden with little sediment was observed to extend up to Mambrui.

While beach accretion in the study stations is in part attributed to sand emanating from the Sabaki River (besides direction of sediment drift), one cannot account with certainty for the discrepancy between the river flow patterns and net sediment deposition on the beach. However, a careful examination of Fig. 6.5 shows that maximum erosion was experienced when the river flow was lowest, and accretion was maximum during the peak river discharge, albeit with a slight time lag.

Fig. 6.5 also shows some trends of the river discharge that correlate with net beach elevations; for example increasing sediment yield from the Sabaki was reflected by an increase in accretion rates between Dec.'93 and Mar.'94; a decline in river discharge between Mar. and Oct.'93 corresponds to a general decrease in beach elevation.

Implications of Historical Shoreline Changes

Historical shoreline analysis of a sequential series of aerial photographs in the period 1954 to 1994 demonstrates that the Malindi Bay coastline has experienced tremendous changes over the last 40 years due principally to the Sabaki River. However, there is no data available to relate the Sabaki River bedload transport and the actual rates of coastal progradation. It can only be speculated that high rates of coastal progradation in the previous years was due to higher sediment discharge from the river attributed to application of inappropriate landuse techniques within the catchment area, and much higher rainfall events which occur at irregular intervals in the historical record. Between 1987 and 1994 progradation was retarded because of a decrease in the amount of rainfall in the catchment area.

Bird (1985) reported that while a few coastlines have advanced by more than 100 m a^{-1}, on a global scale, a gain or loss of more than 10 m a^{-1} has been exceptionally rapid, and that very few shorelines have changed by more than ±1 m a^{-1}. The author further note that variations in rates of beach progradation and alternation of erosion and accretion may be correlated with short-term fluctuations in fluvial sediment yield related to rainfall occurrence. For example in southern California, Bird (1985) reported that beach erosion prevalent in the dry years of 1939-'69 was superseded by accretion in the years when flooding occurred (1969-'83), but in recent decades the erosion trend has predominated.

In the Malindi area, local folklore suggest that the beaches were eroding prior to the floods of 1961, and that since then the shoreline has been prograding. This view is supported by aerial photographs for 1954 which indicate erosional beach scarps in the upper foreshore. Reconstruction of shoreline changes on the basis of subsequent aerial photographs also support this fact. If the average amount of rainfall for a period ranging 1962-'80 and that obtained in 1993 are compared (and if extrapolated to the whole of catchment area) there seems to have been a decrease in recent years from an average of 1058 mm a^{-1} to 922 mm a^{-1} (Abuodha 2000). This rainfall cycle may explain the erosion trend in recent years. Ojany & Ogendo (1973) reported that the average annual discharge at the mouth near Malindi amounts to approximately $1.3X10^9$ m^3 a^{-1} which is comparable to our value for 1992-'94. This points to consistency in discharge. Between 1994 and 2000 an average shoreline progradation of 100 m was recorded; this is probably due to the El-Niño floods of 1997/98.

One cannot account with certainty for the higher progradation rate value in the southern sector compared to that of the northern sector. It is however suggested that the apparent dominance of progradation in the south might be a result of full utilisation of littoral sand in the growth process. In contrast with the south, part of the sand budget in the north is contributed to the accretion of larger sand sheets which result in a landward dunefield transgression (Fig. 6.1). Secondly, all parameters being equal, this difference may reflect higher supply of sediments by the Sabaki during the north-east monsoon. Thirdly, at the scale of aerial photographs used, we can consider the two values to be practically equivalent and the difference only resulting from measurement errors inherent in the resolution.

CONCLUSION

The Sabaki estuary is an environment characterised by suspended sediment transport, perennial stream flow and tidal activity. Due to high wave and current action in comparison to the river discharge, the sediment is transported and deposited away from the mouth. This is in contrast to deltaic environments where the stream flow is more important than nearshore oceanographical processes. To some extent deposition is experienced at the outlet in the area of crescentic bars but the bulk of the sandy component is deposited along the beaches and extensive dune complexes whereas the muddy plumes are transported offshore and northward toward Ungwana Bay. According to the classification scheme of Hoekstra (1987, 1988), the Sabaki River mouth can be regarded as a friction dominated channel type.

The Sabaki River discharges more than 1 billion m^3 of water per year. The contrast between discharges during wet and dry seasons is amply shown by the results of these investigations. The flow characteristics are associated with the two rainy seasons, which in turn, correspond to the south-east and north-east monsoons. Delft Hydraulics (1970) have reported that the wet season flow rates may reach 5000 m3 s^{-1}, but this seems unrealistic given that 1994 was exceptionally wet but the maximum recorded value was only 227 m3 s^{-1}.

The mean annual suspended load was found to be $5X10^6$ tonnes a^{-1}. The annual bedload sediment transport is estimated to be about 20% of the total sediment load transported by the Sabaki River.

The most logical deduction that can be drawn from seasonal beach change data, wind and river discharge is as follows: the fluvial sediment discharge largely results from flood events, during which sediments are deposited in the form of offshore bars. In the period following flooding, wave action transports most of the bar sediments back into the littoral system where it becomes part of the longshore drift. The sand component conveyed through the Sabaki fluvial system to the Indian Ocean is responsible for rapid coastal progradation (averaging 15 m a^{-1}) and the formation of extensive transgressive dunes between Malindi and Mambrui.

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7

Sabaki River Sediment Transport and Deposition in the Indian Ocean

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ABSTRACT

The study aimed at investigating transport and deposition of sediments discharged by the Sabaki River into the Indian Ocean. Suspended solids, bottom sediment grain size distribution and mineralogy, and seasonal sediment discharge rates were measured.

The Sabaki River discharges $1.18x10^6$ to $2.47x10^7$ tons of sediments per annum. The highest sediment discharge occurs during the N.E. monsoon period, attaining a range of $2.96x10^5$ to $1.70x10^7$ tons, while the lowest discharge occurs during the S.E.-N.E. monsoon transition period, attaining a range of $1.11x10^5$ to $2.27x10^5$ tons. Sediments in the study area are moderately well to very well sorted. Grain size decreases both across and along shore and ranges from medium to very fine. During the study period, Malindi-Mambrui beach experienced net sediment gain as most heavy sediment grains from the river mouth were deposited along the beach and inter-tidal zone.

The plume of total suspended solids facilitates along-shore transport more than across shore transport, and travels beyond the North and South limits of the study area at solids concentration levels of 0.010 to 0.500 g/l and 0.010 to 0.900 g/l respectively. The plume moves both to the north and south of Sabaki river mouth, depending on the monsoon direction. Generally, total suspended solids levels decreased both along and across shore. The lowest mean value of suspended solids was 0.010 g/l, while the highest mean value was 1.85 g/l. Deposition of silty sediments occurred from mid-continental shelf seaward.

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INTRODUCTION

Sediments discharged by rivers into the continental shelves of world oceans, especially those in deltaic coasts, play important roles in pollutant transport, nutrient replenishment to the marine ecosystems, and coastline morphological processes. They affect the well being of marine resources. Sediments form part of non-living resources (Suter 1994). The factors governing transport and deposition of these sediments in the continental shelf are complex (they include climate, shelf morphology, waves, and currents), and have been made more complex by human activities (Hanson & Lindh 1993).

The Sabaki River is the main transporter of sediments to the study area. The river arises from streams in the Aberdare Range and the Ngong Hills, and cuts through volcanic, metamorphic and sedimentary beds which range in age from precambrian to recent (Thompson 1956). Research on sedimentology has been done mainly from the shoreline to the mainland. Thompson (1956) found the Malindi area to be characterised by sedimentary rocks, which range in age from triassic to recent. Giesen & Kerkhof (1984) found sediments from the Sabaki river mouth to be well sorted, ranging in grain size between 0.05 and 0.4 mm. These sediments were dominated by shells, corals, and sea urchins. Studies on the heavy mineral grains have reported a grain diameter range of 1.7Ø to 2.8Ø in the study area (Abuodha & Nyambok 1991)

Information on sediment dispersion in the study area is scanty, and focuses mainly on effects of sediments on coral health in the Malindi-Watamu area. Brakel (1984) analysed Landsat images taken from 1973 to 1979 and reported peak sediment discharge during the long rains, which occur during the south-east monsoon wind season, the plume of which moves northwards, and a lesser pronounced peak sediment discharge during the short rains which occur during the north-east monsoon, the plume of which travels southwards, even though offshore, the East African Coastal Current continues moving northwards. Giesen & Kerkhof (1984) reported along-coast transport of sediments from Sabaki river mouth by saltation and traction. Everaarts & Nieuwenhuis (1995) reported significant increases in heavy metals along seaward transects which were perpendicular to the Kenyan coast, with significantly enhanced levels of organic carbon and all heavy metals in the Sabaki river mouth. Analysis of satellite images combined with other studies reveal eroding beach conditions between 1954 to early 1960s, followed by rapid aggradation since then to the present (Kenya 1993). This continuous beach aggradation has resulted in the creation of new land in the seaward direction.

In the Malindi-Watamu area, siltation due to the Sabaki river water is reported as one of the main causes of death of corals, the occurrences of which have been found to be limited to depths of up to 15-20m in the more turbid environments of the East African coast (Blom *et al.* 1985; Hamilton & Brakel 1984; Salm 1983) and occurs during the north-east monsoon winds, during which the sediment plume extends southwards from the river mouth into the Malindi Bay at Vasco da Gama Point. Most coral die-offs are reported to have occurred since early seventies as a result of heavy sediment flux from the river (Samoilys 1988). Katwijk *et al.* (1993) reported an increase in value of combined coral stress indicators with increase in terrigenous sediment load values in the Malindi north and Watamu areas. However, the overall effect of the sediments on the corals in the Malindi-Watamu areas may be debatable, as Obura (1985) reported low impacts of terrigenous sediments on coral growth, and low degree of coral smothering by sediments, resuspended as a result of interactions between water energy, sediment supply and climatic factors.

The main objective of the study was to investigate transportation and deposition of sediments discharged into the Indian Ocean by the Sabaki River, specifically:

- the quantities of sediments the Sabaki River does discharge yearly;
- the nature of these sediments;
- how and where these sediments are deposited in the Indian Ocean.

Study Area

The study area is a strip running from Vasco da Gama Point in Malindi town to Mambrui township and is bounded by latitudes $3^0 13'$S and $3^0 6'$S and longitudes $40^0 7'$E and $40^0 10'$E (Map 1: p.98). It covers an area of approximately 14 km^2. The area is mainly the continental shelf of the Malindi Bay. Midway along the study area is the Sabaki river mouth, which discharges into the ocean.

The hinterland of the study area forms part of the catchment area of the river, and can be divided into the coastal plain, the foot plateau, the coastal range, and the Nyika plain (N.E.S. 1984; Thompson 1956). From Malindi northwards, occasional peaks (such as at Mambrui) and sand dune ridges which rise to 66 m, are found. On the seaward edge of the plain are a coral crag and other deposits.

The continental shelf in the study area is generally a narrow one. It ranges in width from 5 km at Malindi, narrows to about 0.8 km towards Mambrui, then increases again gradually to about 1.5 km northwards (Navigation Chart 2951). Off the Sabaki river mouth, there is a break in the fringing reef, just like in other parts of Kenya's coastline where there is river discharge.

MATERIALS AND METHODS

Sediment Discharge

Sediment discharge was monitored at the river gauge station. A water point-sampler was used to collect surface and near bottom water samples for determination of suspended solids discharge by filtration method. This method of sampling was limited to material transported in suspended form, as the method can not successfully sample material transported by saltation and drag. The river velocity was measured by timing floats placed at the middle of the river with a stop watch. The floats were allowed to gain momentum similar to that of the river, after which the time taken for them to travel through a distance of 15 m was determined using the stop watch. In order to correct for velocity over the depth of the river, the obtained values of mean velocity were multiplied by a correction factor of 0.7 (Shaw 1988). The stream's cross-sectional area was determined by measuring water depths across the river at intervals of 2 m. From this, seasonal sediment discharge was determined.[4]

Sediment Grains Properties, Budget and Total Suspended Solids

Transects were marked according to distance (km) and direction (north or south) from the Sabaki river mouth. Beach surface (up to 5 cm deep) sediment samples were collected along transects from the beach seaward. A 2 litre sediment grab was used to collect bottom sediment samples from sample stations where water depth was higher than 1 m. Samples were placed in well-labelled nylon sample bags and stored for analysis. Each sediment sample was subsampled by quartering method to obtain with minimum bias, 200-300 g of sample for sieve analysis.

After filtration and weighing results were analysed with the GAPP software (Fay 1989). Sediment samples were characterised in terms of mineral types whether colourless (quartz), opaque white (calcareous), dark, and brown (mica). These results will be presented elsewhere.

Along pre-determined transects, beach profiling was done for two seasons. Profiling was done during ebb tide times and changes in sediment level determined. The results were used to describe sediment budget along the beaches.

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4 For formulas and specification of calculation methods see Munyao (2001).

Water samples were collected along transects from the shoreline seawards. with a point-water-sampler from surface, mid-depth and bottom depth.[5] At each depth, 500 to 1000 cc of water sample was collected and stored in two-litre sample bottles.

A combination of the results and satellite images for both N.E. and S.E. monsoon seasons were used to describe the TSS plume in the study area.[6]

RESULTS

Sediment Discharge

During the N.E. monsoon in 1997 sediment discharge exceeded 2,191 kg/s. This period of high sediment discharge continued up to July 1998. The highest discharge during the S.E. monsoon was experienced in June 1998. During the N.E. monsoon in 1998, alternating decreases and increases were observed.

Table 7.1 *Sabaki River sediment discharge by season*

	N.E. MONSOON (Dec-Feb)	N.E.-S.E. TRANSITION (Mar-Apr.)	S.E. MONSOON (May-Oct.)	S.E.-N.E. TRANSITION (Nov.)	TOTAL
No. of Days	121	61	184	30	–
Lowest (kg/s)	5.28	138.1	2.58	42.9	–
Highest (kg/s)	2191.2	180.7	406.6	87.5	–
TOTAL Lowest (tons)	$2.96x10^5$	$7.28x10^5$	$4.09x10^4$	$1.11x10^5$	$1.18x10^6$
TOTAL Highest (tons)	$1.70x10^7$	$9.93x10^5$	$6.46x10^6$	$2.27x10^5$	$2.47x10^7$

Table 7.1 shows a summary of the level of sediment yield by season (lowest and highest that can be expected), assuming constant discharge rates during each season. Total annual discharge by the river can range between $1.18x10^6$ and $2.47x10^7$ tons. The highest sediment discharge occurred during the S.E. monsoon and can range between $2.96x10^5$ and $1.70x10^7$ tons, while the lowest discharge occurred during the S.E.-N.E. transition period and can range between $1.11x10^5$ and $2.27x10^5$ tons.

5 At the shoreline, only surface sample was collected, because for water depth less than 0.5.m, it is not possible to have the vertical sampling required in this study.

6 Images for 21-12-1992 and 25-08-1995 respectively.

Sediment Grains

Sediments in the study area are silt to medium size in grain-size according to the distribution norms of Falk & Ward (cited in Fay 1989) and Trask (cited in Fay 1989). No coarse grains were observed. In 1999, sediments around and near the river mouth showed tendencies to poor sorting. Most sediment are moderately sorted. Others are very well sorted to moderately well sorted. Table 7.2 shows mean grain size by stations between June 1997 and January 1999. Spearman's rank correlation coefficient for shoreline and station 2 was 0.9877, while that between shoreline and station 2 was 0.9473. That between stations 1 and 2 was 0.5446.

Table 7.2 *Mean grain size by station*

	STATION**	T4.2/S*	T2.6/S	T0.7/S	T0.0	T1.5/N	T2.5/N	T4.8/N
1997	Shoreline	0.105	0.148	–	0.293	–	0.301	0.153
1997	stn1	0.166	0.140	–	0.146	–	0.291	0.308
1997	stn2	0.931	0.106	–	0.073	–	–	–
1998	Shoreline	0.151	0.150	–	0.149	–	0.148	0.130
1998	stn1	0.144	0.153	–	0.149	–	0.148	0.150
1998	stn2	0.105	0.128	–	0.108	–	0.124	0.147
1999	Beach	0.164	0.191	0.176	0.187	0.330	0.172	0.179
1999	Shoreline	0.179	0.189	0.270	0.199	0.268	0.213	0.255
1999	stn1	0.151	0.080	0.147	0.135	0.192	0.173	0.138
1999	stn2	0.092	0.076	0.129	0.069	0.113	Silt	0.121

* T=Transect, # = distance to river mouth (km), S(N) = south(north) of river mouth.

** From shoreline seaward to station 2.

Beach Sediment Budget

The beaches of the area experienced gains in sediment budget during the period of the study. Deposition in the immediate south of the river mouth (T0.0/S) was higher than that at the immediate north (T0.0/N). From the river mouth, increase in sediment supply was observed in both directions at T2.6/S and T2.5/N, followed by decrease at T4.2/S and T4.8/N respectively (Table 7.3). Most of the gains in sediments were observed at near beach berm, while most of the losses were observed at middle of transect, between low and high water marks. Total net gain for all the transects was 32.76 m^2.

Table 7.3 *Net sediment supply in the Malindi-Mambrui beach between June '97 and January '99*

	T4.2/S*	T2.6/S	T0.0/S	T0.0/N	T2.5/N	T4.8/N
Net sediment supply (m^2)	1.625	9.042	6.740	4.246	10.396	0.719

Total Suspended Solids (TSS)

Two peak seasons of TSS were observed in April-May-June and November-December-January during each year of study. In 1997, the nov-jan. peak was highest, while in 1998, the apr-jun. peak was highest. In the area, the apr-jun. period lies within the long rains season, while nov-jan. falls within the short rains season. However, El Niño related rains were experienced during the nov-jan. period, extending the rain period to about March 1998.

During all the monsoon seasons, total suspended solids concentration was highest in T0.0. TSS was lowest in T6.9/S (except during the N.E. monsoon in 1997/98 when the level was remarkably high), followed by T2.6/S and T2.5/N. In 1997 and 1998, TSS was higher in T2.6/S than in T2.5/N during the N.E. monsoon, while T2.5/N recorded higher TSS during other seasons except during the S.E. monsoon in 1998, when both T2.6/S and T4.8/N recorded nearly equal levels of TSS. The sector south of Sabaki river mouth recorded higher TSS than the northern one during the N.E. monsoons of 1997 and 1998, and during the S.E.-N.E. transition period in 1998, while the northern sector recorded higher TSS during other seasons (Appendix 7.1: p.131).

Appendix 7.2 (p.132) shows the means of TSS in the study area during the study period. At the shoreline, T0.0 had the highest mean TSS concentration (1.85 g/l). Gradual decrease was observed from T0.0 in both southward and northward directions to 0.01g/l and 0.09g/l at T6.9/S and T4.8/N respectively. A similar trend is observed in stations in the other transects except for transects T0.7/S and T1.5/N, the data of which were collected in the period after the El Niño related rains. At the sample stations, there is a general tendency for mean concentrations to increase with depth, while mean concentration decreases in the seaward direction along each transect.

Plume Movement

During the S.E. monsoon in 1997, the plume of surface suspended solids travelled mainly in northern and slightly southern directions respectively. Zones of higher concentration favoured the northward drift and formed a strip of higher TSS concentration along center of the continental shelf. Plume movement occurred more along shore than in the seaward direction across shore. Sediment concentration decreased from 0.300 to 0.001 g/l both along and across shore, and extended past the limits of the study area. During the S.E. monsoon, high concentration of surface suspended solids was traced past Mambrui north of Sabaki river mouth while to the south of the river mouth, it was traced up to near Malindi town. Low concentration was traced beyond Malindi town.

In December 1997, surface suspended solids concentration was very high and travelled mainly along shore. A part of the plume travelled northwards, while most of it travelled southwards. A concentration of 0.010 to 0.500 g/l occurred past Vasco da Gama Point. In May 1997, Surface Suspended Solids ranged from 0.001 to about 0.300 g/l while in December 1997, the concentration ranged from 0.010 to about 16.500 g/l. In May 1998, plume movement occurred mainly along shore with minimum tendency to travel seaward. The zone nearest to shoreline showed a northward plume movement, while other zones except that of lowest concentration extended past Mambrui and Malindi town to the north and south of Sabaki river mouth respectively. Higher concentrations were observed mainly along shore. Concentration was lower than that recorded in December 1997 and occurred from 0.010 to 0.900 g/l. In December 1998, plume movement was observed in both directions along shore. Three zones of Suspended Surface concentration were observed. The innermost zone with highest concentration showed suspended solids travelling southwards, while the middle zone was near symmetrical with slight bias in northward direction, while the outer zone had mainly a southward direction and extended past the Vasco da Gama pillar. Sediment concentration occurred from 0.100 to 0.010 g/l in whole.

Satellite images for 21.12.1992, and 25.08.1995 representing the N.E. and S.E. monsoon respectively show similar situations as observed from field results, where plume movement occurred more along shore as compared to across shore. At the river mouth the plume appeared to originate from two discharge channels, a major and a minor one, forming two plumes which travelled seaward for short distances before travelling southwards. During the S.E. monsoon in 1995, the plume travelled mainly along shore in a northward direction. Across shore movement of the plume was relatively low. In all cases the plume moves in both along and across shore directions, with larger part of it moving in the monsoon wind direction.

Discussion

Sediment Discharge

In the 1950s, Sabaki River discharge rates were low at 58,000 tons per annum, while in the 1960s, 7.7×10^6 to 1.19×10^7 tons per annum were reported (Giesen & Kerkhof 1984). The possible annual rates reported in this study are 1.18×10^6 to 2.47×10^7 tons per annum. This is indicative of increased discharge rates due to increase in erosion rates in the catchment areas of the river. Peak sediment discharge occurred during rain seasons, conforming to earlier reports on river sediment discharge (Brakel 1984) for the years 1973 to 1979.

Sediments

The mode in which the sediments have been deposited gives them characteristics typical of marine sediment deposits as described by Fay (1989). Sediments in the study area were moderately to very well sorted, except at the shoreline of the transects in the immediate north and south of the river mouth were the sediments were poorly sorted. Sediment grains sorting and size analysis results conform to those by Abuodha & Nyambok (1991) and Giesen & Kerkhof (1984). Sediments are very fine to medium size grained, with silt content increasing in the seaward direction from mid-continental shelf. Sediment grains size distribution in the study area reveals an along-shore transport of bottom sediment from the river mouth, with general fining of grains from the river mouth both across and along shore. Although the sand fraction of the bottom sediments is transported mainly along shore, there is no defined trend in changes of mean grain size with time in each station. This is indicative of varying hydrodynamic conditions along the shoreline and water bottom in the study area. Seaward, decrease in grain size was observed in all years except along the T4.2/S transect and T4.8/N, where in 1997 and 1998 mean grain size was higher in the station 1 of each of the transects. This is indicative of hydrodynamic conditions different from those in other transects. A similar trend was also observed in T2.6/S in 1998.

Sediment Budget

The shoreline in the study area forms a deposition environment. Although both losses and gains were observed along each transect, all transects registered a net gain in sediments. Most sediments were found to be deposited between T4.2/S and the river mouth in the south sector, and between Mambrui and the river mouth in the north sector. The two peaks of sediment deposition are indicative of low energy environments in the affected zones, since deposition occurs were transport energy is not high enough to maintain sediment grains in motion. Although a small difference was observed between sediment budget of northern and southern sectors, the presence of more active dunes in the northern sector as compared to the southern sector is an indication of possibly higher sediment gains in the northern sector than in the southern sector. At beach berms, sediments were generally fine to very fine-grained, indicating selective transport of sand grains by wind, from shoreline landward.

Total Suspended Solids (TSS)

Total suspended solids level is always highest at T0.0, because the river mouth is the main entry point of sediments to the ocean. From the river mouth seaward and along shore, the level of total suspended solids decreases. Vertically, the level increases with depth. From the river mouth, the level of TSS was higher in the sector in the direction of monsoon winds and covered shorter distance across shore. River and tidal currents may be responsible for the transport of some TSS in directions against those of wind generated currents. In a complete monsoon wind cycle, most of the sediments are transported northwards as observed on level of TSS in the northern and southern sectors of the study area. In a complete monsoon cycle, the larger part of it is characterised by northward wind driven currents, because the S.E. monsoon covers a larger part of the cycle.

Similar trends of TSS transportation are observed on satellite images, where the TSS plume travels more along shore than across shore, with most of it travelling in the monsoon winds direction. During seasons of long rains, surface suspended matter is transported beyond both the northern and southern limits of the study area. It travels beyond the northern limit when monsoon wind blow northwards, and past the southern limit when the monsoon winds blow southwards. However, movement of a much small portion of the plume in a direction opposite to that of the monsoon winds makes the water circulation process at the river mouth a complex one. This may be due to river discharge, shoreline orientation, and tidal currents.

Environmental Implications

Sediment discharge by the Sabaki River is reported to be increasing with time. This signals continuous degradation of land in the catchment areas due to increased human activities. In the marine environment, the discharged sediment is separated by water such that sand is deposited at beaches, while silt and clay is deposited from mid-continental shelf seaward and in some areas along the shoreline where hydrodynamic energy is low enough to allow deposition. Due to this, beach aggradation is reported to have occurred since 1960s to present, while dune-forming processes have also been taking place. All the sand deposited in both beach and dunes is terrigenous. Dark minerals are found in the sands, the economic value of which is a subject that requires investigation. In the coastal areas, beaches and dunes are important resources especially in tourism and fresh water occurrences.

CONCLUSION

The Sabaki River plays a major role in the sedimental processes of the study area. It discharges $1.18x10^6$ to $2.47x10^7$ tons of sediment annually. Terrigenous sediments dominate the study area, the sand fraction of which is silt to medium in grain size, and moderately to very well sorted. Unlike across shore, grain size change along shore is irregular. The sand fraction of the sediments occurs from beach up to near mid-continental shelf, from where silt and clay levels appear to increase in the seaward direction. Beaches in the study area are depositional environments, with higher rates of deposition occurring at about 2.5 km both north and south of the river mouth.

Total suspended solids are discharged throughout the year with peak discharge occurring during rain seasons. The plume travels beyond the boundaries of the study area. The plume direction is depend largely on monsoon winds direction although there is a tendency for part of the plume to travel slightly in the direction opposite that of wind. Environmental implications of sedimentation processes in the study area include creation of new land, formation of sand dunes, positive and negative impacts on tourism due to creation of large beach and increased turbidity during rain seasons respectively, and possible addition of nutrients to the sea water in the study area during discharge by the river.

From the river mouth both across and along shore, different sediment types (in composition) are deposited in environments of some ecological importance. This deposition may result in constructive or destructive impacts on ecosystems. There is need for continuous monitoring of sediment discharge by the Sabaki River and their environmental impacts.

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Appendix 7.1

Total suspended solids by sector by season

	MONSOON SEASON	SECTOR	TSS (g/l)
1997	N.E. - S.E.	north	0.019
		middle	0.112
		south	0.017
1997	S.E.	north	0.084
		middle	0.120
		south	0.023
1997	S.E.-N.E.	north	0.544
		middle	1.209
		south	0.035
1997/98	N.E.	north	0.100
		middle	2.086
		south	0.433
1998	N.E.-S.E.	north	0.073
		middle	0.354
		south	0.022
1998	S.E.	north	0.143
		middle	0.643
		south	0.130
1998	S.E.-N.E.	north	0.052
		middle	0.086
		south	0.107
1998/99	N.E.	north	0.032
		middle	0.161
		south	0.066

Appendix 7.2

Means of total suspended solids in the Malindi-Mambrui continental shelf (1997-'98)

Station**	T6.9/S*	T2.6/S	T0.7/S	T0.0	T1.5/N	T2.5/N	T4.8/N
Shoreline	0.01	0.23	0.29	1.85	0.20	0.15	0.09
Station 1 s	0.02	0.11	0.12	0.31	0.02	0.08	0.03
Station 1 m	0.03	0.16	0.15	0.47	0.04	0.18	0.05
Station 1 b	0.05	0.29	0.26	0.96	0.12	0.26	0.13
Station 2 s	0.01	0.08	0.04	0.13	0.01	0.09	0.04
Station 2 m	0.02	0.11	0.04	0.28	0.03	0.13	0.04
Station 2 b	0.04	0.22	0.14	0.49	0.11	0.18	0.15
Station 3 s	0.02	0.05	0.01	0.10	0.01	-	-
Station 3 m	0.02	0.10	0.02	0.17	0.01	-	-
Station 3 b	0.05	0.17	0.11	0.38	0.11	-	-

* T=Transect;
#=distance to river mouth (km);
S(N)=south(north) of river mouth.

** Station: s=sea water surface;
m=sea water mid-depth;
b=sea water bottom depth.

8

Coastal Erosion at Mombasa Beaches
Hydrodynamic and Morphological Interactions

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ABSTRACT

Complex interactions of various natural processes together with anthropogenic activities on the beaches have encouraged coastal erosion along the Kenyan coast. Inadequate information on site-specific hydrodynamic and morphological interactions on the shores has encouraged mitigation measures which are ineffective and expensive to implement.

Hydrodynamic and morphological parameters were measured both in the field and laboratory. Hydrodynamic variables contributed significantly to the morphological variability which consequently accelerated beach erosion and shoreline instability. Nyali beach which was dominantly fine sand (Ø 2.62-2.83), moderately well sorted (Ø 0.56-0.75) and negatively skewed was characterised by low energy surging waves with high swash and low backwash velocity at high periodicity. Sediment composition was mainly quartz. Bamburi beach was of medium sized calcareous sand (Ø 2.79-1.84), moderately to poorly sorted (Ø 1.34-0.87) and negatively skewed. The hydrodynamic conditions were of high energy plunging waves and high backwash velocities. Wave energy contributed about 74.2% to the slope changes and about 83.0% to sediment distribution on the beaches. Generally steep shores of coarse sediments showed active erosion activities with a rate of retreat of about 0.15 m/month to 0.22 m/month of the shoreline.

It is therefore recommended that measures be taken to dissipate wave energy before waves break on the shoreline and to develop effective legislation to protect the shoreline for sustainable planning utilisation and management of the marine ecosystems.

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INTRODUCTION

Coastal erosion due to hydrodynamics is a serious environmental problem affecting the contiguous shoreline of the East African Coast. In many places the rate of coastal erosion and shoreline retreat is rapid and the resultant environmental degradation and economic loss are cause of concern. Many locations along the Kenya coast show signs of wave erosion, which impact the existing coastal developments and marine ecosystems. It is becoming increasingly difficult and expensive to conserve and protect the shorelines, particularly in the absence of a comprehensive and integrated framework for policy planning, implementation and management of resources.

Coastal erosion is caused by a complex interaction of different processes, which are intensified by human activities. Previous studies have generally attributed coastal erosion to the geomorphologic, geological and economic aspects of the shoreline (Ase 1978; Turyahikayo 1987; Oosterom 1988; Munyao 1992; Abuodha 1995; Komora 1995; Odada 1995; Kairu 1997; Mwanje 1997). Natural processes such as hydrodynamics affect sediment distribution and dispersal thus giving a continuously changing environment. Wave erosion has received little attention in Kenya probably because of the complex nature of the hydrodynamics involved. Inadequate knowledge of the hydrodynamics along the coastline and the absence of regulations to deal specifically with coastal erosion have perpetuated the problem of wave erosion (Mwanje 1997). Increased site developments, on low lying coastal settings that are vulnerable to shoreline instability, threaten the tourism infrastructure and marine ecology. The mitigation measures employed by individual beach front owners such as seawalls, have proved ineffective and instead have aggravated shoreline instability and interfered with the aesthetic beauty of the beaches. To protect the coastal environment and beaches from continued erosion and for sustainable planning and management of coastal resources, there is need for adequate knowledge of site-specific hydrodynamic and shoreline processes (Abuodha 1995; ICAM 1996; Marifa 1998).

STUDY AREA

The study area is situated on the Kenya coast along the Nyali-Bamburi shoreline, about 6 km north of Mombasa Island (Map 1: p.98). The area is representative of the erosive part of the Kenyan shoreline with the presence of threatened infrastructure, vulnerability to shoreline retreat and instability due to wave attack.

The Nyali -Bamburi area is characterised by sandy beaches, active cliffs, dunes, a lagoon and fringing coral reefs. The coastal plain is less than 30m above sea level, with some places exposed and covered by tidal waves during low and high tidal fluctuations respectively. It is an area of active wave erosion and sediment exchange. The fringing reef provides shoreline protection, except where it is interrupted by the outflow of the fresh water from rivers.

The climatic conditions are influenced by the passage of the Inter Tropical Convergence Zone (ITCZ) which creates a bimodal rainfall regime. The wind systems are migratory in nature due to the movement of the ITCZ giving four distinct wind regimes along the Kenya coast (Norconsult 1977; Turyahikayo 1987). The north-east monsoon regime is experienced from December to February; a transitional regime from March to April; the south-east monsoon from May to October and a further transitional regime in November. The north-east trade winds on the western Indian Ocean are strongest near the coast of Somalia, causing upwelling but they are calmer towards the Kenyan coast (Norconsult 1977; Marifa 1998). In Kenya the south-east monsoon is stronger and causes rough seas and extensive coastal erosion. The wind systems influence the impact of the wave attack on the shoreline, the stronger the winds the higher the wave heights causing a relatively greater impact on the shoreline. Weak wind systems are associated with a calm ocean and consequently less wave attack.

The tidal period is about 12 hrs 25 min with an average tidal range of about 2.0-2.8 m. The near shore is subjected to a semi-diurnal tides, with two high and low water levels (Odido 1993; Abuodha 1995). This shows the duration of wave attack on the shoreline. The breaker types change with changes in the wind systems, with surging breakers during the north-east and plunging waves during the south-east monsoon.

METHOD

Beach morphological parameters were measured and sediment samples collected. Ten (10) transects were selected along the beach in the study area. Aerial photographs (scale 1:5,000) and topo-cadestral maps (scale 1:50,000) were used to assist in the selection of transects. The specific sites were selected according to morphological characteristics of interest. Human activities on the shoreline were observed and analysed.

Morphological parameters included beach orientation, measured with a prismatic compass with reference to the magnetic north. Beach slope and profile were obtained using a surveyors level and graduated staff along each transect at an interval of 10-20 m beyond the beach. Beach width was measured using a steel tape. Beach sediment samples were collected at 3 sites along each transect, using a scooping technique at a depth of about 1-10 cm where the effect of the percolating water is felt. Statistical grain size distribution analysis was computed using a graphic procedure by Larson, Morgan & Gorman (1997).

Hydrodynamic variables were measured as well. Wave height was obtained by measuring the trough and crest heights on a graduated staff at the breaking point as waves reached the shores. Breaker angle was obtained using a prismatic compass. Surface longshore current velocity was measured on the surf zone by timing the distance covered by a cork attached to a string of known length. Swash and backwash velocities were obtained at the middle of the beach. Swash was measured by releasing a cork when a wave broke, and timing the distance covered by the cork as it was carried by the swash until it stopped on the beach. Backwash velocity was estimated by timing the distance travelled by the cork down the beach as it was carried by backwash until it met a successive coming swash. Wave energy was computed per unit crest.[3]

Laboratory analysis involved sediment grain sizes and tabulation of data. An automatic shaker was used, fitted with standard sieves of the Wentworth scale ranging from Ø -1 to Ø -5, at an interval of Ø 1. The aperture sizes were chosen because beach sediment materials are mainly sand sized along the Kenyan shoreline. Weights of sediments retained from each sieve were converted into percentage of the total sediment samples. Cumulative curves were plotted for graphical grain size analysis.

Carbonate content was established by digesting 5 gm of sub-samples with diluted hydrochloric acid (30%) and further determined by standard laboratory procedures.[4] The weights of the calcium carbonate and non-carbonate residue were converted into a percentage of the total original weight.

Results

Anthropogenic Influences

Shoreline activities such as construction of buildings are common along the Nyali-Bamburi shoreline. Hotels have been constructed up to the shoreline, such that during high tide they are flooded with water surges. Mombasa, Giriama, Pirates and Whitesands Hotels extend beyond the high water mark and are reinforced by sand infilling and concrete walls. Seawalls

3 Using the formula; $E=1/8pgH^2$ where g=acceleration due to gravity ($9.81m/s^2$); H=wave height (m); p=density of ocean water (g/m^3) (Dyer 1986).

4 Detailed information on laboratory procedures, calculations and results are given in Mwakumanya (1998).

constructed on the shoreline have aggravated shoreline instability and they collapse under intensive wave erosion and energy. Sand sack reinforcements have been placed in front of threatened buildings.

Other activities such as sweeping dead sea weeds, playing games and walking on the beaches have accelerated erosion by exposing and loosening of the sand such that during high tides sediments are likely to be washed into the sea. Destruction of coral reefs and sea grass has given a chance for the waves to attack beaches and shorelines. Human activities have a destabilising effect, causing drastic changes by enhancing or deflecting wave attack, leading to shoreline instability.

Morphological Variations

The Nyali-Bamburi shoreline is relatively straight with limited indentations. Bathymetry generally showed that the passive continental shelf is gently sloping for about 2-3 km from the shoreline, after which the continental slope connects to the deep sea beds.

Beach slope varied distinctively from fore beach to the foot of the beach on each transect and season. The slope ranged from 2.62^0-3.34^0 in Nyali and 4.18^0-5.51^0 in Bamburi (Appendix 8.2: p.144). The beach profile along the shoreline depicted deposition at Nyali and erosion at Bamburi. The morphological changes along the shoreline vary from site to site, prompting unequal longitudinal shoreline retreat.

Sediment Analysis

The mean grain size of the sediments generally fell in the fine-sand grade (Ø 2.83-2.62) at Nyali and the medium- and fine-sand grade (Ø 2.79-1.84) at Bamburi (Table 8.1). Beach sediments grain sizes tended to diminish from the fore beach to the foot of the beach. The fore beach is characterised by relatively coarse sediments while the foot of the beach is dominated by relatively fine sediments (Table 8.2). The sediments at the Nyali shoreline were fine, moderately well sorted (Ø 0.75-0.56) and negatively skewed (Ø 0.32-0.13), containing a limited range of grain size indicating long distance transport or reworking and good sorting of materials (Table 8.1). Nyali beach had predominantly quartz sand, with small percentages of calcareous materials from erosion of cliffs and coral reefs. The source of the quartz sand is probably through Mwachi and Kilindini creeks as evidenced by the variation and prevalence of sediment composition along the transects (Table 8.2). Bamburi beach had an approximately equal percentage of recent and mature calcareous and quartzite sand as shown by the shells of molluscs and skeletal remains of marine organisms observed in the field. Bamburi sediments were poorly sorted (Ø 1.34-0.87), negatively skewed and contained a wide range of grain sizes indicating a local source. High energy waves and destruction of the coral reef at this point contribute to the high percentage of shell fragments ($CaCO_3$), which are transported by the long shore current. The seasonal river Bamburi originating from Nguu Tatu brings terrigenous materials to the beach, but at a lower rate than that at which calcium carbonate materials from the sea are transported by waves. The small percentage of calcareous materials along the river could originate from river erosion of limestone beds.

Table 8.1 *Sediment distribution at Nyali and Bamburi beaches*

	MEAN GRAIN SIZE (Ø)	SORTING	SKEWNESS	KURTOSIS	CALCIUM CARBONATE CONTENT (%)	QUARTZ (%)
Nyali						
NY01	2.73	0.65	0.31	2.34	22.50	77.50
NY02	2.76	0.50	0.24	1.49	21.56	78.44
NY03	2.65	0.63	0.13	1.59	22.85	77.15
NY04	2.85	0.75	0.32	2.12	25.05	74.95
NY05	2.63	0.56	0.18	2.25	22.72	77.28
NY06	2.63	0.59	0.13	2.17	25.23	74.77
Bamburi						
BB07	1.84	1.10	0.99	1.23	53.77	46.23
BB08	2.34	0.95	0.18	2.41	56.95	43.05
BB09	1.99	1.06	0.15	1.36	71.10	28.90
BB10	1.94	1.34	0.47	1.15	58.75	41.25
BB08D	2.38	1.19	0.14	2.67	54.95	45.05
BB09D	2.38	0.87	0.14	1.83	55.85	44.15
BB10D	2.79	0.99	0.31	1.92	65.82	34.18

The study revealed strong correlations between mean beach slope and most of the other morphological variables ranging between 0.6629 against mean grain size to 0.9324 against skewness at Nyali (Appendix 8.1: p.143). Mean grain size accounted for 46.5% (R^2= 0.465) of the slope changes. At Bamburi, mean slope also correlated with most of the other morphological variables. Mean grain size accounted for 83.8% of the slope changes. The slope of the beach increases as the sediment grain size increases. Coarse-grained shores have steep slopes while fine sand shores have gentle slopes. The shorelines at Nyali and Bamburi beaches experienced intensive shoreline retreat of 0.15-0.22 m/month during the study period indicating morphological instability. Wave height varied remarkably. Nearshore mean wave heights ranged from 0.33-0.50 m at Nyali beach and 0.33-0.52 m at Bamburi beach (Appendix 8.2). Transitional regimes (September) are generally calm with low wave heights, while the south-east monsoon is characterised by turbulent waves of high wave heights.

Table 8.2
Sediment mean grain size and mineral composition along transects

	MEAN GRAIN SIZE (Ø)		CALCIUM CARBONATE CONTENT (%)		QUARTZ CONTENT (%)	
	Nyali	*Bamburi*	*Nyali*	*Bamburi*	*Nyali*	*Bamburi*
SITE 1*	2.33	2.07	9.67	40.01	90.33	63.37
SITE 2	2.49	2.24	16.57	57.00	83.59	43.00
SITE 3	2.60	2.40	28.73	59.44	71.69	40.56

* Sites: 1=Forebeach; 2=Middle of the beach; 3=Foot of the beach.

Nyali beach was dominated by waves of relatively low wave energy, low periodicity, high swash velocity and low backwash velocity, and slow longshore current velocity that did not encourage much erosion. Bamburi generally experienced high wave energy, high period waves, high longshore current velocity, high backwash velocity and relatively low swash velocity (Appendix 8.2). The disparities in these hydrodynamic variables between the two study sites may be due to the fact that the Nyali shoreline has a fringing coral reef while at Bamburi the reef is discontinued due to siltation from the Bamburi river.

The hydrodynamic nature along the shoreline is determined by the prevailing wind systems (Turyahikayo 1987). Wave breaker angle and breaker type were observed to be changing with changes in the wind system. Nyali-Bamburi shoreline experienced surging and plunging waves. During the south-east monsoon the shoreline was dominated by plunging waves with a breaker coefficient of about 80%. November (transitional regime) was characterised by surging waves of breaker coefficient of about 10%. The area being out of the cyclone zone it is unlikely to experience catastrophic waves and therefore shows gradual changes, which may go unnoticed until damage starts to occur.

Discussion

Hydrodynamic conditions contribute significantly to changes of the shoreline morphology that consequently cause erosion and/or deposition on the shores. The morphology of the beach also limits the hydrodynamic process. The gently sloping Nyali shoreline, characterised by fine sand sediments, experienced less erosion. Steep sloping Bamburi shoreline with short fetch experienced relatively strong hydrodynamic processes that caused shoreline erosion. The rate of retreat at Nyali was about 0.08-0.27 m/month and about 0.05-1.90 m/month in the case of the Bamburi shoreline. Regression analysis showed that wave height accounted for about 79.69% of slope changes and 87.75% of changes in sediment diameter size in Bamburi respectively. Thus wave height contributes significantly to beach instability and beach erosion.

Human activities seem to have aggravated the wave erosion; where human activities were dominant it was observed that there was remarkable shoreline retreat and beach instability. The problem has been noted to be more serious in the areas that are most attractive for tourism development.

Along the Nyali-Bamburi shoreline properties are being protected from wave attack with walls of sand sacks and vertical walls. These mitigation measures have proved ineffective and expensive. Hotels spend millions of shillings annually in man-made structures (ICAM 1996). These shoreline protection measures exacerbate the erosion problem and loss of aesthetic qualities of the beach areas and affect tourist activities such as sand bathing and strolling (Msuya & Nyandwi 1997). The impacts of wave erosion and shoreline instability can be summarised as:

- Erosion of beaches;
- Destruction of fishing grounds as a result of the scouring effect of waves;
- Destruction of coastal developments such as hotels;
- Loss of aesthetic value due to erosion control structures along the shoreline;
- Decline in tourist activities and fish production.

For planning and management purposes, the beach zone should be identified as a problem as well as a resource potential region. Wave erosion is the main factor in beach degradation and erosion along the Kenyan shoreline. Appropriate measures of shoreline protection should be based on the site-specific wave conditions to cause gradual dissipation of wave energy. Positive corrective measures should be capable of intercepting and dissipating wave energy before breaking on the shores. Sediments in the study area are dominantly sand of quartzite and carbonate materials, especially along the Bamburi shoreline. A suggested measure to restore the beaches in case of severe storm erosion is artificial beach nourishment.

Beach erosion and shoreline retreat are influenced by hydrodynamic processes. Beaches as micro-level spatial units between the low and high tide limits characterised by unconsolidated sediments should be conserved to maintain their aesthetic value. Planning and management are necessary at all levels. The government in conjunction with the private sector should intensify measures to curb further shoreline and marine ecosystem degradation.

CONCLUSION

Waves and currents vigorously erode and transport unconsolidated shoreline materials resulting in both erosion and deposition on the beaches. Not all places along the shoreline are equally vulnerable to wave erosion. Shorelines of unconsolidated materials and relatively steep slopes seem to be much affected. Wave conditions contribute greatly to the sediment behaviour changes, which consequently result in morphological shoreline instability. High wave energy levels are associated with medium size sediment and steep shoreline slopes while low wave energy levels are dominant in low shoreline slopes with fine sand sediment. The shoreline retreat is rapid at between 0.15-0.22m/month.

Quartz fine sand indicates travel over a long distance and long-time reworking, found in gentle and stable shorelines. Calcareous materials of fine to medium grain size are found mostly in steep shores that generally appear to be fragile and susceptible to shoreline instability and beach erosion. The main sources of sediment are the creeks and rivers, which supply mainly terrigenous materials. Coral reefs and cliff erosion are the main sources of shell fragments of calcareous materials; shoreline erosion provides additional terrigenous materials.

Seasonal variations of the wind systems influence both sediment distribution, sediment composition and wave conditions. South-east trade winds bring materials with a high percentage of quartz that tend to decrease going northwards. The north-east monsoon shows an increasing percentage of calcareous materials from the creek systems. Tudor and Kilindini creeks and the Bamburi river supply terrigenous materials although at Bamburi the supply of terrigenous materials shoreline is less than that of the supply of carbonate materials by wave attack. The inflow of the river along the shore is the main source of sediments materials, which are distributed and dispersed along the shore by wave action. Human activities along the fragile coastal environment exacerbate the erosion process.

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Appendix 8.1

Correlation coefficient (R) for hydrodynamic and morphological variables along Nyali and Bamburi beaches

		1 MBS	2 MGS	3 SK	4 WH	5 LCV	6 WP	7 SV	8 BV
1. Mean Beach Slope (degrees)	MBS	1.00 *1.00*							
2. Mean Grain Size Ø	MGS	.6629 *.9152*	1.00 *1.00*						
3. Skewness	SK	.9324 *.6652*	.8652 *.6210*	1.00 *1.00*					
4. Wave Height (m)	WH	.7969 *.7306*	.8775 *.9429*	.5421 *.2659*	1.00 *1.00*				
5. Longshore Current Velocity (m/esc)	LCV	.7324 *.2519*	.7279 *.6998*	.3498 *.7851*	.6126 *.6296*	1.00 *1.00*			
6. Wave Period (waves/se)	WP	.4111 *.4059*	.0482 *.5104*	.4048 *.7081*	.2418 *.1222*	.5699 *.3702*	1.00 *1.00*		
7. Swash Velocity (m/sec)	SV	.8059 *.6880*	.5551 *.7454*	.6814 *.3324*	.8115 *.7511*	.8135 *.2833*	.5059 *.6329*	1.00 *1.00*	
8. Backwash Velocity (m/sec)	BV	.8429 *.6380*	.5835 *.7230*	.8070 *.5642*	.1401 *.6561*	.7449 *.2584*	.3580 *.4749*	.6734 *.9903*	1.00 *1.00*

N.B. Figures in italics represent Bamburi coefficients.

Appendix 8.2

Hydrodynamic characteristics at Nyali and Bamburi beaches

	MEAN BEACH SLOPE (degrees)	MEAN WAVE HEIGHT (m)	MEAN WAVE PERIOD (waves/ sec.)	SWASH VELOCITY (m/sec.)	BACKWASH VELOCITY (m/sec.)	LONGSHORE CURRENT VELOCITY (m/sec.)	WAVE ENERGY (joules)
Nyali							
NY01	2.98	0.39	5.46	0.91	0.92	0.15	215.31
NY02	3.34	0.45	6.32	1.22	0.85	0.11	317.99
NY03	2.70	0.40	6.44	1.26	0.80	0.12	258.85
NY04	2.62	0.36	5.84	1.14	0.54	0.16	170.08
NY05	2.62	0.33	6.30	1.02	0.56	0.16	153.23
NY06	3.05	0.50	5.62	0.92	1.10	0.14	324.67
Bamburi							
BB07	5.51	0.45	6.98	1.72	1.97	0.13	294.87
BB08	5.49	0.52	6.20	1.78	1.93	0.14	374.88
BB09	ND	0.50	6.52	1.21	1.21	0.14	326.79
BB10	4.18	0.33	6.40	1.33	1.25	0.14	136.01

9

Solid Waste Management in Mombasa District

Samuel Maende [1]

ABSTRACT
Aspects of solid waste management in Mombasa District are analysed. The findings are from a survey conducted between November 1998 and February 1999, that covered educational institutions, supermarkets, hospitals, hotels and restaurants, markets, recreational parks, industries, waste collectors, residential areas, and waste re-users and recyclers – all drawn from Mombasa District. The paper outlines issues of waste generation, handling, transportation, storage and disposal with special emphasis on waste re-use and recycling. Brief recommendations are included.

INTRODUCTION

Solid wastes are the unwanted residues, discarded materials or by-products, which are no longer required by the initial users, and commonly referred to as garbage. Recently, the change in turnover of waste products has been quite dramatic, due to the combined effects of urbanisation, population growth and economic development. Ours is a 'throw-away' world – the era of plastic bags, tins, bottles and more and more dumps of discarded waste which nobody quite knows what to do with.

The amount of waste, which needs to be disposed of steadily increases each year and will continue to do so in as much as manufacturers produce the so-called disposable goods,

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usually plastics which do not decompose easily. Mombasa like most cities and towns in the developing world is finding it difficult to manage its solid wastes. This is exemplified by the presence of solid wastes in empty spaces, not to mention the roads and – worse still – storm drains.

The findings are from a survey conducted between November 1998 and February 1999, that covered educational institutions, supermarkets, hospitals, hotels and restaurants, markets, recreational parks, industries, waste collectors, residential areas, and waste re-users and recyclers – all drawn from Mombasa District.[2]

Waste Generation

The amount and types of waste generated varies from one institution to another and, in fact, some waste is unique to certain institutions only. For instance, supermarkets generate paper, plastics and sisal ropes only. On the other hand, hospitals generate more waste ranging from simple common waste such as paper, to complex highly infectious waste such as body parts, foetuses and contaminated blood. Handling and disposal of waste therefore varies significantly from one institution to another. For some, such as supermarkets, the amount of waste generated varies with the time of month and year. Generally, more waste is generated at the end of the month and holidays, particularly the Christmas season, when the number of customers is high. Most institutions in Mombasa District do not keep records of the amount and types of waste they generate. On the basis of this, it becomes difficult to monitor trends in waste quantity and waste management costs or, better still, to make monthly or annual projections. There is need for institutions to adopt record keeping based upon an agreed methodology nationally or locally, for ease of documentation.

Waste Handling

Separation of waste at the source is a concept that has not yet been embraced in Mombasa. It is only Severin Sea Lodge hotel that practices separation at each waste generation point with labelled receptacles for papers, plastics, tins and aluminium, glass and organic waste. Some institutions, such as Serena Beach Hotel and Mombasa Hospital, separate their waste

2 Olendo D. (1999). *Solid waste management in Mombasa District.* Report submitted to Kenya Wildlife Service, Mombasa.

at the central collecting unit. This is dangerous especially where health care waste is involved as it exposes the waste handlers to health hazards. Institutions should be encouraged to practice waste separation at the generation points.

In essence, all management options on waste are based on waste separation. There is no doubt that separation will put in place measures for waste reduction where applicable and maximum re-use and recycling of waste components. Actually separation is synonymous with recycling. However it should be noted that separation of waste is quite laborious and requires a great deal of motivation, commitment and financial investment. An aggressive campaign should be mounted in Mombasa on the benefits of an efficient waste management system. This is not a new insight, but it has to be repeated over and over again.

There is evidence that waste handlers in Mombasa are at risk of infection due to exposure. They are ill equipped without the necessary protective gear such as gloves, masks, overalls, boots and caps. Even hospitals which generate highly infectious waste such as body parts and infected blood do not provide their waste handlers with such protective equipment. Instead, they wear surgical gloves, some even sandals and T-shirts despite handling sharp objects such as blood stained needles and syringes. The municipal council workers are not left out in this messy confusion either. They complain of lack of equipment, low salaries and lack of medicine or medical check-up. The crucial issue is, therefore whether to have them well equipped, and therefore more efficient or ill equipped, inefficient and readily exposed to injury and infection.

Waste Transportation

The common mode of transporting waste from generation point to central storage point is the wheelbarrow. However some waste is transported manually (in waste bags and buckets) Manual movement of waste is common especially in supermarkets where the waste is light and the distance involved is short. Nevertheless it raises concern to realise that some hospital waste is also transported manually mainly due to lack of a proper transport mode or ignorance. As mentioned earlier this inevitably exposes the concerned to injury and infection. Trolleys are another common mode of transporting waste. They are particularly used in the markets and middle income residential areas and are the preserve of the municipal council. They are single oil drums of 200-litre capacity attached to a two-wheel cart. Each averages about 130 kg when full. These trolleys are manoeuvrable and easy to push but they are hard to lift onto trucks once full. More often than not the waste is emptied on the ground before being transferred to the vehicle, a process that is both time and labour consuming.

The municipal council is the main waste collector in Mombasa. It collects waste from the hospitals, supermarkets, educational institutions, markets, recreational parks, some industries and the low middle-income residential areas. Recently, private waste collectors have come in. They are four in number – Prima Bins and Pests, Amarnath Enterprises, Keen Kleeners and Mina Bins – and they have really boosted the waste collection services. These companies collect waste from the hotels and restaurants, some industries and the high-income residential areas. Apparently the private collectors are more reliable and efficient as compared to the municipal council.

Most institutions do not have a regular routine of waste collection especially those that are collected by the municipal council. As a result some waste stays longer than it should before collection. For instance hospital waste is collected after about 2-3 days. This is risky as overstay attracts flies and some waste such as body parts can easily cause infection. However for institutions where private collectors collect the waste, there seems to be an organised collocation timetable that is strictly adhered to.

WASTE STORAGE

Storage of waste is a crucial ingredient to effective waste management. Needless to say that very few institutions in Mombasa have refuse houses. Some such as supermarkets and educational institutions do not have refuse houses mainly because of the little amount of waste they generate. What they have therefore are receptacles such as 70 litre aluminium containers. The type of refuse houses vary, ranging from refrigerated ones as in the case of Nyali Beach Hotel, to air-conditioned ones, as in the case of Tamarind Hotel. Of concern though is the fact that some hospitals such as Coast Provincial General Hospital and Port Reitz District Hospital do not have refuse houses. Instead the latter has a waste pit while the former uses a bulk container. It is challenging to observe hospital waste lying loosely in open sites, with crows, insects, dogs and even cats rummaging in them. On the basis of this, all institutions should install refuse houses. These should be impermeable, hard standing with good drainage, easy-to-clean surface, convenient water supply, readily accessible to staff, secure and lockable, good lighting and ventilation and proof against rodents, insects and birds.

INCINERATION

Allied to the problem of refuse houses is that of incinerators. Only one industry (Bamburi Cement), two hotels (Serena and Nyali Beach Hotel) and – encouragingly – most if not all hospitals have incinerators or at least burners. Nevertheless some are out of order (as in the case of Coast Provincial General Hospital) or are poorly located, as in the case of Port Reitz District Hospital where it is located within the staff quarters. Such incinerators may emit toxic fumes into the air if no control devices are applied, with serious health implications for the people concerned. However, incineration of waste has a good disinfecting effect, and also reduces the weight and volume of the waste. On a larger scale, the Municipal Council should acknowledge the need to install an incinerator at its dumpsite. The ultimate aim should be to generate electricity, sell it to national grid and boost the municipal kitty.

Residential Areas

At the start of the new millennium, management of residential waste continues to pose a challenge. Private waste collectors charge about sh.500 per month to collect the waste. It is clear that high-income areas are cleaner than the low income ones and one conclusion that has emerged very clearly, is that the high-income households are able to pay for the available services. It is therefore a case of availability and affordability of services, quite the opposite to the low-income areas.

The door-to-door system of waste collection is common in the middle-income areas. However unlike the high-income areas where vehicles are involved, in the middle-income areas municipal trolleys collect the waste and deposit it at a central site that has either a bulk container and/or a side-loader trailer. In some middle-income areas no collection of waste occurs just as in the low-income ones. In this case, the households throw the waste 20-50 metres away from the house and leave it there. Chickens, goats, ants and crows eat the digestible parts. Human beings, including children, also scavenge for food, playing material and other recoverable goods such as scrap metals.

The low-income residential areas present a challenge to solid waste management due to high population densities, low-income settlements and infrastructural inadequacies such as poor roads. The housing units are knitted very close together making movement of collection vehicles rather impossible. For a majority of these areas, waste collection services by the municipal council are unheard of and where they exist, they are infrequent and unreliable. The private waste collectors have not ventured into these areas because their services are not affordable to the residents. Basically the waste is dumped in any empty space available.

Roadside dumping is very common. Storm drains have not been spared either. This portrays what may be referred to as the 'NIMBY' attitude (Not In My Back Yard). Such loose dumping attracts pests, vermin and rodents that transmit diseases such as cholera. In wet seasons, humidity turns the waste into vast breeding grounds for insects such as mosquitoes and decomposition spreads foul smell. Against such a background, a hard-hitting awareness and education campaign is called for.

Controlling waste by burning is particularly prevalent in the middle and low-income residential areas. Sights of burnt dry cells, aerosol cans, plastics and even medical waste ostensibly from clinics within these residential areas are not uncommon. These release toxic fumes with drastic health effects if inhaled, not to mention the harmful effects on the ozone layer. The scenario thus is a cycle of ecological confusion. In this context burning should be discouraged as much as possible.

RE-USE AND RECYCLING

Waste re-use and recycling is a highly recommended method of waste management nowadays. Waste re-use is largely limited to Mombasa and environs. In the hotels, it has been established that some mineral water bottles are returnable to the manufacturer – Clearly Kenyan who purchase their returned 5 litre bottles for 3 shilling per one and the packaging cartons for 5 shilling each. Some beer, soda and wine bottles are returnable, with London Distillers buying back their bottles at 5 shilling per one. In essence, hotels purchasing policy should target the returnable bottles only, as a way of reducing the amount of waste generated. Food waste from the kitchen is given to pig farmers or the Kenya Society for the Protection and Care of Animals free of charge. Supermarkets re-use undamaged cartons for packaging goods purchased by their customers while hospitals re-use medicine bottles, test tubes, cartons and 5 litre plastic containers that are given to staff members for domestic use such as storing kerosene.

The level and potential of recycling in Mombasa is dependent on the waste type. For instance, paper recycling per se is not undertaken in Mombasa. However there are paper collecting agents. The market for the recovered scrap paper is in Nairobi, and unavailability and unreliability of transport happens to be a big disincentive. The possibility of establishing a paper recycling plant in Mombasa should be looked into.

Like paper, recovered scrap plastics are marketed only in Nairobi and once again transport is the major bottleneck. Industries in Mombasa such as Cables and Plastics that used to purchase the scrap plastics no longer do so as they are able to import cheaper higher quality granulated plastics from Arabian countries. Plastic recovery and recycling requires commitment and effort on the side of industries. They should actually venture into the possibility of producing huge plastic poles (posts) that can be used for fencing, instead of the currently used biodegradable wood.

Recycling of glass is more pronounced in Mombasa due to the presence of a recycling plant, Bawazir Glass Works. The scrap glass is recovered from various sources including Kibarani, the municipal dumpsite, where the collectors do their trade without any protective gear oblivious of the injury risks they expose themselves to. Efforts to enhance recycling of glass should focus on recovering the scrap glass at generation points.

Finally it would be incomplete to conclude without mentioning Kibarani, the municipal dumpsite. It's located next to Makupa causeway – the gateway to Mombasa Island. It causes a stink in the region, with smoke created by constant burning of garbage. The dump also poses great danger to marine life in the nearby Makupa creek, due to seepage of toxic waste into the creek or due to water run-offs during wet season. Worrying is the revelation that the Municipal Council does not vet the wastes being dumped and carefree industries can and have been dumping heavy metals such as mercury here. People inhabit the site, mostly waste collectors who contribute to the waste management by sorting out the garbage and taking plastics, bottles and other objects that have re-sale value as scrap. This site should actually be relocated to avert further environmental catastrophe.[3]

RECOMMENDATIONS

- To reduce waste generation, institutions should classify the different types of waste produced and calculate the amounts generated of each type per day.
- Institutions should practice waste separation at the generation points.
- Institutions should install refuse houses.
- Institutions should form waste management committees comprising of representatives from all departments.
- Since Mombasa's climate is warm, with temperatures ranging from 30^0 to 35^0 Celsius, the waste storage period should not exceed 24 hours. However with refrigerated storage, longer storage periods are possible.
- Waste handlers should be equipped with adequate tools and protective gear.
- The general public should be sensitised on proper waste management.

3 The Kibarani dumpsite has been closed since (editors).

- The council should ensure the enforcement of all the by-laws relating to waste management.
- The municipal council should take stringent measures and control the types of waste dumped at Kibarani as some of it can be dangerous to the environment.
- The council should set up an incinerator at the dumpsite.
- The municipal council should make all possible effort to relocate the Kibarani dumpsite.
- The municipal council should look into possibilities of utilising the abundant organic waste from markets by starting a composting project at the dumpsite.
- The council should call in investors to set up a paper recycling plant in Mombasa.

Conclusion

Waste needs to be managed properly to ensure that it does not become a health and/or environmental hazard. To cope with the problem it has become necessary to sensitise all players in this field, and further still equip them with the necessary techniques and information geared towards combating the problem of waste management.

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10

Solid Waste Pollution Loads In Beach Hotels on the Kenyan South Coast

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ABSTRACT

During the high tourist season between September 1996 and February 1997, solid waste types and quantities from six popular beach hotels in Mombasa and Diani were determined. The factors and processes that affect solid waste management in the region were examined and baseline data on quantities of waste generated in coast hotels are provided.

The mean per-capita waste generation rate was found to be 1.90 kg/person/day and the relative proportions by weight of the respective waste categories were: paper 3.5%, plastics 3.3%, tins 1.7%, glass 4.5%, food waste 79.1%, cartons 2.0%, and residual waste 6.0%. The rates of generation of waste components were also calculated. The annual waste load was found to be 362 tons for Jadini Beach Hotel and Africana Sea Lodge; 200 tons for Leopard Beach Hotel; 159 tons for Diani Sea Lodge; 192 tons for Severin Sea Lodge and 150 tons for Mombasa Beach Hotel.

Limited recycling, re-use and composting practices were undertaken by some of the hotels such as Mombasa Beach Hotel, Severin Sea Lodge and Diani Sea Lodge. Tins were re-used for planting tree seedlings and flowers. Glass waste and cartons were collected by dealers for recycling. Food waste was used to feed pigs.

The results of the study make it possible to develop a feasible waste management concept for the hotels. There is potential for recycling, re-use and composting of the waste generated. It is recommended that hotels effectively separate waste at source to ensure high quality waste components for further processing. This will help to reduce the costs of waste disposal, minimise health risks and improve the quality of the environment.

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INTRODUCTION

The quantity and type of waste generated in hotels and conservation areas through tourism associated activities has been recognised as a major environmental problem. However, few surveys have been conducted to assess the magnitude and effect of this problem. In Mombasa and Kwale in Coast Province, Kenya there are approximately 48 beach hotels and an estimated 20,000 beds producing an average waste at the rate of 1.78 kg/person/day (Munga *et al.* 1993). Using a 78% bed occupancy rate (Wesemba 1992), approximately over 10,000 tonnes of solid waste material are expected from these hotels annually. The disposal of these wastes is a major environmental problem in Mombasa and the other urban centres in the province. The collection and disposal of the waste is the responsibility of the Mombasa Municipality or the respective county councils which invariably have inadequate equipment and therefore provide unreliable services. As a result, waste is left in the hotel premises for a long time with its attendant odour, fly nuisance and implications for human health in the area.

The main waste generation sources in the hotels include the kitchen, guest rooms, public and function areas, food and beverage outlets, receiving and storage areas, offices, parks and gardens. Four main waste categories are easily identifiable. These are pig feed, other organic material, recyclable wastes (e.g. paper, plastics, glass, cartons and aluminium tins) and residual wastes. A rough estimate of their relative proportions by weight is respectively 25%, 33%, 9% and 33% (Weidleplan 1994). In general waste data are hardly available, as waste producers do not keep exact records of the amount of waste they generate. The persistent inadequacies in collection and disposal of waste also make it quite impossible for the responsible institutions to provide any reliable estimates. Few studies have been conducted to determine the actual waste production levels in the hotels located in Mombasa tourism region. Munga *et al.* (1993) estimated waste discharge levels for some hotels from data through questionnaires and found a rate of 1.78/kg/bed/day. Weidleplan (1994), a German consulting firm based in Stuttgart, conducted a similar study using the same methodology for data collection. This study estimated the minimum and maximum quantities of the waste categories produced by sampled hotels and reported the relative proportions by weight of the waste categories as well as the rates of waste generation. However, no measurements were recorded to verify entries in the questionnaires. Therefore it is clear that there is a need for reliable baseline data on waste production levels and waste composition over a period of time (Frost & Murray 1997).

The main objective of this study was to determine the types and quantities of solid waste coming from beach hotels and to relate waste production to hotel waste management practices. Data obtained on per-capita waste loads in the five beach hotels can be used as baseline data for estimating pollution loads for the other hotels in Kwale and Mombasa districts. This data will also be useful for recycling industries, waste generators and authorities responsible for management of the waste.

METHOD

The six hotels included in the study were the combination of Jadini Beach Hotel and Africana Sea Lodge (JBH/ASL), Leopard Beach Hotel (LBH), Diani Sea Lodge (DSL) in Diani and Severin Sea Lodge (SSL) and Mombasa Beach Hotel (MBH) in Mombasa (Map 1: p.98). DSL and SSL were chosen because they have waste management programs. All the hotels had an average bed occupancy of over 50%, and were therefore large generators of solid waste. The study was carried out during the high tourism season in September 1996 and February 1997.

Table 10.1 *Waste components found in the study sites and their sources*

WASTE CATEGORY	DEFINITION
Paper	Office paper, packaging paper from the kitchen, Magazines, books, newspapers and any other paper fibre materials from the guest rooms.
Carton	Mainly brown carton used for packaging foodstuffs, mineral water bottles, wine and spirit bottles.
Plastics	Plastic wrappings, mineral water bottles, plastic containers for storing detergents, cooking oil and plastics for packaging food stuffs.
Tins	Tins used for storing fruit juices and foodstuffs of different sizes, aluminium foil, soda tins and any other metal.
Glass	Empty wine and spirit bottles of all colours, broken glass, beer or soda bottles and broken plates.
Food waste	Food remains from the kitchen and restaurants, vegetable and fruit peelings, eggshells, raw fish and meat cuttings and coffee and tea filters.
Residue	Sanitary waste, cigarette waste, ash, sand, dust, disposable plastic napkins, batteries, wood residues, drugs and medical waste, cloth, used soap, from the guest rooms and the bars (flower cuttings in some hotels).

The criteria for component categories was simple, broad and based upon solid waste separation into feedstock materials for re-use, recycling, and composting (Martin, Collins & Robert 1995). Waste material from the hotels were separated into categories daily. Each waste component was weighed using a 50 kg spring balance or weighing facilities in the hotels; the results were recorded on a daily basis.

Bed-occupancy figures were obtained from the management offices of each hotel. Waste loads and generation rates were calculated from the waste component weight data and bed-night figures. Full details of the study are given in Muthini (2000).

Results and Discussion

Waste Composition

The waste generated from the beach hotels is composed of paper, plastics, tins, glass, food waste, cartons and residue. Table 10.1 fully describes the waste components and their sources.

Appendix 10.1 (p.166) presents the mean and range of quantities of solid waste generated daily in the six beach hotels. Food waste had the highest load recorded, and it ranged from 511-1052 kg/day at JBH/ASL to 106-731 kg/day at Mombasa Beach Hotel. Tins had the lowest load ranging from 11-33 kg/day at JBH/ASL to 1-6 kg/day at Mombasa Beach Hotel.

The mean percentage bed occupancy rate for the six hotels during the study period, sep.'96-feb.'1997, was 71%. Table 10.2 shows the maximum number of beds and rooms available in each hotel and the mean percentage bed-occupancy rates. The mean bed-nights ranged from 274 persons per day at Severin Sea Lodge to 176 persons per day at Mombasa Beach Hotel.

Table 10.2
Mean percentage bed occupancy rates and the annual waste loads at the beach hotels

	JBH/ASL (N=73)	LBH (N=7)	DSL (N=7)	SSL (N=44)	MBH* (N=38)
Max. number of beds	668	324	350	400	302
Bed occupancy (%)	79	82	66	68.5	58
Av. annual bed nights (persons)	192,618	96,973	84,315	100,010	63,933

* Data for Mombasa Beach Hotel not used for calculation of mean per-capita waste generation rate.

Per-capita waste loads

The mean per-capita waste loads for the six beach hotels studied were 1.88, 2.06, 1.89, 1.92 and 2.34 kg/person/day for JBH/ASL, Leopard Beach Hotel, Diani Sea Lodge, Severin Sea Lodge, and Mombasa Beach Hotel respectively (Appendix 10.2: p.167). The mean per-capita waste load from the five beach hotels (excluding Mombasa Beach Hotel) was found to be 1.90 kg/person/day. Single factor analysis of variance shows that there are significant differences in the waste per-capita loads between the six hotels ($F= 11.79$; $p<.000$), but excluding data for Mombasa Beach Hotel the analysis shows that there are no significant differences in the per-capita waste loads for the remaining five beach hotels ($F= 1.73$; $p=.16$).

The per-capita value of 1.90 kg/person/day calculated is very high, compared with the per-capita value of Mombasa District as a whole which ranges from 0.47-0.55 kg/person/day (calculated from Munga *et al.* 1993 and Municipal Council 1991). The former value is comparable to the per-capita value for developed countries which ranges from 1.8-2.0 kg/person/day (UNEP 1994; Martin *et al.* 1995). This suggests that tourists generate large amounts of solid waste. Munga *et al.* (1993) reported a figure of 1.78 kg/person/day for the beach hotels in Mombasa, a figure only slightly below the one obtained in this study.

The per-capita waste generation rate at Mombasa Beach Hotel is higher than in other hotels. This is probably due to the high frequency of non-resident guests who visit the hotel for one meal (lunch) or the cocktail parties organised by various companies in Mombasa. The hotel is near Mombasa town and people working in town visit the hotel because of its accessibility. These visitors do not occupy a room and they are not included in the per-capita computations. Their contribution was estimated to be 0.44 kg/person/day i.e. the difference between the per-capita waste load of Mombasa Beach hotel (2.34 kg/person/day) and that of the other hotels (1.90 kg/person/day). The resulting value is comparable to that of Mombasa and Kwale districts as a whole (0.47-0.55 kg/person/day).

Appendix 10.2 provides a summary of the mean per-capita loads for the waste categories and the percentage weight of each waste category for the five hotels excluding Mombasa Beach Hotel. Food waste had the highest per-capita waste load of 1.51 kg/person/day accounting for 79.1% of the total followed by residual waste (0.120 kg/person/day; 6%), glass (0.084 kg/person/day; 4.5 %), paper (0.065 kg/person/day; 3.5%), plastics (0.059 kg/person/day; 3.3%), cartons (0.036 kg/person/day; 2.0%) and tins (0.029 kg/person/day; 1.7%).

The results in Appendix 10.2 show that 15% of the waste generated in the beach hotels is made up of recyclable materials (like paper, tins, plastics, glass, and cartons). Previous research indicated that recyclables accounted for 8% of the total weight of waste generated from beach hotels (Weidleplan 1994).[3] Food accounted for 79.1% of the total waste which indicates that it should be collected on a daily basis to avoid fly nuisance and offensive odour which accumulates if it is not collected within a day. This figure compares well with the figure reported by Weidleplan (1994) of 80% of the total waste. Owens & Macklin (1979) found that solid waste in Bandung, Indonesia had a high percentage of vegetable matter which resulted in rapid decomposition in the tropical climate. Residual waste accounted for only 6.0% of the total waste generated in the beach hotels. This waste type can be stored in the hotels garbage area for long periods of time without producing offensive odour, as demonstrated by the example of Severin Sea Lodge where the waste was sometimes left for three weeks.

If recycling, re-use and composting programs are to be instituted in the beach hotels successfully, then approximately 90% of the waste generated from these hotels can be recovered and re-used, while only 10% would have to be dumped (approximately 1000 tonnes in each district). Kibwage (1996) reported that 21% and 77% of household waste in Nairobi can be recycled or composted respectively, leaving only 2% of waste to be dumped.

The per-capita waste generation rates for plastics in JBH/ASL and other south coast hotels is higher because of the plastics used in portion packaging of individual margarine and jam in packets for breakfast, which was not the case with north coast hotels. Tins in the south coast hotels had a higher per-capita waste generation rate because of the packaging for the fruit juice instead of using the returnable plastic containers as used in the north coast hotels (a good example of source reduction). Per-capita residue waste at Mombasa Beach Hotel and Leopard Beach Hotel was higher than in other hotels due to the use of flower cuttings for room decorations and the waste was dumped with other room waste.

The annual waste loads for the hotels was estimated to be 362 tons for JBH/ASL, 192 tons for Severin Sea Lodge, 200 tons for Leopard Beach hotel, 159 tons for Diani Sea Lodge and 150 tons for Mombasa Beach Hotel (Appendix 10.2).

Trend Analysis of Waste Categories

Trend analysis of per-capita waste generation rates for food and glass at Severin Sea Lodge and Mombasa Beach hotel showed that there was more waste generated in December

3 The difference between the two studies is probably the result of differences in methods of data collection.

compared to October. This could be attributed to celebrations and parties for tourist and many companies that held their Christmas and end of year parties in the month of December especially at Mombasa Beach Hotel. Increase of glass waste at Severin Sea Lodge in December could probably be due to the increase in temperature and humidity leading to consumption of more liquids.

The general trend for all waste categories showed that the per-capita waste generation rate decreases with time with the increase in the bed occupancy. This is due to the fact that hotels order food stuffs and materials in bulk avoiding portion packaging and thereby reducing the waste load.

Waste Management Practices

In all the six beach hotels waste generated from the various sources was collected in 70 litre plastic bins lined with plastic bags and sent to the garbage room, which was either an enclosed or an open area, for temporary storage before the waste was collected for disposal. Leopard Beach Hotel and Mombasa Beach Hotel had an open garbage area the other hotels studied had enclosed garbage rooms. Open garbage areas attract flies, lizards and crows that feed on the food waste. Maggots accumulate within a day or two after the waste has been left in the hotel premises without collection. Complaints from the local people and tourists on the stench and crow nuisance from the uncollected waste are common.

Diani Sea Lodge and Severin Sea Lodge have waste management programs in place. At Diani Sea Lodge the kitchen waste is sorted into pig feed, compost and refuse. Table 10.3 shows the flow chart of how kitchen waste is sorted in this hotel. The pig feed is given to the pigs owned by the hotel. Composting is not done, although the separation and composting facilities exist. The compost is mixed with the other waste and sent to the enclosed garbage room for dumping at the dumpsite.

At Severin Sea Lodge waste from the kitchen, bars and offices is sorted into food waste, non-food waste (residual waste) and recyclables (tins, plastics, paper and glass) in 70 litre bins and transferred to larger bins (eco-bins) of 200 litre capacity inside and outside the kitchen when full. A pig farmer collects the sorted food waste on a daily basis. This represents 80% of the total waste generated from the hotel. The recyclables and non-food waste is sent to the garbage area where compartments for each waste category exist. The recyclables are stored in different compartments until economically viable quantities are attained for collection by waste dealers, leaving the residual waste for dumping.

Table 10.3 *Sorted kitchen waste types at Diani Sea Lodge*

	DEFINITION	DESTINATION
Bin 1	Food remains from the restaurants and kitchen, fruit and vegetable peelings (boiled).	Pig feed.
Bin 2	Tissue paper, eggshells, coffee and tea filters, bones, unboiled fruit and vegetable peelings, raw fish and rotten food remains.	Compost for shamba.
Bin 3	Plastic foil containers, tins ashtray contents, glass and jars if not re-used, wax and paper.	Refuse for dumping at dumpsite Kwale.

Source Reduction

Studies in Europe, America and Asia have shown that potential for materials recycling and source reduction is high (Lei 1987; Furedy 1990; Baud & Schenk 1994; Papke 1992). Franke (1991) reported that an overall potential of 20-25% source reduction (by weight) of waste generated in Cologne (Germany) was possible

Source reduction is practised in the beach hotels because beer and soda bottles are collected and returned. Some mineral water plastic and wine glass bottles are also returnable though this was not observed in the study area. Burning of solid waste is carried out for combustible waste from the guest rooms and the offices in Leopard Beach Hotel and Serena Beach Hotel (not studied). This reduces the load of waste that has to be dumped. The use of cloth towels instead of paper napkins at JBH/ASL, milk supplied in large containers at Severin Sea Lodge, fruit juices from dealers in returnable plastic containers in some north coast hotels, are all forms of source reduction methods.

Source reduction in the beach hotels has been hampered by certain practices such as soap consumption (one soap per bath), use of disposable cups, plastic napkins, throwing away of books and magazines read by tourists, use of non-refillable ribbons, cartridges and toners. This leads to an increase of the waste load to be dumped. Lester, Hendrickson & McMichael (1994) suggested that packaging products should be returned to the manufacturers for disposal as this would make them think of designing packaging materials that are easily returnable.

Recycling and Re-use

Solid waste is being re-used and recycled extensively through private initiatives, and several attempts have been made to set up large municipal recycling plants with separation at source without success in Asia (Baud & Schenk 1994) and in South Africa (Stander *et al.* 1995).

Previous research on solid waste management in Mombasa has indicated that waste is already being recycled, re-used and composted on a limited scale. Emphasis is on strengthening these methods as a means of managing the high quantities of waste generated and improving the environmental quality at the coast (Nguta & Mwaguni 1995; Owanga 1994; Weidleplan 1994; Munga *et al.* 1993).

Recycling and re-use potentials exist in the beach hotels. Enough quantities of recyclables are generated on a daily basis and the existence of waste dealers and recycling companies reinforces this potential. Informal dealers did not pick paper generated from the beach hotels studied; instead it was mixed with other waste and collected for dumping or burned. Weidleplan (1994) reported that waste paper from South Africa had saturated the local market, therefore lowering the waste paper price and discouraging the local waste paper dealers. Furthermore, the absence of a waste paper recycling industry in Mombasa has limited the chances of paper recycling.

Empty plastic containers of 3-20 litre capacity are in high demand. They are either picked up by hotel workers or sold to them at a fee. The informal dealer operating at the south coast hotels collected plastic containers from the hotels nearby. There are a good number of plastic recycling firms in Mombasa (Weidleplan 1994).

Tins in the hotels studied were not collected for recycling, though Mombasa Beach Hotel and Diani Sea Lodge re-use the tins as flowerpots reducing the load of tins to be dumped by over 90%. Reports indicate that there is a good market potential for scrap metals (tins) in Mombasa. According to scavengers at Kibarani dumpsite who recover tins from hotel and other waste, agents come to the site to buy the tins for recycling in Mombasa (Weidleplan 1994; Nguta & Mwaguni 1995).

Weidleplan (1994) reported that the glass factory in Mombasa has an operation capacity of 100 tonnes. The glass factory now accepts white and green glass for recycling. Robinson Club Boabab Hotel in Kwale District (not studied) crushes the bottles and stores them in bags, separating the green glass from the colourless ones, which are then picked by a dealer for recycling. Glass from the Mombasa Beach Hotel, Severin Sea Lodge, Leopard Beach Hotel and Diani Sea Lodge was picked by waste dealers after economically viable quantities were attained.

A dealer at the south coast bales cartons and sells them to the carton dealers who transport the bales to recycling factories in Nairobi after enough quantities are obtained. According to the analysis done at Mombasa Beach Hotel and Severin Sea Lodge all cartons generated can be sorted from the rest of the waste and stored in the garbage area without any problems, until economically viable quantities were attained. The load of cartons to be dumped was reduced significantly.

Four pig farmers were identified in both districts with an average of 300 pigs each, and who collect the waste from selected beach hotels. Competition for food waste in the hotels in Mombasa District is higher than in hotels in Kwale District. This is because there are more pig farmers in the north coast due to the higher demand for pig meat in the cosmopolitan Mombasa town.

Weidleplan (1994) reported that 3 tonnes of food waste are needed on a daily basis to feed the 300 pigs for the farmer in north coast. The calculated daily food waste generated by the beach hotels in Mombasa and Kwale Districts was 21.5 tonnes.[4] This is enough to feed more than 2,000 pigs (which requires approximately 20 tonnes). This indicates that the 79.1% of the total waste load generated in the hotels can be re-used on a daily basis. But in Diani Sea Lodge only 20-50% of food waste was actually re-used as pig feed and the rest composted.

Severin Sea Lodge, Diani Sea Lodge and Mombasa Beach Hotel had composting programs. However, Mombasa Beach Hotel was the only hotel that had a working composting program. The compost obtained from garden waste was re-used as manure in the hotel gardens.

Some of the residual waste is dangerous to health if not properly handled like sanitary pads, injection needles, expired medicine, and disposable plastic napkins. The sanitary pads and medical waste can be burned. Wax in this category can be recycled as practised at Severin Sea Lodge.

Co-ordination between management of the hotels, waste dealers, pig farmers and recycling firms is poor and it has rendered waste management programs ineffective. This means that waste that could have been recycled and reused ends up in the dumpsites.

4 The average daily food waste was 1.51 kg/day (Appendix 10.2). The available beds in the two districts are estimated at 20,000 (Wesemba 1992) with an occupancy rate of 71% which results in 14,200 beds/day.

Solid Waste Disposal

Solid waste disposal from the beach hotels is a problem all along the Kenyan coast due to poor waste management practices, lack of equipment and unsatisfactory locations of existing dumpsites (Schoorl & Visser 1991). Most hotels dump their waste through Mombasa municipal council at Kibarani site for north coast hotels and Kwale county council at Mwabungo for south coast hotels, which have unreliable collections. The consequence is that waste is left in the hotel premises for over a week with attendant effects.

Kibarani dumpsite is located at a mangrove ecosystem near a creek, which has a direct connection with the Kilindini Creek. Pollutants may reach the sea via tidal currents. The site can be smelled and seen by tourists being transported from the airport to their coastal destinations.[5] The dumpsite at Mwabungo is located about 10 km from the Diani resort area. Land contamination is evident. For the entire research period, the Kwale county council waste collection truck was broken down. Beach hotels in this district hired private collectors for collection and dumping of waste generated. However some of these collectors dump the waste in non-designated areas leading to aesthetic degradation and land pollution. The future costs involved in cleaning these illegal sites for development will be great.

Poorly dumped solid waste from these hotels is not only a potential public health risk, there is also the danger to wildlife and domestic animals feeding on the waste due to exposure of toxic chemicals. Pathogens thrive well in these sites especially in the hot and humid climate of Mombasa and its environs, danger to humans through transmission of communicable diseases is a possibility. Crudely dumped garbage leads to aesthetic degradation, which is displeasing to tourist visiting Mombasa and Kwale.

Conclusion

Potential for source waste separation exists in the hotels that do not sort their waste for recycling purposes. According to the analysis done at JBH/ASL partial waste separation at source was achieved. Hotels like Severin and Diani Sea Lodges have shown that waste separation at source is possible ensuring that materials to be recycled and re-used are of high quality.

The results of the study show that it is possible to develop a feasible waste management concept for the hotels, because the proportions of the individual component materials in the

5 The Kibarani dumpsite has been closed since (editors).

generated waste are fully described in the study. The results of the study indicate that there is potential for recycling, re-use and composting of the waste generated. It is recommended that hotels effectively separate waste at source to ensure high quality waste components for further processing and strengthen linkages with waste dealers, pig farmers and recycling firms. This will help to reduce the costs of waste disposal, minimise health risks and improve the quality of the environment.

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Appendix 10.1

Mean weight (and range) of different categories of waste at coastal hotels in Kenya, September '96 - February '97 (kg/day)

	JBH/ASL (N=73)		LBH (N=7)		DSL (N=7)		SSL (N=44)		MBH* (N=38)	
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Food	761	511-1052	412	376-438	359	289-456	420	285-622	299	106-731
Carton	19	6-39	6.5	4-10	5	2-10	9	2-16	5	1-18
Glass	41	17-91	20.5	16-28	12	10-17	22.5	10-48	12	5-38
Paper	34	19-50	17.5	12-27	10	6-23	17.5	10-28	13	6-21
Plastics	36	21-63	21	15-27	11	7-16	10.5	4-19	7	3-16
Tins	19.5	11-33	8	5-11	5.5	2-10	4	2-9	3	1-6
Residue	49	30-108	56	32-78	32.5	24-46	37	17-68	19	7-35
TOTAL	960	637-1316	542	504-605	435	352-558	521	352-742	358	152-840

Key JBH/ASL = Jadini Beach Hotel & Africana Sea Lodge; LBH = Leopard Beach Hotel
DSL = Diani Sea Lodge; SSL = Severin Sea Lodge ; MBH = Mombasa Beach Hotel.
N = Number of sampling days.

* Data for Mombasa Beach Hotel not used for calculation of mean per-capita waste generation rate.

Appendix 10.2

Per-capita waste generation for all waste categories at coastal hotels in Kenya, September '96 - February '97 (kg/person/day)

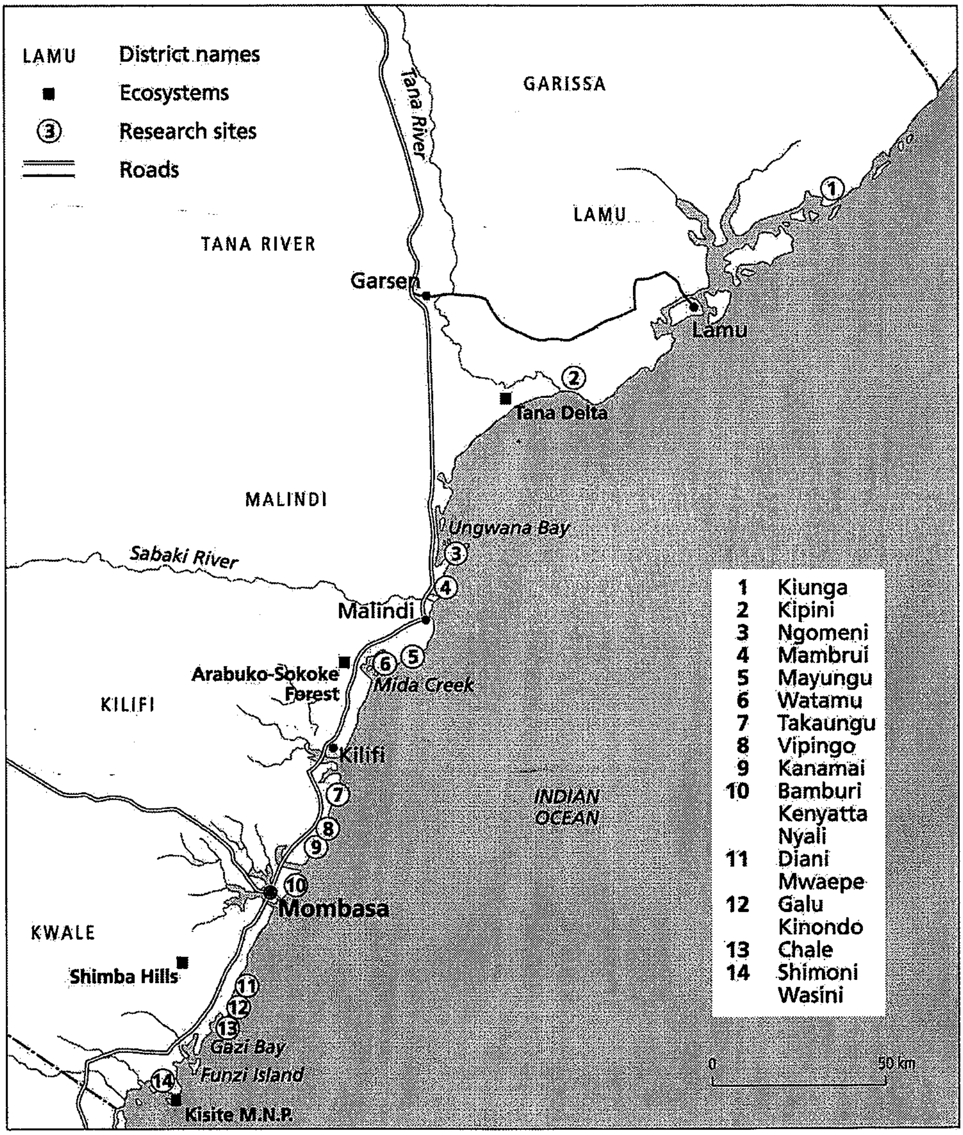
	JBH/ASL (N=73)	LBH (N=7)	DSL (N=7)	SSL (N=44)	MBH* (N=38)	MEAN	% BY WEIGHT
Food	1.48	1.56	1.54	1.53	1.93	1.51	79.0
Carton	.039	.026	.022	.036	.037	.036	2.0
Glass	.085	.078	.054	.088	.082	.084	4.5
Paper	.067	.069	.046	.065	.086	.065	3.5
Plastics	.071	.080	.049	.040	.049	.059	3.3
Tins	.039	.030	.026	.014	.021	.029	1.7
Residue	.098	.220	.144	.138	.136	.120	6.0
DAILY MEAN WASTE RATE	1.88	2.06	1.89	1.92	2.34	1.90	100
ANNUAL WASTE LOAD (tonnes)	362	200	159	192	150	–	–

* Data for Mombasa Beach Hotel not used for calculation of mean per-capita waste generation rate.

Marine

Fisheries

Map 1 *Kenya Coast with location of research sites*



11

The Effect of a Marine Protected Area and the Exclusion of Beach Seines on Coral Reef Fisheries

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ABSTRACT

Fish landing data from adjacent the Mombasa Marine National Park (MNP) and seven sites in Diani were studied from 1995 to 1999 to determine the influence of the park and restrictions of beach seines on fisheries catches. Data were based on sampling for 10 days per month, where fish were separated into the major families, the wet weights estimated by a spring balance, and data analysed based on gear, numbers of fishers, and the area from which the fish were caught. In the case of the Mombasa marine reserve, the beach seine exclusion was done nearly simultaneously with a reduction in the size of the Marine Protected Area. These two factors combined resulted in increased fish catches on a per area and fisher basis. It was, however, difficult to distinguish the effects of the two changes, but the initial pulse (< 6 months) in catch is largely due to opening a previously unfished area to fishing. After the large initial increase in the catch there was a decline over time, but catches were still above those before the management changes. In Diani the two landings that restricted beach seines for over 20 years had the highest per fisher catches, being 13% greater than sites with beach seines, while those that still adopt beach seines had the lowest catches (ANOVA, $F = 4.5$). Data shows a progressive decline in per man catches in all the sites irrespective of the management in place or the exclusion of the beach seines. Nevertheless, the marine reserve had the highest catch per area (5.5 kg/ha) despite having the highest number of fishers per area basis (7±2 fishers/ha/month). There were no strong seasonal patterns from time series plots for the catch statistics. We show that parrotfishes *(Scaridae)*, rabbitfishes *(Siganidae)*, scavengers *(Lethrinidae and Lutjanidae)* and octopuses *(Octopo-didae)* are the major groups dominating these fisheries.

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Introduction

In Kenyan reefs, as in many tropical reefs, fishing is done by small-scale artisanal fishers, who use largely human power to generate large volumes of fish landing (Dalzell 1996). Artisanal fishing is a low expenditure and high return economic activity (Bohnsack, Harper & McClellan 1994) in many regions of the world. Artisanal fishers in Kenya use various forms of gear including hand lines, traps, gill nets, seine nets and spear guns. These gears harvest many species and may be employed from shore to the outer reef edge seldom deeper than 5 meters at low tide (McClanahan & Kaunda-Arara 1996), usually from small boats. Fishing is usually done throughout the year. Most of this fishing is concentrated in the near shore areas in the reef lagoons where coral reef and seagrass associated fishes make the bulk of the landings (Campos, Norte-Campos & McManus 1994). As the fishing effort increases, Catch Per Unit Effort (CPUE) decreases and the reef fish, which are known to have slow growth rates, long life and limited adult mobility (Bohnsack 1990), are overfished. Overfishing signs include decreased total landings, reduced catch per unit effort, shift in catch to smaller sized individuals and different species, and recruitment failures (Bohnsack 1990). The problem of overfishing, in most fisheries, is due to poverty which has made fishers change the fish capture methods from ones that are environmental friendly to ones that are destructive but efficient in capture. An increasing number of people also join fishing due to unemployment. Poverty is so pervasive among fishing societies of the world. This calls for the creation of more appropriate incentives and developing management institutions that can accept and deal with variability and uncertainty, without which, populations of individual species and the structure and functioning of marine ecosystems are likely to continue to decline (NRC 1999).

For many coral reef species, Marine Fisheries' Reserves (MFRs), areas closed to fishing but next to fished areas, may be one effective way to limit fishing pressure and maintain fish populations (Bohnsack 1990, 1996a, 1996b; Roberts & Polunin 1993). MFRs protect genetic diversity from detrimental selection from fishing and provide insurance against stock collapse from human or natural disturbances. In addition, they have the potential benefits of being easy to manage, protect and increase fish stocks for spawning, and export larvae, recruits, and adults into adjacent fishing grounds (McClanahan & Mangi in press; Bohnsack 1993; Alcala & Russ 1990; Roberts & Polunin 1991, 1993; Russ & Alcala 1996). MFRs could deal with many fishery problems that are not effectively addressed by traditional management measures (Bohnsack 1996a, 1996b).

The long-term success of park-related conservation of wildlife may depend greatly on the actual and perceived benefits of parks and reserves on local subsistence-level populations. Where users understand and support the purpose of park and reserves, compliance is high and the zones are largely self-enforcing (Bohnsack 1996a, 1996b). The relative success of Kenya's park system is largely due to the tourist industry which has developed and supported a lucrative business (McClanahan & Kaunda-Arara 1996; Glaesel 1997; McClanahan 1999). However, subsistence-level people not directly benefiting from the tourist industry are slower to appreciate the advantages of parks and reserves.

The exploitation of common property open-access resources, like the fishery, by all users leads to a 'tragedy of the commons' (Hardin 1968). It is the interest of an individual fisher to increase catch, but it is not necessarily in the interest of the whole fishing community (Gordon 1954). There is a tendency of every fisher putting more effort to maximise his catch from the fishery. When every man pursues his interests like this, resource ruin is the result. This is a pressing environmental problem which needs resolution if renewable resources are to be sustainable used. The problem is worsened by the fact that most artisanal fishers fish for food. Individual and community planning is difficult if they do not get food on daily basis. There is a conflict between individual short-term goals and long-term broader societal goals. 'Tragedy of commons' is, however, the outcome when resource users act independently but for those human societies that have traditionally organised themselves in ways that can locally reduce selfish behaviour and alleviate the ecological degradation that might result from sharing common resources, this tragedy can be avoided (McClanahan *et al.* 1997).

In this study we examine a time series of fish landing data from one site where fishing is regulated adjacent a recently created marine park and seven sites from an area where no protective management is in place to compare active and passive management. Two of these sites have traditionally organised themselves and have successfully managed to stop pull seines from landing their catch for over 20 years by passive means. We compare catch trends, fishing effort and fishery yields in a multiple gear lagoon reef fishery where a MPA was formed and when gear changes occurred with an objective of determining which form of fishery management, that is, gear types or closed areas, is best able to maximise and sustain fish yields.

METHOD

Study Sites

The Mombasa Marine Park (MNP) was established in 1991 and was heavily fished before protective management (McClanahan & Kaunda-Arara 1996; Glaesel 1997; McClanahan & Mangi in press). The adjacent reef, to the south, was consequently demarcated as a marine reserve allowing traditional methods of fishing (traps, gill nets, and hand lines). This conversion from unregulated to traditional fishing was slow as it took up to 1995 for the complete removal of pull seines in the reserve. Pull seines or beach seines are a long net of ~150 meters with a small mesh of ~3 cm pulled across the bottom. Around the same time, the park boundary was reduced as part of an integrated coastal area management project (CDA 1996). Kenyatta Beach is the major landing site for the fishing that is done in the near shore coral reefs and seagrass beds in the reserve.

The establishment of a marine protected area in the Diani region in 1990 was proposed by the Kenya Wildlife Services, hoteliers , local people (including fishers) and researchers (McClanahan *et al.* 1997; Glaesel 1997). Management did not begin due to excessive conflicts among the parties, as fishers feared losing their fishing area and it was recognised that the undesired visiting fishers from Pemba would not be eliminated by park regulations, while local officials who hoped to get the revenue from park visitation fees also realised that this was unlikely (see McClanahan *et al.* 1997).

Despite the failure of the marine protected area in Diani, two of the study sites (Mvuleni and Mwanyaza) have successfully managed to eliminate pull seines for over 20 years through passive means. One adjacent site, Mwaepe, also followed this traditional management in November 1996 and restricted pull seines from landing their catch at their site, there were, however, frequent later night beach seining in their fishing grounds although the catch was landed somewhere else. Two large pull seine groups that landed their catch in two sites Mgwani and Chale stopped fishing in March 1998 as their large nets had worn out completely and they had no funds to buy new ones for replacement. Some bought gill nets and started fishing while others moved to join other pull seine fishers in the sites with active pull seines (Tradewinds and Lagoon Reef). This meant an end to pull seines in Mgwani and Chale.

Fish Landing Studies

Fish landing data were collected from September 1995 to June 1999 in all the study sites. The Kenyatta landing site was visited for 12 days and the Diani sites for 3 days per month.

Fish landed by individual fishers or pairs of fishers were identified to family level and their wet weight estimated using a spring balance in kilograms. Recorded data included the number of fishers' boats and types of gear used at each landing site. The total catch, fish groups, and numbers of fishers that participated in fishing was recorded each day fishing was done.

Data were analysed based on the sum of the family groupings into monthly averages. The fishing area was estimated from maps showing the fishing grounds and discussions with fishers. Fishing ground boundaries of each landing site are clearly known and maintained by interactions among fishers from different landing sites. There were four principle fishing grounds based on the type of management in place (Map 1: p.170), namely:

- Kenyatta Beach, adjacent the Mombasa Marine Park, with most of the fishing done in the reserve next to the park. Here only artisanal fishers with traps, gill nets, and hooks and lines are allowed and no shell collecting activities. When this park came under active management in 1991, the fishers lost 63% of their fishing ground but their numbers declined by 68% leaving a constant number of fishers per area. Early efforts to enforce park and reserve status resulted in physical and verbal assaults on park personnel and cases had to be taken to court. By the mid-1990s the situation had calmed and beach seining was completely eradicated in the reserve. In response to repeated complaints about the park by fishers of the Kenyatta beach landing, Kenya Wildlife Services after getting recommendations from an integrated coastal area management study by the Coast Development Authority, accepted to reduce the park-reserve boundary in October 1995. The fisher-state relations have improved and fishers have adapted to park management rules (Glaesel 1997);
- Galu, comprising the sites where traditional management by passive means managed to stop pull seines from landing their catch for over 20 years. These sites have also been attempting to try and stop spear fishing in their area;
- Kinondo area which is characterised by very high fisher numbers and where the beach seines that were using these landing sites had their nets worn out and could not replace them thereby bringing beach seines to an end in March 1998. Fishers here are not as aggressive as those of Galu and it would have taken the beach seine exclusion longer were it not for their worn nets;
- Diani, where beach seines are still adopted. Although one site, Mwaepe took to local management and turned to be very aggressive towards beach seines landing their catch there, this fishing practice continued in their fishing grounds.

Discussions with the fishers showed that fishing is done 24 days a month but catch data was collected for 12 days (± 4.0) for Kenyatta landing, and 3 days (± 1.0) for each site in Diani. We calculated the average number of fishers using each landing site each month. These data were analysed to calculate yearly averages of the catch per fisher changes and regressed with time. To describe the fishery, each gears contribution to the catch was calculated and its associated fish family groups. Plots of catch per area per month changes and mean numbers of fishers were used to determine whether there are differences in fish catches among the landing sites based on the above management categories and whether this could be attributed to the different types of gear used and/or the type of management in place. The number of fishers used here is the average of those participating in the fishing in a month. This lowers our fishers per area calculation by half as some of the fishers are not recorded since they fish at night or are in and out of fishing.

Table 11.1 *Average catch per man/day (kg) in the studied beach seine exclusion categories regressed with time*

	KENYATTA B. Mean (SE)	GALU Mean (SE)	KINONDO Mean (SE)	DIANI Mean (SE)	MWAEPE Mean (SE)
1995	4.28 (0.13)	4.08 (0.36)	3.66 (0.51)	3.60 (0.47)	4.15 (0.57)
1996	3.41 (0.08)	4.59 (0.31)	3.99 (0.23)	4.21 (0.75)	3.59 (0.25)
1997	3.42 (0.10)	3.84 (0.15)	2.90 (0.16)	3.81 (0.51)	3.05 (0.18)
1998	3.13 (0.10)	3.14 (0.12)	2.86 (0.14)	2.53 (0.22)	2.63 (0.17)
1999	3.15 (0.10)	2.83 (0.15)	2.70 (0.19)	2.69 (0.29)	2.76 (0.20)

Kenyatta:	$y=520.7 - 0.25x$	$R^2=0.73$	$F=18.0$	$p<0.0001$.
Galu:	$y=762.7 - 0.38x$	$R^2=0.78$	$F=10.1$	$p<0.0001$.
Kinondo:	$y=498.5 - 0.25x$	$R^2=0.61$	$F= 5.5$	$p< 0.002$.
Diani	$y=618.5 - 0.31x$	$R^2=0.49$	$F= 3.6$	$p< 0.01$.
Mwaepe	$y=686.2 - 0.34x$	$R^2=0.80$	$F= 4.8$	$p< 0.001$.

RESULTS

Fish Landings

All the studied sites showed a significant decline in annual catches over this four-year study (Table 11.1). Over this period, between September 1995 to June 1999, there was a progressive decline in the catch per man despite the differential exclusion of beach seines. (At Kenyatta Beach, the site next to the marine park, there was an initial increase in catch per man during the first few months of our study due to the park boundary change).

Galu, the area with active traditional management, had the highest average catch per man (3.7 kg/day) while the sites that still adopt beach seines the lowest (3.09 kg/day; Table 11.2). There was a general 6.1% increase in per fisher catches along the beach seine exclusion gradient.

Table 11.2
Average catch in the studied beach seine exclusion categories, 1995-'99

	KENYATTA B. Mean (SE)	GALU Mean (SE)	KINONDO Mean (SE)	DIANI Mean (SE)	MWAEPE Mean (SE)
catch/fisher [1]	3.46 (0.05)	3.70 (0.10)	3.21 (0.09)	3.09 (0.09)	–
catch/area [2]	5.50	4.70	4.70	2.80	–

1) kg/man/day
2) kg/ha/month

The marine reserve produced the highest yields per area basis (5.5 kg/ha/month) (Table 11.2). Galu and Kinondo had the same catch per area (4.7 kg/ha/month) despite a difference of 200 ha in their fishing areas (Table 11.3). Due to the active traditional management in Galu, these sites have attracted an increasingly number of fishers to the extent that the once high catch per area (8.8 kg/ha/month) was markedly reduced towards the end of our study to about 4.4 kg/ha/month. Kinondo had the highest number of fishermen using its fishing grounds (41.7±9/ha; Table 11.3), but when the number of fishermen was divided by the area where fishing is done, the reserve at Kenyatta was seen to hold the highest fishermen per unit area (7±2 fishers/ha. Actual fisher numbers should be twice the reported number).

Table 11.3
Total catch per month, fishing area, average number of fishers and the number of fishers per area of reef or lagoon, 1995-'99

Reef/Lagoon	FISHING AREA (ha)	FISHING DAYS (N)	NUMBER OF FISHERS Mean (s.d.)	FISHERS/AREA (#/ha/month) Mean (s.d.)	TOTAL CATCH (kg/month) Mean (s.d.)
Kenyatta	375	24	24.9 (6.4)	7.0 (2.0)	2040.5 (569.3)
Galu	500	24	26.4 (6.8)	5.0 (1.0)	2370.3 (874.2)
Kinondo	700	24	41.7 (9.0)	6.0 (1.0)	3190.0 (1035.3)
Diani	700	24	25.7 (6.1)	4.0 (1.0)	1804.9 (925.4)

Fishing Gears

Five main gears are employed in this near-shore fishery. Traps and spear guns are the most active gears used in all the studied fishing areas (Appendix 11.1: p.183). Spear fishing for octopus contributed the highest to the catch at Kenyatta and that is why spear guns ranked number one at this site. Octopus was also the predominant family in the fish catch from Kenyatta (6.9 kg/day; Appendix 11.2: p.184). Hand lines (hook and lines) are also frequently used since there is a trend of spear fishermen changing to hand lines during neap tides while maintaining spears during spring tides. The more passive gears, traps and gill nets, contributed highly to the catches in Galu and Kinondo. Traps were the most frequently used gear in Galu (N=189) and produced the highest catches (Appendix 11.1). Although gill nets had a small sample size (N=76; Appendix 11.1) they produced the highest catches in Kinondo. Most spear fishermen go for octopus and parrotfishes especially of the genus *leptoscarus*, while trap fishers target rabbitfish and scavengers. This explains our results that, the parrotfishes, octopus, scavengers and rabbitfishes are the predominant fish groups associated with this fishery (Appendix 11.2). The major dermasal catches including scavengers, herbivorous rabbitfish and a high diversity of reef-associated fishes like parrotfishes, and octopus contribute to 78% of the total catch in all the studied sites but for individual sites the percentages differ. At Kenyatta for instance, octopus, scavengers and rabbitfishes make the bulk of the catch as mixed groups mainly composed of parrotfishes follow, while most of the other sites had more parrotfish and octopus as they use spear guns mostly (Appendix 11.2). The diversity of the catch is very high and although fishermen will focus on the preferred fish of their customers, almost all fish species are caught. The direct effect of fishing therefore, is the most-likely explanation for reduced number of fish species.

DISCUSSION

The main fish families caught in this fishery are predominantly seagrass species, which is not surprising as the reef lagoons are the most exploited areas by the artisanal fishers. Fishing is most frequently focused at the shallow-water coral and seagrass beds. The reef lagoons are therefore exploited by fishers throughout the year irrespective of the season and this makes the nearshore reefs being fished at or near their Maximum Sustainable Yields (MSY). Some conservation efforts such as mesh size regulation, the protection of keystone predators like the triggerfish, and the elimination of destructive fishing methods like the beach seines and spear guns needs to be implemented if harvests are to be increased. Comparison of the composition of catches in Kenya and other regions, illustrates the predominance of the same fish groups, rabbitfish and scavengers for Madagascar (Laroche & Ramananarivo 1995), and snappers, emperors, mullets, parrotfish, jacks and groupers for Papua New Guinea (Dalzell & Wright 1990), as most of the fishing in these areas is done on the reef flat.

The declining per man catches in the reserve could be the result of some previous over-exploitation of the fish stocks before the conversion into protective management. The drop in Catch Per Unit Effort (CPUE) may, alternatively, have been due to a decline in fishing effort from the reduction of more efficient gears (McClanahan & Kaunda-Arara 1996). A continuing study of gear types and fisher density on catches is required. Nonetheless, our study suggests that the two management changes, pull seine exclusion and park boundary change, increased the total catch and to a lesser extent the number of fishers. Previous studies have shown that there is some degree of fishery recovery after the establishment of the park (McClanahan & Kaunda-Arara 1996), and that there is a dispersal of adult exploitable fish into the adjacent fishing grounds in the reserve (McClanahan & Mangi in press), this study confirms that the reserve has the highest yield per area basis despite having the highest number of fishers per area (Table 11.3). Despite continued poaching in the park, our study suggests that the Mombasa MPA increases fish stocks in the adjacent fishing grounds. Discussions with the fishers have shown that during the hottest months from January to March, some of them fish at night as they expect more catches during those times. This explains the fluctuating fisher numbers as the night fish landings were not recorded.

Traditional enforcement by local communities as is the case at Galu, may have been more effective in the past, at present, its effectiveness is limited. These two sites have attracted an increasing number of local fishers who in turn have led to a declining total catch and CPUE. The regulation of gears is not the only management practice to maintain fishing stocks and therefore fisheries production as it might also require regulation of effort. The Diani reefs have been reported to have the lowest fish and coral abundance and diversity in Kenya (McClanahan & Obura 1995; Watson & Ormond 1994; McClanahan 1997). Their ecological functions have been affected by fishing such that unless they are managed better, fishery production will keep deteriorating.

There is an increasing recognition that sustaining fishery yields will require sustaining the ecosystems that produce fish (NRC 1999). This is the objective of Kenya's national park and reserve systems. Although the average catch per fisher and area is higher next to the park, the total catch is lower than before the park formation (McClanahan & Mangi in press) and is attributable to the area lost to fishing for the creation of the marine park. This suggests some necessary trade off between maximising total catch and protecting ecosystems. The reduction in destructive gear, such as beach seines, may further help to protect immature fish and corals and associated coral reef complexity (McClanahan & Shafir 1990; McClanahan *et. al.* 1997) and restrictions on destructive gear can be useful as well as closed areas.

These same arguments can be put forward for the intermediate beach seine sites, Chale and Mgwani in the Kinondo area. The removal of beach seines had the immediate pulse of increasing the per fisher catches which lasted for a few months (~14) and later dropped. Since the number of fishers is very high here, it will be seen as though all fishing methods are destructive because, the total removal of fish from the reef has a number of effects on ecological functions and resource production. Restrictions therefore may have to consider the purpose of fishery management and may need to make trade-offs between the factors of production, social equity and ecological functions.

The continued use of pull seines in the Diani area (Tradewinds and Lagoon Reef) appears to be favoured by a few local leaders (S. Kitema personal communication). Discussions with most fishers showed that they are tired of this fishing practice. Most of the fishers we talked to would like to see an end to both pull seining and spear gun fishing, but this is something they would avoid discussing in public. They fear discussing alternative forms of fishery management such as closed areas as they feel they will lose power to control their resources and hence their destinies (Glaesel 1997).

The decline in the catches of these coral reef fisheries from this five-year study indicates that the Kenyan nearshore fishery is at or near a level of full exploitation as evidenced by the declining catch per man over time. It could be due to over-exploitation of preferred species by fishing, and degradation of the marine ecosystems by the use of destructive fishing methods. In Diani there is a need for discussions by all traditional and national fisheries leaders on the value of protective management on fishery catches and how to achieve that management. We conclude that marine parks and reserves, gear and effort remain ways to regulate notoriously complex tropical fisheries. As a result, an effective way to manage these tropical fisheries should start with gear regulations while considering some appropriate incentives for the fishers and lead to closing off areas. However, unless the means to judge the success of this management is in place the benefits may be largely psychological. In order to achieve this goal a knowledge of the fish catches and the impacts of both park design and fisheries management, that is, permitted methods, number of fishermen and mesh size on fish catches needs to be developed. Consequently, our findings could assist in developing the ground work for developing an adaptive fisheries management program where the link between the resource, its use and conservation are tied together by a string of knowledge that determines the impacts of implemented management.

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Appendix 11.1

Per cent contribution by each of the five principle gears used, 1995-'99

(The total number of times the gear was used (n) and a rank (R) based on the catch (%) are shown. Where the sample size was small the rank is not given.)

	KENYATTA			GALU			KINONDO			DIANI			MWAEPE			TOTAL		
	%	(N)	R*	%	(N)	R	%	(N)	R	%	(N)	R	%	(N)	R	%	(N)	R
Trap	21.9	(546)	4	28.3	(189)	1	15.9	(157)	5	16.4	(25)	4	15.4	(91)	4	18.5	(1008)	4
Gill net	22.2	(508)	3	20.7	(23)	4	23.3	(76)	1	20.2	(15)	2	21.9	(28)	1	19.4	(650)	3
Hand line	25.1	(468)	2	24.7	(94)	3	19.9	(104)	4	21.3	(6)	-	19.5	(78)	2	20.3	(750)	2
Spear gun	30.8	(545)	1	26.3	(184)	2	20.5	(166)	2	22.9	(55)	1	18.5	(96)	3	23.3	(1046)	1
Beach seine	–			–			20.4	(106)	3	19.2	(67)	3	24.7	(19)	-	18.5	(192)	4
	100			100			100			100			100			100		

Appendix 11.2

Comparison of the catch composition (kg/gear/day) among the sites plus a percentage total occurrence of each family group in the catch, 1995-'99

	KENYATTA Mean (s.d)	GALU Mean (s.d)	KINONDO Mean (s.d)	DIANI Mean (s.d)	MWAEPE Mean (s.d)	TOTAL %
Parrotfish	1.8 (4.1)	12.1 (10.9)	8.0 (11.0)	5.9 (6.9)	5.8 (8.0)	23.0
Octopus	6.9 (15.2)	8.0 (16.7)	8.4 (20.3)	3.9 (8.5)	6.5 (14.2)	23.0
Scavengers	4.9 (10.2)	5.2 (6.7)	5.8 (10.2)	4.4 (13.5)	4.8 (12.7)	17.2
Rabbitfish	4.0 (9.5)	6.0 (12.7)	5.1 (9.1)	2.9 (5.1)	3.5 (7.5)	14.7
Other	1.8 (6.0)	2.6 (3.9)	3.9 (12.2)	3.5 (7.2)	2.7 (7.0)	9.9
Mixed	3.5 (8.3)	0.0 (0.0)	0.0 (0.0)	0.2 (1.8)	0.0 (0.0)	2.5
Rays		0.4 (1.5)	0.5 (2.4)	0.3 (1.2)	0.5 (2.6)	1.5
Needlefish		0.1 (1.2)	0.9 (6.4)	0.1 (0.8)	0.3 (1.9)	1.2
Wrasses		0.2 (0.7)	0.3 (1.4)	0.2 (0.9)	0.5 (1.4)	1.1
Squid		0.0 (0.3)	0.5 (2.3)	0.6 (3.8)	0.1 (0.8)	1.0
Rock cod		0.3 (1.1)	0.3 (1.5)	0.2 (1.1)	0.3 (1.3)	1.0
Goatfish	0.1 (0.8)	0.3 (0.9)	0.3 (1.2)	0.2 (0.6)	0.3 (1.0)	0.8
Grunts		0.3 (1.1)	0.2 (1.1)	0.1 (0.5)	0.2 (1.1)	0.7
Surgeonfish		0.2 (1.0)	0.1 (1.0)	0.4 (1.8)	0.1 (0.8)	0.7
Lobster		0.4 (1.2)	0.2 (0.8)	0.0 (0.3)	0.1 (0.5)	0.7
Kingfish		0.1 (0.4)	0.3 (6.5)	0.0 (0.2)	0.1 (0.7)	0.4
Pursemouth		0.0 (0.7)	0.0 (0.5)	0.1 (0.8)	0.0 (0.3)	0.2
Queenfish		0.0 (0.0)	0.0 (0.2)	0.1 (1.0)	0.0 (0.1)	0.1
Unicornfish		0.0 (0.4)	0.0 (0.6)	0.0 (0.6)	0.0 (0.3)	0.1
Sea chubs		0.0 (0.2)	0.0 (0.6)	0.0 (0.0)	0.1 (0.5)	0.1
Eel		0.0 (0.4)	0.0 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0
Barracuda		0.0 (0.0)	0.0 (0.0)	0.0 (0.2)	0.0 (0.1)	0.0
Fishers, No.	6.8 (5.1)	10.2 (6.4)	11.6 (8.8)	8.4 (5.8)	8.6 (5.8)	100
Catch/fisher	3.5 (2.1)	3.7 (2.3)	3.3 (2.6)	3.0 (2.1)	3.1 (2.0)	

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Awareness of Resource Degradation among Artisanal Fishers in Kilifi and Lamu

Joseph G. Tunje[1] & Jan Hoorweg[2]

ABSTRACT

The study was carried out in Kilifi (including Malindi) and Lamu Districts of Kenya, focusing on the activities of artisanal fishermen. The fishing methods that the fishermen use and the extent they contribute to coral reef degradation were the major study objective. The fishing methods used, factors for their choice, and their perceived impact on coral reefs were investigated. Indigenous environmental conservation efforts, fishermen's alternative sources of income, and attitudes towards environmental conservation were also examined.

Fishermen mainly use the gear they have experience with and gear that brings them high catches. They did not consider the environmental impacts of the gear they used. The results also revealed that there were few signs of indigenous marine conservation in this part of the coast. Half of the fishermen interviewed observed certain cultural restrictions relating to personal safety at work, good hygiene and fish handling. The other half did not. Finally, local fishermen are willing to initiate and participate in programmes of marine environmental conservation aimed at the fishery resource as long as it enables them to improve their incomes.

INTRODUCTION

Fishing provides employment and income to large numbers of people. It is estimated that the world over more than 120 million people are employed, directly or indirectly, in the fish-

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ing sector (FAO 1996). In Africa, 5% of the population, or about 35 million people depend wholly or partly on fisheries for their livelihood. Apart from fishing as such there is employment in fish trading and processing, the manufacture of fishing gear, boat building and the distribution of fish products (fish meal, fertiliser etc.).

FAO in 1984 gave an estimated number of 12,000 fishermen at the Kenya Coast with about 1,800 fishing vessels, while Ardill & Sanders (1991) gave a figure of 6,250 fishermen. Recent studies by Wamukoya, Ottichillo & Salm (1997) arrived at an approximate figure of between 8,000 and 10,000 fishermen, who operate 2,500 vessels; UNEP (1998) gave a figure of 5,000 fishermen out of whom 4,000 are considered as artisanal.[3] Using the 1997 figures, and assuming an equal number of people being employed in the processing and distribution of fish products, in all about 20,000 people are employed in the fishing industry at the Kenyan Coast. Fishing provides monetary incomes in about 70% of the inhabitants of coastal villages (Malleret & King 1996).

Over 50% of marine fish species depend on the coral reefs at one stage of their life cycle or another. The main type of coral reef along the Kenyan coastline is the fringing reef which closely follows the shoreline at about 500-1500 m with a shallow lagoon between the land and the reef. Marine fishing in Kilifi and Malindi Districts occurs in the lagoons behind the reef, the gaps in the reef (*milango*), the continental shelf and in the deep sea. The lagoons and reefgaps form the main fishing grounds of the artisanal fishermen.

Studies on coral reefs and fishery resources at the Kenya Coast include those by McClanahan & Muthiga (1988; 1989), McClanahan & Mutere (1994), Watson & Ormond (1994) and McClanahan & Obura (1995). The reefs suffer the combined effects of different factors. Discharge of river sediments, domestic and industrial sewage, tourist visits, shell and coral collection play a role. Population growth and increase of tourism has increased the demand for fish and the pressure on the inshore fishery resources. McClanahan (1994) and Glaesel (1997) found that at the same time the local systems of marine management are on the decline if they have not disappeared already.

Artisanal fishermen can cause degradation of the reef in several ways. Intensive fishing may result in loss of local biodiversity through a decreased overall fish population. The removal of keystone fish species can also alter reef ecology. For example, the removal of fin fish adversely affects reef fauna groups and causes imbalance in the reef ecology. Removal of

3 It is difficult to establish the number of people directly involved in fishing because of the seasonality of the occupation. Many small-scale fishermen try to evade paying for licences; making the government number of registered fishermen to be lower than the actual number.

sea urchin predators will result in large urchin populations, which in turn is associated with low coral cover and reduced calcium deposition (McClanahan & Obura 1995). Fishing for juvenile fish, and fishing of large reproductive dominant fish species may cause changes in the reproductive cycles, preventing population recovery. Destructive fishing practices, such as the use of explosives, seine nets and poison may also alter the topographic and ecological balance of the reef.

Coral reef fisheries can be a renewable resource, but unless exploited at a sustainable rate, over fishing may lead to the depletion of the resource and degradation of the reef. In the light of this, the present study investigated how small-scale fishermen interact with the marine environment and to what extent artisanal fishermen contribute to coral reef degradation at the Kenya Coast. The broad objective was to study the awareness of fishermen to fishery resource degradation; specifically the fishing methods most commonly used, the factors for their choice and environmental conservation measures practised by the fishing communities.[4]

Study Area

The study was done in Kilifi-Malindi and Lamu Districts of Coast Province. Kilifi District[5] lies between latitude 2°20' and 4° S, has a shoreline of about 265 km from Mtwapa to Ungwana Bay. Lamu District lies between latitudes 1°40' and 2°30' S and has a coastline of some 130 km. There are an estimated 1,000 artisanal fishermen in Kilifi while the number is about 1,500 in Lamu (D.o.F. 1996).

In Kilifi, data were collected from Mayungu fishing village (Malindi) and Takaungu (Kilifi). In Lamu, data was collected from Kiunga fishing village and Lamu town (Map 1: p.170). The coral reefs in Kiunga and Mayungu study sites fall within marine reserves which entails some protection, while the reefs of Lamu and Takaungu have not been gazetted and are largely unprotected.

Method

Diverse primary data techniques were used: questionnaires, informal interviews, on-the-spot observation, participant observation, in-depth discussions and examination of institutional

4 Further information on findings and methods of study are given in Tunje (2002).

5 Kilifi and Malindi were one district till Dec.'96 and are referred to as Kilifi District.

records. Questionnaires, pre-coded and open-ended, were administered to government officers from KWS, D.o.F. and KMFRI. Secondary data were mainly found in research reports and dissertations. Relevant seminar reports, papers, and journals were also reviewed.

In Mayungu and Takaungu there are 65 and 150 government registered fishermen respectively (D.o.F. 1998), while Kiunga had 350 and Lamu 450 fishermen according to estimates of the village elders. At each study site 25 fishers were randomly sampled; a total of 100 fishermen were interviewed in the 4 sites. Government officers were visited in their respective Mombasa, Kilifi, Malindi, Lamu and Kiunga offices.

RESULTS

Type Fishing Gear

Fishing nets were most popular with 73% of the fishermen using them as their first choice. Fishing lines were next (20%) and one fisherman in Kilifi reported that he used a spear gun. There is little difference between the two districts (Table 12.1). The number of fishermen using fish traps (*malema* and *uzio*) was low in both districts but slightly higher in Lamu than in Kilifi (10% versus 4%).[6]

Table 12.1 *Fishermen by gear type and district* (%)

	KILIFI (N=49)	LAMU (N=50)	TOTAL (N=99)
Fishing net	76	70	73
Fishing line	20	20	20
Fish traps	4	10	7
	100	100	100

Type Fishing Net

The most preferred fishing net is the gill net (Table 12.2), locally known as *mpweke,* and mentioned by a total of 62% of the fishermen. Next follow the floating net *(jarife)* and sar-

6 The results in Table 12.2 refer to fishers who used fish traps as their first choice of gear. (including only one fisherman under the age of 40 years). When second or third choices are also counted, 13% of the fishers reported use of traps, with an average of 7.6 traps per fisherman with no difference between the districts. Clearly, the use of traps is no longer popular in the area.

dine net *(kimia)* mentioned by 16% and 14% of the respondents respectively. Both districts have estuaries and other inlets where large groups of sardine fish are caught with special nets. The seine net is last, they can seriously degrade the marine environment if used inappropriately. The use of gill nets was high in Kilifi with 82% of the fishermen compared to 42% in Lamu. Floating nets were more often used in Lamu by 28% of the fishermen compared to 5% in Kilifi. Only fishermen in Lamu mentioned seine nets.

Table 12.2

Net fishermen by net type and district (%)

	KILIFI (N=38)	LAMU (N=36)	TOTAL (N=74)
Gill net	82	42	62
Floating net	5	28	16
Sardine net	13	14	14
Seine net	0	17	8
	100	100	100

Table 12.3

Net fishermen by mesh size and district (%)[1]

	KILIFI (N=38)	LAMU (N=36)	TOTAL (N=74)
Large 3-6.5"	42	69	55
Small <2.5"	58	31	45
	100	100	100

1) X^2=5.15, d.f.=1, p=.02.

The use of gill nets is associated with groups of fishermen who fish in the shallow lagoons using small dugout canoes and sometimes on foot during the low tides. The large floating nets are more suitable in the offshore waters, and the small fishing vessels of most Kilifi fishermen probably limit their use (JT, pers.obs.). Another factor is that many fishermen in Kilifi can not afford floating nets that can cost Ksh. 40,000 a piece. They have to resort to less expensive nets at prices ranging from Ksh. 425/- to 600/- per piece, but only suitable for inshore waters.

Net Mesh Size

Table 12.3 shows that nets with large mesh sizes of between 3-6.5 inches are most common and used by 55% of the respondents. Nets with mesh sizes less than 2.5 inches are used by 45% of the fishermen. Fishermen in Lamu used more large-meshed nets (69%) while fishermen in Kilifi preferred small-meshed nets (58%).

In general, there is a relationship between the number of trips made per day, the fishing grounds, the fishing gear, the net type and mesh size. The number of fishing trips will be determined mainly by the grounds visited. Most fishermen who go beyond the reef make only one fishing trip per day. These fishermen mainly use large fishing vessels with large-meshed nets *(jarife)*. Fishermen fishing inshore normally use non-motorised small fishing vessels (dug-out canoes and *mashuas*). They use all kinds of gear including small-meshed *mpweke* nets, and these fishermen often go fishing more than once a day.

Choice of Fishing Gear

The parameters used to determine the choice of fishing gear include experience, easy usage, amount of catch, environmental friendliness, cost of the gear, and seasonal changes. Experience with a particular gear is the major factor, while environmental considerations are least thought of (Table 12.4). The majority of fishermen (52%) use a particular fishing gear because they have experience with it. Usually this is the gear which their trainers (often fathers or relatives) used. The ability to use a particular gear with ease was mentioned by 15% of the interviewed fishermen. Other reasons for gear choice included the price of the gear, environmental friendliness of the gear, and seasonal changes all mentioned by fishermen in Kilifi (19%) but not in Lamu.

Table 12.4
Fishermen by reason for gear choice by district (%)

	KILIFI (N=48)	LAMU (N=50)	TOTAL (N=98)
Experience	50	54	52
High catch	17	30	24
Easy to use	15	16	15
Others	19	0	9
	100	100	100

$X^2 = 11.34$ d.f. $= 3$ $p = .01$

Lamu fishermen often mention high catches (30%), an indication that they are willing to invest in gears that will give good returns. In Kilifi this was only 17%; fishermen are not ready to spend on gear and end up using the cheapest equipment.

Destructive Fishing Methods

For the purposes of this paper, destructive fishing methods are those that damage or alter the marine environment or that catch not only the targeted but also the non-targeted fish species and/or non-targeted sizes. Non-destructive methods are those that only harvest the targeted species and sizes and that leave the reef topography unchanged.

Table 12.5 *Fishermen and their perception of destructive methods by district* (%)

	KILIFI (N=49)	LAMU (N=42)	TOTAL (N=91)
Beach Seining	78	86	81
Spearing	6	12	9
Others	16	2	10
	100	100	100

The majority of the fishermen interviewed (81%) mentioned that the beach seining method, locally known as *juya*, is most destructive to the corals, followed by spearing which was mentioned by 9% of the fishermen. Other reef destructive methods given included poisoning and blasting as mentioned by a total of 10% of the fishermen, mainly from Kilifi (Table 12.5). There are some small differences between the districts. Spearing was more often mentioned in Lamu than Kilifi; while others (poisoning and blasting) were more often mentioned in Kilifi.

Beach seining is destructive because it uses nets with very small mesh sizes (*juya*), which catches even the undersized fish juveniles. The net is also dragged on the sea bed, damaging its topographic structure. These nets with their mosquito net mesh sizes do not allow young and immature fish to swim through. In Kilifi, these nets are used by the Wapemba fishermen.

Spearing is considered destructive to the corals because the fisherman using it has to snorkel under the water and 'hunt' for the fish. The fishermen sometimes step on the corals as they snorkel in the water. The arrow can damage the coral when it misses its target. The speargun is often complemented by a metal rod *(mkonjo)* to break and/or overturn the corals in cases where the fish swims and seek refuge under it.

The traditional fish poison *(mkanga* or *mchupa)* is destructive not only to the fish resources, but also to the other marine organisms as well as the birds of the air which eat the dead fish. Though none of the interviewed fishermen admitted using poison, it was learned that it was used in the northern parts of the Malindi coastline between Mayungu and Watamu (Mwagambo 1998) and in the extreme north at Marereni and Mto wa Mawe. Explosives *(baruti)* destroy the coral reef and kill the fish and other marine life indiscriminately. Though none of the interviewed fishermen admitted to using this method, it seems to be used occasionally by fishermen between Mayungu and Watamu (Mwagambo 1998).

Non-Destructive Fishing Gear

The gear considered most coral-reef friendly is the gill net *(mpweke)*. This response was given by 53% of the fishermen interviewed (Table 12.6). Fishing lines were favourably mentioned by 33% of the fishermen; fish traps by only 3%. Eleven percent of the fishermen had no response and presumably were ignorant about the environmental impact of their gear.

Gill nets *(mpweke)* are less destructive to the marine environment as they are mostly used in areas away from the reef where no corals can be damaged e.g. in shallow areas of the lagoon by fishermen who wade on foot. According to the Fisheries Act (Kenya 1991), the recommended mesh sizes of these nets is supposed to be not less than 50 mm, which facilitate the swimming through of small juvenile fish. Mesh sizes are indeed a crucial element in determining the environmental friendliness of fishing nets.

Table 12.6 *Fishermen and their perceptions of non-destructive methods by district* (%)

	KILIFI (N=50)	LAMU (N=42)	TOTAL (N=92)
Gill nets	56	50	53
Fishing lines	42	21	33
Fish traps	2	5	3
Do not know	0	24	11
	100	100	100

Lines are equally non-destructive on both counts. They do not damage the reef structure and the fish size can be regulated by the size of the hooks. More fishermen from Kilifi (42%) view lines as non-destructive compared to Lamu (21%). The fairly light weight of *malema* fish traps, coupled with their fairly large mesh sizes also makes them not to be environmentally damaging. Traps do not cause damage to the reef topography and aim at catching only fairly large size fish.

Table 12.7

List of cultural restrictions by category

PERSONAL SAFETY

1. Whistling or making noise during fishing. Fishing is a risky venture and requires maximum concentration to avoid misfortunes;
2. No fishing should be done when the fisher is annoyed or in a bad mood. This is to make the fisher pay maximum attention to his work;
3. Going out fishing while drunk. Again, this is to make the fisher pay attention to his work and avoid misfortunes such as *dau* capsizing and even drowning;
4 Women are not allowed to move near or enter a vessel. They can easily talk or behave in a seductive manner, making the fishermen loose concentration.

PERSONAL HYGIENE

1. Entering the vessel in slippers or shoes since dirty footwear may contaminate the fish and cause health problems for consumers;
2. Fishing after having sexual intercourse without taking a bath since the fisher is unclean and likely to contaminate the fish;
3. Urinating while standing in the vessel as the last drops of urine are likely to fall back in the vessel;
4. Women who are pregnant or menstruating are not allowed to enter a fishing vessel or hold the basket containing the fresh catch. She is considered 'unclean' and can easily contaminate the fish.

FISH HANDLING

1. Green raffia should not be used in tying fresh fish. Green vegetative material may have a sour taste and could contaminate the fish;
2. Removing the fish scales with a stick is not allowed since the cleanliness of the stick is not guaranteed. The fish can be contaminated easily by the sap of a green stick;
3. A soot-coated *sufuria* cannot be used to take fresh fish from the vessel; since this is likely to contaminate the fish.

Indigenous Environmental Conservation

Of the fishermen interviewed, 49% mentioned the presence of certain cultural restrictions that are associated with fishing activities. In Kilifi District, 78% of the respondents mentioned their existence compared to only 20% in Lamu. The restrictions that were mentioned by fishermen from the study areas, can be divided into three main categories: namely precautions for personal safety while fishing, measures to avoid contamination of the catch and measures to assure hygienic delivery of the catch (Table 12.7). Surprisingly – perhaps disappointingly – the restrictions did not concern marine environmental conservation and today even the other restrictions are gradually disappearing.

Discussion

Fishing Gear

The use of gears such as fish baskets *(malema)* and fish fences *(uzio)* appears to be declining. Older fishermen used these fishing gear in the shallow lagoons and other areas within the reefs. Traditional fish traps are less in use, with the passage of older fishermen. Inquiries by the researcher (JT) about the use of home-made fishing nets did not bear fruit. Traditionallynets were made out of the bark of a *mgboza* tree and they were phased out with the coming of the modern nylon nets. These gears are being replaced by modern ones, which are more popular among the young fishermen since they are more efficient (Glaesel 1997).

The use of a spear gun is prohibited in the Marine Protected Areas (Mwagambo 1998). Some fishermen clandestinely use this gear at night. If used during the day, they try to hide the gear and frequent secluded areas (Thoya 1998; JT, personal observation). Speargun fishing, as already mentioned, has certain destructive effects on the corals but it should be noted that the use of a spear gun is not a great threat to the resource as such, especially when selective harvesting is practised.

There is some use of traditional fish poison in the northern parts of the Kilifi coastline but the method is rare. The poison indiscriminately destroys fish as well as coral reef organisms. The clandestine method is mainly practised by fishermen who cannot afford the necessary fishing gear. The inaccessibility of the areas concerned makes the fishers secure that they will not be apprehended by patrols of the D.o.F.[7]

7 A fisher proven guilty of fishing using poison is liable for a fine not exceeding Ksh. 20,000 or a jail

The modern gear preferred by fishermen are the fishing nets and lines. Of these two, nets are the most commonly used. The type of net that is mainly preferred is the *mpweke* gill-net. Most local fishermen (40%) restrict themselves to fishing nets with mesh sizes between 3.0 and 6.5 inches. Fishermen argue for the use of this type of fishing gear because it only aims at catching large and mature fish, leaving small juveniles to pass through.

The beach-seine net mainly occurs in Lamu District where very long nets (sometimes as long as 100m) with very small mesh sizes are in use. The fishermen here spend several days at sea in remote areas. The nets are dragged along the sea-bed, harvesting targeted and non-targeted fish species alike. Apart from this, the corals – fish breeding, feeding and spawning grounds – are damaged. In the tropical waters, the by-catch of 'trash' or non-targeted fish species can comprise up to 90% of the contents of the net (Don 1990). In Kenya, it is estimated that 75% of the fish caught is immature (Obura *et. al.* 1996), and the use of *juya* drag nets contribute significantly towards this. In Kilifi fishermen mostly do not use beach-seine nets. However, the use of these nets with mosquito mesh sizes does occur at Mayungu and Bofa by the Wapemba fishermen during their seasonal visits. Most of the local fishermen in Kilifi know that beach-seining is destructive when used within the reefs. In fact, there have been occasional physical confrontations with the visiting Wapemba (Mwalimu 1998).[8]

Choice of Fishing Gear

A fisherman starts at an early age, usually on-the-job training with the father or a relative. Older fishermen trained the young in the use of a particular gear type that was socially accepted and had no adverse effects on the resources. In this way, they used to inculcate some sense of resource conservation in the minds of these young fishermen.

The choice of the fishing gear is highly influenced by fisher's knowledge and gear experience. Fishermen also prefer gear which they expect to give relatively high catches. The price of gear is another factor that influences choice. Most fishermen rarely consider the environmental impacts of the gear they use. Fishermen are ready to harvest fish with any type of fishing gear irrespective of the negative impacts caused to the coral reef and the marine environment at large.

In Kilifi, fishermen are particularly sensitive to the prices of fishing gear. They often use cheap gear that are not necessarily efficient and that lead to more resource degradation.

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term not exceeding one year (Kenya 1991).

8 The local fishermen have also been complaining to the D.o.F about the destruction caused by the Wapemba fishermen to their resource but their complaints have usually fallen on deaf ears.

Because of poverty they cannot invest sufficiently in gear to break this poverty cycle. In Lamu fishermen are prepared to spend more on gear to ensure higher catches.

Indigenous Environmental Conservation.

Indigenous knowledge can provide mechanisms to conserve and sustain the natural resources that are both cost-effective and sustainable (Bennun, Aman & Crafter 1992). The existing restrictions had no direct relationship with marine environmental protection or conservation. Most restrictions focused on three issues: fisherman's personal safety at work, cleanliness and hygiene, and good fish handling practices. The researcher (JT) had the chance of participating and observing a *sadaka* ceremony at Takaungu, in a 'holy' place (cave) just next to the sea. *Sadaka* is a thanks-giving ceremony where fishermen offer sacrifices and pray. Yet, fishermen regularly fish in the areas adjacent to this 'holy' place *(mzimu)*. This is in contrast to findings among the Digo community in the Diani-Kinondo region of Kwale District (McClanahan *et. al.* 1996, 1997). There, good fishing grounds were designated as *mzimu*, and were not fished, but conserved.

Fishermen agree that nowadays it is difficult to make a living from fishing and to conserve the marine environment as well.

> ".....today there are no taboos that are meant to conserve the reef fisheries and the marine environment. Taboos were observed long ago by our great grand-fathers. It is impossible for the poor fisherman to conserve the fishery resources and the marine environment because he is hungry and he is always out to get fish no matter the gear he uses and the consequences it will have on the environment. Furthermore, these taboo go against Islam.....(Ali Shaffi 2000)".

Among the young, many have received formal Islamic education and look down on traditional beliefs (McClanahan *et al.* 1996). Following taboos is tantamount to acknowledging the presence of non-existent powers and this is against Islamic teaching. As a result, most of the traditional rites and customs (taboos) are no longer followed, and were last observed by the generation of fishers in the 1960s (Glaesel 1997).

Resource Degradation

The findings on gear usage and cultural restrictions give reason to conclude that resource degradation occurs on a wide scale. Fishermen generally do not consider the environmental impacts of the gear they use, and quite often use gear that have adverse effects on the environment. Since destructive methods were equally mentioned in both districts, degradation of the environment as a result of fishing probably occurs in both Kilifi and Lamu districts. Cultural restrictions on fishing had no direct focus on the conservation of the reef fishery resource and the marine environment in general. Various factors contribute to this situation.

- Fishermen traditionally regard fishery resources as common property with free and unregulated access. Indeed, in the past, the small fisher population did not stress the resources and the thinking is that fishery resources are God-given. Since God is merciful he does not want to see his people suffer and he will continue to regenerate the resource at the same rate as it is used. This is one reason why there has been no traditional marine conservation and why the idea of imposing regulations is not easily accepted. However, with the coming of the Wapemba fishermen who use non-sustainable fishing nets with small mesh sizes, some of the local fishermen start to appreciate the need for conservation measures aimed at the reef fisheries.
- In the past fishing was a Swahili- and Bajuni-dominated activity. Nowadays fishing is open to all, including ethnic groups that do not originate from areas with large water bodies. Some fishers indicated that inland people do not know how to use the recommended fishing gear are to blame for the destruction of fishery resources (Lali 1998). This observation was also made by Glaesel (1997) who noted that an influx of fishers from non-fishing communities is to blame for non-sustainable fishing methods, apart from not observing cultural restrictions. Don (1990) also supports the idea that the sea has become the last resort for many destitute people pushed off-land who use dynamite and poison to put food on the table, initiating a destructive cycle that ruins the resource for everyone.
- Low educational level of the fishermen means that many of them do not comprehend and appreciate the importance of regulations for the long-term health of the resource. This problem is compounded by failure of the government to translate its policies in common language and educate fishermen. Unlike in the past, fishing as an economic activity is also done by some young men who are primary school dropouts and who are keen to make quick money. The little education attained make these young fishermen disregard most advice of their elders
- The economic situation of many artisanal fishermen is such that they are willing to use any fishing gear, legal or illegal, to exploit the fish resource in a bid to put food on the table. Even women have ventured into fish dealing (marketing of fish) because of the need to earn a living. Formerly, it was taboo for a woman to go to a landing beach or

move near a fishing vessel. But today women are a common sight in the landing beaches, particularly those visited by the Wapemba.

Though fishermen are generally aware of the existence of the regulations in the Fisheries Act (Kenya 1991), most ignore them. The use of explosives in an area designated as a marine reserve, the use of *juya* drag nets within the reefs in Lamu and Kiunga areas, beach seine nets seen close to the D.o.F. office in Malindi are examples of the weakness of the government in the protection and conservation of marine resources. The authorities who should take corrective measures lack the necessary facilities such as surveillance equipment, motor boats, mobile phones and political will.

Conclusion

Since coastal communities in Kenya depend mostly on marine resources for subsistence and basic provisions, it is important that proper and effective management strategies are put in place to ensure sustainability of the marine resources and at the same time guarantee social development.

Successful management strategies of fishery resources must be acceptable to the people, and in particular at the grass-root where the resource users are. Successful fishery management strategies should involve the local fishermen in decision making and regulations by giving them the information that will result in appropriate conservation, management and high fish yields. The fishermen should also stand to benefit from such conservation and management efforts.

Fishermen are entangled in a cycle of poverty which degrades the reef fishery resource in a bid to meet their needs. Fishermen cannot be made to contribute towards resource conservation before their incomes are improved. This will require less dependence on fishing as well as environmental education and implementation of fisheries regulations.

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13

Food Security Benefits of the Kisite Marine National Park for the Surrounding Fishing Communities

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ABSTRACT

This paper aims at investigating if and how Marine Protected Areas (MPA) benefit the surrounding communities. The food security status of five fishing communities surrounding the Kisite Marine National Park on the south coast of Kenya was examined. The underlying assumption was that if MPAs benefit the surrounding fisheries, it would show in the socio-economic status of the fishing communities.

Effects of the presence of the park were detected in several ways. First, it was found that households depending for their livelihoods on tourism around the parks were more food secure than the others. Secondly, it was established that the economic structure of the communities was affected by the distance of the communities from the main tour operators linked to the park. Finally, the households fishing nearer the protected reefs were found to be more food secure than the others. However, these benefits of the park are constrained by the distance of the communities from the park.

INTRODUCTION

In the recent years, No Take Zones (NTZ) have emerged as a potential solution to the over fishing problems faced by coral reef fisheries. They are a type of Marine Protected Area (MPA) closed to all extractive uses and their purpose is to promote the sustainable use of

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natural resources by safeguarding species, their habitats and their ecosystems (WWF 1998).

MPAs have been used for decades for tourism and conservation, particularly in Kenya. Their observed benefits on the fish stocks and habitats within them have suggested that they could improve the yields of surrounding fisheries (through fish migration and improved recruitment) and be used as a coral fisheries management tool (Russ 1991; Bohnsack 1993; Roberts 1997). Although numerous ecological studies have been carried out, there is still little evidence of the positive impacts of MPAs on surrounding fisheries. The reason for this is often found in the lack of historical fisheries data (Munro 1996).

Moreover, experience has shown that the lack of involvement of the stakeholders in the management of MPAs has often led to failures (Valdes-Pizzini 1995; Salm & Ngoile 1998). Communityparticipationand community-based management of MPAs are promoted more and more to improve the chances of success of MPAs (White *et al.* 1994). However, little has been done to measure the socio-economic benefits of MPAs for the surrounding stakeholders. Most often in coral reef areas, coastal communities are highly dependent on marine resources and fishing is a livelihood of last resort. MPAs are perceived as threatening the access to the fishing grounds and the stakeholders' food security. They – the MPAs – are often refused violently. For communities to be willing to participate, benefits have to be clear.

The aim of this research was to see if and how MPAs benefit the surrounding fishing communities. The underlying assumption was that if MPAs and NTZ enabled a better management of coral reef fisheries they should improve the socio-economic status of the surrounding fishing communities. In order to investigate the potential benefits of MPAs and subsequent NTZ, the food security situation of five fishing communities around the Kisite Marine National Park was studied.

Between February 1997 and February 1998, 210 households were surveyed, their attributes were examined and their food security was measured. Participatory methods were used as well as more formal questionnaires. Assistants were employed to facilitate the research, one in each village studied.

Study Sites

Kenya is at the forefront of marine resource protection and is the first developing country to have established MPAs (Watson 1996). The Kisite Marine National Park (MNP) on the southern coast of Kenya was chosen as a case study (Map 1: p.170). Tourism development is limited, there has been a 20-year relationship between the park and the local communities,

communities are distinct, and biophysical assessments of the coastal and marine environments are available (Samoilys 1988; University of York and Hull 1993). All extractive activities are forbidden in the park and the Kisite MNP is considered to be well enforced (Watson 1996).

The Park was established in 1978 but it was only enforced fully as from 1988 when, after the protests of angry fishers, the park boundaries were re-designed and part of the communities' traditional fishing grounds (i.e. Mpunguti) were returned to them. It was returned in the form of a Marine Reserve where traditional fishing methods are allowed (e.g. hand lines, traps). The park and reserve cover an area of 39 km^2.

Five fishing communities located in the vicinity of the park were selected. Four communities (Wasini and Mkwiro on the Wasini Island, Kibuyuni and Kichangani on the mainland) had their fishing grounds near the park or the reserve and were easily accessible. Anzwani, the fifth community on the mainland served as a control population. The main activity in the control site is artisanal fishing, its fishing grounds are not located near the park or the reserve, but fishers use the same offshore locations and they fish in the same kind of ecosystem.

METHOD

Qualitative Investigation

First, a qualitative investigation was carried out. Its aim was to understand how the fishers perceived the evolution of their fishery and whether they linked any developments to the presence of the park. The way in which the fishers perceived the park was then investigated.

For information on the fishery, focus groups were organised in each study village. The catch, seasonality, fishing grounds, gear, management strategies (traditional and current), and the evolution of the fishery in the last 10 to 15 years were the themes raised in these groups. Fishers believe their catch to be decreasing. They perceive no link between the fishery's evolution and the presence of the park.

Focus groups also dealt with the way in which fishers perceived the MNP. Three main themes were discussed: the history of the MNP as perceived by the groups, the MNP advantages, its disadvantages and its management. The advantages and drawbacks of the park are listed in Table 13.1.

Only one group mentioned an advantage of the park in terms of fishing. On the whole, fishers were not convinced about the benefits of the MNP. Some fishers, even though positive about it, wished it would disappear. The advantages elicited were the aid associated with

MNP, the reduction of dynamite and seine nets, and tourism-cum-employment. However, the main factors which appeared to have made the fishers tolerate the MNP were the aid they received in the form of boats and the battle they won over the authorities which led, in 1988, to the reduction of the area closed off to fishing.

Table 13.1
Advantages and drawbacks of the Park mentioned by the groups

ADVANTAGES *	DRAWBACKS *
5. Aid (boats, building of classrooms, wells).	5. Unjustified arrests (locking people up).
4. Better control of fishing methods (dynamite and seine nets kept away).	3. Loss of fishing grounds (best).
3. Employment (in tourism, in KWS).	1. - MNP not well marked; - Impounding (often the gear is impounded because someone has done something wrong but it is not only one person's gear); - Less fish (all gone in the park); - Authorities suspicious of good catch.
2. Rescue (if fishers in trouble the Parks sends a boat).	
1. Better size fish.	

* 5 = mentioned by all the groups, 1 = mentioned by one group.

Quantitative Investigation

Household food security is when '... *all people at all times have physical and economic access to adequate, safe and nutritious food for all household members to live a productive life, without undue risk of losing such access*' (FAO 1996). The concept of food security includes notions such as sustainability, vulnerability or security, food sufficiency and access to food (Maxwell 1996). More and more it has been realised that access to food at the household level is crucial to the achievement of food security (Maxwell & Frankenberger 1992).

To make a complete food security analysis is virtually impossible yet in order to detect, predict and prevent crises monitoring is essential (Nyborg & Haug 1995). If properly identified, food coping strategies defined as "*short term temporary responses to declining food entitlements*" (Davies 1993), can have a role in measuring elements of food sufficiency, security and potential vulnerability of the households (Maxwell 1996).

Food coping strategies were considered as an appropriate indicator to compare the food security situation of the fishing communities surrounding the park. A food coping index was adapted from the index developed by Maxwell (1996). In order to gain a more comprehensive knowledge of the vulnerability and potential resilience of the households in the study sites, indices to measure the households' response to long-term crises were established together with accumulation indices (short- and long-term) on non-crisis situations (Appendix 13.1: p.213).

Food coping strategies vary from place to place and from crisis to crisis (Davies 1993; Nyborg & Haug 1995). In-depth interviews were carried out to identify them. Then, focus groups composed of women of different ages and, if possible, of different backgrounds ranked these strategies according to their perceived severity. The strategies identified included changes in diet, sales of liquid assets, maternal buffering (i.e. priority feeding of young children). They were similar in all the selected communities and were comparable to the ones identified in other studies (Maxwell & Frankenberger 1992).[2]

On the basis of the results of the focus groups, a questionnaire was designed. It included questions about: household attributes, the frequency of short-term strategies within the season, and the use of long-term strategies within the last years. The questions asked were for example: "did you have to buy less food?", "how many times in the last weeks?" The number of times was investigated precisely. 210 households were randomly selected and surveyed twice (from May to July 1997 in the south-east monsoon, and from November 1997 to January 1998 during the north-east monsoon). The results of the first round are presented in this paper.

For each household six scores were calculated: a Food Coping Strategy Index (FCSI) (based on the short term coping strategies) and a Short-Term Accumulation Index (STAI) for each season, a Long-Term Accumulation Index (LTAI) and a Long-Term Divestment Index (LTDI). Results are presented in Table 13.2.[3] ANOVA showed that the short-term and long-term scores varied significantly ($p<0.05$) across the villages. On average, the households of Wasini and Mkwiro are more food secure in the short-term and long-term than households in other communities.

2 Frequency scales were worked out and weighted for the short-term (every day, 2-5 times a week, 1-2 times a week, 1-2 times a month, never) and the long-term (more than once a year, once a year, 2-4 times, once, never) (Maxwell 1996). The weighting was inverted for the accumulation strategies so that for all the scores, the higher the score, the better.

3 For detailed descriptions of formulae, calculations and results, see Malleret-King (2000).

RESULTS

Economic Activities and the Scores

The economic activities are part of the household's livelihood system as defined by Davies (1993). They are believed to have an important role in determining the households' food security. In the study sites, six main economic activities were identified: 'fishing', employment in tourism related to the presence of the park (T.MNP), employment in tourism operations non-related to the presence of the park such as sports fishing (other tourism), labour (mainly casual workers), qualified employment (including teachers religious and civil, civil servants) and 'other' which includes mainly the self employed (e.g. traders, shop owners, shop keepers). For each group the percentage of household depending on each activity was calculated [(mean fisher per household/ mean source of income per household)*100]. Fishing is the dominant activity in the area with as much as 54% of the surveyed households depending on fishing, at least partly (Appendix 13.2: p.214).

Table 13.2
Scores averaged at the community level

COMMUNITIES	FCSI	STAI	LTAI	LTDI
Wasini	160.50	14.11	59.71	131.11
Kichangani	136.12	11.33	60.00	111.08
Anzwani	142.19	11.72	54.70	106.09
Mkwiro	149.56	13.66	69.33	114.65
Kibuyuni	145.71	12.63	56.38	124.45
ALL	147.89	12.82	60.23	117.92

Table 13.3
*Significant correlations between activities and scores**

ACTIVITIES	FCSI	STAI	LTDI	LTAI
Fishing	– 0.469	– 0.519	– 0.478	– 0.429
T.MNP	0.413	0.439	0.529	NS
Tourism	NS	NS	NS	NS
Labour	NS	– 0.429	NS	NS
Qualified	NS	0.423	NS	0.446
Other	0.471	0.567	0.519	NS

* R.critical = 0.361 for p = 0.05 (n=30)

Except for Wasini, more than half of the households surveyed depended on fishing in each village. Wasini is the village that is most dependent on tourism with 30% of the households depending at least partly on tourism related to the presence of the park (T.MNP). As shown in Appendix 13.2, the economic structure varied across the communities.

Significant negative correlations were found between the percentage of households depending mainly on fishing and the scores (Table 13.3). The more fishers the lower the scores (FCSI, STAI, LTDI and LTAI) in each village. In contrast, it was found the more households depended on the T.MNP (park tourism) the more food secure the group (on three of the four indicators).

Distances

The other variable linked to the park, which was thought to have an influence on the scores, is distance from the park (Table 13.4). The shortest distance from the selected communities to the park was estimated as well as other distances which could potentially affect the households' situation (i.e. the distance of the communities from the reserve and from the main tour operator). Correlations between the distances and the scores averaged at the community level were investigated (Table 13.5). Significant correlations were found between the short- and long-term accumulation indices and the distance of the villages from the park. The further away from the park, the lower the STAI and the LTAI at the community level.

Furthermore, it was discovered that the economic structure of the communities is strongly affected by the distance of the communities from the main employers (tourism related to the presence of the park). There is a strong positive relation between the percentage of households depending on 'fishing' and the distance of the villages from the main employers ($r=0.953$), particularly in minutes walk ($r=0.955$). In contrast, the nearer to the employer the more households depend on T.MNP ($r= -0.873$ and -0.899 respectively).[4] This suggests that by affecting the economic structure, the distance of the communities from the tour operators (related to the presence of the park), affects indirectly the scores. The nearer the park, the more households depend on T.MNP and the higher the scores.

4 R.critical= 0.79 for $p= 0.05$ ($n=6$).

Table 13.4
Shortest distances between the communities and the Park, Reserve and the main employer (tourism)

VILLAGE	PARK (km)	RESERVE (km)	EMPLOYER (km)	EMPLOYER (mn*)
Wasini	3.25	4	0.5	5
Kichangani	9	6.5	3	25
Anzwani	11	8	4.5	40
Mkwiro	2	1.5	4.5	45
Kibuyuni	8.5	10	8	65
ALL	6.4	5.8	4.1	36.5

Table 13.5
Significant correlations between distances and the scores

SCORES	PARK	RESERVE
FCSI	NS	NS
STAI	– 0.891	NS
LTDI	NS	NS
LTAI	– 0.835	– 0.88

* mn = in minutes walk.
** R.critical = 0.79 for p = 0.05 (n=6).

Fishing Dependent Households

One of the main objective of the research was to determine, from a socio-economic angle, whether the park had any benefits for the surrounding fisheries. The situation of the households depending on fishing was further investigated. Half the surveyed households were found to depend mainly on fishing. Although these households were on average less food secure in the short-term than other households, individual scores varied. To further investigate the variation in scores among 'fishing' households, the surveyed households were divided into short-term food security quartiles[5] corresponding to Very Low (VL), Medium Low (ML), Medium High (MH) and High (H).

5 Based on the average of the FCSI and the STAI scores.

Distance is an important factor in the detection of the effects of the park as most of the benefits of MPA attributed to fish migration are observed at distances less than 1 km of the boundaries (Roberts & Polunin 1991; DeMartini 1993; Russ & Alcala 1996a, 1996b). However, only one score was found to be significantly correlated to the distance of the communities from the park, LTAI. The further away from the park the less accumulation in the long term (r=– 0.874).[6]

In a biological study on the effects of the Kisite MNP, no proof of fish migration from the park to the reserve could be established. One of the reasons for this was believed to be that the coral reef is patchy (Watson 1996). Most of the commercial species fished in the area are demersal and rely on the reef associated ecosystem. However, it was estimated that the minimum distance between the exploited reefs of the reserve and the protected reefs in the park was 1.7 km (University of York and Hull 1993). Although this distance is within the range of the commercial fish species studied it was thought that the sandy substrate between the reefs acted as a deterrent and prevented fish which fed on seagrass or coral from migrating out of the park (Watson 1996).

Table 13.6 *The groups' scores and the fishing zones' median rank**

GROUPS	FISHING ZONES	FCSI	STAI	LTDI	LTAI
VL	3	118.4	10.8	107.1	56.1
ML	3	135.0	11.5	113.2	55.2
MH	2	150.4	11.9	120.0	61.6
H	1	167.0	12.6	126.0	56.1
ALL	2	142.0	11.7	116.3	57.3

* VL = very low, ML = medium low, MH = medium high, H = high

It was thus believed that the likely effects of the park on the surrounding fishery could be better detected if the main fishing zones of the communities and their proximity to the protected coral reef were taken into consideration. The discussions with the focus groups enabled to determine and rank the communities according to the proximity of their main fishing area to protected reefs. The scores of the 'fishing' households were broken down for the

6 R.critical= |0.849| for p= 0.05 (n=5).

short-term food security groups and the median rank for each group was calculated (Table 13.6).

Negative associations were found between the distance of the fishing zones to the protected reefs and the food security in the short-term coping score and the long-term divestment index: FCSI ($r=-0.894$) and LTDI ($r=-0.894$). Thus, the further away from the nearest protected reef, the less food secure in the short-term during the SE monsoon and the less coping capacity in the long run.

The 'fishing' households from Kibuyuni and Wasini are better off than the ones from Kichangani and Anzwani. These results show how important distance is for the benefits to reach the communities. It is suspected that the fishers from Kibuyuni can fish extremely near the park.

CONCLUSION

More and more, the participation of the stakeholders in the management of MPAs and subsequent NTZs is accepted as a necessary element of a successful MPA. However, in order for the stakeholders to be willing to participate, the benefits of MPAs have to be perceived. The aim of this paper is to show the main links between the Kisite MNP and the socio-economic situation of the surrounding communities, particularly the situation of fishing households. The study also demonstrates a way of analysing the impacts of a long established MPAs from the point of view of the surrounding communities.

Household food security indicators were used to compare the situation of the fishing communities surrounding the Kisite Marine National Park with the aim of establishing a link between their situation and the presence of the park. The analysis shows that the park might affect the fishing communities in several ways. First, it was found that households depending on tourism developed around the park for their livelihoods were more food secure than the others. Secondly, it was established that the economic structure of the communities was affected by the distance of the communities from the main tour operators linked to the park. Finally, fisher households nearer to the protected reefs were found to be more food secure than the others.

Some communities see the park as an advantage (Wasini and Kibuyuni). The results of the households food security analysis confirm the perception for these two communities. Wasini households are more food secure than others and this could be partly due to the high rate of households depending on park related activity. Kibuyuni's 'fishing' households are better off in the short term than others and this could be due to the proximity of their main fishing zone to the protected reef of Mako Kokwe.

However, as shown, the advantages of the park are highly constrained by the distance of the communities from the main employers and from the park. Thus, other communities still see the park as a conflictual entity and would rather it disappear. This suggests that when implementing a NTZ, its benefits might not reach all the surrounding communities. Moreover, if tourism is one of the ways in which an NTZ could benefit the surrounding communities, the questions of the environmental and cultural costs of tourism have to be raised. Furthermore, is it possible to assume that tourism will necessarily develop when a NTZ is established?

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Appendix 13.1

Perceptions of various short-term and long-term strategies

A. SHORT-TERM STRATEGIES AND THEIR PERCEIVED SEVERITY RANK*

Coping strategies		*Accumulation strategies*	
Less food	1	More	1
Sell chicken	2	*Leso**	2
Skip meal	3	Meat	3
Porridge	4	Bank	4
Feed children in priority	5		
Credit at the shop	6		
Borrow from family	7		
No food for a day	8		

B. LONG-TERM STRATEGIES AND THEIR PERCEIVED SEVERITY FREQUENCY SCALES*

Divestment strategies		*Accumulation strategies*	
Sell chicken	1	Buy chicken	1
Sell goat	2	Buy goat	2
Use savings	3	Buy *leso* (lady's wrap around)	3
Sell *leso*	4	Buy houseware	5
Sell gold	5	Put money in the bank	6
Borrow from money lender	6	Buy building material	6
Borrow from family	7	Invest in activity	8

* 1 = least severe, least favoured;
8 =most severe, most favoured.

Appendix 13.2

Percentage of households depending at least partly on each category of activity for each community

	WASINI (N=46)	KICHA- [1] (N=26)	ANZWA- [2] (N=47)	MKWIRO (N=50)	KIBUY- [3] (N=41)	ALL (N=210)
Fishing [4]	14.0	43.9	69.9	56.0	82.2	54.0
T.MNP [5]	30.7	15.8	3.0	9.6	3.7	12.1
T.Other [6]	8.8	2.4	7.5	3.2	0.0	4.6
Labour [7]	0.0	18.3	3.0	2.4	2.8	4.5
Qualified [8]	10.5	12.2	1.5	13.6	3.7	8.0
Other [9]	35.9	7.3	15.0	15.2	7.5	16.8
	100	100	100	100	100	100

1) Kicha- = Kichangani
2) Anzwa- = Anzwani
3) Kibuy- = Kibuyuni
4) Fishing
5) Employment in tourism related to the presence of the park
6) Employment in tourism non-related to the presence of the park
7) Labour (mainly casual workers)
8) Qualified employment (including teachers religious and civil, civil servants)
9) Mainly the self-employed (traders, shop owners, shopkeepers)

14

Strategies Used by Local Fishers to Ensure Access to and Control over Scarce Resources in Galu and the Wider Implications for Marine Resource Management

Anthony King [1]

ABSTRACT

An analysis of livelihoods and production systems in the community of Biga, Galu sub-location, showed that there was a high degree of socio-economic differentiation within the community. Differences related to production methods. These included different fishing methods, land use activities, economic activities or different combinations of the above.

The processes by which fishers tackled problems of resource access and control were investigated for three situations: the attempted implementation of the Diani-Chale marine reserve; the grabbing of Trust land earmarked for fisheries community use at Mwaepe; the conflict between local Digo fishers and migrant Wapemba fishers. Using social network analysis the importance of different actors (groups, individuals and organisations) in solving the fishers' problems was determined. The results showed that some unexpected actors, such as those without natural resource management remits, were very important in the process. The social network analysis also showed that although people's resource access and control are shaped by many interacting institutions, ad hoc processes, where people simply seek whatever path is necessary to solve their problems, also play an important role.

The wider implications for marine resource management relate to creating socio-political and institutional environments that enable problems to be solved. Discussion includes the need to have a better understanding of what is going on at the local level, both in terms of livelihoods and institutional arrangements. It also questions the validity and effectiveness of current over structured approaches to management that impinge on peoples' ability to safeguard their food security.

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Introduction

800 million people in the world are chronically undernourished despite the rate of global food production keeping ahead of population growth (Ricupero 1999). It is possible, and not uncommon, for people to starve in the midst of food plenty. Amartya Sen (1981) observed that scarcity is the characteristic of people not having enough; it is not the characteristic of there not being enough. Obviously an absolute lack of resources will cause people not to have enough, but it is only one of many causes. For many people one of the major reasons for scarcity is the loss of access to and command over resources. This study is concerned with the problem of access to and control over resources in the fishing community of Biga in Galu sublocation on the south coast of Kenya (Map 1: p.170).

The community of Biga was found to be made up of different ethnic groups, 90% Digo, 7% upcountry migrant farmers and 3% migrant Wapemba fishers. Socio-economic analysis of Digo households showed that there were different groups according to their production systems, which were either fishing based or not. Most households were dependent on fishing, but the methods and capital equipment differed and this further differentiated the community into subgroups (summarised in Appendix 14.1: p.232). Analysis of household livelihoods showed that all groups depended on a range of activities to provide food and income but the economic role of fish was dominant in the community. Even within fishing households, however, the value of production from land based activities was important for supplementing food and income.

Seasonality was a feature of the production systems, influencing activities both on land and in the sea. Prior to and during the long rains in April and May was the busiest time on land and this coincided with poor fishing conditions and low catches. Consequently households were most food insecure from March -July while the catches were low and crops had yet to be harvested. Fishing conditions were also harder at this time due to strong winds and rain. This made fishers less able to work on the cultivation of crops due to fatigue. There were also more instances of malaria and other illness at this time of the year. Some households stopped fishing at this time and concentrated on cultivating food crops to increase food production.

The trend over the last five decades has been a relative decrease in productivity per household. Traditional systems of cultivation can no longer be practised due to the change in land tenure and land market. The small isolated household plots now cultivated are more susceptible to damage from wild animals than the communal plots previously cultivated. Households depend more on income earning activities, such as fishing or planting fruit trees, to buy food, and this also reduces the time, energy or space available for food cultivation. The lack of different sources of economic employment, despite the proximity of the tourist development, has forced increasing numbers of people into fishing. This has had lead to overfishing, shown by a fall in catch per unit effort and the ecological phase shift to urchin dominated communities in the lagoon.

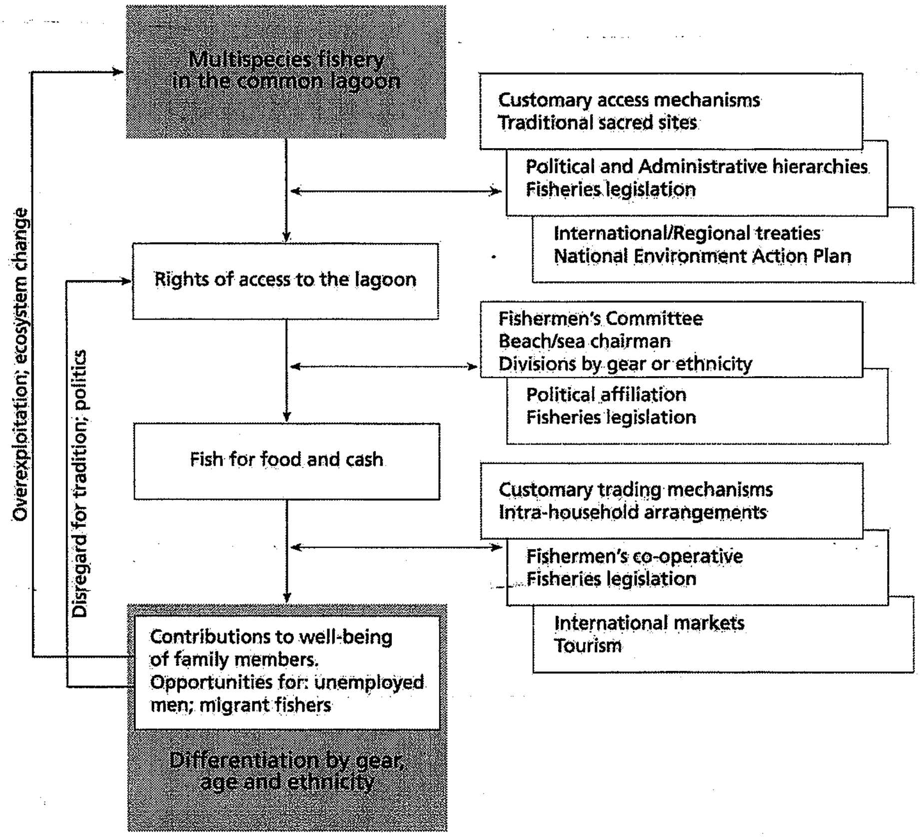
The overall socio-economic situation of the community was found to be poor. This was illustrated by the level of disposable income available to households when compared to the amount of income needed to maintain the household at a productive level (Table 14.1). The highest earning households had the most capital investment with relatively high levels of depreciation. Thus saving money was essential but it was not evident how this was done. Most households were very close to the maintenance threshold. This meant that they could maintain their current level of production. However, with continued pressure on the fishery and the lack of alternative sources of income, the productivity of households is not secure. Consequently any further threats (perceived or real) to their access to and control over the resource base would be expected to provoke a reaction from the community.

Table 14.1
Incomes of the different groups in Biga [1]

	CAPITAL (sh.)	DISPOSABLE INCOME (sh.)	% INCOME FROM FISH
Fishers with boats	±10,000	±63,000	78
Fishers without boats	±1,000	±47,000	96
Non-fishing/farming	±3,500	±43,400	55 [2]
Subsistence agriculture	±100	±11,000	8
Migrant farmers <0.5 [3]	±100	±4,400	-
Migrant farmers >0.5 [3]	±100	±55,000	-
Wapemba [4]	±2,600	±35,000	(high)

1) Maintenance threshold = sh.45,520; Groups are exclusive: each household appears in only one group.
2) This figure is for fish traders.
3) These figures do not account for activities in homelands.
4) No household survey for this group.

Fig. 14.1 *Different institutions at different scale levels influencing the exploitation of fisheries resources in Biga.*



Gaining Access to and Control over Resources

Despite decades of international development work and natural resource management, people in sub-Saharan Africa are worse off nutritionally today than thirty years ago. For people who live in coastal regions the problem is particularly acute. 95% of all fishers in the world do so on a subsistence or small-scale basis and most of them are in developing countries (FAO 1993; 1995). They catch half of the world's fish for direct human consumption. Practically all the fisheries in the world, both small-scale and industrial, are considered to be over or fully exploited (FAO 1995). The implications of resource scarcity for the many millions of subsistence fishers and their families are particularly serious because of the lack of alternative livelihoods. Clearly the mechanisms used to ensure the long-term use of fisheries, and other natural resources, have failed.

Theoretical approaches to natural resource related policies and have evolved over the last five decades from concepts based on oversimplified theories such as the tragedy of the commons and the prisoner's dilemma, to a more recent appreciation that the world is highly differentiated. The early theories led to centralised institutional control which in many instances continues to be the prevailing process of resource allocation and management despite the acknowledged failings. More recent approaches to human-environment policies seek to include local level institutions, greater participation of stakeholders and the appreciation of local histories. In addition there is now greater recognition that the rules by which people gain access to and control over resources are preconditioned by factors such as the biophysical environment and culture. These rules (institutions) are also understood to shape peoples actions and also the biophysical environment.

However, even the most recent theories may continue to be over structured. For example, Environmental Entitlements Analysis includes the wide range of institutions (rules), but does not incorporate *ad hoc* processes (see Figure 14.1: p.218). If human-environment relations continue to be perceived as bounded by rules and the processes having specific directions, it will be difficult to recognise other processes that are important in mediating human-environment problems. This could be a significant constraint to management success because it does not to facilitate problem solving through less rigid processes.

In countries such as Kenya, the formal or state institutional structures relating to natural resources are the legacy of colonial regimes. These systems of governance were not designed to deal with resource access problems of relatively low powered groups. But they persist because they suit those in power. The problems of poverty and constrained access to resources are exacerbated by this situation. Even the significant international pressure for economic and political liberalisation does not deal with the basic structure of governance and may actually increase pressure on subsistence communities by placing more importance on commercial interests. Nevertheless, the populations directly dependent on natural resources for their survival somehow manage to live under these conditions. This suggests that there are a wide range of processes involved in resource access and control situations for low powered groups, and that these processes are not necessarily restricted to the involvement of resource management organisations such as Fisheries Departments or traditional rules.

By looking at the process by which people solved resource access and control problems it was possible to identify the key people or organisations involved and to infer which institutions conditioned people's actions. The method used in this study was Social Network Analysis.

Social Network Analysis of Resource Access and Control Conflicts

Social Network analysis is principally used in the social and behavioural sciences. It is concerned with relationships among social entities and the patterns and implications of these relationships. The social environment can be expressed as patterns or regularities in relationships among interacting units. It provides formal definitions, measures and descriptions. Network research has covered a wide range of topics, such as the transmission of infectious diseases, diffusion and adoption of innovations, and power and consensus and social influence.

METHOD

Information was collected on the communication relations between actors involved in three different conflicts or issues faced by the Digo fishers. The issues investigated were the attempted implementation of a marine protected area that would have included the community's fishing grounds (Diani-Chale marine reserve). The conflict between the Digo fishers and the Wapemba beach seine fishers and the threat to Mwaepe fish landing site due to illegal land appropriation. In this paper the conflict between the Digo fishers and the Wapemba beach seine fishers is discussed in some detail. The results and implications of the two other issues are briefly covered.

Information came from a variety of sources including government documents, letters, semi-structured interviews with government officials and fishing community members, public meetings and informal discussions. The process of data collection was initiated through semi-structured interviews with fishers because it was their response to the issues that was being investigated. This identified other actors in the network who were either interviewed or their roles verified in the documentation or by other actors. Inclusion in the set of actors was determined by their role in an issue and the frequency of their interactions. In this way it was possible to determine who the relevant actors were and to establish a boundary to the set of actors.

The idea that power is inherently relational and therefore a fundamental property of social structures (Hanneman 1997) is the basis for the analysis. The measures of actor importance used in this analysis stem from the concept of centrality which is based on the idea that prominent actors are those that are extensively involved in relationships with other actors (Wasserman & Faust 1994). Two different measures of centrality have been used in this study in order to consider different derivations of importance in the networks based on communication ties.

Degree centrality is the simplest to define because it is based on the idea that central actors must be the most active because they have the most ties (Wasserman & Faust 1994). It is therefore a measure of local centrality (Scott 1991) and does not account for the overall structure of the network. However the direction of the ties are accounted for, which in the context of this study may reflect the importance of an actor depending on whether they are the object (*indegree*) of many ties or the source (*outdegree*) of many ties. Actors with high indegrees can be considered to be prominent because other actors seek to communicate with them. They may be important because they are sources of information or because they perform some sort of supporting role. On the other hand they may simply be the source of instruction or information about the activities of other actors. Actors with high outdegrees set out to communicate with many other actors to pursue a cause or interest and as a result can be considered to be influential. They are often sources of action either co-ordinating or organising activities.

Eigenvector centrality, used in this study, is an extension of closeness centrality with an attempt to incorporate the influence of the overall structure of the network on actor importance. Closeness centrality considers an actor to be important if it lies at short distances from other actors in the network. It is frequently used to measure relative access to network resources and information, and can also be interpreted as measuring the degree of independence from others in the network (Hagen, Killinger & Streeter 1997). However, closeness centrality does not account for the fact that the importance of an actor may also be proportional to the strength of its ties to other actors and the importance (centrality) of these other actors (Faust 1997; Hanneman 1997). Eigenvector centrality (an eigen decomposition method) does this by a identifying the dimensions of distances (by factor analysis) among the actors and giving each actor a value (eigenvalue) based on its location with respect to each dimension identified. The measure takes the distance between two actors as the longer of the direct paths between them in the calculation and as a result considers the overall structure of the network rather than the local patterns. Most of the variability in the locations of the actors are usually accounted for in the first few dimensions (referred to as factor 1, 2 etc.) (Hanneman 1997; Richards & Seary 1997). Eigenvector centrality has been used to study the extent to which actors are in a position to influence other actors in a network (Faust 1997).

In addition to determining the importance of the actors involved in each issue, the overall importance of actors across the range of issue was determined. The aim was to determine whether there was a core group who were consistently important in all the issues. The networks of actors analysed for each issue were also linked to each other through their joint participation in each issue. The three issues being investigated were considered to represent typical resource management problems. Therefore actors common to all the issues may suggest an underlying problem solving network that would be useful for resource management. This in turn would reflect the underlying institutional structures that may usefully be included in alternative management regimes. By linking the actors and the issues (events) it was possible to create an affiliation network. This network consisted of a set of actors and a collection of subsets of actors (issues/events). The information was represented as an affiliation matrix and a bipartite graph.[2]

The Wapemba Beach Seine Issue

The use of illegal fine meshed beach seines by the Wapemba was basis for the conflict between them and the local Digo fishermen in Biga. Although seine nets were partly to blame for the current state of the fishery, the local Digo fishers found the foreign Wapemba to be convenient scapegoats for the lack of fish. The problem of numbers of Digo fishermen was not an issue for the local fishers.

The Wapemba beach seine crews originated from the Island of Pemba in Tanzania. Originally only migrant fishermen, the Wapemba sought permanent bases in Kenya in 1964 following the overthrow of the Zanzibar government. As with many other sites in Kenya,

2 For detailed descriptions of calculations and results, see King (2000).

Wapemba fishermen, seeking refuge from the political unrest in Tanzania and better fishing than in their own overfished waters, approached the elders of Biga. At the time the Wapemba were not considered to be a threat to the fishery and a settlement site was granted. The Fisheries Department legitimised the use of their fine meshed beach seines by granting the Wapemba licences. The Wapemba also capitalised on the establishment of the Co-operative Societies in the 1970s by becoming active members, and by the 1980s the only members, thereby further legitimising their presence in the area in the eyes of the authorities.

Over the following three decades the catch per unit of effort in the fishery declined. During the 1970s and early 1980s some of the Digo fishermen began to suggest that the seine nets were having a detrimental effect on the fishery. By the mid 1980s the Wapemba were perceived by the local Digo fishers to be a threat to their survival and the Digo fishers asked them to fish elsewhere, which they did. In 1988 the Wapemba returned to fish in the area, but said they would only fish outside the lagoon. However the impracticality of fishing outside the lagoon throughout the year brought the Wapemba back into Biga waters. Numerous requests by the Digo fishermen were made to the elders and village level authorities and Fisheries Department personnel to stop the use of the beach seines, but to no avail. The Digo fishermen were convinced that the lack of action by the village authorities and the local Fisheries personnel was because they were being bribed. In addition they were certain that many of the Wapemba had somehow acquired Kenyan identity cards and this would have implicated the chief and possibly more senior officials. By 1992, frustrated by the lack of action by village authorities and the inability of the Fisheries Department to recognise the problem, the Digo fishermen beat up some Wapemba in an attempt to frighten them off. The attack on the Wapemba fishers lead to the arrest and detention of the Digo fishermen and fuelled the conflict and raised its profile.

Concerted efforts by the Digo fishermen to remove the seine crews were supported by local Councillors and KANU representatives who had become sensitised to the 'plight' of the Digo fishers during the marine reserve conflict. In addition, the District Commissioner's (DC) public announcement about the suspension of the marine reserve in October 1995 had encouraged the local fishers to be more organised when presenting their concerns. Galvanised by the marine reserve issue and the DC's announcement the Biga fishermen formed a group, known as the Galu Fishermen's Committee, to present their case to government officials. Intensive lobbying of government officials by both the Digo fishermen

Table 14.2

A summary of the results of the social network analysis of the final phases of each of the three issues, when resolutions to the problems were found

(Actors are listed in order of importance)

A. KEY SOURCES OF INFORMATION OR WELL INFORMED ACTORS, IN ORDER OF IMPORTANCE, IN THE FINAL PHASE (indegree centrality measure)

Wapemba Beach Seining	*Mwaepe Land Threat*	*Diani Marine Reserve*
District Commissioner	Senior Fisheries Officer	Galu Fishermen
Senior Fisheries Officer	Distr. Co-operative Officer	Fisheries Officer
District Officer	Distr. Development Officer	Councillors
Galu Fishermen	District Commissioner	Chief

B. THE PRINCIPAL ORGANISERS OR ACTORS PURSUING A CAUSE IN THE FINAL STAGE OF THE ISSUES (outdegree centrality measure)

Wapemba Beach Seining	*Mwaepe Land Threat*	*Diani Marine Reserve*
District Officer	District Commissioner	District Commissioner
Senior Fisheries Officer	Senior Fisheries Officer	District Officer
MP Msambweni	Distr. Co-operative Officer	Senior Fisheries Officer
Chief		Chief

C. THE MOST INFLUENTIAL ACTORS, IN ORDER OF IMPORTANCE, FOR THE FINAL OUTCOME OF EACH ISSUE (eigenvector centrality measure)

Wapemba Beach Seining	*Mwaepe Land Threat*	*Diani Marine Reserve*
District Officer	District Commissioner	District Commissioner
District Commissioner	Senior Fisheries Officer	KWS
Senior Fisheries Officer	Distr. Co-operative Officer	Galu Fishermen
MP Msambweni	Galu Fishermen	Councillors

and the Wapemba fishermen continued until the middle of 1996, but again with no sign of action on the part of the authorities. The Digo fishers then threatened to burn the houses of the Wapemba if seine netting was not stopped. This caused the District Administration to force the Fisheries Department to instigate a ban on seine nets on the grounds of civil disorder. At a public meeting on the 14th of August 1996 at Mwabungu, the District Officer announced the prohibition of beach seining. The Wapemba stopped their fishing activities in Biga waters although they continue to live in Biga. They now fish in the areas adjacent to Biga to the north and south.

Analysis was carried out on three phases of the issue:

- Phase 1 The arrival of the Wapemba in 1964 to the point when the Digo fishermen requested them to fish elsewhere in 1988.
- Phase 2 The recommencing of seine fishing in the lagoon at the end of 1988 to the physical beatings in 1992.
- Phase 3 The heightened profile as a result of the arrests and the eventual cessation of beach seining in Biga waters in August 1996.

Results

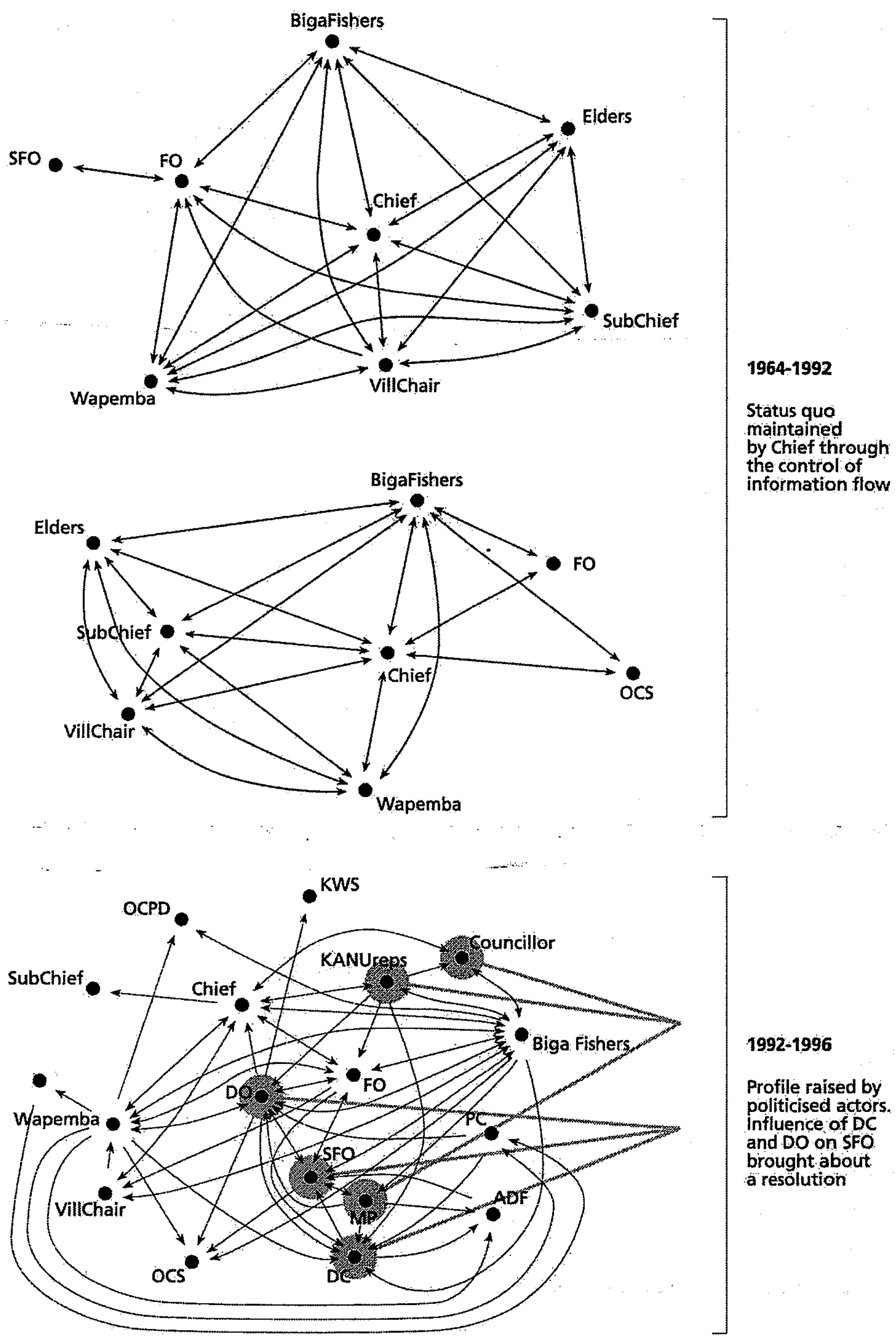
The communication networks for the Wapemba beach seine issue are presented below. The evolution of the networks from the initial arrival of the migrant Wapemba fishers in 1964 to the eventual end to their beach seining in Galu waters Biga are illustrated. The results of the Social Network Analysis for the final network are presented in Table 14.2 with the results of the two other issues mentioned above for the final phases.

Discussion

This discussion only deals with the Wapemba beach seine issue and is based on the results of the Social Network Analysis of each phase of the issue. However the conclusion considers the three issues together.

The early stage of the beach seine issue, illustrated in Figure 14.2 (p.226) did not involve any conflict between the Wapemba fishers and the local fishers. After some time questions were raised by the local fishers about effects of the beach seines on the fishery. The principle organisers, as shown by their outdegree scores, were the local authorities and the local Fisheries Officer, who seemed to support the activities of the Wapemba. The Wapemba,

Fig. 14.2 *Communication networks of the Wapemba beach seine issue.*



local fishers and local Fisheries Officer were important sources of information and were the recipients of instruction from local authorities. Overall the Chief was the most influential at this stage, which is not surprising while the issue remained of local concern. Interestingly, the traditional leaders, the elders, are not prominent in the networks despite being responsible for giving the Wapemba permission to settle in the area.

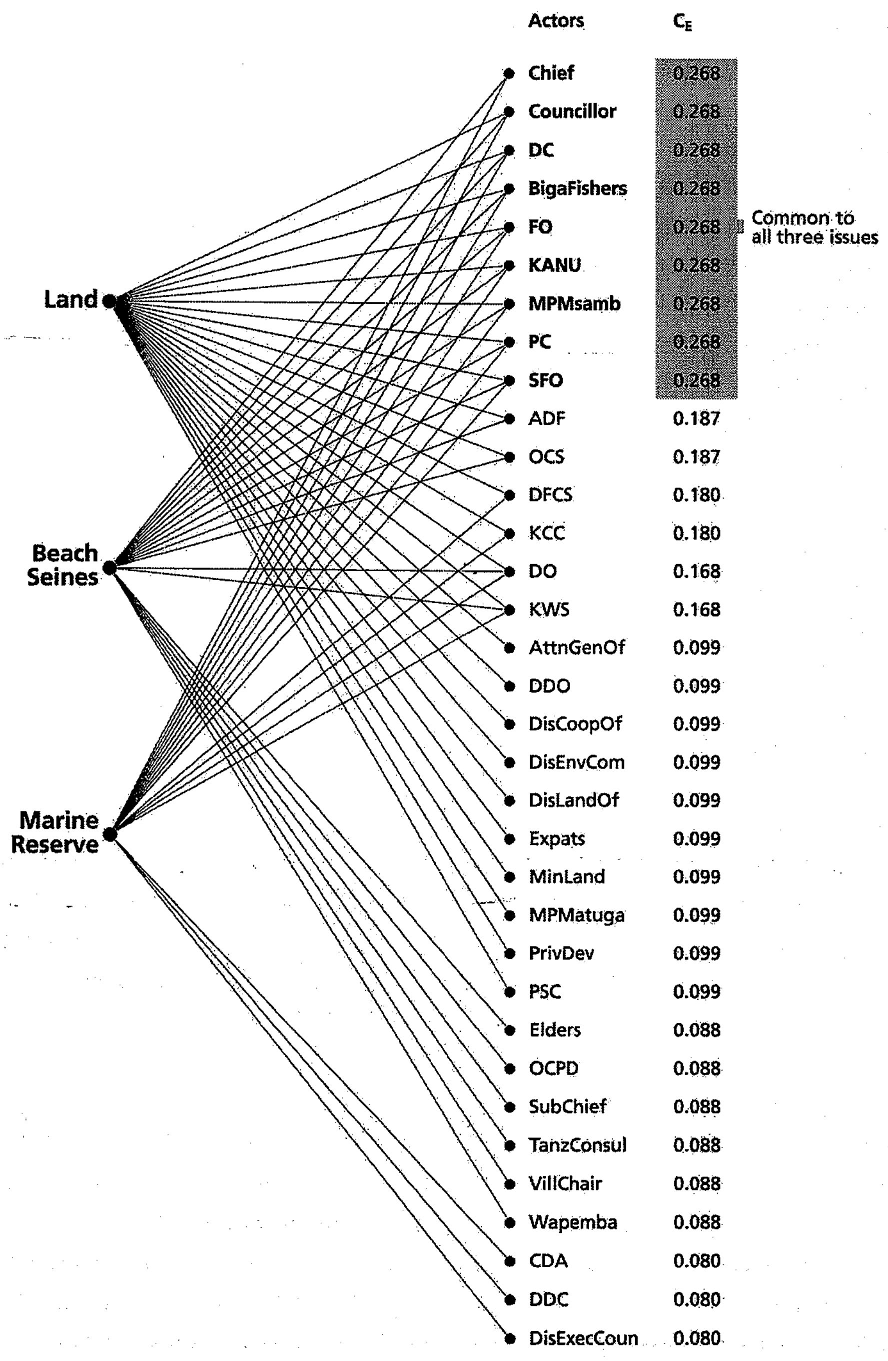
During the second phase the local fishers came into conflict with the Wapemba fishers and attempted to stop their fishing activities in the area. The local fishers continued to seek a solution through local level authorities, hence the importance of the Chief, sub-Chief and Village Chairman as organisers. However the local fishers increased their influence by communicating with many more actors. The Chief and village authorities remained influential (eigenvector centrality) over the outcome of the situation by constraining the flow of information to other actors. This frustrated the local fishers, who had assumed the local authorities would support them, causing them to attack the Wapemba in an attempt to prevent them fishing.

The third phase shows a shift to a different set of important actors reflecting the raised profile of the conflict. District level authorities replace the local authorities as prominent organisers, and the local MP appears to be important. This was probably because the local Councillors and KANU representatives were pursuing the cause for the local fishers. The District Commissioner becomes the most important informed actor, followed by the Senior Fisheries Officer and the District Officer. Ultimately it is the pressure brought to bear on the Senior Fisheries Officer by the District Officer, District Commissioner and MP that led to the ban on beach seining. They are shown to be the most influential in the network (eigenvector centrality; see Figure 14.3: p.228). Interestingly the Chief remains important as an actor with relative control of information by virtue of his position, but the profile of the issue and the importance other actors prevent him from using this to influence the final outcome.

Conclusion

Retrospective analysis of three situations (issues) in which access to or control over community resources was threatened sought to identify how the final outcomes were achieved. The outcomes were known to favour the local fishing community, but in view of their poor socio-economic situation, low status and apathy of certain government departments it was not evident how this was achieved. The analysis sought to identify the important people or organisations and the underlying institutions involved in the process of solving the issues.

Fig. 14.3 *The bipartite graph showing the joint involvement of certain actors in the three issue analysed.*



The importance of an actor was essentially reflected in their ability to influence the outcome of a decision or decision process. Thus communication ties between actors were identified and communication networks for each issue were generated. An actor's importance was understood to derive from their position in the communication network, their relationships with other actors and their inherent characteristics.

The results showed that the initial phases of each issue revolved around the actors that initiated the situation and a *status quo* was maintained. The important actors reflected the nature of the issue and tended to include the Fisheries Department or Kenya Wildlife Service and local authorities such as the Chief. The institutional processes were dominated by these formal State organisations. However, the final phases of each issue reflected a break in the *status quo* and the involvement of different actors. The institutional processes in the final phases also changed to a higher scale level. For example the beach seine issue involved local level institutional processes for many decades, but shifted to district and national level processes at the height of the conflict prior to its resolution.

Throughout all the issues members of the Administration were consistently among the more important actors in the networks, and the District Commissioner was usually the most influential actor. Initially this is surprising because each of the issues could theoretically have been contained by resource management organisations, such as the Fisheries Department or the Kenya Wildlife Service. But the analysis showed that the Administration became important in the processes because of the lack of effective action on the part of resource management organisations. This also reflected the dominance of formal State institutional processes in determining the outcome of the issues.

The analysis also showed that the shift to higher level institutional processes and the involvement of senior members of the Administration invariably involved actors from political organisations. However, the results did not suggest that an issue needed to be politicised in order for the *status quo* to change, the political actors were seldom very important in the issues. Their roles however were related to the course of action pursued by the local fishermen. The fishermen initially pursued a 'standard' course of action (through natural resource related institutions) when seeking to address their concerns, but were frustrated by the lack of action using these channels (earlier phases). They then sought other ways of dealing with their concerns and the local political representatives, either party members or local Councillors, were obvious contacts with inherent influence in the area. The relationship between political actors and civil servants, particularly in the Administration, meant that the fishermen's concerns were likely to be voiced at more senior levels. However, the politicians were not the only actors involved for this reason. The fishermen, for the similar reasons, also drew researchers or expatriate residents living or working in the area into the process. These people tended to have privileged access to senior government officials and also the resources (vehicle) to provide access to government officials. These relations reflected the influence of informal institutions on the final outcome of the issues.

The role of traditional institutional arrangements was not important in the final outcome of the issues. The elders, for example, did not feature as important. The local fishermen were also relatively low powered despite being the main stakeholders and being involved in a high number of relations with other actors. One of the reasons for this was because of their lack of inherent power within the wider community. Thus their high number of communications often reflected their reliance on other actors to raise the profile of their concerns. Significantly these actors were seldom within resource management organisations.

With respect to natural resource management and the processes by which people gain access to and control over natural resources in the study area, the results have identified some key points. Different organisations had different roles. The Government Administration had the most power in the area and was the main authority deciding the outcome of each issue. The natural resource management organisations, which included the Fisheries Department and the Kenya Wildlife Service, merely legitimised the actions taken by the Administration. The principal agitators were local politicians on behalf of the local fishermen. Few of the formative institutional processes involved formal rules relating to natural resources. In fact natural resource related organisations and the associated institutions served to maintain a *status quo* and constrain the process of conflict resolution.

The full involvement of local communities and a high degree of devolution of authority to the local level in natural resource management is acknowledged as the only likely way of achieving sustainable resource use. Understanding the processes by which local communities tackle resource related problems and identifying the key players in the processes would be a fundamental part of redressing current resource management failings. The results in this paper suggest that the role of organsiations such as the Fisheries Department and Kenya Wildlife Service may be more useful as facilitators of initiatives taken by local communities, rather than dictating initiatives themselves. The results also suggest that key members of the wider community should be actively involved in the resource management process.

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Appendix 14.1

The main household groups and subgroups within Biga according to ethnicity and production system

ETHNIC GROUP	GROUP	SUBGROUP (% sampled)	DEFINING CHARACTERISTICS
Digo	Fishers	With canoes (13%)	Traps, lines. gill nets. 80% of fishers aged over 40 years. Original clans.
		Without canoes (7%)	Spear guns. Biggest group, most fishers aged between 18-30 yr.. From fishing families. Living on family land. A few older men using spears. Other fishers sharing canoes.
	Non-fishers	Subsistence agriculture (80%)	Retired fishers for reasons of age, illness or unable to reinvest in capital items (canoe). Only small areas of land cultivated.
		Non-farm/ fishing employment (28%)	Fish traders, shop keepers, traditional doctors. Many not from original fishing clans.
Meru/ Tharaka	Migrant cash crop farmers	Established: Cultivating >0.5 acre/ active producer (44%)	Settled or regular migrants to the area, either men 40-70 yr. old or second generation.
		Recent arrivals: Cultivating <0.5 acre/ active producer (40%)	Either young people recent to the area, lack of capital or established people forced off the land they were cultivating by local Digo.
Wapemba	Fishers	Migrant fishers (not sampled)	Seine nets. Established settlement with fruit trees, supplemented food production, frequent migration of younger men to Tanzania.

Source: Household survey (N=30); group interview with the Galu Fishermen's Committee; discussion with chief Mwarupia and village chairman (Malleret-King 1996)

15

Shrimp Trawling in Ungwana Bay A Threat to Fishery Resources [1]

Bernerd Fulanda [2]

ABSTRACT

This paper examines the landings of three trawlers fishing the Ungwana Bay over a seven-day period totalling about 200 hrs fishing time. A critical analysis is made of the catch and its composition in terms of marketable catch (target species and commercial fish) and by-catch (non-commercial fish, juveniles and debris).

Prawns made up 13.7% of the catch while commercial fish amounted to 14.4% of the total. The remainder (71.9%) comprised of by-catch. Further breakdown showed that non-commercial fish made up the bulk of the by-catch with 42.9%. This group included Branchyura, Apogonidae, Leiognathidae, Squillidae and Gobiidae families. Juveniles accounted for 23.6% of the by-catch. The latter consisted for almost two-thirds of juveniles of commercial fish among which Ariidae were the commonest. Other families included Atherinidae and Carangidae.

In the shallow 'Kipini' area, trawling does considerable damage to the benthic fauna and flora. The trawling attracts a large population of piscivorous birds creating artificial and unstable food webs. A Turtle Excluder Device (Anthony Weedless) was used on one of the trawlers but it appeared to result in lower catch of commercial fish allowing only small species and undersized fish into the cod end. It is concluded that the trawlers pose a threat to both the Ungwana fishery and other marine resources.

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1 The author wishes to thank his co-researchers, E.Mueni, R.Mdodo, J.Mwangi, M.Ongeri and J.Mutiri, for permission to use the data in this paper for publication.

2 Sagana Fish Culture Farm, P.O.Box 26, Sagana (kveveric@africaonline.co.ke).

INTRODUCTION

Marine fisheries form an important source of employment, income and food protein for the fisher folk of many communities world-wide. Kenya's marine fishery runs from the border with Tanzania at Vanga (4°19'S) to the border with Somalia at Kiunga (1°47'S), a sea board of 640 km. The fisheries can be classified into two broad groups. The trawl fishery operates in a zone that extends from 5 nM offshore to 200 nM – the Exclusive Economic Zone (Kenya 1989). By law (Maritimes Zones Act), trawlers are not allowed to fish nearer to the coast and have to respect the so-called Trawl Exclusion Zone (TEZ). The artisanal fishery involves smaller boats and largely occurs in the latter zone. Most of Kenya's coastal communities are engaged in the fisheries sector. Fishing methods include nets, hand lines and traps.

Kenya's trawl fishery is effectively restricted to a stretch of about 200 km between Malindi and Kipini. Most of the remainder is not trawlable (Kenya 1981). The area north of Kipini has a lot of sponges while the area south of Malindi to the Vanga border is only trawlable at 2-3 nM off the coast i.e. within the trawl exclusion zone. The Ungwana Bay therefore forms Kenya's only marine trawling grounds and they are considered to be very productive shrimp grounds. This can be attributed to the nutrient input by the Sabaki and the Tana Rivers at Malindi and Kipini respectively. The grounds are 125 km and further distant from the home port of the vessels in Mombasa.

Vessels employed in the trawl fishery are double-outrigger freezer trawlers (FAO 1986). The first to venture into these waters were probably the Kuvuna (2) and the Alphas (2). With realisation of the potential of this bay, more vessels and more companies invested in the fishery climaxing at 17 vessels of 7 companies in 1989. These vessels range from 365 HP to 970 HP. A fishing trip lasts 20-40 days depending on the cold store capacity of the trawlers which ranges from 100 MT to 197 MT.

The entry of more and more vessels in limited trawling grounds and the decreasing catches may be to blame for the violation of the TEZ by trawlers. In addition, the target species are known to abound in zones with freshwater/nutrient input by rivers on muddy bottoms (Garcia & Reste 1981; Mutagyera 1984). This has made the areas around the mouth of the Sabaki River and the Tana River, to be the first targets of inshore trawling. Conflicts in resource use have been high in these areas with occasional accidents between trawlers and artisanal boats and frequent damage to artisanal gear. An increase in conflicts coupled with increased overhead costs, has forced several companies off the fishery. Such conflicts have also been reported elsewhere, for example in the Caribbean (Jeefers 1983). In

Kenya, the trawler-artisanal consultative committees in Malindi were formed to look into ways of solving the problems facing this fishery.

Due to the nature of the trawl gear, it destroys the benthic fauna, juveniles, feeding and nursery grounds. It is also a threat to endangered turtles and dugongs using the bay for feeding and spawning grounds. The intensification of trawl activities in the bay has rendered many fishermen jobless and many a fisher family without daily food. There is an increasing awareness and negative attitude to trawling activities among the coastal communities (pers. obs.).

This survey was prompted by the unstable trends in trawl catches, observations of birds trailing the trawlers, decreased artisanal catches and increased conflicts between the trawlers and artisanal fishermen (Kenya 1999). During the time of the study, cases of destroyed fishing gear and boats by trawlers were frequent due to the trawler invasion of the TEZ area.

MATERIALS AND METHODS.

A team of 6 researchers (3x2) from KMFRI and the Department of Fisheries (GoK) embarked on three trawlers and recorded the catch in the waters of Ungwana Bay. Primary research objectives were recording the catch data, the fishing areas and the fishing effort. The captains of the vessels were given a free hand with the movement and operations of their vessels. Issues of law enforcement and regulations were temporarily ignored to avoid errors and interference with normal operations. Observations were also made on the use, efficiency and problems associated with the Turtle Excluder Device – TED (see Mueni & Mwangi 2001).

The survey was carried out between 17-24 March 1999, just before the onset of the south-east monsoon. The survey covered a period of seven days on each vessel. The area consists of three major fishing grounds: a coastal stretch of about 9 miles in 'Malindi shallow' (off the coast of Malindi town including the Malindi Bay); 38 miles in Formosa Bay (off the coast of Mto Kilifi, north of Ngomeni village – also known as Ungwana Bay proper); and 5 miles in 'Kipini' (off the Tana River mouth, north of Formosa Bay and south of the *Mwamba Ziwayu* outcrops). (See Map 1: p.170).

The trawlers ranged from 624 HP to 970 HP and were equipped with double rigged (outrigger) trawl nets of 40 mm (≈1.5") cod end mesh. On all the vessels, a pair of trawl nets was towed from the booms of a double outrigger. One of these vessels was fitted with TED on both nets while the other boats fished without the device. Towing time ranged from 2-3 hrs per haul with fishing at 5-50 fathoms in the shallow waters and 60-100 fathoms depth in the deep waters. For each haul, the position was recorded from a Navigational Compass while the depth was read from an Echo sounder.

Each haul was sorted into commercial catch and by-catch, defined as follows:

- commercial catch
  - target species (prawns);
  - commercial non-target species (fish).
- by-catch
  - non-commercial species (not commonly consumed);
  - juveniles (of commercial species and other low value fish);
  - debris (sea urchins, sponges, sea slugs, shells, sea grasses, weeds and litter).

RESULTS

Catch Composition

During the survey, total trawling duration varied from 56 hrs for *Mv Manyara* to 115 hrs for *Mv Tsavo* and 125 hrs for *Mv Venture II,* making a total of 296 trawling hours for a seven-day period on the three vessels. Prawns constituted 13.7% and commercial fish accounted for 14.4% of the catch (Table 15.1). By-catch formed by far the major component, constituting 71.9% of the catch.

Table 15.1 *Catch composition by vessel (kg/%)*

	MANYARA	VENTURE II	TSAVO	TOTAL
Prawns	675 (4.6)	2,279 (8.7)	6,019 (24.4)	8,973 (13.7)
Commercial fish	6,198 (41.9)	1,805 (6.9)	1,448 (5.9)	9,451 (14.4)
By-catch	7,909 (53.5)	22,116 (84.4)	17,170 (69.7)	47,195 (71.9)
TOTAL	14,782 (100)	26,200 (100)	24,638 (100)	65,520 (100)
Trawling Hours	56	125	115	296
Turtle Exclusion Device	no	no	yes	

NB
- Mv Manyara trawled for one day in the Malindi shallow area while heading to the fishing grounds in Formosa bay.
- Mv Venture II did most trawling in shallow waters at less than 3 nM offshore (in the Trawl Exclusion Zone) at depths of less than 20 fathoms in the Kipini area.
- Mv Tsavo trawled for two days in the shallow waters of Malindi while heading for Formosa bay where it trawled for the remaining five days.

Prawns landed in this fishery mainly belong to two categories viz. *Penaeus* and *Metapenaeus* species. The *Penaeus* species includes the species P.*monodon* (Jumbo prawn), *P.merguiensis* (Banana prawn), *P.semisulcatus* (Tiger prawn) and the *P.indicus* commonly known as the white prawn (Fischer & Whitehead 1974; Burton, Devaney & Long, no date). *M.monoceros* or the brown shrimp was the only Metapeneas species found. The commercial fish caught are mainly demersal fish due to the nature of the trawl gear, and include the families listed in Table 15.2.

Table 15.2 *Commercial fish species in catch*

SCIENTIFIC NAME	ENGLISH NAME
Lethrinidae	Scavengers and Emperors
Lutjanidae	Snappers
Theraponidae	Grunters / Therapon-perches
Siganidae	Rabbitfishes
Carangidae	Jacks (trevallies, runners, cavallas etc.)
Clupeidae	Sardines, shads
Epinephelidae	Groupers
Scomberomonidae	Mackerels
Sphyraenidae	Barracudas
Mobulidae	Rays
Atherinidae	Silversides / Silverbellies.

By-Catch Composition

It was found that *Mv Venture II,* fishing in Kipini landed the highest amount of non-commercial fish, juveniles and debris with 9,731 kg, 5,595 kg and 6,790 kg respectively (Table 15.3). Non-commercial fish formed the highest percentage of the by-catch in the study; 39.8% on *Mv Manyara*, 44.0% on Mv Venture II, 42.8% on *Mv Tsavo*; while juvenile by-catch formed the lowest percentage with 19.0% (Mv *Manyara*), 25.3% (Mv Venture II) and 23.4% on *Mv Tsavo*.

The large amount of by-catch is caused firstly by non-commercial fish, making up 42.9% of the total (Table 15.3) – fish of no commercial value and only fit for manufacture of fish-meal, poultry feed, bait for line fishing etc. Although no measurements were made on the lengths of these fishes, their sizes were noted to be smaller than for mature individuals of the same species.

Table 15.3 *By-catch composition by vessel (kg/%)*

	MANYARA	VENTURE II	TSAVO	TOTAL
Non-commercial fish	3,147 (39.8)	9,731 (44.0)	7,348 (42.8)	20,226 (42.9)
Juvenile fish	1,503 (19.0)	5,595 (25.3)	4,018 (23.4)	11,116 (23.6)
Debris	3,259 (41.2)	6,790 (30.7)	5,804 (33.8)	15,853 (33.6)
TOTAL	7,909 (100)	22,116 (100)	17,170 (100)	47,195 (100)

Branchyura (crabs), leiognathidae (ponyfishes), Apogonidae and Squillidae made up the majority of the non-commercial fish with 30.8%, 14.5%, 13.9% and 11.3% respectively (Table 15.4). Members of other families such as Gobiidae, Siganidae, Drepanidae (sicklefishes) and Pomadasyidae (sweetlips/grunts) were also commonly found in the by-catch samples but were less abundant.

Juveniles made up 23.6% of the total by-catch (Table 15.3). The high landings of under-sized fish can be attributed to the mesh size of the trawl nets (<1") as well as the areas trawled (shallow and <5 nM). The high percentage of juveniles of commercial fish in the by-catch poses a big threat to the artisanal fishery, which targets these very fish.

Table 15.4 *Composition of non-commercial fish by family*

	WEIGHT (kg)	% OF NON-COMMERCIAL FISH	% OF TOTAL BY-CATCH
Branchyura (crabs)	6,230	30.8	13.2
Leiognathidae (common/goldstrip pony fish)	2,937	14.5	6.2
Apogonidae	2,811	13.9	6.0
Squillidae (sea squids)	2,286	11.3	4.8
Gobiidae (goby fish)	1,650	8.2	3.5
Siganidae (rabbit fish)	1,157	5.7	2.5
Drepanidae (sickle fishes)	985	4.9	2.1
Pomadasyidae (grunts & sweetlips)	930	4.6	2.0
Fistulariidae (cornet fishes)	243	1.2	0.5
Muraenidae (eels)	239	1.2	0.5
Other	758	3.7	1.6
TOTAL	20,226	100	42.9

Juveniles of the commercial fishes made up the highest percentage of the juvenile by-catch by weight (65.4%, Table 15.5). The rest of the juvenile by-catch was made up of Soleidae (13.7%), Cynoglossidae (3.1%), Sepioidae (1.6%), Crabs (8.5%) and Octopodidae (0.9%). Target species (prawns) accounted for about 6.8% of the juvenile by-catch. The juvenile prawns consisted mostly of brown and jumbo prawns. They were found together with by-catch due to errors in sorting by the processing crew, were undersized or were too badly damaged. The size of these prawns – *Metapenaeas* and *Penaeus* species – in the juvenile by-catch averaged at 4.6 cm and 5.2 cm, and they weighed 5.0 g and 5.5 g respectively.

Table 15.5 *Composition of juvenile by-catch*

	WEIGHT (kg)	% OF JUVENILE BY-CATCH	% OF TOTAL BY-CATCH	% OF TOTAL CATCH
Commercial fish	7,270	65.4	15.4	11.1
Soleidae (soles)	1,523	13.7	3.2	2.3
Crabs	945	8.5	2.0	1.4
Prawns	756	6.8	1.6	1.2
Cynoglossidae (tongue soles)	345	3.1	0.7	0.5
Sepioidae	178	1.6	0.4	0.3
Octopodidae	100	0.9	0.2	0.2
TOTAL	11,117	100	23.5	17.0

The juveniles of commercial fishes were too small to be sold commercially. In addition, due to the limited room in the vessel cold stores, storage of these juveniles and undersized fish remained uneconomical. In the majority of the cases, these fish were only about a third of the mature size. Ariidae (catfish) species made up the highest percentage 69.1%, silversides made up 18.3%, jacks 5.4%, rays 3.8%, sharks 2.9%.

Environmental Concerns

In the shallow 'Kipini' area, trawling was found to turn the waters brown due to the dragging of the trawler on the bottom sediments. This does a lot of damage to the benthic fauna and flora. In addition, the venture was found to attract a large population of piscivorous birds which have migrated to this area depicting cases of 'artificial food webs' which are very unstable due to the nature of the fishery. The birds may also cause the risk of a health threat from *Salmonella spp*. due to the decay of the by-catch that is being dumped overboard.

One of the vessels (Mv Tsavo) was fitted with a Turtle Exclusion Device (Anthony Weedless bottom exit hole model) (John *et al.* 1995). The other trawlers fished without this device. The trawlers that are not equipped with TED pose a big threat to endangered species such as dugongs and sea turtles.[3]

CONCLUSION

In the areas trawled, prawns and commercial fish constituted only 13.7% and 14.4% of the catch respectively, while 71.9% was by-catch. Non-commercial fish made up the bulk of the by-catch landed (42.9%). Found in this category were the families Branchyura, Apogonidae, Leiognathidae, Squillidae and Gobiidae. The juvenile by-catch consisted largely of commercial fish (65.4%). Most juveniles were about a third of the mature sizes. Ariidae was the commonest family while Atherinidae and Carangidae were found also in notable numbers. The prawns in the by-catch were mostly due to errors in sorting by the vessel crew, while species such as Mobulidae, Sphyridae etc. made up only a small percentage of the juvenile by-catch.

The juvenile by-catch is less in volume than the non-commercial fish. It constitutes only 23.6% of the by-catch but it is nevertheless important for the future of the fisheries. The large amount is worrisome because juveniles are essential to the survival and the future of the fishery (Schaefer 1954). A stop must be made to the destruction of the juveniles, either by use of a more selective gear while catching prawns or by use of nets with bigger cod end mesh sizes. The cod end must also be of a single 'phase' net and not the trammel model of fabrication currently used by the trawlers of the Ungwana Bay.

Trawling in the deltas as well as shallow areas was found to turn the waters brown as these grounds are shallow with a lot of sediment deposits from the mainland. Thousands of piscivorous birds have also migrated to these trawl grounds. With the current downward trend in the Ungwana fishery coupled with the increasing cases of conflicts in resource use between the artisanal and trawler fisheries, the survival of these artificial food webs remains uncertain.

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3 MV Tsavo which fitted a TED had the highest landings of the target species (6,019 kg). However, it also recorded a higher amount of by-catch than MV Manyatta (without TED) at 17,170 kg and 7,909 kg respectively. On the other hand, MV Manyara recorded the highest catch of commercial fish (6,198 kg). This trend cannot be explained and research is needed into the effect of the TED on the landings of target and non-target species.

Juvenile by-catch dumped back into the waters is an environmental and health hazard because of fouling and contamination of the waters and fish harvested by the artisanal fishermen. A better use of the by-catch can be done by 'off-loading' it on to the artisanal fishing boats which spend long hours of fishing with very low catches given the low levels of technology employed in this sub-sector.

There is a need to study the potential health risks posed by the piscivorous birds (some are known to harbour *Salmonella sp.*) and the nutritional levels of the coastal fisher communities due to the threats posed by the trawling to the fish resources as well as to other ecosystems. Other possible areas of research are the changes in benthic/deltaic sediments near the shallow waters of Kipini around the Tana delta in order to explore changes in flora and fauna both of the delta and the river in relation to migratory species etc.

During the study, it was noted that only one vessel had a Turtle Excluder Device (TED). We also learned that vessels which had nets fitted with TED used such nets only when the vessels were boarded by Fisheries Officers. The complaints were that mature fish exited through the TED exit hole together with the turtles. The trawlers therefore pose a large threat to endangered species such as Sea Turtles and Dugongs since Ungwana Bay is known to be home to these animals.

Research needs to be done in the applicability of the TED in commercial fishing. Research is needed on the best TED design, position and size of turtle exit hole, the TED angle, floatation, exit hole flaps etc. in order to ensure its success as well as that of the commercial fishery. A device developed by liaising with the trawlers fishermen would require less legislation as complaints of loss of catch due to the TED would be avoided. Standardisation of the TED observation exercises should also be done e.g. by having one of the nets on one vessel fitted with TED while the second remains as a 'control' as well as the use of different TED designs. This is important since comparison of data from different fishing areas, from different vessels of unequal HP, with and without TED etc., will result in statistically 'unrelated' data and hence faulty conclusions.

From the large percentage of the by-catch landed, the areas fished and the continuous violation of the Fisheries Act, it is observed that trawling as a method of fishing remains a big threat to the local fish resources. Patrols by the (ill-equipped) fisheries department are a key factor to prevent trawling in near-shore waters as well as near river mouths and deltas such as Kipini which represent the richer brackish ecosystems of the Tana Delta. Due to lack of patrol vessels and inadequate staff, other department such as Kenya Wildlife Service and Kenya Navy should come in to ensure proper enforcement of the Fisheries- and KWS-Act. No sustainable management regimes can be formulated without stock assessment and this urgently needs to be done for the Ungwana Bay. Formulation of strict preventive and remedial measures for this 'ailing' fishery should be done to avoid further destruction of the habitat and resources of the only highly potential but threatened commercial marine fishery in the country.

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The Kenya Pearl Oysters

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ABSTRACT

This report provides a brief description of the pearl shell trade and the occurrence of pearl oyster species between Shimoni and Malindi, in Kenya and the population densities and structure of the most important commercial species, *Pinctada margaritifera* L from preliminary data collected in 1998 and 1999. *Pinctada margaritifera* L, and *Pteria chinensis* Leach, were widely distributed in the study area. The species, *Pteria penguin* Roding, only occurred in the Wasini Channel in Shimoni. *P.margaritifera* population density was highest in shallow sites dominated by seagrass within Gazi Bay. Pooled population density data showed that the oysters were more abundant in shallow water, less than 5 m depth. Most of the individuals in the samples were between 10 to 60 mm in size. The largest individual was 123 mm and was collected from a sheltered reef in Shimoni. There were more males than females and the mean size of females was larger than that of males. The size at first maturity of males was smaller than that of females. The proportion of males was higher in small-size class oysters and lower in large-size classes. These reproductive adaptations appear to be a strategy to sustain the oyster population.

INTRODUCTION

The black-lip pearl oyster, one of the largest among pearl oysters, is harvested for the rare pearl, the flesh and the thick nacreous shell or Mother of Pearl (MOP) used in the button and jewellery industry. The species occurs in lagoons, bays and sheltered reef areas to a depth of 40m and is distributed from Beja in California to the eastern Mediterranean sea (Jameson 1901, George 1978). Black pearl is harvested through out the region and cultured in French

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Polynesia, the Cook Islands, Fiji and the Ryukyu Islands in southern Japan. The value of the pearl shell has increased more than seven fold in the last decade. For example from US$ 741 in 1981 to US$ 5,531 per tonne in 1989 (Skewes 1990). The species is therefore an ideal candidate for culture because of the expected high returns in the long term due to the limited world supply making price decline unlikely.

Research on the biology, ecology, genetics, diseases, and culture of pearl oysters is going on mainly in the Pacific. Little research has however been conducted on pearl oysters in the East African coast despite the existence of a pearl shell fishery in the region for decades, and the economic potential of pearl culture. Unknown quantities of pearl oyster shell are exported from Kenya to Asia and Europe. Little information exists on the black-lip pearl oyster population ecology and biology despite the value and economic potential of the fishery. The culture, and processing of the oyster shell to produce button blanks in small scale industries, if successful, will add value to the product and provide fishers with an alternative income source. The aim of this study was therefore to examine some social-economic aspects of the pearl oyster fishery, assess the stocks in near shore reefs habitats, study the population biology and conduct some culture trials of the black-lip pearl oyster in Kenya. This report briefly describes the pearl oyster fishery, the occurrence of pearl oyster species and the density and population structure of the black-lip pearl oyster from preliminary data collected in a survey between Malindi and Shimoni in 1998/9.

Study Areas, Materials and Methods

Artisanal fishers and shell collectors were interviewed where possible in an attempt to locate oyster fishing grounds and the state of the fishery as regards to demand, supply and economic returns. The Fishery Department offices in Malindi, Mombasa and Shimoni were visited in an effort to collect oyster shell landing statistics. Two shell exporters in Mombasa, Mombasa Chandeliers and Norshad Enterprise were also visited to find out the quantities of MOP exports.

To establish the occurrence and to conduct oyster population surveys, I visited the Malindi Marine National Park (MNP) and Marine National Reserve (MNR), Vipingo, Kanamai, Mombasa MNP and MNR, Diani, Gazi, Funzi and Shimoni (Map 1: p.170). I conducted belt transect surveys for the pearl oyster population survey in 3 sites within Malindi MNP, 1 site in Mombasa MNP, 2 sites within Mombasa MNR, 2 sites within Gazi Bay, 1 site in Funzi Bay and 3 sites in Shimoni. Belt transects were inefficient in sites with very low population densities.

Timed searches were therefore adapted in Vipingo and Kanamai lagoons. A timed search was conducted in the shallow reefs in Shimoni (Kisite Island), while belt transects were conducted in the reef slope at more than 5 m depth. The belt transect method was used in Malindi MNP (South and Tewa reefs), Mombasa MNP (coral garden) Mombasa MNR (Ras Watini and English Point), Gazi Bay (back reef and lagoon) and Shimoni (Kisite Island reef slope, Wasini back reef and Wasini Channel).

All surveys were conducted one hour before to one hour after spring low tide, during the day. In each of the study sites a 50 m weighed nylon line, marked every 5 meters, was laid along the reef. Two SCUBA divers carefully searched one meter on either side of the transect line and collected all the oysters that could be seen. The Dorsal Ventral Measurement (DVM), shell height, width, valve width, heel length, shell weight and colour of all oysters occurring within the transects was recorded. The dominant substrate cover within the belt transect was noted.

Shell weight and dry meat weight of oyster samples from Kisite Island, Gazi Bay and Mombasa were determined in the laboratory. The shells were air-dried for 24 hours and then weighed on an electronic balance.

Results

The Pearl Oyster Shell Fishery

Most fishers, whose main resource is fin fish, recognised the black-lip pearl oyster known as *mashaza* or *shaza ya bahari kuu* in Swahili and were able to differentiate it from other oysters and pen shells. However, most could not pin point where they last saw individuals or aggregates of the species. Seashells, including oysters, continue to be sold as souvenirs to tourists in Malindi, Watamu, Vipingo and Kanamai. The fishery officials reported that truckloads of mixed shells are occasionally transported from Lamu to Mombasa for export despite there being no shell collector licensed to operate in this area.

No fishers in Diani responded to inquiries on the oyster fishery and shell collection freely because they assumed we were conducting a survey that would lead to the establishment of a marine park. One respondent, however, confirmed occasional sightings of the species in sea grass beds and among coral outcrops. Fishers in Gazi and Shimoni areas, who specialise in lobster, octopus and shell collection recognised the species and knew where the population aggregations could be found. Fishers in Vanga were aware that the species occasionally contains valuable jewels known as *lulu* in Swahili, but were not aware of the use and value of the oyster shell. Licensed shell collectors operate in Funzi, Shimoni and Vanga, buying shells mainly from lobster and octopus fishers, to sell to dealers in Mombasa for export. One shell collector operated from Gazi village until 1994 when he changed to collecting sea cucumbers for unknown reasons. The shell collector in Vanga reported that oyster shell landings have declined during the last few years and attributes the decline to weather changes, and not over-harvesting. He currently pays the fishers about one shilling (approximately US$ 0.01) per oyster shell and sells to the exporter, Norshad Enterprise, in Mombasa at sh.70/kg (US$ 1). The fisheries department shell landing statistics of Shimoni show a price range of sh.9-30 for a single shell between June 1997 and June 1998 (Table 16.1).

Table 16.1 *The black-lip pearl oyster, Pinctada margaritifera, landed from Shimoni and prices (sh.)**

MONTH		NUMBER OF INDIVIDUALS	PRICE	PRICE /SHELL
June	'97	145	3,460	23
Sept.	'97	9	270	30
Dec.	'97	18	270	15
Jan.	'98	15	225	15
Feb.	'98	160	2,000	12
Mar.	'98	18	270	9
Apr.	'98	98	1,510	15
May	'98	318	1,380	10
June	'98	44	440	10

* Adapted from Fisheries Department Marine Fish Landing Statistics (1997, 1998).

The proprietor of an establishment that deals with shell trade, Jiwa Import and Export Company, reported that he does not deal with pearl oyster shells any more. The principle shell exporter in Mombasa, Norshad Enterprises, exports oyster shells (about three 70 kg sacks were observed drying at the warehouse during my visit) but would not divulge any details or allow us to examine the shell stock in the warehouse. The Fisheries Department only records, and is paid for shell exports in terms of chests or boxes of mixed species. No information on the quantities, prices or destination could therefore be obtained from the Fisheries Department officials and shell dealers.

Pearl Oyster Species and Occurrence

The black-lip pearl oyster *Pinctada margaritifera* occurred in most of the areas surveyed (Table 16.2). Individuals were found attached to a variety of substrates including other bivalves such as penshells, mussels, and honeycomb oysters, teeth pearl shells, dead and live corals and bare rock. The wing oyster, *Pteria penguin*, was only found in the Wasini Channel attached to rock substrate, in water more than 5 m deep. *Pteria chinensis* individuals were found in aggregates of three or four, attached to live hard and soft corals, and on sponges in Malindi, Mombasa and Shimoni.

Table 16.2 *Occurrence of pearl and wing oysters species, Family Pteriidae, the substrates attached on and the size of the largest individual (mm)*

	PLACE*	SUBSTRATE ATTACHED TO	LARGEST INDIV. DVM mm
Pinctada margaritifera (Linnaeus)	MLD, VPN, KNM, MBS, GZ, SMN	Dead coral, sea grass, shells	126 (SMN)
Pteria chinensis (Leach)	MLD, MBS, SMN	Sponges, live coral, soft coral	89 (MLD)
Pteria penguin (Roding)	SMN	Bare rock	235 (SMN)

* MLD=Malindi MNP and MNR, VPN=Vipingo, KNM=Kanamai, MBS=Mombasa MNP and MNR, GZ=Gazi Bay, SMN=Shimoni.

Black-Lip Pearl Oyster Occurrence and Abundance

Preliminary results show that oyster populations exist in most of the areas visited during the study (Table 16.3). In Malindi MNP, oysters were found between the branches of dead *Acropora* to about 6 m depth in the South Reef and between *Montipora* branches in deeper water more than 10 m in the Barracuda Reef. One belt transect on the submerged Tewa Reef crest within Malindi MNR dominated by dead and live *Montipora* yielded no oysters. Belt transects in Vipingo, Kanamai and Diani yielded no oysters. Two observers walking or snorkelling in straight lines perpendicular to the reef for one hour conducted searches in these areas. A few individuals and freshly dead loose oyster shells, which are easier to find because of the exposed shiny inner shells, were located using this method. In the Kanamai lagoon, two oysters measuring less than 20 mm DVM were encountered in a seagrass bed and one measuring 90 mm DVM on a coral outcrop during a one hour search by two observers. A 100 m^2 belt transect at the mouth of the Tudor Creek channel within the Mombasa MNR, dominated by seagrass and bare rock, yielded 7 oysters. Two observers snorkelling at spring low tide in the Diani lagoon found no oysters during a two hours search.

Pearl oysters were most abundant in the Gazi Bay and in Shimoni (back reef south of Wasini Island and Wasini Channel – Table 16.3). The highest oyster abundance occurred in Gazi Bay (42.0±11.9), dominated by seagrass, sand, and scattered coral out-crops. The oysters here were attached to the shells of dead and live molluscs including, teeth pearl oysters of the genus *Isognomon*, mainly *I. Isognomon*, mussels of the genus *Modiolus*, arch shells, mainly *Barbatia decussata*, and penshells, mainly *Atrina vexillum, Pinna muric-*

Table 16.3
Mean density of black-lip pearl oysters, Pinctada margaritifera, in 100m² belt

PLACE	SITE	DOMINANT SUBSTRATE TYPE WITHIN TRANSECTS	DEPTH	N*	MEAN	(s.d.)
Shimoni	Wasini Back Reef	Rock, sand, soft coral	2	6	15.7	(9.8)
	Wasini Channel	Sand/rock	6	2	10.5	(9.2)
	Wasini Channel	Sand/rock	8	1	5	
	Wasini Channel	Sand/rock	10	2	7.0	(9.5)
	Wasini Channel	Sand/rock	16	1	1	
	Kisite Isl. Reef Slope	Dead/live coral	6	2	-	
	Kisite Isl. Reef Slope	Dead/live coral	10	2	-	
Gazi	Lagoon	Seagrass/sand	2	5	42.0	(11.9)
	Lagoon	Seagrass/sand	4	5	6.0	(5.7)
Funzi	Lagoon	Seagrass	2	1	7	
Mombasa	Lagoon	Live/dead coral, sand	2	5	0.6	(0.9)
MNP & MNR	Channel	Seagrass/rock	2	1	7	
Malindi	Lagoon	Dead/live coral, sand	6	3	7.3	(6.7)
MNP & MNR	Lagoon	Dead/live coral, sand	10	2	4	(5.7)
	Reef Slope	Dead/live coral, sand	6	1	-	
	Reef Slope	Dead/live coral, sand	10	1	-	
	Reef crest	Dead/live coral	6	1	-	

* N=number of replicate transects.

ata and *P. bicolor*. Others were attached to isolated stands of *Acropora formosa* within the lagoon. A few of the large individuals in Gazi were found loose, on the bottom. The seven oysters found in the one belt transect in the Funzi Bay were all attached to the blades of the seagrass *Enhalus acoloides*.

The oyster population density in Shimoni (Wasini back reef) was one of the highest (15.7±9.8). Most of the oysters here were found on soft corals, bare rock and on the honeycomb oyster *Hyotissa hyotis*. In the Wasini Channel adjacent to the Ncha Mwamba reef, a moderate density of oyster (10.5±9.2) was found, between 4 and 6m depth. The pearl oysters here were attached to bare rock, other oyster species of the genus *Isognomon*, and on large sponge colonies. No oysters were found in the exposed reef slope in Shimoni (Kisite Island) and Malindi MP although the substrate cover was mainly live and dead coral, encrusting coral, coral rubble and sand. Other bivalves such as penshells, clams, scallops and arch shells were present within the belt transects surveyed in the reef slopes within the two parks. The largest oysters measuring, 116 and 123 mm DVM, were collected in the sheltered reef in Shimoni at Kisite Island.

Table 16.4
Frequency distribution of the back-lip pearl oyster (Pinctada margaritifera L.1758) by size and location

SIZE	MALINDI	SHIMONI	MOMBASA	GAZI	KANAMAI	FUNZI
0-9 mm	2	5	-	-	-	-
10-19	17	20	4	15	2	2
20-29	7	23	3	61	-	4
30-39	4	30	1	38		1
40-49	-	14	1	12	-	-
50-59	-	6	-	5	-	-
60-69	-	-	-	-	-	-
70-79	-	1	-	-	-	-
80-89	-	1	-	1	1	-
90-99	-	1	-	2	-	-
100-109	-	-	-	-	-	-
110-119	-	3	-	-	-	-
>120	-	1	-	-	-	-
TOTAL	30	105	9	134	3	7

Population Structure

The oysters in Malindi MNP, Mombasa MNP and MNR and Kanamai were dominated by the 10-20 mm DVM size classes (Table 16.4). The oyster population in Gazi and Funzi was dominated by the 20-30 mm size class, while the Shimoni population was dominated by a large-size class, 30-40 mm. Oysters larger than 60 mm occurred iin shallow reefs and tidal pools on the reef platform in Shimoni and in Gazi Bay.

The oyster population structure was similar in all the depths surveyed with the majority of the oysters in the size classes less than 60 mm DVM (Table 16.5). Only one oyster of more than 60 mm was found at more than 2 m depth.

Table 16.5
Frequency distribution of the back-lip pearl oyster (Pinctada margaritifera) from Shimoni by size and depth

SIZE (mm)	0-2m N(%)	4-6m N(%)	8-10 m N(%)	>10 m N(%)
0-19	20 (26.7)	3 (13.6)	-	2 (66.7)
20-39	36 (48.0)	14 (63.6)	3 (60.0)	1 (33.3)
40-59	13 (17.3)	4 (18.2)	2 (40.0)	-
60-79	1 (1.3)	-	-	-
80-99	1 (1.3)	1 (4.5)	-	-
100-119	3 (4.0)	-	-	-
120+	1 (1.3)	-	-	-
TOTAL	75 (100)	22 (100)	5 (100)	3 (100)

Sexual Maturity and Male/Female Ratios

Seventy-four individuals collected from Wasini Channel and Gazi Bay and Mombasa MP were examined for sexual maturity. Of these 68 individuals (93.2%) were sexually mature. Table 16.6 shows the size frequency distribution of the females males and juveniles. The mean size of females in the sample (37.4±9.47) was significantly larger than the mean size of males (30.4±9.18; $p=0.0013$). The size of males in the samples ranged from 15.5 to 53.8 mm, females ranged from 23.2 to 57.2 mm and juveniles ranged from 10 to 24 mm DVM. Of the mature oysters, 38 were males and 30 were females (male/female ratio, 1.26/1.0). The proportion of males progressively decreases, and the proportion of females increases as the size class increases (Table 16.6). The size range between 15 and 30 mm is mainly males

(75%). The proportion of males to females in the 30-45 mm size range is approximately similar (54.2 and 45.2%) while the majority (66.7%) of large oysters in the sample were females.

Table 16.6
Frequency distribution of the back-lip pearl oyster (Pinctada margaritifera) by size and sex status

SIZE (mm)	FEMALES N (%)	MALES N (%)	JUVENILES N (%)
5-9	-	-	-
10-14	-	-	1 (16.7)
15-19	-	3 (7.9)	4 (66.6)
20-24	3 (10.0)	9 (23.7)	1 (16.7)
25-29	4 (13.3)	8 (21.1)	-
30-34	6 (20.0)	8 (21.1)	-
35-39	6 (20.0)	2 . (5.3)	-
40-44	5 (16.7)	4 (10.5)	-
45-49	3 (10.0)	2 (5.3)	-
50-54	2 (6.7)	2 (5.3)	-
55-59	1 (3.3	-	-
60-64	-	-	-
TOTAL	30 (100)	38 (100)	6 (100)

DISCUSSION

The Fishery and Species Distribution

A lucrative oyster shell fishery has evidently existed on the Kenya coast until the last few years. It is clear from the Fishery Department statistics that collection and trade in oyster shell continues to date. Harvesting of all kinds of shells is more prevalent in the south coast, where a few shell collectors licensed by the Fisheries Department operate. There are no licensed shell collectors in the area between Mombasa and Malindi. One shell dealer in Mombasa certainly exports oyster shells. The volume of this trade and the returns obtained by the licensed collectors and the exporters are however difficult to estimate. Lobster and octopus fishers in Vanga only collect oyster shells on the side, due to the decline of the populations in the lagoons and poor prices offered by the licensed collectors.

This is the first report on the occurrence of the wing oyster, *Pteria penguin,* a conspicuous shallow water oyster species. *P. penguin*, so far only encountered in the Wasini Channel, is harvested for the shell in the Solomon Islands (Philipson, unpubl. data). It is also used to produce half-pearls in Fiji Islands and Borneo (Wada 1973) and in Thailand (Saraya 1982). It is not known if this species is harvested for MOP in the East African coast. The preliminary results of this study show that the black-lip pearl oyster is widely distributed throughout the Kenya coast. Considerable stocks exist in Gazi Bay, Malindi MP and Shimoni. Low population densities were observed in Kanamai, Vipingo and Mombasa MP lagoons. These are probably too shallow (0.5-2.5 m at spring low tide) for the successful establishment of pearl oyster populations. However, higher population densities could exist in reef slopes deeper than 16m which have not been extensively surveyed so far.

Abundance

The abundance of black-lip pearl oysters/100 m^2 in the sites surveyed where they occurred ranged from 0.6±0.9 to 42.0±11.9. The population density variation within the study area was low in high-density areas such as Gazi (23.8%) and high in low-density areas such as Malindi (142.1%) and Mombasa (158.8%). This density is higher than in the Cook Islands with 0.4±0.2 and 6.7±4.4/100 m^2 in Suwarrow, Penrhyn and Manihiki lagoons (Sims 1992). The variation here is however moderate (between 50 and 65.7%). The mean density was much higher in the sheltered backwaters in Gazi (24.0±5.7) and in the Wasini Channel (14.4±8.9). The densities observed in this study are comparable to those in the Andaman and Nicobar Islands in India, which ranged between 200 and 20 individuals /100 m^2 (Alagarswami 1983). However, the Cook Island study was conducted in mainly coral substrate and also includes deeper waters up to 36 m, whereas the Indian survey and this survey covered shallow sites, i.e. less than 10 m in India and less than 16 m in Kenya. In the Cook Islands study the abundance increased with depth to 36 m, after which no more oysters were found. In contrast, oysters in this study were generally more abundant in shallow water, less than 5 m.

Population Structure and Sexual Maturity

Small individuals, less than 60 mm DVM, dominated the oyster population. Large individuals, more than 60 mm, were found in shallow water less than 1m depth. However, the population survey only went to 16 m depth in the Wasini Channel. Reefs in the areas so far surveyed do not go more than 12 m deep. Black-lip pearl oysters are found down to 40 m depth and it is possible that large individuals occur deeper than 16 m. The data is not statistically comparable because of the poor replication in some of the study areas, the topography and bottom substrate types of the study sites. All large individuals, more than 100 mm, were collected from shallow reefs in Shimoni. The population structure of oysters in depths more than 3 m is similar (Table 16.5). SCUBA, and trekking surveys in the Andaman and Nicobar Islands as well as in India found oysters ranging from 38.2 and 109.5 mm. Surveys in the Cook Islands using SCUBA in Manihiki and Penrhyn Lagoons using free-diving surveys found oysters ranging between 65 and 225 mm. However, samples from Suwarrow Island to the south found oysters ranging from 15 to 265 mm. From these studies, black-lip pearl oysters in the South Pacific appear to grow bigger than in the Indian Ocean.

Few studies on reproduction of pearl oysters have been reported. The majority of the oysters in this study were mature at about 20 mm, approximately 3-4 months old. The male/female ratio in the samples (1.26/1.0) is similar to that (1.29/1.0) reported in the Andaman and Nicobar Islands in India, for a population that included larger individuals (Alagarswami 1983). Protandric sex expression, where males change to females as they grow is common in bivalves, and partly explains the sex ratios observed in the size classes in this study. However, environmental stress influences the sex ratios of pearl oyster populations. For example, the sex ratio changed from (1.75/1.0) in a population on a rocky shore to (5.75/1.0) on an oil polluted drilling platform the South China Sea (Dolgou 1991). From the above studies, it is evident that in black-lip pearl oyster populations, there are usually more males than females in natural populations, and even more in populations subjected to some forms of environmental stress. The bulk of the oysters in this study was composed of small individuals, but the majority (93.2%) were sexually mature, ensuring reproduction success even in heavily exploited populations.

Conclusion

The black-lip pearl oyster supports a thriving MOP export fishery in the East African coast. Significant population concentrations occur within shallow bays and lagoons with seagrass, coral and bare rock bottom substrate. Small sizes are predominantly male while females dominate in the large individuals. Early sexual maturity ensures reproductive success even in heavily exploited populations. The wing oyster, *Pteria penguin*, which occurred within the Wasini Channel in Shimoni has potential in culture for MOP production and pearl culture.

ACKNOWLEDGEMENTS

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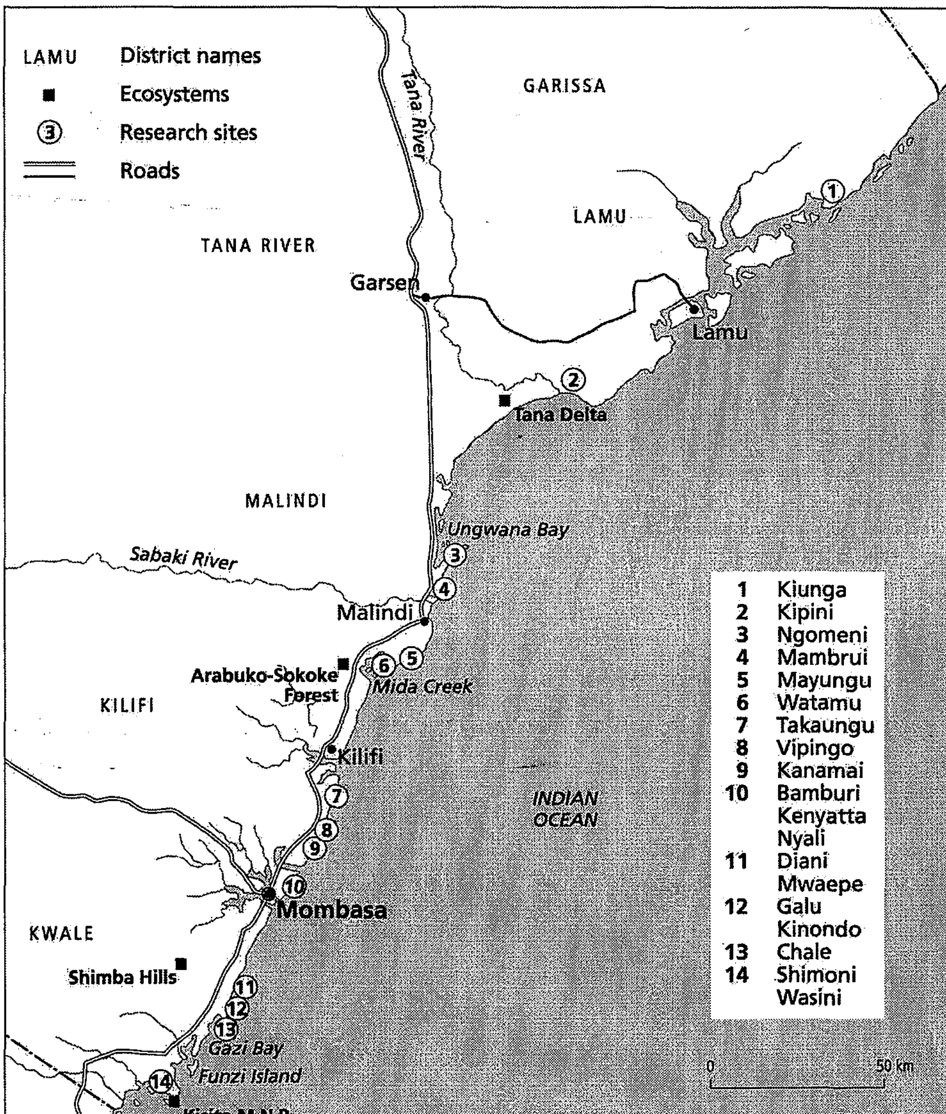
Mangroves

Map 1 *Kenya Coast with location of research sites*



17

The Status of Mangrove Exploitation and Trade along the Kenyan Coastline

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ABSTRACT

Exploitation of mangroves in Kenya is controlled by the Forest Department through the licensing of users and subsequent supervision of harvesting and removal of the produce. Marketing of the produce is undertaken by the licensees and individual traders; the department has a role through the issuance of movement permits. The state is the only stakeholder who invests in the conservation and management of forest resources in-spite of the benefits accruing to the other stakeholders. In view of this, there is need to look at ways of easing this burden from the government through decentralisation and devolution of some of the activities and powers respectively to the other stakeholders.

INTRODUCTION

Mangroves are highly valued for their richness in biodiversity and provide habitats for many species of fauna and flora. The resource contributes considerably to the local economy. Trade in mangrove products provides employment opportunities to many people: dhow transporters, vehicle transporters, cutters and sellers. Indirectly it contributes to employment in building industry, fishing, carpentry and hotel industry. Mangrove exploitation has existed

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Table 17.1 *Areas and locations of mangrove forest*

DISTRICT	LOCATION	AREA (ha)
Lamu	Lamu	30,475
	Kiunga	3,025
Tana River	Kipini	1,595
	Kilifi	820
	Mto Tana	250
Kilifi	Kilifi Creek	360
	Mida Creek	1,600
	Mto Fundisa	330
	Mto Kilifi	1,550
	Mtwapa Creek	525
	Ngomeni	1,815
	Takaungu	30
Mombasa	Mtwapa Creek	115
	Port Reitz	1,575
	Tudor Creek	1,465
Kwale	Funzi Bay	2,715
	Maftaha Bay	625
	Kwale	1,195
	Ras Mwachema	5
	Vanga	4,265
TOTAL		54,335

Source: Doute *et al.* (1981) quoted in Wass (1995).

for many years. Mangroves were exported to the Middle East since early this century. This export was banned in 1982 but there have been concerted efforts to have the ban lifted.

The estimated mangrove cover in Kenya is 54,335 ha (Table 17.1). Mangroves in Kenya are spread over six districts: Lamu, Tana River, Malindi, Kilifi, Mombasa and Kwale (Map 1: p.256) with Lamu making up about 68% of the resource cover as well as having the most productivestands.

During the colonial period at the turn of the century, mangrove poles were the major forest products exported from the coast region. They are still the main forest product. Recognising the importance of mangrove resource, the German administration in East Africa was the first to attempt to control the cutting of mangroves. The first forest management plan by Germans for Tanzania involved limitations for quantities to be cut for mangrove poles and firewood. In order to improve quality of the mangrove forests, replanting of cleared areas and the replacement of lower quality trees with those of higher commercial value were undertaken. Successive governments in the region, both colonial and independent, have also been concerned with the management of the mangrove resource (Semesi & Howell undated).

G. A. Park, a forester stationed in Lamu between 1958 and 1968, is the first person reported to have attempted trials of replanting mangroves in Kenya. Other attempts to replant have been in Ramisi River, Mida Creek, Tsunza and Gazi. The latter constitutes the largest attempt and has also involved the local population.

Mangrove forests were gazetted in 1932 (Ferguson 1993) with some areas later being gazetted again as marine reserves like Mida Creek in 1968. Management of mangroves is done at local level. For example, Gede forest station manages all the mangrove formations south of Malindi while Jilore station manages all the mangrove formations north of Malindi. In each station there are forest guards and patrolmen who police to stop illegal activities, supervise the cutting and removal of mangrove products.

The state remains the main stakeholder who invests in the management of mangroves though the other stakeholders continue to benefit from the resource as well. Mechanisms to facilitate the implementation of collaborative partnerships in resource management are lacking. The current policy allows uni-sectoral management, which vests all the powers in the Forestry Department (FD). Kenya Wildlife Service (KWS) has management responsibilities in the marine parks and reserves (like Kiunga in Lamu and Watamu in Malindi) but all mangrove formations are gazetted forests whose management wholly rests with the FD.

Other stakeholders such as licensees, cutters, forest adjacent communities, the tourism industry, and non-governmental organisations have potential for management and are willing to do so. Organisations that should be involved in the management of mangroves include the Kenya Forestry Research Institute (KEFRI), Kenya Marine and Fisheries Research Institute (KMFRI), Coast Development Authority (CDA), National Museums of Kenya (NMK). Local and international bodies such as public universities, the United Nations Environment Programme (UNEP), United Nations Education, Social and Cultural Organisation (UNESCO) and International Union for the Conservation of Nature (IUCN) also should be involved. The combined capacity of these potential partners needs to be utilised to supplement the efforts of FD through collaborative partnerships in forest management. This will improve the management of the resource thus ensuring it provides multiple products to satisfy the many needs of the participating stakeholders.

The Forest Department is the government department authorised to co-ordinate the utilisation of forest products in gazetted forests like the mangroves. The utilisation procedure is through application of an annual licensee. The granting of the license and payment of the license fee gives the applicant the right to exploit the resource at specified quantities within a designated area for one year. Each licensee has cutters who know the area they are supposed to operate within. They are expected to cut and inform the licensee when they have finished whom in turn informs the FD. The numbers cut are counted, government fees paid and the poles are hammer marked. The licensee is free to move his materials on issuance of a movement permit. All mangrove products are for local use as there is a ban on the export of mangrove products since 1982.

METHOD

A survey on the status of mangrove exploitation and trade along the Kenyan coastline was done in 1997 using a semi-structured questionnaire and a checklist of issues to be covered with each category of interviewee. The interviewees were selected through random sampling. The questionnaires were supported by structured observations on the general state of the resource and the level of erosion in the mangrove swamps.

The interviewees were categorised as follows

- Licensees;
- Merchants;
- Users (local people for building houses and as fuelwood);
- Mangrove cutters;
- Government officers (FD, KMFRI and KWS).

The interview venues were chosen for the convenience of the respondents and they consisted of:

- Landings — where the poles are landed after cutting for counting and hammer marking by the FD;
- Selling yards — where the merchants display and sell the poles to the public;
- Offices — this involved the Government officers and the large-scale licensees;
- Mangrove forest — this involved wading through mud with the officers, fishermen and cutters. The survey tools consisted of a semi-structured questionnaire and structured observation;

- Households — from the forest adjacent communities whose main use of the mangroves is for fuelwood and house construction and who are also cutters.

Observations were used to categorise the districts as regards level of exploitation and the status of the mangrove forest and swamps. Secondary sources of data were consulted for purposes of comparison.

Results and Discussion

The exploitation of mangroves is difficult mainly because of the inaccessibility to the swamps where the trees are growing. This situation has also made supervision and monitoring of exploitation by FD staff difficult. This has made the cutter who has access to be the exploiter and the supervisor; the one to decide where and what to cut within the licensees' compartment. The officers come into contact with the poles at the landing bay. Since the cutter is paid as per the number of poles cut, temptations to over-exploit in zones with better trees are high, often resulting in bare swampy grounds which are prone to erosion.

The cutters range from subsistence ones; those who cut poles from forests within a walking distance from their houses to the mobile commercial cutters of Lamu. The latter own dhows and they are contracted by the licensees to cut poles from far-away islands. They are paid on delivery of the product at Mkowe jetty. This means that the cutters are the decisive factor in the exploitation of mangroves. Logistical difficulties make it impossible for the

Table 17.2
Official data on the number of scores extracted per district

	LAMU	KILIFI	KWALE
1990	16,164	3,190	41
1991	16,266	7,312	331
1992	12,712	10,047	135
1993	10,395	3,672	1,437
1994	7,087	5,355	1,945
1995	9,201	20,461	1,947
1996	9,467	4,072	1,073
AVERAGE	11,611	7,230	987

Source: FD annual reports.

FD to have reliable data on the number of trees cut in identified areas. Consequently, the department is not in a position to make decisions to close one area and shift the licensee to other blocks at the right time.

Over 90% of the licensees interviewed started trading in mangroves poles during the colonial era when it was easy to get the top classes of mangroves poles; *Banaa* (diameter at butt 20.1-35.0 cm) and *Magogo* (diameter >35.0 cm). Most of the licensees have their own timber selling yards where they sell their produce except in Lamu where all licensees except one sell their products to merchants and selling yards in Malindi, Kilifi, Mtwapa, Mombasa, Likoni and Ukunda.

There is both domestic and commercial use in mangroves. Domestic use is for construction of houses and as fuelwood. The demand for mangrove poles is high during the low tourism season when most tourist establishments are closed down for renovations. This is also the time most workers have for their holidays and they use this time for building or renovating their houses. There is also use of mangroves for cottage industries in Lamu, namely the burning of coral to make lime. The use of mangrove firewood by Kenya Calcium Factory to fire it's kilns has been replaced by coal from South Africa. Commercial use is for the construction of residential houses in the urban centres along the coastline. The mangrove forests in Malindi, Kilifi, Mombasa and Kwale can not meet the local demands for mangrove products. Lamu exports 95% of its mangrove poles to meet the deficit in the other coastal towns. Mombasa takes the largest share and small quantities are also sold as far as Likoni and Ukunda (Table 17.2).

The surplus in Lamu exists because there are few hotels, the low population densities of forest adjacent communities, the relative high cost of mangrove poles and abundance of land poles[3] that are cheaper. Most of the mangrove poles sold in Ukunda are from Tanzania which are sold as far north as Mombasa. Ukunda gets more than half it is requirements for mangrove products from Tanzania. These poles are in high demand because of their superior quality in that they are straight and much longer than the local ones. They reach the country illegally through Bodo and then they are disguised as poles harvested from the local forests.

The severity of erosion in the mangrove swamps, the extent and frequency of bare sites and the presence of mother plants were categorised in better, bad, worse and worst. Worst, the lowest score, was forest which had been seriously degraded, low frequency of mother

3 Commercial term used by the FD to refer to poles from indigenous terrestrial forest trees.

plants and very little materials for harvest. Mombasa had the worst score as it had the most degraded forests followed by Malindi and Kilifi. Kwale had the third score of bad and Lamu had the best score of better. Lamu had it swamps least eroded, mother plants were more frequent and it had trees which could be harvested at all the sites that were visited. Also it did not have any visibly over-cut areas. Tana River was not covered by the study.

These findings can be attributed to the distance from major consumers like in Mombasa, Malindi and Kilifi. The tourism industry in Malindi and high population densities offer a ready market for the poles which exerts pressure on the nearby mangrove forests. In Lamu it was the opposite in that the mangrove forests nearby were least exploited with the cutters decrying over exploitation in faraway islands like Faza and Ndau. This is attributed to lack of FD personnel and the distance from the Lamu forest station.

Erosion of the swamps is being caused by over-cutting in some areas where the cutters find the poles of the size they require. They know they are hardly supervised and that the officers lack the means to supervise. Though the FD has boats in Kilifi and Lamu, most of the time it did not have fuel or the pilot had retired like in Lamu under the civil service retrenchment programme. The other districts do not even have a canoe. If they want to supervise they have to rely on the goodwill of the cutters to provide them with their canoes or dhows. In areas like Mombasa the bare sites as a result of mangroves dying due to pollution and siltation.

Customers preference for the most utilised species is as follows: *Rhizophora mucronata, Ceriops tagal* and *Bruguiera gymnorrhiza* (Mbuvi, Luvanda & Wandabwe 1997). In some areas *R. mucronata* has been over cut and the licensees are now turning to *C. tagal*. This is having an impact on the species composition of the mangrove formations. This is evident in Ndogo Kundu area of Mida creek where *R. mucronata* is being replaced by *C. tagal* which regenerates faster than the former (field observation). Lamu exports mostly *R. mucronata* to the other areas of the coastline while the other species are used locally (Mbuvi *et al.* 1997).

SUSTAINABLE MANAGEMENT

There are various indications that the resource is not being sustainably managed. Among these indicators are the following:

- The absence of large size classes poles like *banaa* (20.1-35.0 cm) and *magogo* (13.1-20.0 cm). These classes are not recorded anymore by the FD as being harvested these

days. The cutters reported that they are only to be found in Lamu after a long search;
- Ban on the cutting of *fitos* (size class less then 4 cm diameter at butt). This is a measure to enable the resource to recover. With sustainable harvesting it would not be necessary to ban the cutting of one size of mangroves since each class would be removed in quantities that leave enough stock to grow to the subsequent size classes;
- The illegal importation of better quality poles from Tanzania which are in high demand in the construction industry because of their superior quality. All the straight long poles with few knots in selling yards on the south coast are from Tanzania;
- The evident erosion within the mangrove swamps. This was less the case in Lamu but visible in Kurawa, islands in Kilifi Creek and also within the mangrove formation on the south coast;
- The cutters report that it now takes much longer to cut the same number of scores than it took about twenty years ago;
- The short and crooked poles with multiple knots that are being cut from the forests against customer demand for straight and long poles;
- Encroachment by developers, fish farms and salt farms on mangrove stands and pollution from industries and hotels.

Management Problems

The stakeholders cited several difficulties that hinder their efforts towards attaining sustainable utilisation and management of the mangrove resource. They are listed below without further comment:

- Lack of inventory data;
- Lack of involvement of other stakeholders;
- In-appropriate policy;
- Lack of management plans;
- Insufficient resources of personnel, motor boats and vehicles;
- High licensee fees;
- High transport costs;
- Lack of involvement in the management of the resource;
- Low morale among staff;
- Inadequate knowledge on mangrove silviculture;
- Areas of double gazettement are a source of conflict between KWS and FD;

- Illegal mangrove cutting;
- Tourism industry mostly jetties;
- Illegal allocation of mangrove forest areas to developers;
- Salt farming.

CONCLUSION

Inventory and re-surveying of the mangrove area are necessary. This will enable managers to draw appropriate management plans. The inventory data will enable them set sustainable quotas that allow only pole off take limits that do not affect the forest regeneration. It will enable the planners to allocate adequate resources towards the management of the mangrove resource. For example, the Kilifi District master plan for the period 1995–2020 (Kenya 1994) gives mangroves minimal recognition though it is a major revenue earner in the district. Lamu district has the highest mangrove cover but it has only one forester for the whole area. This makes the monitoring of legal and the policing of illegal activities difficult considering that most areas are only accessible by boats and dhows (Kahuki 1993).

Policy changes should aim to facilitate management through the involvement of other stakeholders like the Fisheries Department, forest adjacent community, KWS, NGO's, the tourism industry etc. FD should push for the new policy to be approved and start involving other stakeholders in the management and utilisation of the forest resource. Awareness and training programmes should be held involving all stakeholders. Awareness training should not leave out the government officers. Training should be aimed at imparting skills of advocacy, as well as how to built effective alliances and collaborative partnerships.

The stakeholders should facilitate mangrove growing on-farm considering that water and cost of seedlings remains a major hurdle for the poor members of the community. These households form the majority in the region and they have to be involved if illegal activities are to be reduced. The FD should strictly follow a compartment felling system while at the same time taking a lead in facilitating and co-ordinating the replanting of mangroves.

The local peoples' illegal use of the mangrove resource is attributed to poverty within the community. This can be alleviated through facilitating the community to start other income generating activities like fish farming, bee farming etc. Village based licensees should be allowed to cater for the needs of the community members who have to incur extra cost tracing the urban-based licensees.

The current system where the cutter is the patrolman of the mangrove forest should be supplemented by the FD with its own patrols. This is only feasible if the department is strengthened in terms of personnel and other resources. Quotas allocated to each licensee should be adhered to and they should set the number of specific species to be removed in each block. This will prevent over-cutting of individual species. For example, in Mida, *C. tagal* is replacing *R. mucronata* because the latter has been over cut to satisfy the customers' demand and preference and because the former is a faster coloniser. Quotas for such an area should not include such over utilised species. This will maintain the natural composition of the mangrove forests and retain the associated flora and fauna.

Research will need to be properly co-ordinated and a working group formed in view of the importance of this resource. Conflicts of interest between for example KWS and FD should be resolved in an open and transparent manner before they spill over to the licensees, the forest adjacent communities and developers. The policy should also be clear as to which prevails in case of double gazettement. It should make it clear how to handle the management of mangroves in areas where private developers have title deeds to the mangrove forests as is the case with the salt farms. Allocation of mangrove forest should be stopped.

All development adjacent to mangrove areas should be allowed only after an environmental impact assessment has been carried out and after it is confirmed that the development will not have a negative impact on the mangrove ecosystem.

Concluding there was a general feeling among the managers and other stakeholders that exportation of the mangroves should not be allowed. The ban should not be lifted as the resource is insufficient to meet local consumption. There is an absence of authoritative inventory data, and a shortage of the mangrove materials in all the coast districts except Lamu .

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18

Concentration and Distribution of Trace Metals in Mangrove Sediments

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ABSTRACT

Trace metal concentrations for Fe, Al, Mn, Cr, Zn, Pb, Cu, and Cd, were measured at several stations in the Ngomeni area from Oct.- Dec.'96. The concentration levels were found to decrease in the order Mangrove Forest 2 (MF2) > Salt Pond (SP) > Mangrove Forest 1 (MF1) > Degraded Mangrove Area (DA) > Aquaculture area (AQ). Station AQ was especially poor in available trace elements. If rehabilitation or restoration activities were to be initiated in the degraded sites and non-operational salt pans, trace metals levels will not be the limiting factor (either in terms of deficiency or toxicity); rather the salinity levels could be.

INTRODUCTION

Mangrove forests play an important role in energy and nutrient cycling on most tropical and sub-tropical coasts. With growing industrial activity in many such areas, these ecosystems can also contribute to the cycling of certain pollutants to marine food chains (Silva, Lacerda & Rezende 1990). Among the trace elements that have been shown to be essential for plants include Al, Cu, Fe, Mn and Zn (Alloway 1993). Reducing conditions in mangrove sediments will favour metal precipitation and immobilisation as sulphides (Lacerda & Abrao 1984). The

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trace metals that are adsorbed to suspended matter and dissolved in the water may ultimately be hazardous to both plants and animals if they occur in high concentrations (Ndiokwere 1984).

At Ngomeni, mangrove forests have been cleared to pave way for aquaculture and saltwork developments. This replacement of mangrove ecosystems probably alters the physical and chemical properties of the soils, such that natural recolonization from adjacent mangrove stands becomes impossible (Saenger, Hegeri & Davies 1983), even after these activities have ceased operation. One possible effect of these physico-chemical changes in the sediment will be concentration and distribution of trace metals, both essential and non-essential. Concentration of trace metals, where scarce, may limit plant growth, and where excessive, may result in phytotoxicity (Alloway 1993) with possible accumulation in marine food chains. Bare, cleared patches that once supported mangrove forests, and non-operational saltponds existing in this area call for deliberate, sustained, restoration and rehabilitation efforts.

The present study aims to quantify the concentration and distribution of available trace metals (Al, Mn, Fe, Zn, Cu, Cr, Cd and Pb) in sediment from mangrove forests, aquaculture and saltwork ponds at Ngomeni, in order to point to the remedial measures required to institute successful rehabilitation.

Materials and Methods

Study Area

This study was carried out along the tidal flats and lagoons at Ngomeni, Ungwana Bay (Map 1: p.256). Five stations were selected for the present study, and included:

- MF2 – a relatively undisturbed mangrove stand dominated by *Bruguiera gymnorrhiza*, *Rhizophora mucronata* and *Ceriops tagal*;
- MF1 – a dominantly tall *Rhiziphora mucronata* forest interspersed with *Ceriops tagal* and *Sonneratia alba*, with slight disturbances that may have occurred during aquaculture ponds construction;
- DA – represents an area initially cleared of mangrove forest to pave way for aquaculture activities but that was never developed;
- AQ – an operational aquaculture pond; and
- SP – a pond of disbanded saltworks.

Sampling Protocol

The study was carried out from Oct.- Dec.'96 during a dry season period. Sampling was done once per month. Salinity and pH of overlying water for saltwork and aquaculture ponds were measured in the field. For the other stations, the above parameters were measured by digging a hole up to 20cm and measuring these parameters from the seeping water.

The concentrations of the trace metals were measured in sediments of different depths. Plastic sediment cores were collected at each station once per month for three months to a depth of 1 meter, sectioning after every 5 cm, pooling the sections into a polythene bag to reduce spatial heterogeneity and treating them as one sample. In the laboratory, sediment samples were air-dried, desegregated, and sieved through 100 mesh. Available (loosely held fraction) trace metals were extracted by leaching with 0.1N HCl (Ramadhas, Rajendran & Venugopalan 1975; Silva *et al.* 1990) for 48 hours at room temperature. This was achieved by accurately weighing 10 grams of dry sediment and extracting with 50 ml of 0.1N HCl. After 48 hours, the extracts were centrifuged for 10 minutes, decanted, and the trace metals measured in duplicate using an Atomic Absorption Spectrophotometer (Spectra - AAS).

Table 18.1
Overall means for pH, salinity, and trace metal concentrations in the sediment by station

	Fe	Zn	Pb	Cu	Cd
DA	1278.5	3.796	1.841	0.683	0.208
MF1	1228.2	3.978	1.631	0.413	0.228
MF2	1718.5	5.878	1.641	0.503	0.178
SP	2373.6	4.318	2.521	0.153	0.128
AQ	960.4	2.618	1.621	0.303	0.208

	Cr	Mn	Al	pH	Salinity
DA	6.22	21.321	434.21	6.81	48.44
MF1	6.28	23.361	296.71	6.63	40.22
MF2	15.79	15.111	713.07	6.47	43.41
SP	23.86	24.81	323.86	8.09	56.96
AQ	2.760	16.961	203.50	8.23	45.15

RESULTS

Table 18.1 shows the grand means for pH, salinity, and trace metal concentrations in the Ngomeni sediments. Salinity was highest in the saltwork pond (SP) (56.96), followed by degraded area (DA) (48.44), aquaculture ponds (AQ) (45.15), and was lowest in mangrove forests MF2 (43.41) and MF1 (40.22). The pH was highest in AQ (8.23), SP (8.09) and DA (6.81), and lowest in MF1 (6.63) and MF2 (6.47). Station AQ had the lowest concentrations for all the elements, except for Cd. Stations MF2 and SP generally had the highest concentrations, especially for Fe, Zn, Cr, and Pb. Stations MF1 and DA had intermediate values, but had the highest concentrations of Cd and Cu respectively.

Figure 18.1 (pp.279-280) shows the variation of concentration of the trace elements with depth profile for the trace elements. For Iron, there was a general increase with respect to depth followed by a gradual decrease in stations DA, MF1 and MF2. In station SP the Fe concentration was very low for the upper 20 cm, with dramatic rise at 25 cm, followed by a decline at 90 cm. In station AQ, Fe concentrations increased with depth, to a peak at 30 cm, followed by a dramatic fall at 65 cm to very low levels. There were no major variations in Pb concentrations with respect to depth except station SP with maxima at the upper 5 cm and general decreases with depth. The Zinc concentration was lowest in station SP for the first 20 cm with sharp peaks, followed by falls, with a maximum at 75 cm. For the rest of the stations, zinc concentrations generally decrease with depth. Copper concentration was lowest in station SP and there was general decrease with depth for all the stations, except for station MF1, which showed a dramatic rise at 25 cm, and station DA, with a maximum at 80 cm depth.

Chromium was in low concentrations or below-detection limit for the upper 20c m in station SP, and from 60 cm downward for station AQ. For all stations, except AQ, the concentration generally increased with depth, with alternating peaks and falls. For cadmium concentrations there was not much variation of concentration with depth, except for station SP which had the highest concentration among all the stations in the upper 10 cm, decreasing to a minimum at 30 cm, before rising again. Aluminium was below detection limit for the first 10 cm, with gradual increase afterwards. In station AQ, Al concentration was very low or below detection limit from 70 cm downwards. In stations MF1, MF2 and DA, Al concentration increased with depth to around 25 cm and started declining gradually downward, except for a sharp maximum at 60 cm in station DA.

Finally, there is a sharp decline in concentrations of manganese in the upper 5 cm in station DA. Generally, in all the stations, except SP, the manganese concentration decreases

Fig. 18.1 *Trace metal concentrations (micrograms/gram) by depth and station.*

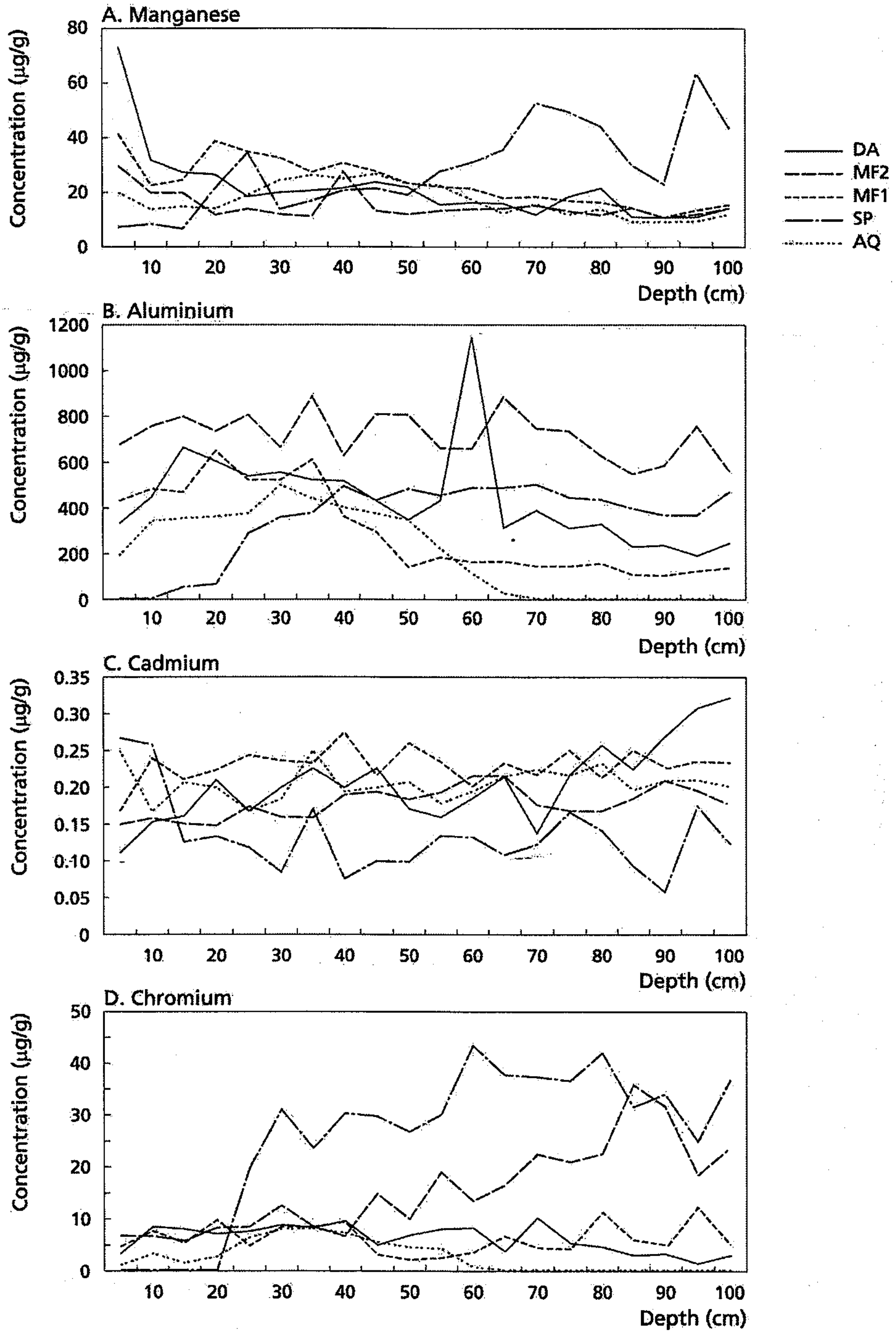
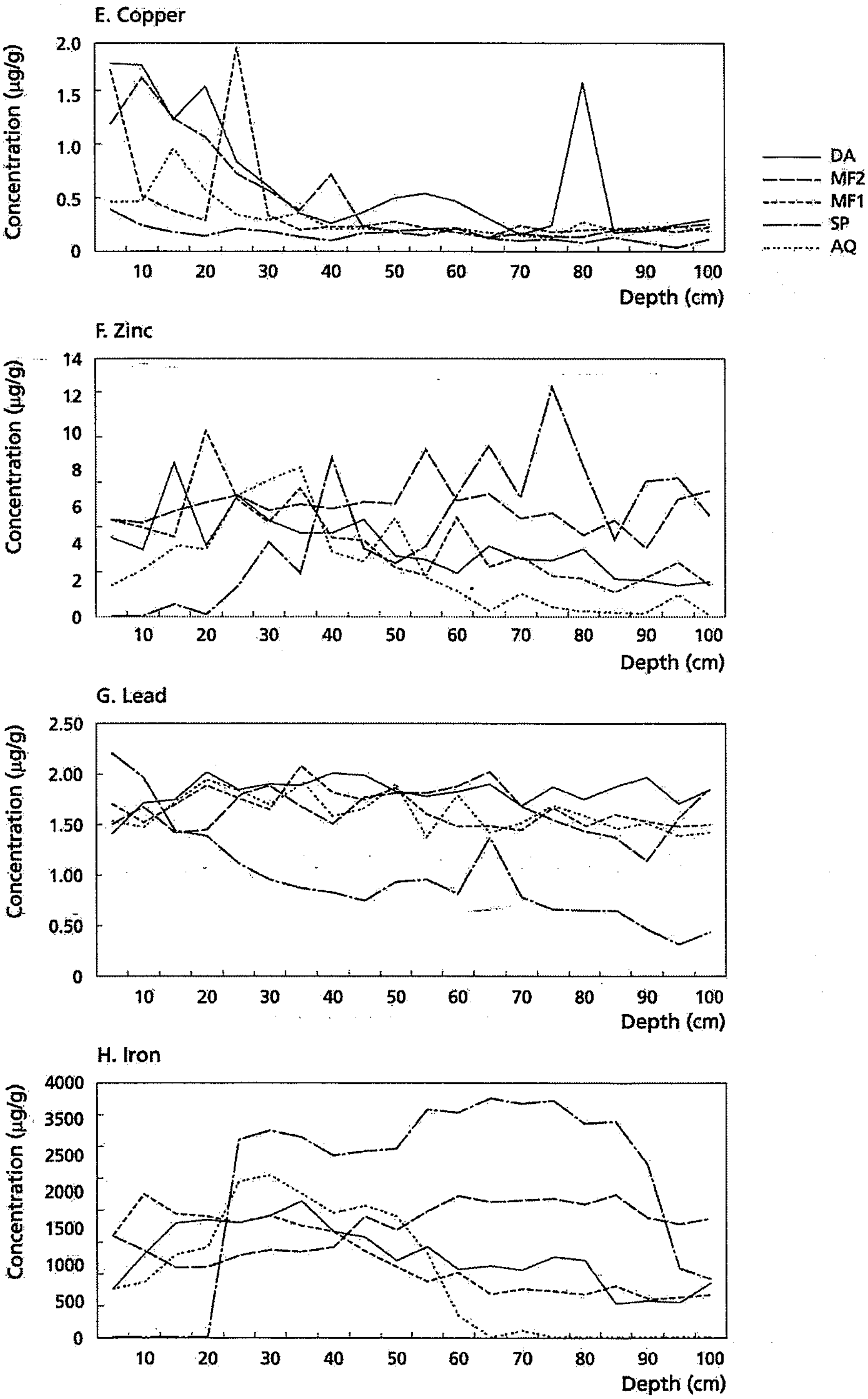


Fig. 18.1, *continued*



with depth. Station SP's Mn concentration is lowest among all the stations in the upper 15 cm and gradually increases with depth. The relative concentrations of trace elements in sediments were found to be Fe > Al > Mn > Cr > Zn > Pb > Cu > Cd.

Comparisons of the trace metal concentrations among the different stations and with respect to depth profile and month was carried out using analysis of variance (Zar 1984). Appendix 18.1 (p.278) gives a summary of ANOVA. For Fe, Cu, Mn, Cr, and Al there are statistically significant differences between stations, and with respect to months and depth profile at $p<0.05$ level of significance. There are statistically significant differences between stations, and with respect to months for Zn and Cd, but none with respect to depth. There are no statistically significant differences between stations, months, and depth, for lead.

Discussion

The mangrove station MF2 was found to have highest concentrations of available trace metals, followed by the saltwork pond. The degraded area (DA) and mangrove forest (MF1) had intermediate concentrations, with aquaculture pond (AQ) being the poorest in available trace metal concentrations. Many factors may influence bioavailability of trace metals. As regards physico-chemical parameters pH, salinity, temperature and organic matter have been mentioned as the main factors influencing bioconcentration of metals (Karez 1995). Suspended matter is the most important pathway for the distribution and transport of metals. It has long been appreciated that organic matter is involved in geochemical transport and concentration process. The zinc concentration of lake sediments is directly related to their organic content (Livens 1991). Lacerda & Abrao (1984) demonstrated that Zn and Cd are found almost totally bound weakly to the suspended particulate fraction, and Cr and Pb are strongly bound, decreasing their biological availability.

The presence of metals in sediments may be as a result of natural (volcanism and weathering) or anthropogenic release. Ngomeni is quite remote from any industrial activities (other than salt manufacture and aquaculture), and there are no visible human activities which can directly introduce trace metals. The texture and mineralogical characteristics of the sediments is important for interpretation of results of heavy metal concentrations. Heavy metal content is governed by sediment properties; for instance, fine fraction composition and specific area, and correlation with these variables have been reported (Forstner & Salomons 1980). The main part of the metal can be expected to be bound onto small sized sediments which have relatively the highest surface area (Onyari 1985). It can be hypothesised that in any given area, dark grey, soft, fine particle sediment types will in general have higher metal content than brown coarse sediment type. The relative concentration in sediments found, namely Fe > Al > Mn > Cr > Zn > Pb > Cu > Cd, is similar to that reported by Silva *et al.* (1990).

Stations MF2 had the highest concentration of available trace metals and this could be attributed to low pH, sandy mud texture, and high organic matter content (See Kamau 1997). Stations MF1, SP, DA and AQ had muddy sand texture and this greatly varies down the profile affecting the trace metal concentration. The low concentrations of available trace metals in station AQ may be attributed to low organic matter, high pH values and great demand for the essential trace metals for phytoplankton growth that support the prawns. In station SP the concentration of Fe, Zn, Cr, Al and Mn were very low in the upper 20 cm. This may be attributed to accumulation of filamentous algae over time. Within this upper 20 cm dark slimy algal mass dominates before one reaches the hard sediments substrate. Results under laboratory conditions have shown that Zn is strongly bound to cellular sites of algae (Karez 1995), and this may also hold for the other elements.

In station AQ there was a dramatic decrease/fall in concentration for Fe, Zn, Cu, Cr, Al, and Mn from 60 cm downwards. This may be attributed to change in sediment textural characteristics which become coarse from this depth. The concentration of trace metals in stations MF2, MF1 and DA may also be attributed to presence of organic matter. Generally decomposition of organic matter in sediment area decreases pH through formation of humic acids. This in turn increases solubility of iron and manganese (Keefe 1972 in Ramadhas *et al.* 1975) two elements that have been shown to limit phytoplankton production in both field and laboratory conditions (Ramadhas *et al.* 1975).

Oteko (1987) studied elemental distribution up to 28 cm in the sediments of Gazi Creek. He reported that Al, Fe, Mn increase gradually to attain subsurface maxima at about 5 cm followed by a sharp decrease, then a gradual increase down the core. In the above study the total concentration for the trace metals in μg/g were Al (4521-14,710), Fe (365-6239), Mn (2-36), Zn (0-10), Cu (2-10), Cd (<0.03) and Pb (2-7). The above concentrations were low compared to others taken at Tudor Creek and were attributed to the high % of quartz, which dilutes other mineral phases as reflected in the sandy nature of Gazi sediments.

Another important factor that could contribute to distribution and concentration of trace metals is microbial activity. Agate (1988) contends that micro-organisms participate in conversion of ferric into ferrous ions in two ways viz.: altering the redox potential and pH through their metabolic activities, and by using ferric ion directly as an electron acceptor. The microbial mineralisation of organic substances in the oxic zones of sediment is the dominant factor in release of Cd, Ni, Zn and Cu to the overlying waters (Petersen *et al.* 1995). Gerringa (1990) in Song & Muller (1995) found that dissolved Cu, Cd and Pb and organic carbon increases rapidly after addition of easily degradable organic matter. Kraetzer (1976) quoted in Macintosh (1982) showed that fiddler crabs *Uca* concentrate the trace metals Mg, Mn, Zn and Mo in their faces and may lead to subsurface maxima.

It has been suggested that salt marsh plants transfer oxygen from aerial roots, and may release it through roots into anoxic sediment; Silva *et al.* (1990) showed higher available Fe, Mn and Cu concentrations in fine roots of *Rhizophora mangle* in the surrounding sediment. They also reported peak concentrations of Fe, Mn and Cu in fine roots around 40 cm depth, which may be due to a process involving the releasing of oxygen by mangrove roots. Therefore, the peaks and falls in stations MF2, MF1 and DA could be attributed to microbial/macro-invertebrate activity and subsurface oxidation of sediments by fine roots of mangrove trees. Studies in metal export from mangals have shown that plant litter is very poor in trace metal content leading to a very low export rates (Lacerda *et al.* 1988 quoted in Silva *et al.* 1990).

In case rehabilitation or restoration efforts are undertaken, the following should be done

- Breaching the dikes surrounding the non-operational ponds and the degraded areas to allow free flow of tidal waters. Where possible channels should be constructed to direct water into these areas during neap tides, to ensure lower salinity levels.
- Restoration of mangroves in the non-operational saltwork ponds would call for dredging of the upper 20 cm algal mass to improve aeration within sediment, and not to interfere with root development of planted mangrove trees.
- Species tolerant to high salinity levels be used for restoration e.g. *Avicennia marina* and *Ceriops tagal.*

Conclusion

The effect of trace metals on aquatic organisms depends both on concentration of the metal and its availability to the biota. The uptake of metals by the biota is also affected by factors such as pH; lower pH means increased availability and increased uptake of the metal. Trace metals such as Cr, Mn, Co, Cu, Zn, and Fe play a biochemical role in the life processes of aquatic plants and animals and their presence in trace amounts in the aquatic environment is essential. However, high concentration may be toxic. The relative concentration in the Ngomeni sediments were Fe > Al > Mn > Cr > Zn > Pb > Cu > Cd. Station-wise the concentration levels were as follows MF2 > SP > MF1 > DA > AQ. Station AQ was especially poor in available trace elements. If rehabilitation / restoration activities were to be initiated in the degraded sites and non-operational salt pans, trace metals levels would not be the limiting factor (neither in terms of deficiency nor toxicity); rather the salinity levels could be.

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Appendix 18.1 *Analysis of variance (ANOVA) of the influence of station, month, and depth profile on trace metal concentrations*

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
ZINC					
Station	331.342	4	82.836	8.760	.000
Month	147.874	2	73.937	7.819	.001
Depth (cm)	291.810	19	15.358	1.624	.057
Residual	1437.298	152	9.456		
LEAD					
Station	35.177	4	8.794	.317	.866
Month	53.215	2	26.608	.960	.385
Depth (cm)	502.976	19	26.472	.955	.517
Residual	4213.464	152	27.720		
IRON					
Station	73464012.996	4	18366003.249	35.875	.000
Month	34389403.508	2	17194701.754	33.587	.000
Depth (cm)	51229325.701	19	2696280.300	5.267	.000
Residual	77815567.686	152	511944.524		
COPPER					
Station	9.784	4	2.446	11.841	.000
Month	1.997	2	.998	4.833	.009
Depth (cm)	26.248	19	1.381	6.687	.000
Residual	31.401	152	.207		
CHROMIUM					
Station	18079.826	4	4519.957	96.424	.000
Month	2003.607	2	1001.804	21.371	.000
Depth (cm)	4254.974	19	223.946	4.777	.000
Residual	7125.109	152	46.876		
CADMIUM					
Station	.386	4	.096	32.208	.000
Month	.027	2	.013	4.466	.013
Depth (cm)	.034	19	.002	.596	.905
Residual	.455	152	.003		
ALUMINIUM					
Station	9245965.726	4	2311491.432	48.212	.000
Month	1857334.572	2	928667.286	19.370	.000
Depth (cm)	3176420.495	19	167180.026	3.487	.000
Residual	7287521.433	152	47944.220		
MANGANESE					
Station	4129.763	4	1032.441	9.273	.000
Month	5327.025	2	2663.513	23.922	.000
Depth (cm)	6529.442	19	343.655	3.086	.000
Residual	16923.882	152	111.341		

19

Die-Back in Sonneratia Alba in Kenyan Mangroves is due to Attack by a Cerambycid Beetle and a Metabellid Moth

Ian Gordon[1] & Koen Maes[2]

ABSTRACT

Extensive die-back in the pioneer mangrove tree, *Sonneratia alba*, along the Kenyan Coast was investigated. It was caused by a cerambycid beetle *(Bottegia spinipennis)* and a metabellid moth *(Salagena obsolescens)*. The beetle attacked small branches, laying its eggs singly, while the moth attacked large branches, laying its eggs in batches. The beetle was found at two sites, Mida Creek in the north and Gazi in the south. The moth was only found at Gazi. Three parasitoids belonging to two species of *Echthromorpha* were reared from the beetle larvae. Some basic observations on the life histories of the two species are reported. Both species are Afrotropical in their distribution.

INTRODUCTION

The impetus for this research came from observations in 1992 of extensive damage to *Sonneratia* trees in Lamu and Gazi. There appeared to be considerable die-back of both mature and young trees. J. Kairo collected some of the affected branches and found them to be infested with insect larvae which he was able to rear through and which produced moths.

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The moth was initially identified as *Salagena discata*, a cossid or goat moth. These kinds of moths are frequent pests of ornamental and fruit trees, less commonly also of timber species. They are characterised by long life histories and high fecundities with single females able to lay over 1,000 eggs. Typically eggs are laid on the bark or inside emergence tunnels and the larvae bore into the pith of the stem.

The scale of the infestation, with in some cases almost every tree affected, attracted the attention of the various institutions concerned with Kenyan mangroves (FD, KWS, CDA, KEFRI and KEMRI). Concern was raised on two grounds: (i) that *Sonneratia alba* is a pioneer tree that buffers the effects of the open seas and assists other trees to establish themselves, stabilising the coastal profile; and (ii) that the infestation appeared to be increasing. A number of institutions were therefore invited to a workshop in Mombasa in September 1995 hosted by the KWS Netherlands Wetlands Programme together with CDA.

At this meeting the problem was discussed, institutional roles were assigned and proposals were invited. Some doubts were expressed as to how serious the problem was. Apart from an observation by Martin Johnson of the Lamu COMMIFOR Project that 70% of the Lamu *Sonneratia* had suffered crown die-back and 5% were dead, no quantitative data on infestation rates were available. Johnson also noted that: (i) *Sonneratia* was a relatively minor component of the mangrove accounting for only 3.5% of the trees; (ii) that its economic importance was very limited; and (iii) that attack seemed to be confined to levels above the peak spring tides, allowing survival and recovery. The question was raised as to whether or not the insect responsible was an exotic. If it was endemic to the region, then it was possible that the infestations were cyclical or were not threatening to the long-term survival of *Sonneratia*.

The major objectives of this study were to (i) verify the identity of the pest or pests, and (ii) to determine whether or not natural enemies in the form of insect parasitoids could be detected. This last point was critical because it would be a good indicator as to whether or not the pest was a recent invader of the Kenyan mangroves. The main reason why exotic pests are so damaging is that they escape their natural enemies from their place of origin and have no natural enemies in their new locality.

Study Sites and Methods

Field work was almost entirely at Mida Creek, although there were three trips to Gazi. (Map 1: p.256). At the beginning of the study at Mida, a quick survey was done of the distribution of the main stands of *Sonneratia* in the creek as a guide to future collecting efforts. Identifications were done by Dr. Maes and by M.L. Cox of the International Institute of Entomology (London). All material collected has been through sampling dead branches and dissecting them for the pests. Light trapping was carried out at Gazi over 4 nights (8-11 January, 1997). Immature insect specimens were either reared in split *Sonneratia* twigs or preserved in 70% alcohol and adults were killed with ethyl acetate, set and pinned. Some adults were retained alive for mating and oviposition and were kept in plastic containers or in insect net sleeves on live plants in growbags or in the field. Moth genitalia were dissected and mounted on slides and photographed at the National Museums of Kenya (NMK). All preserved insect material has been deposited in the NMK collections.

RESULTS

Taxonomy

Two different species of *Sonneratia* borers were collected, one a beetle and the other a moth. They are formally described in Appendix 19.1 and 19.2 (pp.288-289).

Field Collections

Eleven stands of *Sonneratia* at Mida were located ranging in size from 3-4 trees to more than 20 and were found mainly on the northern margins of the creek. A noticeable feature of the *Sonneratia* at Mida in comparison to that at Gazi was the relative absence of larger mature trees.

Table 19.1 *Summary of field collections at Mida and Gazi*

SPECIES	STAGE	MIDA	GAZI	TOTAL
Bottegia	Larvae	168	54	222
Bottegia	Pre-pupa	0	1	1
Bottegia	Pupae	12	0	12
Bottegia	Adults	11	1	12
Salagena	Larvae	0	152	152
Salagena	Pre-pupa	0	1	1
Salagena	Pupae	0	28	28
Salagena	Adults	0	0	0

Appendix 19.3 (p. 290) shows the collection dates, numbers and life history stages of the two species in the field samples from Mida and Gazi. These data are summarised for the two sites in Table 19.1. It appears that *Salagena obsolescens* is not present at Mida. The vast majority of specimens were larvae (91% for *Bottegia* and 84% for *Salagena*). Pupae were more common in the *Salagena* (15%) than in the *Bottegia* (4%) samples. No adults were observed in the field and the light trapping at Gazi failed to attract either of the two borers.

Life Histories

Because of the apparent absence of *Salagena* at Mida Creek, most life history observations were made on *Bottegia*. Neither species was reared all the way through its life cycle. In the case of the moth, the larvae died quickly in the split twigs in which rearing was attempted. One unmated adult female moth laid 1071 infertile, greyish brown eggs on the walls of a plastic container over 6 days (13-19 February) after eclosing on the 12th. Observations on the moth in the field at Gazi revealed a similar mode of attack to that reported by De Villiers & Mathee (1973), with the larvae tunnelling initially in the bark and subsequently into the hardwood, concentrating their attacks at the forks of branches. The attack sites are conspicuous in the field because of the large amount of frass and silk that collects on the bark at the tunnel openings. The damage is severe causing the death of large branches. As many as 25 late instar larvae were recovered from a single branch about 75 cm long.

The *Bottegia* larvae survived reasonably well in the split twigs although the adults which developed from them were small in comparison with those found in the twigs collected from the field, suggesting poorer nutrition. The longest period for which larvae were maintained in the twigs was 47 days. The length of the pupal stage was not monitored accurately but was about 2-3 weeks. The higher percentage of pupae in the field collections of *Salagena* (15% vs. 4%) suggests that the moth pupa lasts somewhat longer. Adult beetles were observed mating on four occasions, in each case 1-2 days after emergence. One mating was timed as lasting 5 minutes. Females laid eggs freely on the sides of plastic containers when so confined, laying between 4 and 30 eggs in one day. The greatest number of eggs laid by a single female was 51, laid on two successive days. Eggs were yellow in colour. When female beetles were confined on live *Sonneratia* seedlings in grow bags, they cemented the eggs singly on the fresh stems. Records of egg durations were inconsistent with some reported as hatching after 7 days and others after 31 days. The larvae disappeared on hatching and were presumed to have bored immediately into the stems. Leaf wilting followed rapidly, being observed in one case 4 days after the first egg had hatched. The larvae bore down into the stem towards its base. The orientation of 25 larvae in their twigs was recorded and in every case they had their heads pointing down the stems in which they were found.

The two species show a number of differences in their mode of attack of which the most obvious is that *Bottegia* attacked the small stems while *Salagena* went for the larger branches (Table 19.2).

Table 19.2
Differences in mode of attack between Salagena and Bottegia

FEATURE	*SALAGENA*	*BOTTEGIA*
Oviposition Behaviour	Eggs laid in masses at forks in large branches.	Eggs laid singly near stemtips.
Fecundity	Higher, capable of laying >1,000 eggs in 6 days. .	Lower, maximum recorded number of eggs laid was 51 in 2 days.
Behaviour on Hatching	Feed gregariously on bark before boring in stem and tunnelling up into branch.	Bore directly into stems and tunnel downwards.
Size of Branches Attacked – Mean Diameter (s.d.)	Large; 140.5 (34.0) mm.	Small; 54.7 (13.0) mm.
Signs of Attack	Large branches die back; Conspicuous collection of frass and silk at branch forks.	Small stems die back; Little external signs of attack other than die-back.

Natural Enemies

Two Hymenopteran parasitoids were bred from beetle larvae during this study. They were identified by Koen Maes after comparison with named material from the collections of NMK as *Echthromorpha agrestoria variegata* Brulle and another unidentified *Echthromorpha* species. Parasitism rates were low with only 3 parasitoids recovered from a total collection of 273 *Bottegia* specimens at various stages.

Ants were also found in some of the stems that had been tunnelled by *Bottegia* larvae and they may also be occasional predators. No parasitoids were recorded from *Salagena* but sample sizes were much smaller.

Discussion

The major finding of this investigation is that more than one stem borer is currently attacking *Sonneratia* on the Kenyan coast and that the relative importance of the two species varies with location. At Mida the moth appears to be absent, while both species are found at Gazi. The strong preference of *Salagena* for the larger more mature *Sonneratia* trees may explain its apparent absence at Mida where such trees are rare.

It is clear that neither the moth nor the beetle are recent invaders from outside Africa. Each belongs to a genus with an Afrotropical distribution and all recorded localities for the two species are African. The presence of hymenopterous parasitoids attacking *Bottegia* is further evidence that this is an indigenous stem-borer. No parasitoids were recorded on *Salagena* but De Villiers & Mathee (1973) reared two unidentified species of parasitic Hymenoptera from the pupae. It is likely that larger samples of the moth would also reveal natural enemies at Gazi and elsewhere on the Kenyan coast.

However, it remains possible that one or both of the two species has made a recent host shift to *Sonneratia*, thus accounting for both the severity of the attacks and the lack of previous records. Such a host shift may enable an escape into enemy-free space if natural enemies of the stem borers on the old host orient specifically to the old host or its habitat. Nothing is known of alternative hosts of *Bottegia* (this report gives the first record for a hostplant for this genus), although one of its parasitoids (*E. agrestoria variegata*) has been recorded from caterpillars of *Katochalia junodi* Heylaerts (Lepidoptera, Psychidae) on coffee in Foumbot, Cameroon (Nonveiller 1984). Host plant records for *Salagena* species are more numerous and include various indigenous and fruit trees including cashew (De Villiers & Mathee 1973; Pinhey 1975; Latis 1990). Given the prevalence of cashew along the coast, a host shift from it to *Sonneratia* might not be difficult. The possibility of a host shift therefore seems to be higher for the moth than the beetle.

There is clearly an element of resource-partitioning in that the beetle attacks small stems while the moth attacks large branches. Such resource partitioning is sometimes the result of a long co-evolutionary history in which there is selection for individuals which avoid interspecific competition. This is however unlikely to be the case in the present instance.

The differences in attack characteristics between the two species are most probably due to fundamental differences in their life history biologies.

There is no available information in the literature on control of *Bottegia* but several measures have been used against *Salagena* on fruit trees. De Villiers & Mathee (1973) mainly used chemical control in litchi plantations. After 26 days of the treatment with 0.04% methidathion or 0.047% methomyl or 0.075% azinphos-methyl or 0.075% parathion, 95-100% of the larvae were dead. Latis (1990) also used chemical control in cashew plantations. The populations of the larvae were also reduced by manually removing the larvae and pruning affected branches.

Whether any control measures will be necessary to protect *Sonneratia* in Kenya's mangroves remains an open question that can only be settled by further monitoring at particular sites over a longer time period, by more extensive sampling at different sites, and by an analysis of costs and benefits. The relative importance of the moth and the beetle needs to be further investigated in different mangroves along the coast. Because of its greater fecundity and the size of the branches attacked, the moth is likely to be the more damaging of the two species, although not at all sites (e.g. not at Mida). Since *Sonneratia* has little commercial importance, any case for control measures would have to be made on the basis of its ecological importance as a pioneer species.

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Appendix 19.1

Bottegia spinipennis Fuchs 1961
(Coleoptera: Cerambycidae, Cerambycinae).
Fuchs, 1961, *Kol. Runds.*, 39, 28.
Type locality: Kidugallo, Tanzania.

Origin: Larvae, pupae and adults of this coleopteran were collected in fresh, dead and dying shoots of *Sonneratia* at Mida Creek (Malindi District) on the north coast of Kenya and at Gazi (Kwale District).

Systematics: Identification was done by M.L. Cox using the key in Quentin & Villiers (1971). *Bottegia* belongs to the tribe Psebiini. Quentin & Villiers recognise 12 genera in this tribe and four species of *Bottegia* Gestro, all found in Africa, namely *spectabilis* Gestro; *rusellae* Quentin & Villiers; *rubra* Aurivillius; and *spinipennis* Fuchs. There are no other species of *Bottegia* in the NMK collection.

Description: The elongate cylindrical larvae of this genus have not previously been described. Those of *B. spinipennis* closely resemble the larvae of *Pseudobottegia* sp. described by Duffy (1957) especially with respect to the elongate head and body, 2 pairs of black ocelli, segmented antennae with the basal segment usually long, the labium greatly extended and the legs 3-segmented. They differ in that the hypostoma is not smooth, but bears several longitudinal carinae and the body length in the last instar is 50 mm rather than 36. The pupae are exarate and are of the general form described by Duffy (1957). A description of the adult male and female is given in Quentin & Villiers (1971). According to these authors, the sexes may be distinguished by the colour of the tibia of the first two legs which are black in the female and reddish brown in the male.

Larvae and Hostplant: According to Duffy (1957), the larvae of *Pseudo-bottegia* are associated with *Syzygium* species (Myrtaceae) and attack the shoots which soon die off from the point of attack. The galleries are mostly in the hardwood. Prior to this study, no data were known as to the hostplants of *Bottegia* species. For more details of its mode of attack on *Sonneratia,* see below.

Distribution: Prior to this study this species was only known from Tanzania.

Appendix 19.2

Salagena obsolescens Hampson 1910
Lepidoptera: Metabellidae.
Hampson, 1910, *Ann. Mag. Nat. Hist.*, 8, 120, 164.
Type locality: Durban, South Africa.

Origin: Larvae and pupae of this moth were collected from dead and dying branches of *Sonneratia in* the mangrove forest at Gazi in Kwale District. Adults were eclosed from the pupae.

Systematics: Identification was done by Dr. Koen Maes. The following species of *Salagena* Walker occur in East and Southern Africa: *tessellate* Distant; *spiculata* Karsch; *albonotata* Butler; *narses* Fawcett; *atridiscata* Hampson; *irrorata* Le cerf; *albicilia* Hampson; *obsolescens* Hampson; and *discata* Gaede. The collections of NMK contain a further 5 to 6 undescribed species and some doubtful identifications.

Description: Thorax variegated pale and dark brown. Abdomen grey with prominent black or brown dorsal tufts near base followed by reddish-brown ones. Forewing cream with rows of black rings encircling reddish-brown spots; plain brown dots on the costa. Hindwing grey, sometimes pale white. Forewing 15-23 mm.

Larvae: Eggs are laid on the bark. A female was observed to lay 276 eggs (De Villiers & Mathee 1973). The larvae tunnel first in the bark and later in the wood, generally entering at a fork. Large quantities of frass and silk around the openings of the tunnels indicate the sites of attack. Pupation takes place in the tunnel. Though the larvae do not kill the trees, they cause die-back.

Hostplant: Reported as a borer in *Eugenia,* guava (Pinhey 1975), litchi, pecan, macadamia, avocado and several indigenous trees (De Villiers & Mathee 1973). Cashew was first mentioned by Latis (1990) for Zambia. It is here reported as a borer in *Sonneratia* in Kenya.

Distribution: Natal, Zululand, Transvaal and Mozambique to Zimbabwe, Zambia and equatorial East and West Africa.

Distribution in Kenya: South Coast, Mangroves of Gazi; Kitale (Stoneham Estate).

Appendix 19.3

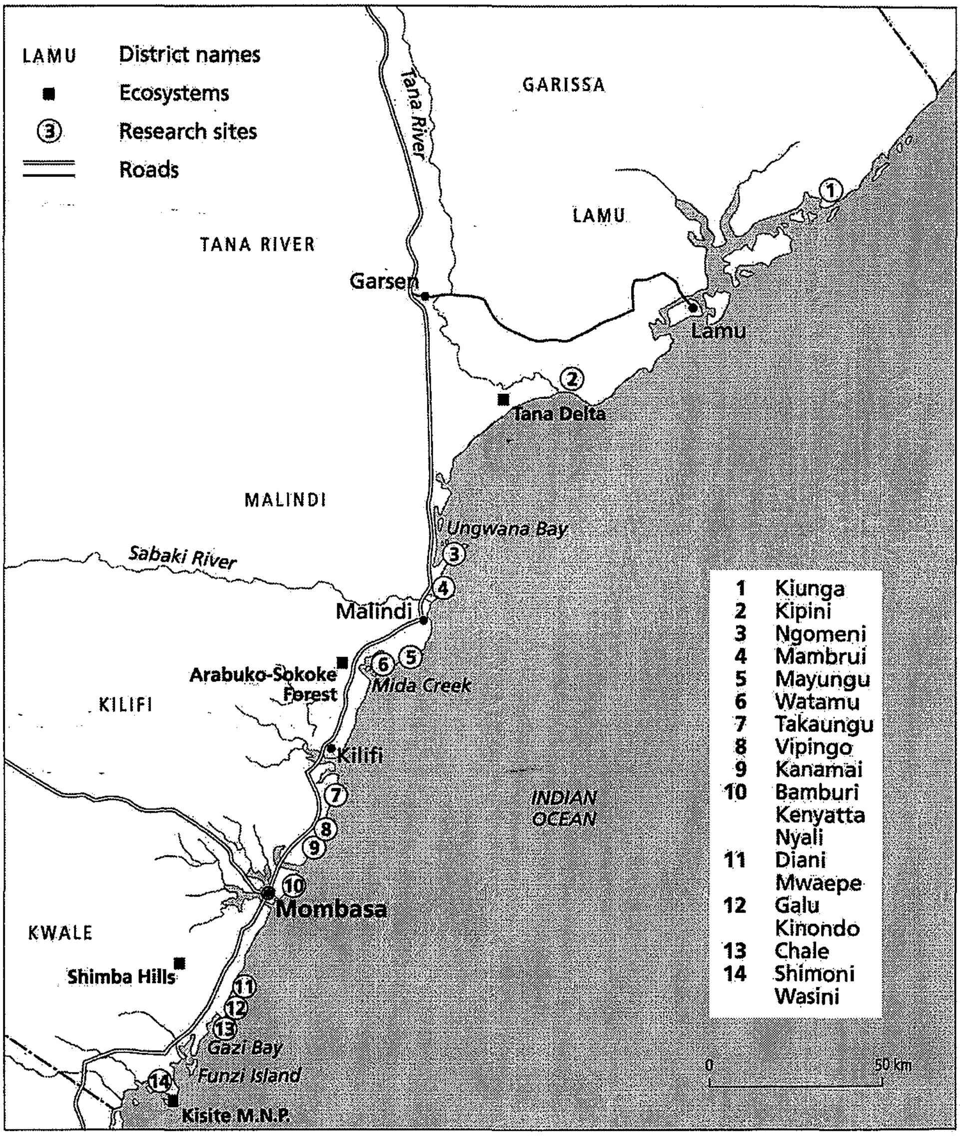
Field collections of Sonneratia stemborers at Mida and Gazi

	DATE	SPECIES	STAGE	NUMBERS
Mida	23-25 Sep.'96	Bottegia	Larvae	49
	27-30 Dec.'96	Bottegia	Larvae	22
	2 Jan.'97	Bottegia	Larvae	28
	1-6 Mar.'97	Bottegia	Larvae	31
	1-6 Mar.'97	Bottegia	Pupae	10
	1-6 Mar.'97	Bottegia	Adults	4*
	20 Mar.'97	Bottegia	Larvae	13
	20 Mar.'97	Bottegia	Adults	3
	2 Apr.'97	Bottegia	Larvae	25
	2 Apr.'97	Bottegia	Pupae	2
	2 Apr.'97	Bottegia	Adults	4
Gazi	8-11 Jan.'97	Bottegia	Larvae	26
	8-11 Jan.'97	Salagena	Larvae	40
	8-11 Jan.'97	Salagena	Pupae	13
	5-7 Apr.'97	Salagena	Larvae	41
	5-7 Apr.'97	Salagena	Pre-pupa	1
	5-7 Apr.'97	Salagena	Pupae	15
	5-7 Apr.'97	Bottegia	Larvae	28
	5-7 Apr.'97	Bottegia	Pre-pupa	1
	5-7 Apr.'97	Bottegia	Adult	1
	19-22 Jun.'97	Salagena	Larvae	71

* 3 with parasitoid larvae

Biodiversity

Map 1 *Kenya Coast with location of research sites*



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Biodiversity and the Kaya Forests

W.R.Q. Luke[1] & A.N. Githitho[2]

ABSTRACT

This paper contains a review of the work of the Coastal Forest Conservation Unit in protecting the traditional kayas with their large biodiversity. Ongoing botanical research as well as research of a wider nature is listed and activities such as a field herbarium and an indigenous plant nursery are briefly described. A list of selected references on coastal flora is attached.

THE KAYA FORESTS

The Kaya forests are relict patches of the once extensive and diverse lowland forest of Eastern Africa classified within White's (1983) Zanzibar-Inhambane Regional Mosaic. This region occupies the coastal belt from southern Somalia to the mouth of the Limpopo River in Mozambique.

The Zanzibar-Inhambane mosaic is 50-200 km wide, except where it penetrates further inland along broad river valleys. Most of the land lies below 200m, with the exception of a few plateaux and scattered hills that rise considerably higher, including the Shimba Hills (c. 400m). More recently, Burgess, Clarke & Rodgers (1998) have proposed splitting the Zanzibar-Inhambane region into two, the Kenyan coastal area then falls within the 'Swahili Regional Centre of Endemism'.

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Kaya means 'homestead' in several Bantu languages and historically the forest locations once sheltered fortified villages set up by Mijikenda people fleeing enemy groups in the north. Over time, the people moved out of them and cleared the surrounding areas for farms. The forested sites have been left intact, protected and revered as sacred places.

Apart from their cultural and historical importance, many of these small forest patches are very diverse and have a high conservation value as determined by various biological studies. More than half of Kenya's rare plants are found at the coast, many found within these sacred forests. At present over 60 of these forest patches have been identified in Kwale and Kilifi/Malindi Districts, ranging from the smallest of 5 ha. to the largest at over 400 ha.

Over the past few decades, a declining respect for the elders and traditional values, a rising demand for land for agriculture and development, mining and forest products, has led to loss and damage to these small forests and associated sacred groves.

It is difficult to make estimates of the numbers of people actually using the Kayas in various ways. Between fifty and two hundred people (depending on the size of the Kaya and the number of people living in the vicinity) may attend Kaya cultural ceremonies with about half of the sixty identified Kayas actually active. This gives some indication of the numbers of people who have a close relationship with the forest, but in both Kilifi/Malindi and Kwale areas, Kaya forests protect areas of vital water catchments.

There are subtle differences in the extent of their ceremonial use between Kilifi/Malindi and Kwale. In Kilifi/Malindi on the North Coast, the traditional rites and protocols related to Kayas are more rigorously maintained by the Elders than in Kwale. This may be due to the effect of religion, as most of the Digo and Duruma on the South Coast are Muslim. However the desire to protect the sites is equally strong both in the North and in the South.

The Coastal Forest Conservation Unit (CFCU)

The Coastal Forest Conservation Unit was set up in 1992 by the National Museums of Kenya (NMK) with support from the World Wide Fund for Nature (WWF-I). This followed recommendations made by the preceding WWF-I funded project, Coast Forest Survey, a three-year project to document the flora and forest conservation status of coastal Kenya.

CFCU was charged with the task of continuing investigation of coastal flora and associated fauna as well as assisting the Kaya Elders and local communities to protect the Kayas for their biological and cultural values. It was planned to build on this nucleus of conservation practice through educational programmes and training. CFCU hoped to check and reverse the trend described above. The CFCU activities cover 45 of the over 60 known sites on the North and South Coasts.

In the fiscal year 1994/95 the Project received a boost in resources due to the approval of funding support from the British Government (DFID) to WWF-UK for CFCU under the Joint Funding Scheme (JFS). The additional support enabled the Unit to broaden its mandate and activities including opening a second office in Kilifi town (the first being at Ukunda in Kwale District). The goals and objective of CFCU under the new funding scheme are listed as follows:

Goal

To conserve the coastal Kaya forests and sacred groves for their biodiversity and cultural significance and to conserve the cultural heritage of the local communities associated with the Kaya forests.

Immediate Objectives

- The capacity of the Coastal Forest Conservation Unit (CFCU) to conserve the Kaya forests maintained or expanded.
- Antiquities and Monuments Act of Kenya and other legislation revised so as to strengthen its use for conservation of coastal forests and associated Kaya culture.
- Increased number of Kaya forests and sacred groves legally gazetted.
- Increased body of scientific and social data relevant to management for conservation of coastal forests and associated culture.
- Increased awareness of the need for, and participation in, Kaya conservation by Kaya adjacent communities.
- Decreased pressure from local communities and external agents on Kaya land and resources.
- Creation of enabling institutional framework and capacity for Kaya conservation.

These objectives and goals are to be achieved through a number of activities including community consultation and Kaya protection assistance; survey and gazettement; taxonomic and other surveys and research; education and awareness programmes; forestry extension, and a legal review programme.

RESEARCH

Since its inception, CFCU has set out to gather data on the biology of these forests and to encourage research in many disciplines including archaeology, anthropology, sociology and ecology. An early approach was to offer one or two bursaries a year for support of M.Sc. students in the field amounting to UK£ 900 per student per year.

Initially these bursaries were offered through the various departments of NMK but due to a very poor response, were then offered to the Universities. Of the six bursaries budgeted for over the five year period, only three were taken up:

- Edward Waiyaki — The effects of forest fragmentation, isolation and structure on the richness and abundance of bird communities in major coastal forests of South Coast, Kenya.
- Mohamed Pakia — The ethnobotany of selected Mijikenda Kayas.
- Festus Musila — The Sokoke Pipit.

CFCU has received support from UNESCO through its Peoples and Plants Programme in the form of funding for our Ethnobotanist to study at Durban University, both for his Honours Degree and now for his M.Sc. UNESCO has recently undertaken to fund a student at Jomo Kenyattta University of Agriculture and Technology, Staline Kibet, with his research-based M.Sc. on the ecology of Kaya Mudzimuvia.

OTHER STUDIES

CFCU has encouraged other researchers to study various facets of the Kayas by offering accommodation at either the Ukunda or Kilifi offices, limited use of transport, the expertise of CFCU staff in seeking permission from Kaya Elders to work in the forests and as guides within the different forest patches.

- Ingo Lehman and Esther Kioko have been looking into the butterfly and moth populations in two Kayas, Kinondo and Muhaka. Their preliminary report, *Notes on Butterflies and Moths and their Habitats in Two Kaya Forests* (1998), shows that some 112 species of butterfly and 165 species of moth were recorded from a 30 ha. plot in Muhaka. The richness of the Muhaka butterfly fauna (representing 12.8% of Kenya's total and including 3 Kenyan endemics and 6 species classified as rare in Kenya) strongly supports the argument in favour of conserving even small patches of coastal forest for their biodiversity value.
- Richard Helm, a Ph.D. student from Bristol University, spent some time based at the Kilifi office looking at the archaeology of various early settlement sites. His study has shown

conclusively that Kaya settlements go back far beyond the popular 16/17th century dates given by oral history, to the 8th century Iron Age and possibly earlier.

- Professor Celia Nyamweru of St Lawrence University, USA was originally requested by CFCU to produce a socio-economic report on the Kaya communities. This study evolved into a socio-cultural study (1997) and Celia has continued to visit the project area to study various aspects of the Mijikenda culture.

Several other students have been assisted by CFCU including:-

- Camilla Herd — M.Sc. on human/wildlife interaction.
- Bettina Ng'weno — Land inheritance amongst the Digo.
- Thomas Engel — Seed distribution by animals and regeneration potential, Shimba Hills.
- Raymond Obunga — Woodcarving industry.

BOTANICAL RESEARCH

Database and Checklists

The origins of CFCU lie in the previous WWF funded project, Coast Forest Survey. This three year study with Mrs Ann Robertson of Malindi, looked at the conservation status and flora of the forests of Coastal Kenya. The Coast Forest Survey (1993) lists 3037 taxa to be found within coastal Kenya (i.e. excluding Taita District) and gives some indication of geographical distribution (country-wise), a more exact distribution (district-wise) and a rarity rating.

On the completion of CFS, the plant database consisted of some 20,000 records. CFCU has continued to update and add to this database, so that the total records from the Coast region now stands at 27,152. CFCU's plant collections continue to be sent to taxonomic experts in the various families in the on-going work by the Royal Botanical Gardens (Kew, U.K.) and the East African Herbarium to complete the Flora of Tropical East Africa (FTEA). Checklists for individual Kayas, Forest Reserves, Districts and the whole region, continue to be updated both with new records and, with the constant movement in taxonomic concepts, the resultant name changes. These checklists are available from CFCU on a *quid pro quo* basis to researchers within our area. The current totals for the Coastal Districts are listed in Table 20.1

The total species list for the region (more correctly the K7 area of FTEA) currently stands at 3986 taxa and 3099 if Taita District is excluded. This would suggest that 62 new taxa (3099-3037) have been recorded in our coastal area since 1993. This is not exactly so since some taxa have been combined, others split into two or more sub-taxa, others found to be incorrect determinations and still others found to be incorrect geographical records.

Table 20.1
Number of plants contained in district checklists

KWALE	KILIFI/MALINDI/MOMBASA	TANA	LAMU	TAITA
2125	1941	1507	1000	2100

Field Herbarium

Early in the project, it was felt that a reference collection of plant specimens would be very useful to researchers, allowing many ID's to be made 'on the spot' rather than having to consult the specimens at EAH. With the donation of cupboards by EAH, the field herbarium was started in 1994. With the addition of two 40 watt bulbs in each cupboard to counter the humidity and otherwise standard herbarium practises in drying, mounting and poisoning, the collection has grown steadily. It now holds 1929 sheets representing 1561 taxa from the Kenya Coast/East Usambaras or 1465 taxa from the Kenya Coast alone.

Ongoing Projects and Collaboration

CFCU has worked closely with the Kew Gardens Conservation Projects Development Unit, in particular with their Darwin Initiative funded courses in Plant Conservation Techniques for East Africa, providing the venue, support and expertise for the field trips for two of the three courses held. The first of these Conservation Assessment and Management Plan (CAMP) workshops examined 14 globally rare plants found on the Kenyan coast. The second workshop, held in the East Usambaras, continued looking at two of these plants in addition to endemic Tanzanian species. The third workshop, held early this year in the Mwaluganje Elephant Sanctuary, Kwale District, examined the ecology of forest areas seriously damaged by elephant.

The proposed Titanium mining project in Kwale District called on CFCU to conduct the Vegetation and Floristics Baseline Study of both the mine site and the proposed ship-loading facilities. CFCU then participated in the EIA and contributed to the final report. It is hoped that the data and recommendations will go a long way to preventing or minimising any environmental degradation.

Indigenous Plant Nursery

The Project has maintained a plant nursery at the Ukunda office since 1994. The nursery serves two main objectives, the first being to supply well-grown indigenous ornamental trees and shrubs to local hotels and householders to counter what has been termed "exotic imperialism" i.e. the overplanting of Bougainvillaea, Frangipani and exotic palm trees. The second objective is to propagate rare and endemic species both as a conservation measure and to extend of knowledge of species little studied until now.

It has also proved useful in a third area, that of education. Many school students, particularly from towns like Mombasa, have no exposure to indigenous species and certainly no knowledge of local names and traditional uses of these plants. CFCU, through its Environmental Education Officers (and, hopefully in the future, its ethnobotanist when he completes his studies) uses the plant nursery to illustrate many points about Kayas and the conservation of the biodiversity they hold.

New Plant Records

If a two year period is examined immediately prior to this meeting, the plant database gives a total of 48 plants that have been found for the first time in one of the coastal districts, 25 plants that have been recorded in the K7 area for the first time and 7 plants that appear to have been collected in Kenya for the first time. This last group contains the following species:

Cassipourea gummiflua Tul.	(*Rhizophorae*)
Clitoria rubiginosa Pers. *var glabrescens* Verdc.	(*Papilionaceae*)
Diplacrum africanum C.B.Cl.	(*Cyperaceae*)
Eleocharis geniculata (L.) Roem. & Schult.	(*Cyperaceae*)
Scleria boivinii Steudel	(*Cyperaceae*)
Scleria lagoensis Boeck. *ssp canaliculato-triquetra* (Boeck.) K.Lye	(*Cyperaceae*)
Scleria tesselata Willd.	(*Cyperaceae*)

Also of note are the following: '2nd collections': 2 species

Huernia andreaeana	(*Asclepiadaceae*)
Cyperus boreobellus	(*Cyperaceae*)

Both *Huernia andreaeana* and *Cyperus boreobellus* were only known from Type collections, the former in 1961 and the latter in 1953.

'New species': 2 species

Duvalia sp. nov.	*(Asclepiadaceae)*
Kalanchoe sp. nov.	*(Crassulaceae)*

CONCLUSION

We are fortunate that, due to the cultural beliefs and traditions of the Mijikenda, remnant patches of coastal forest have been saved in areas where the ancient forests have all but disappeared. Apart from giving us the opportunity to study the ecology of rare and little known species, the Kayas also serve as invaluable conservation tools in teaching all the peoples of Kenya, of East Africa, and indeed the world, that forests are not necessarily dark places of fear and danger. If an effort is made to study and protect them, they can be places of wonder, beauty and awesome complexity.

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21

Elephant Management in the Shimba Hills Ecosystem

Moses Litoroh [1]

ABSTRACT

This paper concerns elephant management in the Shimba Hills ecosystem in Kwale District. The Shimba Hills ecosystem is completely surrounded by communities whose main economic activity is intensive agriculture. Animals (particularly elephants) regularly raid the farms even causing injury or death to people. KWS initiated all around fencing in 1994 to keep the animals within the reserve.

However, the confinement of an increasing elephant population within a small area has resulted in serious destruction of trees, opening up of the forests and erosion of biodiversity resources. As a result, some endemic species in the area are critically threatened. Options available to manage an increasing and confined elephant population are briefly discussed as well as experience with a translocation project.

INTRODUCTION

There is scanty information on the history of elephants (*Loxodonta africana*) in the Shimba Hills ecosystem. The available information indicates that traditionally elephants moved throughout Kwale District, migrating regularly from the Shimba Hills area to Mkomazi Game Reserve in northern Tanzania and Tsavo National Park, 40 km to the south-west and 60 km to the north-west, respectively (Poole *et al.* 1992; Risley 1966; Ross 1981;

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Stewart & Stewart 1963). Makin (1968) concluded that a game corridor should be established between Shimba Hills, across the Ramisi river, and west of Mt. Jombo into Tanzania. Controlled shooting of elephants by the Game Department contributed significantly to a decline in migration.

Heavy elephant poaching occurred along some parts of the migration routes (Risley 1966; Stewart & Stewart 1963). Shimba elephants were also hunted for their ivory in the surrounding areas. According to the Game Department records, Pat Ayre, a professional hunter, killed 12 elephants on control near Mrima Hill in September 1934. Further elephant mortality was caused by deliberate government action of eliminating them to settle people. In 1961/62, for instance, a total of 250 elephants were shot on control by Game Department. The establishment of Shimba Hills settlement scheme and the resultant cultivation interfered with their migratory routes. The recent construction of an electric fence has firmly curtailed the natural migration of elephants. Currently, there are approximately 700 elephants confined in the Shimba ecosystem where they pose considerable management problems. This paper describes the elephant management issues in the Shimba Hills ecosystem and how they have been resolved.

STUDY AREA

The Shimba Hills ecosystem includes the Shimba Hills National Reserve, Mkongani Forest Reserves, Mwaluganje wildlife migration corridor and the Mwaluganje Forest Reserve (Map 1: p.292). The National Reserve has an area of 192.5 km^2, while the neighbouring forests and corridor are 47.9 km^2, giving approximately an area of 240 km^2 for utilisation by wildlife. It is situated in the south-eastern part of Kenya, stretching from $39^0 17'$ to $39^0 30'$ East and from $4^0 09'$ to $4^0 21'$ South. The climatic condition is humid semi-hot equatorial (FAO/UNESCO 1977), with a mean annual temperature of 24.2^0C (Braun 1977). The Shimba Hills has two rain seasons, the 'long rains' from mid March to end of June and the 'short rains' in October and November. A mean annual rainfall of 1150 mm has been reported by Jaetzold & Schmidt (1983). Mist and fog contributes considerably to total precipitation.

The Shimba Hills Forest Reserve was first gazetted in 1903. Its size was increased to 21,740 ha in 1956. In 1967 the Shimba Hills National Reserve (19,250 ha) was gazetted, and superimposed on the bulk of the Shimba Hills Forest Reserve. By this gazettement it became the responsibilities of the Wildlife Conservation and Management Department, the predecessor of KWS, and the Forest Department to manage the reserve jointly. Mkongani West (1366 ha) and Mkongani North (1113 ha) Forest Reserves were not gazetted as National Reserve. Mwaluganje Forest Reserve (1715 ha) lies approximately 5 km north of the Shimba Hills National Reserve.

The Shimba Hills rise abruptly from the coastal plain to form a table-plateau. The plateau is surrounded by an escarpment rising from about 120 m above sea level (asl) on the coastal plain to 300 m asl for most of the plateau. The plateau is generally flat but rises to 450 m asl at Marere and Pengo Hills. This plateau encourages precipitation from water-laden clouds blowing in from the Indian Ocean. The water flow during the wettest and driest months is stabilised by the forest.

Michieka, Pouw & Vleeshouwer (1978) described the soils of Shimba as 'deeply weathered' and made up of sediments derived from Shimba grits and Mazeras sandstone. These yield coarse-grained ferralitic soils. A cover of medium-grained magarine sands was deposited on top of Shimba grits in centre of the reserve. This yields soils with a higher cation exchange capacity, base saturation and larger water storage capacity in some areas like Longomwagandi.

The vegetation of Shimba Hills has been described in detail by Schmidt (1991). Generally, it consists of a mosaic of tropical seasonal evergreen rain forest, woodland (eight forest types) and fire-induced grassland. An analysis of 1991 aerial photographs of the Shimba Hills/Mkongani reserves, suggest that 48% is forest formations, 36% scrub formations and 13% grasslands. In Mwaluganje, 23% is forest/woodland and 76% thicket and scrub. Shimba Hills National Reserve is probably the richest among the coastal forests for plant species (Davies & Bennun 1993). Together with the nearby Arabuko-Sokoke Forest it accounts for most of the coastal biodiversity in Kenya. About 15% of the rare plants in Shimba Hills are coastal endemic (Schmidt 1991), and over 50% of the 159 rare plants species known to occur in Kenya are found in Shimba Hills (Beentje 1988).

Such combination of habitats undoubtedly provides for a varied fauna: 295 butterfly species (35% of Kenya's species) of which 13 are rare, 24 are forest-dependent, two are endemic; 35 mammal species, including elephant, giraffe, yellow baboon, colobus and sykes monkeys, Grimm's duiker, bushbucks, ring-backed water buck, warthog, buffalo, Burchell's zebra, leopard, spotted and striped hyena etc. (excluding bats, rats and mice). Shimba is known for its threatened population of the sable antelope endemic to the reserve. A total of 111 forest bird species have been recorded, of which 20 are coastal birds.

The level of species endemism is low: 2 butterflies, 20 coastal birds and 1 coastal mammal, to which can be added several coastal sub-species of the threatened species, there are 5 mammals, including the sable antelope, only protected in Shimba; 13 butterflies and 9 birds.

Management Objectives

The Shimba Hills Ecosystem Management Plan (1993-'98) is consistent with the goals of (a) conserving biodiversity, (b) strengthening partnerships and (c) promoting nature tourism (KWS/FD 1993). The primary management objective for this particular ecosystem is the:

- Conservation of biological diversity by:
  - preserving the different forest communities;
  - preserving populations of endemic and threatened species of fauna and flora and other categories of species of special concern;
  - preserving areas important for maintaining the genetic diversity of plants and animals the functioning of ecological processes that regulate water flow, soil conservation and the nutrient cycle.

Other objectives are:

- Protect watershed by conserving the lowland rain forest which is an important water catchment area by protecting the forest resources from degradation;
- Manage the forest and wildlife resources for visitor enjoyment;
- Conserve the remnant populations of the sable antelope which is endemic to the area;
- Produce wood products to satisfy local requirements by intensifying forest extension work in the areas close to the reserve;
- Promote the sustainable utilisation of natural resources for the economic development of the local people;
- Contain wildlife in the reserve to reduce crop damage by constructing electric fences to encompass the Shimba Hills ecosystem; and
- Facilitate research and education activities.

Elephant Management Challenges

- There has been a high incidence of human/elephant conflict;
- There is significant habitat degradation due to high elephant density. This is particularly

the case in Mwaluganje Elephant Sanctuary;

- In Mwaluganje Elephant Sanctuary there is a conflict between tourism development and conservation of biodiversity. The challenge is to reconcile the two issues;
- Identifying suitable elephant management technology to reduce elephant density.

STATUS OF HUMAN/ELEPHANT CONFLICT

The Shimba Hills ecosystem is completely surrounded by communities whose main economic activity is intensive agriculture. This has resulted in conflict between people and wildlife, with animals regularly raiding the farms and causing injury and/or death to people. The elephant is responsible for most of the reported cases of human-wildlife conflict in the area.

Conflicts between people and elephants have reached unacceptable levels in areas without fences. Reports of crop destruction by elephants, children not going to school, destruction of infrastructure development by elephants are common in the surrounding areas. Between 1980 and 1994, for example, a total of 2171 cases involving crop or livestock damage, human death or injury and other forms of property damage were recorded in Shimba Hills National Reserve and its outposts. Out of these cases, 57.3% were caused by elephants. Within the same period, there were 43 cases of human death and injury!

CONFLICT RESOLUTION

To minimise these conflicts, KWS initiated comprehensive fencing in 1994 to keep the animals within the reserve. To date, Shimba Hills National Reserve is ring-fenced and is the first wildlife sanctuary in Kenya to have a totally enclosed elephant population. However, the Ecosystem Management Plan recognised that if the proposed fences were erected, "the dispersal areas of the elephants would be reduced which could eventually lead to overcrowding and inevitable adverse effects on the ecological processes and aesthetic appeal of Shimba Hills" (KWS/FD 1993). To address the concern, the same document proposes that elephants-habitat interactions be studied and monitored to "shed light on the extent and type of damage caused to the habitats by elephants" to help "make decisions on control measures to be taken if it is found that habitat degradation is eminent".

It should also be recognised that human/elephant conflict was greatly reduced through the creation of the Mwaluganje elephant sanctuary. The sanctuary comprises of Mwaluganje

Forest reserve and farmlands of the local community living around Mwaluganje. The farmlands which the elephants would have invaded have now been left to elephant use thus reducing potential conflict.

Previous Studies and Concerns

Kenya Wildlife Service felt that elephant barriers will solve the conflict between people and elephants but they will further decrease elephant migration and increase the potential for habitat degradation associated with compression. Consequently, in 1993, KWS initiated a study to investigate the impacts of elephants on biodiversity to give insight into the management strategies to be adapted to maintain a viable elephant population in an ecologically stable ecosystem. Additionally, monitoring of elephant numbers and trends was initiated. The last aerial survey (Litoroh 1997) obtained a minimum of 464 elephants while through Dung Count technique an estimate of 700 elephants was obtained (Litoroh, in press). Results from elephant habitat interaction study have shown a negative correlation between elephant density and various vegetation parameters (Mwathe 1995; Litoroh, in press). Other studies that have addressed the elephant question include: Robertson & Luke (1993); Davies & Bennun (1993); Hoft & Hoft (1995); Schmidt (1991, 1992). All these studies have expressed the need to take urgent conservation measures to protect biodiversity in Shimba Hills and the concerns are:

- The confinement of an increasing elephant population within a small area has resulted in serious destruction of trees, opening up of the forests and erosion of biodiversity resources. As a result, some endemic species in the area are critically threatened;
- The size of the highly diverse natural forest is at its lowest critical margin, a factor contributing to a high fragility of the ecosystem. The resilience potential of the forest disturbance resulting from previous anthropogenic activities are high but the insulation of the reserve coupled with a high density of mega-herbivores has interfered with the natural regeneration and succession processes;
- The presence of a high density of elephants may result in a cascade of large scale extinction that can not be predicted, neither can the economic loss be calculated.

Changes in the vegetation structure and composition in the various types within the reserve have become evidently clear. The challenge for KWS is to provide a sound management to ensure that the natural biological processes are maintained while at the same time encouraging tourism development.

WHICH WAY AHEAD?

The KWS recognised that Shimba Hills National Reserve can not sustain the large number of elephants within the small confines of a fence without destroying the habitat. In an effort to resolve the conflict between elephants and biodiversity in the most pragmatic way KWS convened a workshop at Tiwi in March 1997. The participants were drawn from KWS, both local and international NGO's, conservationists, universities, community leaders and research organisations. The workshop agreed that elephant density needs to be reduced, and recommended *culling* as the immediate and short-term intervention management option. Other options available to manage an increasing and confined elephant population include:

- Translocation;
- Elephant Drive;
- Fertility Regulation;
- Win space for elephant.

However, not all of these options are applicable to the Shimba situation. While the southern African states resorts to *culling* of elephants as a habitat management tool, Kenya does not subscribe to it for ethical reasons. (It should also be remembered that only four years earlier Kenya had spearheaded the ban on ivory trade, and it would have been untenable for KWS to make an abrupt about-turn and resort to culling – what would happen to ivory accumulated from culling?) Experience from Narok has shown that *Elephant Drive* is not an efficient way of managing elephants because they will return. *Fertility Regulation* takes a minimum of 25 years to yield any results. Shimba Hills ecosystem is surrounded by an increasing human population, which makes it an ecologieal island. This means that there is no more space (as buffer zone) to be won for elephants.

Elephant Translocation

In a generally good terrain and open country, *Translocation* has emerged as a common tool used by KWS in managing wildlife populations. Shimba Hills and Mwaluganje present special difficulties due to rough terrain and relatively thick vegetation. Despite this, KWS took a bold step and successfully moved 29 elephants from Mwaluganje to Tsavo East National Park during the month of November 1999. The decision to move elephants was based on the outcome of the Tiwi workshop taking socio-political considerations into account.

CONCLUSION

- Through the creation of Mwaluganje Elephant Sanctuary and construction of an electric fence, KWS has addressed the human/elephant conflict in the medium and long term;
- Construction of an electric fence coupled with human settlement around the reserve firmly curtailed elephant migration resulting in localised vegetation destruction associated with compression;
- Translocation of 29 elephants from Shimba to Tsavo is thought to be an appropriate management intervention measure to address issues of habitat destruction;
- More elephants need to be translocated to achieve the desired results.

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22

Natural Enemies of Cereal Stem Borers Cotesia Flavipes Cameron as a Model Indicator Organism

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ABSTRACT

The response of various insects to perturbation varies from species to species, and the same goes for their re-establishment in the perturbed areas. The stability of natural enemies could be challenged by both natural and anthropogenic factors. The efficiency of the establishment of the maize stem borer parasitoid, *Cotesia flavipes*, in the coastal region of Kenya can be seen as a pointer, and used as a model system to predict the future success of classical biological control in the natural environment and in perturbed ecosystems. Effects of chemicals and phytochemicals on non-target arthropods is currently being studied on various non-target model systems, and preliminary results indicate that there is urgent need to carry out detailed studies in this area. Heavy use of synthetic chemical pesticides is seen as the major threat to the establishment and impact of natural enemies in the Kenyan coast. The cultural practice of burning alternative host plants and host plant residues during land preparation may drastically affect the establishment of natural enemies in this region. It is also possible that certain components of botanical extracts used for pest management have a negative influence on natural enemies. This paper reports on some anthropogenic and natural factors challenging the establishment and stability of natural enemies of insect pests.

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INTRODUCTION

In the agricultural sector, one of the greatest drawbacks to productivity is insect pests. In East Africa, some of the methods known for the management of insect pests include chemical control, early planting and intercropping (Minja 1990), use of botanical pesticides (Otieno-Ayayo 1999) and use of insect pathogens (Brownbridge 1991). There are numerous natural enemies of stemborers that can be manipulated to control the pests in East Africa with success (Bonhof *et al.* 1997). The recently introduced classical biological control of stem borers in East Africa is currently making an impact even beyond the areas where initially applied (Omwega *et al.* 1995; Overholt *et al.* 1997). The noctuids, *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson, and the pyraloids, *Chilo partellus* Swinhoe, *Chilo orichalcociliellus* (Strand) and *Eldana saccharina* Walker, are the most important stemborers of maize in East Africa. Together with these insect pests are also found their natural enemies which attack various stages of their development. These include predators, parasitoids, pathogens.

The exotic stem borer, *Chilo partellus* is considered to be the dominant and the most destructive species in many parts of East Africa (Mohyuddin & Greathead 1970; Harris 1990; Overholt *et al.* 1994a). It invaded Africa from Asia in the beginning of the 20th century, and occurs throughout eastern and southern Africa. In most of the areas where found, *C. partellus* is one of the major pests of maize and sorghum, which are staple food crops for millions of people in sub-Saharan Africa. In a collaborative project of the International Centre of Insect Physiology and Ecology (ICIPE) and Wageningen Agricultural University (WAU), the co-evolved natural enemy of *C. partellus*, the parasitoid *Cotesia flavipes* was introduced from India and Pakistan to Kenya in 1993 (Overholt *et al.* 1994b). The parasitoid has been successfully established and is now found throughout southern Kenya (Overholt *et al.* 1997) and in northern Tanzania (Omwega *et al.* 1997). Recent studies have revealed a dramatic spread of *C. flavipes* populations up to several hundred kilometres away from the release sites, with parasitism in different areas from the coast inland to Taita Taveta ranging from 10% to more than 50%. The percent parasitism was however highly variable over sampling sites, and *C. flavipes* is still rare in some locations. It has in the past been unclear why levels of parasitism are highly variable between sites. This paper discusses some possible challenges contributing to this scenario.

In addition to maize and sorghum, the *Chilo* complex inhabits alternative (wild) hosts, especially wild sorghum and other large-stemmed grasses. This helps to sustain the parasitoids during the off-seasons when their cultivated hosts are not available. According to

Attique *et al.* (1980), availability of natural vegetation and weeds could hinder the dispersal of *C. flavipes*. This argument is however debatable, since wild hosts such as wild sorghum (*Sorghum arundinaceum*) would be habitat for *Chilo* spp. as well as for *Cotesia flavipes* during off seasons. Stemborers have two mechanisms by which they survive during the dry season: they diapause until the wet season when the crops are in vegetative growth phase, or they infest alternative hosts. On the other hand, *Cotesia* is not able to diapause and would only survive on the wild hosts stems.

Altitude plays a big role in the distribution of various stemborers (Seshu Reddy 1983) and would therefore also influence the establishment of their natural enemies. For example *Busseola fusca* is more damaging at high altitudes (>1500 m), while *Chilo partellus* is most abundant at low altitudes (<1500 m). Attique *et al.* (1980) reported on the effect of diapausing (overwintering) of *Chilo partellus* on *Cotesia flavipes* and attributed this effect to reduction of parasitoid population.

Materials and Method

Cotesia flavipes was reared and released as described by Overholt *et al.* (1994b). Challenging factors to the establishment and dispersal of *Cotesia flavipes* were considered in relation to mortality, incapacitation and barrier effect. Data were collected through field surveys and dissection of host plants to recover *Chilo* spp. The recovered larvae were reared in the laboratory and observed for emergence of parasitoids. Geopositional data on stemborers and *Cotesia flavipes* occurrence were related to various climatic factors using the Almanac Characterisation Tool (ACT), a GIS tool developed by Texas A&M that consists of a suite of geographical data for several African countries. Various environmental features of each location were identified and related to the occurrence of *Chilo partellus* and *Cotesia flavipes.*

Results And Discussion

Chilo partellus, the host for *C. flavipes*, was found to survive in the alternative large stemmed wild grasses and wild sorghum. *C. flavipes* parasitised middle to large sized larvae, after which larvae emerged and formed cocoons outside the host. The emerging adult parasitoids parasitised fresh *Chilo* larvae. After rearing of the imported parasitoid, the initial release was done on the wild host grasses. Soon after, the parasitoids moved to parasitise

Chilo in the adjacent maize fields and vice versa. *C. flavipes* soon dispersed from the original areas of release to other conducive locations, moving as far as hundreds of kilometres away. Parasitism started in the wild host habitat and later picked up in the maize plantations. Tables 22.1 and 22.2 show the density of *Chilo partellus* and its parasitoid over a period of time in subsequent rainy seasons. GIS aided predictions indicate that altitude and precipitation are factors aiding the establishment and impact of *C. flavipes.*

Table 22.1
Parasitoid recovery table for coastal Kenya; long rains 1999

REGION	NO. OF SITES	BORERS SAMPLED	*Cotesia flavipes* recovered	*Cotesia sesamiae* recovered	OTHER BORERS
Taita Taveta	36	6,030	346	32	284
South Coast	43	12,925	. 378	230	193
North Coast	39	6,904	289	289	123

From the GIS aided prediction of the distribution of *C. partellus* in Kenya, the areas found to be possible habitats for the spotted stemborers are mainly the coastal region of Kenya, parts of Western Kenya along Lake Victoria and a small patch of the area around the Kenya-Ethiopia border. The predictions for the distribution of *Cotesia flavipes* closely match those of *Chilo partellus*. It is evident from the GIS predictions that neither the pest nor its natural enemy are likely to establish themselves in the highlands of Kenya. They are also unlikely to establish themselves in the arid north-eastern parts of Kenya. The former is due to temperatures below the optimum for *Chilo partellus* to develop, while the latter could be due to lack of habitat for *Chilo partellus.*

Cotesia flavipes parasitises develop in 3rd-6th instar larvae of *Chilo* complex (Overholt *et al.* 1994b; Ngi-Song, Overholt & Ayertey 1995). Preliminary analyses based on one out of the scheduled three sampling regimes reveal that the use of chemical pesticide has not reduced the % age parasitisation of the complex by *C. flavipes*, as opposed to expectations. It is possible that the pests that receive sublethal dose of the pesticide will be vulnerable to *Cotesia* attack, and hence the high level of parasitisation in areas where chemical pesticide has been applied. It is worth mentioning that these fields were not sprayed during the season when sampling was expected and done (but the area is generally characterised by heavy use of chemical pesticides). Otieno-Ayayo (1999), however, suggested that *Trioxys sp.* is only vulnerable to pesticides during about 1/8 of its life time (as an adult), and the rest of the time it is well protected inside the host. The parasitoid was found not to be affected by neem oil application on the aphid mummies (data not presented here). This could be the case with *Cotesia* lodged inside the insects receiving sublethal doses.

Table 22.2
Parasitoid recovery table for coastal Kenya; short rains 1999

REGION	NO. OF SITES	BORERS SAMPLED	*Cotesia flavipes* recovered	*Cotesia sesamiae* recovered	OTHER BORERS
Taita Taveta	27	2,599	191	13	75
South Coast	27	5,939	. 95	67	64
North Coast	42	18,455	108	152	130

Topography and precipitation played a significant role in the distribution of *Chilo* spp., and hence the distribution of their parasitoid, *Cotesia flavipes*. Predictions were made based on field surveys on the distribution of the pest and its natural enemy. It should be noted that from our experience in the coastal region, about 80% of recovered *Cotesia* belonged to the species *flavipes*.

There are natural barriers like large water masses that would hinder direct movement of the parasitoids to a particular location. This would be evident for example in coming from one point of a land mass crossing Lake Victoria to the other land mass. There must be a limit to which *C. flavipes* can fly without landing to enable it to cross certain natural barriers. Large forest masses may also affect the dispersal to some areas. As far as we are concerned, this aspect of the capability of the parasitoid has not been studied.

The popular slash-burn-plant practice that is rampant in the coastal Kenya is likely to have an effect on the establishment and activity of *C. flavipes* that attack larvae lodged in plant remains and in alternative host grasses. It would be important to carry out investigations that would quantify the losses on abundance and diversity of natural enemies due to this human practice.

The reproductive potential of *Cotesia flavipes* is in the range of a total progeny of 35 per oviposition (Omwega & Overholt 1997). With the estimated population of *Chilo* spp. per plant of 1.8 (Ngao 1999), it is evident that the clear-burn-plant practice would consume *Cotesia* lodged in the plant remains. The same story would be true for the *Cotesia* lodged in the alternative host plants during the off-season for growing maize and sorghum. Imagine this kind of loss of a natural resource was extended all along the eastern coast of Africa and probably further inland where *C. flavipes* is established, it would be a big challenge to the establishment of the parasitoid that is not easily compensated.

Table 26.1 gives the impression that there would be no effect of chemical spraying in a given location to percentage parasitisation by *C. flavipes*. However, our view is that once the challenge is made on the parasitoid by spraying chemicals there would be the survival initiated parasitisation effort. The subsequent purges of chemicals in the ecosystem drastically reduce the parasitoids that are either directly affected by the purge or die as a result of premature death of their hosts. In this scenario, therefore, only very few parasitoids manage to establish and disperse further.

As far as phytochemicals like neem are concerned, where there is no mortality of the host and the parasitoid is protected from direct contact with the extract by being inside the host, the parasitoids would emerge normally (Otieno-Ayayo 1999) but still respond to the challenge by increased parasitisation. Subsequent exposure to the pressure of the chemicals would probably lower the potentials of the natural enemies to survive competition with other forces in the ecosystem. Since the neem treated larvae usually develop less rapidly, the nutritional limitations in the host may trigger some response in the parasitoid which may require further studies to fully understand.

Other Factors That Would Be Seen As Challenging The Course

Other factors that challenge the establishment and dispersal of *Cotesia flavipes* include interspecific competition and hyperparasitism. The only hyperparasite found attacking *C. flavipes* is *Aphanogmus fijiensis*. However, in our studies we have found that levels of parasitism of *C. flavipes* by *A. fijiensis* are typically below 1%. In as much as this is a very small percentage, if the contribution of other factors like diseases is also considered, there could be reason to appreciate the role of 1% hyperparasitism in *Cotesia flavipes* population dynamics.

Other Related Studies in Western Kenya

Effect of neem seed oil on immature stages of *Cheilomenes lunata* indicates a possible reduction in potential to reach out for prey and probably to mate and produce progeny in a competitive ecosystem. The emergence of adults from larval stage was affected by higher concentrations of neem oil. There seemed not to be any detectable effect of neem oil on mature stages of the predator. This calls for more studies on effect of neem extracts to be carried out on immature stages of test organisms. On the same note, there was no detectable effect of neem oil on the immature parasitoids of aphids lodged inside the mummies of *Aphis gosypii.* This, however, does not mean that neem oil has no adverse effect on the parasitoids. There is need for systematic studies to report on this subject matter.

Conclusion and Recommendation

A number of factors challenge the establishment and activities of natural enemies. It would be useful to further study the contribution of each of the factors implicated in this paper in an effort to enhance the activities of natural enemies in the ecosystem. This would make the reduction in the use of harmful chemicals a reality in pest management. Little has been reported on the diseases of *C. flavipes*, and it is possible that there could be, like is the case in all other organisms, possible epizootics that would from time to time affect the establishment of the parasitoid. Some of these studies could be assigned to graduate students under existing projects. Information on the effect of slash-burn-plant on natural enemies could probably be studied under socio-environmental entomology.

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Antiprotozoal Activities of Lyngbya Majuscula, Abudefduf Sexfasciatus and Thallassodendron Ciliatum

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ABSTRACT

Methanol (MeOH) extracts of the pan-tropic marine Cyanophyte *Lyngbya majuscula*, *Thallassodendron ciliatum* (sea grass) and gill extracts of the Striptail damsel *Abudefduf sexfasciatus* were examined for in-vitro antiprotozoal activity against *Ochromonas danica* cultured in hemin enriched media at room temperature using a 50% serial dilution technique. Respiratory inhibition at the 660 nm wavelength was shown to be proportional to the concentration of the extracts with R^2 values of 0.992, 0.996 and 0.542 for *L. majuscula*, *A. sexfasciatus* and *T. ciliatum* respectively. *T. ciliatum* exhibited lower inhibition potential whereas *A. sexfasciatus* had the highest. Malnourished *O. danica* at the elevated dilutions of 75% were especially susceptible. In addition to the anticipated antibiosis, rhodamine toxicity and brine shrimp artemia bioassay suggest a role by haemolysin toxins of *L. majuscula* and *A. sexfasciatus* in the 24 hour respiratory inhibition process.

INTRODUCTION

The ever looming threat of resistance to current antibiotics by microbes/pathogens as is the case with the malaria parasite *Plasmodium spp*. and the serious side effects by drugs in clini-

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cal use such as Nifurtimox and Benznidazole for Chagas' disease (the American trypanosomiasis) necessitates concerted efforts for the search for bioactive compounds with anti-protozoal activity. Whereas about 24 million people suffer from Chagas' disease with around 70,000 deaths yearly (Aldunate & Morello 1993), malaria has since the last two decades regained its status as an extremely important threat to the health and economic prosperity of the human race claiming in excess of 1.5 million lives each year (Wright & König 1996). Incidentally, these diseases are restricted to the tropical and subtropical regions of the world which can ill afford the high technology facilities needed to do adequate research.

Until very recently, the focus on protozoan antibiotics has been on terrestrial alkaloids especially the hydroquinones and its derivatives (Aldunate *et al.* 1992; Boveris *et al.* 1978; Hudson *et al.* 1985, Morello *et al.* 1994, 1995). *Trypanosoma cruzi*, *Toxoplasma gondii*, *Plasmodium spp*. and *Trichomonas vaginalis* have been target micro-organisms. This notwithstanding the fact that Protozoa evolved from algae (Halevy 1991). It has also been established since the early sixties (Nemec, Balan & Ebringer 1963) that antibiotic substances which inhibit or destroy protozoa have general cytotoxicity. In fact Rhodamine positive toxins (fish toxins, haemolysins) have been shown to be present in various algal strains among which are *Ochromonas spp*, *Prymnesium parvum* and *Chilomonas paramecium* (Halevy, Saliternik & Avivi 1971).

O. danica, the protozoa under the current study belongs to the order kinetoplastida as well as the family Trypanosomidae (Corliss 1967). Paradoxically, fish preceded terrestrial animals during the millennia of evolution, carrying with them their physiology as well as their parasites as they colonised the land (Halevy *et al.* 1971). In fact well over 50 years ago, it was suggested (Lavier 1943) that Trypanosoma originated in fish and became terrestrial thereafter. As algal toxins are probably much more potent than those of their protozoa offspring, they could be used for immunisation against the pathogens themselves. The same applies to fish toxins. Wright & König (1996) have isolated substances containing –NC, –NCS and –NCO functionalities with anti-malarial properties some of which are from the red algae *Laurencia papillosa* (Hudson). *L. majuscula*, the blue green marine algae we are investigating has been the subject of very serious prospecting for anti-tumour compounds (Harrigan *et al.* 1998a, 1998b; Orjala, Nagle & Gerwick 1995; Orjala & Gerwick 1996) and has afforded us *Barbamide* and the cytotoxic peptolide *Dolastatin 12* and its closely related analogue *Lyngbyastatin 1* from both the cyanophyte itself and its assemblages with *Schizothrix calcicola.* Fish toxins and antibiotics like *Eptatretin* and *Tetradotoxin*, TTX have been reported in several fish species (Ebesu, Nagai & Hokama 1994; Burkholder & Sharma, 1969).

The purpose of this work is therefore twofold:

- To screen for and compare the antiprotozoal activities of the pan-tropic marine cyanophyte *L. majuscula*, the striptailed damsel *A. sexfasciatus* representing the fish species and the sea grass *T. ciliatum* using the growth inhibition technique;
- To ascertain whether or not the respiratory inhibition is due to antibiotic activity or due to haemolysin toxins or to both.

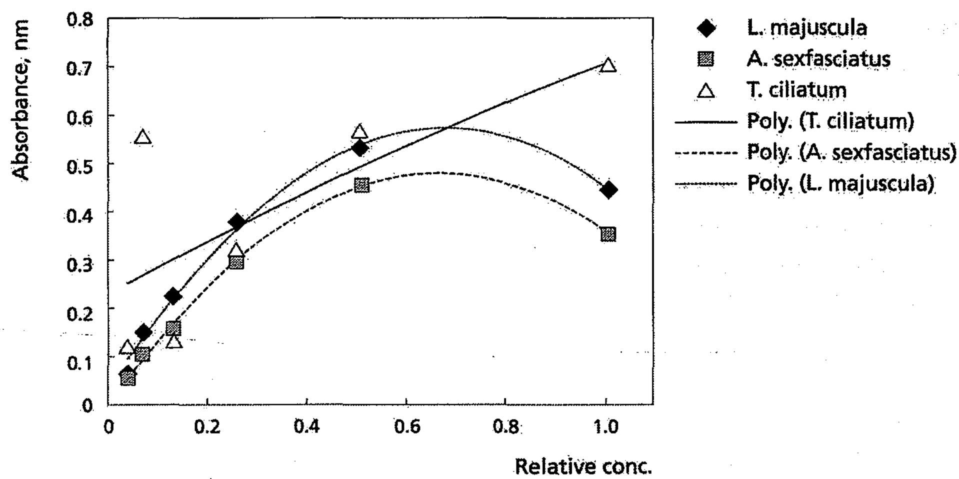
Materials and Method

Specimen of the pan-tropic marine cyanobacteria *L. majuscula* were collected from Wasini Island near Mombasa (Map 1: p.292). The sea grass *T. ciliatum* and the striptailed damsel *A. sexfasciatus* were collected from the English channel in Mombasa. In all cases, the specimen were stored in sea water prior to the laboratory preparation. *L. majuscula* and *T. ciliatum* were air dried and ground with a glass grinder before soaking a known mass of the sample in MeOH just enough to cover it. As for *A. sexfasciatus*, the gills of a freshly caught specimen were macerated and soaked in methanol (q.s.). After 48 hours, the extracts were dried in anhydrous Sodium sulphate (Na_2SO_4), filtered and concentrated using a rotor evaporator at 40^{0}C. The residue collected was preserved for anti-microbial assays and for haemolysin toxin tests.

The *O. danica 933-7* was ordered from the Sammlung von Algenkulturen Planzenphysiologisches Institut, Universität Göttingen, Germany. It was cultured in 0.3% Lactalbumin hydrolysate, 0.1% Glucose, 0.4% Yeast extract and enriched with 2 mg Hemin (dissolved by adding 1 drop of NaOH). Seven (7) tubes of the media were prepared to contain 5 ml in the first and 2.5 ml subsequently; 0.1 ml of the methanol extract of each sample was added to tube 1 and serial dilution (2.5 ml) made. No extract was added to the 7th methanol control tube. 0.25-0.5 ml *O. danica* culture was then inoculated to each tube, incubated at room temperature and the red filter read at 600 nm with a blank of an uninoculated media.

A slurry of the residue in Chloroform ($CHCl_3$) was made and run with Diethyl ether (EE), Ethyl Acetate (EA), Acetone (A) and Methanol (M) through an activated Silica Gel (E. Merck) and Hyflo Super cell column 4:1. Pigments especially with the EE and EA fractions were exhaustively extracted when no colour was given to the boiled solvent aliquot with

Fig. 23.1 *Trends in absorbances for respiratory inhibition of Ochromonas danica.*



Lyngbya majuscula	$y = -1.19x^2 + 1.60x + 0.04$;	$R^2 = 0.992$
Abudefduf sexfasciatus	$y = -1.09x^2 + 1.44x + 0.01$;	$R^2 = 0.996$
Thallassodendron ciliatum	$y = -0.11x^2 + 0.60x + 0.22$;	$R^2 = 0.542$

Rhodamine 6G (25 mg. per 100 ml.). Rhodamine toxins of the various fractions were read at 560 nm using a double beam Shimadzu UV/VIS Spectrophotometer. The residues (ca. 50 mg.) of *L. majuscula, A. sexfasciatus* and *T. ciliatum* were placed in 250 ml tap water into which the tilapeen species *Oreochromis niloticus* had been acclimatised (Bakus 1974; Rao *et al.* 1985). Experiments were terminated when fish showed consistently normal behaviour or had died. Violent escape behaviour, paralysis and loss of equilibrium indicated the presence of toxin. Strong toxicity was defined as that which causes death in the *O. niloticus* within 15 minutes (often 10 min.) whereas weak toxicity caused death in 20 to 45 minutes. Control experiments were conducted simultaneously.

RESULTS

The order of antiprotozoal activity was *A. sexfasciatus*>*L. majuscula*>*T. ciliatum* (Figure 23.1). The absorbances for *A. sexfasciatus* and *L. majuscula* increased with the first dilution before falling sharply with increased dilution. This was not the case with *T. ciliatum.*

Absorbance values were higher in *T. ciliatum* (values highly scattered) and *L. majuscula*. Under the microscope, *O. danica* appeared sleepy or lysis had occurred for *A. sexfasciatus* and *L. majuscula* extracts.

The EE and EA fractions extracted most of the pigments in both *T. ciliatum* and *L majuscula*. No pigments were detected in the final MeOH fraction. Absorbance values at 560 nm for Rhodamine 6G haemolysin toxins were higher in *L. majuscula* than in *A. sexfasciatus*. Those for *T. ciliatum* were no more than those of the blank (distilled water in rhodamine). The same trend was observed with R_F values (Tables 23.1 and 23.2) with the EE and M fractions of *A. sexfasciatus* producing 2 spots each on the TLC plate. Spotted extracts of *T. ciliatum* remained stationary at the solvent front even after a number of runs. Most of the toxins extracted did not move with the solvent front.

No toxins were observed in *T. ciliatum*. Even though *L. majuscula* appeared to have more potent toxins than *A. sexfasciatus*, the experiments with *O. niloticus* had to be terminated since none of the fish died. The toxins were generally mild apart from the abnormal violent escape behaviour in the EA fractions of *A. sexfasciatus* and *L. majuscula*.

Table 23.1
Absorbance values for Rhodamine 6G toxicity at 560 nm

	DIETHYL ETHER EE	ETHYL ACETATE EA	ACETONE A	METHANOL M
A. sexfasciatus	0.01	0.00	0.00	0.02
L. majuscula	0.16	0.02	0.15	0.22
T. ciliatum	0.00	0.00	0.00	0.00

Table 23.2
R_F values of residues of toxin fractions

	DIETHYL ETHER EE	ETHYL ACETATE EA	ACETONE A	METHANOL M
A. sexfasciatus	0.10; 0.21	0.15	0.25	0.18; 0.23
L. majuscula	0.15	0.51	0.15	0.42
T. ciliatum	nil	nil	nil	nil

Discussion

The extracts inhibited the respiratory potential of the *O. danica*. In the first instance when the absorbance values increased at the initial dilution as was the case with *A. sexfasciatus* and *L. majuscula*, it could be assumed that *O. danica* produced toxins to counteract the extracts. Protozoa have been reported to contain haemolysins (Perla 1935; Kokan 1968). The antiprotozoal activity in the Striptailed damsel *A. sexfasciatus* is mainly due to antibiotic activity unlike in *L. majuscula* where toxicity plays a significant role. The lack of activity coupled with lack of toxicity rules out *T. ciliatum* as a potential source for bioactive compounds. The presence of pigments in the EE and EA extracts of *L. majuscula* and *T. ciliatum* did not imply the presence of haemolysin toxins. Neither was pigmentation an indicator of the presence of antibiotics.

The linear range of rhodamine colour development could be manipulated by increasing or decreasing the concentration of rhodamine without exceeding the linear range. This is because the fluorescence of rhodamine almost disappeared under ultraviolet light after numerous dilutions and at elevated concentration of haemolysins. The EE and M extracts had stronger haemolysins than the EA and A fractions. In fact no toxins were found in the EA and A fractions of *A. sexfasciatus*. Practically all the haemolysins were polar substances as they did not run with the solvent front as observed in the relatively low R_F values. It was generally assumed that the red colour of the extracts with rhodamine was due to toxins. It may therefore have been possible to miss out the components not tested for here.

Conclusion

The mild toxicity of the extracts especially in *A. sexfasciatus* is quite helpful in chemotherapy as there must always be a compromise between toxicity and antimicrobial activity. These results also suggest that a link between algal antibiotics and pathogenic protozoa could give a lead to the development of antiprotozoal vaccines in spite of the very close phylogenetic relationship between marine algae and protozoa.

Acknowledgements

This work could not have been successful without the material support of the Kenya Marine and Fisheries Research Institute (KMFRI) and the School of Pharmacy, Hebrew University of Jerusalem (HUJI). I would like to thank sincerely Jacqueline N. Uku of the KMFRI for identifying the L. majuscula and the T. ciliatum. The A. sexfasciatus was identified by Rashid Anam also of KMFRI to whom I am equally indebted. Lastly, the constant encouragement of Professor Mike T. Davies-Coleman of the Chemistry Department, Rhodes University, South Africa, cannot go unnoticed.

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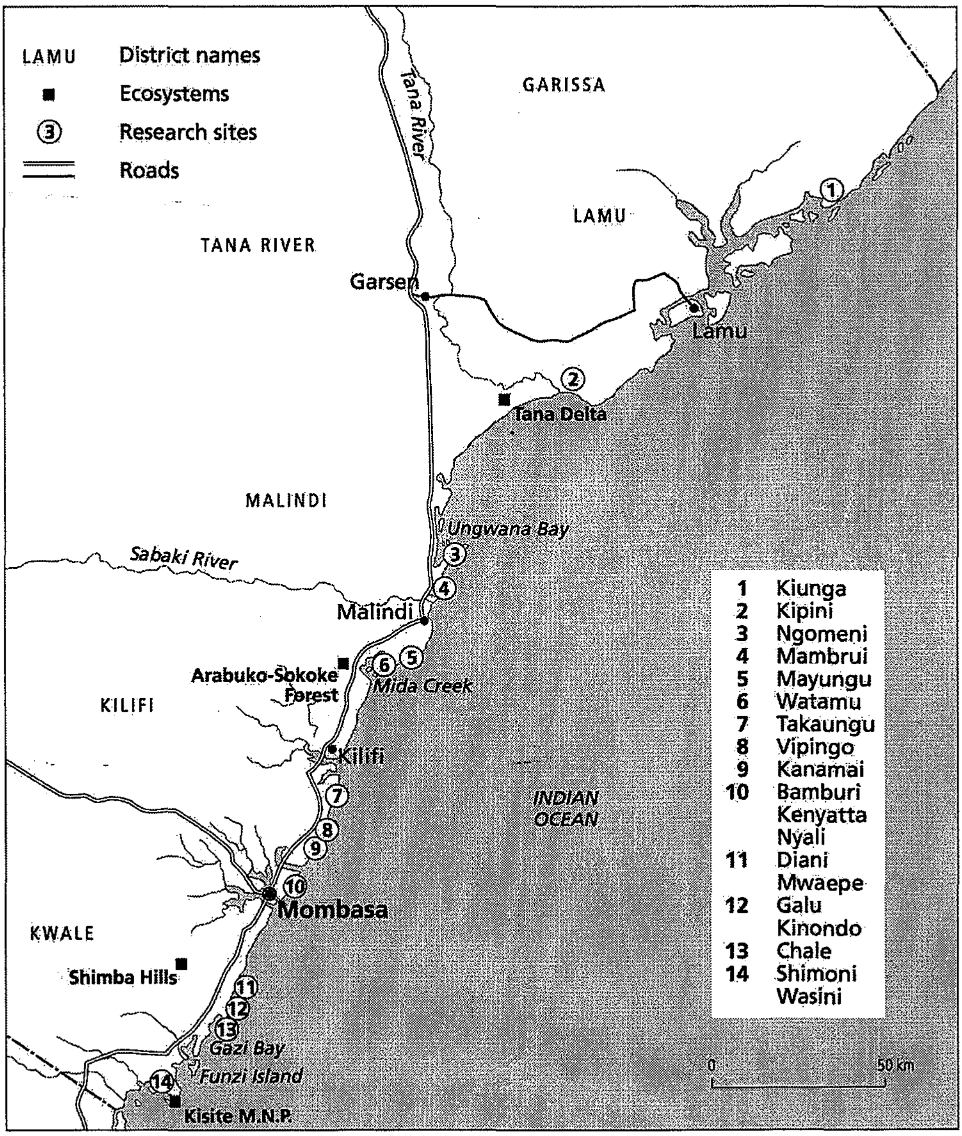
Community

Participation

Map 1 *Kenya Coast with location of research sites*



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Tana Delta Environment Awareness Survey [1]

H. Becha[2]

ABSTRACT

This survey aimed to identify the current stakeholders of the Tana Delta wetland as well as their legal status, mandate, objectives, current activities and vision for the Delta. The stakeholders of the wetland include the Kenya Government (departments and agencies), Non-Governmental Organisations (national and local), Community-Based Organisations and individual resource users. All stakeholders value the wetland for its goods and services. Key issues mentioned are land accessibility and ownership; human/wildlife conflict; resource conflicts; resource depletion; reduced water volume in the main river; insecurity and banditry; poor infrastructure; poor law enforcement; and negative attitudes towards agencies on the ground.

INTRODUCTION

The importance and benefits of the Tana River Delta cannot be overemphasised (Map 1: p.330). It provides a wide range of valuable products and services as a result of its richness and its many natural resources. People and institutions use the resources of the Tana Delta in multiple ways often resulting in conflicts about resource use and user rights. Efforts to create a harmonious mix between development and nature conservation are a challenge.

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1 This paper comprises a summary of Gathinji I.C., Kamau P.C., Gatheru S., Mbai H.M. & Ngunjiri R. (1999). *The Tana Delta wet-lands analysis of the situation on the ground.* Nairobi: EAWS.

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Discussions about the sustainable management of the Tana Delta wetlands are ongoing, with the concerted efforts by all in the government, NGO's, private sector and the civil society.

The Tana Delta Wetlands Steering Committee (TDWSC), established in 1993, has sought to develop a holistic and integrated management plan for the delta. The degree of involvement and participation of the stakeholders in the decision making process is critical in this respect. To ensure informed participation of the local communities, the TDWSC started the Tana Delta Environmental Awareness Programme (TDEAP) in 1994. The basic aim of the programme is to create environmental awareness and to sensitise the stakeholders on the importance of the wetlands. TDEAP was designed as a prelude to the development of a comprehensive management plan but the programme has stalled because of lack of consensus on land tenure in the Delta. Following the declaration of the Tana River District as a land adjudication area, there was need to revive the awareness project beginning with the grassroots stakeholders.

The overall objective of the survey was to identify the Tana Delta Wetland stakeholders, their objectives, interests, legal status and activities as well as their vision for the wetlands. The information will eventually be used to revise the TDEAP project document.

METHOD

The survey took place from 12-27 September 1999 by a team of consisting of personnel from KWS, TARDA, NMK, NES, CDA, EAWLS and representatives of the local communities.[3]

A total of 25 villages, out of 48 villages in the Delta, were visited and included in the survey. Selection criteria to include villages comprised accessibility, unique characteristics, ethnic composition, resource use and logistic constraints. Villages were selected on the East and West bank of the river; up the river, near the river mouth and on the coastline respectively.

The review team was divided into two groups of six i.e. four technical officers, and two community representatives (an Orma and a Pokomo). Each team covered three villages a day, on average, and the two groups met every evening to review the day and plan for the following day. The target groups in each village comprised of representatives from the elders, youth and women's groups, religious leaders, councillors and resource users. In some

3 The IUCN-EARO, KWS, TARDA and EAWLS facilitated the exercise.

villages, respondents preferred to be interviewed as one but each target group was given an opportunity to respond. The discussions were based on questions prepared in advance.

The information from the various groups was analysed in terms of strengths, weaknesses, opportunities and threats and ordered in the so-called SWOT matrices which can be found in the original report. This paper presents a review of the main stakeholders and a discussion of the key issues that emerged.

MAIN STAKEHOLDERS

Elders

Elders were present in each of the villages visited. Among the Pokomo, elders are referred to as the *Wazee wa Gasa* and among the Orma they are called *Matadeta*. All elders are men. They are not registered but are recognised by the communities. They have key roles and are influential as custodians of culture; decision makers on matters affecting the community, allocation of land and conflict mitigation. They make rules and regulate use of natural resources.

Government Institutions

- The Ministry of Lands and Settlement featured prominently in the discussions due to the ongoing process of land adjudication and settlement. A land adjudication office was established in 1995 at the District Headquarters in Hola and the area was gazetted as 'land adjudication' area in 1997. Land adjudication will be on trust land in Kibusu, Ngao, Golbanti, Oda and Kipao. Areas that will be reserved as common resource include forests, water masses and watering points (Malkas), social and recreation areas like market centres, schools, Ngao airstrip, etc.

The settlement process will involve the regularization of squatters on government land and the relocation of communities from the Primate Reserve. One thousand families will have to be relocated, four hundred families will go to Witu Settlement Scheme (15,000 acres) and six hundred families to Lango la Simba (28,000 acres). Pastoral communities will be settled in the Danisa/Galili area (1,600 acres). Regularization of squatter settlement will be in Danisa, Lango la Simba, Galili, Witu and Kipini. The land adjudication office has initiated awareness sessions but by the time of the survey only one seminar had been held with another planned.

The adjudication process faces constraints that are administrative in nature (no aerial maps, lack of special expertise to map land for common use, no authority to revoke title deeds earlier issued to politically connected individuals); cultural constraints (adjudication starts from customary law, low level of general education, little local knowledge about land adjudication); and political constraints (conflict of interests between farmers and livestock keepers, recent influx of outsiders to take advantage of the settlement process, poor political leadership pursuing their self-interests).

- The Department of Culture and Social Services is crucial in the development of community based organisations. Numerous CBO's are registered in the District. At divisional level, the Community Development Assistants work with CBO's especially women's groups and provide assistance with activities. However, the department was also cited as a hindrance to progress. Some women's groups reported that on several occasions the department had offered to help individual groups with their specific projects but failed to provide help resulting in delay in implementation and loss of earnings.

- Kenya Wildlife Service (KWS), a parastatal, was formed in 1990 as a successor to the Department of Wildlife Conservation and Management. Its major role is to manage and conserve the wildlife resources of Kenya. Its role in the delta concerns wildlife conservation and management in collaboration with the community. A community officer is based at Minjila. In the pre-delta area, KWS are involved in conservation and management of the Tana River National Primate Reserve. The process of gazettement of the Reserve and the planned relocation of the resident communities has negatively influenced the attitude of the local communities towards KWS.

- Tana and Athi Rivers Development Authority (TARDA) is a government parastatal with a mandate to initiate, promote and co-ordinate development in the Tana and Athi River Basins. One activity is the Tana Delta Irrigation Project (TDIP) with large-scale rice cultivation. Phase one of the main project was started in 1991 and was completed in 1997. The project suffered extensive damage during the El-Nino floods and funds are needed to rehabilitate the project.

Non-Governmental Organisations (NGO's)

- The Kenya Water And Health Organisation (KWAHO), a national NGO, aims at promoting access to clean water and sanitation for health. It has been operating in the delta since

1985. Clean water for villages is provided by sinking boreholes. KWAHO has also built demonstration units of ventilated pit latrines in some schools. The organisation also works with selected women's groups to promote vegetable gardening and to promote environmental protection of areas around the boreholes.

- World Vision (WV) is an international religious NGO dealing with social development and relief work. The main focus is to assist the communities with starting their own development activities; in hardship areas relief work is also undertaken. In 1995, WV started development programmes in Ngao and Golbanti villages but later expanded to Garsen and Kipini. Their main activities concern education (advocating increased enrolment in schools, assistance with school facilities, providing bursaries for college students, training of school committees); agriculture (extension among farmers and pastoralists, exchange programmes to improve livestock breeds, exposure tours, demonstration farms); health (training health workers to start primary health care activities, seminars on sanitation, disease prevention, dissemination of health information); economic development (support for income generating activities among women and youth groups, training in group management skills); relief work (provision of drugs, food and vitamins to hospitals and communities) and religion (spreading Christianity).

- The Tana Delta Conservation Organisation (TADECO) is a registered NGO established in 1997. Its aim is environmental conservation and promotion of environmental awareness among local communities. Since its establishment, the organisation has focused on creating awareness of its objectives among the communities and on building rapport with governmental agencies in the District. The organisation is also working with women's groups in areas of agro-forestry and bee keeping.

- Kipini Community Conservation Group is a registered NGO established in 1996. Its objective is to create awareness and build capacity in the area of environmental conservation. Activities since its inception have focused on marine life (sea turtles, dugongs, monitoring of trawling fisheries). Due to leadership problems, the organisation has been paralysed to the extent that it does not have current activities despite the fact that there are funds in the bank account.

Community Based Organisations (CBO's)

• Women's groups were present everywhere, with an average of three groups per village, and an average of 30 members. Some groups date back to the early 80's, others were formed as recently as 1997. They operate at village level, sometimes they are limited to the households from which the members come. Most women's groups aim at social development. Together, they pool resources, time, skills and money, to help each other with basic needs such as shelter, school fees, weeding and harvesting. Groups are involved in various activities: merry-go-round[4], share contribution[5] and income generating activities (e.g. bakery, eating house, rental houses, boat transport, mango processing, livestock trading, purchase of pumps for irrigation, handicraft, soap making, bee-keeping, selling of bore-hole water, tie and dye, religious, spiritual activities, delivery services by traditional birth attendants and petty trading).

• Youth Groups were widespread, at least one per village covered. About half are registered by the Department of Social Services and the rest have been formed recently. Most groups consist of young men, a few also include young women. There were no female groups but it may be that young women prefer to associate with existing women's groups as was the case with a women's group in Itsowe which is mainly made up of young women. Most youth groups are village based and aim at the social development of the members.

Activities vary and reflect youthful creativity, e.g. a group in Ngao that is selling water and is already looking for land to develop a market place and rent it out to market sellers. A *Jua Kali* group is promoting skills accessibility and utilisation by bringing together school leavers who want to be trained in artisan skills (carpentry, masonry, plumbing, construction) and sourcing for contracts for those trained to earn money. Only Golbanti Mazingira Youth Welfare Group has environmental conservation activities namely the monitoring the lakes to prevent over-harvesting of fish and poaching of hippos, mosquito control and general clean-ups. They are currently developing a tree nursery to promote agro-forestry and earn revenue from the sale of the seedlings. Other activities of youth groups include horticultural farming, poultry keeping, fish farming, fishing and fish smoking, livestock keeping and trading, bee keeping, canoe making and wine tapping.

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4 Women contribute an agreed amount of money which they give to one member for personal use or in some cases for purchase of a specific agreed item.

5 Money contributed is banked in a savings account (Hola or Malindi) with an aim of investing in a income generating activity.

- Three self-help groups were identified during the survey. In Itsowe a unique group is committed to keeping the Pokomo gospel music alive. It aims at identifying the original music, teaching it to the current generation, recording and selling the music, and publishing a music book. To do this they travel widely throughout Pokomo land. In Laini Village, a 3-year old group is involved in fishing and fish smoking with plans to develop fish ponds. In Ozi village, a group, registered in 1997, is involved in conservation of natural resources and self-development through apiculture and agro-forestry.

- The Kilelengwani and Ozi (KOZI) Community Conservation Group is a recently formed group that promotes sustainable resource utilisation and environmental awareness. Activities include the development of tree nurseries for aforestation and agro-forestry.

Resource Users

- Farmers traditionally are from Pokomo origin but Orma and other newcomers now take on farming as well. Crops (maize, rice, bananas, green-grams, vegetables), fruit trees (mangoes) and economic trees (coconut, cashew nuts) are grown. The issues raised by farmers concerned natural phenomena (lack of regular flooding, salination of rice fields due to marine water incursion, degradation of agricultural land, wild animals destroying crops) and social phenomena (pastoralists grazing cattle on farms that are not fenced, influx of people from outside the delta, projects such as TDIP, the Primate Reserve and Coastal Aquaculture; minimal extension services).

- Livestock keepers mainly consist of Orma and Wardei although some Pokomo leave their livestock under the care of their Orma neighbours. The livestock herds are large, the milking cows return to the bomas in the evening, leaving the main herd in the grazing areas. The most pressing issues are accessibility to watering points and grazing areas. They experience competition by pastoralists from outside the delta who bring in their animals. Livestock disease is another problem causing loss of livestock. Some complained that the Department of Livestock Development provides minimal extension services.

- Fishers on the lakes mention numerous conflicts. Large numbers of outsiders, mainly Luos, have moved in to fish and trade in fish. Traditionally, the elders had mechanism through which they would ban fishing in one lake for some time until the fish numbers increased. Respondents felt that the fisheries department favours commercial fishermen over the local fishermen and this has caused hostility between the two groups. The main issues concern the use of inappropriate methods of fishing causing depletion of fish and destruction of water vegetation.

The fisheries department licenses commercial fishing and issues standards for fishing gear. However, there is no personnel to monitor fishing and to ensure that the regulations are adhered to. Commercial fishermen are mainly newcomers to the Delta. The traditional Pokomo fishing trap ensures that only large fish are caught. This method is mainly used by the local fishermen who catch fish for subsistence and a few extra for sale. In Kipini the issue of deep-sea fishing by trawlers versus the artisanal fishermen in shallow waters was highlighted. Trawler fishing has caused destruction of habitats, and death of turtles and dugong. There is minimal patrol activity and this leaves room for foreigners to fish illegally in the region. The elders at Kipini complained that when these issues are raised there is no response from the relevant authorities.[6]

- The traditional beekeepers, in majority Pokomo, use traditional cylindrical beehives. The modern beekeepers, mainly women's and youth groups use the Kenya Top Bar Hives. Honey production in the Delta is still low. The women's groups indicated that they are unable to harvest the honey and depend on a man to bring down the hives thus delaying the harvesting.

- Forest users extract timber, fuelwood and wood for crafts. Other forest users include women's groups who make mats and tie-and-dye. The problem of logging in the remaining forests in Witu was highlighted during a discussion with governmental department heads. In some villages, women remarked that they have to walk further than before to collect firewood. This is a serious issue because of the high chances of encountering wild animals in the forest. Consequently, women have to organise themselves in large groups to enter the forest.

- Wine tappers are mainly from the Giriama and Pokomo communities. They tap sap from the coconut palm and the doum palm. Growing shoots are cut off and a collecting container is attached over-night and brought down in the morning. There is no processing involved and the longer the sap stays the more it matures into wine. In some areas, the death of doum palms has been associated with wine tapping although the tappers claim that they select the tips carefully ensuring that some will continue to grow. Moreover, the doum fruits are used as food during severe droughts.

6 Riverine fishing did not come up because the Mswakini village did not accept to be interviewed.

- Canoe makers supply important means of transport across and along Tana River. The vessels are usually made of large mango trees and other selected trees. These raw materials are getting scarce to the extent that the craftsmen are no longer able to make large canoes.

- Brick Makers. A group of young brick makers was found in Tarasaa town. Bricks have a good market because they make better houses than the ordinary mud houses. The brick makers dig soil from their own land but use firewood from the forest to fire the bricks. They have not experienced any shortage of soil or firewood since the trade is still relatively new.

Review of Key Issues

Land Accessibility and Ownership

- Several communities raised fears about the process of land adjudication and the accessibility of common resources such as the river, lakes, forests and grazing areas. The farmers felt that the pastoralists are claiming the flood plain, which in their view does not traditionally belong to them. The pastoralists on the other hand need access to the river to water their animals and they also need access to dry season grazing grounds. The heads of respective departments claim they are ready to start with the adjudication exercise but according to the local residents there is general lack of progress.

- The Coastal Aquaculture company has purchased part of Kon-Dertu Ranch and this has created apprehension in nearby villages such as Marafa, Chamwanamuma and Ozi. In fact, the elders in these villages adamantly refused to be interviewed unless the team had a clear statement on the status of the acquired land. In Ozi, the elders agreed to give their views only after a protracted debate on land issues. Most of the groups interviewed want land to be returned to the traditional owners. The environmental impact of large-scale prawn farming did not emerge as a major concern.

- KWS manages the Tana River National Primate Reserve. The Reserve is outside the delta as such and the decision to gazette it was reached by councillors elected by the people. However, its effect is felt in the heart of the delta where the displaced families will be settled. This project – rightly or wrongly – has perpetuated the view that KWS and the government is more interested in the welfare of animals than of people. The fact that the project officers are from outside the district and none were employed from the local communities has raised further complaints.

- The Tana Delta Irrigation Project has negatively affected access of the local population to some resources notably the flood waters that are vital for crop growing. The local communities report that they were promised opportunities as out growers of rice. This was not planned for by TARDA and has resulted in apprehension about further project expansion.

- The influx of people from outside the delta consists mainly of increased numbers of pastoralists from the northern part of Tana River District and Garissa District that have moved in with their livestock. In some villages such as Mswakini.

Human-Wildlife Conflict

Traditionally, the people of the Delta used to deal with wildlife problems themselves. If there was a crocodile that attacked livestock or people, the elders would direct that it be killed. Animals that destroyed crops were snared. However, nowadays KWS handles all issues pertaining to wild animals and the communities complain about a slow response in the case of problem animals. At the time of the survey, a resident of Chara Location sustained serious stomach injuries as result of a buffalo attack). The buffalo was still in the neighbourhood a week after the attack. Wildlife named as most destructive were hippos, buffaloes, crocodiles, lions, baboons, quaelea-quaelea birds and antelopes. Pastoralists indicated that some diseases are transmitted from wild animals to their livestock especially tick borne diseases. Grazers and browsers also compete with their livestock for grazing space and water particularly during drought. Human activities have increased human/wildlife conflict as in the case of Hangada Brook diversion where crocodiles and hippos have been transferred closer to the villages. Encroachment of farmlands into the forests has increased the rate of crop destruction by wild animals as well as increasing the risks of attack. Many young people are of the opinion that KWS favours foreigners in licensing wild life utilisation such as harvesting of crocodile eggs.

Resource Depletion

Reduced fish catch, loss of tree species such as the doum palm in some parts of the delta, degradation of habitats such as grazing grounds and watering points were some examples of the depletion of resources. Reduced agricultural productivity was attributed to both lack of seasonal flooding as well as less opportunity to allow fallowing of land. The elders expressed concern about modern resource use which has little concern for inter-generational equity.

Resource Conflict

Resource conflicts emerged prominently in respect of fishing and access to the flood plain. Both Pokomo and Orma claim ownership of the flood plains and this evidently causes friction between the communities. Since long, the land in the flood plain has been used by the Pokomo to grow bananas, rice, mangoes and coconuts. Traditionally, pastoralists have been allowed to water their animals at agreed points. With pastoralists settling down and establishing farms, they also lay claim to ownership of land. In fishing, the licensing of newcomers and their use of inappropriate fishing gear has caused depletion of large fish in the lakes as well as destroying the water lilies which are an important food for the Pokomo during drought.

Reduction of River Water Volume

Construction of hydro-electric power generation dams upstream, diversion of river water through man-made brooks and canals (such as Hangada Brook), and the TDIP water diversion were named as causes of reduced water volume in the main river course. This leads to imbalance in the rates of erosion and deposition and, in turn, increases the degree of siltation on the river banks, reducing the width of the river channel. This process has also affected regular flood farming downstream. One effect is increased salination in the lower part of the delta resulting in degradation of rice fields and loss of rice varieties.

Insecurity

Insecurity was cited as a problem affecting development in the area due to inaccessibility of communities and its resources. It affects communities and is responsible for current settlement patterns. Frequent banditry attacks have negatively affected development in the delta. Banditry hinders day-to-day activities such as trading.

Poor Infrastructure

Poor roads, lack of roads, telephone, electricity are major constraint to development because the costs of transportation and communication is very high. This hinders accessibility to markets to sell produce as well as timely and accurate information on market developments.

Poor Law Enforcement

Laws and regulations pertaining to resource management and conservation are not enforced at community level due to the poor infrastructure and the lack of personnel on the ground. The government has so far made little effort to use traditional structures in efforts to enforce resource management. This was seen as one reason behind the erosion of traditional institutions such as *Wazee wa Gasa* and the over-exploitation of resources.

Negative Attitude towards Outside Agencies

Government institutions and other agencies have initiated projects, sometimes causing conflict with the local communities (e.g. KWS and TARDA). As often as not, this is due to lack of consultation and involvement of the communities i.e. in lack of information about project intentions and lack of appreciation of local knowledge. Several NGO's have been on fact-finding missions in the Delta but did not report back on the progress of their missions. This has left the local communities apprehensive of any initiatives by such agencies. NGO's that have introduced projects that touch on cultural values have experienced resistance, for example the boreholes of KWAHO as an alternative to river water. Although borehole water is a solution to contaminated water and human/wildlife conflicts, local communities prefer river water over salty borehole water.

Conclusion

Various community based legal entities have been initiated by residents of the Tana Delta. These are community-based organisations such as women's groups, youth groups and self-help groups. There are also two local non-governmental organisations within the delta. The majority of the community-based organisations are development-oriented and were initiated to assist their members in improving their livelihood by exploiting the available (natural) resources.

Elders are not a legal entity but are recognised by their communities and have knowledge of the wetland resources and their uses. They are custodians of traditional resource management and traditional conflict resolution. Women have limited awareness, and are largely restricted to the female domain. The youth have scanty awareness, mixed with both new and traditional knowledge of resources and their use.

The key issues that stand in the way of development and sound environment management are the following:

- Lack of modern knowledge and skills in resource utilisation such as agriculture and livestock keeping and other resource harvesting;

- Superficial awareness about the land adjudication process and little understanding of its implications under customary law and the management of common resources;
- Negative attitudes of communities towards initiatives by government and development agencies while at the same time entertaining misconstrued expectations of the same;
- Lack of organisational development and management skills in the CBO's and the local NGO's;
- Lack of formal linkages between government agencies and traditional institutions responsible for management and conservation of resources.

25

Participatory Learning and Action Res earch Among Communities Adjacent to Arabuko-Sokoke Forest

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ABSTRACT

The Arabuko Sokoke Forest is a protected forest and nature reserve. Efforts are being made to conserve the forest because of its important biodiversity. The approach is by means of poverty alleviation through alternative initiatives among forest adjacent communities. Agroforestry is one of the initiatives being tested on a pilot scale. A diagnosis and characterisation of Dida sub-location was undertaken using participatory learning and action research. A brief census was done to capture the diversity of the people in terms of household composition. Farmers were able to identify 3 soil types by their indigenous names i.e. *Ngama, Tsabwa* and *Mtsanga mwarube*. They were also able to give relative fertility levels based on their own criteria. A gender analysis using territorial mapping revealed that women farmers were more informed about the soil fertility status compared to men and the men more knowledgeable about boundaries and common resources like pasture. An inventory was also done of the village organisations and their activities. A total of about 15 groups were found to exist in Dida sub-location. Of these Tumaini Women Group and Uma-Umoja wa Maendeleo were identified as the most important by the farmers. Potential for income generation was the most important criterion for the ranking of groups followed by the stability of the group. This information is being used to target farmers who are going to be involved in agroforestry initiatives.

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INTRODUCTION

About 7% of Kenya's surface area has a conservation status and consists of National Parks, Wildlife Reserves, Wildlife Sanctuaries and Forest Reserves. The Arabuko Sokoke Forest is the largest remaining East African Coastal Forest measuring between 40-42,000 ha (Map 1: p.330). It has generally been classified as a lowland moist forest. It is a gazetted forest hence protected in the Kilifi and Malindi districts. Table 25.1 shows some of the indigenous trees (found in the forest) and exotic trees that were introduced many decades ago. The indigenous tree species are under threat of extinction. Data available shows that tropical deforestation increased from 0.61% in 1976-1980 to 0.71% in 1981-1990 which is equivalent to 4.1 million hectares annually. Dida sub-location is in Sokoke location, Vitengeni division in Kilifi District. The sub-location has four (4) villages, three of which are forest adjacent and these are Dida, Kafitsoni and Kahingoni with a population of approximately 3,000 people. It was revealed that the agricultural potential of the area has been decreasing with time as a

Table 25.1
Botanical, English and Kiswahili names of commonly found tree species in and around the forest

BOTANICAL NAME	ENGLISH	KISWAHILI
INDIGENOUS SPECIES		
Acacia Xantophloes	Yellow Thorn	
Afzelia Quanzensis	Lucky Bean Tree	Mbambakofi
Ficus Natalensis	African Fig	Mgumu
Adansonia Digitata	Baobab	Mbuyu
Milicia Excelsa		Mvule
Tamarindus Indica	Tamarind	Mkwaju
EXOTIC SPECIES[1]		
Azadiracta Indica	Neem	Mkilifi
Anacardium Occidentale	Cashew-nut	Mkorosho
Casuarina Equisetifolia	Casuarina	Mvinje
Eucaliptus Grandis	Gum Tree	Mgamu
Mangifera Indica	Mango	Mwembe
Cocoa Niciferu	Coconut Palm	Mnazi

1. *Azadiracta Indica, Anacardium, Casuarina Equisetifolia, Mangifera Indica* and the Coconut Palm are virtually naturalised species along the East African coast, having been brought here several centuries ago.

result of poor farming practices, which include continuous cropping and lack of use of fertiliser or manure. Dida community has a low standard of living (average income of sh.2,500 ($35)/month/ household of 7-8 people) and this makes it difficult to purchase fertiliser and other farm inputs. There is therefore a need for intervention using agroforestry practices to try and improve soil fertility and crop yields while at the same time providing fuelwood. Increase in yield will reduce the amount of money that has to be spent on food purchases.

The area soils present a fairly constant vertical soil profile – a 3 feet upper layer consisting mainly heavy loam (black cotton soil) and an underlying layer of sand. The soils have a fairly good structure with acceptable salinity levels. The soils are generally low in nitrogen (<0.02%) and phosphorus (<5mg/kg soil) which are important elements for crop growth. However the soil pH ranges from neutral to slightly alkaline.

Due to increasing human population, areas under forest in Kenya have come under pressure since most of these areas have high rainfall and good natural soil fertility, and are suitable for agriculture. These agro-ecological zones cover less than 10% of the total Kenyan land surface and are characterised by high human population density. These factors have lead to increased human pressure characterised by uncontrolled exploitation or utilisation of natural resources thus leading to environmental problems such as land degradation, forest degradation, pollution, etc. Forest designated areas are mostly seen as the source of forest products. Timber and other wood resources are generally a limited commodity in Kenya. High quality indigenous timber species are facing extinction, while demand for forest products, e.g., charcoal for domestic energy continues to escalate.

The above pressure on forest areas are further compounded by increased demand for food security and hence space for agricultural expansion. This has caused impoverishment of soil structures and is currently characterised by soil erosion, soil infertility, poor food production, and general land degradation. This has resulted in poor and unsustainable management and development of natural resources.

Arabuko Sokoke Forest Reserve has benefited from EEC funding, under Budget Line B7-6201, co-ordinated by Birdlife International, a British NGO. This project is in collaboration with the Forest Department, Kenya Wildlife Service, Kenya Forestry Research Institute and the National Museums of Kenya. The project aims at conserving the forest through alternative income generating projects while at the same time protecting the forest. The project is currently focusing on the conservation of the forest through community based interventions aimed at poverty alleviation. Examples include the butterfly project under the auspices of Kipepeo, bee keeping (Apiculture) and on-farm tree planting of *Casuarina equisetifolia* (a cash tree crop). However agroforestry has recently been introduced on a pilot scale in Dida sub-location to strengthen the on-farm tree planting component as well as improving soil fertility through hedgerow inter cropping and improved fallows.

Legal and policy aspects that are not conducive to improvements in the standard of living among natural resource users such as farmers are also in focus. Such problems can be addressed if consultation among stakeholders is developed. Hence, issues that negate the efforts of technical approaches and better farming practices to sustain production is another dimension of problems to be solved. It has been realised that we have to replace government dominated issues with development initiatives that are community driven.

MATERIALS AND METHOD

The Participatory Learning and Action Research (PLAR) approach (Defoer & Budel-man forthcoming) was used to carry out the diagnosis and characterisation of Dida sub-location in the three adjacent villages of Kafitsoni, Kahingoni and Dida. The PLAR process has the aim of assisting farmers in becoming better soil fertility managers. The process does more than simply analyse the soil fertility strategies of farmers or set a research and development agenda. It demonstrates how a participatory approach can be used at every stage of technology development and change. The change agents use discovery and learning tools to stimulate farmers ideas on soil fertility management and to support their decisions. In the field PLAR was utilised with the change agents and villagers interacting at three levels:

- Community meetings with representatives from all farms (village or watershed level);
- Group meetings with selected farmers;
- Household meetings with members of the selected farms.

The most important part of this iterative and interactive process was communication, open ended conversations and regular exchange of findings. Visualisation was crucial using maps, diagrams or matrices drawn by farmers. Each of the tools was accompanied with an interview form with guidelines. This facilitated the exploration of issues with a proper background and structured in such a way that maps, diagram and matrices were drawn by farmers. The process thus began with an analysis of the households through a *brief census*. The listing was done to include the diverse types of household heads and their status. The second analysis looked at the land use system at community level through *territorial mapping*. This entailed analysing the settlement pattern and its history, and how the natural resources are managed within the community's land use system. The analysis took into account the diversity of these elements. The third step was to analyse information and communication networks through mapping *social organisations*. It was important to understand farmers social relations and the type of activities they carry out in these social relations. The various social organisations and their linkages were looked into as well as the types of information they share, its sources and how they use it.

RESULTS AND DISCUSSION

Household Census -

Table 25.2 shows the results of the brief census. Kafitsoni village has slightly over 70 homesteads with an approximate population of about 400 persons as per 1997 population census. Kahingoni village has about 150 homesteads with a population size of about 1200 people, whereas Dida village has over 200 homesteads with a population of about 1200.

Table 25.2

Head of household by village, Dida sub-location

	KIFATSONI N (%)	KAHINGONI N (%)	DIDA VILLAGE N (%)
Father Headed	52 (71)	127 (78)	170 (78)
Wife Headed (husband absent)	9 (12)	12 (7.4)	16 (7.3)
Widow Headed	1 (1.4)	15 (9.2)	19 (8.7)
Single / Divorced	2 (2.7)	–	1 (0.5)
Wife Headed (husband present)	6 (8.2)	–	1 (0.5)
Head employed and present	2 (2.7)	2 (1.2)	5 (2.3)
Head employed and absent	–	–	3 (1.4)
Headed by son	1 (1.4)	1 (0.6)	–
Shifting HH	–	6 (3.7)	3 (1.4)
Total	73 (100)	163 (100)	218 (100)

Although the majority of the households are headed by men in Dida sub-location, the data shows that there is a substantial group of female headed (widows, single mothers or divorced) households. Mwendwa *et al.* (1998) reported that the poorest farmers generally were female headed households due to limited access and control of resources. In Dida this would mean that a deliberate attempt has to be made to target this households as they are the ones who are likely to have low food production compounded with poor farming practices.

Territorial Mapping

Kafitsoni village borders Dida to the north and Rare sub-location –Nyari village to the South. It borders Kadzandani to the West and Arabuko-Sokoke Forest to the East. Most homesteads are clustered near the forest and where Red soils (*Tsabwa*) are. The lower part of the village is covered by black cotton soil where agricultural farming takes place. Very few people settle here, because of the slippery nature of the soil during the rains. The Red soil (*Tsabwa*) found near the forest is low in production and mostly people leave it fallow. The crops planted in Black cotton soils (*Ngama*) are: Maize and cowpeas while in Red soil (*Tsabwa*) are cashew trees, coconut palms and mango trees. Little land degradation takes place despite poor farming methods practised by the local community. The settlement pattern revealed that the inhabitants are natives hence the land is set for different purposes such as farming and settlement.

Kahingoni village borders Dida to the South and Kaembeni to the north. It borders the forest to the East and Vitengeni sub-location – Matano Mane village to the West. Kahingoni is divided into three (3) land units parallel to the Arabuko-Sokoke Forest with Red soils (*Tsabwa*), bordering the forest. The middle unit has black cotton soil (*Ngama*), which is used for agricultural crops such as maize and cowpeas. The unit is also inhabited which is a clear indication that people bought land here. The last unit borders the Vitengeni sub-location has red soils (*Tsabwa*), which keep reducing in fertility. Few homesteads are also found in this unit. When the virgin land in the Red soil (*Tsabwa*) unit Kahingoni was opened, crops such as pineapples, maize, cowpeas, mango trees and coconut trees were planted, production was good but this reduced as time went by, this may be as a result of poor farming practices. Now cassava and maize are grown but yields are very low. No soil conservation practices are in place but land degradation is minimal. Population is evenly distributed with areas left for farming Livestock such as cattle, goats and sheep are reared.

Dida village borders Kahingoni to the north and Kafitsoni to the South. It borders the forest to the East and Bale village to the West. It is divided into four (4) land units. Red soil (*Tsabwa*) land bordering the forest with crops grown such as coconut palms, banana plants, cassava, citrus trees and cashew nut trees. Another unit has loam soils (*Mtsanga Mwarube*) with crops such as mango trees, coconut palms, maize, cowpeas, citrus trees and groundnuts. There is a black cotton soil (*Ngama*) unit where most agricultural farming takes place and crops grown are maize, cowpeas, sweet potatoes, cassava and groundnuts. Red soils (*Tsabwa*) are found in either end of the village bordering the forest and Bale villages, farming is done but low yields are realised due to the nature of soils. Black cotton soil (*Ngama*) is the most fertile with reasonable yields being realised. Although much land of the Red soil unit (*Tsabwa*) is left fallow due to low yields but those who bought land continue farming. There is minimal soil conservation practices although soil erosion is not pronounced.

Table 25.3 *Indicators and causes of low soil fertility as given by the farmers*

INDICATORS OF SOIL INFERTILITY	CAUSES OF SOIL INFERTILITY*
Weeds stunted in growth.	Continuous cropping without fallowing.
Poor crop performance, especially maize.	Excessive rains causing erosion.
High population of certain weeds such as Kambimbi, Kadago, Kavumbani, Katsai and Karahani.	Failure to use manure or commercial fertilisers.

* Listed in order of relative importance.

Soil Fertility

Through a small group resource persons a historical analysis of the soil fertility status of the soil was carried out. The history was that the area was initially covered by forest similar to the Arabuko-Sokoke forest. In 1963-65, the forest was cleared for farming purposes. On clearing the forest, the land was found to be very fertile. The high soil fertility level was indicated by the good performance of some crops (Bananas, maize, pumpkins, pawpaws, simsim and cassava). As time went by performance of these crops dropped gradually. By 1987, the performance of bananas, pawpaws and simsim had dropped drastically while cassava and maize performed relatively better. The situation worsened from 1990 henceforth. Currently the soils are very poor in fertility and the local community has named it *Mtsanga Sheshe* meaning loose sandy soils and very poor in fertility. Table 25.3 shows the indicators of soil infertility and causes as given by the farmers.

Social Organisations

All the three villages were found with a diverse set of social organisations involved in several activities and that are listed in Appendix 25.1-25.3 (pp. 354-357). A good number of groups have been formed due to the influence of change agents like Heifer and Plan International. One group was formed through the involvement of the social services. Several of the groups were however indigenous and have been formed solely by the villagers to uplift their standard of living. Their sources of information are either the change agents or extension officers. A number of them also have their own rules like, membership fees, monthly contributions, consistent attendance of meetings, attendance of meetings while sober and even good faith. Mwendwa *et al.* (1998) and Defoer *et al.* (1998) found similar results in the Western part of Kenya, although a major difference was an absence of organisations based on clans in the Dida sub-location. These indigenous groups can be utilised as entry points for development agencies due to their already existing structures. The farmers were also able to rank the three most important organisations. For example, in Kahingoni village, Uma-Umoja wa Maendeleo was ranked first in importance because it has most members and it is present in each village. It is sponsored by Plan International, a renowned organisation and also has good co-operation among its members. The Tumaini women group was ranked second because its aims are appreciated by they have relatively many resources. Kaembeni women group was then ranked third in terms of importance due to its initiatives, which are commonly visible in the area.

Two groups, Tumaini Women Group and Uma-Umoja wa Maendeleo, appear in all the three villages indicating their importance and wide network in the Dida sub-location. In Dida village the community ranked the Tumaini Women Group as the most important group, followed by Nyota ya Asubuhi women group and lastly UMA-Umoja wa Maendeleo. The reasons given for ranking Tumaini first were as follows: (i) it has more members; (ii) it has more resources compared to other groups; (iii) it has no leadership problems; (iv) it receives support from Heifer International.

In Kafitsoni village it was found that at least each group was linked to another one through some members. This gives the possibility that by working through one group, other groups will have access to the same information and technology. This kind of set-up can promote a dialogue between farmers and extension workers (Defoer & Hilhorst 1995) and can be exploited for the sake of the whole village. However information flows have to be studied further.

Conclusion

From the survey in Dida sub-location, it was found out that all the three villages (Dida, Kahingoni and Kafitsoni) are suitable for the Agroforestry Programme. However, Kahingoni and Dida need more attention because there are more widows who are the most disadvantaged households in the community. Also Kahingoni village community was found more co-operative and has bigger land unit of red soil type, which is poor and calls for urgent improvement. The majority of the village organisations in all the villages seemed to have been formed when change agents are involved. However more detailed information is still being collected so as to find out whether there are other organisations which were formed without the involvement of change agents. Wealth ranking, labour calendars, soil fertility management classification, gender analysis (activities/ access and control of resources and benefits profile), income-expenditure information and resource flow models are going to be conducted.

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Appendix 25.1

Social organisations, their activities and sources of information in Kafitsoni village of Dida sub-location

NAME	ACTIVITIES	SOURCE OF INFORM. /MEMBERSHIP
Nyota ya Asubuhi	• Vegetable production for sale; • Livestock production – rearing 5 local cows; • Agricultural production – maize growing for sale.	• The group gets technical skills and information from agricultural extension officers and Plan International rural development workers. The group has 12 members, all women.
Umoja ni Nguvu Women Group	• Bee keeping (Has 7 KTBH); • Agricultural production (crop farming); • Merry go round, membership seven, contribution sh.50 each week per individual.	
Nauvoya Women Group	• Rear 2 indigenous cows; • Had a poultry project with 15 local chicken but they all died.	
Tumaini Women Group	• Bee keeping; • Crop production; • Construction of zero grazing units in preparation for dairy animals produced by Heifer Project International.	
Dida Shooting Star	• Play football.	

Appendix 25.2

Social organisations, their activities and sources of information in Kabingoni village of Dida sub-location

NAME	ACTIVITIES	SOURCE OF INFORM. /MEMBERSHIP
Kaembeni Women Group	It started as a church group but later others were allowed to join. • Sukuma wiki and cowpeas for sale; • Operate retail business (small kiosks); • Used to contribute sh.20 which they used to buy rabbits and after selling them they bought beehives; • Abandoned vegetable growing due to water problem.	• Late registration one is to pay sh.500; • Loans to members who repay the loan with a fixed interest of sh.50 which is deposited in the group account; • Membership of 8.
Ushirika Women Group	Income generating activities. • Growing maize for sale; • Operate retail business of selling maize flour.	• Loans to members are interest free; • Income generated by the group is divided between members and what remains is banked; • Initially membership was 8 but it has dropped to 5.
Tumaini Women Group	• Plan International assisted with dairy animals with a sire. A bull was given to sire the local cows and a heifer; • Heifer Project International promised to give them dairy cows. The bull sires the local cows at a cost of sh.50 and sh.20 per extra day.	• Member contributes sh.2000 and plants an acre of napier grass before Heifer International gives a dairy animal; • Late attendance to meetings is fined sh.10; • In case one does not attend 3 consecutive meetings a certain amount is deducted by the group as a fine.
Maendeleo Women Group	• Merry go round; • Contribute sh.50 weekly.	• Membership of 9.
Ukombozi Self help Group	• Members contribute sh.250 per month to buy iron sheets.	• Gender balance of 3 women/3 men.

Appendix 25.2, *continued.*

NAME	ACTIVITIES	SOURCE OF INFORM. /MEMBERSHIP
Uma – Umoja wa Maendeleo	• To generate income through retail business; • To buy ox-drawn plough and oxen; • To rent the plough to whoever wants; • Constructed a hotel with fees from contribution-registration at sh.150; • A Harambee realised sh.9000.	• Membership of 56, 30 women and 26 men; • Committee has 14 members of which 7 are women.
Kahingoni Mwangaza Youth Group	• Have income generating projects such as vegetable farming and retail businesses; • Have no land hence a vegetable nursery in set and every member is supposed to collect the seedlings and plant them to their own farms.	• Registration fee of sh. 100 and late registration of sh.500; • Initial membership was 25 but this has dropped to 12 with time.
Zia ra Lufa Youth Group	• Rearing of goats. Now have 12 goats.	• Monthly contribution of sh.100; • Membership , 4-15 women + 11 men; • Registered with social services; • Registration fee of sh.25.

Appendix 25.3 *Social organisations, their activities and sources of information in Dida village of Dida sub-location*

NAME	ACTIVITIES	SOURCE OF INFORM. /MEMBERSHIP
Tumaini Women Group	• Membership of 59; • Bee keeping (4 hives); • Crop production (commercial); • Constructing zero grazing sheds in preparation for dairy animals to be donated by Heifer Project International; • Has one bull donated by Plan International to sire the local breeds.	
Nyota ya Asubuhi Women Group	• Has 4 Indigenous cows as a source of income; • Have four(4) acres of land where they farm horticultural crops e.g. sukuma wiki, tomatoes for sale; • Have cultivated the four acres and planted maize which they will sell for income.	• Registration fee of sh.50 and weekly contributions of sh.10; • Opened an account with Kenya Commercial Bank – Kilifi branch; • Membership is 7.
Changani sub-village self-help group	• Have merry-go-round to enhance income-generating activities.	• Contribute sh.30 weekly; • Has a membership of 52.
Uma – Umoja wa Maendeleo self help group	• Community activities initiated by Plan International e.g. registering foster child programme.; • Has income generating activities; • Receive and approve proposals from the community and send to Plan International.	• Registered with the Ministry of Culture Social Services and National Heritage; • Membership is 22.
Shibe sub-village group (mixed)	• Traditional song dancing group; • Merry go round and contribute sh.20 per week per individual.	• Membership 30-29 women and 1 man.
Dida Shooting Star	• Youth group for football; • Does not involve itself in income generating activities.	• Has a membership of 30; • Contribute sh.25 registration and sh.10 weekly; • Composed of members from Dida/Kafitsoni.

26

The Utilisation of Arabuko-Sokoke Forest Butterflies is Sustainable

Washington O. Ayiemba [1]

ABSTRACT

Butterfly counts were initiated in 1993 before the start of butterfly rearing by Kipepeo Project. The survey was conducted over nine months to collect baseline data on the Arabuko-Sokoke Forest butterfly diversity, their abundance and seasonality. In 1997 butterfly counts were repeated along six of the nine transects that were set up in 1993 to assess the impact that harvesting had on the wild populations. When the butterfly abundance in 1993 and 1997 are compared, a strong positive Spearman's rank correlation (r_S=0.9698) is obtained. The mean ranks of the harvested and non-harvested species when compared for 1993 and 1997 increased and decreased respectively. There was no significant difference between the butterfly species abundance ranks before and after harvesting for rearing. Impact of harvesting wild butterflies for the community butterfly breeding activities was therefore judged to be negligible.

INTRODUCTION

Sustainable Use and Monitoring

There has been a move from the practice of total preservation of wild lands to that of sustainable use within the last two decades. This is in response to the realisation that most of these wild lands are in the developing world within the tropics where the poor people are highly dependent on natural resources for their survival. Through the implementation of

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projects that combine conservation and development it is hoped that natural resources can pay for their continued existence (Kiss 1990). The enormous support for the sustainable use paradigm from the leading world conservation bodies (UNEP, IUCN & WWF 1980; 1991) has led to the start of such projects. Despite the fact that these biodiversity rich ecosystems had human influence in their evolution prior to the era of total preservation, increases in population, poverty and commercial exploitation of natural resources leaves begging the question as to whether use can be truly sustainable.

The responsibility of ensuring that use is sustainable rests with the biologists who must provide information on the resources and recommend the sustainable levels for harvests. Research into the ecology of the resource and follow-up monitoring of its level and use is the prime mode of determining whether use is sustainable. Spellerberg (1991) defines monitoring as the systematic measurement of variables and processes over time but assumes that there is a specific reason for that collection of data, which is usually to assess whether standards are being met. In monitoring the changes (in direction, size, rate) in the resource, when they occur, reasons for the changes and prediction of their consequences are looked into. It is recommended that before-after comparisons are conducted for a project at a specific site – it is also enlightening to continue monitoring (BSP 1993).

Co-ordinated monitoring activities and use of standardised methods with existing systems at the national and international levels allow for comparisons between sites over a long period of time. Monitoring techniques may be at a large scale like in the use of remote sensing and satellite imagery or a small-scale as in transect surveys. It is prudent, where possible, for monitoring to be carried out by the local people who are likely to be aware of species and habitats that are used on a regular basis. This dictates that the level of data collection and analysis be assessed from the outset in order to ensure the sustainability of monitoring systems (BSP 1993).

Arabuko-Sokoke Butterfly Farming

The Kipepeo Project is one example of a conservation and development project in Kenya. It was initiated among the local community living on the eastern border of Arabuko-Sokoke Forest (ASF) in 1993 (Map 1: p.330). Through butterfly rearing the local communities could obtain income benefits from the ASF butterflies and this would hopefully facilitate the establishment of local support for the conservation of the forest (Gordon & Ayiemba 1996). Local attitudes towards the forest were negative with more than 80% of the community members advocating for the forest to be cleared to give way to settlement (Maundu 1993). At the start of the Kipepeo Project a nine-month survey of the ASF butterflies was conducted in which the diversity and fluctuation abundance of the forest's butterflies was studied (Ayiemba 1997). This information was then used in planning the Kipepeo Project's breeding activity and would later provide a baseline upon which impacts of butterfly harvesting would be assessed.

In 1997 a re-survey of the butterfly abundance was conducted and the participation of local butterfly farmers in monitoring butterflies initiated (Ayiemba & Maundu 1998). One local recorder is now able to continue counting butterflies along the six transects set up in 1993 thus allowing for continuity of the counts along these transects. The 1997 survey was targeted at:

- determining whether commercial rearing had impacted on wild butterfly populations of Arabuko-Sokoke Forest by comparison of baseline data with data collected in the later years of the project;
- refining monitoring methods to the point where they can be carried out by the local community;
- establishing local community participation in the long-term monitoring of butterfly abundance in Arabuko-Sokoke Forest.

The butterfly monitoring counts continue to date. This paper presents the results from the 1997 re-survey as the first objective assessment, to the author's knowledge, of the impact of butterfly rearing activity. Only the results relating to the first objective are presented as an initial step towards developing a standard method of analysis for such monitoring data.

Materials and Methods

Study Area

The Arabuko-Sokoke Forest on the north coast of Kenya covers over 400 km^2 and is located between $03^{0}11'$ and $03^{0}29'$ S and $39^{0}48'$ and $40^{0}0'$ E. There is a range of soils within the forest that support different vegetation stands: at the coast there are white sands that give way to the red infertile loam soils further inland (Moomaw 1959). More than two thirds of the forest lies on the red soils and is dominated by the Cynometra woodland. The remaining area of the forest is covered by the Mixed forest and the Brachystegia Woodland. The highest floristic diversity is in the Mixed forest with *Manilkara sansibarensis, Hymenaea verrucosa* and *Afzelia quanzensis* as the three dominant species (Robertson & Luke 1993).

The rainfall is bimodal with about 900 mm to 1,100 mm falling annually and 60% humidity; December to February is the driest period of the year (Blackett 1994).

The Arabuko-Sokoke Forest is of conservation importance because it supports distinctive flora and fauna which is now seriously under threat from the increasing local human population. Six threatened birds are found in the forest (Collar & Stuart 1988) together with four threatened mammals (KIFCON 1992). Six species/subspecies of butterflies endemic to the coast are also found in the forest: *Acraea matuapa, Baliochila latimarginata, B. minima, B. stygia, Charaxes blandae kenyae, C. lasti lasti* (Larsen 1991). The information gap on the extent of change in the forests' quality and quantity (Wass 1994) in the face of constant threat of excision for alternative land-use by local communities needs to be addressed.

Butterfly Transect Counts

Butterflies were counted using Pollard (1977) transect walks modifications in temperature and transect width. The temperatures were considered to be above the threshold suitable for butterfly activity and hence counting could be conducted throughout the year. Nine transects had been selected in 1993 for the initial counts. Each transect was approximately 1.5 km in length and reasonably representative of the habitat in which it was established. Transect widths were maintained at about 5 m. Recording along each transect was conducted at least once every week between 08:00 to 12:00 hrs except under rainy or extremely cloudy conditions. A sweep net was carried and used to catch butterflies not identified in flight, for close examination. The monitoring counts conducted in 1997 have been in only six on the nine transects established in 1993.

Records of Harvested Butterflies

The members of the local butterfly rearing community groups who were in charge of harvesting butterflies from the forest were trained on butterfly counts and recording of harvested stock. They were provided with record sheets that were collected at the end of each month, from January to November.

Climatic Data

Climate data was collected for rainfall and temperature at the Gede Forest Station.

Data Analysis

Spearman's rank correlation was used to compare overall butterfly abundance between the years. Mean ranks were calculated for the harvested and non-harvested species and compared for the different years. The hourly abundance of the butterfly species, harvested and non-harvested, for the years were compared with the Wilcoxon's signed test.

RESULTS

Rainfall in 1993 was 891.9 mm, compared to 2,052.7 mm in 1997. The higher precipitation in 1997 particularly occurred in the months of April '97 (190.8 vs. 33.5 mm), May '97 (645.3 vs. 96.5 mm) and Oct '97 (524.4 vs. 43.5 mm).

During the 1997 census period, February to October, counts were conducted over 32 weeks with a total of 187 hours walked for the six transects. In 1993 the total hourly counts for the same period was 189. The total number of individuals counted were 40,672 and 15,175 for 1997 and 1993 respectively. Individuals counted in an hour averaged 217.5 in 1997 as compared to 80.3 in 1993 (Table 26.1 & Appendix 26.1: p.367).

The Spearman's rank correlation tests gave strong positive correlation's in all three data sets; non-harvested, harvested and all species of butterflies (Table 26.2). There were no differences between species abundance ranks before and after butterfly farming ($p>0.05$). The mean rank for the harvested species was higher in 1997 than in 1993 while that of the non-harvested species was less.

Table 26.1
Individual butterflies counted in the different vegetation zones of Arabuko-Sokoke Forest by family

	MIXED FOREST ZONE		BRACHYSTEGIA FOREST ZONE	
	1993	1997	1993	1997
Papilionidae	1,115	2,785	750	2,017
Pieridae	4,253	8,298	5,496	15,350
Nymphalidae	2,058	7,063	1,463	5,159
TOTAL (N)	7,466	18,146	7,709	22,526
Count hours	94	94	95	93
No. per hour	79.4	193.0	81.2	242.2

Table 26.2
*Comparison of species counts for non-harvested and harvested species, 1993 vs. 1997**

	NON-HARVESTED SPECIES		HARVESTED SPECIES		ALL SPECIES	
	1993 (N=37)	1997 (N=37)	1993 (N=23)	1997 (N=23)	1993 (N=60)	1997 (N=60)
Wilcoxon signed test	z=2.949 (p=.003)		z=3.832 (p<.001)		–	
Spearman correlation	0.9772		0.9926		0.9698	
Mean Rank	28.68	30.18	33.23	30.98	–	

* See Appendix 26.1 for detailed listings of individual species.

Wilcoxon's signed test on the average hourly abundance of the harvested and non-harvested butterfly species (the non-harvested species used as the controls for the differences that are unrelated to butterfly farming) revealed that both had significantly increased ($p<0.05$) from 1993 to 1997 (Table 26.2).

Appendix 26.2 (p.369) gives a record of the butterflies that were captured by the local community from Arabuko-Sokoke Forest for breeding activities.

Discussion

The significant difference of average hourly abundance for the harvested and non-harvested butterfly species was expected in view of the far higher number of individuals counted in 1997. The difference in rainfall must have been the main reason for the significant difference in butterfly abundance: rainfall strongly affects butterfly abundance through its influence on the availability of larval food plants, reproductive behaviour, temperature, humidity and level of predation.

Because the two years were so different with respect to rainfall and overall butterfly abundance, the comparison of the mean ranks and correlation tests are better indicators of whether or not butterfly farming had adversely affected the wild populations. The assumption here is that changes within the habitat of the butterfly community impact similarly on all butterfly species. If harvesting had affected the abundance of the harvested species we would expect their mean rank to decrease in magnitude while that of non-harvested species should have increased. In fact the changes in ranking were non-significant in the reverse direction. This is good evidence that butterfly farming at current levels is sustainable.

Individual species comparison are necessarily less informative and any change in abundance between the two years may owe more to factors other than butterfly farming. But even here the picture is encouraging: for example, Appendix 26.2 shows that *Papilio dardanus* was most heavily harvested butterfly (ignoring the Charaxes which were bait-trapped), yet it ranked higher in abundance in 1997 than in 1993. Of the swallowtails (which were heavily farmed), only *Papilio nireus* ranked lower.

CONCLUSION

The impact of harvesting wild butterflies for commercial breeding activities was judged to be negligible. However, a larger data set over time should help confirm whether the activity is sustainable.

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Appendix 26.1

Counts of butterflies in Arabuko-Sokoke Nature Reserve in 1993 and 1997 by species

	TOTAL COUNT 1993	TOTAL COUNT 1997	MEAN/ HOUR (1) 1993	MEAN/ HOUR (2) 1997	RANK 1993	RANK 1997
* *Papilio constantinus*	522	1259	2.76	6.73	10	8
* *P. dardanus*	265	832	1.40	4.45	16	14
* *P. nireus*	470	639	2.49	3.42	12	20
* *P. demodocus*	81	768	0.43	4.11	31	16
* *Graphium philonoe*	120	255	0.63	1.36	26	32
* *G. leonidas*	14	2	0.07	0.01	49	54
* *G. kirbyi*	70	20	0.37	0.11	34	46.5
* *G. colonna*	135	547	0.71	2.93	24	24
* *G. antheus*	164	270	0.87	1.44	20	29
* *G. porthaon*	64	210	0.34	1.12	35	34
Dixea charina	158	604	0.84	3.23	21	22
Catopsilia florella	727	883	3.85	4.72	7	12
Eurema sp.	1722	4292	9.11	22.95	2	2
Pinacopteryx eviphia	21	28	0.11	0.15	45.5	45
Nephronia thalassina	234	446	1.24	2.39	19	26
Eronia cleodora	1406	2355	7.44	12.59	3	6
Colotis regina	495	783	2.62	4.19	11	15
C. ione	732	629	3.87	3.36	6	21
C. euippe	913	976	4.83	5.22	5	9
C. eris	252	118	1.33	0.63	17	38
C. auxo	114	265	0.60	1.42	28	30
C. evagore	24	0	0.13	0.00	43	58
Belenois creona	316	5114	1.67	27.35	14	1
B. gidica	7	335	0.04	1.79	56.5	27
B. thysa	621	2551	3.29	13.64	8	5
Appias epaphia	48	934	0.25	4.99	36	10
Leptosia alcesta	1883	3301	9.96	17.65	1	4
Mylothris agathina	76	34	0.40	0.18	33	43.5
* *Danaus chrysippus*	104	264	0.55	1.41	29	31
* *Amauris niavius*	7	5	0.04	0.03	56.5	51
A. ochlea	8	0	0.04	0.00	54	58

* Species harvested.
(1) 189 hours.
(2) 187 hours.

Appendix 26.1, continued.

		TOTAL COUNT 1993	TOTAL COUNT 1997	MEAN/ HOUR(1) 1993	MEAN/ HOUR(2) 1997	RANK 1993	RANK 1997
*	*Melanitis leda*	22	134	0.12	0.72	44	35.5
	Bicyclus safitza	142	297	0.75	1.59	22	28
	Ypthima asterope	28	0	0.15	0.00	41	58
	Euryphura achlys	80	36	0.42	0.19	32	42
	Bebearia chriemhilda	29	20	0.15	0.11	40	46.5
*	*Euphaedra neophron*	327	856	1.73	4.58	13	13
	Neptis sp.	235	133	1.24	0.71	18	37
	Byblia ilithyia	45	518	0.24	2.77	38	25
	Eurytela dryope	25	4	0.13	0.02	42	52.5
*	*Hypolimnas misippus*	574	1450	3.04	7.75	9	7
	H. deceptor	102	903	0.54	4.83	30	11
	H. anthedon	6	14	0.03	0.07	58.5	48
*	*Salamis anacardii*	12	134	0.06	0.72	50	35.5
*	*Junonia oenone*	279	766	1.48	4.10	15	17
	J. hierta	21	34	0.11	0.18	45.5	43.5
	J. natalica	141	575	0.75	3.07	23	23
	J. terea	6	4	0.03	0.02	58.5	52.5
	Phalanta phalantha	919	4216	4.86	22.55	4	3
	Acraea spp	125	744	0.66	3.98	25	18
	Pardopsis punctatissima	46	10	0.24	0.05	37	49
	Phsycaeneura leda	119	672	0.63	3.59	27	19
*	*Charaxes varanes*	43	242	0.23	1.29	39	33
*	*C. candiope*	8	9	0.04	0.05	54	50
*	*C. cithaeron*	18	95	0.10	0.51	47	39
*	*C. protoclea*	17	39	0.09	0.21	48	41
*	*Euxanthe wakefieldi*	11	1	0.06	0.00	51	55
*	*Tirumula petiverana*	4	47	0.02	0.25	60	40
	Pseudacraea boisduvali	10	0	0.05	0.00	52	58
	Harma theobene	8	0	0.04	0.00	54	58

* Species harvested.
(1) 189 hours.
(2) 187 hours.

Appendix 26.2 *Monthly collection of butterflies arranged from Arabuko-Sokoke by the community groups for their breeding activities by species*

	JAN	FEB	MAR	APR	MAY	JUN
Papilio constantinus	11	33	26	46	94	36
P. demodocus	20	54	67	92	8	63
P. nireus	21	35	30	126	82	77
P. dardanus	22	53	47	87	133	27
Graphium colonna	0	39	0	70	0	0
G. philonoe	0	40	0	27	0	0
Colotis ione	0	42	0	0	0	0
Eronia cleodora	0	37	0	0	0	0
Byblia ilithyia	0	10	0	0	0	0
Charaxes candiope	0	1	0	1	8	0
C. cithaeron	81	310	.214	204	236	147
C. guderiana	0	0	43	121	12	0
C. jahlusa	0	0	88	124	47	0
C. lasti	0	90	27	13	80	19
C. protoclea	22	140	108	145	104	46
C. varanes	66	259	306	219	688	356
C. violetta	0	63	72	0	0	0
C. castor	32	78	55	148	93	132
Danaus chrysippus	0	116	34	9	0	0
Euphaedra neophron	0	58	0	68	9	53
Euxanthe wakefieldi	0	5	2	0	10	0
Melanitis leda	0	0	79	114	14	0
Neptis spp.	0	0	6	2	0	0
Phalanta phalantha	0	0	0	0	11	0
Salamis anacardii	0	22	30	0	0	1
Tirumula petiverana	0	0	2	0	0	0
TOTAL	275	1,485	1,236	1,616	1,629	957
Total collection days	29	92	93	81	90	65

Appendix 26.2, continued.

	JUL	AUG	SEP	OCT	NOV	TOTAL
Papilio constantinus	13	12	21	26	14	332
P. demodocus	54	8	12	14	36	428
P. nireus	7	23	15	27	20	463
P. dardanus	6	24	92	21	33	545
Graphium colonna	0	0	0	0	0	109
G. philonoe	0	0	0	0	0	67
Colotis ione	0	0	0	0	0	42
Eronia cleodora	0	0	0	0	0	37
Byblia ilithyia	0	0	0	0	0	10
Charaxes candiope	0	0	0	0	0	10
C. cithaeron	146	110	119	52	83	1,702
C. guderiana	0	0	0	0	0	176
C. jablusa	0	0	0	0	0	259
C. lasti	94	0	0	0	0	323
C. protoclea	72	73	36	31	49	826
C. varanes	300	97	144	70	118	2,623
C. violetta	18	14	14	23	1	205
C. castor	85	102	54	27	18	824
Danaus chrysippus	3	0	0	0	0	162
Euphaedra neophron	45	27	48	18	43	369
Euxanthe wakefieldi	17	6	10	25	0	75
Melanitis leda	2	0	0	0	0	209
Neptis spp.	0	0	0	0	0	8
Phalanta phalantha	0	0	0	0	0	11
Salamis anacardii	15	0	0	0	0	68
Tirumula petiverana	17	0	0	0	0	19
TOTAL	894	496	565	334	415	9,902
Total collection days	72	72	59	47	44	744

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Mangrove-Friendly Aquaculture Development of Silvofisheries in Kenya

Joseph Rasowo[1] & Ted Kombo[2]

ABSTRACT

The mangrove ecosystem has traditionally provided physical advantages for aquaculture development and has usually attracted individuals and corporations eager to invest in aquaculture with the tacit approval from local governments. The Kenya government has made an unsuccessful attempt at developing the coastal aquaculture through promoting pond shrimp culture in the mangroves. There is now growing awareness of the environmental degradation of the mangrove ecosystem as a result of pond shrimp culture and the resultant deprivation, displacement and marginalization of the mangrove based communities. This paper reviews some factors which may have been responsible for the non-growth of aquaculture at the Kenyan coast. It further discusses the introduction of silvofisheries, a non-destructive mangrove-friendly aquaculture technology as an alternative method in the effort towards promotion of coastal aquaculture in Kenya.

INTRODUCTION

There is no thriving coastal aquaculture as yet in Kenya despite the fact that the government initiated a coastal aquaculture development programme some twenty years ago. The Kenya government in collaboration with FAO and UNDP conducted a survey along the Kenyan coastline in 1979 which highlighted the existing potential for the development of coastal

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aquaculture. A pilot aquaculture project, the Ngomeni Prawn farm, was subsequently set up opposite the Gongoni lagoon next to Ngomeni village (Map 1: p.330). The pilot farm was supposed to serve several purposes amongst which were the increase of local food production, the generation of foreign exchange and the provision of livelihood and employment opportunities especially for the rural poor communities (Yap & Landoy 1986; Rasowo & Ochieng 1998). It was hoped that the pilot farm would act as a model, which would eventually stimulate the growth of other aquaculture farms along the coast. Two decades later, none of the above aims and objectives have been achieved. The project has had no discernible impact on the Ngomeni village community, leave alone other coastal communities.

Possible Causes of Failure

Several mistakes seem to have been made which doomed the pilot project to failure. Firstly, the project concentrated on shrimp monoculture and completely ignored finfish culture. Shrimp is essentially a luxury crop which is generally export oriented and whose culture makes only a very small contribution towards addressing the socio-economic aspects of the local community. It provides limited employment opportunities for local residents and most of those are typically poorly paid seasonal and non-skilled jobs, offering no long-term job security. Virtually all the shrimp harvest is snapped up by the tourist hotels leaving practically nothing for the food needs of the community.

In contrast, the culture of finfish usually leaves some food fish (e.g. the undersized fish) for the domestic consumption by the local communities. The survey conducted in 1979 had identified mullets, rabbit fish, milk fish, tilapia, and shrimp (*Penaeus indicus, P.monodon, Metapenaeus monoceros*) as possible candidate species for culture. Maybe the pilot project should have adopted the culture of both shrimp and finfish. Indeed it has been observed that these food fishes occur as pest species in the ponds and forms part of the harvest. The interesting thing is that these food fishes are in high demand from both the farm employees and villagers resulting in a scramble for them whenever the shrimp ponds are harvested.

Another mistake was the culture system adopted in the pilot project. To construct the shrimp ponds, a large portion of the Gongoni mangroves had to be cleared. This involved uprooting the mangrove tree trunks, the building of dikes and elaborate supply and drain gate systems. The relatively large investment required to develop the production units was therefore a major obstacle towards the adoption of fish farming by the coastal communities. These are people who are generally poor and who have adapted to small scale marine capture fisheries for their daily subsistence needs. Any innovations towards aquaculture development in these communities needed to take into account their financial capacity and should have also been able to demonstrate some positive outcome related to solving some of their immediate problems.

SILVOFISHERIES

Experience has shown that replacing mangroves with aquaculture ponds interferes with the detrital food chains that support fisheries production and eventually disturbs the livelihood activities of mangrove based communities (Pool, Lugo & Snedaker 1975). In Kenya, concerted efforts have been made to create awareness of the importance of mangroves and now most mangrove based communities have some understanding of the mangrove benefits although this is frequently not backed by any depth of scientific understanding of its workings (Anon. 1998; Gang 1998). The people have realised that they depend directly or indirectly on the mangroves for their livelihood. Taking into account the development needs of the rural communities and knowing the potential of aquaculture in promoting rural development in small communities (Schmidt 1982) we should encourage aquaculture development but strictly support ecologically responsible forms of aquaculture in these mangrove based communities. Actually, aquaculture in the mangroves can either enhance the value of the entire ecosystem when it is sustainable and non-destructive or it can degrade the ecosystem if it is non-sustainable (Kapetsky 1986). Nearly all aquaculture uses of the mangroves with the exception of pond aquaculture are sustainable and non-destructive (Kapetsky 1986). One such non-destructive mangrove-friendly aquaculture compatible with the principles of sustainable ecological development is silvofisheries.

Silvofisheries integrates mangrove tree culture (silviculture) with mariculture. It is low-input, labour-intensive and is usually quite appropriate for individual, family or community operations. There are several silvofishery models (pond/mangrove alternation, mangrove enclosures, empang parit etc.) and each can be deployed depending on the prevailing local conditions. All rely on the concept of sustainable mangrove forest management in combination with the careful developments of brackish water aquaculture to take care of the economic needs of the local communities. The vegetation density of the naturally growing or replanted mangrove trees can be adjusted depending on the chosen aquaculture species. In case some ponds are to be constructed then the ratio of pond culture area to forest area is also carefully adjusted in order to create minimum ecological disturbance to the fragile mangrove ecosystem. The density of the mangrove trees influences the quantity of litter produced which in turn influences the quantity and diversity of flora and fauna that form an important part of the diet of the cultured aquaculture species (Fitzgerald 1997). The development of silvofisheries yields a significant positive socio-economic and environmental impact on the community. It enables the mangrove based communities to address issues of their economic empowerment using the resources available to them which is the mangroves. In cases where the mangroves have been overharvested, silvofisheries gives them a chance to rehabilitate their degraded environment and at the same time enhance their livelihood from harvest of the mangroves and from aquaculture.

PILOT SILVOFISHERY PROJECT AT TSUNZA VILLAGE

Tsunza village is a mangrove based fishing community located at Gandini location, Kwale district. It is situated at the western shore of the Kilindini Creek between the rivers Mteza on the south-east and Mwachi on the north west (Kombo 1998). Aside from fish, most families gather crabs, shellfish and other marine products for subsistence as well as for sale. Mud crabs and mangrove clams are caught in mangrove swamps while shrimps and prawns are commonly caught in the rivers. Other families gather firewood from mangrove areas as part-time livelihood. The village residents therefore depend heavily on the mangrove resources for survival and livelihood. However, due to its close proximity to the rapidly growing Mombasa town, the community has lost vast tracts of its mangroves and this has impacted negatively on the people. The destruction of the mangroves has resulted in the loss of fish spawning and nursery grounds leading to decreased fish landings and general deterioration of the living standards of the people. The mangroves have largely been cut by commercial mangrove cutters from outside the village who supply the building construction industry, brick making factories, firewood and charcoal for Mombasa town.

The villagers having realised that their livelihood is pegged on the health and survival of the mangroves decided to rehabilitate the degraded ecosystem. Through the initiative of a community based organisation, the Tsunza Conservation and Development Programme (TCDP) they have started mangrove replanting to restore the degraded mangrove forests. It is not easy to effectively undertake conservation measures if the people are impoverished. The project therefore introduced a silvofisheries component to complement the mangrove reforestation programme so as to offer a source of income to the villagers. The silvofisheries is carried out directly by the villagers under the guidance of a management committee headed by the chairman TCDP. The research (ecology, species for culture, seed, design and construction, site selection, water management, feed, stocking rates, harvesting, marketing etc.) is undertaken by scientists from Moi University, Kenya Marine and Fisheries Institute, Forestry Department and Fisheries Department.

CONCLUSION

Once the silvofishery demonstration trials are successful at Tsunza, we aim to use the village as a model to promote the technology in the other mangrove based communities. We have in mind the promotion of silvofisheries in the vast tracts of mangrove forests of Lamu, Tana, Kwale and Kilifi which have been found unsuitable for conventional pond aquaculture (Rasowo & Ochieng 1998; Rasowo 1992). We know that despite the heightened awareness of the need to conserve the mangrove wetlands in Kenya, our mangroves are not yet safe from unscrupulous developers. A case in point is the Tana Delta where a private company seems determined to convert about 20,000 ha. of the delta into shrimp ponds. Maybe what we need is to actively encourage the establishment of community run silvofisheries projects in all our mangrove forests. This will motivate the people to form an effective barrier against illegal mangrove cutters and developers out to convert the mangrove zone into other non-sustainable uses. Coastal communities, if empowered to plan and implement their own resource management decisions can take action on issues that directly affect their survival and livelihood (Alcala 1998; Janiola 1996; Katon, Pomeroy & Salamanca 1997; Katon *et al.* 1998). This should then form the basis for the development of coastal aquaculture in Kenya.

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