Advances in Coastal Ecology

People, processes and ecosystems in Kenya

Jan Hoorweg &
Nyawira Muthiga (editors)

African Studies Centre

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Edited by

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Abbreviations /Acronyms

ANOVA	Analysis of Variance
BA	Basal area
BMU	Beach Management Unit
CAP	Community Action Plan
CD	Coefficient of dispersion
CI	Complexity index
CITES	Convention on International Trade in Endangered Species
CO_2	Carbon dioxide
CORDIO	Coral Reef Degradation in the Indian Ocean
CORE	Conservation of Resources through Enterprise
CPUE	Catch per unit effort
CRCP	Coral Reef Conservation Project
D_{30}	Stem diameter at 30 cm above highest prop root
D_B	Diameter at first branching
DBH	Diameter at breast height
DCMT	Diani-Chale Management Trust
DOA	Dead on arrival
EAWLS	East African Wildlife Society
FOB	Free on board
GLM	General Linear Model
KCWA	Kuruwitu Conservation and Welfare Association
KESCOM	Kenya Sea Turtle Conservation Committee
KMFRI	Kenya Marine and Fisheries Research Institute
KMNP	Kisite Marine National Park
KPBOA	Kisite Private Boat Owners Association
KWS	Kenya Wildlife Service
MAMA	Malindi Marine Association
MPA	Marine Protected Area
MSL	Material style of life
MSL	Minimum size limits
NEM	North-east monsoon
NGO	Non-governmental organization
NMNR	Mpunguti Marine National Reserve
NWCTP	Netherlands Wetlands Conservation Training Programme
PCA	Principal Component Analysis
PIDA	Participatory and Integrated Development Approach
PRA	Participatory Rural Appraisal
RC	Regeneration class
s.d.	Standard deviation
S.E.	Standard error
SEM	South-east monsoon
TAC	Total allowable catch
WCS	Wildlife Conservation Society
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association

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Introduction

Jan Hoorweg[1] and Nyawira Muthiga[2]

Coastal ecology

Ecology is the science of living organisms and their interaction with the natural environment. As such, it straddles the natural and behavioural sciences and is best understood as a collection of sub-disciplines depending on the choice of central concept, such as population, or the field of application, such as conservation (Dodson 1998). Ecology can also be distinguished according to the types of organisms or habitats being studied. These sub-disciplines, in turn, overlap into ever more specialised branches. Examples of habitats include marine and coastal ecosystems, rain forests and deserts, to name but a few. Coastal areas usually offer a mix of marine and terrestrial ecosystems ranging from coastal lowlands to coral reefs with their unique characteristics. Coastal ecology is the study of coastal ecosystems and is the common feature of the contributions in this volume. Coastal ecosystems serve as breeding and nursery grounds for fish and other aquatic organisms, seasonal migration grounds for marine mammals and birds, and feature plants such as mangroves, seaweed and seagrasses that require brackish to salty water to thrive. Certain valuable minerals are also found in coastal areas.

Thirty-nine percent of the world's population live within 100 km of the sea coast (Earthtrends 2009). This figure is currently about 30% for Sub-Sahara

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Map A. Kenyan coast

Africa but by 2025, Africa's coastal population is projected to have grown by 81%, a much higher figure than expected for other continents (Duedall & Maul 2005). Generally, coastal areas are fragile environments that are easily disturbed and easily damaged when overexploited. With the rapid growth of the human population, coastal zones have become centres of habitation and industry – including tourism. Today, many coastal ecosystems are under extreme anthropogenic pressure and coastal zones need well-thought management of resources with contributions from scientists, policy makers, development agencies and local government to realize both environmental sustainability and potential socio-economic benefits. In a way, coastal zone management is the interventionist wing of coastal ecology and requires the effective integration of scientific and technical information into appropriate management interventions.

The Kenyan coast

The Kenyan coast lies between latitudes 1^0-5^0 south, stretching from Kiunga on the border with Somalia in the north to Vanga on the border with Tanzania in the south: an estimated 600 km of coast line. Two major rivers flow into the Indian Ocean north of Malindi, within 100 km of each other. The Sabaki River flows through the Athi and Tsavo regions and the Tana River traverses the Mount Kenya area and North-East Province. Together they drain nearly all of Eastern Kenya (Map A, p.2).

The coastline offers a diversity of habitats including rocky cliffs, sandy shores, creeks, estuaries, mangrove swamps, sand dunes and coral reefs (Frazier 1993). The landscape changes below the mouth of the Sabaki River, near Malindi. To the south the main characteristics are a fringing reef, the coastal strip, and nearby coastal uplands. To the north, the main features are lowlands and river deltas, islands and creeks. The hinterland consists of an extended shrub zone that is sparsely inhabited and separates the coastal plains and uplands from the fertile highlands in the centre of the country.

The seasons are governed by the trade winds with the hot north-east monsoon (*kaskazi*) and the cool south-east monsoon (*kusi*). The terrestrial fauna ranges from rare insects and endemic birds to monitor lizards and forest elephants while the marine waters harbour numerous species of tropical reef fish as well as sharks, billfish, sea turtles and the endangered dugong.

Although only 10% of Kenya's population currently lives in the coastal area this does not mean that population growth here has been slow. In 1948, when the first census was held, the Kenyan population numbered 5.4 million and Coast Province had 501,121 people (EASD 1950; Kenya 1953). In 2008, the population of Coast Province was estimated at 3.1 million. The southern part of the coast has more rainfall and better soils and the majority of the population (80%) lives in the Kwale, Mombasa, Kilifi and Malindi districts. Most of the population growth in Coast Province in the past 60 years has occurred in these districts which have seen an increase in population of more than 2.1 million people (Kenya 2002).

Environmental concerns

The Kenyan coastal environment is affected by the impacts of the subsistence needs of the local population, various naturally occurring processes and the demands of the modern economy. Naturally occurring processes include coastal erosion and sedimentation carried by the Sabaki River that affect not only the beaches but also the coral reefs of the Malindi area. These factors are, however, being exacerbated by global climatic changes. Coral reefs and mangroves, for example, were affected by the extreme El Niño event in 1997 that led to increased sedimentation and erosion that smothered mangroves (Bosire *et al.* 2006) and coral bleaching that killed many corals (McClanahan *et al.* 2001). The coral reefs, mangroves and seagrass beds are also negatively affected by the liquid and solid waste from human settlements and industries.

The economic activities in Kenya's coastal zone have changed over time. The local population still relies primarily on subsistence agriculture and cash-crop cultivation although there are a number of limiting factors such as poor rainfall and marketing difficulties. In the nineteenth century, grains, mangrove poles and ivory were exported to the Middle East. Artisanal fishing was probably always modest in size but it has expanded considerably since the 1960s. The growth in population means that both the space required for settlement and the area of land under cultivation have increased. This puts great pressure not only on the remaining coastal forests but also on the mangrove forests, with the results that stands have been drastically reduced.

Human settlement and subsistence activities in the past largely depended on the carrying capacity of the local ecosystems. With the advent of the modern economy other activities have come to the fore but these are not evenly distributed. The mainstays of the coastal economy are the port of Mombasa and its associated activities and tourism with its more than 5,000 daily guest-nights in coastal establishments (Kenya 2005). In terms of employment, the modern economy, is a mix of services, manufacturing, transport, trade and tourism offering a reported 175,000 salaried jobs almost all of which are concentrated in Mombasa (Kenya 2005). Tourism is mostly centred around the beach areas with most of the accommodation being in Diani, Bamburi, Malindi and Lamu and it extracts a heavy environmental price because of the high levels of water consumption, increased demands for fish and other marine products, and a lack of appropriate sewage disposal facilities. Mombasa is East Africa's largest seaport and it serves the rest of Kenya as well as Uganda, Southern Sudan, Rwanda and even DRC-Congo. The docking of large ships and the transhipment of cargo have resulted in the pollution of the harbour waters and have also affected air quality due to the heavy road transport to move goods to local and up-country destinations. Most of the local manufacturing is also concentrated in Mombasa where it aggravates the water and air pollution already present because of the harbour. Limestone mining takes place on the north side of Mombasa, within a few kilometres of the beach areas. Other mining activities are smaller in scale and found further inland, for example the lead mine near Kaloleni.

In summary, there are major environmental concerns ranging from beach erosion and (local) sedimentation to air and water pollution, overexploitation of mangroves and coastal forests, and destructive exploitation and deterioration of coral reefs.

Coastal conservation and management

There was an early awareness at government level of the need to protect the natural resources of the country. The Tsavo Parks had been established in 1948, during the colonial period. The Shimba Hills Reserve was gazetted shortly

Table 0.1 National parks & reserves in coastal Kenya

Name	Designation	Size (km^2)	Year
Marine Protected Areas			
Kiunga	Marine National Reserve	250	1979
Malindi	Marine National Park	6	1968
Watamu	Marine National Park	10	1968
Malindi-Watamu	Marine National Reserve	245	1968
Mombasa	Marine National Park	10	1986
Mombasa	Marine National Reserve	200	1986
Diani	Marine National Reserve	75	1995
Kisite	Marine National Park	28	1978
Mpunguti	Marine National Reserve	11	1978
Terrestrial Protected Areas			
Shimba Hills	National Reserve	240	1967
Tsavo East	National Park	13440	1948
Tsavo West	National Park	7010	1948
Arabuko-Sokoke	National Park	6	1990
Arabuko-Sokoke	National Reserve	420	1932
Tana River	National Primate Reserve	170	1976
Dodori	National Reserve	875	1976
Boni	National Reserve	1340	1976
Arewale	National Reserve	530	1974

Source: WIOMSA 2009; KWS 2009

after Independence, in 1968. The first Marine Protected Area was set up in 1962 in Watamu – it was then called the Coral Garden Fish Reserve (Kenya 1964:17). This was soon followed by a second protected area near Malindi. The two were officially merged in 1968 to become the Malindi-Watamu Marine Park and Reserve. Ten years later, the Kisite Park and the Mpunguti Reserve were established to the south. Today in 2009, sixteen marine protected areas and land refuges have been designated to preserve the rich biodiversity of the plants and animals (Table 0.1). In National Parks and Terrestrial Reserves extractive activities are forbidden. In Marine Reserves certain activities, such as fishing using traditional methods, are permitted.

Marine Protected Areas (MPA) are important instruments in coastal conservation but they cannot, and should not, cover the whole coastline. However, management of the coastal resources along the remaining coastline is also needed and it is referred to under various names such as coastal conservation, coastal protection, integrated coastal management and coastal zone management etc. In 1994, the first national environment plan was published and it already listed the issues mentioned above notably the threats to reefs, overexploitation of reef fisheries, the over-harvesting of mangrove trees, sewage and waste disposal and also the management of freshwater supplies (MENR 1994). Coastal management requires legislation in combination with sound management plans and their implementation. Environmental legal provisions can be found in the Fisheries Act (Kenya 1991), the Wildlife Act (Kenya 1989), the Maritime Zones Act (Kenya 1999a) and the Environmental Management and Coordination Act (Kenya 1999b). The first integrated management and action strategy was implemented late 1995 in the Nyali-Shanzu area to the north of Mombasa town (Okemwa *et al.* 1998). Priority areas that were identified were land use, water supply, fisheries, and critical habitats such as mangroves, coral reefs and beaches. Because of the nature of the area selected, the plan focused mostly on containing the environmental effects of heavy tourism; it was also implemented in the Diani-Chale area, another important tourist destination. In an evaluation of experiences since early 1990, it was noted that all MPAs had management plans in place (see Chapter 13) but that the local communities were often left out of the decision-making process because they lacked the necessary organization and funding. With hindsight, the efforts at ‘integrated coastal management’ in these areas seem to have focused more on infrastructural development and resource access than resource management and the protection of biodiversity (McClanahan *et al.* 2005). The recent creation of Beach Management Units may prove to be an important step involving the local communities in coastal management although it is mainly limited to the management of fisheries resources and fish landing sites (see Chapter 6).

Research and publications

A number of organisations including government institutions, NGOs and university field stations are involved in research activities on the Kenyan coast (Table 0.2). Standard reference publications include *East African Ecosystems* with comprehensive chapters on coastal ecosystems (McClanahan & Young 1996) and *Coral Reefs of the Indian Ocean* which has chapters on the Kenyan Coast (McClanahan *et al.* 2000). Descriptions of plants and animal species are to be found in the *Guide to the Seashores of Eastern Africa* (Richmond 1997). The *Eastern Africa Atlas of Coastal Resources* was published by UNEP (1998) and the culture, history and economy of coastal society are reviewed in the *Kenya Coast Handbook* (Hoorweg *et al.* 2000).

Table 0.2 Research institutes in Coast Province, Kenya

Institute	Acronym	Town	Website
Kenya Marine and Fisheries Research Institute	KMFRI	Mombasa	www.kmfri.org
Kenya Wildlife Service	KWS	Mombasa	www.kws.org
Coral Reef Conservation Project	CRCP	Mombasa	www.wcs.org
Coastal Oceans Research and Development in the Indian Ocean	CORDIO	Mombasa	www.cordioea.org
Moana Marine Biology Station (University of Nairobi)	---	Diani	---
Coast Environment Research Station (Moi University)	CERS	Malindi	---
Coastal Forest Conservation Unit	CFCU	Kilifi	www.museums.or.ke
Kenya Agricultural Research Institute	KARI	Mtwapa	www.kari.org
Kenya Forest Research Institute	KEFRI	Gede	www.kefri.org

A series of conferences has been convened since 1997 on the ecology of the Kenyan Coast. These meetings were organized as a forum for the exchange of information among scientists, development agency staff and government officers. At the same time it was a means to stimulate Master's students to publish their thesis results. The first proceedings contained fifteen contributions on existing environmental management and research/training facilities while the second volume presented nine papers on dunes, groundwater, mangroves and the region's birdlife (Hoorweg 1997, 1998). The third volume presented twenty-seven papers on coral reefs, sediments, fisheries, mangroves, biodiversity and community participation (Hoorweg & Muthiga 2003). This volume, the fourth in the series, contains seventeen papers that were presented at the Coastal Ecology Conference in Mombasa in 2006 with the emphasis on fisheries, mangroves, and management, conservation and rehabilitation. Most of the studies are situated in a particular geographical location but some cover the entire coastline or longer stretches of it (see Chapters 2, 3, 4 and 14).

Section 1 of the monograph, deals with fish and fisheries and starts with a paper by *Sigana et al. (1)* on the distribution of fish and crustaceans in an open lagoon in Kilifi. *Okemwa et al. (2*) examined the characteristics of marine aquarium fisheries including the trade and management of this fishery. Both papers confirm the rich diversity of fish in the country's coastal waters. Even though Kenya is one of the main exporters of marine aquarium fish in the Western Indian Ocean, little was known about this fishery prior to this review. Artisanal fishers play an important role in the management of marine and coastal resources and several studies give details of their social-economic characteristics but also mention the expectations on their side. *Hoorweg et al. (3)* focused on the contribution of fishing to the income of fisher households, more in particular the degree of income diversification. Activity diversification among fishers did not reduce the pressure on the marine environment, instead, fishers who also had employment onshore, fished less prudently. *Cinner et al. (4)* examined the key socio-economic factors that affect coral reef fisheries and particularly the fishers' perceptions and expectations regarding the sustainability of the fisheries. The survey found that the appreciation of MPAs was lowest among fishers who had experience with neighbouring protected areas. A large proportion of the fishers engaged in destructive fishing practices and had a poor understanding of the factors influencing fisheries. The in-depth study by *Versleijen & Hoorweg (5)* focused on fishers' attitudes towards conservation and found that fishers living close to an MPA had developed quite negative attitudes towards it and, had their own opinions about how conservation should be undertaken. Fishers who did not live adjacent to an MPA were more willing to participate in environmental protection but were constrained by livelihood needs. The impetus to empower local communities through marine conservation led to the Beach Management Units (BMUs) legislation in Kenya but the ability of communities to govern these BMUs is unclear. *Oluoch et al. (6)* assessed the governance processes and structures of BMUs in the Diani area and reported a large gap between official expectations and the management capacity of fisher organizations.

Section 2 is devoted to studies of the region's mangroves and their rehabilitation. Mangroves help protect beaches and offer vital breeding grounds for marine life but they also play an important role in Kenya's coastal economy. As elsewhere, the mangrove forests along the Kenyan coast have been decimated in that the total area has been reduced, the tree density is lower and the maturity of the trees has decreased – all leading to loss of productivity. *Bundotich et al. (7)* presented a structural inventory of the mangrove forests in Ngomeni, and showed extensive degradation due to overexploitation for wood products and conversion to salt production and aquaculture. Although afforestation is the commonly recommended management intervention in such circumstances, little is known about the appropriate species and conditions for effective reforestation. The following three studies present the results of plantation experiments in Gazi. *Kirui et al. (8)* examined the effect of mangroves on carbon storage and the influence of variations in soil moisture and temperature respectively. *Lang'at et al. (9*) reported on the use of mangrove species to mitigate coastal erosion. Efforts to protect the saplings with bamboo encasements failed to be successful in terms of survival and growth performance indicating that this commonly used method may not, in fact, be appropriate here. Estimates of mangrove biomass are important because of its role in wood-yield determination, nutrient turn-over and its potential to store carbon. *Tamooh et al. (10),* developed allometric equations that allow an estimation of below-ground biomass and shows that it composes a large proportion of the total-biomass.

Section 3 deals with some organisms on coral reefs, MPA management and the abundance of sea turtles. Coral reefs are extremely complex ecosystems and specialist knowledge is required of the different components of the coral reef ecology. *Grimsditch et al. (11)* examined micro-algae that have a crucial symbiosis with coral polyps but this symbiosis is disrupted when coral bleaches. The study examined the extent of naturally occurring variations in the density of zooxanthellae. Only two of the ten species showed significant seasonal variations although a few of the other species showed non-significant differences. *Orwa et al. (12)* assessed the population of sea cucumbers, organisms that play a crucial role in the recycling of nutrients in benthic communities although they are also of commercial value and susceptible to overexploitation. Their abundance was shown to be dependent on habitat and substrate cover and it was higher in protected areas. *Muthiga (13)* evaluated the management of Kisite-Mpunguti MPA, in terms of biophysical, socio-economic and governance achievements. There was a higher biomass of fish and more coral cover; nearby communities enjoyed higher incomes and better food security, and resources allocated to manage the MPA increased over time. However, there were weaknesses concerning formal stakeholder participation, imperfections in the management plan and conflicts due to overlapping mandates with other natural-resource institutions. Sea turtles have been earmarked as flagship species that are indicative of the general state of marine and coastal habitats (Frazier 2005). *Wamukota & Okemwa (14)* examined the status and trends regarding sea turtles along the entire Kenyan coast as well as the perceptions among the local communities of these turtle populations. Respondents indicated a steady decline in sea turtle numbers since the early 1980s with marine fisheries being seen as a leading cause of turtle strandings. In principle, communities were supportive of conservation measures but a lack of capacity to protect turtles reduced community effectiveness.

The final section comprises studies on the rehabilitation of terrestrial environments, in this case exhausted limestone quarries. Two successful examples of former quarries – Haller Park, a nature park that is now open to the public, and Forests Trails, a recreational site used for jogging and cycling – are reviewed. *Kahumbu (15*) examined the forest characteristics of quarries after thirty-five years of rehabilitation. The trees were tall in stature but the forest was structurally less complex than a native coastal forest. It was noted that the red legged millipede played an important role in nutrient turnover. *Okanga (16)* took the evaluation a step further by examining tick infestation of the wildlife introduced in the rehabilitated quarries. There were differences in tick density between the two quarries, probably due to the greater variety of animals present. Control measures included burning and pesticides both of which were effective in reducing tick densities. The contribution by *Nguli et al. (17)* stands more or less on its own as it is a study of the hydrography and tides of Tudor Creek with measurements of sea levels, water temperatures, ebb and flood velocities and water salinity. Ebb periods were shorter than flood periods with higher ebb velocities and possible reasons for this phenomenon are discussed.

Coastal and marine ecosystems on the Kenyan coast include mangrove forests, coastal marshes, seagrass beds, sand dunes and coral reefs. These coastal and marine ecosystems process nutrients, sediments and water and provide feeding and breeding grounds for a diversity of organisms. Coastal systems also provide a wide range of ecosystem services including shoreline protection, production of fish and shellfish, enhancement of water quality, recreation, tourism and support of aesthetic, spiritual and cultural values (MA 2005). Since these systems are interconnected, a broad understanding of their biological, physical and socio-economic characteristics is crucial for effective management. The present volume not only provides information on a broad range of ecosystems useful for their conservation and management but also addresses the perceptions of key stakeholders. The integration of this knowledge in management and information sharing amongst sectors should enhance the effectiveness of the management of these key ecosystems.

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Fish and Fisheries

1

Fish species composition and distribution in Kilifi Creek

D.O. Sigana[1], K.M. Mavuti[2] & R.K. Ruwa[3]

Introduction

Estuaries with mangroves and mudflats have high aquatic biodiversity. These ecosystems play important roles as sheltering, feeding, nursery and spawning grounds for finfish and shellfish (Vidthayanon & Premcharoen 2002). Some species occur both as juveniles and as adults in these areas while others move as adults to other biotopes such as deep zones in the coral reef and *vice versa* (Van der Velde *et al.* 1995). Kambona (1974) observed that commercial fisheries yield in the Indian Ocean are based mainly on coastal species particularly migratory pelagic and demersal species from estuaries and coral reefs. Highly detrimental fishing methods such as the use of dynamite and beach seines as well as indiscriminate shell fish collection have contributed to the depletion of various coastal resources on the Indian Ocean coast (Matthes 1974).

Understanding the assemblages of organisms and how they change in species numbers and abundance depending on existing biotopes is of great interest to ecologists as well as fisheries managers (Washington 1984). Ter Morshuizen *et al.* (1996) studied the distribution patterns of fishes in the Great Fish River (South Africa) and established that euryhaline marine taxa of the families Mugilidae and Sparidae dominated the catch in the river (salinity of <1‰), the

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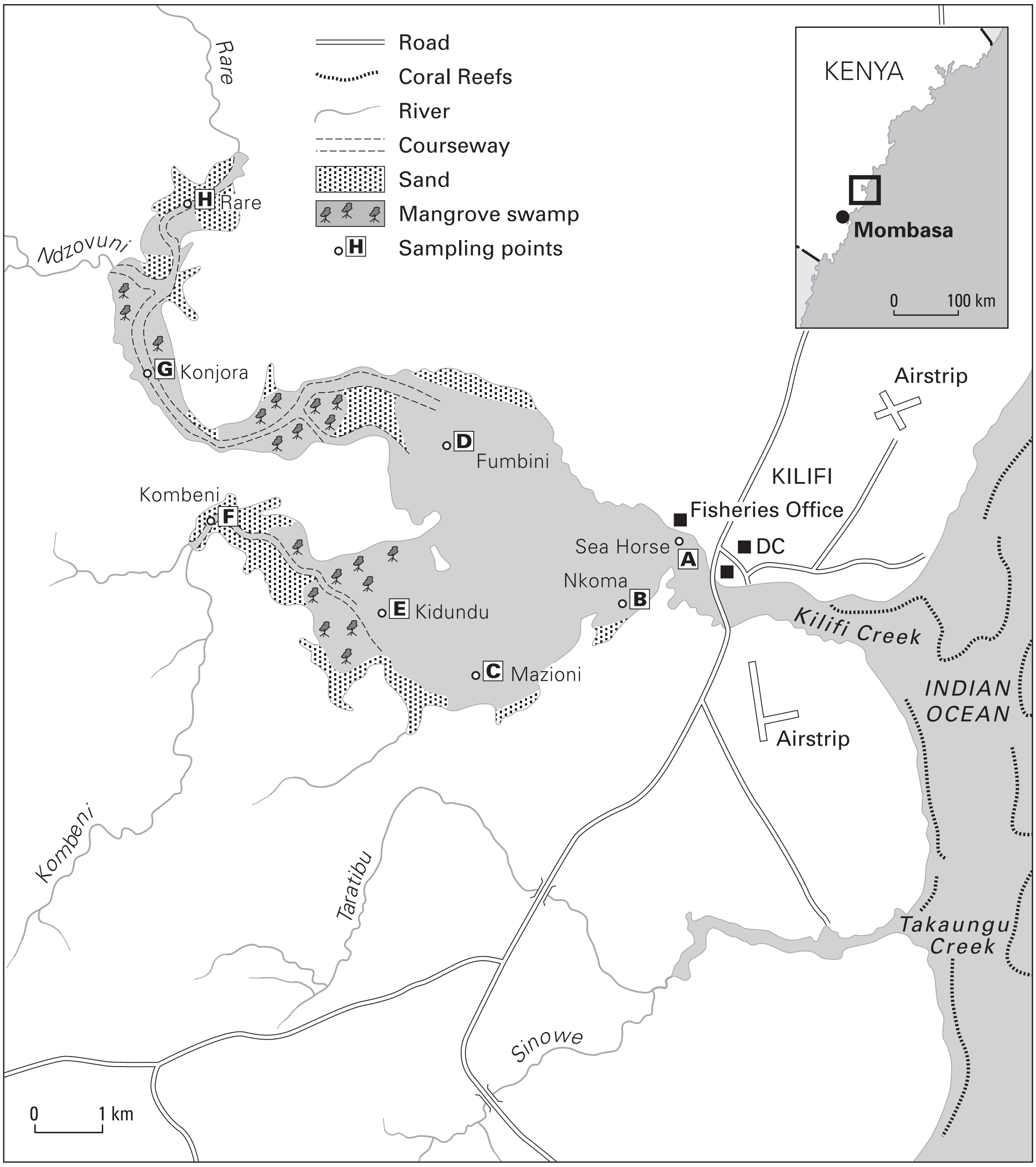


Map 1.1 Kilifi Creek with location of sampling points

head (salinity of 1-4‰) and the estuary (salinity of >4‰). This was attributed to the fact that estuarine associated fish taxa are usually more tolerant of low rather than high water salinity. At Kariega estuary (South Africa), Paterson & Whitfield (2000) observed that the intertidal salt marsh creek and adjacent eel-grass beds function as nursery areas for juvenile fish although the two habitats are dominated by different ichthyofaunal families.

Along the Kenyan coast, shallow-water fish fauna have been documented at Gazi (Kimani *et al.* 1996; Wakwabi 1999); Tudor Creek (Little *et al.* 1988), Diani (Obura 2001) and unprotected and protected reefs along the Kenyan coast (McClanahan 1994). The distribution of fish and other marine organisms shows large variation depending on different biotopes with different physico-chemical characteristics. Kilifi Creek is one of the largest creek systems along the Kenyan Coast, comprising various biotopes that include patches of coral reef, mudflats with and without seaweeds and estuarine ecosystems. This research utilized the opportunity offered by the variation in conditions to study the relationship between fishery organisms and various physico-chemical parameters in the creek.

Study area

Kilifi Creek is located some 55 km north of Mombasa city. The deepest part of the creek is approximately 38 m at the entrance and a distance of about 4 km (500 m wide) separates the ocean from an open lagoon known as Bahari ya Wali. The total area of the creek and Bahari ya Wali is 22.4 km^2. The western side of the creek is extensively covered with mangrove trees of different species covering an area of approximately 360 ha. There are two main water channels winding in between the mangrove forest of which the southern arm is short, without permanent streams, while the northern arm is longer with two permanent streams, Ndzovuni and Rare that join to form the Konjora which leads into Bahari ya Wali (Map 1.1). There are two rainfall seasons, the long rains between April to July and short rains between October to December. Fishing goes on continuously within the creek. Eight sampling sites were selected: Sea Horse, Fumbini, Konjora and Rare to the north and Nkoma, Mazioni, Kidundu and Kombeni to the south towards the creek mouth.

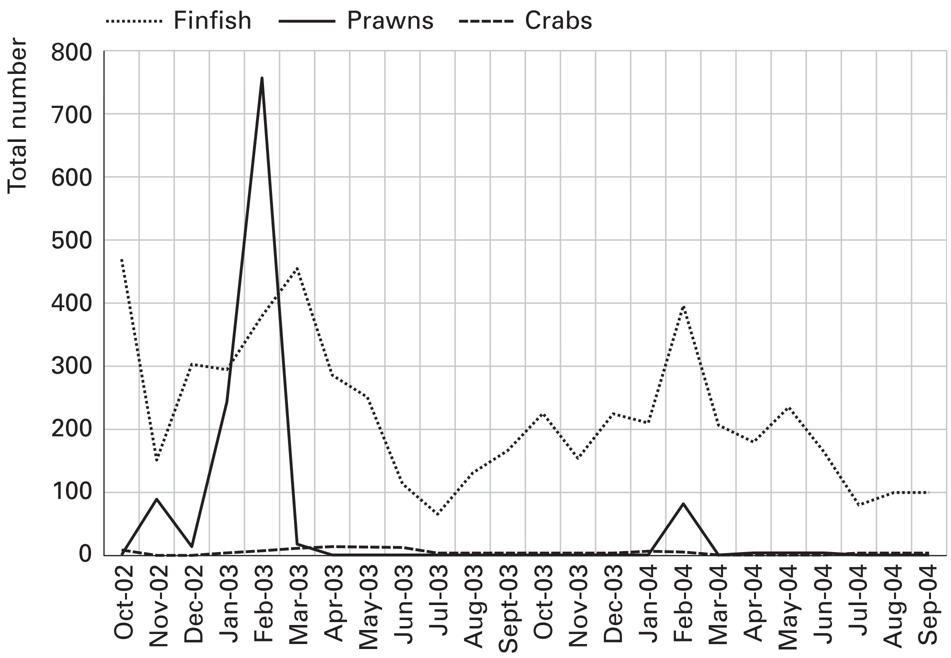
Method

Fishing was carried out at each sampling site during the day using a canoe. The sampling period took four days during neap tides every month from October 2002 to September 2004. A castnet (19.1 mm mesh size, 7.6 m^2) and gillnets

(50.8, 63.5 and 76.2 mm mesh sizes, depth 166 cm and 100 m long each), were used for fishing at all sites. Water was obtained from the surface (below 10 cm) using a scoop bucket (Volume 5 litres) and from the bottom region using an improvised bottom water sampler (Volume 3 litres) for analysis of physico-chemical parameters. These included temperature (mercury thermometer), dissolved oxygen (Winkler method), salinity (Hand held Atago refractometer), inorganic phosphate and nitrate (Parsons *et al.* 1984). Depth and secchi disc transparency was also measured directly at each site. The overall monthly means for each site were calculated from means of both surface and bottom water samples for the above parameters.

All organisms obtained during fishing were identified and classified into orders, families and species where possible according to Smith & Heemstra (1986); Whitfield (1998); Fischer & Bianchi (1984) and Eccles (1992). The individuals of each group were counted and the total numbers recorded. To assess spatial and seasonal variation between finfish communities, the following four diversity indices were used: i) Margalef's species richness index (R) (Zar 1966), ii) Shannon-Weiner diversity index (H') (Zar 1996), iii) Pielou's evenness index (J') (Zar 1996) and iv) Simpson's diversity index (D) (Krebs 1978).

Figure 1.1 Total monthly fishery organisms landed from October 2002 to September 2004



Multi-Dimensional Scaling (MDS), clustering analysis and diversity indices calculations were performed using PRIMER. Principal Component Analysis (PCA) was performed using Pc ord 4 programme, for multivariate analysis of ecological data. SPSS was used to relate physico-chemical parameters to seasons and the diversity indices.

Results

Crustaceans

Four crustacean species were caught but in low numbers at most study sites. Though there were site-specific variations in totals, the crustaceans were always present at Kidundu, Kombeni and Rare (Table 1.1). Specifically, the prawn species *Penaeus indicus* was abundant at Kidundu and Rare, while *P. monodon* dominated at Kombeni. These sites were mudflat areas, but at the Kidundu site mudflats were covered with seaweeds hence were a nursery and feeding ground. The site at Kombeni was hypersaline with high temperatures and high concentrations of phosphates and nitrates and hence *P. monodon* which prefers these conditions dominated. However, it is worth noting that prawns were absent from Sea Horse and Nkoma. The abundance of prawns for both species peaked in February and *P. indicus* was the most abundant species on average (Figure 1.1).

All crabs caught during the study belonged to the Brachyuran order. The crabs were caught every month throughout the study period and in all sites except Konjora. More *Portunus pelagicus* were caught at Mazioni, Kidundu and Fumbini while *Scylla serrata* were more abundant at Rare. There were more *P. pelagicus* individuals caught on average than *S. serrata* (Table 1.1).

Table 1.1 Composition and distribution of crustaceans (prawns and crabs) collected at study sites within Kilifi Creek.

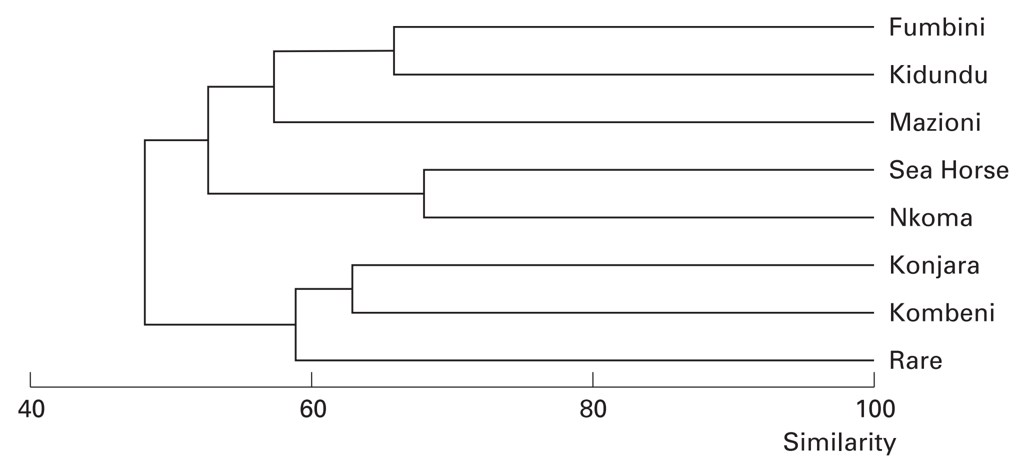
Species/Site	SH*	NK	MZ	FU	KD	KM	KN	RA	Total
Penaeus indicus	0	0	85	1	845	5	1	356	1293
Penaeus monodon	0	0	0	0	3	13	0	4	20
Scylla serrata	2	4	2	3	3	4	0	6	24
Portunus pelagicus	5	6	20	39	23	1	0	4	98
Total	7	10	107	43	874	23	1	370	1435

* Legend SH-Sea Horse NK- Nkoma MZ- Mazioni FU- Fumbini
KD- Kidundu KM- Kombeni KN- Konjora RA- Rare

Finfish

Finfish landings were high during the north-east monsoon and low during the south-east monsoon (Figure 1.1). From the nine orders identified at Kilifi and their distribution at each study site, the order Perciformes had the largest number of species (50 total) and this order also had the highest number of species at each site (Table 1.2). Finfish in the order Clupeiformes and Perciformes occurred at all the study sites but other finfish orders were found at some sites and not others. The highest number of species were recorded at Nkoma over the study period (39) while the lowest number of species were encountered at Konjora (21). Although the site at Sea Horse had only four orders of finfish, the total number of species (34) was still amongst the highest of the sites due to the large number of species in the order Perciformes (31). Only two finfish orders were recorded at Konjora and hence the low diversity recorded at this site. Figure 1.2 shows the Bray-Curtis species similarity dendrogram of fish species rank order during the study period. Sea Horse and Nkoma were distinctly different from the other sites since they were the deepest sites within the study area.

Figure 1.2 Similarity dendrogram of fish assemblages rank order in Kilifi Creek by site



Diversity indices

During the first year, diversity indices were high at all sites but a sharp decrease was observed towards the end of the second year. The indices were again notably high during the north-east monsoon. F-test showed no significant differences between the north-east and south-east monsoon seasons when the diversity indices were compared [R ($F_{1,178}$=0.02, p=0.88); J' ($F_{1,172}$=3.89, p=0.05); H' ($F_{1,184}$= 0.15, p=0.6); and Simpson's ($F_{1,178}$=0.57, p=.45)].

The site at Fumbini had the highest abundance of finfish collected during the study period (Table 1.3). Comparisons between sites showed that the Margalef's species richness index was highest at Sea Horse (2.2) followed by Nkoma (1.8) and Kidundu (2.1) but lowest at Konjora (1.2). The site at Mazioni had the highest mean Pielou's evenness (0.90) while Fumbini (0.68) had the lowest evenness. The mean Shannon-Weiner diversity index was high at Kidundu (1.5), Sea Horse (1.45) and lowest at Konjora (0.73). However, Simpson's index was high at all sites within the Bahari ya Wali (between 0.56 and 0.76; Map 1.1).

Table 1.2 The number of species in each finfish order and the total number of species recorded at each study site.

Order	SH*	NK	MZ	FU	KD	KM	KN	RA
Anguilliformes	1	1	1	1	1	0	0	0
Aulopiformes	1	1	0	0	1	1	0	0
Clupeiformes	1	3	3	2	3	2	1	1
Elopiformes	0	0	0	0	0	1	0	0
Gonorhynchiformes	0	1	0	0	0	1	0	1
Perciformes	31	30	19	22	29	23	20	23
Pleuronectiformes	0	1	1	1	1	0	0	0
Siluriformes	0	1	0	1	1	0	0	0
Squatiniformes	0	1	0	1	1	0	0	1
Total	34	39	24	28	37	28	21	26

* Legend: See Table 1.1

Physico-chemical parameters

Table 1.3 shows the means of the physico-chemical parameters together with the mean number of fish collected for each study site. The parameter with the largest mean variation was nitrates that was highest at Rare and lowest at Mazioni. Mean phosphate concentration was high at Rare but low at Kidundu. Variation among sites, however, was low in respect of salinity, temperature and dissolved oxygen. Both Sea Horse and Nkoma were deep sites and also had the highest secchi transparency. Fumbini and Kidundu had the highest mean number of fishes, followed by Sea Horse and Nkoma, but Konjora had the lowest.

Variation in physico-chemical parameters between the north-east monsoon and south-east monsoon was tested and a significant difference was observed in the concentration of phosphate and temperature ($F_{1,184}$=22.51, p=0.00; $F_{1,184}$= 48.06, p=0.00 respectively) while no significant difference was observed in the concentration of nitrates, dissolved oxygen, salinity, secchi transparency and depth ($F_{1,184}$=0.71, p=0.40; $F_{1,184}$=0.88, p=0.35; $F_{1,184}$=0.10, p=0.75; $F_{1,184}$=1.20, p=0.27; $F_{1,184}$=1.16, p=0.28 respectively).

The PCA analysis identified two groupings based mainly on environmental characteristics of the different biotopes of Kilifi creek (Figure 1.2). The secchi transparency and depth were important physico-chemical factors at the sites at

Table 1.3 Means and S.E. of physico-chemical parameters and the number of fish (N=24 months).

Parameters	SH*	NK	MZ	FU	KD	KM	KN	RA
Phosphates (μg/l)	0.65 (0.03)	0.72 (0.04)	0.63 (0.02)	0.7 (0.03)	0.58 (0.02)	1.06 (0.06)	0.65 (0.04)	1.11 (0.06)
Nitrates (μg/l)	1.37 (0.06)	1.27 (0.04)	1.21 (0.05)	1.28 (0.05)	1.32 (0.05)	1.49 (0.04)	7.08 (0.12)	11.06 (0.34)
Dissolved Oxygen (mg/l)	6.50 (0.02)	6.29 (0.02)	6.24 (0.02)	6.34 (0.03)	6.19 (0.02)	5.32 (0.02)	6.02 (0.04)	6.19 (0.04)
Temperature (^{0}C)	28.02 (0.06)	28.17 (0.06)	28.55 (0.07)	28.38 (0.07)	27.76 (0.07)	30.12 (0.09)	29.58 (0.08)	30.08 (0.08)
Salinity (‰)	35.19 (0.06)	35.22 (0.06)	35.46 (0.07)	35.32 (0.08)	35.48 (0.06)	37.46 (0.16)	33.21 (0.17)	29.85 (0.23)
Depth (m)	8.67 (0.08)	8.05 (0.08)	3.76 (0.02)	1.61 (0.01)	1.96 (0.02)	1.37 (0.02)	3.87 (0.03)	2.22 (0.03)
Secchi (m)	2.92 (0.03)	2.55 (0.03)	1.57 (0.02)	1.21 (0.01)	0.95 (0.01)	0.43 (0.01)	0.92 (0.01)	0.62 (0.01)
Fish (mean no. collected)	34 (1.59)	32 (1.36)	12 (0.56)	52 (2.14)	41 (1.44)	18 (0.8)	8 (0.36)	26 (0.9)

* Legend: SH- Sea Horse, NK- Nkoma, MZ- Mazioni, FU- Fumbini, KD- Kidundu, KM- Kombeni, KN- Konjora, RA- Rare

Sea Horse and Nkoma. The analysis of finfish species also showed that these sites were utilized by coral reef species. The site at Kidundu had a large area with a mudflat without seaweeds while the sites at Fumbini, Kombeni, Mazioni, Rare and Konjora grouped together because they were generally shallow with slightly varying physico-chemical parameters between the sites. The sites at Sea Horse and Nkoma had very high finfish diversities followed by Kidundu, though the most utilized areas based on the average number of individuals recorded were Fumbini and Kidundu (Table 1.3). The sites at Sea Horse and Nkoma that were situated at the entry point into the mangrove area of the creek also had some of the highest abundances of fish.

Discussion

Vance *et al.* (2002), reported that the distribution of *Penaeus merguiensis* is affected by mangrove type, water depth and topography/water currents. Of the two prawn species identified and collected from mangrove areas within Kilifi creek, high abundances of *P. indicus* were recorded at sites at Kidundu, Rare and Mazioni while the site at Kombeni had the highest number of *P. monodon*. The Portunid crabs recorded were both absent from Konjora, however, *Portunus pelagicus* was more abundant at Mazioni, Kidundu and Fumbini. These study sites were adjacent to both mangrove and sandy areas and did not show a distinct pattern with crustacean distribution. The shell fishes contributed to the fishery activity of Kilifi Creek both as a source of food and economic activity for fisher communities at the creek (Kyomo 1999).

The structure of an estuarine fish community depends on both biotic and abiotic factors such as salinity, temperature, turbidity and dissolved oxygen which varies between sites. Previous studies on other estuarine communities include Vidthayanon & Premcharoen (2002) with 199 finfish families in Thailand; Loneragan *et al.* (1986) with 24 families in Australia; Lin & Shao (1999) with 14 families in Taiwan; Mbande *et al.* (2005) with 31 families at Mngazana and 24 families at Mngazi estuary; Kimani *et al.* (1996) with 50 families at Gazi. The diversity of species recorded in this study included 38 families and 63 species and compares favourably with the previous studies. Whitfield (1994) observed that tropical and sub-tropical estuaries have higher species diversity than temperate ecosystems due to richer ichthyofauna associated with rivers and marine habitats on the Western Indian Ocean.

This study concurs with observations of Loneragan *et al.* (1986) that finfish species diversity correlates with distance from the estuary mouth. For example, the mean number of species was significantly higher at Sea Horse, Nkoma, Fumbini and Kidundu that were situated closer to the mouth of the Kilifi creek and lower at the remaining sites that were deeper in the creek. The main marine immigrants into the creek included *Leiognathus equula*, the *Mugilidae mugil-cephalus* and *Valamugil buchnani*, and *Gerres filamentosus* which were also recorded by Whitfield (2005).

Ohowa (1996) reported that a mean phosphate concentration of 0.55 µg P/L limits phytoplankton growth. The mean phosphate values at all sites within Kilifi were higher than this level as well as phosphate concentrations reported for Vipingo and Nyali (Uku & Bjork 2001) which is not surprising since these are shallow lagoon reef sites. This indicates that phosphate concentrations are unlikely to be limiting phytoplankton growth in the Kilifi creek. The mean nitrate concentrations were highest at Rare where it could be attributed to decomposing organic matter from the freshwater Rare stream. Uku & Bjork (2001) report higher nitrate concentrations than at the Kilifi study sites and it not clear why this would be the case. Among other parameters that may have been affecting fish fauna in Kilifi, dissolved oxygen, temperature and salinity had the least variations and concurred with observations of McClanahan (1988). It was also observed that the areas most utilized by fish were Fumbini and Kidundu followed by Sea Horse and Nkoma that were near the mouth of the creek. The least utilized areas were Mazioni and Konjora, Rare that had the lowest salinity while Kombeni was hypersaline. This confirms finding from Ter Morshuizen *et al.* (1996) in the Great Fish River that showed that finfish spatial distribution was related to salinity changes.

A combination of various parameters influenced fish distribution within the study sites but the most outstanding physico-chemical factors were secchi transparency and depth at the sites at Sea Horse and Nkoma. The concentration of phosphates was the outstanding factor at the sites at Rare, Kombeni and Mazioni and to a small extent at Sea Horse and Nkoma. The concentration of nitrates was the outstanding factor at the Rare site, while dissolved oxygen, temperature and salinity were more or less uniform at all sites. These physico-chemical parameters were optimum at Fumbini and Kidundu sites where fish mean number were the highest observed but variations at the Konjora site in these physico-cheminal factors contributed to low numbers of finfish observed.

The diversity indices in aquatic ecosystems are controlled by a combination of history, biotic and abiotic factors but abiotic factors are the stronger influence on biodiversity (Therriault & Kolasa 1999). From this study, it can be observed clearly that the species number decreased significantly from the lagoon at Bahari ya Wali, towards the fresh water end as observed by Loneragan *et al.* (1986). This suggests that the species composition of the study area shows a spatial distribution from the creek mouth to the freshwater end since fish species of Konjora, Rare and Kombeni were distinctly different from those at Fumbini, Kidundu, Mazioni, Sea Horse and Nkoma (all within the lagoon). It also shows the use of various biotopes within the study site and that most members are marine immigrants visiting the area specifically to feed. Further research to study feeding habits of each species needs to be carried out to discern the importance of each study site for fisheries management.

Acknowledgements

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Summary

Ecological variation along the Kenyan coast influences fisheries composition. Kilifi Creek is a unique ecosystem along this coast because it is an open lagoon. A study of the fisheries fauna of Kilifi Creek was conducted between October 2002 and September 2004 at eight sites situated from the mouth to deeper waters within the creek. Monthly sampling for diversity and distribution revealed four crustacean and 63 finfish species. The crustaceans included two prawn species (*Penaeus indicus*, *P. monodon*) and two crab species (*Portunus pelagicus*, *Scylla serrata*). Crabs were absent from the Konjora site while prawns were absent from the deep sites within the creek. Fish in the order Perciformes dominated the catch at all the sites consisting of 74-95% of the catch. The fishery species landings were higher during the north-east monsoon (October-March) compared to the south-east monsoon (April-September) but Margalef's species richness index (p=0.88), Shannon-Weiner (p=0.6), Pielou's evenness (p=0.05), and Simpson's index (p=0.5) were not significantly different between seasons. Monthly measurements of

physico-chemical parameters also revealed that there were significant differences in the phosphate concentration (p=0.0) and temperature (p=0.0) between the north-east and south-east monsoon season but not in other physico-chemical parameters. The finfish composition differed at the different sites and a principal component analysis indicated that water transparency and depth were the main determinants of finfish distribution.

2

Exploitation of marine aquarium reef fisheries at the Kenyan Coast

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Introduction

Ornamental marine species (corals, invertebrates and fish) are the highest value-added product that can be harvested from coral reefs and are an important source of income for rural, coastal communities in developing countries (Lem 2001). The global aquarium trade (both marine and freshwater) involves approximately 350 million fish annually with a value of $963 million (Tissot & Hallacher 2003). The marine aquarium trade accounts for approximately 10% to 20% of the global aquarium trade with an estimated 1,471 species of fish being traded (Wabnitz *et al.* 2003). With over 1.5 million people keeping marine aquaria in their homes or businesses, the value of the trade is estimated to be between $200 to $330 million per year (UNEP 2003).

The trade involves over 40 countries in the supply market, with the top suppliers including Indonesia, Philippines, Brazil, Maldives, Sri Lanka, Singapore, Hawaii, Yemen and Egypt (Wood 2001). Within the Western Indian Ocean, Kenya ranks first among countries that include Mauritius, South Africa, Madagascar and Tanzania respectively. The fishery in Kenya is medium in size, involving the annual collection of 50,000-200,000 individuals (Wood 2001).

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Kenya's marine aquarium fisheries was established in the early 1970's but it has received limited attention by way of research and monitoring. The industry is important in providing a source of foreign exchange for the country as well as a source of livelihood for fish collectors and their families. The limited knowledge on the dynamics of exploitation has contributed to increased concerns by stakeholders (artisanal food fishers, dive-tourism operators, resource managers and environmentalists) that the fishery is having negative impacts on targeted populations and their habitats. This study was initiated to address the concerns of stakeholders by providing baseline information on the trade links and dynamics of the supply network, the key sites of harvest, harvest methods used, the species exploited and the catch and effort trends.

Method

Data was collected on species traded based on customs shipping lists acquired from the Department of Fisheries. It was observed from preliminary assessments that the shipping lists were often underreported and thus not reliable for extraction of trends. The daily logbook returns of fishermen that were employed by a leading exporter were therefore used to determine the species harvested for export and the catch per unit effort (CPUE=number of individuals man^{-1} day^{-1}). Visits were also made to the holding facilities to confirm the identification of species. Photos of some problematic species were also taken for further identification.

Semi-structured interviews were conducted with the exporters and fish collectors to better understand the resource use patterns. Data from air freighting companies was also collected from the main airport in Mombasa from January to July 2005 to determine export destinations and the volume exported. Preliminary analysis of the CPUE data indicated non-normal distribution patterns (Shapiro Wilk's test for normality, $W=0.988$, $p=0.5311$). To quantify the dead on arrival (DOA) mortality rate, the percentage of dead fish (grouped by family) in each landed catch was calculated by summing the number of dead individuals in each recorded catch divided by the total number of individuals in the catch. The daily means of the percent mortality were then calculated for further statistical analysis.

Study area

The Shimoni area was selected to monitor catch dynamics of the aquarium trade since it is highly favoured by aquarium fish collectors. Shimoni is situated off the southern coast of Kenya near the Tanzanian border (Map 2.1). The area consists of a Marine Protected Area (MPA) offshore complex containing three coral

Map 2.1 Kenya coast with key collection sites of aquarium fish

islands and submerged reefs. The Kisite Marine National Park (KMNP) and Mpunguti Marine National Reserve (MMNR) cover an area of approximately 39 km^2 (Emerton & Tessema 2001). Kisite Marine Park is managed as a no-take zone where no consumptive utilisation is allowed. Fishing activity by aquarium collectors and other artisanal fishers is allowed in Mpunguti Marine Reserve.

Results

Trade links and dynamics of the supply network

The supply network in Kenya is fairly simple, running directly from the collectors to the exporters and straight to the export market. Thus, there are no middlemen involved in Kenya's trade. The industry has experienced notable growth, with the number of export companies licensed to export marine aquarium fish doubling from 4, during 2000 (Wood 2001) to 8 at the time of this study. However, the airfreight data indicated that only two companies dominate the market exporting approximately 65% of the consignments. Similarly the number of registered fish collectors increased from 65 to 145 indicating that the fishery is experiencing increased pressure.

The exporters contract local fish collectors who are paid according to a set price per fish that has been determined for each species that is delivered alive and in a healthy state to the holding facilities. The price paid to the collectors varies among companies and is competitive as it is determined by various factors including the size of the fish, market demand, rarity, and catchability, ornamentation, and seasonal abundance.

To maintain high quality of fish and minimal mortalities, the exporters invest heavily on aquarium maintenance equipment (e.g. aeration and filtration equipment). However, the handling of fish also varies among the companies although there are some standard measures. Generally, the harvested fish are temporarily packaged in plastic bags or containers at the jetty and transported in vans to the holding facilities where they are kept in quarantine for acclimatization to life in captivity, as well as to detect and treat any injuries or infections before shipment. Any fish with infections are isolated and treated accordingly but treatment depends on the level of expertise of the handlers. The fate of fish that do not recover remains unknown although it can be assumed that they eventually succumb to injuries or infections of a fatal nature.

Upon receipt of an order from a client, the exporter must obtain an export permit from the Fisheries Department before any consignment can leave the country. Once this is done, the fish that have been certified to be in good condition are then packaged in plastic bags filled with oxygen and sealed. The sealed plastic bags are placed in insulated boxes and taken to the airport. Upon clearance by the customs department, the consignments are then air freighted to the destination markets.

Packaging is an important and costly aspect of the export trade. The airlines charge a freight charge, which may determine more than 50% of the final market price of the fish because any delays or mishandling of the consignments during transit can influence the ultimate quality of the fish when it lands at the destination market. Analysis of air freight data revealed that boxes are frequently rejected or returned by the airline companies due to inferior packaging resulting in leakages while in transit. Airline carriers incur the costs of transporting rejected consignments back to the exporters. Thus, they are not only major beneficiaries of the marine aquarium trade but they are also negatively affected due to lax enforcement of the set regulations

The Free on Board (FOB) export value of the fish is negotiated with the client and is influenced by factors such as the quality of fish, size, market demand, and the presence of rare species in the consignment. Consequently, the exporters charge different prices in different countries, according to the production costs, stock quality, and local inflation levels (Olivier 2003).

The survey indicated that fish collectors were men of 25 to 42 years, with a mean age of 34 years. At the time of the study there were 145 licensed fish collectors working full time in the fishery. We however noted that there are some unlicensed fish collectors who collect aquarium fish for the local market (mainly hotels). The study also revealed that some fishermen who are licensed to target other fisheries (e.g. lobsters) occasionally collect aquarium fish to supplement their income on a part-time basis.

Harvest methods

Fish collectors use masks and snorkels in shallow areas or SCUBA gear in deep waters and employ a selection of dip and scoop nets. The length of fishing trips varies from 3-4 hours a day with fishing expeditions ranging from 1-7 days depending on the distance of the fishing site, lunar cycle, the weather, and the resource demand. The fish collectors deliver their daily catch to a vehicle waiting and the catch is immediately transported to the holding facilities. The fishing teams using SCUBA usually set out to fish in large groups of 5-10 fishers while snorkellers fish alone or in pairs. There was no report or observation of explosives or chemical substances being used; the use of these destructive methods is not permitted in Kenya.

The exporters provide their fish collectors with full fishing gear, which includes fishing nets, snorkels, and diving gear flippers and diving suits. The exporters also hire motorized planked boats (7-10m in size) for use during the fishing trips and also transport the catch from the collection site to the holding tanks. There are however some smaller companies that do not employ fishers on a long-term basis preferring to hire by contract on demand or to subcontract employees of rival exporters thereby resulting in inevitable conflicts between exporters.

Monitoring and regulation of the trade

The management regime for the marine aquarium trade is described in the Fisheries Act (Cap 378). Currently aquarium fish exporters and collectors are charged a minimal fee to obtain annual licenses from the Department of Fisheries. An export fee of 3% tax on the FOB value of each consignment is currently charged by the Department. Collection of fish and invertebrates from marine parks are prohibited although this rule is not well enforced. The use of poisons and explosives is prohibited in the Act as well. There are however no restrictions on species harvested except those listed under CITES such as the seahorse *Hippocampus spp*. The Fisheries Act stipulates that exporters must furnish a monthly return of their exports using a set form by the Department, failure to which the license can be cancelled. However, the use of logbooks documenting details of catch and effort is not an official requirement, although some of the exporters prefer to keep logbooks for their own records.

Standards for packaging of the fish are regulated by the Customs Department using guidelines provided by the International Air Transport Association (IATA) in respect to transportation of animals by air. The guidelines convey information on container construction; dispatch preparations (e.g. number of fish per box, oxygen content and air temperatures); and general care and loading of the consignments. Kenyan exporters often flaunt the packaging guidelines in order to minimize costs. An official of Kenya's national cargo carrier expressed the opinion that there is a need for the government to establish standards on the packaging materials that should be used for the aquarium industry. This would reduce the number of rejected consignments and consequently the rate of mortality of fish in transit.

Key collection sites

All aquarium fish exported from Kenya are caught from the wild. Fish collection is carried out almost throughout the entire coastline (Map 2.1). Some of the fishing areas are quite popular for the collection of specific species of aquarium fish and the exporters have detailed knowledge of the species found in each area. Key fishing sites identified include Shimoni, Diani, Nyali, Jumba, Mtwapa, Vipingo, Shariani, Msumarini, Kanamai, Kilifi, Watamu, Malindi, and Lamu. Of these areas, the most frequented were Shimoni followed by Nyali.

Export markets

During the study, the exported fish were destined to 15 countries which included United Kingdom, USA, South Africa, Hong Kong, Germany, France, Japan, Netherlands, Austria, Israel, Denmark, Poland, Hungary, Italy, Romania and Austria. Seasonal fluctuations in the volume of exports were observed with peaks occurring during the months of December to April. Interviews with the exporters confirmed that these are the peak months in terms of orders. The orders in the months of May to August are low and this coincides with the rough south-east monsoon when conditions are not favourable for collection of aquarium fish.

Species harvested

Selection of species results from a demand for colourful fish as well as fish that are easily maintained and fed in aquaria. A total of 193 marine aquarium fish species, from 35 families, were harvested from the Shimoni area during the study. A full list of harvested fish species is documented in Appendix 2.1. Of the 16,373 individuals landed during the study (including fish and invertebrates), fish made up approximately 97% of the catch. Approximately 70% of the catch belonged to 4 families namely Pomacentridae (damselfish-31%), Labridae (wrasses-23%), Acanthuridae (surgeonfish-13%) and Gobiidae (gobies-8%). The greatest diversity of species harvested was among the wrasses (42 species), butterflyfish (23 species), damselfish (17 species) and gobies (12 species).

Table 2.1 The top 10 ornamental fish harvested from Shimoni by a leading export company (March 2004 to April 2005).

Common name	Scientific name	Total harvested	Percent harvested
Allard's anemonefish	*Amphiprion allardi*	1666	10%
African pygmy angelfish	*Centropyge acanthops*	1442	9%
Rainbow wrasse	*Halichoeres iridis*	1192	7%
Palette surgeonfish	*Paracanthurus hepatus*	979	6%
Lyretail anthias	*Pseudanthias squampinnis*	851	5%
Striped sailfin tang	*Zebrassoma veliferum*	791	5%
Beautiful prawn goby	*Amblyeleotris aurora*	669	4%
Fire dartfish	*Nemateleotris magnifica*	641	4%
Skunk anemonefish	*Amphiprion akallopisos*	594	4%
Vermiculate wrasse	*Macropharyngodon bipartitus*	520	3%

Fifty-eight percent of the fish landed belonged to 10 species (Table 2.1). Species of high value which are often difficult to catch or are rare included the puffers *Arothron stellatus*, *A. meleagris*, *A. mappa*, and *A. nigropunctatus*, the triggerfish *Balistoides conspicullum*, the angelfish *Pomacanthus chrysurus* and *P. maculosus* and an extremely rare hybrid of the two angelfish species which was the highest valued fish. A variety of invertebrates were also harvested including starfish, brittlestars, tubeworms, sea anemones, coral shrimp, feather-worms, anemone crabs, sea urchins and lobsters. Assessment of airfreight data also revealed that 'live rock' is also exported by some companies.

Catch dynamics

Collectors generally target juveniles which tend to be more colourful than adults of the same species. Juveniles are also easier to handle and package for air freighting compared to adults.

The SCUBA divers landed approximately 71% of the catch in Shimoni and also landed significantly more diverse species compared to snorkellers (Table 2.2). Overall, the daily mean CPUE of fish collectors was estimated to be 25 individuals per fisherman per day. However differences were observed between divers and snorkellers with divers landing significantly more individuals (Table 2.2).

The mortality rate averaged at approximately 2% dead on arrival (DOA) at the holding facility. Fish caught by divers exhibited a significantly higher incidence of mortality compared to snorkelers (Table 2.2). Butterflyfish and angelfish exhibited the highest frequency of mortality (33% and 28% of the total number of dead individuals respectively).

Table 2.2 Summary of catch dynamics of the Shimoni fishery (Mar.2004 to Apr.2005)

Fishing Method	No. Fish	# Species day^{1} (s.d.)	# Individuals man^{1} day^{1} (s.d)	% Mortality day^{1} (s.d)	Earnings man^{1} day^{1} (US$ (s.d)) *
Snorkelling	5,408	5 (2)	20 (22)	1 (2)	5 (6.4)
SCUBA	10,634	9 (4)	29 (19)	3 (4)	12.6 (6.8)
All Groups	16,042	7 (4)	25 (21)	2 (5)	9 (7.8)
Mann-Whitney U-test		$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$

* exchange rate 1 USD= 72Ksh

Mean earnings per fisherman ranged between US$ 8-10 per day and between US$ 200-340 per month. Snorkellers were inclined to advance to SCUBA diving after some years in the fishery due to the higher financial returns. Although not estimated, many of the divers admitted not to have acquired any professional training as divers but rather learned on the job.

Discussion

Kenya's marine aquarium trade is among the oldest in the Western Indian Ocean, having existed since the 1970's. Like in other parts of the world, there have been concerns over the potential impacts on targeted species in Kenya due to the highly selective nature of aquarium fish collection. Wood (2001) affirms that the main threats emanate from local level depletions rather than regional or global species extinctions which may alter the population dynamics of targeted species as well as the ecological balance of their reef habitats. The level of threat on targeted populations remains unknown and offers an avenue for further research to better understand the impacts of the fishery.

Of the 4,000 species of fish that live on coral reefs, 1,471 species are traded worldwide (UNEP 2003). Of these species, only 200-300 are highly exploited (FAO 1995). This study has documented a first time estimation of 193 fish species harvested in Kenya's export trade, refining a recently published estimate of only 22 species by Green (2003) which was based on calculations from the Global Marine Aquarium Database (GMAD). The latter is based on only a select number of wholesale companies that import fish from Kenya for re-export and thus does not provide a realistic national estimate. The estimate in this study is deemed as more comprehensive since it is based directly on logbook catch data and on-site confirmation at the holding facilities.

Clownfish (*Amphiprion sp.*) are among the most harvested marine aquarium fish worldwide, and results of this study indicate a similar trend for Kenya. The CPUE estimate provides a baseline reference point for future monitoring of the fishery considering that the study area is one of the most preferred sites for marine aquarium fish collection in Kenya. The mean daily CPUE of fish collectors in Shimoni was found to be comparable to the Cook Islands (24 to 36 fish per fisherman per day) and Sri Lanka (30 to 50 fish per fisherman per day) as documented by Wood (2001).

During the study period, the mean mortality rate was approximately 2% on arrival at the holding facilities. Mortality rates will however vary between different exporters depending on the handling methods used during harvest and while in transit. Because many people are involved through the 'chain of custody', there are a number of possible causes of post-harvest mortality which include: physical damage to the fish during collection; poor handling; inferior water quality during transportation and in the holding tanks, diseases, stress and collection of species which are difficult to sustain in aquaria (Rubec & Cruz 2005; Schmidt & Kunzmann 2005).

Although no studies have been done to establish the environmental impacts of the aquarium export trade in Kenya, damage to the corals is inevitable during collection of species that inhabit corals such as damselfish (Wood 1985). Various studies on the effects of artisanal fisheries in protected vs. non-protected coral reefs at the Kenya coast have revealed that changes in abundance of fish species and a number of secondary and tertiary effects are occurring in unprotected reefs due to intensive fishing and the use of destructive fishing gears such as beach seines and spear guns (McClanahan & Muthiga 1988; Samoilys 1988; Watson & Ormond 1994; McClanahan & Obura 1995; Watson *et al.* 1996; McClanahan *et al.* 1997; McClanahan & Mangi 2001). Furthermore, recent surveys of reefs in many parts of the world have found that many target species of high commercial value are either absent, or in drastically low numbers when compared to non-fished areas (Hodgson 1999; Tissot 1999; Tissot & Hallacher 1999, 2003). When heavy harvesting is exerted on a small area for a long time, aggravated by the selective removal of a few target species, shifts in the community structure and ecological balance of the reef habitats may occur (Gasparini *et al.* 2005). Because collection is spread out throughout the Kenya coastline, the risk of localized pressure may be reduced; however the threat of site-specific and species-specific localized depletions could be occurring in highly frequented fishing sites such as Shimoni. Further studies are needed to determine the extent of the impacts of aquarium fisheries on targeted populations.

Although the ornamental fish trade remains a complex network, involving collection, distribution and marketing in many countries (Olivier 2001), the network in Kenya is fairly simple, running directly from the collectors to the exporters and straight to the export market (wholesalers and retailers). The marine aquarium fish industry is gaining increasing popularity at the Kenyan coast with a growing interest from both local and international investors as is evidenced by the increased number of fishers and export companies.

Recommendations on regulation and management of the fishery

To ensure minimum mortalities of harvested fish, the collection of fish that have been documented to have low survival rates in captivity should be prohibited. For instance, aquarists have confirmed that *Chaetodon meyeri*, *C. trifascialis* and *C. trifasciatus* are very difficult to maintain in captivity because they feed exclusively on coral polyps (Edwards & Shepherd 1992). These species were nevertheless found to be harvested in this study, despite there being a low probability of their survival in aquaria.

There is a need to improve current regulatory and monitoring mechanisms concerning the marine aquarium fishery. Enforcement of the current regulations stipulated in the Fisheries Act needs to be improved at all stages of the local supply chain. Strengthened monitoring of the fishery will be an instrument for improved validation of data thereby leading to better characterization of changes and trends in the volume of exports and ecological impacts of the trade. Although exporters are required to submit monthly records of their shipments to the department of fisheries using set forms, the records are often underreported and poorly maintained. The form currently in use does not provide for detailed information (e.g. location of harvest, method used, number of fishers) that can allow for assessments on CPUE to be monitored. A selection of index sites should also be established to specifically monitor the environmental impacts of the fishery. Through such initiatives, for instance, species most vulnerable to collection pressure will be easily identified so that precautionary measures can be put in place.

The quality of fish is highly influenced by the quality and management of the holding facilities, thus standards regarding the harvesting and handling of fish, the holding facilities and packaging materials should be developed and incorporated into the relevant legislation. Training of fish collectors should also be carried out in collaboration with the exporters and relevant governmental and non-governmental institutions so as to ensure that best fishing and handling practices are maintained and to increase their awareness of the various environmental and social issues pertaining to the fishery. Furthermore, customs inspectors should also be trained to identify the marine species of fish and invertebrates and be facilitated with appropriate reference material to enhance comprehensive inspection of export consignments.

There is a need to develop policies that will maximize the survivorship of the targeted species, conserve the integrity of their asssociated reef habitats and reduce illegal or underreporting of harvests. However, any regulatory measures that are developed should not hamper the economic viability of the industry, as this will exarcerbate user conflicts. Thus, it is important to reiterate that collaborative dialogue with all stakeholders is imperative for successful management of the fishery.

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Summary

Kenya ranks among the top exporting countries in the marine aquarium trade within the Western Indian Ocean region. However the fishery has received limited attention by way of research and monitoring despite being established during the mid 1970's. This paper provides a detailed overview of the dynamics of the fishery based on results of a one-year survey conducted during 2005 to determine the species harvested in the fishery and the harvest and export trends. Available government statistics, logbook returns of fish collectors at the Shimoni area and airfreight data were examined to assess the catch and export dynamics of the fishery.

An estimated total of 193 fish species were harvested from the Kenya coast for export. Of the total number of individuals landed in Shimoni during the study period (including fish and invertebrates), fish made up approximately 97% of the catch with about 71% of the fish landed by divers. Approximately 70% of the fish belonged to 4 families namely Pomacentridae (damselfish), Labridae (wrasses), Acanthuridae (surgeonfish) and Gobiidae (gobies). Ten species made up 58% of the harvested catch topped by two species, *Amphiprion allardi* (10%) and *Centropyge acanthops* (9%). The mean daily CPUE of fish collectors in the Shimoni area was estimated to be 25 individuals per fisherman per day, with divers landing significantly more fish than snorkellers. Among the key recommendations are the need to strengthen monitoring, to improve current regulatory mechanisms, and to promote strong stakeholder involvement in the management of the fishery. This study provides essential baseline information for further assessments of the status and sustainability of the fishery.

Appendix 2.1 List of species harvested in the aquarium fishery

ACANTHURIDAE
Acanthurus leucosternon
A. lineatus
A. nigrofuscus
A. triostegus
A. xanthopterus
Ctenochaetous strigosus
Naso annulatus
N. brevirostris
N. elegans
N. vlamingi
Paracanthurus hepatus
Zebrassoma desjardinii
Z. scopas
Z. veliferum

ANTENNARIIDAE
Histrio histrio

APOGONIDAE
Apogon cookii

BALISTIDAE
Balistapus consipicullum
B. undulatus
Melichthys indicus
Odonus niger
Pseudobalistes fuscus
Rhinecanthus aculeatus
Sufflamen bursa

BLENNIIDAE
Aspidontus taeniatus
Atrosalarias fuscus
Ecsenius midas
Exallias brevis
Meiacanthus mossambicus
Salarius fasciatus

CARACANTHIDAE
Caracanthus sp.

CARANGIDAE
Gnathanodon speciosus

CENTRISCIDAE
Aeoliscus strigatus

CHAETODONTIDAE
Chaetodon auriga
C. bennetti
C. dolosus
C. falcula
C. guttassimus
C. kleinii
C. leucopleura
C. lineatus
C. lunula
C. madagascarensis
C. melannotus
C. meyeri
C. nigropunctatus
C. trifascialis
C. trifasciatus
C. unimaculatus
C. vagabundus
C. xanthocephalus
C. zanzibariensis
Forcipiger flavissimus
F. longirostris
Heniochus acuminatus
H. monocerus

CIRRHITIDAE
Cirrhichthys oxycephalus
Paracirrhites arcatus
P. forsteri

DASYATIDAE
Dasyatis kuhlii
Taeniura lymma

EPHIPPIDAE
Platax orbicularis
P. teira

GOBIIDAE
Amblyeleortis stenitzi
A. wheeleri
Amblyogobius sphinx
Cryptocentrus aurora
Cryptocentrus sp.
Gobiodon citrinus
Paragobiodon echinocephalus
Valencienna helsdingeni
V. puellaris
V. sexguttata
V. strigata

HAEMULIDAE
Plectorhincus orientalis
P. picus

LABRIDAE
Anampse caerulepunctatus
A. meleagrides
A. twisti
Bodianus anthioides
B. axillaris
B. bilunulatus
B. diana
Cheilinus chlorourus
C. trilobatus
Cirrhilabrus exquisitus
Coris aygula
C. caudimacula
C. formosa
C. gaimard
Epibulus sp
Gomphosus coeruleus
Halichoeres cosmetus
H. hortulanus
H. iridis
H. nebulosus
Hemigymnus melapterus
Hologymnosus annulatus
H. doliatus
Labroides bicolor
Labroides dimidiatus
Labropsis xanthonota
Macropharyngodon bipartitus
M. cyanoguttatus
M. negrosensis
Novaculichthys macrolepidotus
N. taeniorus
Paracheilinus carpenteri
P. mccoskeri
P. octataenia
Pseudocheilinus evanidus
P. hexataenia
Pseudodax moluccanus
Pseudojuloides cerasinus
Stethojulis strigiventer
Thalassoma hardwicke
T. hebraicum
T. lunare

LUTJANIDAE
Lutjanus kasmira
L. sebae

Appendix 2.1, continued

MALACANTHIDAE
Malacanthus latovittatus

MICRODESMIDAE
Nemateleotris magnifica
Ptereleotris evides

MONACANTHIDAE
Aluterus monocerus
A. scriptus
Oxymonacanthus longirostris

MULLIDAE
Parupeneus cyclostomus
Parupeneus macronemus

NOTOPTERIDAE
Xenomystus nigri

OSTRACIIDAE
Lactoria cornuta
L. diaphana
Ostracion cubicus
O. meleagris

PLOTOSIDAE
Plotosus lineatus

POMACANTHIDAE
Apolemichthys trimaculatus
A. xanthotis
Centropyge acanthops
Centropyge multispinnis
Pomacanthus chrysurus
P. imperator
P. maculosus
P. semicirculatus
Pygoplites diacanthus

POMACENTRIDAE
Abudefduf saxatilis
A. sexfasciatus
Amphiprion akallopisos
Amphiprion allardi
Chromis dimidiata
Chromis vanderbilti
Chromis viridis
Chromis sp.
Chrysiptera annulata
Dascyllu. aruanus
D. carneus
D. trimaculatus
Plectroglyphidodon dickii
P. lacrymatus
Pomacentrus sp.
P. pavo
P. sulfureus

PTERELEOTRIDAE
Ptereleotris evides

SCORPAENIDAE
Dendrochirus brachypterus
D. zebra
Pterois antennata
P. radiata
P. volitans / mombasae
Rhinopias frondosa
Scorpaenopsis sp.
Synanceia verrucosa

SCARIDAE
Cetoscarus bicolor

SERRANIDAE
Cephalopolis argus
Cephalopolis sp.
Epinephelus flavocaeruleus
Nemanthias carberryi
Pseudanthias evansi
P. kashiwae
P. squampinnis

SIGANIDAE
Siganus stellatus

SPHYRAENIDAE
Sphyraena barracuda

SYNGNATHIDAE
Corythoichthys haematopterus
Doryramphus dactiliphorus
D. excisus

TETRAODONTIDAE
Arothron hispidus
A. mappa
A. meleagris
A. nigropunctatus
A. stellatus
Canthigaster amboinensis
C. janthinoptera
C. solandri
C. smithae
C. valentini

TORPEDINIDAE
Torpedo fuscomaculata

ZANCLIDAE
Zanclus cornutus

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Income diversification and fishing practices among artisanal fishers on the Malindi-Kilifi coast

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Introduction

Kenya's coastal and marine environment is threatened by naturally occurring processes, the growing subsistence needs of the coastal population and increased economic activities (Hoorweg 1998). Examples of natural processes are coral bleaching, sea-level change and beach erosion. Growing subsistence needs are behind the over-harvesting of mangrove trees, illegal shell collecting and intensive fishing. Increased economic activities result in greater sewage and waste disposal from tourist hotels, the industrial pollution of the waters near Mombasa and siltation at river exits as a result of soil erosion upcountry. The first national environmental plan in 1994 listed many of these issues but efforts at Integrated Coastal Management since then have been limited to the Mombasa and Diani areas (MENR 1994; CDA 1996, 2001; McClanahan *et al.* 2005b).

Artisanal fishers also contribute to the degradation of marine resources, as intensive fishing can affect the ecological balance and result in a loss of local biodiversity (McClanahan & Shafir 1990; McClanahan & Arthur 2001). Destructive fishing practices, such as the use of seine nets, poison and explosives, alters the terrain as well as the ecological balance of the reef and seafloor. Local fishers

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generally do not approve of destructive fishing methods since they are aware that these will ultimately lead to lower catches. Indeed, nearly all fishers interviewed in another study were concerned with the degradation of marine resources and mentioned declining catches (Hoorweg *et al.* 2009). Other reasons for reduction in marine resources given by fishers included the increased number of fishers, gazettement of no-take areas, rough weather (notably the heavy El-Niño rains of 1997/98) and competing fisheries such as commercial trawling.

Faced with dwindling resources and more competition, not only from fellow fishers but also from tourism and human settlement, fishers have little choice but to adjust to the changing circumstances. One alternative is to fish more intensively, for example, by investing in vessels and gear, but this is beyond the means of most of them. Another alternative lies in livelihood diversification, i.e. engaging in economic activities other than fishing. Already, most fishers do not set out during the windy and rainy season when waters are too rough, using this period of seasonal unemployment for other economic activities instead.

Livelihood diversification is a widespread survival strategy employed by rural households in Africa (Ellis 2000). Most studies on household diversification have focused on farm households and pastoralists but little attention has been given to fisher households (Allison & Ellis 2001). Diversification is generally expected to improve income, if not resulting in increases in income then at least resulting in a wider income spread, although other researchers consider specialization as the more efficient way of improving incomes. It is important though to distinguish between 1) 'activity' diversification at the individual level, where the household head has income from more than one economic activity, and 2) 'earner' diversification at the household level where the household has more than one income earner (Ellis 1999).

Poverty has long been associated with an overexploitation of natural resources, and it was generally assumed that income improvements among the local population are needed to reduce the pressure on natural resources (Ellis 2000). The focus of the present research was on the income diversification of fishers and its impact on marine resources. The RDM[5] project studied the income diversification of fishers on the Kenyan Coast, the pressure on marine resources and the relationship between the two. The importance of diversification for fisher incomes and household poverty is discussed elsewhere (Hoorweg *et al.* 2008). Fishers and fishing crew in the study area had higher incomes than non-fishers living in the same neighbourhood. And although fishers had higher incomes from

5 RDM is the acronym for '*Resource Diversification and Management among Coastal Fisher-folk in Kenya*'. This was a joint project of Moi University (Kenya), Ben Gurion University (Israel) and the African Studies Centre (the Netherlands). The project was funded by the Netherlands Israel Research Project under contract NIRP-97-145-7. Detailed descriptions of surveys, studies, methods and sample characteristics can be found in Hoorweg *et al*. (2003, 2009).

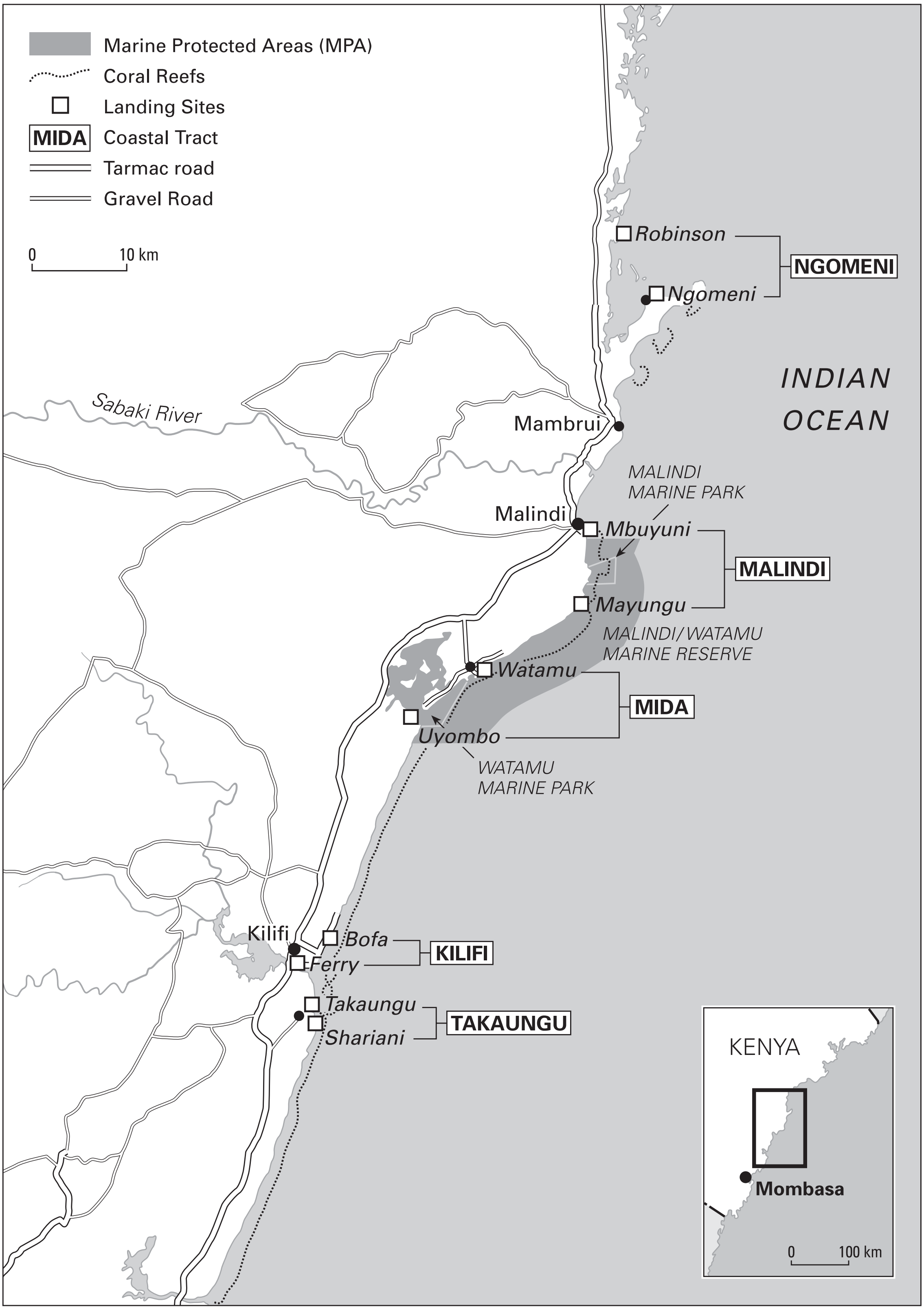
fishing, their crew members whose income was lower, compensated for this with income from non-fishing activities.

Modern methods of marine conservation attempt to minimize the impact of intensive fishing in various ways, notably by limiting the number of fishers, restricting access to fishing grounds and controlling the type of equipment used and the frequency of fishing. This paper explores these features in relation to income diversification. Since additional income sources should strengthen livelihood strategies and improve household security, these fishers might be expected to have a more positive attitude towards conservation measures and to exact less pressure on marine resources.

Study area

The study area was situated in Malindi and Kilifi districts, extending from Ras Ngomeni (the Ngomeni Peninsula) to Takaungu Creek, a distance of roughly 125 km. The study locations consisted of five coastal tracts with two landing sites at each. From north to south these were the Ngomeni, Malindi, Mida, Kilifi and Takaungu coastal tracts, covering, more or less, the coast of Kilifi and Malindi districts (Map 3.1). The area of study was chosen for logistical reasons and to ensure cultural consistency.

- The *Ngomeni* coastal tract is characterized by the absence of a fringing reef, open access to the sea, mangroves, mud flats and sandy beaches. There are two landing sites: one opposite Robinson's Island and one at Ngomeni village.
- The *Malindi* coastal tract is near Malindi National Park. There is one landing site in Malindi town at the very end of the reef, which is polluted and covered by sediment from the Sabaki River. The second landing site, Mayungu, lies in the middle of the Malindi Reserve where the reef is relatively far out to sea; it is a small cove surrounded by dry, rocky land.
- The *Mida* coastal tract consists of the Watamu and Uyombo landing sites. Watamu is situated within the Watamu Marine Park and while Uyombo is adjacent to this park, the fishers have to pass through it to reach their fishing grounds. Watamu is on a sandy beach with coral rocks nearby that tower over the sea. Uyombo lies at the entrance to Mida Creek, a large estuary that is mostly dry during ebb tide.
- The *Kilifi* coastal tract consists of two landing sites, Bofa and Kilifi Ferry, both of which are within easy reach of Kilifi town. Bofa is further up the coast with small rocky outcrops and Kilifi Ferry is at the mouth of the deep Kilifi Creek that serves as a harbour for coastal dhows and pleasure yachts.
- The *Takaungu* coastal tract is characterized by coral soils and palm cover and includes landing sites at Takaungu town and Shariani. The coral reefs at these sites are patchy in nature and further out to sea. Takaungu town is situated next to a deep creek that is largely dry at ebb tide; Shariani is on the sea side and has a steep rocky coast.



Map 3.1 Malindi-Kilifi coast with landing sites studied

The coastal population is of mixed origin (Middleton 2000), with the Mijikenda being the largest group. They are agriculturalists who live inland on the hilly coastal range but have moved onto the coastal strip in large numbers over the last 150 years. The traditional inhabitants of the coastal strip were the Swahili and Bajun. The Swahili inhabited the 'stone' towns, were mainly involved in trading and dominated politically. The Bajun were the fishers *par excellence* but the Mijikenda have joined the fisheries in large numbers since the 1960s and they now pose considerable competition. The Mijikenda do not have a history of fishing, have little traditional knowledge of how to manage marine resources and do not provide apprenticeships for young fishers (Glaesel 1997).

Fishers are flexible in what gear they use although they usually have strong preferences based on past experience and the expected catches (Tunje & Hoorweg 2003). Equipment differs greatly in its effect on the environment, with some types being more destructive than others. There are different types of destructive effect: damage to the marine environment, the capture of non-targeted species and capture of immature targeted species. Not only the type of gear but also the area and the way it is used determine how destructive the gear is. Traditional equipment is generally considered more benign than its modern equivalent but the use of traditional gear appears to be on the decline.

In the past, there were traditional restrictions on fishing, such as the *sadaka*, but these have largely fallen into abeyance. The main restriction that is actively implemented today is that of the Marine Protected Areas (MPAs) that consist of marine national parks where marine resources are fully protected and marine national reserves where fishing activities are regulated. To reach fishing grounds in a reserve, fishers are allowed to pass through the park with their vessels. MPAs are managed by the Kenya Wildlife Service (KWS) under their regulations, and KWS rangers patrol the areas regularly. Fishers in unprotected areas were expected to follow general fishing regulations but there were few inspections by fisheries personnel. In 1997, there were four marine parks and six marine reserves along the entire length of the Kenyan Coast, together encompassing 100 km of seafront (Map A, p.2). The positive effect that can be expected from fishing restrictions is an increase in fish biomass, which should spill over into the reserves and the surrounding areas to the benefit of local fishers (McClanahan & Mangi 2000; Roberts *et al.* 2001).

Method

The data presented are from two surveys that were part of the larger RDM project, namely a Fisher Survey and a Household Survey (Hoorweg *et al.* 2009). Supporting studies were by Versleijen (2001) and Tunje (2000).

The Fisher Survey was carried out between June and October 1999 and covered five tracts of coastline, each with two landing sites (described above). At each landing site, 20 fishers were randomly selected and interviewed, either on-site or in their homes. The sample consisted of boat captains, crew and independent fishers (who fished by themselves). In total, 199 fishers were interviewed about their fishing practices, catches and incomes, catch destination, crew and ownership arrangements and household characteristics.

The Household Survey was conducted between October 2000 and March 2001 at four landing sites that differed in distance from the marine reserves and the potential access to employment in nearby urban centres.[6] A group of fishers who landed catches frequently at the sites were contacted and accompanied to their homes. This group comprised 83 boat captains and independent fishers and they were interviewed about their living conditions, household composition, employment characteristics, farming activities, fishing activities, the income of the household head and other household members and about resource conservation.

Two types of income diversification were distinguished: 'earner' diversification where more than one member in the household had an income, and 'activity' diversification where the head of the household had income from more than one source. Fishing pressure was analyzed by examining the four features of artisanal fishing : 1) fisher numbers; 2) the fishing grounds; 3) the type of gear used; and 4) the frequency of fishing.

Results

Fisher numbers

At the time of study, a fishing licence, costing Ksh 100 for a one-year period (about US$1.25 at the time), was required from the local Fisheries Office to fish on the Kenyan Coast. However, controls were lax and many fishers did not have a licence. At most landing sites there was a fisher committee headed by a chairman, and new fishers usually had to be approved by the chairman before they could obtain permission to fish at the site. Reasons for denying someone permission to fish were mainly related to the type of gear used and the reputation of a particular fisher. Otherwise, they were generally allowed access to the fishing grounds. In addition, the role of the fisher committees was to deal with complaints, facilitate internal communication and represent fishers in negotiations with external parties such as the KWS concerning, for example, the Marine Protected Areas.

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6 The landing sites selected for the household survey were Ngomeni, Mayungu, Uyombo and Takaungu.

At the start of the research, the most up-to-date count came to a total of 1,000 fishers along the Malindi and Kilifi coasts (Dept. of Fisheries 1996). However, the respondents at the five coastal tracts in the Fisher Survey estimated that there were as many as 1,800 fishers. This number had to be increased to take into account the landing sites that were not covered in the survey, as well as for other smaller, unknown landing sites, giving a rough estimate of 2,500 to 3,000 fishers, almost triple the official figure.[7-8] The largest numbers of fishers were reported for Ngomeni (398), Malindi (492) and Mida (347). In Kilifi (330) and Takaungu (234) further south, the number of fishers was somewhat smaller. Based on the respondents who made the estimates, about half the fishers in the three northern locations were of Bajun origin.[9] In Kilifi and Takaungu, the large majority were Mijikenda (68%). About 85% of the latter were first-generation fishers, and only 15% were second generation.

Nearly all the fishers in the Household Survey (91.3%) were negative about current fishing trends and reported declining catches. The increased number of fishers was most frequently mentioned as the reason for this trend because of the sector's easy access and the lack of alternative employment. The fishers believed that anyone could fish whenever he wanted to and in the way he wanted to but many also felt that if there were other jobs available they would chose to do something else, but jobs were hard to find.

Asked about their willingness to stop fishing, 87% of fishers responded positively. This was an unexpectedly high percentage but somewhat deceptive because old age was mentioned as the foremost reason to stop fishing (71%). But, it is noteworthy that 54% of fishers were willing to take alternative employment, if available, although it is unlikely that they would stop fishing completely even if the opportunity occurred.[10] Only 1.2% mentioned low catches as a reason to stop.

Willingness to stop fishing was related to age and fishing income. Older fishers mentioned 'age' more often as a reason than younger fishers.[11] Younger fishers were more willing to try other employment than older fishers, who possibly saw fewer opportunities.[12] In addition, fishers with a low fishing income were less willing to exchange fishing for other employment, perhaps because

7 Reasons for the lower official estimate of the number of fishers in Kilifi and Malindi were that only official landing sites were covered and that many fishers did not have a fishing licence.

8 Extrapolation of these figures to the whole of the coast, from Vanga to Kiunga, would arrive at roughly 10-12,000 fishers.

9 The Bajun group also includes a few fishers of Swahili origin that were found among the respondents. Similarly, the Mijikenda group includes a few fishers from other inland groups.

10 Certain questions allowed for more than one answer by the respondent so that percentages may add up to more than 100%.

11 Household Survey: Fishers <39years (56%) vs. Fishers >40 years (91%). X^2, df=1, p=0.00

12 Household Survey: Fishers <39years (65%) vs. Fishers >40 years (34%). X^2, df=1, p=0.008.

they were realistic enough to know that, at best, they would only be able to obtain unattractive menial jobs.[13]

Fishing grounds

Most fishers frequented two or three different types of marine habitats on their fishing trips. These included the lagoon and inshore grounds, the reef itself, the fishing grounds beyond the reef and deep waters. Nearly all fishers visited one or more of these habitats. Many ventured into the deep waters on occasion where they were outside the protection of the reef and more exposed to the sea and possibly inclement weather. For most fishers, the deep waters were their second or third choice because of their inadequate vessels. Regular deep-sea fishing was the domain of the larger, sturdier vessels as well as the sports fishers and commercial fleets.

During the low season (south-east monsoon) when the sea can be rough, fishers avoided the deep-water areas and the outer-reef areas. During the high season (north-east monsoon), they fished less in the lagoon and inshore areas, giving these grounds some respite. The pressure on the reef is more or less the same in the two seasons (Hoorweg *et al.* 2009). Fishers from landing sites near the marine parks often mentioned the parks as no-go areas (80%). Artisanal fishers were aware of the important role of the reef as many species spawn and breed there.

The large majority of fishers from landing sites near a protected area mentioned that they did indeed avoid the latter.[14] However, marine parks offer advantages as well as disadvantages for fishers living nearby. Restricting access to fishing grounds by means of a seasonal or all-year ban is an important conservation measure because of the increase in fish biomass that can be expected and the spillover into the adjacent reserves, although this effect can be nullified by a greater concentration of fishers in a smaller area (McClanahan & Mangi 2000). Another disadvantage is that parts of the traditional fishing grounds are off-limits and almost three-quarters of the fishers at the Watamu landing site listed the Watamu Park as one of the main problems with which they had to cope. Fishers in Uyombo showed considerable resentment towards the park and the KWS wardens there (Versleijen & Hoorweg 2009).

Fishing gear

Traditional gear included traps, fences, spear guns and poison. The portable fish traps *(malema)* were fairly light and could be used on the reef without adverse

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13 Household Survey; Fishing Income <Ksh.999/week (32%) vs. Fishing Income >Ksh.999/week (59%). X^2, df=1, p=0.04

14 In Mayungu and Uyombo, 80% of the fishers mentioned the parks as off-limits in both the high and low seasons.

effects. Spearing was considered destructive to the corals and although the method is not damaging in itself, fishers often use long metallic rods *(mkonjo)* to break the coral where the fish take refuge. Sometimes, spears also damage the coral when fishers miss their target. Spear gun fishers have to be in good physical condition to swim long distances and hunt moving targets and for this reason nearly all the spear gun fishers were younger than 39 years of age. Traditional fish poison (*mkanga* or *mchupa*) is destructive not only for fishery resources but also for other living creatures, such as the birds that eat the dead fish.[15]

Modern gear included nets and lines in almost equal proportions. The use of a gill net (*mpweke*) is destructive if it entails fishers trampling on the reef. When used in areas where coral is absent, it rarely causes damage although small fish easily get entangled in the nets. Beach seines *(juya*) are destructive because they have very small mesh sizes, and therefore net many young and immature fish as a by-catch. The net is dragged along the seabed, churning up the sea bottom and damaging underwater vegetation. Explosives (*baruti*) not only kill fish and other marine life indiscriminately but also damage the habitat.[16] Baited hook and line (*mishipi*) when used without breaking off the coral are not considered destructive.

Table 3.1 Reported fishing gear by respondents in the Fisher Survey (%; multiple response)

Fishing gear *		*Net mesh size* **		*Use of destructive gear* *	
Nets	73.4	< 1.0 inch	3.4	Beach seine	}
Lines	62.8	1.0-2.5 inch	77.4	Net mesh < 1.0'	} 15.6
Traditional	9.0	3.0-4.5 inch	72.6	Spear gun	}
Other	9.5	> 5.0 inch	31.5		

* N=199 ** N=146

Fishing vessels and gear differed considerably among coastal tracts. The differences related mostly to the local marine conditions and the abundance of fish. The most popular gear reported among fishers was the (gill) net with mesh sizes that varied from small (<1.0 inch) to large (>5.5 inch). The majority of net fishers used nets between 1.0 and 5.5 inches. More than half the fishers used lines (long lines were reported by 25% of fishers). Traditional gears were reported by less than 10% of the respondents (Table 3.1).

15 None of the fishers admitted using poison but reliable sources mentioned that it was used in the far northern parts of Malindi District near Mto Kilifi.

16 Again, none of the fishers admitted to this but it was understood that dynamite was used occasionally between Mayungu and Watamu.

Only 30% of fishers limited themselves to one type of equipment; the large majority reporting two or more kinds of gear (Table 3.1). About 15% of fishers freely admitted to using destructive equipment – 9% reported using spear guns, 5% mentioned beach seines and 3% used a net mesh size of less than 1 inch. These gears were used more often by Mijikenda fishers than Bajun fishers.[17] The use of destructive gears was not related to age although it was found slightly more often among younger fishers because of their use of spear guns.[18]

Fishing frequency

A final factor that affects the pressure put on the marine environment is the frequency of fishing, that is, the frequency with which fishers set out to sea. Fishers reported that they generally fished 5 or 6 days a week and rested for 1 or 2 days. Fridays were non-fishing days for many (57%), while others chose not to fish on other days of the week. Reasons that were given for taking a day off included religious observance, time for their family, maintenance of gear/craft and avoiding high tides and rough waters.[19]

Most fishers fished once a day for about four hours. Six times a week was mentioned most often, namely by 40% of the fishers, with a large variation among the other 60%. About a third of the fishers reported eight or more trips a week and, thus, either went out more than once a day or combined day and night fishing.[20] This occurred particularly among fishers in Takaungu.

Table 3.2 Reported fishing frequency by season (average/s.d.)*

	High season	*Low season*
Duration season (No. of months)	5.4 (1.9)	3.9 (1.2)
Fishing frequency (No. of trips/week)	8.2 (2.9)	7.2 (2.5)
Fishing frequency (No. of trips/season)	193.1 (99.8)	121.1 (58.9)

* Fisher survey (N=197)

Table 3.2 provides further information on fishing frequency during the high and low seasons, notably the duration of the fishing season and the number of trips per week. The duration of the high season averaged about 5.5 months and

17 Fisher Survey: Mijikenda (25.0%) vs. Bajun (2.4%): X^2, df=1, p=0.00.

18 Fisher Survey: Fisher <39years (18.0%) vs. Fisher >40 years (11.3%): X^2, df=1, p=0.21.

19 Some fishers preferred to set out at weekends because the frequency of government patrols was reportedly lower then.

20 An interesting phenomenon that was noted in Mayungu was that of ‘joy’ fishing (analogy of ‘joy’ riding). Since most fishers at this landing site lived inland, their boats were left largely unattended at night and other fishers sometimes used them then without the owners’ permission.

the low season almost 4.0 months, which left about 2.5 months with no fishing activities. Many fishers did not go out at the height of the *kusi* season (south-east monsoon). The frequency of fishing trips differed slightly between 8.2 trips per week in the high season and 7.2 trips a week in the low season. The average number of annual fishing trips was estimated at 315 although there was considerable variation. About 25% of fishers made an estimated 210 trips or fewer, while 25% made 360 trips or more.

Frequency of fishing was related primarily to the type of vessel used. Motorboats generally went out more often. During the low season, fishers with large vessels (*jahazi* and *mashua*) went out more than fishers with smaller vessels (*dau* and different canoes). The fisher's age was also a factor; younger fishers went out more often than average.

Income diversification and fishing practices

Further analysis focused on the four features discussed thus far, namely fisher numbers, the type of fishing ground, the fishing gear used and the intensity of fishing. For each feature, an indicator was selected to test the relationship with income diversification: 1) willingness to stop fishing for alternative employment (indicating possibilities of reductions in number); 2) frequenting the lagoon and inshore grounds which are heavily utilized; 3) the use of destructive gear such as beach seines, small-mesh nets and spear guns; and 4) the frequency of fishing, that is whether the number of annual trips was above or below average (or 300 trips to be more exact). In addition, these indicators of fishing practices were examined among fishers with and fishers without income diversification.

Table 3.3 presents the results of 'earner' diversification, comparing fishers who are the sole earners in their households with fishers in households with more

Table 3.3 Fishing practices by earner diversification

	Single earner	*Multiple earner*	*Chi square test*
A. Fisher number (%) ** Willingness to stop fishing if alternative employment opportunities available	57.8	45.5	p=0.28
B. Fishing grounds (%) * Mentioned lagoon and/or inshore grounds	43.4	42.5	p=0.92
C. Fishing gear (%) * Mentioned use of damaging gear	17.6	7.5	p=0.12
D. Fishing frequency (%)* Number of annual trips above average	49.0	48.7	p=0.97
* Fisher survey	N=159	N=40	
** Household survey	N=45	N=33	

than one income earner. No significant relationship was found between earner diversification and any of the fishing practices examined.

Results for 'activity' diversification, however, did reveal differences (Table 3.4). Of the four indicators, two were significantly different between fishers with a single economic activity and those with multiple activities. The fishers with multiple activities mentioned the lagoon and inshore grounds more often as their fishing grounds.[21] These fishers also reported using destructive gear significantly more often.

The two remaining indicators, concerning fisher numbers and fishing frequency, were not significantly different between single and multiple activities. There was, however, a small difference: fishers with multiple activities were slightly less willing to search for alternative employment than those with single activities. Although not significantly different, the opposite was certainly not the case, that is, there was no indication that fishers with multiple incomes were more willing to exchange fishing for other employment than fishers with single incomes.

Table 3.4 Fishing practices by activity diversification

	Single activity	*Multiple activity*	*Chi square test*
A. Fisher number (%) ** Willingness to stop fishing if alternative employment opportunities available	58.8	51.2	p=0.50
B. Fishing grounds (%) * Mentioned lagoon and/or inshore grounds	33.3	57.3	p=0.00
C. Fishing gear (%) * Mentioned use of damaging gear	8.5	25.6	p=0.00
D. Fishing frequency (%)* Number of annual trips above average	50.0	47.5	p=0.73
* Fisher survey	N=117	N=82	
** Household survey	N=34	N=43	

Discussion

Poverty has often been associated with the overexploitation of natural resources (Ellis 2000) and it has been widely agreed that environmental degradation worsens the degree of poverty in marginal groups, which in turn leads to more intensive exploitation of accessible resources. The implicit assumption is that improvements in income will reduce the pressure on resources and halt further

21 There was also a significant difference in the number of landing sites frequented. Fishers with multiple activities reported fewer landing sites, which is understandable if they had other work to do onshore (ANOVA, df=1, F=14.0, p=0.00).

damage to the natural environment. Poverty itself has to be addressed; the poor, in particular, have to be provided with access to other sources of livelihood. However, the expectation that improvements in income will halt environmental destruction has not generally been confirmed (Ellis 2000). People show great flexibility in finding and utilizing new opportunities while state and commercial interests are equally, if not more, responsible for the overexploitation of resources.

Efforts to halt the downward spiral of poverty and resource degradation among fishers depend on the possibilities of improving the efficiency of small-scale fisheries, enforcing restricted access to some fishing grounds to conserve fish stocks, and offering incentives to reduce fishing activities (Allison & Ellis 2001). State-imposed regulations to limit access reportedly have a high failure rate and there is tension between the two objectives of modern fishery policies, namely increasing efficiency and regulating the catch. The weakness of the enforcing institutions in many developing countries also plays an important role. Most fishers in the study area were aware of the degradation of marine resources and mentioned declining catches, attributing this mainly to an increased number of fishers. This paper has discussed the latter feature and three other elements of fishing activities that affect the marine environment, namely the number of fishers, the fishing grounds, the type of gear, and the frequency of fishing.

The number of fishers has been increasing over the past decades with the entry of many Mijikenda into the arena, a group not known for its fishing until recently (Glaesel 1997). The reasons for their entry into this sector were: the open and easy access of the resource, the lax enforcement of license regulations and the need for employment. Half the fishers expressed an interest to opt for alternative employment, if it was available, although it is doubtful whether they would abandon fishing completely if they found other employment. It is more likely that they would try to combine the two, as was the case with many of the new entrants. Fishers with a low fishing income were less willing to choose alternative employment, which is in line with the finding that families with higher incomes are usually in a better position to diversify than poor families (Ellis 1999).

In developing countries, fisheries management depends mainly on two sets of instruments (Allison & Ellis 2001): controls to limit access (operating licences, vessel capacity, closed seasons, closed zones) and technical measures to restrict efficiency or selectivity (prohibited gear, mesh size regulations). On the Kenyan coast, traditional restrictions on fishing grounds have largely fallen into abeyance, although they are still reported to exist on the south coast (McClanahan *et al.* 2005b). Their role has been taken by the marine parks and marine reserves. Integrated Coastal Management is still in its infancy. The Marine Protected

Areas have posed effective restrictions on fishing grounds and were often mentioned by fishers at nearby sites. However, they also had distinct disadvantages for the fishers and often occupied good fishing grounds. The fishers thus showed considerable resentment towards these authorities (Versleijen & Hoorweg 2009).

The majority of fishers used nets with approved mesh sizes and hook and line (including long lines). Traditional equipment (such as traps and fences) has become less popular with time (Glaesel 1997) and was used by only 10% of fishers. Generally, methods, which involve walking or standing on the shallow coral reef, turning over rocks and dragging gear over the reef or sea bottom are destructive. This leads to a loss of diversity in the benthic substrate, resulting in fewer places for concealment and less habitat diversity for fish species. Gear that were destructive includes spear guns, beach seines and other nets with very small mesh sizes. Nets with small mesh sizes were particularly harmful as they capture non-targeted species and juveniles of the targeted species. Although these methods are illegal, 15% of fishers, mainly from Mijikenda origin, reported using them, but the true figure was probably higher (recently McClanahan *et al.* 2005a reported a much higher figure).

Frequency of fishing differed greatly and there were differences in the duration of the fishing season and the number of weekly trips made. Fishing was divided into a high season of about 5.5 months and a low season of about 4 months, which left about 2 to 3 months without fishing (generally the height of the *kusi* season). The term ‘high’ season was ambiguous and this probably contributed to the large variation that was found. The high season is most commonly referred to as the season with the largest catches and this may differ for fishers depending on their specialization. The high season can also be defined as the season with the highest prices and for popular species this can be the time when catches are low, and demand-supply interaction can affect this definition. The average number of annual trips was estimated at slightly more than 300.

Further analysis focused on four indicators, one for each of the selected features: willingness to stop fishing, inshore fishing grounds, destructive gear and annual number of trips. There was no significant relationship between earner diversification and any of the fishing practices. The reason may well be that income in rural households is in general not pooled and not under the direct control of the fisher himself. The income of other household members, therefore, offered the fishers little incentive to alter their dependence on fishing and to change their fishing practices. However, activity diversification (fishers who reported more than one economic activity) correlated positively with two of the four selected practices: use of destructive gear and inshore fishing grounds. Fishers with multiple activities went on (long) trips outside the reef less often, presumably because they had work commitments onshore. They also reported using destructive gear more often, possibly because they had less time than that needed for regular boat trips. Fishers with multiple activities were slightly less willing to stop fishing for alternative employment possibly because they already had alternative employment and were used to combining this with an income from fishing.

Conclusion

Neither earner nor activity diversification provided fishers with the feeling that their fishing incomes had become any less important for survival. Instead, what emerged was that fishers with multiple income-generating activities fished in a smaller area of water, used destructive gear more often and did not show any more willingness to stop fishing for alternative employment.

The results can be interpreted in different ways. It is likely that fishers who take up additional economic activities need to stay inshore and are tempted to use illegal gear. However, it may also be the case that fishers who are active inshore and fishers who use illegal gear tend to take up additional employment more often, although this is a less likely scenario. It can also be speculated that the catches of inshore fishers are insufficient and this forces the fishers to find other work. Alternatively, fishers with only a fishing income need to travel far out to sea to realize a sufficient income. But this overlooks the issue of 'new' fishers who do not have the equipment or the experience needed for offshore fishing and who lack knowledge of the traditional dos and don'ts. Whatever the correct interpretation may be, activity diversification of fishers correlated with more destructive fishing practices. This is not only contrary to expectations but also lowers the positive environmental effects one might expect from policy initiatives aimed at generating employment opportunities.

Woodhouse (2002) postulated that diversification at the level of an individual's activity is likely to provide the advantage of flexibility in a context of risk. In this case, fishers with activity diversification indeed showed adjustments to changing circumstances. However, Woodhouse also claims that diversification at the level of household not only has the advantage of flexibility but also offers the possibility of specialization for individual household members. In the case of earner diversification, fishers indeed appeared to behave in this way and were not showing any signs of changing their fishing practices.

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Summary

The fishing practices of fishers at ten landing sites in Malindi and Kilifi Districts that were surveyed in 1999 as part of a larger research project are discussed in this article. The focus of the research was on income diversification among fishers, pressure on marine resources and the relationship between the two. It was hypothesized that fishers with additional resources strengthen livelihood strategies and improve household security, and those who succeed in diversifying their incomes can be expected to have a more positive attitude towards conservation measures and will exact less pressure on marine resources. Two types of income diversification were distinguished: 1) ‘activity’ diversification at the individual level where fishers had other income besides fishing, and 2) ‘earner’ diversification at the household level where fishers belonged to a household with more than one income earner. Key indicators were selected that represented four features of artisanal fishing, namely: 1) the number of fishers; 2) the fishing grounds; 3) the type of equipment; and 4) the frequency of fishing. There was no significant relationship between ‘earner’ diversification and fishing practices while ‘activity’ diversification correlated significantly with two selected indicators. Fishers with ‘multiple’ activities used more destructive gear and fished inshore grounds more often, while there was no sign that they were more willing to stop fishing in favour of alternative employment. It was concluded that an activity diversification of fishers did not reduce the pressure on the marine environment. Instead the opposite occurred, fishers who had other employment onshore fished less prudently.

4

Human dimensions of conserving Kenya's coral reefs

J.E. Cinner[1], T.R. McClanahan[2], C. Abunge[3] & A.W. Wamukota[4]

Introduction

As conservation theory and practice moves away from excluding resource users to creating partnerships with them, it is becoming increasingly clear that coral reef conservation is as much about understanding people as it is about understanding ecological processes (Groom *et al.* 2006). Social, economic, and cultural factors can influence whether and how individuals and communities overexploit resources or cooperate to conserve them (Ostrom 1990: Becker & Ostrom 1995). Many conservation projects may fail because they do not adequately understand, address, and incorporate the socioeconomic needs and concerns of stakeholders (Christie 2004). For example, restrictions of gear, effort, or fishing area will not be willingly or adequately complied with by a group of stakeholders who do not believe that the condition of natural resources has a connection to human resource use (McClanahan *et al.* 2005a). Likewise, conservation strategies are unlikely to be complied with when they are designed in ways that conflict with traditional beliefs and practices, disproportionately disenfranchise particular segments of the community, and are insensitive to the needs of those dependent on the resource (McClanahan *et al.* 2005b).

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It is beneficial to understand the human dimensions of conservation in attempts to involve local people in community-based or co-management efforts, as successful resource management projects may need to either direct outcomes at local values or somehow change these values. Integrating social science at conservation sites can help to adapt and refine management strategies to reflect the needs and desires of the stakeholders, select strategies that are appropriate for the local conditions, and utilize scarce resources more wisely by targeting specific strategies (i.e. awareness and alternative income generation) at the segments of the population where they are most needed.

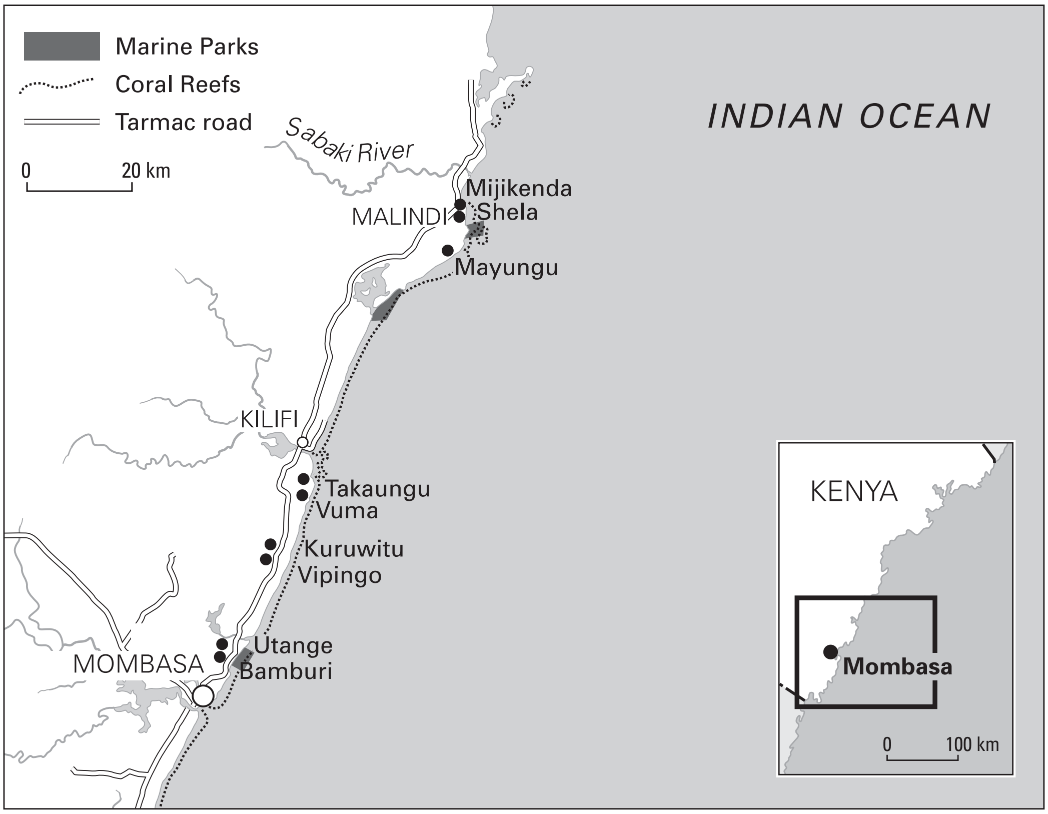
We conducted a socioeconomic assessment within the so-called North coast of Kenya, above Mombasa, between June and August 2005. Here we ask: What are the socioeconomic conditions at these sites? What are the major socioeconomic factors that may affect the condition of coral reef ecosystems? How can understanding local perceptions and uses of coastal resources help with the enhancement or implementation of effective management strategies?

Method

We studied nine coastal communities along the Kenyan coast between Mombasa and Malindi (Map 4.1). A combination of systematic household surveys (for example, surveying every second or third household), semi-structured interviews with key informants (community leaders and resource users), recording of oral histories, transect walks (walking through the community with a local to identify and verify issues), participant observations, descriptions of daily and seasonal time-use, and analyses of secondary sources such as population censuses and fisheries records were all used to gather information and triangulate results. A total of 434 household interviews were collected.

Sampling of households within villages was based on a systematic sample design, where a sampling fraction of every 1st household (e.g. 2nd, 3rd, 4th) was determined by dividing the total village population by the sample size (Henry 1990; de Vaus 1991). A household was defined as people living together and sharing meals. The head of the household was interviewed. If the head of the household was not available, the household was revisited later. If the head of the household was still not available, another adult from the household was interviewed. Variance from the systematic sample was assumed to be equal to the estimated variance based on a simple random sample (Scheaffer *et al.* 1996). The number of interviews per community ranged from 29-87 depending largely on the population of the village, and the available time per site (Cinner & McClanahan 2006).

Due to the low density of fishers in Bamburi and Utange villages, it was necessary to supplement these household surveys with interviews of fishers at the



Map 4.1 Malindi-Mombasa coast with fisher villages studied

landing sites.[5] Landing site chairmen provided lists of all fishers at the site and fishers were randomly selected from the list. These lists were crosschecked with fisheries department information to validate the total number of fishers at each location. A total of 18 fishers were interviewed at Bamburi beach and 23 at Marina (from a total of 60 and 55 fishers respectively).

Population, settlement pattern and infrastructure were examined as indicators of local community development and potential pressure on reef ecosystems. Population was determined by: (1) counting the number of houses, (2) calculating the average number of persons per household (adults and children) from the household surveys, and (3) multiplying this by the number of houses in the community. This was thought to be more accurate than relying on census information because the census records were typically collected at the district or sub-district level, which was at a larger scale than our study. Population movement can be a useful indicator of the confidence that people have in the local resources. Information was collected on how many respondents immigrated and their reasons for doing so. Respondents listed all the occupations the household engaged in for food or money and were then asked to rank these activities in order of importance. Respondents were also asked where they were from and were considered immigrants if they came from another village.

Key informants were selected using non-probability sampling techniques, including convenience sampling (for example, a respondent may be approached during resource use activities) or snowball sampling (where community members will suggest appropriate respondents) (Henry 1990).

In developing countries, Material Style of Life (MSL) can be an indicator of relative wealth or social status within a community (Pollnac & Crawford 2000; Cinner & Pollnac 2004). MSL is a method of measuring wealth based on the presence or absence of household possessions or structure. To determine culturally appropriate indicators of wealth, key informants were asked to describe the house of a rich person and the house of a poor person. A list of 22 items was developed including items such as a television, VCR/video machine, satellite antenna, gas stove, electrical generator, type of bathroom (septic system or pit latrine) and the type of walls, roof, and floor. Wealth is presented as both fortnightly expenditure and MSL.

The number and types of occupations in which households participate was examined by asking respondents to describe the work that they do that can bring food or money into their house. Occupational categories include fishing, selling marine products, agriculture, tourism, salaried employment (positions such as

5 Bamburi Beach and Marina were the fish landing sites associated with the Bamburi and Utange communities, respectively.

secretarial work, teaching, security, etc.)[6] and the informal sector (participation in informal markets, such as selling food or clothes from a kiosk, casual work, etc.).

Respondents were also asked, 'What can affect the number of fish in the sea?' and probed about the mechanisms by which their response could impact the number of fish. For example, if a respondent mentioned that gill nets could affect the number of fish in the sea, they were asked how. Responses typically included ideas such as habitat destruction, fish moved or hid, or influencing reproduction. Additionally, respondents were asked, 'What could be done around [this community] so there would be more fish in the sea?' For both of the above questions, responses were then grouped into relevant categories and a response could have been included in more than one category. Responses that mention unspecified gear (such as small meshed nets, destructive gear, etc.) or a gear category that was not common (such as octopus spears) were recorded in the 'other category'.

Results

Demographics and immigration

There was a mean of 5.8 people per household in all the villages, though this ranged from 4.9 in Mijikenda to 6.5 in Shela (Cinner & McClanahan 2006). There was considerable variability in both total population size and settlement pattern of the communities examined. Bamburi and Vipingo had the largest overall population of 4,042 and 3,870 individuals, respectively. Mayungu had the smallest population of 224 individuals. There was a mean of 1,800 people per community for all study sites.

The mean age of all respondents was 38.5, although this varied from a mean of 33 years in Kuruwitu to 46 years in Shela. Just over 60% of respondents were males. In Mijikenda village, which is a temporary settlement, almost all respondents were males. The mean number of years of formal education of all respondents was 5 years, and ranged from 4.1 (1.5) in Shela to 5.9 (1.0) in Vipingo.

Approximately 50% of all respondents had immigrated, however, only 7% of these were not from the Kenyan coast (Cinner & McClanahan 2006). Mijikenda had the highest rate of immigration, and Kuruwitu had the lowest. Immigrants in Kuruwitu had resided there for an average of almost 25 years. Immigrants in Mijikenda had resided there for the shortest average period (8 years). Reasons for migration included increasing proximity to employment (46%), family and friends (42%), and fishing (12%).

6 Salaried jobs in the tourism sector (e.g. hotel security) are listed in the tourism category.

Material style of life and fortnightly expenditures

The Material Style of Life (MSL) measure indicates that Shela was clearly the most developed community, with almost 70% of the community having electricity, almost all walls and floors were concrete, and 45% of the roofs were metal (Table 4.1). In stark contrast, the neighbouring temporary settlement Mijikenda was the least developed. There was no access to electricity, few amenities, all of the houses were made entirely of thatch, and almost the whole population had no access to sanitation.

There was considerable variation in the fortnightly expenditures of respondents. Shela had the highest mean expenditures (but the lowest mean education) and Vipingo had the lowest mean expenditures (but the highest mean education). However, there was no significant correlation between education and expenditure (Spearman's rho=0.3, p=0.47, n=9). As expected, the communities proximate to urban areas (i.e. Utange, Mijikenda, Shela, and Bamburi) had the highest expenditures and the rural areas had the lowest education. The mean expenditures of rural communities was lower than urban communities but only significant at the $p < 0.10$ level (t=-2, df=7, p=0.09).

Livelihoods

The number and types of occupations that households participate in indicates that the most rural and remote sites (i.e. Vuma, Takaungu, Kuruwitu) had the highest number of occupations per household (a mean of 1.9-2.1 occupations per household), and the urban areas (Bamburi and Shela) had the lowest (a mean of 1.3 and 1.5, respectively). Respondents ranking of activities indicate that the informal sector had the broadest participation, with over 50% of respondents being involved (Figure 4.1). This estimate may, however, be biased by disproportional sampling at the sites (i.e. sampling more households in one community than in another). The agriculture sector had overall involvement of 41% of respondents, but with expected disproportionately higher involvement in the rural areas. In Vipingo and Kuruwitu, the large sisal plantation provided an important income source for many respondents.

Almost 31.3% of all household survey respondents were engaged in fishing (the total proportion of fishers sampled was 38% when the fisher surveys from Bamburi beach and Marina sites were included). The highest participation was in the Mijikenda and Mayungu communities, respectively. Both communities were very small (<100 households), but with a very high proportion of the community involved in the fishery. Participation in the fishery was very low in the two communities around Mombasa (3% of households in Bamburi and 0% of surveyed households in Utange). Gleaning activity in most sites was negligible.

Table 4.1 Distribution of household items (% of households) and average fortnightly expenditure (Ksh)

	Bamburi village	Kuruwitu	Mayungu	Mijikenda	Shela	Takaungu	Utange	Vipingo	Vuma	All sites
# Villagers (incl. fishers)	31	32	29	34	31	87	39	63	47	393
# Fishers	2	5	18	32	12	25	0	14	15	123
Outhouse	83.9	75.0	75.9	20.6	71.0	80.2	79.5	92.1	78.7	75.5
Thatch roof	25.8	90.6	69.0	94.1	38.7	87.2	69.2	76.2	89.4	74.7
Dirt floor	38.7	81.3	69.0	91.2	9.7	64.0	89.7	71.4	80.9	67.6
Mud/Thatch wall	35.5	75.0	69.0	94.1	16.1	62.8	76.9	73.0	72.3	65.3
Radio	74.2	68.8	72.4	55.9	74.2	57.0	59.0	49.2	66.0	61.7
Cement floor	61.3	18.8	31.0	5.9	96.8	39.5	10.3	28.6	21.3	33.7
Cement wall	41.9	9.4	31.0	5.9	93.5	36.0	10.3	22.2	21.3	29.3
Metal roof	74.2	9.4	31.0	5.9	45.2	11.6	30.8	22.2	10.6	23.5
No toilet	0.0	12.5	24.1	70.6	0.0	8.1	10.3	3.2	34.0	16.3
Electricity	9.7	6.3	6.9	5.9	67.7	14.0	5.1	1.6	2.1	11.7
Coral block wall	22.6	15.6	3.4	0.0	0.0	4.7	17.9	4.8	8.5	7.9
TV	9.7	6.3	6.9	0.0	38.7	5.8	2.6	3.2	4.3	7.4
Flush toilet	12.9	0.0	0.0	2.9	29.0	11.6	5.1	1.6	0.0	6.9
Piped water	3.2	0.0	10.3	0.0	12.9	8.1	5.1	0.0	0.0	4.3
Fridge	0.0	0.0	3.4	0.0	19.4	3.5	5.1	1.6	2.1	3.6
Public toilet	3.2	12.5	0.0	5.9	0.0	2.3	5.1	1.6	0.0	3.1
Fortnightly expenditures (Ksh.)	3626	3409	3767	3679	7235	3058	4886	2602	3729	3765

There were no reported or observed gleaning activities in any site except Bamburi beach, where fishermen were observed gleaning for algae and small invertebrates for bait. Although less than 50% of most communities were involved in fishing, fishing was the most important occupation for many of those that participated in the fishery, as indicated by the high proportion of respondents that ranked fishing as the primary occupation (Figure 4.1).

Salaried employment (e.g. jobs such as teaching and working for the government) and other economic activities (which included remittances, traditional healing arts, etc.) made up 19% and 5%, respectively. Although tourism is an important economic activity in coastal Kenya, less than 7% of respondents were involved in the sector, many of whom were informally involved as ‘beach operators’ (i.e. selling curios). Tourism was most important in the communities of Shela and Utange, where almost 20% of households were involved.

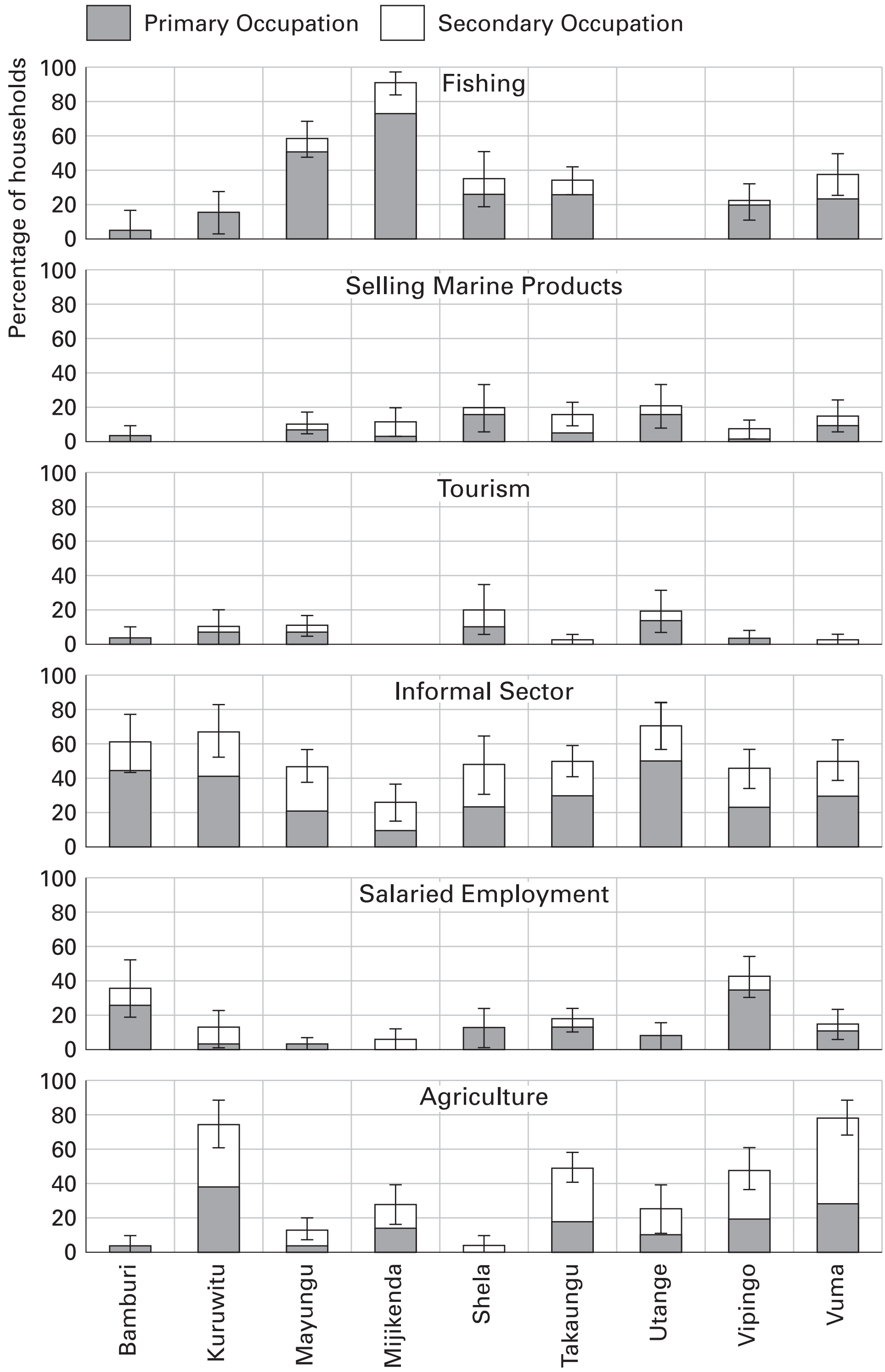
Market influences

At the sites examined, fish marketing was done primarily by small and medium-scale traders. Small-scale traders include fish mongers and middlemen that generally bought fish at landing sites, did some processing (scaling, gutting, and possibly cooking), and either sold fish in local open air markets or transported fish to urban centres (i.e., Mombasa or Malindi) for sale in retail fish shops. In sites like Vuma, Marina, Vipingo, Kuruwitu, Mayungu, Mijikenda, and some landing sites in Takaungu, fish was sold mostly to small-scale traders on the beach. These small-scale traders typically lacked private motorized transportation and were limited by what they could carry on a bicycle, their head, or as ‘carry-on’ luggage on public transportation.

Medium-scale traders included traders with freezers or refrigerated storage capacity. Most medium-scale traders purchased fish directly from fishers and later sold to consumers in Mombasa or Nairobi and hotels in Malindi and Mombasa. Medium-scale traders were present in Bamburi, Shela, and one landing site in Takaungu. In the one site in Takaungu with a medium-scale trader, the trader owned a variety of vessels and gears and hired people to utilize his gear to capture fish. Large-scale traders that export fish by the ton were only present in Mombasa and Malindi.

The shortest distance to a proximate market was in Shela (Malindi) and Bamburi where traders sold fish at a medium-scale trader’s shop approximately 50-100 meters from the landing site. In Mijikenda, the distance to the nearest fish market was only 500 meters, yet fishers themselves did not sell directly to the shops, but rather allowed middlemen to purchase their fish. This may be, in part

Figure 4.1 Percentage of households participating in selected occupational sectors.



due to the small size and resultant low demand for their particular fish, which would not likely have sold in a fish shop. The longest distance to market was from Vuma, at a distance of at least 40 km.

Coastal governance

Currently marine protected areas (MPA) exist between the Bamburi Beach and Marina landing site in Mombasa (Mombasa Marine Park and Reserve), and between Mayungu and Shela (Malindi Marine Park and Reserve) in Malindi (Fishers from neighbouring Mijikenda had no access to boats and frequently fished adjacent to the park). The Malindi MPA has been in existence since the 1960s and the Mombasa MPA since the early 1990s (although the park area was reduced in the late 1990s). There were no reported closures or marine kayas (i.e. sacred areas) in any of the study sites. However, at Takaungu and Vuma, there are caves near the sea that are believed to have spiritual properties. Fishers at Takaungu reportedly made ritual sacrifices at a particular cave to ensure a bountiful harvest. Some fishers were embarrassed by this tradition and claimed the practice had died out, but other informants (including the Beach Management Unit (BMU) chairman) claimed the practice still occurs.

Perceived threats to coastal resources

Overall, there was a relatively low understanding that human activities can impact the environment (Table 4.2). Only 55% of all respondents suggested that anthropogenic activities affect the number of fish in the sea. Mijikenda had the highest proportion of respondents mentioning this category, while Utange had the lowest. As expected, the percentage of people that mentioned human activities could influence the marine environment is significantly correlated to the proportion of respondents that were fishers (Spearman's rho=0.60, p=0.04, n=11). The most frequently cited (~30% of all respondents) mechanism that influenced the fishery was that the fish moved, were hiding, or altered their behaviour. Almost 20% of all respondents did not know what could affect the condition of the fishery, and 5% said it was God or Allah that influenced the fishery.

The most commonly mentioned human factor affecting fish abundance was the use of specific fishing gears, such as small meshed nets (included in the ‘other gears’ category), beach seines, gill nets, purse seines (ring nets), and spear guns. Even among the communities with a high proportion of fishers, there was a low degree of awareness that more complex issues such as land-based activities and political and economic conditions could affect the condition of coastal resources.

Table 4.2 Percent of each community that mentioned specific factors that could decrease the number of fish in the sea *

Response category	Bamburi beach	Bamburi village	Kuruwitu	Marina	Mayungu	Mijikenda	Shela	Takaungu	Utange	Vipingo	Vuma	All sites
Human activities	59	48	47	48	66	85	55	48	38	56	61	55
Specific gear	29	35	33	26	59	76	45	33	21	34	50	40
Fish behaviour	29	6	17	52	31	32	48	20	26	31	24	27
Fishing effort	35	26	17	35	34	29	13	27	23	31	24	26
Life history stages	18	23	17	4	38	41	23	16	18	21	30	22
Fish mortality	24	23	20	17	17	35	19	17	8	32	22	21
Other gear	6	26	23	22	21	65	29	5	10	16	13	19
Don't know	6	29	33	4	10	3	6	20	31	27	17	19
Over fishing	24	16	17	30	21	29	6	15	15	15	9	17
Habitat	18	13	3	30	28	29	26	7	8	13	13	15
Weather	6	6	13	17	14	21	19	16	5	18	15	14
Number of fishers	24	10	10	22	7	3	10	11	5	23	15	13
Reproduction	6	6	7	4	28	35	16	5	13	8	11	12

* Listed are the response categories mentioned in >10% of the communities pooled together. Categories with <10% of responses include: political/economic conditions, supernatural forces, spear guns, religion/God/Allah, fishers from outside, land-based pollution, gill nets, beach seines, purse seine, climate change, seasons, maritime pollution, social cohesion, market demand

Perceptions of ways to improve coastal resources

Responses to ‘what could be done around [this community] so there would be more fish in the sea?’ indicated that very few respondents suggested that closed areas were a means to improve fishery resources (Table 4.3). Overall, most respondents did not know what could improve the marine environment. Those that had suggestions cited reducing the use of nets, supernatural factors (common answers included giving sacrifices, repenting, and going back to traditional ways), and improved enforcement most frequently. The communities with the highest proportion of respondents that mentioned closed areas nearby were Vipingo (11%) and Takaungu (8%), neither of which had closed areas, although a community-based organization operating in Vipingo and Kuruwitu (the Kuruwitu Conservation and Welfare Association – KCWA) had proposed a community-based closure.

Land tenure

Key informants claimed that disproportional ownership by the rich meant that it was difficult for poor people to own or access land. The village chief in Takaungu noted, ‘A few people own a lot of the land.’ To maintain ownership, some landowners would allow their land to be farmed, but collect a nominal fee for use each season (on the magnitude of 100 Ksh).

In Malindi, respondents claimed that the introduction of the salt production industries have been a big problem to the locals in two ways. The companies have been expanding taking more farming land from the locals and the few remaining farms have not been productive because of the salt-water intrusion. Tourism was cited as a problem in Marina and Mayungu, where tourism development has constrained access to fish landing sites.

In Vipingo, Takaungu, Bamburi, and especially Mijikenda, key informants and other respondents highlighted land rights as a significant problem. In Vipingo, the local sisal plantation of the same name, controls the majority of land. In Takaungu, respondents reported that the majority of land still belongs to Arabs and therefore the local population can only use the land for subsistence needs. In contrast, land tenure issues in Bamburi result from population growth and associated development projects have displaced landowners.

Mijikenda is a squatter settlement that was recently relocated. The original community was moved to allow for the development of a handicraft market. Residents claimed that the new settlement was temporary and they were not allowed to build permanent or semi-permanent structures (all houses were made

Table 4.3 Percent of each community that mentioned specific factors that could increase the number of fish in the sea *

Response category	Bamburi village	Kuruwitu	Mayungu	Mijikenda	Shela	Takaungu	Utange	Vipingo	Vuma	All sites
Don't know	25.8	53.1	17.2	2.9	9.7	30.2	30.8	38.1	17.0	25.8
Reduce gillnet use	12.9	25.0	24.1	14.7	12.9	20.9	23.1	12.7	27.7	19.7
Supernatural factors	12.9	6.3	13.8	14.7	29.0	15.1	17.9	11.1	12.8	14.5
Improved enforcement	16.1	12.5	13.8	14.7	22.6	10.5	5.1	9.5	8.5	11.8
Political/economic factors	12.9	3.1	6.9	2.9	12.9	10.5	10.3	15.9	0.0	8.8
Reduce effort	19.4	3.1	6.9	5.9	6.5	4.7	0.0	14.3	6.4	7.3
Reduce trawlers	0.0	0.0	0.0	58.8	12.9	2.3	0.0	0.0	0.0	7.1
Reduce seine net use	0.0	3.1	13.8	2.9	9.7	10.5	0.0	0.0	14.9	6.9
Reduce # of fishers	9.7	0.0	3.4	11.8	9.7	5.8	5.1	11.1	4.3	6.6
Education/awareness	3.2	3.1	13.8	5.9	0.0	9.3	5.1	1.6	4.3	5.9
Closed Areas	6.5	6.3	0.0	0.0	0.0	8.1	2.6	11.1	0.0	4.5

* Listed are the response categories mentioned in >4.5% of the communities pooled together. Categories with <4.5% of responses include: closed areas, land-based pollutants, exclude outside fishers, nothing, social cohesion, introduce better gear, reduce poison fishing, reduce small mesh nets, reduce explosives.

entirely of palm thatch). Local residents were attempting to secure rights to land in the community.

In many areas, access to landing sites was constrained by tourism development and expatriate land ownership. Of the sites surveyed, Bamburi beach and Marina landing sites (in Mombasa) had the most tourism and development along the coast and creek. Respondents noted that access to fishing sites was a significant problem in Marina and expected it to be a problem in the near future in Bamburi.

Sea tenure

Traditionally, some communities restricted outsiders from accessing marine resources. For example, in Takaungu, elders described how fishers from other communities would have to meet with the oldest fisherman, request permission, then typically pay a nominal fee for fishing in the adjacent waters. Elders noted, however, that this served more as a form of patronage than as a means to restrict resource use. Indeed, elders in Takaungu and Vuma described how 50 years ago, resources were abundant and outsiders were encouraged to fish there as a means to establish trade relations and technology transfers. This form of patronage still exists to a degree. Fishers from outside are required to pay a fee to fish in areas such as Takaungu.

Involvement in community associations and decision-making

Participation in community associations was low in all communities except Mijikenda (Table 4.4), where most households were members of the Mijikenda fishermen's association. This organization collected approximately 2 shillings per kilogram of fish landed to put toward communal fishing gear or assist other members. In the Vipingo/Kuruwitu area the grassroots conservation group KCWA had around 60 active members, many of whom were fishermen. This organization had established a no-fishing zone, sea turtle protection, beach clean-ups, and mangrove restoration. In many of the other areas community groups included merry-go-rounds whereby all members would donate a set amount of money, and this pool of money would be sequentially re-distributed to a single member each month, self-help groups, and women's organizations. There was also a community-based conservation organization in Malindi, called Malindi Marine Association (MAMA). However, we did not encounter any members in our household surveys. The group was reported to be active in local fisheries meetings and conservation advocacy. In Mombasa, there was a fishers groups (Nyali, Bamburi, Utange fisherman's group) operating at the Bamburi landing site. There are also several umbrella fishermen's groups that aimed to advocate fisher's needs, such as the North Coast Fishermen's Association.

Table 4.4 Involvement in community organizations and decision-making

Community	Community organizations per household (mean number)	Percent of community involved in community organizations	Percent actively involved in decision-making
Mijikenda	0.3	97.1	70.6
Takaungu	0.3	58.1	43.0
Shela	0.5	45.2	38.7
Vipingo	0.3	46.0	34.9
Utange	0.2	51.3	33.3
Vuma	0.2	57.4	29.8
Bamburi village	0.3	41.9	29.0
Kuruwitu	0.2	53.1	25.0
Mayungu	1.4	41.4	24.1
All communities	0.4	53.8	36.3

Community leaders claimed that community decisions were made primarily through chiefs, village elders, and community meeting forums. Women were involved in community meetings, but leaders claimed that they were mainly passive (i.e. did not speak or set agendas frequently). Participation in community decision-making was also highest in Mijikenda (97%, with 71% actively involved). This high incidence of participation may be in part due to a movement to make the squatter community recognized as a permanent settlement, but also could be a result of surveying exclusively males in that community. The lowest incidence of involvement in decision-making was in the large urban Bamburi and the small remote Mayungu site, suggesting that involvement in decision-making is not a function of community size (Spearman's rho=-0.3 for total involvement and 0.2 for active involvement, neither of which are significant, n=9).

Respondents suggested that three main issues facilitated a woman's ability to be involved in decision-making: membership in women's groups, education level, and marital status. The formation of women's groups enabled the sharing of ideas and enabled women to influence changes in their community; they could approach the chief's office easily to present their problems. In Takaungu and Vipingo, some women used women's groups as a catalyst for small business ventures. Many women complained that they were confined to making decisions about family issues rather than issues influencing the wider community, largely because of a lack of education. Yet educated females were appointed to positions in the community. For example, one Kayanda (Vuma) woman had been selected as secretary of a self-help group after she began attending adult education classes. In Shela, the ability to make decisions also relied on a woman's marital status. Unmarried women were not typically involved in decision making.

Conflicts

There were reportedly considerable conflicts at most sites over both land and sea resources. Land conflicts were reportedly frequent in Takaungu, Vipingo, Mayungu, and particularly Mijikenda, where the community was struggling to get permanent access to land. Conflicts over marine resources were also reported, and typically were between gear users. Only Mayungu, Vuma, and Kuruwitu did not report fishery conflicts. Key informants in Bamburi Beach and Takaungu reported conflicts with Pemba (Tanzania) fishermen using a small purse seine net called a ring net. Local resource users complained that the gear was destructive and wanted the gear banned from use. In Takaungu, the gear was allowed by the landing site chairman for a fee of 5 shillings per kilo of fish landed. The money reportedly disappeared and was never accounted for. Interestingly, in Mijikenda, the chairman supported the use of the ring net because it would provide employment and when used properly in pelagic waters, would divert pressure from inshore marine resources. In Vipingo, community leaders suggested conflicts existed between local fishermen and aquarium fishermen.

Discussion

There was considerable variation in socioeconomic conditions both within and between the examined communities. Our study sites ranged from peri-urban areas in Mombasa and Malindi to very remote communities such as Vuma and Mayungu. In the study sites, there was a wide range of access to and dependence on marine resources. It was evident that despite the relatively low proportion of households in most communities, many of those that were dependent on fishing considered fishing to be their most important occupation. The number of occupations was relatively low compared to studies conducted in other countries. For example, in 21 communities investigated in Indonesia, the number of occupations per household ranged from a low of 1.6 to a high of 3.9 (mean=2.3) (Cinner, unpublished data). This suggests that households in Kenya have a relatively low diversity of livelihood strategies to draw upon.

Governance of coastal resources

Institutions governing coastal resources in Kenya are currently in a state of transition with the implementation of a number of new laws (McClanahan *et al.* 2005a,c). The recently conceived BMU legislation began the process of the codification of an increase in local control of fisheries resources in 2006. The BMU essentially delegates local management authority of the fishery from the government fisheries department to elected representatives at each landing site. These local representatives form a beach management committee that can develop local by-laws to manage the fishery. Local by-laws could include closed areas, gear restrictions, effort, size, and species limits. Areas with limited access to fish landing sites may be able to use the BMU legislation to secure continued rights and access, which may be particularly important in Marina and Mijikenda.

This legislation could be particularly helpful in several of the communities. For example, the KCWA has established a trial community-based MPA for several years. This legislation has enabled the community to pass a by-law and temporarily establish a no-take area. Although the legislation has yet to be officially enacted, in some locations the BMUs are de facto already operating as community-based organizations.

The decentralization of management authority to the stakeholders through the BMU is a positive step in enabling communities to develop locally appropriate rules and regulations. However, BMUs will need capacity building and technical support to make informed decisions regarding the sustainable use of marine resources. It is recommended that NGOs support the BMU process and become involved in informing fishers about research findings to assist with local management and policy decisions.

Five of the study sites were proximate to MPA's. Bamburi and Utange/Marina were on either side of the Mombasa MPA. Mayungu and Shela were on either side of the Malindi MPA, and the Mijikenda settlement neighboured Shela to the north. Both MPA's had nearby landing sites that practised the use of small meshed nets, particularly beach seine and small meshed gill nets. The prevalence of illegal gear use (particularly small meshed nets) and the correspondingly small fish catch at several sites is concerning (McClanahan *et al.* 2005a). Fishers at Marina and Mijikenda had the highest incidence of illegal gear use. Yet fishers at these sites had a high dependence on marine resources and relatively low occupational mobility. Consequently, there are not many other options for these fishers. Rather than removal of these gears, we recommend that a gear exchange program be commenced whereby fishers can trade in illegal for legal nets of a larger mesh size. In order to increase involvement and commitment to these programs, we suggest that fishermen's groups raise matching funds for this program.

Perceptions of the environment

There was generally a low degree of understanding that human activities influenced the marine environment. Twenty five percent of respondents either did not know what could influence the environment or attributed changes to God or Allah (McClanahan *et al.* 1997). Furthermore, the most frequently cited mechanism by which respondents believed fish abundance changed was that the fish moved, hid, or changed their behaviour. We also found that, overall many resource users had a negative perception of the marine parks and few respondents mentioned closed areas as a means to improve the condition of coastal resources. While some respondents cited that they received benefits from the parks (particularly spillover, improved recruitment, and increased reproduction of target species), the majority of fishers adjacent to the park did not understand the rationale behind the closures. We suggest that providing fishers with direct comparisons of fish catch based on proximity to parks and type of gear used may help to explain the benefits of the closures and consequently improve support for the parks.

There is a clear need to improve the understanding of how anthropogenic activities influence the marine environment. Government and NGOs should continue to encourage the efforts to raise awareness about the marine environment. In particular, MAMA and KCWA should be encouraged to increase the knowledge of these programs and continue their awareness campaigns. We found that there was often poor communication among fishers that made it difficult for ideas and training to spread. This suggests the need for larger and more inclusive forums where finances permit.

The development of the BMUs provides a unique opportunity to examine the transformation of common property regimes by de-centralizing control to fishermen's groups at individual landing sites. Essentially, this will create a marine tenure system and provides an opportunity to examine the organization of fishing communities to change, and how they develop, implement, and monitor common property rules. This re-organization into decentralized control may become participatory, locally-adapted, and a resilient governance structure, but alternatively has the potential to devolve into a patchwork of individualistic regimes that could make effective management at the larger scale, at which ecological processes and externalities occur, more difficult. We propose that it will be important to involve multiple scales of governance to insure that governance structures remain flexible and adaptive but not so myopically focused that larger national and ecological issues are not considered.

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Summary

We conducted a socio-economic assessment in nine coastal communities in Kenya to identify key socio-economic factors affecting inshore coral reef fisheries. Communities varied considerably in regards to their dependence on marine resources. Smaller communities had more than 60% of households engaged in the fishery, but the proportion of fishers was relatively small in the communities close to highly urbanized areas. Households that fished generally ranked fishing as their most important occupation.

There was an array of marine resource governance structures either instituted or in development at the study sites. Four communities bordered established marine protected areas (MPA) and two communities bordered a proposed MPA, and the level of appreciation of protected areas was lowest near the established areas. Despite legal prohibitions, a large proportion of fishers at one site adjacent to each established MPA engaged in destructive fishing methods, particularly beach seining. There was poor understanding of the factors that influence fisheries and the means to improve them and the marine environment.

5

Marine conservation: The voice of the fishers

Nicole Versleijen[1] & Jan Hoorweg[2]

Introduction

There are an estimated 10,000-12,000 artisanal fishers on the Indian Ocean coast of Kenya with some 2,500-3,000 based along the Kilifi/Malindi coast (Hoorweg *et al.* 2009a; McClanahan 1996). The fringing reef is generally close to the shore and the fishers do not necessarily need boats to reach these fishing grounds. Many of the near-shore areas along the Kenyan coast are heavily utilized and over-fished (with catches above the maximum sustainable yield). Over the last decade, many of the reefs have started to show signs of degradation as a result of overexploitation and pollution (UNEP 1998; McClanahan & Obura 1996; Obura 2000, 2001; Aloo 2000). Some areas further offshore have the potential to increase their yields (McClanahan & Obura 1996) but this requires investments in vessels and equipment that are beyond the means of most fishers. Major increases in fish catches are unlikely in the near future. Artisanal fishers are contributing to the degradation of marine resources because intensive fishing in a certain area can affect the ecological balance and result in a loss of fish stock. Destructive fishing practices, such as the use of explosives, seine nets and poison, can alter the terrain as well as the ecological balance of the reef and the sea floor. Fishers are aware that their increasing numbers are putting pressure on

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marine resources but do not know how to deal with the situation (Versleijen 2001; Versleijen & Hoorweg 2008).

Traditional gear includes traps, fences and poison. The portable fish traps *(malema)* are fairly light and are used on the reef. Fixed fences (*uzio*) are set up perpendicular to the shore and up onto it. Both the traps and fences are made of local materials and are generally considered to be more environmentally friendly than modern equipment, although they are on the decline and mainly used by older fishers. Traditional fish poison (*mkanga* or *mchupa*) is sometimes used too but it kills other marine organisms as well as the birds that eat the dead fish. Modern equipment includes nets and lines in almost equal proportions. Traditional nets and lines used to be made of cotton, bark and sisal that were organic and biodegradable (Glaesel 1997) but they have been replaced by stronger nylon nets and lines that are manufactured industrially. These give much higher catches than traditional ones but can cause damage and, if lost at sea, do not disintegrate naturally. The use of a gill net (*mpweke*) sometimes involves fishermen trampling on the corals and gill nets can snag on the reef and break off branching or plate corals. When used in grounds without corals, gill nets rarely cause environmental damage. Beach seines have very small mesh sizes *(juya*) and young and immature fish can become entangled as a by-catch. The net is dragged along the seabed and churns up the sea bottom, damaging underwater vegetation. Baited hooks and lines (*mishipi*) do not usually interfere with the marine environment. Spear fishermen use long metallic rods *(mkonjo)* to break the coral where the fish take refuge but these spears may damage the coral when fishermen miss their targets. Explosives (*baruti*) kill fish and other marine life indiscriminately and also damage the local habitat.

Traditional conservation methods generally aim to sustain harvests or catches in the medium and short term. The objectives of modern-day conservation are the protection of the local flora and fauna for its own sake and the sustainability of natural resources. Currently the most common method of conservation of marine resources is the establishment and management of Marine Protected Areas (MPAs). Marine Protected Areas in Kenya include Marine National Parks and Marine National Reserves. Kenya has about 600 km of marine coastline and a number of Marine Protected Areas, which have been instituted successively since the early 1960s. The first marine reserve (then called the Coral Garden Fish Reserve) was established in Watamu in 1962, followed by a reserve in Malindi in 1964 (Kenya 1964). They were officially designated as Marine Parks in 1968. A marine park is an area where neither fishing activities nor plant or animal collection are permitted. Flora and fauna are fully protected inside these parks and although fishing by artisanal fishers is allowed in the marine reserves, it is restricted by regulations stipulated in the Fisheries Act (Kenya 1993). Marine

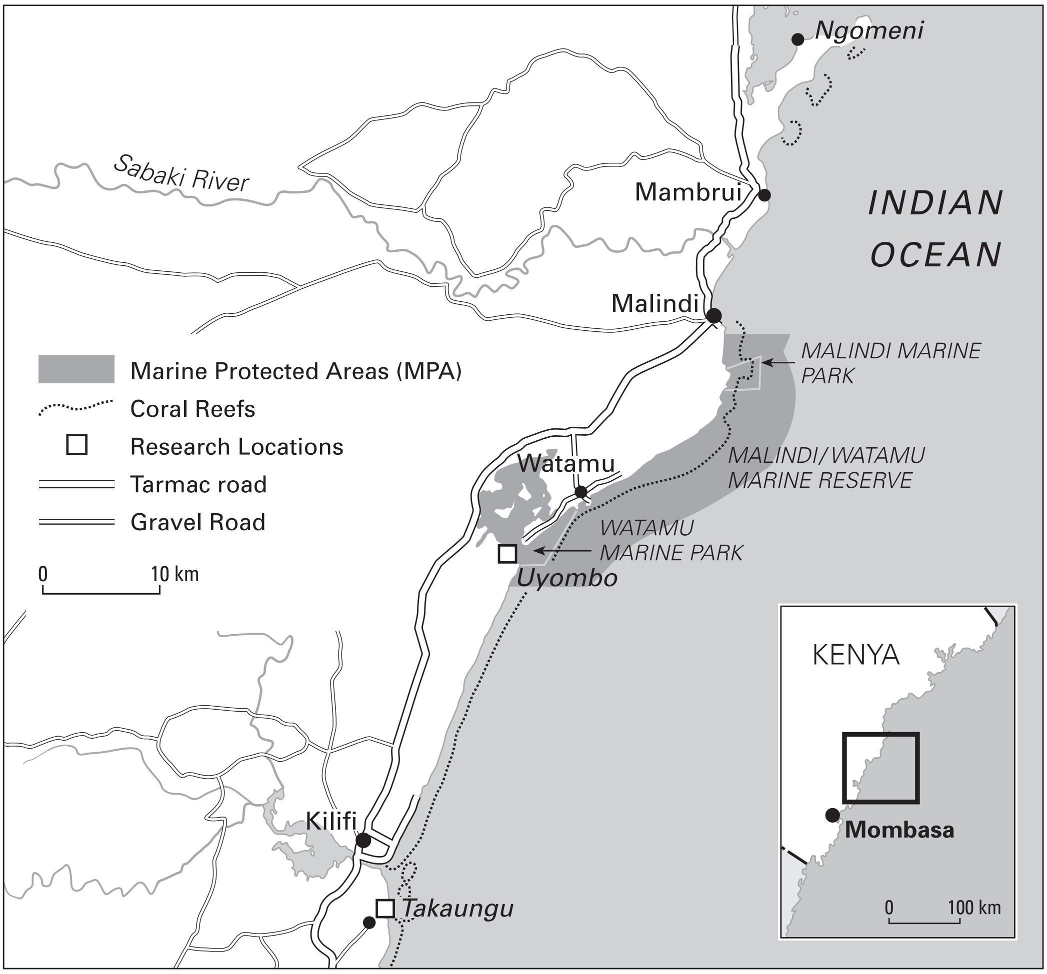
Protected Areas are managed by the Kenya Wildlife Service (KWS) and rangers patrol regularly. Fishers are allowed to pass through the parks with their vessels to reach their fishing grounds in the reserves. Fishers living near a marine park, however, often face a struggle to gain access to sea resources. Collecting shells, fishing, harvesting forest products from mangrove swamps and leisure pursuits associated with water have been restricted or curtailed by the requirement of a fee or a license. In addition, ecological and socio-cultural considerations have not been taken into account in the construction of beach hotels at picturesque beach sites. It could be claimed that the construction of tourist hotels has foreclosed the sea ethic of the local people and has alienated them from tourism development (Sindiga 1999).

With the advent of community-based natural resource management, the ecological focus has shifted to the people who are bearing the costs of this conservation (Western & Wright 1994). Community resource management works on the principle that conservation will only flourish if it is embedded in local communities and is voluntary rather than enforced (Western 1994). In addition to knowing who the stakeholders are, it is important to understand their attitudes towards traditional conservation practices, modern conservation efforts – in particular, the MPAs and the advantages and disadvantages of these management regimes – and their relations with the environmental authorities. An attempt is being made in Kenya to involve stakeholders in controlling access and entry with the introduction of the Beach Management Units (BMUs). Each BMU will have jurisdiction over a landing site and the Fisheries Department designates a co-management area where the BMU and the Fisheries Department join in management activities (Oluoch *et al.* 2006). In addition, fishers who want to fish at a different landing site will have to seek permission from the local BMU.

The present study examined the attitudes of fishers towards marine conservation in locations that differed regarding restrictions on fishing practices. The study explores the views of the fishers about traditional ways of conservation, present-day conservation, the benefits of protected areas, other marine resource users and relations with the KWS, and how conservation efforts should, or should not, be implemented.

Study area

This study was carried out at two landing sites in Kilifi District on the Kenyan coast: Uyombo and Takaungu (Map 5.1). Extra information was gathered in Watamu on the employment patterns associated with the local marine park. Takaungu is situated between Kilifi and Mombasa, while Uyombo is situated between Kilifi and Malindi and, as the crow flies, is not far from Watamu and the Watamu Marine National Park.



Map 5.1 Malindi-Kilifi coast with landing sites studied

Takaungu was settled in the early 19th century by members and clients of the Mazrui family (Koffsky 1977). Migrating fishers from the Bajun Islands to the north had probably founded a temporary fishing village there before the Mazrui arrived. The landing site at Uyombo (also known as Bandarini) has a much shorter history with the first settlement dating from only 70-75 years ago when a Bajun fisher from Lamu decided to build a house and move his family there. The Bajun are the traditional fishers on the Kenyan coast and they are regarded to be the fishers per excellence.

The differences between Takaungu and Uyombo are pronounced and evident. Takaungu is a small town of 1500 people (Wikipedia 2008) with many houses whereas Uyombo is a village with fewer than 30 houses. Uyombo can be reached on foot or by bicycle and although it is possible to reach the area by car, this involves negotiating a route through *shambas* and mangrove forests. From Takaungu there is a road connection with the Malindi-Mombasa trunk road and a choice of transport ranging from bicycle taxis and *matatus* to private cars and occasional small trucks. Uyombo is located near the Watamu Marine National Park and there is no marine park in the vicinity of Takaungu.

As a result of its modest size and poor accessibility, income-generating activities in Uyombo are related to either fishing or agriculture, such as fish mongering, palm-wine tapping and selling, cash-crop cultivation, plaiting *makuti* (roofing material from palm leaves) and farm labour. A more diverse scale of activities might have been expected, especially considering the nearby marine national park. Other groups of people have found employment in Watamu as Kenya Wildlife Service (KWS) rangers, hotel employees, safari guides, beach operators (curio sellers) and boat operators. In Takaungu there is a much wider range of income-generating possibilities such as furniture making, block cutting, building construction and teaching. In addition there are shops and small eating places. There are craftsmen and tailors resident in Takaungu but none in Uyombo so that people have to go to Matsangoni on the Malindi-Mombasa road.

The population in the study areas consists mostly of Swahili, Bajun and Mijikenda. In Takaungu, the Swahili and Bajun tend to live in the town centre (the oldest part) and the Mijikenda live mostly on the outskirts of the town. Similarly in Uyombo, the Bajun live at the landing site where few Mijikenda have built permanent houses. The main population group is the Mijikenda who traditionally were agriculturalists and lived mostly on the coastal uplands. In the course of the last century, they spread out along the coastal strip and came to sea fishing later (Waaijenberg 1993, 1994, 2000). The Mijikenda, except for the Digo subgroup in the south mostly adhere to traditional African beliefs or Christianity. The large majority of the Swahili and Bajun are Muslim (see Prins 1972; Elliot 1925-1926; Middleton 2000).

Method

The study, which was conducted between 1999 and 2001, was part of a larger research project on income diversification and resource management among coastal fishers in Kenya.[3] The project comprised four surveys (referred to as companion surveys) and four support studies. The present study was one of the support studies undertaken in the course of 2000 in the two areas described above. In Uyombo, 23 informants, 13 fishers and 10 household members, were interviewed on a number of occasions using different techniques. In Takaungu, 21 informants, 11 fishers and 10 household members were interviewed. Fishers were contacted at the respective landing sites and accompanied to their homesteads in order to interview other household member(s) such as wives. Data techniques included semi-structured, unstructured and informal interviews, life and career histories, participant observation, time allocation studies and discussion groups (see Versleijen 2001 for full details). Households and informants were contacted more than once to verify or elaborate on earlier information. On the first visit, semi-structured interviews were conducted and during later visits, unstructured and informal interviews as well as life and career histories were compiled. Most of the fishers (65%) were followed for a whole day using a technique known as participant observation. The other fishers refused to participate in this because they did not want an extra person on their boat who could not contribute to their fishing efforts and was, moreover, a woman. Time allocation studies were done by visiting all the informants once an hour for a whole day. Discussion groups took on an organized form in Uyombo and were conducted informally in Takaungu.

Informal follow-up interviews were held in 2001 and 2003 with several fishers and others in Takaungu and with fishers from Uyombo. Most had been part of the earlier samples and wanted to add something or update their situation, while others had become involved in the general conversation and wanted to add their own views. Discussions focussed on questions such as their household's present income, the possibility of income diversification and their views concerning marine conservation and the Marine Protected Areas.

Table 5.1 summarizes the views of the fishermen on traditional ways of conservation, present-day conservation, the benefits of the marine park, other marine resource users and relations with the KWS.

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3 This was a joint project involving Moi University (Kenya), Ben Gurion University (Israel) and the African Studies Centre (the Netherlands) between 1999 and 2001 that was funded by the Netherlands Israel Research Project (contract NIRP-97-145-7) and first reported in Hoorweg *et al.* (2003).

Table 5.1 Views of fishermen on marine resource management, by landing site (% responding affirmatively)

	Uyombo (N=13)	Takaungu (N=11)
Need for *Sadaka* and related rules and regulations	0	18.2
Need for marine conservation	100	90.9
Willingness to participate in marine conservation but only on an equal partnership basis	30.8	81.8
MPA suitable way of marine conservation	0	0
MPA suitable way of employing marine conservation if managed differently from at present	30.8	9.1
Perceived park benefits	15.4	--
Other marine resource users contributing to declining fish catches	15.4	36.4
Poor relations with the KWS	100	--

Results and discussion

Traditional methods of conservation

Traditional methods of conservation focused on access and fishing methods. In the two study locations, access regulation took the form of a regulating committee and a ceremony called *sadaka*. The ceremony used to exist in Takaungu but had not been performed in Uyombo in living memory. Most of the fishers from Takaungu are aware that there used to be something called *sadaka*, although descriptions of the purpose of the ceremony and the precise rituals are different according to the citations given below (see also McClanahan *et al.* 1997; Glaesel 1997, 2000a for descriptions of the *sadaka* among the Digo).

> *We used to bring offerings to the sea and then we would not fish in that area for at least a week. Some areas you would not go to at all.* (Bajun fisher)
>
> *Some Mavumba (pounded fish which has a very strong smell, the smell is the important thing about it, it can be rotten fish as well) are taken to the sea and some words are said and celebrations are done. This can be anywhere in the sea, the place is chosen by all the fishers together.* (Mijikenda fisher)
>
> *The fishers go to the beach with rice. A few fishers go out fishing. When the fishers are back, the catch they have is prepared and taken together with rice. The fishers and some other villagers (especially young children) eat and celebrate together. After the sadaka, the leftover food and the fish are divided up and taken home. On the day of the sadaka only the fishers who go to collect the fish for the sadaka are supposed to go fishing. Before the sadaka is conducted, the gods have to be pleased. The elder fishers have to speak some words and then some rice and fish have to be given to the sea.* (Bajun fisher)

> *There is a sadaka in which blood should be given to the sea. A goat is slaughtered and prepared and eaten. Some is given to the sea. Older fishers say some words to the gods of the sea to ask them for a higher catch. After the sadaka there should not be any fishing at the spot of the sadaka for a week. This sadaka is not done there anymore, there are too many fishers now and they are not cooperating anymore, the older fishers who were always arranging this died years ago. I think the last sadaka like this must have been 10 years ago.* (Swahili fisher)

In November 2000, some of the fishers in Takaungu decided to organize a *sadaka* once again. Only nine fishers, all of whom were Muslim and over forty, participated in the ceremony. The rest did not see the need for it. The reasons for conducting a *sadaka* were that it had been part of their tradition and they should continue with it; and the gods had to be pleased in order for the fishers to get higher catches. The *sadaka* itself consisted of eating on the beach, giving some food to the sea and not fishing in that spot on the day in question. However, this last rule only applied to the participants and did not include the people who were not involved in the *sadaka*.

In the past, the *sadaka* was a way of conserving marine resources since it prohibited fishing in certain periods and/or in certain areas. For the *sadaka* to have an impact on marine resources, the majority of the fishers would have to be prepared to participate and observe the rules. By now, the *sadaka* has lost its conservation value (Table 5.1) although it retains an emotional and ritual value for the few older Swahili and Bajun fishers (see also McClanahan *et al.* 1997).

> *In the past, our fathers had ways to make sure the fish had some time to grow and to multiply. However we lost those ways, we can't use them anymore as they did. You know how the sadaka went last year, there were too few of us, all the other fishers just went on like nothing was happening. Everybody has low catches; nobody wants to lose a day's fishing. And if most of us don't fish for one day or longer in one area, another fisher will come and have a good catch there. We are too few now. The only reason we do the sadaka is that it is how we are used to talking to the sea, maybe we can still please the sea and it will help us and keep us safe. But for the fish, it won't make a difference. There are too many of us now and it won't work. We have to think of something else but it is a very difficult thing.* (Swahili fisher)

One reason for the decline of the *sadaka* is that fishing has become a multi-ethnic activity. Fishing used to be dominated by the Bajun and Swahili and their beliefs and practices were strongly connected to the sea. When the agriculturalist Mijikenda started fishing they did not value the *sadaka* and it lost its importance. Religious convictions also played a role as Mijikenda fishers refused to participate in the ceremony because they considered it non-Christian.

> *The sadaka used to be conducted every year to please the gods, regardless of a high or a low catch. In those days most fishers were Muslims and they all agreed that the sadaka should be performed, nowadays however there are a lot of non-Muslim fishers. There is no cooperation between the fishers anymore and the non-Muslim fishers are afraid that if they conduct the sadaka, a few days afterwards a non-Muslim might drown.* (Swahili fisher)

An additional reason is that there are more young people involved in fishing who do not adhere to or who even reject the customs of the older fishers, including the *sadaka*. Glaesel (1997, 2000a) reported a loss of confidence in the *sadaka* among Digo fishers. Due to declining catches, the 'younger Kenyans' faith in their elders' ability to commune with sea spirits has waned and the elders' authority has been challenged leading to intergenerational conflicts' (Glaesel 2000a: 35). According to Glaesel, these conflicts have fractured fishing communities and allowed the arrival of fishers with destructive fishing techniques.

> *The sadaka? What should I have to do with that, you are only wasting your time, that is something for the older fishers, it is something from the past, not for us!* (Mijikenda fisher)

Another element regarding traditional conservation practices concerns fishing methods, especially the fishing gear used. Fishers used to be flexible in their choice of gear, although they usually had strong preferences that were influenced by their knowledge and experience as well as economic and environmental considerations (Tunje & Hoorweg 2003). One of the companion surveys to this study showed that many fishers reported two or more kinds of gear and only 30% of fishers limited themselves to one specific gear (Hoorweg *et al.* 2009a). Gear differed greatly in their effects on the environment, some were potentially damaging, others less so. Roughly, there were three types of destructive effects: (i) damage to the marine environment; (ii) the capture of non-targeted species; and (iii) the capture of immature fish among the targeted species. Not only the type of gear but also the area where the gear was used and the way it was used determined whether or not it caused damage. Traditional gear was generally less harmful than modern gear but use of the former was on the decline. Glaesel (1997) also mentioned that fishers were increasingly turning to less expensive and more harmful forms of fishing due to declining fish stocks and the loss of their elders' fishing knowledge. In one of the companion surveys, 15.6% of fishers reported using destructive gear, namely beach seines, small-mesh nets and spear guns (Hoorweg *et al.* 2009a).

Some fishers in Takaungu pointed out that conservation could only be done in traditional ways if one was wealthy, i.e. if a person's catches were high throughout the year. Nowadays, it would immediately have a negative effect on their income and their household's standard of living. Households have to be fed every day and the indigenous ways of conservation are, therefore, no longer suitable.

> *I have to feed my family, if I don't fish for some days or so, then who will feed my family? It is already difficult enough to get money to send the children to school.* (Swahili fisher)

Present-day conservation

Although fishers in Takaungu did not explicitly practice traditional conservation methods anymore, a large majority of fishers admitted the need for marine conservation (Table 5.1). Takaungu and Uyombo both had committees: in Takaungu it was a committee of fishers and in Uyombo there was a village committee. The chairman of the fishers' committee in Takaungu explained that anybody fishing with destructive fishing gear would have to account for his actions. However, he also stated that:

> *We don't have ways to enforce things, except that when we are all together we are strong. I mean that when we all agree that something should not be done, we can chase the people who do it. In the past, all fishers came to me to ask permission to fish here, but nowadays that is not the case. Not that that is a problem, it is okay as long as they don't fish with bad gear, like the nets with very small mesh sizes.* (Chairman of the fishers' committee in Takaungu)

Although the committee and its chairman had lost the power and position they used to have in the past, they were still there as a tool, and through them fishers could try to protect their interests as a fishing community. The chairman of the Uyombo village committee mentioned in particular that people using destructive gear were challenged about the negative effects of their fishing. One example was that of fishers from Pemba Island who were chased away from Uyombo in a joint action by fishers, the KWS and the police. (The Pemba fishers were considered to be especially destructive because of the *juya* nets they used with a very small mesh size.)

The main restrictions enforced nowadays are those related to the MPAs. In the case of Uyombo, there was the nearby MPA that takes its name from the village of Watamu although there was no park or reserve in the vicinity of Takaungu. The Watamu Park is part of the complex of marine national parks and reserves at Malindi and Watamu. Fishers from Uyombo had to cross the Watamu Park to reach most of their fishing grounds. Although fishing in the marine park was prohibited, poaching did take place and the KWS had regular problems with artisanal fishers. However, as much as artisanal fishers constituted a concern for the KWS, the Watamu Park had become a severe problem for the fishers in return (see also Glaesel 1997 and 2000b on other marine parks in Kenya). The area at the entrance to the creek, for example, offers good fishing grounds but this is now a restricted park area. One positive effect that was expected from fishing restrictions was an increase in fish biomass (Cinner *et al.* 2005), and a spillover of exploitable fish into the reserves (McClanahan & Mangi 2000) but the fishers claimed that since the gazetting of the Watamu Park, fish stocks had been declining just as quickly as before. They also claimed that fishers had been left with a smaller area, resulting in a higher density of fishers and lower catches.[4]

> *There is no spillover benefit from the marine national park. It is a lie, even before the marine national park was founded, there were more fish than nowadays, today fish are rare and the fish that are there, they escape to the park.* (Bajun fisher)

Glaesel (1997) also reported that the fishers found the loss of fishing grounds hard to accept and that spillover from the protected areas was not making up for this loss. Others have also confirmed that fishers are often dissatisfied with the benefits of the marine parks (Ochiewo 2004; McClanahan *et al.* 2005). None of the fishers in the study regarded the establishment of a marine park as a suitable conservation method but 30.8% of the fishers in Uyombo said they would be more positive if the park was managed differently (Table 5.1). Most fishers claimed that the main goal of the marine park was the promotion of tourism and that the tourists were the people who benefited the most from the marine park. 'Apparently, the government would prefer foreigners to benefit rather than the local people.' Others narrate similar concerns, namely that marine-protected areas were seen as a means for the wealthy to gain at the expense of the poor (Glaesel 1997) and as a means of attracting tourists and raising government revenue (Malleret-King 2000) although the latter author also showed that communities close to MPA's had better food security.

> *For me, I do not know why the marine national park is here. What was told to us was that the marine national park would be just outside the creek and not inside here. I do not know why the marine national park is here. During the colonial era when they started creating the marine national park they were just operating at the other side of Watamu, but later on they covered even the Uyombo areas.* (Bajun fisher)

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4 The catch and income per fisher in Uyombo and the surrounding area are considerably lower than in Takaungu with an average catch/trip of 4.7 kg vs. 18.8 kg and an average income/crew member/trip of Ksh 158 vs. Ksh 692 (Hoorweg *et al.* 2003).

> *According to me, the reason why the government took that place to conserve it as a marine national park is that there are a lot of tourists around this area. And they formed the marine national park so they can get money from the tourists, from the entry fees they charge them. Before they took only a small area, later on they expanded it, with an area which is never visited by tourists and which is the area of main interest for the fishers.* (Mijikenda fisher)

In fact, the fishers claimed that the area of the Watamu Park had expanded over time and was now larger than the 10km^2 which they were informed it would officially occupy. The fishers also complained that the KWS applied park regulations in the reserve areas, effectively making the area of the marine park even larger.

> *When they established the marine national park in 1968, they came to the fishers of Uyombo who were very few in number in those days and explained to them that they were going to preserve the area so that the others who would come later could benefit from what they were doing. But now the number of fishers is increasing, the reason for this is that most parents who are fishers cannot afford school fees for their children so they take them fishing too, so the number of fishers has increased and the area of fishing here at Uyombo is not large enough since the main part of the area has been taken by the KWS. What the KWS said to them before was that they were going to cover an area of 10 km^2 but later on they just extended the area, and this area is more than 10 km^2. They should reduce the size of this.* (Mijikenda fisher)

The need for conservation was not denied by the fishers and most agreed that it was important in order to secure their future livelihoods. In one of the companion surveys, 91% of the fishers were pessimistic about current fishing trends and reported declining fish catches (Hoorweg *et al.* 2009a). However, the fishers in Uyombo and Takaungu uniformly rejected the MPA as a suitable tool for marine conservation (Table 5.1) but had slightly different views on marine parks. Fishers in Takaungu were more willing to participate in conservation efforts but were adamantly opposed to the enforced measures by government agencies and insisted on an equal partnership (Table 5.1). They had a dislike of marine parks and anything associated with them because they feared that the government or others would gain control over the area and place the fishers in a dependent position. Some of the fishers in Uyombo though, were still willing to give the marine park a try if the park was managed differently and only if they, the fishers, stood to benefit directly. Most fishers, especially those in Uyombo, were finding themselves in a situation that did not leave them room to consider the long term. They had to meet the short-term needs of their households. This made conservation something to consider 'later' and prevented the fishers from playing an active role in the conservation of marine resources. Furthermore, fishers are unlikely to alter their livelihood strategies when they are averse to conservation measures. Even community-based management is then not likely to be effective, as it did for example in Tanga (see Verheij *et al.* 2004). The effective management of marine resources cannot ignore the short-term demands of fishers' households.

Park benefits

A few fishers mentioned benefits from the marine park (Table 5.1), although they emphasized that these would never outweigh the disadvantages, particularly the loss of their best fishing grounds. The benefits included improved security because of the presence of KWS rangers. Visits by tourists and resident foreigners gave local people the chance to sell fish at a higher price but the downside was that tourists like to look around the village and the villagers regarded their style of dress as highly improper. Fishers did tend to blame their contact with the 'other culture' for some of the problems they were facing with the younger generation. Disrespectful behaviour towards parents, AIDS, prostitution and drug use were increasing problems. Sindiga (2000) also suggested that tourism caused all kinds of social problems at the coast.

It was mentioned that some nets had been donated by KWS. These were, by now, the property of the Uyombo youth group and were rented out but disagreements within the youth group about what to do with the money were making the group function less efficiently. The KWS or researchers occasionally tagged certain fish and if anyone caught one of these fish, he received some money.

Another possible spin-off concerns employment but none of the fishers was or had been employed by the marine park. This was not because the fishers did not want to be but because they often did not have the necessary qualifications. However, they complained that they were not given jobs requiring a lower level of education either, as these jobs usually went to people from nearby villages and people from upcountry. Somebody from Uyombo would have to cross the creek every day or travel the whole distance by road.

> *Almost everybody would accept any job offered. There are people who tried but they were not accepted. They do not offer the jobs to us but to outsiders.* (Mijikenda fisher)

Fishers suggested several ways they might benefit from the marine park. First of all, parts of the Watamu Park could be opened up to fishing during the low (*kusi*) season. Secondly, the fisher communities could receive a proportion of the KWS's gate collection. Thirdly, employment, or related employment such as in hotels, should be offered to the fishers in the Watamu Park. As it is, the benefits of the park were minimal for fishers, which had resulted in frustration with and anger directed towards the park. This was all the more so because, according to them, their voices were not being heard by officials or the KWS.

> *Everybody knows conservation is needed but how can you ask me to think about the distant future when I don't even know whether my children will eat tomorrow or whether they will be able to go to school.* (Mijikenda fisher from Takaungu)
>
> *Everybody is talking about how we are to blame for the fact that there are fewer fish in the sea. But those people at the KWS are paid, they are sure that their families will eat, can't they understand that we are worried about our children more than about the fish and that we need the fish to feed our children?* (Bajun fisher from Uyombo)
>
> *Everybody says we kill all the fish, but what else can we do? They should give us something else to live off if they want us to stop fishing.* (Mijikenda fisher from Uyombo)

Views about other marine resource users

Some fishers expressed frustration that enforcement of marine conservation seemed to focus on them in particular and that little or no attention was being given to the activities of outsiders like the Pemba fishers and the commercial fleet (Table 5.1).

> *The KWS is only after the small and poor fisher, why are they not doing anything about these big and rich foreign fishers?* (Bajun fisher from Uyombo)
>
> *Why should we talk about conservation, what can we do as long as the government does not do anything against the Wapemba and the trawlers?* (Mijikenda fisher from Takaungu)
>
> *Why is the government not helping us but only favouring these foreigners?* (Mijikenda fisher from Takaungu)

The Wapemba are seasonal fishers from Pemba Island, Tanzania, who come to the Kenyan coast during the high season. They often acquire national identity cards and fishing licences from the government authorities and effectively become legitimate fishers in Kenyan waters. Their favourite equipment is the small-mesh seine net (*juya*), which is held responsible for the overexploitation of their native fishing grounds in Pemba (Glaesel 1997; Tunje 2000; Hoorweg *et al.* 2003; Mangi & McClanahan 2003). Local fishers considered the Wapemba and their nets to be partially responsible for declining catches in their own areas too. In fact, there had been skirmishes with visiting Pemba who had been turned away at certain landing sites[5] (Tunje & Hoorweg 2003).

5 On the other hand, at nearby Mayungu the local fishers teamed up with the visiting Pemba.

In addition to the Wapemba, fishers also pointed at the commercial fishing fleet – mostly trawlers – as being responsible for declining catches. In their opinion, these vessels frequently operated near the shore, although this is prohibited, catching large numbers of fish at a time and damaging the marine environment with their trawl nets in the process (see also Glaesel 1997). Incidents have been reported of trawlers damaging local fishers' gear. Tole (2000) also mentioned illegal trawling by ships from Japan and the former Soviet Union in Kenya's territorial waters.

Relations with the KWS

The relationship between fishers in Uyombo and the KWS can only be described as tense (Table 5.1). Nearly all fishers related occasions on which they were caught when passing through the marine national park returning from fishing outside the park. Their catches were taken or they were forced to give up part of the catch. Other complaints were about equipment and vessels that were not returned after being seized by the KWS.

> *They took our best fishing grounds and they are beating us and arresting us for no reason. The entrance to the creek is the best fishing area; they took it but don't make any use of it. It is like, putting a very fertile shamba in front of a farmer and telling him not to use it.* (Mijikenda fisher)
>
> *Sometimes you are caught by the KWS with your vessel and gear and they take you to court and you are fined or put in jail but after the court hearing you won't get your vessel or gear back.* (Mijikenda fisher)
>
> *When you come back from fishing and you meet a KWS officer who wants to have something to eat for free but your catch is so low, you cannot give him anything, then you have problems, he will get you next time, and then you are in big trouble.* (Mijikenda fisher)

Some of the older fishers recalled a different situation in the past. During the *kusi* season or at other times of low catches, the then-warden sometimes allowed them to fish in certain areas of the marine park. Since this was a gentlemen's agreement nobody violated the rules and fished in the areas of the park where they were not allowed to. It became the responsibility of the fishers themselves to ensure the rules were adhered to and they claimed that their relationship with the KWS was much better then.

The existing communication between the KWS and the local fishers did not succeed in making fishers understand the reasons behind the KWS regulations. This was aggravated by the fact that most fishers have little or no formal education and had to rely on others to inform them about the standing regulations.

> *We were not informed about the regulations, we just found them there, all of a sudden they told us that what we were doing was not allowed. We did not know anything, how should we know, they did not tell us and then they started to beat us for things we did not know were not allowed.* (Mijikenda fisher)
>
> *We do not even know if they are following the right regulations, you know the regulations are there but we are unaware of them so how can we know if what we are doing is allowed or not. You have to learn it by experience, you know, first somebody has to be caught and then we know that it is not allowed, and we cannot even check if they are lying or telling the truth.* (Mijikenda fisher)
>
> *A book was given to us concerning the management plan but what they state in it is not the truth, it is not how the situation really is.* (Shop owner, vice-chairman of the committee)

To understand the attitude of the fishers of Uyombo towards conservation in general and the Watamu Park in particular, it is important to realize that the interests of the KWS and the fishers are contradictory. While the fishers want to make an income out of fishing, the KWS is out to control and limit fishing activities. The clearest example of the conflict situation between the KWS and the fishers occurred when someone was caught fishing illegally in the marine park and subsequently fined and deprived of his vessel and equipment. Since the fishers associated all forms of conservation with the Watamu Park and the KWS, this did little good for the case of marine conservation and it may be difficult to involve them in any meaningful conservation activities in the future.

Conclusion

Local fishers in Uyombo believe that they are carrying most of the costs associated with marine conservation. They have lost large parts of their fishing grounds, had lower catches and are being blamed for the degradation of marine resources, while they depend on these very resources for their livelihoods. In the meantime, they perceive that foreigners benefit from the areas they have lost as fishing grounds without any government restrictions being imposed on these outsiders. This perceived favouring of tourists, Wapemba fishers and trawlers over local fishers gave the fishers – and especially those from Uyombo – little reason to trust the government. It has also made them suspicious of attempts at marine conservation. Kamukuru *et al.* (2004) point out that there is a difference between evaluating MPAs as a protective measure in general terms and what the local needs are in a fishing village that depends on the adjacent reefs for food and income. Fishers felt that their livelihoods have been put last, after the fish, the coral, foreigners and so on.

The long-term success of the park-related conservation of natural resources depends on the actual and perceived benefits of parks and reserves by local subsistence-level populations (Mangi & McClanahan 2003). The basic tenet of community-based resource management is that if fishers become aware of the (indirect) benefits of marine parks, they will change their attitudes towards the parks. King (2000) states that there is a need to understand people's socio-economic predicaments prior to developing strategies aimed at managing resources. But what if the relationship between the national parks and the local population has already deteriorated to such a level that even the benefits from tourism are unlikely to change their attitude towards conservation? What if fishers feel that they have already considered all the ways they can benefit from the park but are still struggling to make ends meet?

McClanahan *et al.* (2005) found that the perceptions of resource users improved with the age of the MPA but this was not the case in Uyombo. Fishers in Uyombo had reached such a level of frustration at the time of the study that they were holding meetings in 2000 at which "catching all the fish in the marine park", "stopping glass-bottom boats from operating in the marine parks, if no fisher's boat is allowed then no boats go at all" and "chasing any foreigners visiting Bandarini from the village with force" were some of the ideas being discussed. Fishers in Uyombo had a negative attitude towards the park, the KWS, the government and, to some extent, foreigners, and this should not be ignored.

The solution to the problem probably lies in where things went wrong in the first place, communication between local fishers, on the one hand, and the KWS and other environmental organizations, on the other (McClanahan *et al.* 2005). Firstly, communication should focus on the benefits the fishers could achieve from conservation measures in the short term. And those benefits should be put in place as soon as possible. The fishers had received many promises, many of which had not yet materialized. They had therefore adopted a see-then-believe attitude. Secondly, the fishers should be given a forum to present their views, ideas and problems and these should be recognized as important and taken into consideration. The experiences of older fishers in Uyombo have shown that their attitude is highly influenced by the way they are dealt with.

Certainly fishers were not waiting for outsiders to tell or show them imaginary benefits. Before stakeholders are willing to participate, they first have to perceive the benefits of MPAs (Malleret-King 2003). Glaesel (1997) mentions ways that might improve fishers' views of marine parks, such as seasonal park openings, compensation for fishers and, perhaps, park-related employment. Many fishers consider alternative employment to be a good way to relieve the pressure on marine resources although the reality is not as simple (see Hoorweg *et al.* 2009b). Various researchers have also suggested that smaller parks might improve fishers' attitudes towards marine parks (Glaesel 1997; McClanahan & Arthur 2001).

Fishers in Takaungu were more willing to participate in conservation efforts but were adamantly opposed to enforced measures and insisted on an equal partnership. The problem in Takaungu was that the fishers did not have any idea as to how to deal with declining fish stocks and the degradation of marine resources. They feared that when this issue was raised with the authorities, they were to face the same fate as their colleagues in Uyombo, namely the establishment of a marine park. The fishers in Takaungu are proud of their creek, their beaches and their reefs. They see them as better and more beautiful than those in Uyombo and feel they are lucky to have so far escaped the burden of having a marine park on their doorstep.

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Summary

This paper examines attitudes towards marine conservation among fishers from two villages in Kilifi District, Kenya. It focuses on how the views of fishers have contributed to their willingness to engage in marine conservation and considers how these attitudes developed. Uyombo is situated near the Watamu Marine National Park and Reserve and the fishers from this village have encountered formal methods of conservation in their daily fishing activities. There is no marine park in the vicinity of Takaungu but fishers in Takaungu have used informal methods of conservation in the past, unlike those employed in Uyombo. These traditional ways have, however, lost most of their effectiveness. Data were collected in 2000, 2001 and 2003 and the study shows how experiences have shaped fishers' attitudes towards conservation and their perceptions of how conservation efforts should, or should not, be carried out. The fishers from Uyombo, as a result of their experiences with the Marine National Park, have developed such a negative attitude towards marine conservation that it may be difficult to involve them in any meaningful activities in the future. The fishers in Takaungu, on the other hand, are willing to participate in marine conservation activities provided these do not endanger their livelihoods and are on an equal partnership basis.

6

The capacity of fisherfolk to implement beach management units in Diani-Chale

Stephen J. Oluoch[1], D. Obura[2] & A. Hussein[3]

Introduction

The Kenyan coastline stretching from the Somali border in the north to the Tanzanian border in the south, covering an approximate distance of about 600 km, is endowed with high marine biodiversity. The area is rich in marine resources that include coral reefs, fisheries, mangrove forests and seagrass among others. It also has sandy beaches that attract tourism related activities.

Many communities along the coastline depend on the marine and coastal environment and its associated resources for livelihood. Marine fishing, for example, directly and indirectly employs approximately 20,000 people (Tunje 2002) and provides monetary incomes to about 70% of the coastal communities in Kenya (Malleret & King 1996). High population increase, influx of immigrants, poverty, unemployment and lack of livelihood options has exerted increased pressure on coastal resources. The marine fishery in Kenya is considered to be heavily exploited and catches are declining over much of the coastal region (FAO 2001; McClanahan & Mangi 2001; Obura 2001).

The current management regime has not been effective in ensuring sustainable exploitation of the many resources, fisheries included. The continued use of destructive gears, illegal fishing activities, increased fishing effort, conflict

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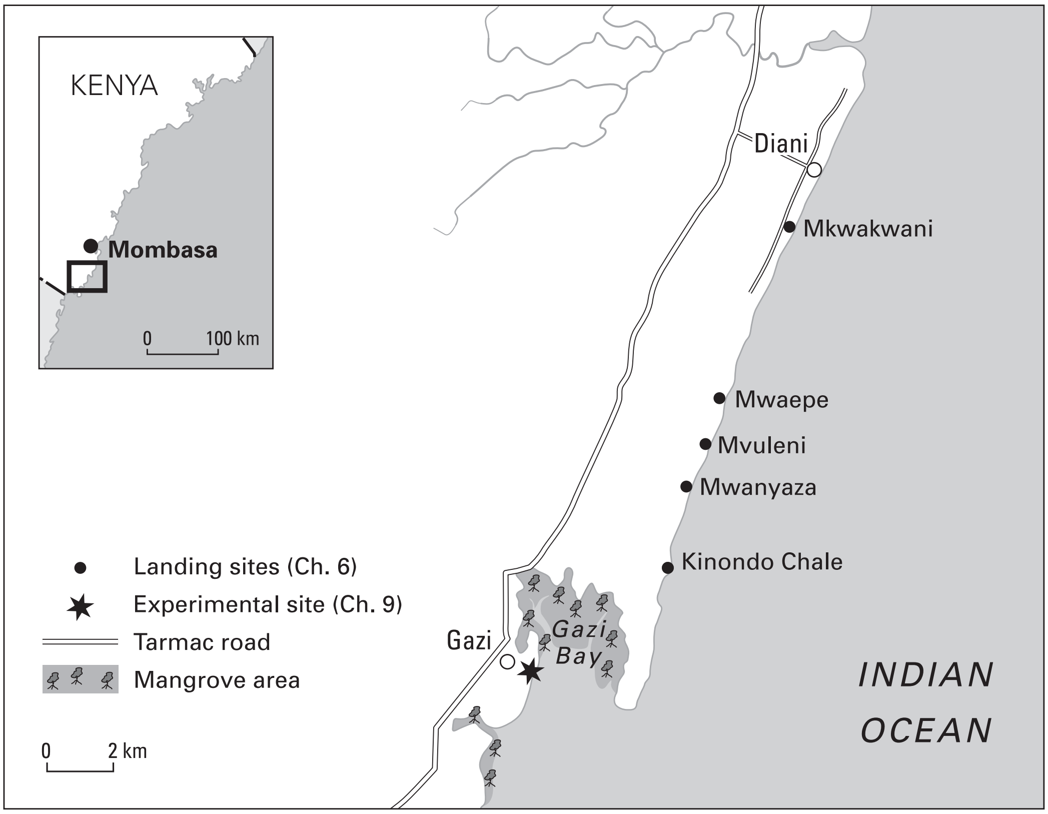


Map 6.1 Diani-Gazi area with location of landing sites (Chapter 6) and mangrove forest (Chapter 9).

among fishers and other resource users has made the management of fishery resources increasingly difficult. The bureaucratic procedures that the Kenya Government inherited at independence have until recently dominated the management of the natural resources including fisheries. Government policies, so far, have given marine fisheries little attention, and coupled with the inability of the state to enforce management regulations; this has further complicated their management. The coastal artisanal fisheries in Kenya are therefore at best poorly managed (Alidina 2004).

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

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

Study area

The study focuses on 6 landing sites in Kwale District – the Diani-Chale area between the Mwachema River and Gazi Bay in the south (Alidina 2004). Mkwakwani, Mwaepe, Mvuleni and Mwanyaza landing beaches are situated in Diani location, while Chale and Gazi are in Kinondo location (Map 6.1). A total of 8 fisher organizations were selected for the study (See legend with Table 6.2). Three officials and five group members from each organization were sampled and interviewed separately in order for the respondents to be able to speak confidentially and for the officials not to dominate responses to the questions.

Method

A structured questionnaire was developed and administered to the groups capturing the following key areas comprising the objectives for the group formation and the group administration, election and meeting patterns. Also covered were the membership fee structure, other charges and accountability; the funding of the fisher groups; the total annual income; as well as the expenditures of the fisher groups. Resource management and conservation were also included. Secondary data sources largely consisted of literature from CORDIO East Africa (OCA 2002), PACT-Kenya and the Fisheries Department, Mombasa. Data was augmented by personal interaction with the groups, observations on resource use practices during field visits and informal discussions with fishers.

Results

The main objective for the formation of fisher groups in Diani-Chale was the initiation of development projects to improve their living standard and achieve self-reliance (20 out of 61 respondents; Table 6.1). Advocacy for fisher rights, equipment/gear purchase and fishers welfare were mentioned as additional objectives (in order of importance). Revenue collection and conflict resolution were stated as objectives by a few members, but not by officials. Conversely, conservation/sanitation and marketing of fish was an important objective for group officials but not for the membership.

Table 6.1 Objectives for the group formation from the perspective of both the officials and members (N=61 respondents)

Ranking	Type Objective	No. of times mentioned by members	No. of times mentioned by officials	Total
1	Development / Self reliance	10	10	20
2	Advocacy / Fisher rights	3	9	12
3	Equipment purchase	5	6	11
4	Fishers welfare	5	5	10
5	Conservation / sanitation	0	3	3
6	Market fish	0	2	2
7	Revenue collection	2	0	2
8	Conflict resolution	1	0	1

Table 6.2 Membership fee structure, landing charges and accountability among groups in Diani-Chale

Group*	# Members	Member -ship fee (Ksh)	Monthly sub-scription (Ksh)	Total annual income (Ksh)	Cess collec-tion /kg	Financial reporting	
						Officials	Members
GG	60	500	50	30,000	ksh 2.00	Yes	No
GC	9	100	n/a	Not reported	n/a	Yes	No
CH	60	3,000	n/a	20,000	ksh 5.00	Yes	No
MZ	30	50	50	12,000	n/a	Yes	No
MV	33	200	30	60,000	1/3 part	Yes	No
MW	36	100	50	20,000	n/a	Yes	No
SC	100	200	n/a	Not reported	n/a	Yes	Yes
MK	50	n/a	50	12,000	n/a	Yes	Yes

* GG= Gazi Fishermen Self-Help Group
GC= Gazi Beach Management Committee
CH= Chale Fishermen Self-Help Group
MZ= Mwanyaza Fishermen Self-Help Group
MV= Mvuleni Fishermen Self-Help Group
MW= Mwaepe Fishermen Self-Help Group
SC= South Coast Fishermen Self-Help Group (Mwaepe)
MK= Mkwakwani Fishermen Self-Help Group

Elections among fisher groups in Diani-Chale

Elections were only held once when groups were initially formed but not thereafter. Some officials retained leadership for 3-7 years and there was frequently collusion of family members serving as officials. In addition, group by-laws were ignored by the leadership or members.

Membership fee structure, other levies and accountability

Fisher groups in Diani-Chale numbered from 9-100 members (Table 6.2). Membership fees varied from one group to another with Mwanyaza charging as little as Ksh.50 and in Chale as high as Ksh.300. In addition, other landing sites like Gazi and Chale obtained income from cess collection, a charge on the kilogram of fish traded, which varied from Ksh.2 per kg in Gazi to Ksh.5 per kg in Chale, or even one-third of the catch.[4]

Fisher groups in Diani-Chale lacked accountability and transparency in financial management. The members and officials gave conflicting responses concerning financial reporting to the groups. There were only two fisher groups (South Coast and Mwaepe) where both the officials and members were in agreement

4 In Mvuleni, members had access to a motorized boat provided by Eco-Ethics International Union Kenya Chapter. As a result, the catch was substantially higher and it was divided into three parts, one part for home consumption, the second was sold for funds for the maintenance of the boat, the third part was again sold and taken to the Bank to boost the group's kitty.

that the reports were ever given. Although the officials from all the groups claimed that they tabled their financial reports, members from six fisher groups denied having been given reports since the group's formation. In general, there was a high level of unaccountability and lack of transparency among the organizations studied.

Funding for the fisher groups

The main source of funding among the fisher groups were the membership (joining) fee and the monthly subscriptions though the amount varied from one group to another depending on how long the group had been in existence (Table 6.2). Cess collections on fishers catch (tax charged on weight of fish traded), donations from external organizations, contributions from beach operators, and charges for using the weighing balance were among other sources of income. Overall, internal sources of funding comprised 82% of all responses (18 out of 22) with external sources being mentioned in only 18% of the responses. Chale Fishermen Self-Help group started with a joining fee as low as 100 shillings but now charged up to 3,000 shillings while some groups adjusted their membership fees up to 400 shillings. Hiring out of fishing vessels, levies from foreign fishers and payment for vacating the previous landing site are among the least mentioned sources of income among the groups.

Total annual income for the fisher groups in Diani-Chale

The total annual income reported by the fisher self-help groups in Diani-Chale ranged from Ksh 10-60,000 per year. Mvuleni reported the highest level of income followed by Gazi at Ksh 30,000. Chale and Mwaepe reported income of up to Ksh 20,000, while such groups like Mkwakwani (Trade Winds) and Mwanyaza had slightly above Ksh 10,000 each. South Coast and Gazi Beach Management Committee did not report their earnings.

Expenditures among fisher groups

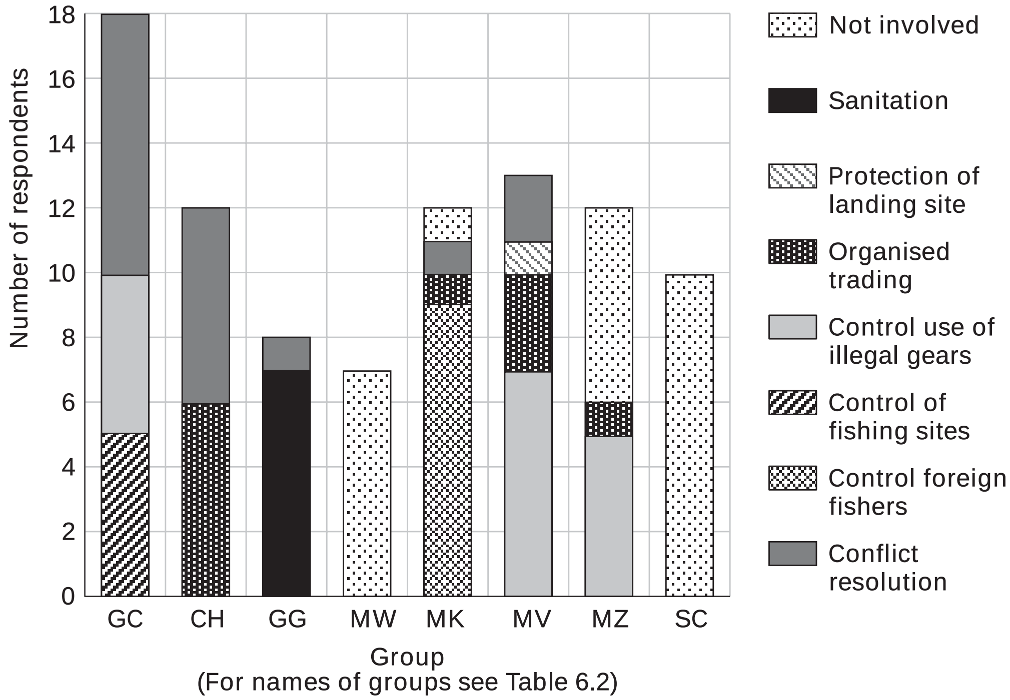
Fisher groups spent their income primarily on gear purchase and maintenance, administrative costs and fisher's welfare. Construction and maintenance of buildings at the landing sites, traditional sacrifices and fishing expenses were also mentioned. Some funds were reported by groups members to be spent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

Resource management and conservation among groups

The activities of fisher groups differed considerably from one landing site to another (Figure 6.1) General hygiene of the landing site was mentioned by all groups except Mwaepe, Mwanyaza, and South Coast Fisher Group. Chale, Mkwakwani, Mvuleni and Mwanyaza were involved in regulating the operations of traders at their landing sites by deciding which traders buy their catch. Fisher groups like Mvuleni, Mwanyaza and Gazi Management Committee had managed to control the use of illegal fishing gears.

Three fisher groups, Mwaepe, Mkwakwani and South Coast Fisher Group were not involved in an official role in the management and conservation of resources. Mkwakwani fisher group was the only group in Diani-Chale that had managed to control an invasion by external fishers using destructive beach seines into their fishing zones.

Figure 6.1 Number of times that key management issues were mentioned by respondents.



Discussion and conclusion

In Diani-Chale fishers formed groups to improve their standard of living, earnings and fishing capacity. Members focused on revenue collection to support their livelihoods, gear purchase and fishers welfare. Officials, on the other hand, tended to focus on resource management, conservation and marketing. However no single group has managed to initiate a development project to raise incomes on its own. Putting development as a priority by some groups could have been influenced by the perception that coming together as a group would attract donor funds. Such makeshift groups often disintegrate soon after when they realize no such funding is forthcoming (Mulwa 2002). For example, the South Coast Fishermen Self-Help group and Gazi Beach Management Committee existed on paper but during surveys were not found to be functional.

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

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

Importantly, the groups lacked transparency and accountability; few financial reports were tabled to the members, leading to continuous suspicion and conflict. Elections were held irregularly with some groups retaining the same leadership up to 7 years in office. This situation contributed to in-fighting and lack of trust among group members. Furthermore, some landing sites had several fisher groups established, some of which were confrontational and in conflict with each other, conflicts that obstructed open and accountable action.

The expectations and requirements of setting up and running an operational BMU are quite demanding. From our analysis most landing site institutions did not have the required level in terms of their human capacity, skills and experience to undertake tasks such as financial administration, conflict resolution and management of resources. It is therefore important that during establishment of BMUs the Fisheries Department should ensure there is adequate preparation, capacity building and technical support provided to fishers. Two of the most important areas were:

- Lack of trust and openness within and between groups was a significant barrier to transparent and accountable activities at the group and landing site (BMU) levels. For example, fisher groups did not conduct revolving fund schemes, as the lack of trust within groups undermined each individual's confidence that their savings would be safe and could be available when needed. Training and assistance in democratic and equitable organization of the groups is critically important to future BMU success.

- Although the groups had shown the ability to generate funds locally, the high dependence on membership fees and other forms of local funding both discouraged the involvement of many fishers in the groups and limited how much the groups could achieve. BMUs will need additional sources of funding to support their new responsibilities, including a regular financial disbursement from the central government in recognition of the responsibilities devolved from government.

Implementation of BMUs should be conducted on a case-by-case basis and should consider previous interventions at the landing sites and why they may have failed. Some landing sites had several fisher groups, some of which were in conflict with each other. Many such fisher groups had assumed responsibilities of managing landing site activities and had assumed some BMU functions.

Other local institutions may also be relevant, such as the Diani-Chale Management Trust (DCMT) which was established in 2001. The DCMT had been attempting to establish an over-arching fisheries/reef management role for some years, though with limited success. Establishing new BMUs in Diani-Chale must build on these groups and institutions and gain their support rather then isolating them and imposing new structures that may be rejected. Among other problems, these pre-existing groups might compete for revenue with the BMUs. Already in Diani-Chale, DCMT considers the BMUs in the area as competitors, a conflict that must be resolved to avoid further conflict and competition.

Finally, as with most other issues that relate to fisher landing sites in Kenya, land tenure is a major constraint. The majority of the designated landing sites are on private land, therefore their existence is threatened and future occupancy is not guaranteed. This has been an issue that has preoccupied fisher's minds and has discouraged management or development interventions in Diani-Chale – without security of land tenure no permanent structures can be built at the landing sites.

Acknowledgements

We would like to thank the fishers and fisher groups of Diani-Chale for the ten years of work we have conducted with them, and hope this analysis can contribute to improved management of their fisheries. Many thanks to CORDIO East Africa for providing the necessary funds and support to undertake this study.

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Summary

The management of the artisanal fisheries resources in Kenya has hitherto been the responsibility of the government with the stakeholders playing little or no part. At this moment in time, the Kenya Government is in the process of finalizing the Fisheries Regulations which, upon being gazetted, shall provide a legal framework for the operation of Beach Management Units (BMU); essentially local management units with which the Fisheries Department shall share fisheries management functions. However, a key consideration in such transfer of authority relates to the capacity and preparedness of the local management units concerned to handle the management responsibilities delegated to them. The structure and functions of fisher folk organizations present in Diani-Chale, Kenya, are examined to assess the capacity of fisher groups to adopt and undertake the functions detailed in the BMU regulations. There was a large gap between the expectations in the BMU Regulations and the capacity of the fisher organizations. The dominant issue was the lack of transparency in management of funds, conflicts between and among members of the groups and lack of tenure of the landing sites. A thorough analysis of the capacity of each group followed by training in BMU management and conflict resolution are recommended.

Mangroves

7

Structural inventory of mangrove forests in Ngomeni

G. Bundotich[1], M. Karachi[2], E. Fondo[3] & J.G. Kairo[4]

Introduction

Mangrove forests provide goods and services that are of economic, ecological and environmental value to man. In Kenya, mangroves have played an important role in the history of human activity along the coast as they were locally utilized and exported before the colonial period (Rawlins 1957; Roberts & Ruara 1967). In the 1950s export of mangrove poles, charcoal and bark to Yemen, Saudi Arabia, Kuwait and others, was ranked third among Kenya's export of forest products (Rawlins 1957). Between 1965 and 1982, an average of 33,288 mangrove scores were exported annually with a maximum of 1,969,500 scores in 1981 (Kairo 2001). However, mangrove forests have been overexploited and converted for other activities like aquaculture and salt harvesting as witnessed in Ngomeni, where the present study was based.

Salt harvesting has been practiced since the colonial period. Currently there are seven major salt companies operating in the Ngomeni area occupying 9,500 ha of intertidal area and producing an estimated 70,000 tons of salt annually (Abuodha & Kairo 2001). Most salt ponds have been constructed in the low intertidal areas close to mangroves. The ponds were originally designed to receive seawater during spring tides. However, with increasing demand for salt

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as well as poor surveillance mechanisms, some companies in Ngomeni have encroached adjacent healthy mangrove stands and expanded their salt works. Field observations indicate continued mangrove cutting at Marereni, Fundisa Kibaoni and Gongoni for the expansion of salt pans. It is estimated that an additional 500 ha of mangroves have been reclaimed in the area for salt pan expansion.

Shrimp farming was established in Ngomeni in the 1980's and destroyed more than 100 hectares of mangrove area (Abuodha & Kairo 2001). This aquaculture enterprise, however, did not continue; mostly due to changes in soil chemistry as well as limited capacity to address the problem. Shrimp aquaculture all over the world has been blamed for extensive destruction of mangroves (Spalding *et al.* 1997; Valiela *et al.* 2001). For instance, in South East Asia alone, 1.2 million hectares of mangroves had been converted to aquaculture ponds by 1991 (Primavera 1995). Using the ecological foot print concept (Wackernagel & Rees 1996), it has been possible to quantify the ecosystem support area that is required to support shrimp farming in mangroves. For it to be sustainable, a semi-intensive shrimp farm requires a mangrove area that is 35-190 times larger than the surface area of the pond (Kautsky *et al.* 1997). If similar calculations are applied to the shrimp aquaculture in Ngomeni, about 10,000 hectares of mangrove area would be required. This is more than the total area of mangroves in the whole of Ngomeni.

The present study that was part of a larger project on *'Effects of Mangrove Deforestation on Mangrove Mud Crab Fishery'* aimed at making an inventory of the mangrove wood resources within and adjacent to Ngomeni and assessing the condition of the principle species. Specific objectives of the project were to estimate the standing stock of mangrove wood products, to provide information on the size/class distribution of mangrove species, and to conduct linear regeneration sampling for the principle mangrove species.

Study site

Ngomeni is situated in Malindi district about 150 km north of Mombasa (Map A, p.2). The project area contains a combination of forest types including riverine, fringing and creek mangroves (Lugo & Snedaker 1974). For the sake of this study, mangroves in Ngomeni have been divided into two broad areas. Ngomeni-1 forests encompasses all the mangroves near Ngomeni village on the pensinsula. Ngomeni-2 mangroves combine Gongoni, Kibaoni and Marereni areas on the mainland. The two forests are separated by a large creek. In Ngomeni-1 mangroves occur in discontinuous patches but the mangrove forest stands are separated by several small creeks in Ngomeni-2.

Eight species of mangroves are known to exist in Ngomeni, the dominant being *Rhizophora mucronata* and *Avicennia marina* (Ferguson 1993). Other aquatic flora in the project area include seagrasses, algae and fungi which play an important role together with bacteria in the rapid breakdown of mangrove leaf litter. Open sandy areas common in the area are covered by herbs, *Sesuvium portulacastrum* and *Salicornia* species; grasses and sedges. Terrestrial trees which occur in Ngomeni include neem, palms and pines.

Mangroves in Ngomeni suffer from over-exploitation of wood products and conversion of mangrove areas for salt works and aquaculture (Abuodha & Kairo 2001). Most salt pans are located in Ngomeni-1 and Ngomeni-2 of the pilot area. Currently there is no active shrimp farming going on in the area although abandoned ponds occupying close to 100 ha are found in Ngomeni-1.

Method

Vegetation data was generated using the stratified sampling technique. Medium scale panchromatic aerial photographs (1:25,000) were used to mark line transects perpendicular to the water line. Vegetation data was collected inside 10x10 m^2 quadrats for adults and 5x5 m^2 for juveniles laid along the transects. A total of 24 quadrats were sampled in Ngomeni-2 and 20 in Ngomeni-1 in 8 transects.

Measurements included tree height (m), stem diameter (cm), measured at 1.30 cm above ground (D130), and canopy cover (%). For *Rhizophora* trees, stem diameter was taken 30 cm above the highest prop root. From these data were derived basal area (m^2/ha), stand density (stems/ha) and frequency. Following the same procedures, the ecological importance of each species was calculated by summing its relative density, relative frequency and relative dominance (Cintron & Schaeffer-Novelli 1984). The complexity index of the study sites was obtained as the product of number of species, basal area (m^2/0.1 ha), maximum tree height (m) and number of stems/0.1 ha, times 10^{-3} in a 0.1 ha plot (Holdridge *et al.* 1971). Tree height was measured in meters using Suuto clinometer, while DBH was measured in centimetres using a forest calliper.

Information on the composition and distribution pattern of natural regeneration was obtained using Linear Regeneration Sampling (Sukardjo 1987). Inside 5x5 subplots (of the main quadrats), occurrence of juveniles of different species was recorded according to their heights. Seedlings less than 40 cm in height were classified as regeneration class I (RCI). Saplings of between 40 and 150 cm height were classified as class II (RCII), while class III (RCIII) was for all small trees with heights greater than 1.5 m but less than 3.0 m.

Table 7.1 Structural characteristics of Ngomeni mangroves

Site	Species	Density (Stems/ha)	Volume (m^3/ha)	Mean height (s.d.) (m)	Basal area (m^2/ha)	Relative values (%)			Importance value	Complexity index
						Frequency	Dominance	Density		
Ngomeni 1	Rm	763	7.80	8.67 (11.63)	11.82	30.96	53.85	45.18	129.99	20.39
	Am	500	38.23	6.71 (3.24)	6.32	23.82	28.79	29.60	82.21	
	Ct	205	6.88	4.20 (1.18)	1.25	19.05	5.69	12.15	36.90	
	Bg	137	4.23	6.14 (3.88)	1.22	16.67	5.56	8.10	30.33	
	Sa	84	98.06	6.89 (2.47)	1.34	9.53	6.10	4.99	20.62	
	Total	1688	155.20		21.95					
Ngomeni 2	Rm	799	21.49	8.11 (4.39)	13.64	36.39	48.56	2.05	87.00	32.31
	Am	620	51.11	6.41 (3.59)	7.47	25.47	26.59	1.12	53.19	
	Ct	807	105.67	4.02 (2.00)	4.68	29.11	16.66	0.70	46.48	
	Bg	133	17.90	10.01 (5.06)	2.22	7.28	7.90	0.33	15.52	
	Xg	8	0.28	5.00 (0.00)	0.08	1.82	0.28	0.01	2.12	
	Total	2367	196.45		28.00					

Legend: Rm: *Rhizophora mucronata*; Am: *Avicennia marina*; Ct: *Ceriops tagal*; Bg: *Bruguiera gymnorrhiza*; Sa: *Sonneratia alba*; Xg: *Xylocarpus granatum*

The analysis of spatial pattern of trees and juveniles in the field was carried out inside 10x10 m^2 plots along transects. The measure of dispersion used was Morisita's (1959) index, the application of which is described in Greig-Smith (1983). The standing volume was calculated using the relation[5]:

$$V = (\pi d^2/4) \times h \times f$$

Data analysis

Data collected was analyzed using the STATISTICA program. Stand table data was presented graphically as frequency diagrams. The stand densities were harmonized using De Liocourt's Model (Clutter *et al.* 1983), and fitting a negative exponential curve of the form[6]:

$$y = ke^{-ax}$$

Results

Floristic composition

The structural characteristics of mangroves in Ngomeni are given in Table 7.1. Five species of mangrove were encountered in the present study. Based on the importance value index, *R. mucronata* was the principal species in Ngomeni, followed by *A. marina*. Ngomeni-2 forest was structurally more complex (C.I. 32.31) than Ngomeni-1 (C.I. 20.39) signifying the trees in Ngomeni-2 had higher stand densities, basal area and height among other structural attributes.

Zonation of mangroves in Ngomeni

The horizontal distribution of mangroves in Ngomeni is illustrated in Figure 7.1. The seaward margin is occupied by *Sonneratia alba* followed by *R. mucronata* then *B. gymnorrhiza*. *Ceriops tagal* occupied the middle zones while *A. marina* displayed a more complex zonation occurring both on the landward and seaward sides. Tall *R. mucronata* and *A. marina* were the most seaward in some areas. *Xylocarpus granatum* was also common near the creeks in Ngomeni-2. The tallest trees were observed 40 to 60 m from the seashore in both Ngomeni-1 and Ngomeni-2. The density of *R. mucronata*'s juveniles was highest in the mid zones of the forests. *A. marina*'s juvenile distributions resembled their adults in Ngomeni-2 but were only present near the sea in Ngomeni-1. Adult trees were evenly distributed ($I_o<1$) in the two forests while the distribution of juveniles ranged from even ($I_o<1$), random ($I_o=1$) to clumped ($I_o>1$) per species. *R. mucronata* juveniles showed a near random distribution in the mid-zones of Ngomeni-2 forest.

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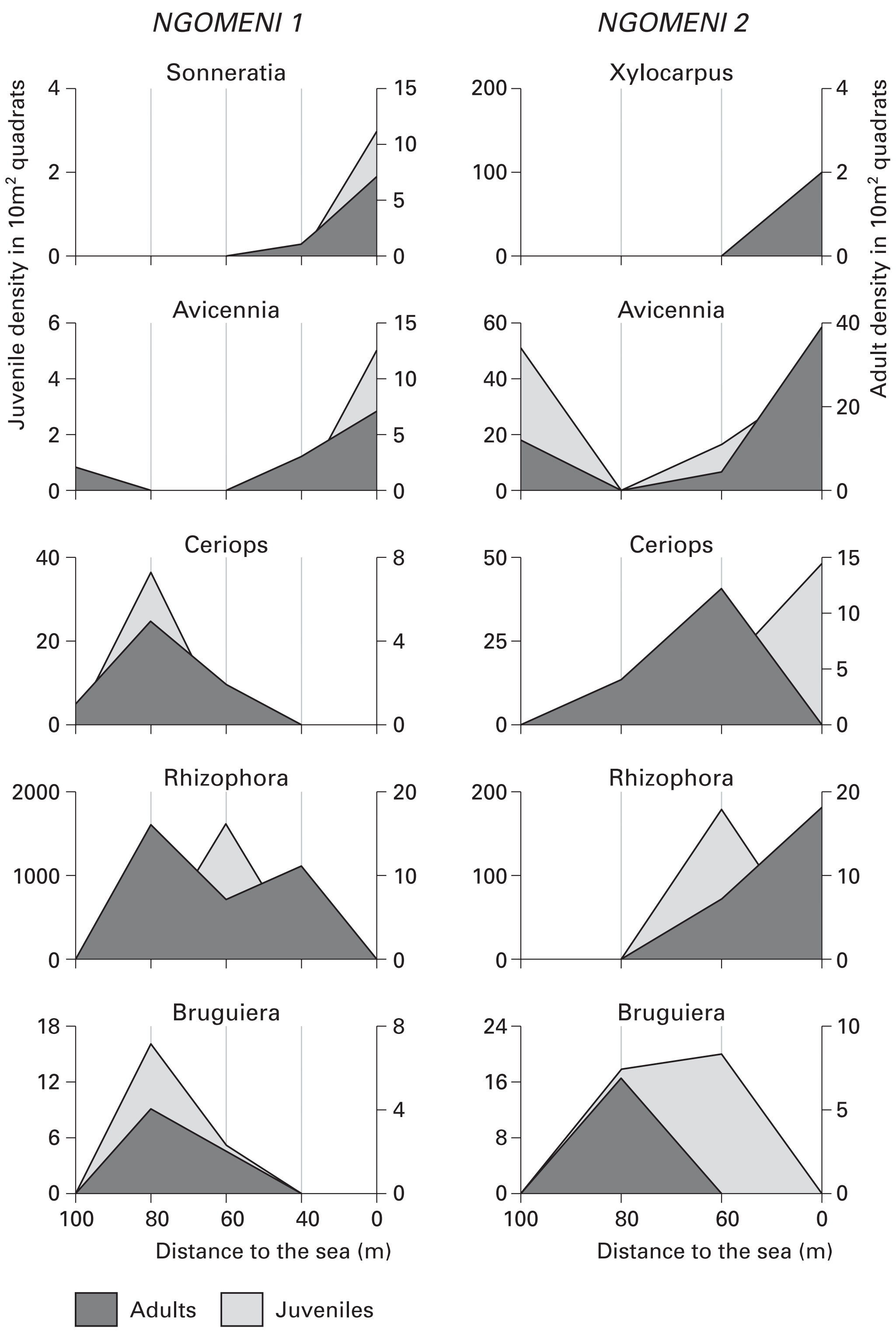
5 V=volume (m^3), d=DBH (cm), h=tree height (m) and f=form factor. In this study we used a general form factor of 0.7 that was initially estimated for Lamu mangroves by Roberts & Ruara (1967).

6 y=number of trees in diameter class x; e=base of natural log (2.718); a and k are constants.

Figure 7.1 Distribution of mangroves in Ngomeni forests



Stocking rates and volume

The stand density of mangroves in Ngomeni-1 was 1688 stems ha^{-1} of which 45.17% was *R. mucronata* (Table 7.1). In Ngomeni-2, the stand density was 2367 stems ha^{-1} and *C. tagal* contributed 34.09 % of the total. Ngomeni-1 recorded wood volume of 155.2 m^3 ha^{-1} dominated by *S. alba* (98.06 m^3 $ha^{-1)}$. The stand volume in Ngomeni-2 was 196.45m^3 ha^{-1} with *C. tagal* having the highest volume (105.67 m^3 ha^{-1}).

The density of *mazio*-sized poles (5-9.0 cm diameter) was 695 stems ha^{-1} (41.17%) and 1310 stems ha^{-1} (55.34%) in Ngomeni-1 and Ngomeni-2 respectively (Table 7.2). *Boriti* (9.1-13 cm diameter), which are the most preferred in the Kenyan market, had the third largest densities of 410 and 445 stems ha^{-1} in Ngomeni-1 and 2 respectively. The least abundant size classes were *banaa* (>20 cm DBH) with 131 stems ha^{-1} in Ngomeni-1 and 218 stems ha^{-1} in Ngomeni-2.

There was significant difference in stem diameters among Ngomeni-1 and Ngomeni-2 mangroves ($F_{(df\ 890)}$=0.7; α=0.05; p=0.001) but heights did not differ significantly ($F_{(df\ 890)}$=1.01; α=0.05; p=0.442) (Table 7.3). There were more straight poles (Quality 1) in Ngomeni-2 (166 stems/ha) than in Ngomeni-1 (138 stems/ha) most of them being *R. mucronata*. However, there was no significant difference ($F_{(df\ 890)}$=0.32; α=0.05; p=0.24) in the overall wood quality in the two forests.

Forest regeneration

The juvenile density in Ngomeni-1 (78,805 juveniles/ha) was not significantly different (p<0.05) from that in Ngomeni-2 (65,591 juveniles/ha) - Table 7.4. High concentration of RC1 seedlings in Ngomeni forests signifies a secondary forest under rapid recruitment. Most of the juveniles were *R. mucronata*. The regenerative ratio, RCI: RCII: RCIII, was 10:17:36 in Ngomeni-1 and 10:16:19 in Ngomeni-2.

Table 7.2 Stand table of mangrove forests in Ngomeni (stems/ha - %)

Site	Utilization classes (butt diameter-cm)				
	5.1-9.0 cm (Mazio)	9.1-13.0 (Boriti)	13.1-20.0 (Nguzo)	20.1-35.0 (Banaa 1)	>35.1cm (Banaa 2)
Ngomeni 1	695 (41.2)	410 (24.3)	453 (26.8)	131 (7.8)	0 (0.0)
Ngomeni 2	1310 (55.3)	445 (18.8)	394 (16.6)	210 (8.9)	8 (0.3)

Table 7.3 Merchantable wood in Ngomeni mangrove forests (Mean - s.d.)

Site	Species*	DBH (cm)	Height (m)	Quality 1 wood density (stems/ha)
Ngomeni 1	Rm	14.13 (6.61)	8.69 (5.06)	95
	Am	11.75 (4.31)	5.00 (2.82)	17
	Ct	7.40 (0.17)	4.66 (1.15)	16
	Bg	18.10 (0)	16.00 (0)	5
	SA	17.90 (0)	8.00 (0)	5
	Total			138
Ngomeni 2	Rm	16.4 (6.90)	12.31 (2.08)	75
	Ct	8.62 (2.74)	3.93 (1.23)	62
	Am	13.82 (3.12)	8.5 (3.1)	17
	Bg	25.03 (1.60)	17 (1.0)	12
	Xg			0
	Total			166

* Legend: See Table 7.1

Table 7.4 Juvenile density of mangroves in Ngomeni

Site	Species*	RCI **	RCII **	RCIII **	Total/ha	%
Ngomeni 1	Rm	19357	15159	10446	44962	57.1
	Ct	19883	7133	1157	28173	35.8
	Am	2504	968	279	3750	4.8
	Bg	905	358	526	1788	2.3
	SA	63	26	42	132	0.2
	Total	42711	23644	12450	78805	
	(%)	(54.2)	(30.0)	(15.8)		
Ngomeni 2	Rm	13878	11253	7213	32344	49.3
	Ct	7505	4909	5974	18387	28.0
	Bg	4318	1918	1656	7892	12.1
	Am	4867	890	1211	6968	10.6
	Total	30568	18970	16053	65591	
	(%)	(46.6)	(28.9)	(24.5)		

* Legend: See Table 7.1
** RCI = 0-40 cm
RCII = 40.1-150 cm
RCIII = 150.1-300 cm

Discussion and conclusion

Ngomeni mangroves have visibly been subjected to widespread overexploitation as well as conversion for salt development and shrimp aquaculture. Increasing costs of pumping water into the salt pans has led to further encroachment into the mangrove forests. The effect of human pressure is indicated by the low basal area, tree height and stem density. Basal area (BA) is a good measure of the overall stand development and is reported to be low in degraded forests (Kairo *et al.* 2002). The stem densities and basal areas in Ngomeni-1 and Ngomeni-2 (1688 stems ha^{-1}; 21.95 m^2 ha^{-1}) and (2367 stems ha^{-1}; 28 m^2 ha^{-1}) although low by standards of a healthy forest were high compared to mangroves of Tudor Creek (1145 stems ha^{-1}; 16.16 m^2 ha^{-1}) (Omar *et al.* 2008) and Mida Creek (1391 stems ha^{-1}; 4.93 m^2 ha^{-1}) (Kairo *et al.* 2002). This showed that mangrove forest degradation increased from the northern to the southern parts of the Kenyan coast and can be attributed to increased cutting pressure towards areas of higher population density. Ngomeni's stem density was comparable to Gazi Bay (1747 stems ha^{-1}) where high anthropogenic pressure has also been reported (Dahdouh-Guebas *et al.* 2004). Higher basal area and stem density (2343 and 1980 stems/ha; BA 35.51) occur in Kiunga, Lamu (Kairo 2001). Mangrove forests in the northern part of Tana River are structurally more complex than south of the Tana where Ngomeni is located (Kairo 2001).

The average wood volume in Ngomeni (175.8 m^3 ha^{-1}) was higher than in Kiunga (145.88 m^3 ha^{-1}) (Kairo 2001). This indicates that Ngomeni mangroves are one of the most productive in Kenya possibly due to high influence of freshwater from the Tana River (Kairo 2001).

The overall development of a forest stand can be assessed by its Complexity Index (CI), which is a factor that takes into account basal area, stem density, tree heights and number of species. Ngomeni mangroves with a CI of 29.84 are structurally more developed than the southern mangroves at Gazi Bay (25.16) (Bosire *et al.* 2003) but lower than the northern forests at Kiunga (43.97). Apart from deforestation, Ngomeni mangroves are subjected to other stresses, both human and natural ones. Ferguson (1993) attributed the death of mangroves adjacent to the salt ponds to hypersalinity created by evaporating ponds. Extensive sedimentation which is responsible for the death of fringing mangroves in Ngomeni was reported to be due to the prevailing winds (Ferguson 1993; Abuodha & Kairo 2001).

The mangrove distribution in Ngomeni-1 and Ngomeni-2 is typical of mangrove zonation in many parts of Kenya; such as, in Gazi Bay (Kairo 1995), Mida Creek (Kairo *et al.* 2002) and Kiunga (Kairo 2001). The presence of juveniles in zones occupied by adults of different species is attributed to the creation of habitats suitable for colonization by a more competitive species. This might possibly lead to changes in distribution patterns and forest composition in future forests. Since Ngomeni mangrove forests are of uneven age, it was expected that the ratio between the numbers of trees in successive diameter classes will be constant. However, this was not the case possibly due to selective cutting.

The presence of pioneer abundant parent trees in the Ngomeni mangrove forest shows the potential for natural regeneration. Studies from Matang forests in Malaysia rated juvenile density of 5,000 to 10,000 as sufficient for regeneration (UNDP/UNESCO 1991). Therefore, Ngomeni forests with 72,265 juveniles ha^{-1} respectively can be said to have high regeneration potential and do not require restocking. However, there is a need to control further expansion of salt works into mangroves as well as restock recently cleared sites.

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Summary

The structure of mangrove forests in Ngomeni was studied using the quadrat method and aerial photographs. Belt transects perpendicular to the water line were laid from Ngomeni village (Ngomeni-1) to Marereni (Ngomeni-2). A total of 8 transects comprising of 44 quadrats were studied. Six mangrove species were encountered in the study area. Based on the importance value index, *Rhizophora mucronata* and *Avicennia marina* were found to be the most dominant species. The stand densities were 2367 stems ha^{-1} and 1688 stems ha^{-1} in Ngomeni-2 and Ngomeni-1 respectively. Overall, mangroves in Ngomeni-2 had a higher complexity index and stand volume compared to the Ngomeni-1 forest signifying less human pressure and environmental stresses in Ngomeni-2 forests. There were more young than old trees in both forests. This is expected for non-even aged forests. Based on Morisita's dispersion index, adult trees were evenly distributed ($I_o<1$) but juveniles dispersion ranged from even ($I_o<1$), random ($I_o=1$) to clumped ($I_o>1$) according to species. Although the pilot area is suitable for mangrove development, compared to other mangrove sites in Kenya the standing volume in Ngomeni is relatively low. Reasons for this could be overexploitation of wood products as well as conversion of mangrove areas for salt production and aquaculture. The degradation has amplified sediment accretion on the seaward side causing burial of mangrove roots and eventual death of the fringing forest. There is obviously a need to reforest degraded areas and control further encroachment of salt pans into the mangrove forests in Ngomeni.

8

Seasonal dynamics of soil carbon dioxide flux in a restored young mangrove plantation at Gazi Bay

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Introduction

Soil carbon dioxide (CO_2) flux or soil respiration includes respiration from roots (autotrophic respiration) and soil micro-organisms (heterotrophic respiration) and is a major component of the forest carbon cycle (Law *et al.* 2002; Tüfekçioğlu & Küçük 2004). Measurements of soil CO_2 flux have a great potential as an indicator of ecosystem processes including metabolic activity in soil, persistence and decomposition of plant residue in soil and conversion of soil organic carbon to atmospheric CO_2 (Rochette *et al.* 1997; Ryan & Law 2005). Integrated measurements can be used to estimate below-ground carbon allocation (Giardina & Ryan 2002) and can be tied with the estimates of canopy photosynthesis to enhance our understanding of carbon allocation (Ryan & Law 2005). Frequent measurements of soil CO_2 flux can help uncover environmental controls over decomposition (Irvine & Law 2002) and aid with the understanding of the links between above and below-ground processes.

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Worldwide, forests are estimated to release 80 Pg (Petagrams) of CO_2 into the atmosphere annually nearly balancing the 90 Pg of CO_2 that forests remove from the atmosphere and higher than the total annual release of CO_2 from anthropogenic sources which is estimated to be 4 Pg per annum (Schimel *et al.* 2000). Given that 60–80% of all CO_2 released by forests emanates from the soil (Davidson *et al.* 1998), it is clear that assessing the global CO_2 cycle demands an understanding of how forest soil respiration is regulated not only at individual sites but over broad temporal scales (Ryan & Law 2005).

The rate of forest soil CO_2 flux is influenced by several environmental factors inherent to a given site and may also be influenced by land use practices (Kowalenko *et al.* 1978). To a large extent, temporal and spatial variation in soil CO_2 and its components is driven by differences in soil temperature and moisture (Singh & Gupta 1977). Warmer temperatures stimulate microbial activity, resulting in greater CO_2 emission from decomposition (Silvolva *et al.* 1996). Rochette *et al.* (1997) reported that CO_2 flux in moist soils is 2 to 3 times greater than in drier soils.

Estimates of soil CO_2 flux have been made in a variety of terrestrial ecosystems. Mangroves, found in intertidal areas are relatively less studied ecosystems especially with regard to emission of greenhouse gases. Being coastal wetlands they are often considered as insignificant sources of CO_2 to the atmosphere (Mukhopadhyay *et al.* 2002). Ong (1993) estimated the rate of carbon sequestered in mangrove mud to be around 1.5 t C ha^{-1} yr^{-1}. Given the global mangrove cover of 170,000 km^2 the total amount of carbon sequestered by mangroves is approximately 25.5 $x10^6$ t C yr^{-1}.

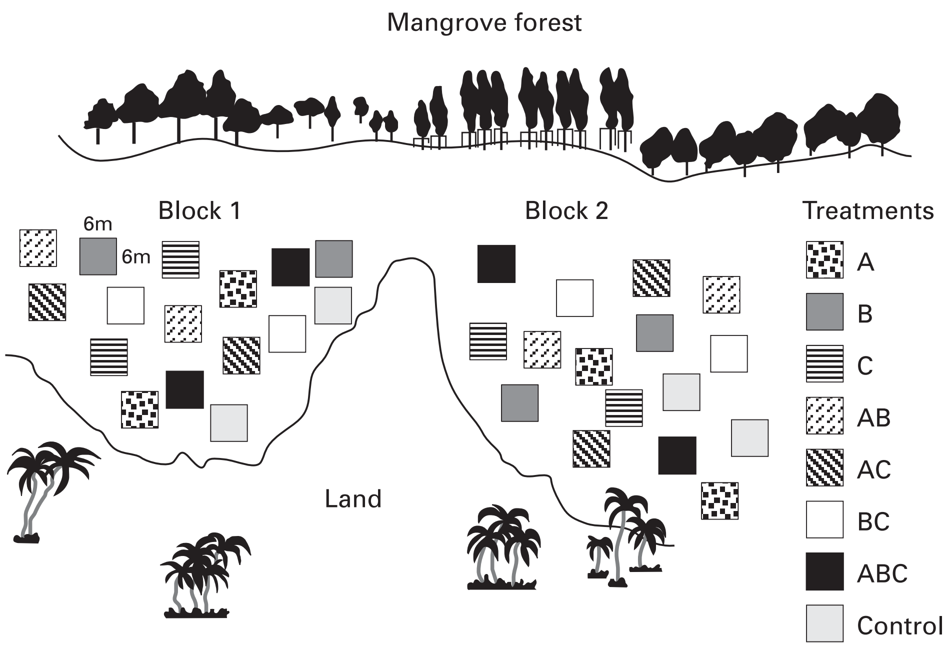
In July 2004, a 5-year large-scale experiment was initiated in a clear-felled mangrove area at Gazi Bay, 55 km south of Mombasa. The experiment aimed to measure how the diversity of mangrove species in replanted stands affects a range of ecosystem functions including soil CO_2 flux. This paper presents the preliminary findings of soil CO_2 flux measurements carried out at the established plots at the site. The objectives of this study were to compare seasonal variation in rates of CO_2 flux in two blocks of young replanted mangrove trees and to identify the underlying environmental variables most likely causing any variations at the two blocks and among seasons within the sites. We hypothesized that soil CO_2 flux follows a seasonal pattern and is strongly influenced by soil temperature and moisture content.

Study site

The study was conducted at Gazi Bay, Kwale District, 55 km south of Mombasa (Map A, p.2). The bay has a surface area of 18 km^2, and is sheltered from strong sea waves by the presence of Chale Peninsula to the east and a fringing coral reef to the south. On the landward side, Gazi Bay is bordered by 6.2 km^2 of mangrove forests. These forests are heavily used by local people as a fishing ground and a source of wood for building and fuel. As in other areas of the Kenyan coast, mangrove deforestation is widespread. The mangrove forests of Gazi have been exploited for many years especially for wood that was used for industrial fuel (in the calcium and brick industries in the 1970s) and building poles (Kairo 1995; Dahdouh-Guebas *et al.* 2000). The clear-felling due to the industrial extraction left some areas along the coastline completely denuded.

The climate in Gazi is typical of the Kenyan coast and principally influenced by monsoon winds. Total annual precipitation varies between 1,000 and 1,600 mm showing a bimodal pattern of distribution. The long rains fall from April to August under the influence of the south-east monsoon winds, while the short rains fall between October and November under the influence of the north-east monsoon winds. Air temperature in Gazi Bay varies between 24^0 C and 39^0 C (data recorded by the Meteorological Department). Relative humidity is about 95% due to the close proximity to the sea.

Figure 8.1 Schematic representation of the distribution of the treatment plots at the experimental site in Gazi Bay.



Method

The study site is divided into two sections (blocks), separated by a narrow incursion of the terrestrial zone (a grass tongue, ~15m wide). Block 1 contains sixteen plots while block 2 has twenty-two plots all measuring 6m by 6m, and is situated on a previously deforested area (Figure 8.1). Each plot contains a differing combination of three types of mangrove species, *Avicennia marina*, *Bruguiera gymnorrhiza* and *Ceriops tagal* – A, B and C respectively. Within each plot 121 trees were planted. In general the distribution of the plots within block 1 (mean height above chart datum = 3.34 m) was higher, on the mangrove shoreline, than in block 2 (mean height above chart datum = 3.24 m). Block 2 also received the tide earlier than block 1 since this block is slightly lower on the shore.

Measurement of CO_2 emissions

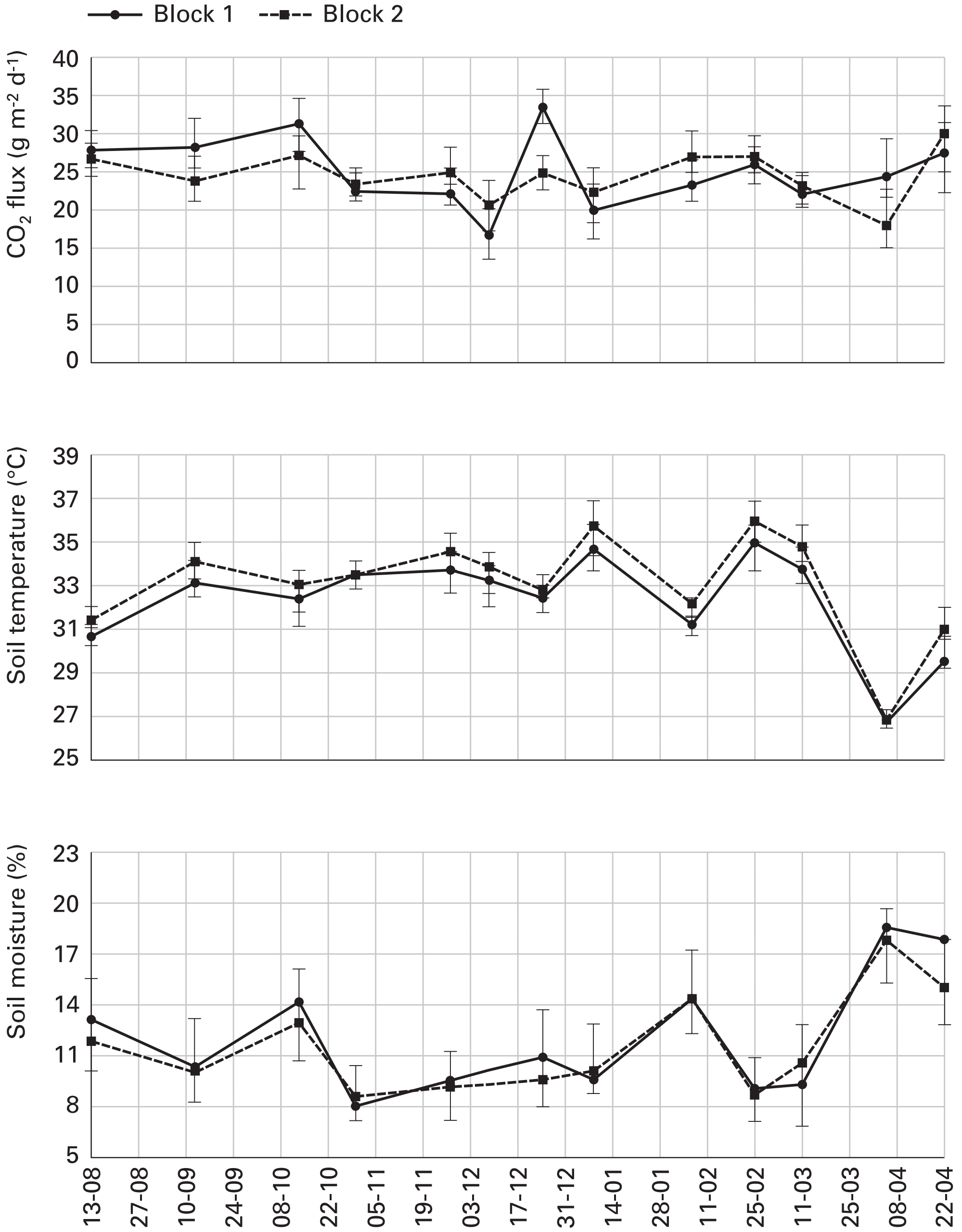
Soil CO_2 flux rates were measured every fortnight immediately after the spring tide and at the middle of neap at two random locations within each plot from October 2004 to January 2006 using the soda-lime method (Edwards 1982; Raich *et al.* 1990). The soda-lime method may underestimate actual soil CO_2 flux rates at high flux rates (Ewel *et al.* 1987). However the method does distinguish between higher and lower flux rates and therefore, it is an appropriate method for comparing sites.

Plastic buckets (14.8 cm high and 20 cm in diameter) were inserted 2 cm into the sediment in the young mangrove plots. Glass jars with a surface area containing approximately 30 g of soda-lime (pre-dried 48 hrs at 80^0C) were placed at the centre of each of the buckets for a period of 24 hours with the tops of the buckets covered. Jars were subsequently sealed and taken to the laboratory and oven-dried for 48 hrs at 80^0C and their dry weights recorded. Blanks were used to account for CO_2 absorption during drying and handling (Raich *et al.* 1990). The soda-lime weight gain was multiplied by 1.69 to account for water loss (Grogan 1998). The difference in dry weight before and after the sampling represents the carbon dioxide absorbed.

Soil moisture and temperature

Soil temperature and moisture at a depth of 5 cm was measured within each chamber immediately after soda lime jars had been collected using a single temperature logger buried at a depth of 5 cm in the centre of each chamber (Hobo temperature logger, Onset Computer Corporation, Warner, NH). Each time soil respiration measurements were made; plot-level soil moisture was determined by taking soil samples at 0-4 cm depth and drying them at 80^0C for 24 hours.

Figure 8.2 Seasonal variations in pooled CO_2 fluxes, soil temperature and soil moisture (mean-s.d.) between 13-08-2005 and 22-04-2006



Statistical analysis

Differences between the parameters were tested using General Linear Models (GLMs) ANOVA after checking for normality and homogeneity of variance. Where the above criteria were not met, data was log transformed. Linear regressions and Pearson-product moment correlation was used to explore the relation between CO_2 fluxes and abiotic factors (temperature and soil moisture). Linear regression analysis was used to estimate seasonality in flux rates by regressing concentrations with time. A significance level of p=0.05 was accepted.

Results

Seasonal trend of soil CO_2 flux

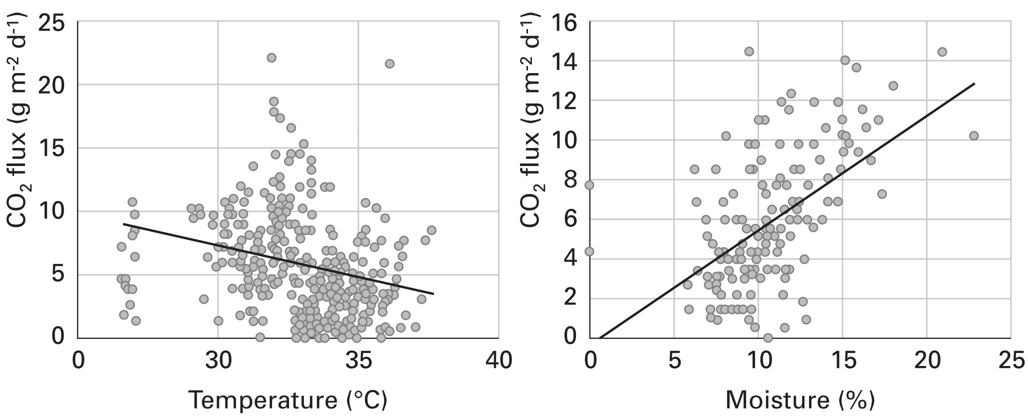
There was significant difference in soil CO_2 flux among sampling dates (F test, df=12, p=0.005), however, there was no clear seasonal pattern in CO_2 flux (Figure 8.2). Mean daily CO_2 flux ranged from 16.86 to 33.23 g m^{-2} d^{-1}. The highest mean rates were observed in December, while the lowest rates were observed in April. However there was no significant effect between block 1 and 2 due to the different treatments (F test, df=1, p=0.615).

Seasonal variation in soil moisture and temperature

Mean monthly soil temperature ranged between a high of 36.1^{0}C in February 2006 in block 2 to a low of 27^{0}C in both blocks in April (Figure 8.2). Mean monthly soil moisture varied between 18.1% in April 2006 in block 1 and 8.6% in block 2 in October 2005 (Figure 8.2).

Both soil temperature and soil moisture were treated as covariates in the general linear model (GLM) analysis model and both had an effect on CO_2 flux

Figure 8.3 Scattergrams of observed values of CO_2 flux and soil temperature and CO_2 flux and soil moisture



(Figure 8.3). When data from the blocks were pooled and correlated with soil temperature and CO_2 flux, a negative correlation was found between the two parameters (r^2=0.28, p=0.35). However this correlation was not significant (F test, df=1, p=0.96). There was a weak positive correlation between soil moisture and soil CO_2 flux (r^2=0.07, p=0.03).

Discussion

The CO_2 fluxes observed were consistent throughout the study period with periodic minimum shifts which appear to be controlled by the soil moisture variation. The soil moisture pattern is consistent with the local climatic variation. Gazi Bay has two rainfall peaks occurring in April and November. The drought period occurs between January and late March. Our data shows that a combination of varying soil temperature and soil moisture reduced soil CO_2 fluxes during this period. Martin & Bolstad (2005) in a study of temperate forest soils have attributed variations in soil respiration between years to soil moisture and the influence of drought. Both soil saturation and drought suppress soil CO_2 flux and weaken flux response to changes in soil temperature.

The mean soil CO_2 flux values recorded in this study at both blocks are higher than the ranges reported by Tüfekçioğlu & Küçük (2004) but compares favourably with the findings by Chmura *et al.* (2003). The significant variation in sampling dates could have been driven by variation in soil moisture and soil temperature. These two factors are considered the most influential environmental factors affecting soil CO_2 flux (Schlesinger 1977; Singh & Gupta 1977; Raich & Schlesinger 1992) and interact to influence the productivity of ecosystems and the decomposition rate of soil organic matter, thereby driving seasonal variation in soil CO_2 flux (Wiseman & Seiler 2004). In this study, seasonal variations in the CO_2 emission were moderately influenced by the moisture levels in the soils. The increasing soil moisture levels could have enhanced biological activity by the autotrophic and heterotrophic organisms. Birch (1958) reported that in drying and subsequently rewetting of soil by precipitation, there is a sudden ‘burst’ of decomposition, mineralization and CO_2 release Also, recent observations in the Mediterranean climate in southern Europe using eddy covariance methodology have demonstrated this effect (Jarvis *et al.* 2005).

Finally, observations of these inherent CO_2 flux driving environmental variables and other site parameters can be utilized in developing empirical models for soil CO_2 flux of mangrove trees. Quantifying these controls on the seasonal mangrove carbon CO_2 flux, will enable a better understanding of the sensitivity of forest growth and health to a changing climate, which includes increasing atmospheric temperatures This research indicates that future efforts to predict carbon losses from replanted mangroves plantations will have to give consideration to the spatial and temporal trends of soil CO_2 flux. Other aspects that need to be addressed include influence of sampling period, age of the plantations as well as silvicultural practices.

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Summary

One of the proposed strategies to help mitigate atmospheric carbon emissions is afforestation. This has the potential to contribute to carbon storage directly through biomass and soil carbon accumulation. The little work that has been done on the potential of mangrove forests to sequester atmospheric carbon, estimated the rate of carbon sequestered in mangrove mud to be around 1.5 t C ha^{-1} yr^{-1} or a global total of 25.5 $x10^6$ t C yr^{-1}. Several factors are responsible for the rate of carbon sequestered, these include substrate type, temperature, moisture content, age of the forest among others. This study, aimed to index the seasonal variation in soil CO_2 flux as well as the influence of temperature and soil moisture content in young replanted mangrove stands at Gazi Bay. Soil CO_2 flux was measured every fortnight from August 2005 to April 2006 in thirty two plots with different mixes of mangrove species as well as controls using the soda-lime technique. Results indicated variations due to sampling time (season) and other variables i.e. species treatment. There was also a significant effect of soil moisture and soil temperature on soil CO_2 flux. Mean daily respiration ranged from 16.86 to 33.23 g m^{-2} d^{-1}. Seasonal changes in soil respiration were moderately negatively related to temperature changes and positively related to soil moisture. This study suggested that future efforts to predict carbon losses from replanted mangrove plantations should take into consideration the spatial and temporal trends of soil CO_2 flux.

9

Mangrove plantation experiments for controlling coastal erosion at Gazi Bay

J.K. Lang'at[1], F. Tamooh[2], J. Okello[3] & J.G. Kairo[4]

Introduction

Mangrove forests provide goods and services that are of economic, ecological and environmental values to the people. Environmentally, mangroves offer coastal protection against erosion, storm damage, prevent siltation of adjacent seagrass beds and control floods (FAO 1994). The value of mangroves in coastal protection was demonstrated during the 2004 Indian Ocean tsunami in which areas with degraded coastal mangroves were more affected than areas with intact forests (Dahdouh-Guebas *et al.* 2005). However, around the world mangroves are being degraded at an alarming rate due to human induced activities (Spalding *et al.* 1997). Losses of mangroves in many nations exceed 2-5% of forest area per year (Wilkie & Fortuna 2003).

In Kenya, the main threats to mangroves are overexploitation of wood resources, conversion of mangrove areas for other land uses and oil pollution. Losses of mangroves have affected the local economy as witnessed by shortages of firewood and building poles, reduction in fishery, and increased coastal erosion (Abuodha & Kairo 2001; Bosire *et al.* 2003).

For most coastal areas in Kenya, coastal erosion has become of major social, economic and environmental concern (Kairu & Nyandwi 2000; Abuodha 2003).

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The problem is severe in a number of sandy beach areas at Vanga, Gazi, Malindi, Mambrui and Ngomeni. Considerable amounts of money have been invested in shoreline stabilization throughout the Western Indian Ocean region, including use of rock revetments and seawalls (Kairu & Nyandwi 2000). Mangrove reforestation can provide a long-term and cost-effective solution while at the same time providing aesthetically and ecologically functioning habitats. Mangrove reforestation as a means to control coastal erosion has been used in Hawaii (Walsh 1976); Florida (Teas 1977); China (Lin & Xin-Meng 1983); Bangladesh (Saenger & Siddique 1993); Vietnam (Hong 1996) and Cuba (Padron 1996). In Florida, use of encasement piping to protect propagules led to improved performance of the saplings (Kent & Lin 1999; Riley & Kent 1999).

No information exists on the use of mangroves to control coastal erosion in the Western Indian Ocean region, thus the purpose of this study was to test growth performance of mangrove saplings grown in a high erosion zone. We tested the effectiveness of locally available bamboo encasements in protecting replanted propagules.

Study site

The study was carried out at Gazi Bay, located 55 km south of Mombasa (Map 6.1, p.100). The Bay supports coral reefs, seagrass beds and mangroves. All the nine mangrove species recorded in Kenya occur in Gazi, the dominant species being *Rhizophora mucronata* and *Ceriops tagal* (Dahdouh-Guebas *et al*. 2004).

The experimental site was located on the landward side of a fringing *Sonneratia alba* zone. Mangrove deforestation in the 1970's for industrial fuelwood left a huge contiguous bare area with no natural regeneration to date (Dahdouh-Guebas *et al*. 2004). Inside the fringing stand of *S. alba*, scattered individuals of adult *R. mucronata* were found. It is the presence of adult *R. mucronata* that prompted us to use the species in the reforestation. In addition, Rhizophororacea is the easiest mangrove family to use in reforestation programs (Kairo *et al*. 2001).

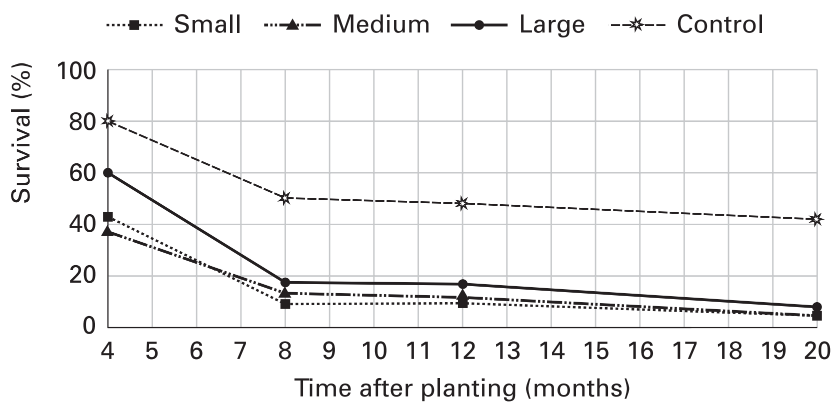
Method

Mature *R. mucronata* propagules were collected from the forest floor in a nearby natural stand. After collection, the propagules were sorted out to remove the predated, premature and partly dry ones before putting them in a moist gunny bag for transportation and storage. Planting was carried out in March 2005.

Three blocks (A, B and C) each measuring 10x10m lying side by side with a path of 2 m in between were marked. Within each block, bamboo encasements of three size classes, large (6.0 cm), medium (5.0 cm) and small (4.0 cm) in diameter resepectively, were firmly installed at spacing of 1.0 m within each row, leaving 15 cm above the ground. These were then filled with sediment to the brim, pressure applied and the propagules planted. Propagules were planted in a spacing of 0.5 m by 1 m. with the directly planted propagules put in between every two bamboo embedded lines to serve as controls. Each plot had, at the beginning of experiment, a total of 221 propagules, 100 directly planted and 121 bamboo-embedded. Enhancement planting was done for the first three months in order to remove any human error likely to have risen.

Mortality/survival rate of the saplings was monitored monthly for 13 months and a final assessment was carried out in the 20th month. Growth performance of the survivors was assessed every two months for the study period. The following growth parameters were recorded; shoot height (cm), diameter at the second internode (mm), and number of leaves. Data collection was done in two phases; 1) pre-establishment (the first 3 months) and 2) post-establishment (after 3 months).

Figure 9.1 Post-establishment survival of *Rhizophora* propagules planted in an eroding beach at Gazi Bay.



Results

Survival

Pre-establishment mortality was higher for bamboo embedded propagules than for the direct planted propagules. During the post-establishment phase saplings survival for all treatments declined, but stabilized in the 8th month after planting (Figure 9.1). In the 12th month of growing, the direct planted saplings (control) had the highest survival of 48.48±13.12%; while the small bamboo encasement had the lowest survival (9.85±8.18%; means±s.d.). Since there was no significant difference ($p=0.20$) between the treatments, the data was pooled together under one parameter (bamboo encasement) and compared with the control. At 20 months after planting the bamboo encased seedlings had a significantly lower % survival (6.9±6.3%) than the directly planted ones (33.03±8.6%) ($p=0.01$).

The causes of sapling mortality were attributed to washing away by tidal waves, crab attack and scorching by the sun. The most pronounced loss was due to seedlings being washed away. Quite unexpected, most washing away was experienced in the bamboo-embedded propagules, pointing at the possibility of human error while setting up the experiment rather than natural causes.

Table 9.1 Growth performance of *Rhizophora* saplings at Gazi, 13 months after planting (values are means - s.d.).

Treatment	Total height (cm)	Shoot height (cm)	Diameter (mm)	Leaf number
Bamboo	61.4 (8.9)	38.2 (8.6)	5.8 (1.1)	8.9 (3.2)
Control	82.1 (12.0)	45.6 (10.1)	6.6 (0.9)	16.1 (7.8)

Growth rate

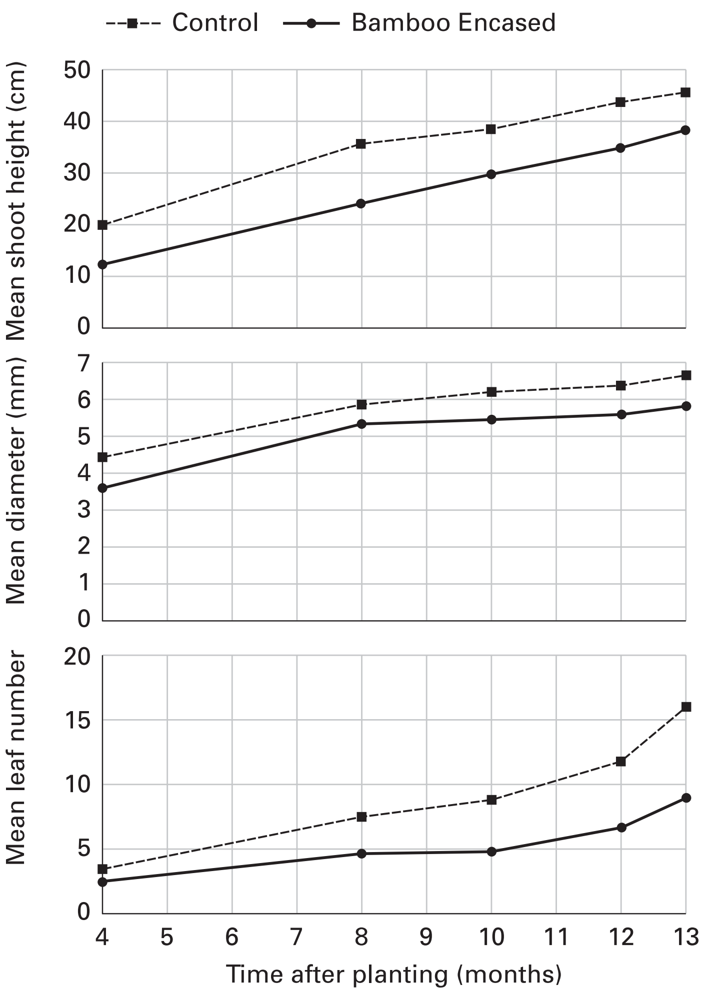
The growth variables in April 2006, 13 months after planting are given in Table 9.1. For all growth variables, the encased saplings performed significantly poorer than the directly planted saplings ($p<0.01$ in all cases).

Figure 9.2 shows the trend in growth performance of the bamboo encased versus the directly planted propagules, 13 months after planting. The mean annual shoot and diameter increment for directly planted saplings were 42.1 cm/yr and 6.1 mm/yr while those for encased saplings were 35.2 cm/yr and 5.4 mm/yr respectively.

Discussion

The experimental site is subjected to high wave energy due to past deforestation. Even though mortality in all cases was greater than 60% at 20 months after planting the saplings in bamboo encasements were hardest hit. The causes of mortality could partly be attributed to experimental error whereby the bamboo encasements were shallowly installed causing them to be easily washed away by tidal waves. Other factors contributing to high mortality of the replanted propagules included predation by crabs, washing by tides, as well as natural deaths. In the encased saplings, the incoming waves scooped out sediment from the bamboo tubes exposing the saplings. The tubes also provided ample hiding places for predatory crabs that ended up feeding on the propagules and saplings.

Figure 9.2 Growth performance of *Rhizophora* saplings at Gazi Bay



Earlier studies by Kairo (1995) in the same area provided suitable planting heights for different mangrove species in Gazi. The seaward zone is mostly suitable for *S. alba,* whereas *R. mucronata* prefer muddy substrate in sites receiving water at least twice every week; in the inundation class 3 of Watson (1928). Elsewhere in the world, saplings of *Rhizophora stylosa* have been reported to show reduced growth in low intertidal elevations (Smith 1987).

Although *R. mucronata* saplings in the present study were able to attain greater height increments they produced relatively few leaves per plant at 13 months as compared to *R. mucronata* planted in its natural site after 10 months (16.1 vs. 26.9; Kairo 1995). The leaves in the present experiment were also narrow and concentrated at the tip of the sapling; compared to saplings growing in ideal conditions whose leaves are uniformly distributed along the lead stem (Kairo

1995). Physiological explanations for observed condition could be that *R. mucronata* growing at low inundation tend to develop elongated shoots to enable the leaves to escape submersion.

Conclusion

This study aimed at testing whether we could use the easily cultivable mangrove species, *R. mucronata*, to control soil erosion. The inherent root architecture in *R. mucronata* (Tomlinson 1986) makes the species ideal for use in coastal protection. Under natural settings, the intertwined rooting complex of *Rhizophora* species stabilizes sediment by reducing erosive capacity of water passing through the root system (Wolanski *et al.* 1992). In fact, countries like Bangladesh have introduced large scale mangrove afforestation programs to minimize damage to coastal village and agricultural land from frequent cyclones (Saenger & Siddique 1993). The high mortality observed in encased saplings may be partly associated with poor installation of the bamboo tubing rather than natural causes. In the future we plan to experiment with different encasement types and installing saplings deeper into the sediment to reduce the probability of washing away.

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Summary

Horizontal distribution of mangrove species is a common phenomenon in mangrove ecosystems. In Kenya, where 9 species of mangroves occur, the seaward zone is normally occupied by *Sonneratia alba* and occasionally by *Rhizophora mucronata*. The present study was conducted in a low lying site previously dominated by *S. alba*. Our study aimed at testing the suitability of replanting *R. mucronata* propagules in low elevation site to control soil erosion and stabilize sediments. The experiment was set up in March 2005 with three treatments and a control group. *R. mucronata* propagules were planted directly into the sediment or inside bamboo encasements of various diameters. Field measurements included percentage mortality, shoot height increment (cm), diameter at second internode (mm), and leaf number. The results showed that the directly planted saplings had a significantly high % survival ($p=0.01$) as well as better growth performance ($p<0.01$) than the encased saplings. There was no significant difference between the bamboo treatments in both survival and growth performance.

10

Biomass accumulation in a rehabilitated mangrove forest at Gazi Bay

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Introduction

Global mangrove coverage is estimated to be 0.4% of the forested areas globally (Spalding *et al.* 1997). Despite this small areal coverage, mangroves are important because of the range of ecological, economic and environmental services they provide (Saenger 2002; FAO 1994) In the last few decades, unsustainable utilization of mangrove resources has resulted in a loss of 50% of their original cover (FAO 2005).

The global mangrove biomass is estimated to be in excess of 8.7 gigatons dry weight (i.e. 4.0 gigatons of carbon; Twilley *et al.* 1992; Ong 1993). This is stored in both above-ground and below-ground tree components (Twilley *et al.* 1992). Most biomass studies on mangroves have concentrated on natural stands (Soares & Novelli 2005; Sherman *et al.* 2003; Saintilan 1997; Clough *et al.* 1997) with very few studies on managed and replanted forests (Ong 1993; Putz & Chan 1986).

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The estimation of biomass in mangroves is required for a number of reasons. Foresters are interested in the yield of wood as a function of age, stand density and other factors. Ecologists require information about stand biomass because of its relevance to nutrient turnover, stand structure and function and competition studies. Ecophysiologists have used biomass as indicators of atmospheric and soil pollution input and forest health. More recently, governments have realized that there is a potential for woody ecosystems to store carbon and thereby contribute to mitigation strategies to offset carbon emissions (Eamus *et al.* 2000). Accurate estimates of biomass are important for describing current forest condition and for predicting change (Comley & McGuinness 2005). Further, such estimates are of considerable practical significance for modelling the potential consequences of climate change and for national and international carbon offset programs. With the threat posed by climate change, there is an urgent need for us to collect information on mangrove biomass (Komiyama *et al.* 2005).

A number of researchers working on mangrove biomass (e.g. Clough & Scott 1989; Clough *et al.* 1997; Ong *et al.* 2004) have developed equations relating above-ground biomass with easily measurable parameters such as DBH and height. However, few studies have developed allometric relations between total tree biomass and DBH and height. This is because little information exists on below-ground biomass, although it may contribute about half of the total standing biomass (Comley & McGuinness 2005; Briggs 1977).

The aim of this study was to estimate total biomass of replanted mangroves and in addition to develop allometric equations predicting total biomass, above-ground biomass, and below-ground biomass using D_{30} alone or combined with height. Earlier work on mangrove biomass and productivity of mangroves in Gazi (e.g. Kirui 2006; Kairo 2001; Slim *et al.* 1997) have focused on the above ground component. This study complements the previous studies in arriving at estimates of the total biomass in replanted mangrove stands and hence contributes to our understanding of the potential role of mangrove reforestation to sequester atmospheric carbon.

Study site

This study was conducted at Gazi Bay, some 50 km south of Mombasa in Kwale district (Map 6.1, p.100). The climate in Gazi is typical of the Kenyan coast and principally influenced by monsoon winds. All the 9 species of mangroves described in Kenya occur in Gazi. The dominant species are *Rhizophora mucronata* and *Ceriops tagal*. The mangrove forests of Gazi Bay have been exploited for many years especially for building poles and fuel wood (Kairo *et al.* 2001). In 1991, a program to rehabilitate degraded mangrove areas was initiated at Gazi.

The present study is based on a six-years old *Rhizophora mucronata* plantation established in 2001 in an originally El Niño impacted site.

Method

Measurement of above-ground biomass

Twelve isolated trees with a diameter range from 0.8 cm to 5.2 cm were selected randomly and sampled using a destructive method. Height (H-cm), stem diameter at 30 cm above the highest prop root (D_{30}) and diameter at first branching (D_B) were recorded. For trees below 2.0 m in height, stem diameter was taken at half the height of the tree. The trees were then cut at ground level using hand saws. Trees were subdivided into their separate component parts: stems, branches, leaves and prop roots and the total fresh weight of each component recorded in the field. Subsequently, a representative sub-sample (about 500g) of each component were taken and oven dried to constant weight 80^0C to obtain wet to dry weight ratio.

Measurement of below-ground biomass

After the above-ground parts of each tree had been removed, the stump of each root was followed down to its tip as far as possible (down to at least 1 m depth) by excavating the soil around the root using shovels and forks. The root systems were carried to the seashore and separated from the soil by passing through 1mm meshed screen to separate the root from the soil. Roots were transferred into labeled plastic bags, and kept under refrigeration until processed. Roots were later sorted into diameter classes: < 5 mm, 5-10 mm, 10-20 mm, 20-30 mm, 30-40 mm, >40 mm and necromass (dead organic matter). Subsequently, a representative sub-sample from each root class was oven dried at 80^0C to constant weight in order to obtain wet:dry matter ratio.

Allometric relationships

Allometric relationships were derived by linear regressions of dependent variables (Total biomass, above-ground biomass and below-ground biomass) on several independent variables (D_{30}, H, D_{30}^2H, D_B, D_B^2H and basal area). The rationale for using allometric relationships is the assumption of a regular proportionality between the predictor variables (e.g. DBH and height) and mangrove biomass. The relationship between the two variables was expressed by a generalised allometric equation of the form:

$$Y=bx^k$$

where x is the independent variable, y the dependent variable, b and k are the allometric constants.

Table 10.1 Relations of biomass indicators with different independent variables for 6 year old *R. mucronata* (r^2; N=12).

Tree component	D_{30}	H	D_{30}^2H	Basal area	D_B	D_B^2H
Leaf	.91	.84	.91	.93	.82	.89
Branch	.81	.80	.96	.91	.76	.96
Stem	.85	.81	.88	.89	.69	.81
Prop root	.89	.86	.94	.94	.75	.86
Below-ground biomass	.83	.83	.98	.93	.79	.97
Above-ground biomass	.91	.88	.97	.97	.80	.92
Total biomass	.90	.87	.98	.97	.80	.94

Results

Above-ground biomass relations

Allometric relationships for leaves, branches, stem, and prop roots were examined with independent variables (D_{30}, H, D_{30}^2H, D_B, D_B^2H, and basal area). Leaf showed the highest r^2 when it was regressed against basal area (r^2=0.93). Other variables also showed strong relationship with r^2 ranging between 0.84-0.91 (Table 10.1). The relationship for stem was highest when basal area was used (r^2=0.89). Branch showed similar strength when variables D_{30}^2H and D_B^2H were used (r^2=0.96). Prop root similarly showed the same strength (r^2=0.94) when D_{30}^2H and basal area were used as independent variables. Overall above-ground biomass showed the best fit when it was regressed against D_{30}^2H (r^2=0.97). Their dry weights and correlation coefficients are summarized in Table 10.1.

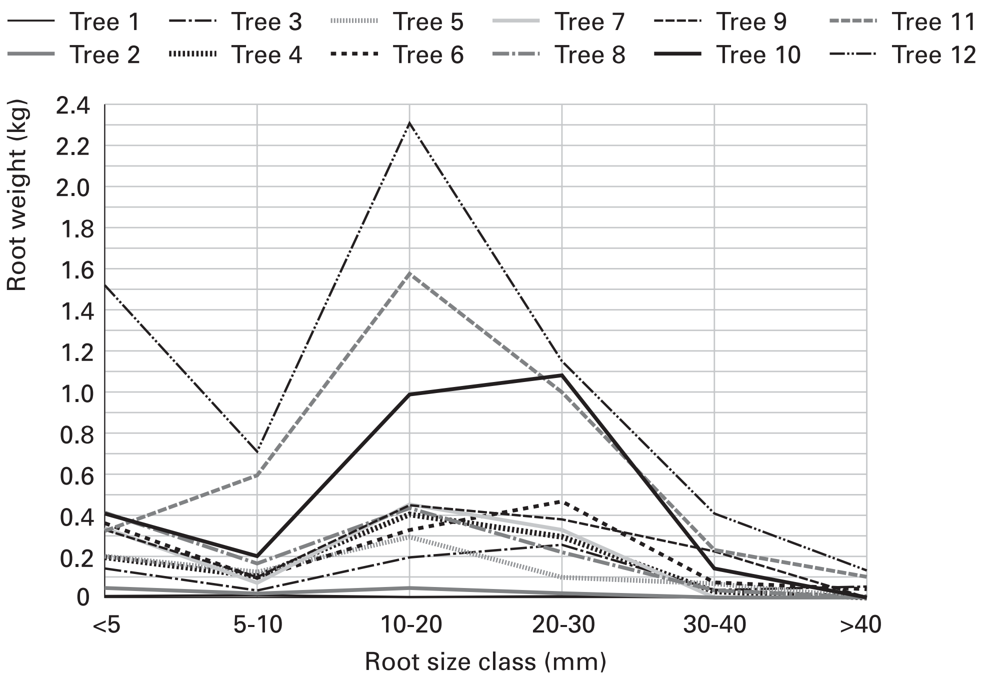
Below-ground relations

Allometric relationships between below-ground biomass and various independent variables with their correlation coefficients are shown in Table 10.1. The correlation coefficients range between 0.79-0.98. D_B gives the lowest correlation coefficient (r^2=0.79) while D_{30}^2H gives the highest correlation coefficient (r^2=0.98).

Root distributions

The root size-class compositions in each tree are illustrated in Figure 10.1. The root weight in each class increases with the size of the tree stem diameter. The root weight in all trees had a mode in class 10-20 mm.

Figure 10.1 Root size distribution in 12 trees with different stem diameter



Total biomass relation

Allometric relationships for total biomass were examined with the independent variables D_{30}, H, D_{30}^2H, D_B, D_B^2H, and basal area of the 12 sampled trees. The relationships for all these variables showed strong correlations, with r^2 ranging between 0.8-0.98. The best correlation was between total biomass and D_{30}^2H (r^2=0.98) while D_B had the lowest with 0.80 (Table 10.1).

Biomass partitioning

This refers to the proportion of biomass apportioned to different components of a tree as shown in Table 10.2 while Table 10.3 shows the mean biomass estimates. The ranges of the total biomass were as follows; Leaves: 0.030 to 3.356 kg, Branches: 0.007 to 3.051 kg, Stem: 0.047 to 1.754 kg, Prop roots: 0 to 7.910 kg, below-ground (BG) roots 0.026 to 6.237 kg, Total biomass: 0.110 to 22.495 kg. The shoot: root ratio ranged from 1.7 to 4.5.

Table 10.2 shows that leaf has the lowest variability with the size of the tree (12-27%) as compared to prop roots which has apportioned as high as 46.2% and as low as 0% of the total biomass. Total below-ground root biomass represented between 18-37% of the total tree biomass based on the 12 sampled trees.

Table 10.2 Biomass partitioning in *R. mucronata* for all components (%)

Component	Proportion %
Leaf	12.2 - 27.0
Branch	6.6 - 14.7
Stem	4.5 - 42.4
Prop root	0 - 46.2
Below-ground biomass	18 - 37.0
Above-ground biomass	62.7 - 81.7

Table 10.3 Mean biomass estimates (kg) of *R. mucronata* components

Component	Mean (SE)
Leaf	1.11 (0.09)
Branch	0.79 (0.08)
Stem	0.53 (0.05)
Prop root	2.52 (0.23)
Below-ground root	1.74 (0.16)
Total biomass	6.8 (0.6)

Discussion

In this study the D_{30}^2H is the most reliable predictor for estimation of the total biomass, above-ground biomass and below-ground biomass of the young *R. mucronata* in Gazi Bay. This result supports the findings of Komiyama *et al.* (2000, 2005) and Ong *et al.* (2004). The equations based on D_{30}^2H provide the best prediction probably because the inclusion of height introduces the aspect of tree shape into the equation.

Allometric relationship concerning leaf biomass revealed basal area as the best predictor. However, many researchers in mangroves have used the variables D_{30}^2H (Komiyama *et al.* 2000, 2005; Kairo 2001), D_{30} (Comley & McGuinness 2005; Clough & Scott 1989) and GBH (Ong *et al.* 2004) because of the ease of measuring these variables in the field. The same applies to other above-ground components (branch, stem, and prop root).

Table 10.4 gives a comparison of various allometric relations with those of earlier studies in other parts of the world. These relationships were based on the original equations based on the independent variable used. Similar correlation coefficients were obtained from all these studies though they were from different sites. However, varying sample size could account for the slight differences in correlation coefficients observed in different studies. Large sample size such as in Kairo (2001) could have resulted in several outliers leading to scattering and hence low correlation coefficient r^2=0.66). In addition, the sampled trees are from an old stand with very large and old trees whilst in the present study the trees are from a young plantation. There are three studies to compare for total biomass (Ong *et al.* 2004; Comley & McGuinness 2005 and this study). The correlation coefficients are very close probably because their sample sizes are small. Regression models may also vary at different localities, depending on site-specific factors such as tree density, location on the ground, and management practices (Kairo 2001).

Table 10.4 Comparison of different allometric relations for *Rhizophora* species from different studies in different parts of the world

Study	Species	r^2	Indep. variable	n
Total biomass				
Ong *et al.* 2004	*R. apiculata*	0.99	GBH	11
Comley & McGuinness 2005	*R. stylosa*	0.99	D_{30}	5
This study	*R. mucronata*	0.98	D_{30}^2H	12
Total above-ground biomass				
Clough & Scott 1989	*R. apiculata*	0.99	D_{30}	21
Kairo 2001	*R. mucronata*	0.66	D_{30}^2H	56
Ong *et al.* 2004	*R. apiculata*	0.98	GBH	57
Comley & McGuinness 2005	*R. stylosa*	1.00	D_{30}	6
This study	*R. mucronata*	0.97	D_{30}^2H	12
Total below-ground biomass				
Comley & McGuinness 2005	*R. stylosa*	0.92	D_{30}	5
Ong *et al.* 2004	*R. stylosa*	0.99	D_{30}	5
This study	*R. mucronata*	0.98	D_{30}^2H	12

Figure 10.1 shows the root size distribution in different tree stem diameters for the 12 trees. The variability of the root size distribution is pronounced in trees with big stem diameters. With the smaller trees, the amount apportioned to each diameter class is relatively constant. The root weight in all trees was highest in class 10-20 mm. This is probably because the decomposition turnover of large roots is low compared to the fine roots. Table 10.3 shows the proportion of biomass values for different components of *R. mucronata* at Gazi Bay.

Data on root biomass of mangrove trees are scarce mainly because it is difficult and time consuming to measure (Matsui 1998). It can be seen that even when total biomass is regressed, the correlation coefficient remains tight and high (Table 10.1; r^2=0.98). Although the variability is low the problem associated with root excavation cannot be underestimated. A tree of 5.2 cm diameter required 10 person-days of labour to excavate the whole root system. It also took much time to wash, sort, dry and weigh the roots in the laboratory. However, in the present study a strong allometric relationship was also realised between below-ground biomass and D_{30}^2H with a strong correlation coefficient (r^2=0.98). This is probably because this study sampled trees within a narrow diameter range and therefore was possible to excavate all the roots. Our results were similar to studies that used D_{30} and GBH; r^2=0.92 and r^2=0.99 (Comley & McGuinness 2005; and Ong *et al.* 2004 respectively). The present study is unique in that it is the first one in Eastern Africa WIO region to include below-ground biomass in the allometric relations.

Total above-ground biomass provided a stronger fit compared to Kairo (2001) where a similar independent variable was used. The poorest fit was that for stem biomass (r^2=0.69) based on diameter at first branching (D_B). This may be because first branching in different trees is not distinct since some trees branch very low while others branch high leading to inconsistency in measurement.

Table 10.2 shows the partitioning of the total biomass among different components. The variability is lowest in leaves (12-27%) and highest in prop roots (0-46%). The proportion for stem (4.5-42%) and the prop root (0-46%) varied depending on the size of the tree. This is because these components do not respond sensitively to environmental changes because they are not very active metabolically. The amount apportioned to below-ground biomass ranged between 18-37%. The variability is similar to that of leaves. Leaves and roots are least variable in terms of biomass partitioning probably because they are the metabolically active components of the tree. The proportions for different components are summarized in Table 10.2. The proportions varied considerably depending on the size of the tree.

The shoot/root ratio is a standard judgement for biomass-allocation pattern to underground part of the plant. In the present study, shoot/root ratio ranged from 1.7-4.5. The shoot/root ratio in tropical inland forests ranged from 5.10 to 10.68 (Ong *et al.* 2004) while those in primary tropical mangroves were 1.05 for *Ceriops tagal*, 5.25 for *Sonneratia alba*, 3.01-4.58 for *Bruguiera* forests and 1.71-2.66 for *Rhizophora* forest (Komiyama *et al.* 2000).

Conclusion

Researchers have now recognized the value of allometric equations but there are few equations developed for total biomass estimation in mangrove forests and none in the Eastern Africa WIO region. The equations presented here should of use in quantifying above-ground and below-ground biomass for *R. mucronata* in Gazi Bay and elsewhere. While general equations appear to work well for total above-ground and total below-ground root biomass in this study prospective users should be cautioned against extrapolating allometric equations beyond the original sample diameter range.

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Summary

Estimation of biomass in woody ecosystems is important because of its role in wood yield determination, relevance to nutrient turnover, and the potential to store carbon. Most studies on mangrove biomass have over the years tended to concentrate on standing biomass with very little on below-ground biomass. The present study estimates total above and below ground biomass in mangroves. Allometric relations were developed relating biomass with easily measurable parameters in a young six-years *Rhizophora mucronata* plantation established in 2001 in an originally El Niño impacted site at Gazi Bay. Twelve isolated trees were sampled using destructive method. The stem diameters were measured at first branching (D_B) and diameter at 30 cm from the highest prop root (D_{30}). Total above-ground biomass gave the best fit (r^2=0.97) when regressed against the independent variable D_{30}^2H. There was a clear correlation between below-ground biomass (BGB) and D_{30}^2H (r^2=0.98). The best estimator for total biomass gave the best fit when regressed against D_{30}^2H (r^2=0.98) using the equation B total (g dry weight) =2.0095 x D_{30}^2H (cm^3) + 1463.1. Overall, above-ground biomass and below-ground biomass accounted for 63-82% and 18-37% of the total dry weight respectively. Allometric equations developed in this study provide a useful tool of estimating total biomass in replanted mangroves and hence improve on forest management.

Conservation and Management

11

Seasonal fluctuations in zooxanthellae densities in corals in the Mombasa Marine Park, 1998-2006

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Introduction

Tropical reef-building corals contain micro-algae known as zooxanthellae within their tissue with which they exist in an obligate symbiosis (Muscatine & Porter 1977). Zooxanthellae are crucial to coral polyps because they provide them with photosynthates, energy, oxygen and pigmentation. They in turn receive carbon dioxide, nutrients, protection and access to light (Muscatine 1973; Trench 1979). This symbiosis underpins the existence of coral reefs. When a coral bleaches, this symbiosis is disrupted and zooxanthellae are expelled (Hoegh-Guldberg & Smith 1989). Severe bleaching can cause significant negative effects on coral colonies, including heightened mortality (Glynn 1993; Brown 1997). Mass bleaching events in the last decade have prompted increased research into zooxanthellae population dynamics, as zooxanthellae density counts are useful in quantifying bleaching responses (Fagoonee *et al.* 1999; Fitt *et al.* 2000; Chen *et al.* 2005).

Several studies around the world have observed that zooxanthellae population densities undergo marked seasonal fluctuations. Research in Thailand (Brown *et*

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Table 11.1 A summary of results from previous studies showing fluctuations in zooxanthellae density reported in different locations from 25^0N to 20^0S

Reference	Study location	Latitude	Study period	Species	Regular seasonal fluctuation	Lowest densities
Warner *et al.* (2002)	Florida	~ 25^0N	5 years	*Montastrea annularis* *Montastrea faveolata* *Montastrea franksi*	Yes	Mid- to late summer
Fitt *et al.* (2000)	Bahamas	~ 24^0N	4 years	*Montastrea annularis* *Montastrea faveolata* *Acropora palmate* *Acropora cervicornis*	Yes	Late summer
Chen *et al.* (2005)	Taiwan	~ 23^0N	18 months	*Acropora palifera*	No	Maybe due to short sampling period
Stimson (1997)	Hawaii	~ 20^0N	5 years	*Pocillopora damicornis*	Yes	Summer
Brown *et al.* (1999)	Thailand	~ 7^0N	4 years	*Coeloseris mayeri* *Goniastrea retiformis* *Porites lutea* *Goniastrea aspera*	Yes	Summer
Fagoonee *et al.* (1999)	Mauritius	~ 20^0S	5 years	*Acropora formosa*	Yes	Summer

al. 1999), Mauritius (Fagoonee *et al.* 1999), the Bahamas (Fitt *et al.* 2000), Hawaii (Stimson 1997) and Florida (Warner *et al.* 2002) has shown that zooxanthellae population densities and photosynthetic capacities are highest during the colder winter months and lowest during the warmer summer months, with intermediate densities in between (Table 11.1). These fluctuations have been explained in terms of temperature (Fitt *et al.* 2000; Warner *et al.* 2000; Brown *et al.* 1999), solar radiation (Fitt *et al.* 2000; Stimson 1997; Warner *et al.* 2002; Brown *et al.* 1999), dissolved NO_3 (Stimson 1997; Fagoonee *et al.* 1999) and possibly dissolved oxygen (Fagoonee *et al.* 1999).

High temperatures could lower zooxanthellae densities by causing decreases in the growth rates of zooxanthellae, by causing heat stress and photo inhibition resulting in irreversible photosystem damage in zooxanthellae, and by causing reductions in carbon fixation by zooxanthellae (Fitt *et al.* 2000). Increased solar radiation can also cause decreases in zooxanthellae densities by causing photo inhibition and damages to the photosystem (Hoegh-Guldberg & Jones 1999). Decreases in levels of dissolved NO_3 can cause decreased zooxanthellae densities because zooxanthellae assimilate inorganic nitrogen from seawater for nutrition (Stimson 1997). Increases in dissolved oxygen could possibly cause decreases in zooxanthellae densities due to oxidative stress caused to the algal cells (Fagoonee *et al.* 1999). Furthermore, zooxanthellae densities have also been shown to fluctuate with salinity levels (Muthiga & Froelich 1988).

There thus appears to be seasonal variability in zooxanthellae population densities, with regular natural bleaching events occurring in seasonal cycles caused by environmental fluctuations. However, these studies were mostly conducted at higher latitude sites where seasonal environmental parameters are more variable and the difference between summer and winter conditions is more marked than at sites closer to the equator.

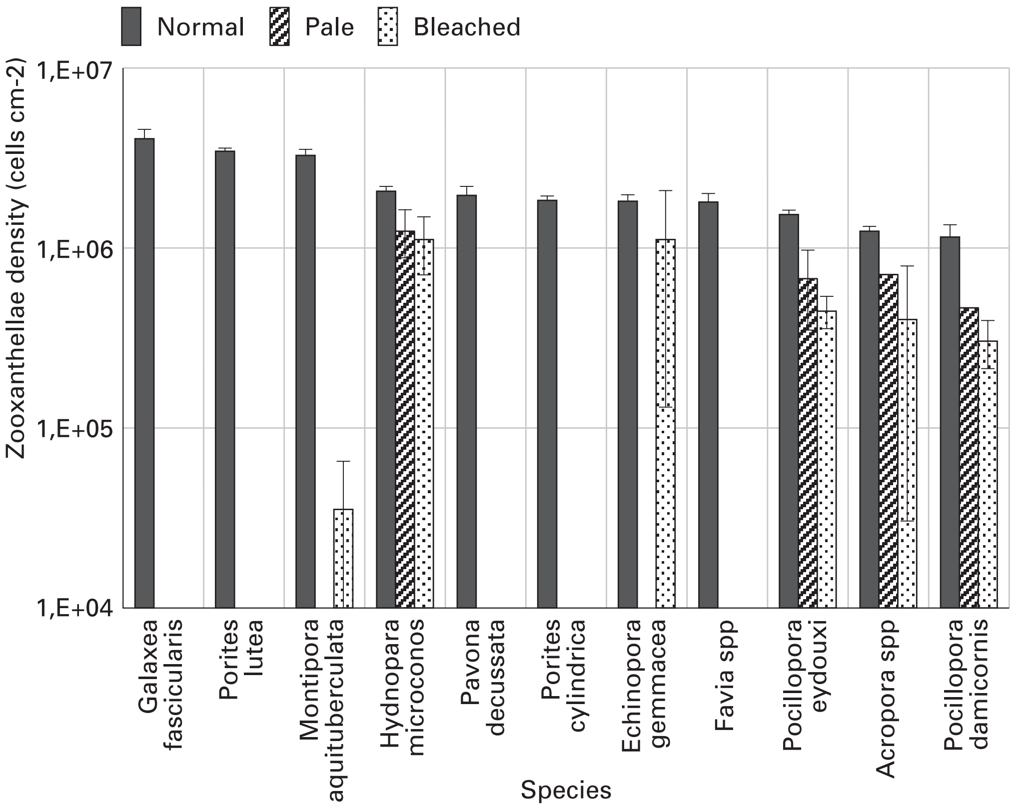
This study examined zooxanthellae density data collected in corals at a shallow lagoon in the Mombasa Marine Park (Map 12.1, p.164) between 1998 and 2006, and will determine trends during this time period. Mombasa Marine Park lies at a latitude of about 4°S, and thus the objective of this paper is to provide a comparison to higher-latitude sites.

Method

Target species/genera were selected because they were relatively abundant and easy to find in the study site. Large and healthy coral colonies for each of the target species/genera were located and mapped in the shallow lagoon of Mombasa Marine Park. *Pavona decussata*, *Porites cylindrica*, *Porites lutea*, *Acropora* and *Montipora aequituberculata* were sampled from 1998 to 2006 and

Galaxea fascicularis, *Echinopora gemmacea* and *Hydnophora microconos* from 2002 to 2006. *Pocillopora damicornis* and *Pocillopora eydouxi* were sampled from 2004 to 2006 and *Favia* from 1998 to 2002. In total, 11 genera or species were covered. For the most consistent part of the dataset from 2004-2006, 5 replicate colonies were sampled per species. Samples were taken during the north-east and south-east monsoon seasons.

Figure 11.1 Zooxanthellae density in normal, pale and bleached corals during the late north-east monsoon (mean - standard error). (Significance of ANOVA tests within each species are as follows: *Montipora aequituberculata* p<0.001, *Hydnophora microconos* N.S., *Echinopora gemmacea* p<0.05, *Pocillopora eydouxi* p<0.01, *Acropora* spp p<0.001, and *Pocillopora damicornis* p<0.001.



During sampling, coral fragments were collected from the mapped colonies using a chisel. The fragments were transported to the lab while submerged in seawater in a small plastic bottle and were held in aerated seawater tanks until analysis. To prepare samples for counting, coral tissue was first removed from the skeleton using a water jet. Seawater was then added to the tissue slurry up to a practical volume, usually between 500 and 1000 ml. The tissue slurry was homogenised using a hand-held homogeniser and 1.0 ml of homogenate was loaded into a Sedgwick-Rafter chamber. Using a compound binocular microscope and a magnification of 400, the numbers of zooxanthellae in 10 random quadrates were counted and recorded. The counting chamber was then reloaded and another 10 random quadrates were counted. The area of the coral skeleton was measured using the foil method. First, the area/weight ratio of a silver foil was determined. The coral skeletons were then individually wrapped in this foil and trimmed to fit. The trimmed foil pieces were then weighed, and using the weight/area ratio calculated for the foil, the area of the coral skeleton was determined.

For analysis of seasonal patterns in zooxanthellae density, samples were grouped at two levels. Two main seasons are distinguished, the north-east monsoon (NEM) from November to April and south-east monsoon (SEM), from May to October. For finer scale analyses, two transition periods were distinguished to give 4 periods; NEM (16 dec-15 mar), late NEM (16 mar-30 apr), SEM (1 may-31 oct) and the transition from SEM and NEM (1 nov-15 dec). The two transitional periods (late NEM and transition) are doldrums periods when warming of surface waters is most intense between the two monsoon winds and severe bleaching was most prevalent (Obura 2001).

Results

Severe bleaching of corals in Kenya has previously been shown to occur during the late NEM period during doldrums conditions (Obura 2001). Comparison of zooxanthellae densities between corals labelled normal, pale and bleached across all years (1998-2006) for this season is shown in Figure 11.1. No bleaching was recorded in colonies of *M. aequiturbeculata*, *G. fascicularis* and *Favia* spp. In the rest of the corals where bleaching was recorded, all had significantly lower zooxanthellae densities compared to normal and pale corals, except for *P. damicornis* where all three categories showed similarly low zooxanthellae densities.

Examining seasonal fluctuations in zooxanthellae densities of corals for the two main seasons, NEM and SEM, there was high variability in the patterns recorded (Appendix 11.1) but few significant differences between NEM and SEM densities (Table 11.2). Only two species, *Acropora* spp (p=0.048) and *M. aequituberculata* (p=0.000) displayed significant variability in zooxanthellae densities between the NEM and SEM seasons. Neither species, however, displayed a consistent pattern of higher densities in one season compared to the other. Two species, *P. cylindrica* and *P. decussata*, had consistently higher zooxanthellae densities during the NEM, but this variation was not significant (p=0.124 and p=0.272 respectively). *P. lutea* had consistently higher densities during the SEM season, but this variation was also not significant (p=0.439). *E. gemmacea* also had higher densities during the SEM season.

Table 11.2
Results of ANOVA comparisons of zooxanthellae density between seasons, between years and between years and seasons for all species monitored*

Coral	Season	Year	Season/Year
Acropora spp	0.048	0.176	0.176
Echinopora gemmacea	0.711	0.790	0.789
Favia spp	0.740	0.000	0.000
Galaxea fascicularis	0.582	0.451	0.451
Hydnophora microconos	0.863	0.021	0.021
Montipora aequituberculata	0.000	0.000	0.000
Pavona decussata	0.272	0.036	0.035
Pocillopora damicornis	0.894	0.854	0.854
Pocillopora eydouxi	0.524	0.894	0.894
Porites cylindrica	0.124	0.933	0.937
Porites lutea	0.439	0.400	0.398

* Significant factors highlighted in grey

Breaking down data into two seasons with two transitional periods allows closer analysis of density fluctuations (Appendix 11.2). Species showed variable patterns along a continuum with two extremes - those with higher zooxanthellae densities during the NEM (*Acropora* spp, *G. fascicularis* and *P. decussata*) and late NEM (*M. aequituberculata*, *Favia* spp and *P. cylindrica*), compared to those with highest zooxanthellae densities during the SEM (*E. gemmacea* and *H. microconos*) and the transitional period (*P. lutea* and *P. damicornis*). The significance in seasonal variability is more pronounced over four seasons in comparison to the two-season analysis (all corals show at least $p<0.05$ except for *H. microconos* and *P. eydouxi*. (Appendix 11.2 compared to Table 11.2).

Discussion and conclusion

Studies have shown that average zooxanthellae densities in reef-building corals vary considerably, but that healthy corals should contain densities greater than $1x10^6$ cells cm^{-2} (Stimson 1997; Brown *et al.* 1999, Fagoonee *et al.* 1999; Fitt *et al.* 2000), while bleached corals can contain densities lower than $0.5x10^6$ cells cm^{-2} (Fagoonee *et al.* 1999; Fitt *et al.* 2000). The results of this study confirm these figures, except in the case of *P. damicornis* (Figure 11.1). In fact, according to Amiyo & Grimsditch (unpublished data), *P. damicornis* colonies in the Mombasa Marine Park tend to exhibit lighter colouration and lower zooxanthellae densities than colonies found in other Kenyan sites such as Kanamai or Vipingo. Thus it seems that *P. damicornis* colonies in the Mombasa Marine Park generally contain low zooxanthellae densities even when they are supposedly 'healthy', and it is possible that this species is being stressed in some manner at this site.

Previous studies (Warner *et al.* 2002; Fitt *et al.* 2000; Stimson 1997; Brown *et al.* 1999; Fagoonee *et al.* 1999) have shown zooxanthellae densities to display marked seasonal fluctuations, with highest zooxanthellae densities in the colder season and lowest densities in the warmer season. However, this study does not show these regular fluctuations. There is high variability in seasonal zooxanthellae densities, although differences between densities in the NEM and SEM seasons are not generally significant. This could be explained by Mombasa's low latitude (4^0S) in comparison to other study locations (Florida ~ 25^0N, Bahamas ~ 24^0N, Taiwan ~ 23^0N, Phuket ~ 7^0N, Mauritius ~ 20^0S), and thus its less pronounced seasonality of environmental conditions. Considering temperature, sea surface temperatures (SST) at Mombasa show fluctuations between 25^0C during the SEM and 30^0C during the NEM. This 5^0C difference is markedly lower than differences of 13^0C in Florida (fluctuation from 21^0C to 34^0C; Warner *et al.* 2002), and 12^0C in the Bahamas, (fluctuation from 21^0C to 33^0C: Fitt *et al.* 2000).

Nevertheless, when the transitional periods between seasons is taken into account in the data analysis, seasonal variability in zooxanthellae densities becomes more significant, and corals can be grouped into three broad patterns. Firstly, those with higher densities in the NEM season: *Acropora* spp (fast growth up to 73 mm radial growth per year), *M. aequituberculata* (fast, up to 88 mm year^{-1}), *P. cylindrica* (fast growth), *G. fascicularis* (fast/intermediate, up to 33 mm year^{-1}), *P.decussata* (fast growth) and *Favia* spp (slow, up to 7 mm year^{-1}; Obura 1995). Secondly, those with higher zooxanthellae densities in the SEM season: *H. microconos* (slow growth), *P. lutea* (slow, up to 18 mm year^{-1}) and *E. gemmacea* (medium growth) and, thirdly, those with very little difference between the two seasons namely *P. eydouxi* (fast growth) and *P. damicornis* (fast, up to 49 mm year^{-1}). It is possible that the growth strategies of these species affect their seasonal zooxanthellae density fluctuations as long as stress levels are not high enough to cause bleaching, with fast-growing corals generally exhibiting higher zooxanthellae densities during the warmer NEM and slow-growing corals generally exhibiting higher densities during the cooler SEM (Appendix 11.1). However, anomalies include the high SEM densities of fast-growing *Acropora* spp in 2004 and 2005 (Appendix 11.1), and the high late-NEM densities of slow-growing *Favia* spp (Appendix 11.2). Furthermore, Fitt *et al.* (2000) found the same seasonal symbiont fluctuations in the Bahamas for slow-growing *Montastrea* corals and for fast-growing *Acropora* corals, but their study took place at a higher latitude and in very different environmental conditions.

Another possible explanation for these trends is that because the tips of branches for fast-growing colonies were sampled, in periods of higher SST's and slower colony growth (NEM), zooxanthellae densities become concentrated in these branch-tips and are thus relatively higher than in periods of lower SST's and faster colony growth (SEM).

It is also possible that at higher latitudes seasonal variability of environmental factors is so great that it dictates zooxanthellae density fluctuations, while corals closer to equator are less influenced by seasonal variability of environmental factors, and other mechanisms, such as growth strategy, have greater influence on zooxanthellae densities. Furthermore, many other environmental factors such as light, dissolved NO_3 and dissolved oxygen can influence zooxanthellae densities within corals, and this data is not readily available for the Mombasa Marine Park

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Summary

This paper examines whether zooxanthellae population densities in corals in the Mombasa Marine Park undergo seasonal fluctuations. Eleven species or genera were sampled periodically between 1998 and 2006: *Acropora* spp, *Echinopora gemmacea*, *Favia* spp, *Galaxea fascicularis*, *Hydnophora microconos*, *Montipora aequituberculata*, *Pavona decussata*, *Pocillopora damicornis*, *Pocillopora eydouxi*, *Porites cylindrica* and *Porites lutea*. Coral fragments were collected from 5 replicate colonies of each of the 10 species during the north-east and south-east monsoon seasons from 2004 to the present and zooxanthellae densities were measured. The study did not find regular seasonal fluctuations in zooxanthellae densities for all species. Species with faster growth rates displayed higher densities during the north-east monsoon while those with slower growth rates displayed higher densities during the south-east monsoon. The lack of regularity in fluctuations could be due to Mombasa's low latitude and therefore less pronounced temperature fluctuations. It is possible that the zooxanthellae density of corals closer to the equator are not influenced by the lower seasonal variability of environmental factors.

Appendix 11.1 Zooxanthellae density for normally coloured corals categorized by season and year (mean x10^6 (standard error))

Species	Season*	1998	1999	2000	2002	2004	2005	2006
Acropora spp	NEM		0.7 (0.1)	0.9 (0.1)	1.5 (0.4)	1.2 (0.2)	1.1 (0.1)	1.3 (0.2)
	SEM	1.5 (0.1)	0.8 (0.1)	0.4 (0.1)	1.4 (0.2)	2.0 (0.2)	1.7 (0.4)	1.1 (0.2)
Echinopora gemmacea	NEM					1.4 (0.3)	1.4 (0.2)	1.5 (0.2)
	SEM					3.8 (1.1)	2.8 (0.3)	1.3 (0.1)
Favia spp	NEM		1.1 (0.2)	1.3 (0.2)	2.3 (0.2)			
	SEM	2.1 (0.2)	1.2 (0.1)	0.7 (0.1)	1.3 (0.2)			
Galaxea fascicularis	NEM					1.6 (0.4)	6.4 (1.5)	1.9 (0.3)
	SEM					2.4 (0.3)	2.2 (0.4)	1.7 (0.5)
Hydnophora microconos	NEM					2.7 (0.5)	1.6 (0.2)	1.1 (0.2)
	SEM					2.6 (1.0)	2.3 (0.6)	2.4 (0.5)
Montipora aequituberculata	NEM					4.6 (0.7)	4.1 (0.3)	1.8 (0.3)
	SEM					2.4 (0.6)	4.3 (0.8)	3.4 (0.6)
Pavona decussate	NEM		1.5 (0.2)	1.3 (0.1)	4.0 (1.4)	1.6 (0.3)	1.6 (0.1)	3.0 (0.7)
	SEM	1.7 (0.2)	1.0 (0.2)	0.6 (0.1)	1.0 (0.3)	1.5 (0.5)	1.8 (0.3)	1.4 (0.3)
Pocillopora damicornis	NEM				1.0 (0.1)	0.3 (0.1)	1.2 (0.3)	1.0 (0.1)
	SEM				0.6 (0.1)	1.9 (1.5)	1.1 (0.2)	0.6 (0.1)
Pocillopora eydouxi	NEM					1.9 (0.4)	1.0 (0.2)	1.7 (0.6)
	SEM					1.4 (0.3)	1.7 (0.3)	1.2 (0.2)
Porites cylindrica	NEM		2.0 (0.1)	2.0 (0.1)		2.3 (0.2)	2.1 (0.3)	2.8 (0.6)
	SEM			1.3 (0.3)	1.2 (0.4)	2.1 (0.3)	1.8 (0.1)	1.3 (0.1)
Porites lutea	NEM							
	SEM	3.5 (0.6)	4.1 (0.7)	2.8 (0.3)	3.9 (0.7)	4.2 (0.4)	3.5 (0.4)	4.9 (0.7)

* NEM (November 1 to April 30) / SEM (May 1 to October 31)

Appendix 11.2

Zooxanthellae density in normally coloured corals during four selected periods (mean x 10^6 (standard error)). Significance levels of ANOVA between seasons are given for each species (n.s.=not significant)

Species	NEM*	NEMLate*	SEM*	Trans.*	ANOVA
Acropora spp	1.0 (0.1)	0.9 (0.1)	0.9 (0.0)	0.5 (0.1)	p<0.001
Echinopora gemmacea	1.5 (0.1)	1.0 (0.2)	2.3 (0.4)	2.3 (0.5)	p<0.05
Favia spp	1.8 (0.1)	2.1 (0.3)	1.3 (0.1)	0.5 (0.2)	p<0.001
Galaxea fascicularis	6.8 (1.5)	2.7 (0.8)	2.9 (0.4)	3.2 (1.2)	p<0.05
Hydnophora microconos	1.7 (0.2)	2.0 (0.4)	2.2 (0.3)	1.9 (0.2)	n.s.
Montipora aequituberculata	2.3 (0.5)	4.3 (0.4)	1.3 (0.2)	0.5 (0.1)	p<0.001
Pavona decussata	1.8 (0.2)	1.2 (0.2)	1.2 (0.1)	1.4 (0.2)	p<0.05
Pocillopora damicornis	1.0 (0.1)	0.4 (0.1)	1.0 (0.4)	2.2 (0.8)	p<0.10
Pocillopora eydouxi	1.4 (0.3)	1.2 (0.3)	1.5 (0.1)	1.5 (0.2)	n.s.
Porites cylindrica	1.9 (0.1)	1.4 (0.3)	1.4 (0.2)	1.6 (0.6)	p<0.01
Porites lutea	2.5 (0.1)	2.4 (0.3)	2.3 (0.2)	4.1 (0.4)	p<0.01

* NEM: December 16-March 15
NEMLate: March 16-April 30
SEM: May 1-October 31
Trans(ition) between SEM and NEM: November 1-December 15

12

Holothurian population resource assessment: Mombasa Marine National Park and nearby unprotected reefs

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Introduction

There are many marine invertebrate resources that are a source of livelihood to coastal communities such as crustaceans, sea urchins and sea cucumbers. Holothurians (sea cucumbers) are highly diverse, elongate, exclusively marine invertebrates that commonly inhabit tidal flats, seagrass beds and coral reefs (Richmond 1997; Samyn 2000; Marshall *et al.* 2001). They play crucial roles in the recycling of nutrients and bioturbation processes in marine benthic communities (Uthicke 1999, 2001; Bruckner *et al.* 2003). Approximately 1400 species are reported worldwide, about 140 species of which occur in the Western Indian Ocean (WIO) (Humphreys 1981; Richmond 1997; Conand & Muthiga 2007). Sea cucumbers have been harvested for centuries in Asia, and have become an important source of income for coastal fishing communities worldwide (Conand 1990, 2004). The commercial value of a species is generally determined by its size, and thickness and quality of the body wall and abundance in shallow waters.

Sea cucumbers are vulnerable to overexploitation due to their sedentary nature and shallow water habitat preferences, and form an important multi-species

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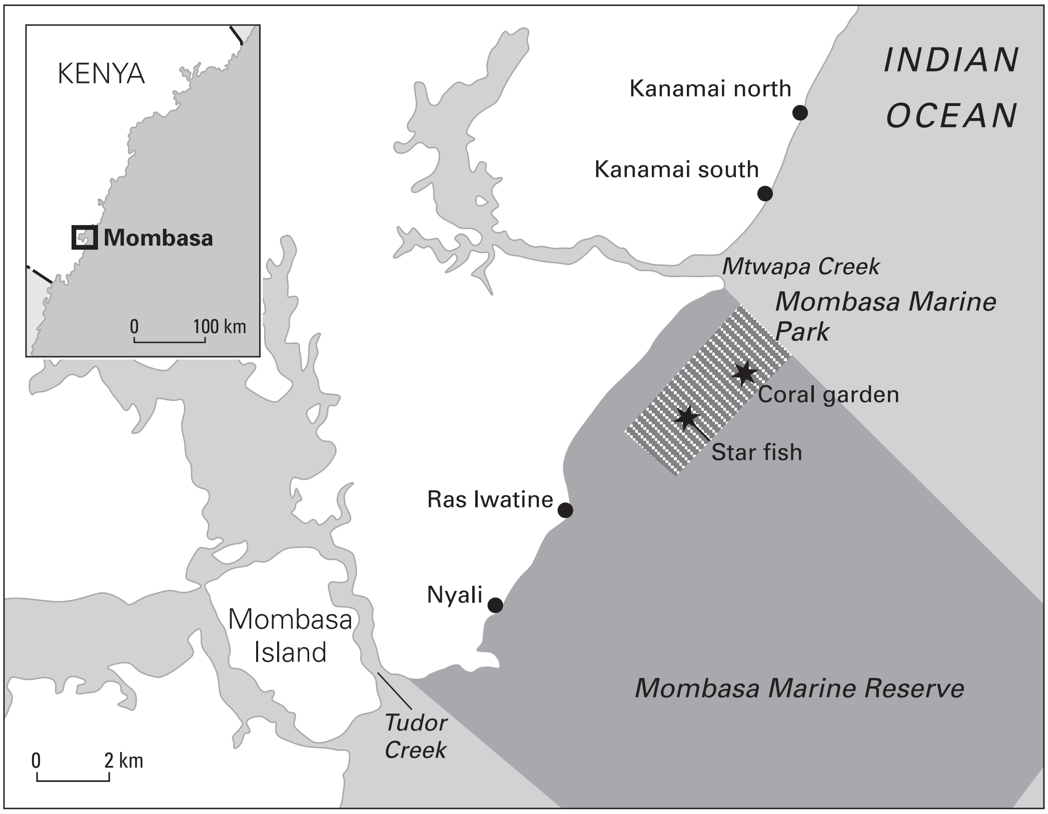
invertebrate fishery. Heavy fishing pressure can easily cause decline in the density and biomass of the target species and populations may not recover if they fall below a critical biomass. Most holothurians in the tropics and subtropics are broadcast spawners with high fecundities (Bruckner 2004; Lovatelli *et al.* 2004). Their fertilization success is highly dependent on population density (Bruckner *et al.* 2003).

The sea cucumber fishery in Kenya has experienced rapid changes in the last one and a half decades due to high demand for bêche-de-mer on the international market, and the higher prices offered (Muthiga & Ndirangu 2000). The fishery is primarily artisanal and sea cucumbers are collected and sold to exporters for foreign markets (holothurians are not part of the Kenyan diet). This previously unimportant and poorly regulated fishery has transformed into one where fishers are investing a higher effort resulting in a decline in catches. Collection is either done by hand while walking in nearshore waters and reef flats during low water or by SCUBA diving in deeper waters. The leading sea cucumber collection districts are Kwale and Lamu although some collection is also done in Malindi, Kilifi and Mombasa districts and fishing occurs throughout the year (Marshall *et al.* 2001). The Kenyan sea cucumber fishery exports increased from 79 metric tonnes (1989) and peaked at 277 mt (1992), and has subsequently exhibited decreasing trends (Muthiga & Ndirangu 2000; Marshall *et al.* 2001). Although licenses are required for the collection or trade of sea cucumbers (GOK 1991), it has been difficult to make a thorough assessment of production due to inconsistencies and poor collection and storage of catch statistics by the concerned authorities.

Any reports of increasing scarcity of sea cucumbers should be of concern from both a biological and socio-economic point of view. The abundance of sea cucumbers depends on various natural conditions, such as habitats, their community structure and oceanic physico-chemical conditions as well as the type of management employed. The management of the holothurian resources should balance sustainable exploitation and conservation of marine habitats that they inhabit. In order to evaluate the status of sea cucumbers it is necessary to determine their population distribution, density, abundance, diversity and species richness patterns, and how these parameters are affected by management, habitat and substrate types.

The study aimed at examining the factors that determine population density and structure of the holothurian population in the Mombasa area. It was hypothesized that factors including management, habitat, substrate categories and topographic complexity (rugosity) play a role in regulating the population and community structures of these holothurian populations.



Map 12.1 Mombasa-North coast showing study sites

Study area

The study area covered a stretch of approximately 21km along the Mombasa coast from Nyali to Kanamai north and is bordered by a nearly continuous fringing reef that lies between 100m and 3km from the shore (McClanahan 1989). Six sites were surveyed (Map 12.1), including fully protected sites at Mombasa Marine National Park (two sites) and partially protected sites at Nyali and Ras Iwatine in the marine reserve to the south of the marine park (two sites) and unprotected sites at Kanamai to the north (two sites). All sites had similar reef structure but differed in respect of substrate cover in the reef lagoons.

Method

Sampling was undertaken during daylight low tides: walking on reef flat and snorkeling within lagoons (only shallow (≤ 2m) reef lagoons were sampled). Sampling was undertaken at different times for each reef between November 2005 and February 2006.

Two quantitative survey methods were used: the belt transect (three 100m by 4m i.e. 400m^2 replicates per habitat per site) and the search sampling (1hr random walk or swim) method, which is estimated to cover approximately 1000m^2 (McClanahan 1989). The two methods allowed for calculation of density, diversity, distribution, abundance and species richness. Coral boulders were overturned and examined whenever encountered on the reef flat. The detailed sampling procedures for the two methods have previously been described by McClanahan (1989), Conand (1990) and McClanahan & Muthiga (1992).

The search sampling method results have been used in this study only in instances where there is concurrence with the results from belt transect method due mainly to two major weaknesses of the method; (1) it has no absolute measure of density and (2) the possibility of observer bias. Rates of movement and fields of vision should be quantified, and compared between observers where possible, before beginning of data collection. The method however, has the merit of time efficiency in the intertidal zone, allowing observer (s) to cover large areas within reefs and complete large surveys within reasonable time limits. Ecological measures like species richness and diversity have been calculated from the results of the surveys. Substrate cover and topographic complexity of each site (only reef lagoons) were determined by the 10m-line intercept transect method described in McClanahan & Obura (1995).

Data was initially tested for normality using cumulative frequency distributions (Sokal & Rohlf 1981). Coefficients of dispersion (CD=s^2/x) of sea cucumber population density estimates were analysed to determine the species spatial distributions between management categories and habitats (i.e. random, CD=1;

clumped, CD>1; repulsed, CD<1). Density (#/m^2 or #/h) and diversity (modified Simpson's Index; $D=1-\sum(n_i/N_t)^2$); where 1=highest and 0=lowest diversity), were calculated for management regimes and habitats. Simpson's Index was used because it can deal with small sample sizes (Routledge 1979), hence more representative of diversity when densities are low.

Species richness was determined by species-time and species-individual curves. Regression analysis was done to express species richness in terms of time (t) and individuals (I) using the equation $S=Cx^z$ (to obtain the C and z constants; where x is time in h (t) or individuals (I), and S is the number of species). Data from protected and unprotected reef sites were pooled for comparisons of population distribution, abundance, density, diversity and species richness. Multivariate analysis (with nested ANOVA) was performed to test how substrate cover types and rugosity relate to the sea cucumber population parameters under the two different management categories.

Table 12.1a Holothurian population attributes categorized by management and habitat (belt transects)

	Density (# /400m^2)	Mean abundance	Total abundance (# /area)	Distribution (CD)	Diversity index	# Species
PRF	6.67	20	40	0.12	0.66	3
PRL	15.33	46	92	2.50	0.67	5
URF	2.58	7.75	31	0.41	0.63	4
URL	5.42	16.25	65	1.96	0.56	8

Table 12.1b Holothurian population attributes categorized by management and habitat (search sampling)

	Density (# /hr)	Mean abundance	Total abundance (# /time)	Distribution (CD)	Diversity index	# Species
PRF	38	38	76	0.75	0.78	5
PRL	127	127	254	40.88	0.58	7
URF	35.75	35.75	143	8.52	0.64	6
URL	41	41	164	13.50	0.58	7

PRF=Protected reef flat
PRL=Protected reef lagoon
URF=Unprotected reef flat
URL=Unprotected reef lagoon

Results

Data indicated a normal distribution pattern at the 0.05 significance level for both the belt transect and search sampling methods. Results of belt transect and search sampling for holothurian population attributes (abundance, density, distribution, diversity and species richness) under different management regimes (protected vs. unprotected) and different habitats (reef lagoons and reef flats) are presented in Table 12.1. In general, more species were encountered by the search sampling method than by the belt transect method. The holothurian assemblage was characterized by high diversity and high variability in species composition and density. Densities were higher in the reef lagoons (16-46) and protected areas (20-46) than reef flats (7.75-20) and unprotected sites (7.75-16.25) respectively (Table 12.1). Diversity, measured by the Simpson's Index, was high (>0.56) for most sites and there were no significant differences between the diversity between the management categories or the habitats. A comparison of the diversity between protected (D=0.66 (0.007) and unprotected sites (D=0.59 (0.036) showed a statistically significant difference. Tests of between-subjects effects for abundance and densities showed that both management and habitat had significant effects for both survey methods used. However, management had a stronger influence in controlling the population densities and abundance of sea cucumbers in both search sampling (p=0.000 vs. p=0.001) and belt transects (p=0.001 vs. p=0.016).

A total of ten different species belonging to 2 orders (Aspidochirotida and Apodida) and 3 families (Holothuriidae, Stichopodidae and Synaptidae) were recorded, the four most abundant being *Holothuria leucospilota*, *H. atra*, *Synapta maculata* and *Stichopus chloronotus* in descending order. Three least abundant species were *H. hilla*, *H. impatiens* and *Stichopus hermanni*. High densities (6.67 /400m^2) of *Synapta maculata* were observed within the shallow (ca.0.3m deep) Kanamai reef lagoon. The number of species ranged from 3-7 within the protected sites (*H. leucospilota* dominating) and 4-8 at the unprotected (*S. maculata* dominating) sites. In general, there was a slightly higher number of species occurring in unprotected habitats although the difference was not significant, but in lower abundance and/or densities than at protected sites (Table 12.1). Whereas *H. atra* had the highest relative abundance (30.30%) on the protected reef flats, the unprotected reef flats were dominated by *H. leucospilota* (51.61%). The dominant species within the protected and unprotected lagoons were *H. leucospilota* (45.65%) and *S. maculata* (63.08%), respectively.

Apart from *S. maculata*, all the other nine species recorded in the study area have a commercial value, varying from medium to low (Table 12.2). The overall average density of sea cucumbers of commercial value in the study area was

Table 12.2 Species composition of commercial sea cucumbers sampled in belt transects in the study area

Scientific name	Common name	Commercial value	Density (# /400m^2)	% composition by abundance
Actinopyga mauritiana	Yellow surffish	Medium	0.19	3.74
Bohadschia atra	Tigerfish	Medium	0.11	2.14
Bohadschia subrubra	Bohadschia white belly	Medium	0.14	2.67
Holothuria atra	Black sea cucumber	Low	1.47	28.34
Holothuria hilla	Tigertail	Low	0.03	0.53
Holothuria impatiens	--	Low	0.03	0.53
Holothuria leucospilota	Lollyfish	Low	2.22	42.78
Stichopus chloronotus	Greenfish	Medium	0.97	18.72
Stichopus hermanni	Curryfish	Medium	0.03	0.53

5.20/400m^2. The most abundant commercial species in the study area was the low value *H. leucospilota* (42.78%) that occurred at a density of 2.22/400m^2 followed by the lollyfish (*H. atra*) with a relative abundance ~28%, followed by the greenfish (*S. chloronotus*) at ~18% and the yellow surffish (*A. mauritiana*) ~4% (Table 12.2). The least abundant commercial value species were *H. hilla*, *H. impatiens* (both low value species) and the medium value *S. herrmanni*, that had a relative abundance of <1%.

The overall density of commercial sea cucumbers in protected sites (11.00 /400m^2) was higher than unprotected sites (2.29/400m^2). The three most abundant species in protected sites were *H. leucospilota* (4.33/400m^2; 39.39%), *H. atra* (3.33/400 m^2; 30.30%) and *S. chloronotus* (2.92/400m^2; 26.52%), whereas the three most abundant species in unprotected sites were *H. leucospilota*, *H. atra* and *A. mauritiana*, at densities and relative abundance of 1.17/400m^2 (50.91%), 0.54/400m^2 (23.64%) and 0.30/400m^2 (12.73%) respectively. A comparison of the densities of holothurians of commercial value between habitats under different management regimes indicated greater densities in protected than unprotected sites while reef lagoons had almost twice the density of reef flats (6.44/400 vs. 3.94/400m^2 respectively).

A comparison of the coefficients of dispersion between protected and unprotected sites indicated clumped distribution (CD=1.63) in protected sites and repulsed distribution (CD=0.82) in unprotected sites. Pooled habitat data indicated repulsed distribution on reef flats (CD=0.43) and clumped distribution (CD=1.29) in lagoons. There was a positive relationship between the number of species and the number of individuals encountered and the duration spent on sampling. Data fit well to species-individual and species-time curves (r values were above 0.60, but averaged 0.794). Species-individual and species-time curves indicated that species richness within management categories did not reach an asymptote. Reef lagoons were the only habitats with significant community structure differences between protected and unprotected reefs (Table 12.1).

The topographic complexity (rugosity) was higher in protected reef lagoons (1.32) than unprotected lagoons (1.11). A comparison of the major substrate categories (hard coral, algal turf, sand) with seacucumber population parameters (abundance and density, distribution, diversity) and topographic complexity indicated strong relationships (r >0.80; Table 12.3). There was no sigificant relationship between abundance/density, distribution and diversity with calcerous, fleshy or coralline algae and soft coral. Rugosity had a positive significant correlation with the sea cucumber abundance and densities (p<0.005 for both abundance and density; Appendix 12.1). The nine broad substrate categories indicated high variability between lagoons under different management regimes. Coral cover was higher in protected than unprotected areas, whereas algal turf, sand and seagrass were dominant in the unprotected sites.

The correlation matrix for the holothurian fauna population attributes and the various substrate categories indicate both positive and negative significant relationships (Appendix 12.1). Hard coral had a positive significant (p=0.04) correlation with both density and abundance, whereas algal turf (p=0.049) and

Table 12.3 Nested ANOVA for population parameters and substrate types

S/No.	Dependent variable	Predictor			r	F	p	t
1.	Abundance and/or density	Hard coral			0.832	9.00	0.040	3.00
2.	Distribution (CD)	Sand			0.893	15.74	0.017	3.967
		Sand and algal turf	Sand and algal turf		0.977	32.12	0.009	-
				Sand	0.893	-	0.021	4.447
				Algal turf	-0.813	-	0.005	-3.260
3.	Diversity (Simpson's Index)	Sand			0.919	21.88	0.009	-4.678
4.	Topographic complexity (Rugosity)	Hard coral			0.820	8.19	0.046	2.863
		Hard coral and sand	Hard coral and sand		0.971	25.01	0.013	-
				Hard coral	0.820	-	0.006	7.046
				Sand	-0.084	-	0.032	-3.793

sand (p=0.017), showed negative and positive significant correlations respectively, with the coefficient of dispersion of the holothurian density estimates. Sand also correlates negatively, but significantly (p=0.009) with sea cucumber species diversity.

Discussion

Bêche-de-mer (the processed body wall of sea cucumbers) is in high demand principally in China and South-east Asia. The main world markets for bêche-de-mer are Hong Kong and Singapore, whereas smaller markets include Korea, Taiwan and Malaysia (Conand 1990; Marshall *et al.* 2001). It is likely that the current high demand for bêche-de-mer will increase, partly due to the high economic growth in China and will have an increasing negative impact on the sea cucumber resources of Kenya. This suggests that management of wild stocks is crucial to the maintenance of these resources now more than ever. Effective management relies on a knowledge of the population dynamics of target species. The challenge of managing this resource in Kenya has been the lack of information on sea cucumber species especially species of commercial value (Muthiga *et al.* 2007).

The results of the present study show that the shallow reef-associated holothurian fauna of Mombasa, like other tropical Indo-Pacific regions, is typified by low density and high variability and diversity (Marshall *et al.* 2001; Bruckner 2004). With the exception of a new species *Holothuria arenacava* (Samyn *et al.* 2001), to date found only in Kenya, there is no evidence of endemism within the holothurian assemblage in Kenya. Samyn & Berghe (2000) listed 32 species in deep and shallow waters, in the Kiunga Marine Reserve in northern Kenya. The ten species that were recorded within the narrow expanse of the study area, are a good indication of the sea cucumber resource within the intertidal coral reef areas of the Kenyan coast from Nyali north to Kanamai. The high variability recorded in the species composition between reef sites, may have been caused by unaccounted for differences in reef height, water depth and aspect/wave energy which may have overridden the reef zone distinction.

Despite the species composition differences, species richness and diversity were less pronounced between sites under different management regimes i.e. protected vs. unprotected locations. Differences were also reported between reef habitats with both sampling methods indicating more species in reef lagoons than reef flats. Many common lagoon-inhabiting holothurian species generally are reported to have large adult sizes compared to reef flat species. Reef lagoon environments expose sea cucumbers and other invertebrates to greater predation pressure than reef flats (McClanahan & Muthiga 1989; Pouget 2005) and larger adult body sizes have been hypothesized to be a form of predator avoidance life-history strategy (Mangion *et al.* 2004). At least nineteen species of fish including sharks and trigger-fish, gastropods, loggerhead turtles and starfish have been reported to prey on sea cucumbers (Conand 1990; Marshall *et al.* 2001). With the exception of sharks and loggerhead turtles, the other predatory taxon were common within the study area. Predation may therefore be one of the mechanisms controlling sea cucumber populations in the area, but until predation studies and species-focused life histories and population dynamics studies are undertaken, the exact role of predation cannot be validated.

Some species of sea cucumbers like *H. leucospilota* and *H. atra* that were dominant in the present study, are ubiquitous throughout their distribution range and may not be strongly associated with any particular location/site. Such holothurian fauna may not be a group of highly interacting species forming a community (McClanahan 1989), but rather are affected by external biological and physical factors like water movement, desiccation stress, recruitment, and predation by other taxonomic groups that affect their distribution and limit their population densities. Other species of holothurians have specific diet, depth and substrate requirements (Bruckner 2004) that allow for resource partitioning mechanisms that support species coexistence. It is, however, also possible that physical factors such as intense storms may keep these species at densities below levels that require interspecific coexistence mechanisms. Since the coral reefs of the area rarely experience large storms and waves apart from seasonal monsoons of low intensity (McClanahan 1988), it is expected that storms are not an important influence in the area.

Sites within the marine park that were fully protected from fishing had higher densities of sea cucumbers than unprotected sites which indicates that protection from exploitation was effective in conserving the holothurian fauna in the Mombasa marine park and supports findings from other studies in Kenya (Muthiga & Ndirangu 2000) and in the Solomon Islands (Lincoln-Smith *et al.* 2000). Some shallow water medium value species such as *A. mauritiana*, *Bohadschia atra*, *B. subrubra* and *S. herrmanni* occurred at relatively low densities, which could be a sign of local depletion although this is difficult to verify since data prior to closure from fishing in 1991 were not available. Other species such as *H. atra* and *H. leucospilota* that are of low commercial value occurred at relatively higher abundances in both the protected and unprotected sites indicating that these are probably not currently overfished. The global increased demand for bêche-de-mer products has been shown to cause a shift in collection from the more scarce high to mid-values species to low value species across the Indo-Pacific (Conand 2004; Lovatelli *et al.* 2004). This has also been reported in Kenya (Muthiga & Ndirangu 2000), Mozambique and Tanzania (Marshall *et al.* 2001).

In the present study, abundance and diversity were strongly correlated with the substrate cover (especially hard coral cover) and topographic complexity (rugosity), supporting the hypothesis that habitat variables play a role in sea cucumber abundance and distribution (Long & Skewes 1997; Conand 1990). High topographic complexity (higher in protected than unprotected sites), has been reported to be correlated with higher densities and diversity in other sedentary and/or less mobile marine invertebrates such as molluscs in Kenya (McClanahan 1989). Topographic complexity serves to create refuge from predators and also diversifies niches. It is therefore not inconceivable that full protection of the Mombasa marine park that resulted in the increase in hard coral cover from 8% prior to full protection to 45% by 1997 contributed to the increase in the density of sea cucumbers (Muthiga 2007). This is also supported by a study by Conand (1990) that showed that species diversity, density and biomass of sea cucumbers increased with the gradient from the open sea to the coast, and from outer slopes to inner reef lagoons where topographic complexity is greater.

Several studies have shown that the establishment of relatively small (1 to 10 km^2) marine protected areas (MPAs) in the tropics resulted in consistently higher biomass of the relatively site-attached species (like the sea cucumbers) in the MPAs than in the adjacent fished areas (McClanahan *et al.* 1989; Polunin & Roberts 1993; Jennings & Kaiser 1998). The establishment of the Mombasa MPA fits this model and the density and biomass of other key coral reef associated marine species including finfish have also increased to levels comparable to the older MPAs in Kenya (McClanahan 1994, 2000). However, small MPAs may not operate as desired if fishing effort is not effectively controlled outside the protected areas or if the protected habitat is impacted by pollution (Obura 2001), and other anthropogenic activities. Also, populations may fail to recover because spawning biomass may have been reduced below optimal levels even after fishery closures. For example, some studies have shown that populations of sea cucumbers in overexploited fishing grounds may require as much as 50 years in the absence of fishing pressure to recover (Bruckner *et al.* 2003). The density of some high to mid-value commercial species was relatively low in the Mombasa marine park and it is not known whether this density is below optimal levels, hence continued monitoring of stocks will be required to track recovery.

The results of this study show that the Mombasa MPA is effective in protecting sea cucumber biomass since the density of sea cucumbers in the MPA is significantly higher than adjacent fished sites. Whether protection will continue to increase the biomass of sea cucumbers within the MPA overtime however remains to be seen. Full protection, may not prove viable in protecting sea cucumber biomass along the rest of the Kenyan coast due to socio-political limitations in the establishment of additional MPAs, an over dependence by fisher communities on currently fished areas and weak enforcement within reserves (McClanahan *et al.* 2005). In addition, there is strong evidence that a significant proportion of the sea cucumber population should be protected to be of any utility for ensuring sustainable exploitation of the resource which necessitates large areas of protection (Uthicke *et al.* 2004). Given these uncertainties, and the difficulties in identifying, establishing and enforcing closed areas, additional management options should be considered. Currently due to concerns about the fishery, a ban on the use of SCUBA for collection of sea cucumbers is in force (Legal notice No. 214, Part 2 (c), Cap. 378 of 2003). Fishers, also voluntarily limit collection to individuals that are larger than 20cm. These measures are reported to be ineffective due partly to a lack of enforcement and a low level of awareness of the prohibition by fishers (Muthiga & Ndirangu 2000; Beadle 2005). In order to restore the severely overexploited sea cucumber stocks along the Kenyan coast, corrective measures to reduce the current overfishing are required as well as other management interventions such as restoration through mariculture and restocking.

Conclusion

This study has shown that there is a significant resource of commercial sea cucumbers throughout the study area, and that the shallow water-medium value species probably suffer local depletions. It is also apparent that MPAs enhance conservation and management of the holothurian resources since abundances are greater within protected than unprotected sites. Habitats (reef lagoons and flats) also influence sea cucumber populations (lagoons being richer than flats in sea cucumber resources), as well as the specific substrate cover types examined in this study.

Although this study is limited in spatial scope, the information derived corroborates findings from previous studies (Muthiga & Ndirangu 2000; Marshall *et al.* 2001) and support the following recommendations: (1) that the MPA should work with the fisheries department to improve the management of the resources in the marine reserves; (2) that further studies should be conducted on stocks and reproduction of key commercial sea cucumber species that will be the basis for development of management measures such as total allowable catch (TAC), and minimum size limits (MSL); (3) that a monitoring program should be developed to assess the performance of the current management strategies including logbooks and catch datasheets that include biological data such as size and species of sea cucumbers.

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Summary

A comparative survey of shallow water (< 2m) holothurian fauna was undertaken to determine patterns of distribution, abundance and diversity, and the possible role of management, habitat (reef flat and lagoon), topographic complexity and substrate cover, in six sites within protected and unprotected reefs near Mombasa. Visual surveys were done by use of belt transects (100m by 4m) and search sampling (1-h time counts), and 10m-line intercept transects for substrate cover and rugosity. A total of ten different species belonging to 2 orders (Aspidochirotida and Apodida) and 3 families (Holothuriidae, Stichopodidae and Synaptidae) were recorded, four most abundant being *Holothuria leucospilota*, *H. atra*, *Synapta maculata* and *Stichopus chloronotus* in descending order. Three least abundant species were *H. hilla*, *H. impatiens* and *Stichopus herrmanni*. The total holothurian fauna was typified by low densities and high diversity, although no significant differences occurred in diversity (Simpson's Index) between management and habitats. Protected reefs had higher densities on the reef flats and in lagoons than the unprotected reefs. Between-subjects effects analysis indicated that management was more powerful than habitat in controlling holothurian population densities. Rugosity was higher in the MPA than unprotected sites, and there was a positive significant correlation between rugosity and sea cucumber densities and abundance. The nine broad substrate categories indicated high variability between lagoons under different management regimes. Coral cover was higher in protected than unprotected areas, whereas algal turf, sand and seagrass were dominant in the unprotected sites. Hard coral had a positive significant correlation with sea cucumber density, whereas algal turf and sand, showed negative and positive significant correlations respectively. Sand also correlated negatively, but significantly with sea cucumber species diversity. Apart from *S. maculata*, all the other nine species recorded in the study area have commercial value, varying from medium to low. The overall average density of sea cucumbers of commercial value in the study area was 5.20/400 m^2. The most abundant commercial species in the study area was the low value *H. leucospilota*. Commercial sea cucumber densities in protected and unprotected sites were 11.00/400m^2 and 2.30/400m^2, respectively. Resource assessment of holothurian populations can be useful for designing, developing and evaluating sea cucumber fishery management plans and strengthening conservation of the resource.

Appendix 12.1 Correlation matrix (Pearson correlations) for sea cucumber population parameters and substrate categories*

	1. Density	2. Distribution	3. Diversity	4. Abundance	5. No. species
1. Density (# /400 m2)	- (n.s.)				
2. Distribution (CD)	.362 (n.s.)	-			
3. Diversity (Simpson's Index)	.149 (n.s.)	-.855* (p=.03)	-		
4. Abundance (# /area)	1.000** (p=.000)	.362 (n.s.)	.149 (n.s.)	-	
5. No. of species (# Sp.)	.75 (n.s.)	.125 (n.s.)	.359 (n.s.)	.75 (n.s.)	-
Hard coral	.832* (p=.04)	.712 (n.s.)	-.354 (n.s.)	.832* (p=.04)	.36 (n.s.)
Algal turf	-.627 (n.s.)	-.813* (p=.049)	.538 (n.s.)	-.627 (n.s.)	-.241 (n.s.)
Sand	.064 (n.s.)	.893* (p=.017)	-.919** (p=.009)	.064 (n.s.)	-.187 (n.s.)
Rugosity	.944** (p=.005)	.22 (n.s.)	.238 (n.s.)	.944** (p=.005)	.578 (n.s.)

* Significant correlations are highlighted in grey (n.s.=not significant). There were no significant correlations with any of the population parameters and the substrate categories of Calcareous Algae, Fleshy Algae, Coralline Algae, Seagrass, Soft Coral and Sponge

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Evaluating the effectiveness of management of the Kisite-Mpunguti marine protected area

N.A. Muthiga[1]

Introduction

Management of marine and coastal resources in Kenya presents particular challenges because of the governments need to balance the reduction of poverty while providing for the protection of biological diversity (Muthiga *et al*. 1999, 2000). Nevertheless, the Kenyan government is committed to sustainable management of marine and coastal resources under the framework of the Nairobi Convention and has established several marine protected areas (MPAs) for this purpose (Muthiga 1998).

Marine protected areas have been shown to be effective in the protection of marine species and are increasingly being used as a fisheries management tool (Roberts & Polunin 1991; Allison *et al*. 1998; McClanahan & Arthur 2001). In Kenya, higher abundances, biomass and diversity of coral reef finfish have been reported in MPAs than in unprotected reefs (McClanahan & Shafir 1990; McClanahan 1994; McClanahan & Arthur 2001). Irrespective, whether an area is being managed for fisheries or for biodiversity protection, certain key elements are essential for effective management including adequate human, financial and infrastructural resources as well as the mechanisms and processes that lead to the achievement of management objectives (Pomeroy *et al*. 2004). Given that the Kenyan government has made substantial investments in the establishment of

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MPAs, there is need to ensure that these are providing the benefits for which they were established.

Kenya has six MPAs, including four no-take marine parks and six restricted-fishing marine reserves (Muthiga 1998), that cover approximately 9% of the coastal shelf (Wells *et al*. 2007). Although these MPAs have been in existence since the 1960's and are relatively well resourced – except for the Diani-Chale MPA – in terms of staff and infrastructure (Muthiga 1998; Muthiga *et al*. 2000), it is only recently that attention has been given to the effectiveness of their management (Wells 2004; Muthiga 2006). The MPA management plans that are a prerequisite and key component of management effectiveness evaluations were only developed in 2000 (Weru *et al*. 2001).

In 2003, Kenyan MPAs were part of a regional management effectiveness evaluation (MEA) under the auspices of the Group of Experts on Marine Protected Areas (GEMPA) of the Nairobi Convention, where training in the concepts and methodologies of MPA management effectiveness assessments was conducted (Wells 2004). Management effectiveness assessments were subsequently carried out in all Kenyan MPAs (except the Diani-Chale MPA) between 2003 and 2005. The findings of the MEAs of the Malindi and Watamu MPA complex and the Mombasa MPA have been reported in Muthiga (2006, and 2007 respectively). The present study details the evaluation of the management of Kisite-Mpunguti MPA to determine whether the management objectives are being met and to identify challenges and shortcomings of the management systems and processes. The ultimate goal of the study was to establish a baseline of information that will ultimately be useful for improving management.

Study sites

The evaluation was carried out in the Kisite-Mpunguti MPA (Map A, p.2) that includes the Kisite Marine National Park covering an area of 28 km^2 and the Mpunguti Marine National Reserve that covers an area of 11 km^2 (Weru *et al*. 2001). Tourism and fishing – the main activities – were concentrated around 4 coral islands; Kisite and Mako Kokwe in the park, and Mpunguti Juu and Mpunguti Chini in the reserve. The coral islands are surrounded by coral reefs that slope to a depth of 10 to 15 meters to sandy bottoms that are covered by seagrass beds on the leeward sides. The MPA is managed by the Kenya Wildlife Service (KWS), a state corporation that is responsible for managing all protected areas in Kenya.

Method

The assessment process was adapted from Pomeroy *et al*. (2004) and included collection of information from published scientific studies and reliable reports and evaluating this information against the management objectives as detailed in the MPA plan (Weru *et al*. 2001). Two goals were selected from the MPA plan namely: Goal 1) enhancing biodiversity conservation through participatory approaches and Goal 2) promoting sustainable nature tourism. One objective was selected for each goal: Goal-Objective 1) maintaining the variety of marine life and Goal-Objective 2) encouraging local tourism - based on the availability of data. For each objective, biophysical, socio-economic and governance indicators were selected as detailed in Pomeroy *et al*. (2004), in turn at least three parameters were selected as a measure of these indicators (Table 13.1).

Results are presented as a narrative to show the changes that occurred as regards the respective indicators. In addition, a scoring system was designed (Appendix 13.1) to gauge progress towards achieving the MPA objectives: a

Table 13.1 Selected biophysical (B), socio-economic (S) and governance (G) indicators matched against the parameters that were used to evaluate each indicator*

Indicators	Parameters
Biophysical indicators	*Biophysical parameters*
B1. Habitat distribution and complexity	1. Hard coral cover and topographic complexity
B2. Focal species abundances	2. Coral reef finfish and sea urchin abundances and biomass
B3. Food web integrity	3. Sea urchin predation rates, urchin predator abundances and fish abundances
Socio-economic indicators	*Socio-economic parameters*
S1. Local marine resource use patterns	1. Participation of community in fishing and tourism activities
S2. Community and business infrastructure	2. Contribution of MPA to community and business infrastructure
S3. Distribution of formal knowledge to community	3. Types and number of awareness and environmental education activities
Governance indicators	*Governance parameters*
G1. Availability and allocation of MPA administrative resources	1. Infrastructure, staff and park revenue
G2. Clearly defined regulations and enforcement	2. MPA regulations and enforcement schedules
G3. Level of stakeholder participation	3. Formal and informal mechanisms for stakeholder participation

* Adapted from Pomeroy *et al.* 2004

plus (+) sign indicated a positive trend, a minus (-) sign indicated a negative trend, an equal (=) sign indicated the change was both positive and negative, and a question mark (?) indicated that the change was unknown. It should be noted that these scores were not intended to be used for ranking among MPAs but rather to allow each MPA to assess its performance against its stated objectives.

Results

The results for each indicator are summarized and scored in Appendix 13.1 and more details are provided below.

BIOPHYSICAL INDICATORS

Habitat distribution and complexity

Hard coral cover dominated the substrate and was higher in the MPA than in unprotected reefs (McClanahan *et al*. 1999). Samoilys (1988) reported less coral cover at sites in Mpunguti (24 ± 7.1) than at Kisite (30 ± 8.4) as did University of York and Hull (Anon 1993) while Muthiga & McClanahan (1997) reported a cover of 20 to 25% at Kisite in 1996.

In 1997-98, a severe coral bleaching event caused high coral mortality across the region (Goreau *et al*. 2000). Unfortunately, no measurements were available of coral mortality for the MPA immediately after the bleaching event, however, it is highly likely that there was a decrease in coral cover due to bleaching related mortality as occurred in other coral reefs in Kenya (McClanahan *et al*. 2001, 2004; Obura 2001).

Hard coral cover in Kisite increased from 22% to 44% and turf algae decreased from 44% to 36% between 1996 and 2004 (McClanahan *et al*. 2006). Corresponding coral cover data were not available for Mpunguti marine reserve.

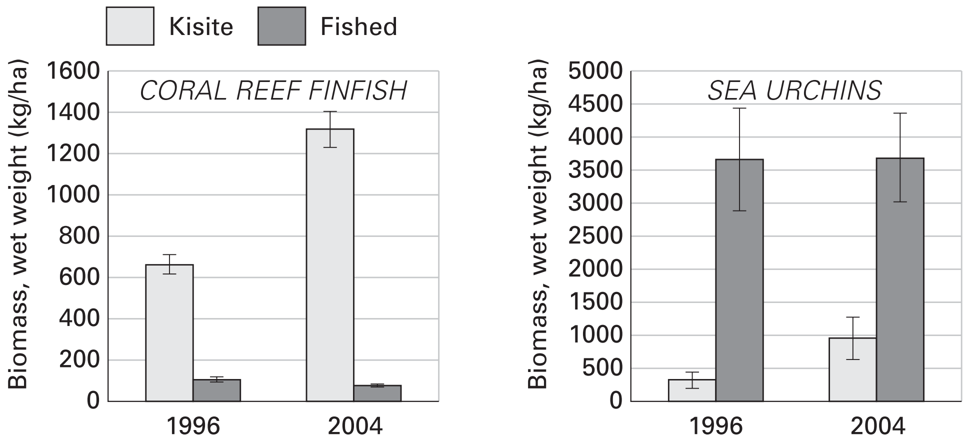
Focal species abundances

The numbers of coral genera were not only higher in the MPA than unprotected reefs in Kenya (McClanahan *et al*. 2001); there were more coral genera in Kisite (35) than in Mpunguti (10-16) in 1996. Coral diversity decreased after the bleaching from 35 to 27 genera at studied sites at Kisite (McClanahan *et al*. 2001).

The abundances and biomass of commercial coral reef fish species were significantly greater in Kisite than in Mpunguti in 1992 (Watson & Ormond 1994). The biomass of coral reef finfish were also significantly higher in Kisite than on unprotected reefs and increased significantly from 682 ± 48.9 to 1354 ± 89.1 kg/ha between 1996 and 2004 (McClanahan *et al*. 2006; Figure 13.1).

Sea urchin abundances, however, were significantly lower at Kisite than in the Mpunguti marine reserve (Watson & Ormond 1994) and abundances and biomass were lower at Kisite than on fished reefs (McClanahan *et al.* 2006). While the sea urchin density did not show significant changes at Kisite between 1996 and 2004 (McClanahan *et al.* 2006), the biomass increased from 320 to 960 kg/ha (Figure 13.1).

Figure 13.1 The biomass of coral reef finfish and sea urchins at Kisite and fished sites (Kanamai and Vipingo) in 1996 and 2004. (modified from McClanahan *et al.* 2006)



Food web integrity

McClanahan *et al*. (2006) showed that the biomass of Balistids, the key fish predators of sea urchins on Kenyan reefs was higher in Kisite (19 ± 3.0 kg/ha) compared to fished reefs (1.0 ± 1.0 kg/ha) in 1996 and that the biomass increased to 31 ± 4.8 kg/ha in 2004 at Kisite. The predation rate was significantly higher in Kisite than in unprotected reefs in Kenya and did not change significantly between 1996 and 2004.

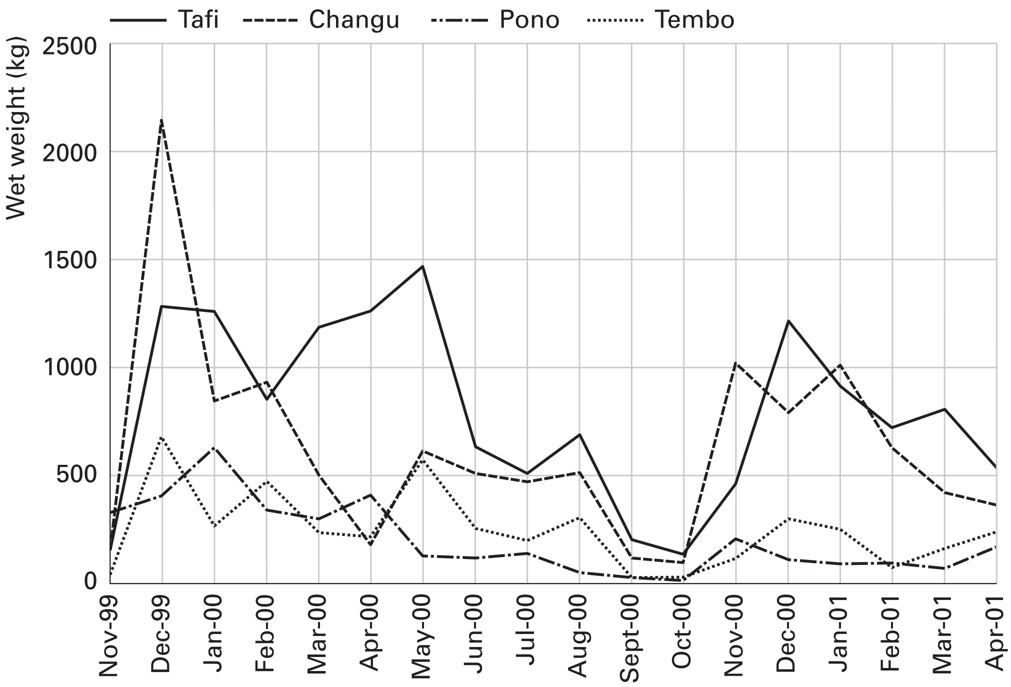
SOCIO-ECONOMIC INDICATORS

Local marine resource use patterns

Mkwiro and Wasini villages on Wasini Island and Kibuyuni, Kichangani and Shimoni trading center on the mainland were the main communities utilizing the MPA (Emerton 1999; Malleret-King 2000). The dominant livelihoods included fishing (~50%), tourism (~12%) and agriculture. The dependence on tourism-associated activities was especially high (~30%) in the community at Wasini that is adjacent to the MPA while Kibuyuni households had a very high dependence (82.6%) on fishing (Malleret-King 2000).

Fishing was mainly artisanal using dugout canoes and less than half of the fishers owned vessels although a higher percentage (75%) of fishers owned boats at Wasini where dependence on fishing was lower than at Kibuyuni (20%) where dependence on fishing was highest (Malleret-King 2000). Traps and hand lines were the dominant gear followed by tidal weirs, spears and nets. A survey of fish catches landed at Shimoni from 1999 to 2001 (Weru 2001) indicated that fishing was seasonal and that rabbitfish (Tafi) comprised 40% of the catch (Figure 13.2). Within the period of study 34,019 kg of fish were landed (684 fishing days) earning fishers an income of Ksh 223/man/day. This study suggested that catches were declining, as did a study of the perceptions of the fishers in the area (Malleret-King 2000).

Figure 13.2 The monthly catch landed by fishers in the Mpunguti marine reserve at Shimomi between 1999 to 2001 of Tafi (Siganids), Changu (Lethrinids), Pono (Scarids) and Tembo (Lutjanids). (Modified from Weru *et al.* 2001).



The tourism industry in the area was estimated to contribute 137 million Ksh/year (Emerton 1999) and MPA related tourism represented ~76% of total tourism employment in the area. Depending on the type of boat tour, a company could make between 270 thousand and 1.6 million Ksh/year (K-Rep Holdings 2000). Indirect and underestimated benefits from tourism included income from sale of food, fish and curios.

Community and business infrastructure

Several community projects were supported through donor funds channeled through KWS (Table 13.2). For example, boats and engines provided to the Kisite Private Boat Operators Association (KPBOA) through the Wildlife for Development Fund enabled this association to grow to dominate the boat tour business in the area by 2003 (Warden Kisite pers. comm.). The Wasini Women's Boardwalk provided the women of Wasini village with visitor revenues that were used for community projects including provision of bursaries. Donor funds also supported the building of classrooms, a nursery and provided desks for Kibuyuni, Shimoni and Mkwiro communities (Emerton 1999; Mwadzaya *et al.* 1995).

Table 13.2 Community projects and initiatives established by the Kenya Wildlife Service in the Kisite-Mpunguti marine protected area

Component	Activity	Comments
Training	Basic marine biology Visitor handling Mooring installation Boat maintenance and repair Business management Code of conduct	Funded primarily by the KWS/NWCTP and the USAID CORE project
Awareness	Marine Environment day (annual) International Coastal Clean-up (annual) Brochures, posters, fact-sheets School programs Periodic Beach clean-ups Visitor center	Funded by KWS/NWCTP in collaboration with Wildlife Clubs of Kenya, KESCOM, Dolphin Safaris and other NGOs
Boat repairs	Provision of snorkelling and safety equipment Provision of boats Provision of boat engines Provision of nets	Funded through the Wildlife for Development Fund (a consortium of donors) and the KWS/NWCTP
Infrastructure development	Building class rooms and nursery Mooring installation Building of Wasini Women's boardwalk	Funded by the Wildlife for Development Fund and the KWS/NWCTP
Associations	Establishment of the Wasini Women's group, the Kisite Private Boat Operators association and the Mkwiro Women's group	Supported by the Wildlife for Development Fund and the KWS/NWCTP

Source: Weru *et al.*, 2001; K-Rep Holdings 2000; KWS/Netherlands Wetlands Conservation and training program reports (KWS/NWCTP). USAID Conservation of Resources through Enterprise (CORE)

Distribution of formal knowledge to the community

MPA annual and monthly reports indicated that there were regular awareness and educational activities organized jointly with the local community (Table 13.2). The establishment of community associations such as the Wasini Women's

Group, KPBOA and the Mkwiro Women's Association had allowed for improved channels of communication hence the ease of organizing educational and awareness programs. Local and foreign student groups also frequently utilized a visitor centre and bandas within the MPA premises.

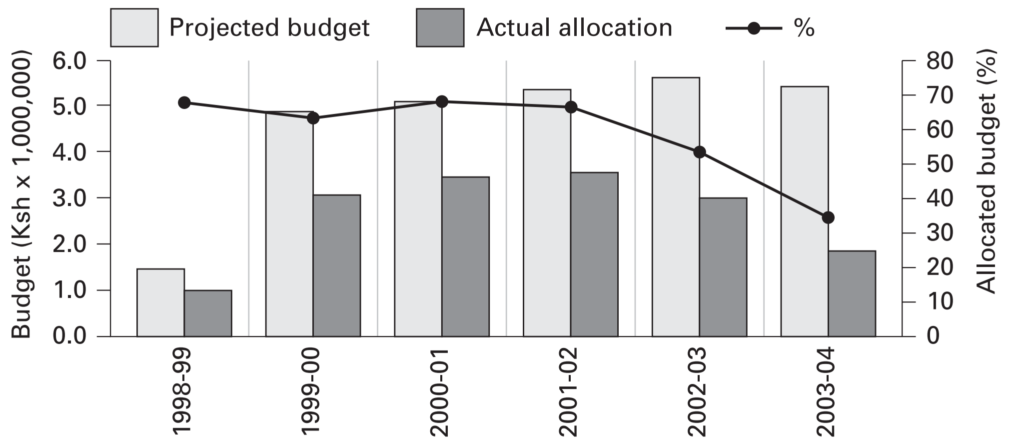
GOVERNANCE INDICATORS

Availability and allocation of MPA administrative resources

The administrative resources of the MPA had increased over time to include staff, offices, housing, a visitor centre and patrol boats (Weru *et al*. 2001). The infrastructure and equipment in the MPA were generally in good condition and regularly maintained, although the age of the boat engines were a cause for concern (Weru *et al*. 2001). Unfortunately, the MPA had over the years received less than the projected budget (Figure 13.3) from KWS despite generating surplus revenue (Emerton 1999) that severely constrained its financial stability.

Visitor numbers increased fourfold between the 1980s and 2003 peaking at 47,000/annum. However, visitor numbers decreased to less than 10,000 in 1998 (Kenya 2003), due to the combined effects of the 1997 civil disturbance on the Kenyan coast, the heavy El-Nino rains of 1997 that caused flooding in many areas and the election campaigns (Malleret-King 2000).

Figure 13.3 The projected budget and actual allocation (Ksh) of the Kisite-Mpunguti MPA between fiscal years 1998-99 to 2003-04. (Modified from Weru *et al.* 2001; KWS Reports)



Clearly defined regulations and enforcement

All protected areas in Kenya are governed under the Wildlife (Conservation and Management) Act Cap 376 of the Laws of Kenya (1989 Amendment), the existing wildlife policy and protected area regulations. Although no information was available on the mechanism used to inform communities on existing regulations most people in the area were aware of the existence of the MPA, the boundaries and the no-take and fisheries restrictions (Malleret-King 2000). There was a high level of surveillance despite the distance between the park base and the MPA and records indicate a general increase over time in the efficiency of surveillance and hence enforcement of regulations.

Level of stakeholder participation with a focus on the local community

Participation of the local communities of the Kisite-Mpunguti MPA took the form of community projects primarily geared towards improving livelihoods, and education and awareness initiatives (Table 13.2). Many of these projects were suggested by the community and implemented in collaboration with numerous stakeholders (Emerton 1999; K-Rep 2000; Malleret-King 2000). In addition records showed that the MPA collaborated with other stakeholders including government departments such as fisheries and forestry, NGOs for research and monitoring and the tourism sector for management of tourism activities (Weru *et al*. 2001).

Discussion

Protected areas have existed in Kenya for decades; however, the need for the systematic evaluation of the actions and outcomes of management – management effectiveness evaluation – has only recently been recognized (Wells 2004; Muthiga 2006). The economic, political and socio-cultural conditions having changed over time, the management of protected areas has been adapted in various ways. In particular, a major strategic shift towards involving stakeholders in management required a culture change within KWS whose effects have yet to be measured (Norton-Griffiths 1998). At the coast, this strategic change led to the development of participatory management plans for MPAs (Weru *et al.* 2001) and for the first time, allowed the evaluation of management effectiveness (Wells 2004; Muthiga 2006).

This study examined the effectiveness of management of the Kisite-Mpunguti MPA based on selected biophysical, socio-economic and governance indicators. The principal limitations of the evaluation were i) the lack of targets for the objectives of the MPA and ii) the dependence on the available data. Despite these shortcomings, the indicators that were selected (Table 13.1) gave a reasonable first assessment of the management of the Kisite-Mpunguti MPA and provided a baseline against which future assessments can be based. In general, the evaluation indicated that over the years, considerable progress has been made in the management of the MPA, however, variation occurred across the indicators as summarized below:

Biophysical indicators

Coral reefs – the major ecosystem within the MPA – showed progress (Appendix 13.1) in terms of retaining high coral cover, high finfish biomass and low urchin biomass (Watson & Ormond 1994; Watson 1996; McClanahan *et al.* 2001, 2006). Although the lack of a time series makes it difficult to distinguish trends, there is evidence that improved management led to increased commercial coral reef finfish from 1988 to 1992 (Watson 1996) and increases in the biomass of coral reef finfish from 1996 to 2004 (McClanahan *et al.* 2006) within the MPA. This indicates that investments in surveillance and improved enforcement were paying dividends in terms of coral reef biodiversity. External drivers, such as global warming leading to extreme El Ninos that cause severe bleaching such as the 1997-98 event (Hoegh-Guldberg 1999), however, threaten the gains made through protection since reduced coral cover due to bleaching related mortality could result in decreased topographic complexity and reduced overall biodiversity of reefs. The MPA management will require other strategies in addition to full protection such as improved water quality to enhance the long-term sustainability of the coral reefs of the MPA.

Socio-economic indicators

The goal of promoting sustainable nature tourism by encouraging local tourism made substantial progress over the years (Appendix 13.1). The local community benefited in numerous ways, directly through projects such as KFBOA and the Wasini Women's Boardwalk and indirectly due to the presence of the MPA that contributed 75% of the total tourism revenue in the area. In addition, families whose livelihoods were highly dependent on the MPA had a higher income and higher food security than families that depended only on fishing and agriculture in the area (Malleret-King 2000). The fact that the KPBOA grew to dominate the boat tourism industry in the area is another good example of the importance of MPAs in contributing to local community livelihoods. Despite these benefits, some reports (Watson 1996; Emerton 1999; Malleret-King 2000) indicated negative perceptions of the MPA especially by the fisher community. This shows there is still work needed to increase and improve communication and understanding of the benefits of the MPA amongst stakeholders.

Governance indicators

The three main governance indicators that were tested showed varying degrees of progress (Appendix 13.1) with the level of stakeholder participation showing the greatest change. In particular, involvement of the local community contributed to the reduced level of conflict and decreased infringement of the MPA regulations (Malleret-King 2000). Improved management of fishing activities in the reserve was largely due to the request and collaboration of the Mkwiro community that resulted in the control of the destructive beach seines used by the foreign fishers from Pemba Island.

The lack of a formalized mechanism for stakeholder participation made it difficult to track resolution of issues, indicating that a mechanism such as an Advisory Committee suggested in the MPA plan should be considered. In addition, the development and implementation of specific regulations and improvement of financial sustainability, especially the allocation of funds commensurate with the needs of the MPA, showed little progress and, although these are not directly within the scope of the MPAs to resolve, these strategic issues need urgent attention by KWS.

Conclusion

This study provides the first assessment of management effectiveness of the Kisite-Mpunguti MPA in Kenya. Despite the limitations of the available data it illustrates the application of the WCPA-Marine methodology (Pomeroy *et al.* 2004) to one of the MPAs in Kenya, and also highlights the strengths and challenges of meeting the MPAs objectives. The study suggests that efforts to incorporate such assessments within the management cycle of Kenyan MPAs could ultimately result in improved management and allow adaptation to the rapid changes that occur in the national and international resource management environment. Additional general issues that require attention for all MPAs include: revision of the MPA plans to target objectives more closely, creation of formalized communication mechanisms, improvement of financial sustainability, retention of technical expertise and systematic data gathering to inform management.

Acknowledgements

This work was part of a regional initiative funded by NORAD under the IUCN-East African Regional Office Jakarta Mandate project and they are gratefully acknowledged. The Wildlife Conservation Society provided technical and in-kind support. I am grateful to the Warden and staff of the Kisite-Mpunguti marine protected area for their support during the assessment.

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Summary

Managers of Marine Protected Areas (MPAs) are faced with many demands and often do not have the opportunity to reflect on the results of their actions. Management evaluations allow managers to learn from successes and improve management through time. This first assessment of the management effectiveness of the Kisite-Mpunguti MPA used existing information to evaluate the actions and outcomes measured against the MPA's goals as outlined in the MPA management plan. Selected biophysical, socio-economic and governance indicators were used for this purpose.

The Kisite-Mpunguti MPA showed progress towards meeting the tested objectives. The coral reef habitats in the MPA had higher biomass of fish, higher coral cover and fewer urchins and showed signs of recovery from the late 1980s. Community initiatives geared primarily to improve the livelihoods of MPA-dependent communities showed good progress with increased incomes and food security. Resources for managing the MPA including staff and infrastructue

increased overtime at pace with the development needs of the MPA but not with the operational and recurrent needs of the MPA. The number of partnerships and relationships with MPA stakeholders also increased with time.

Areas that showed less progress included the lack of a formal mechanism for stakeholder participation, decreasing fisheries catches in the marine reserve, lack of MPA specific regulations and financial stability of the MPA. Weaknesses in the management plan and conflicts due to overlapping mandates with other natural resource institutions further reduced the effectiveness of management actions while, external factors such as global warming and terrorism had a negative impact on biodiversity and the financial sustainability of the MPAs respectively. Revision of the MPA plan to more closely target objectives, creation of formalized communication mechanisms, improving financial sustainability and retention of technical expertise and systematizing data gathering to inform management were recommended.

Appendix 13.1. Summary scores for the biophysical (B), socio-economic (S) and governance (G) indicators in Kisite-Mpunguti MPA

Indicators	Score*	Comment for each parameter
B1. Habitat	(+) (?)	Coral cover increased but bleaching related mortality due to global warming a potential threat.
B2. Focal species	(+) (+)	Coral reef finfish abundances and biomass increased and remained high in the park, while sea urchin abundances and biomass remained low.
B3. Food web integrity	(+) (+)	Urchin predator abundances and biomass remained high and predation rates remained high.
S1. Resource use	(+) (-)	Tourism's contribution to MPA dependent communties was substantial and grew overtime. There were signs that fish catches have declined.
S2. Community infrastructure	(+) (?)	Initiatives to improve community livelihoods were available, however benefits were variable depending on level of dependence on tourism and fishing.
S3. Knowledge distribution	(+) (=)	MPA infrastructure and programs for awareness available, better coordination with partners needed.
G1. MPA infrastructure and staff	(+) (-)	Park infrastructure and staff were adequate but funding for operations was inadequate.
G2. Regulations and enforcement	(+) (-)	Enforcement in parks was successful but regulations specific to the MPA were not available.
G3. Stakeholder participation	(+) (=)	Community participation was high but a formal mechanism for participation has not been implemented.

* Scores are based on the general direction of change: (+) indicates a positive trend, (-) indicates a negative trend, (?) indicates that the trend could not be elucidated with the available data and (=) indicates that no change had occurred. Two scores correspond to indicators that have more than one parameter.

14

Perceptions about trends and threats regarding sea turtles in Kenya

A.W. Wamukota[1] & G. Okemwa[2]

Introduction

Sea turtles are an integral part of marine ecosystems as prey, consumers (especially in seagrass beds and reef systems), and competitors. Hence sea turtles act as flagship species whose conservation contributes directly towards maintaining the integrity of other marine resources and their habitats (Bjorndal 1985).

In Kenya, the marine and coastal environment is under increasing pressure from a wide range of human related threats that have a detrimental impact on marine resources (Wamukoya *et al.* 1997). Besides being exploited illegally by coastal communities for consumption as well as trade, sea turtles have also acquired a high economic value as ecotourism attractions in several sites along the Kenyan coast (KESCOM 2005).

In the last 15 years, sea turtle conservation efforts in Kenya have employed the use of a cash incentive scheme, voluntary community action, ecotourism (adopt-a-nest schemes), conservation education and implementation of legislative measures to protect nesting turtles and their eggs. Although voluntary local action has been regarded as the most cost-effective approach to the conservation and management of sea turtles and their habitats, the approach is limited by lack of understanding by conservation agents on the perceptions of local communities about sea turtles, and their capacity to implement desired conservation actions.

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Several studies have been conducted in the past with the aim of promoting sea turtle conservation in Kenya. They include Frazier (1975), Wamukoya *et al.* (1997) and Okemwa *et al.* (2004). Recommendations from these studies included further scientific research, effective implementation of legislative measures and conservation education as key factors in the conservation of sea turtles. However, experiences along the Kenyan coast (Nzuki *et al.* 2004) as well as elsewhere (Troëng & Drews 2004; Kiambo *et al.* 2001) have shown that for management and conservation measures to be successful and sustainable it is essential to understand the local communities and involve them in coastal management. The present project was therefore conducted with a view to overcome the limitations associated with conventional research by involving local communities and stakeholders. The project sought to determine local perceptions about the status and threats to sea turtles, identify conservation problems and priorities, review intervention measures, assess the willingness of local communities to share responsibility in the conservation of sea turtles and other marine resources, and develop local action plans for the conservation of sea turtles and their habitats.

Study sites

The selection of sites was based on already established turtle conservation groups, adjacent areas and where anecdotal information about the presence of sea turtle activities was reported. The sites selected for the study included the coastal stretches of Malindi-Ngomeni, Takaungu-Kilifi, Vipingo, Gazi-Msambweni, Funzi-Bodo and Vanga (Map A, p.2).

Method

Participatory Rural Appraisal (PRA) methodology included consultations, planning meetings to standardize techniques and site visits within 23 communities to identify contact personnel, determine entry points and create rapport with the local people. The project was undertaken by a multi-disciplinary team with a good understanding of rural institutions and processes.

Within the selected sites, the team visited villages, beaches, fishermen camps, boat yards, fishing vessels, landing sites, fisheries and wildlife offices and tourist establishments. Over 99 transect walks were accomplished targeting sea turtle nesting and foraging areas. Data gathering took eight months.

Formal interviews were administered to 605 respondents. Fishermen and other local persons comprised 350 and 200 respondents respectively, the rest were government officials and key informants. Informal interviews were also administered to 189 local stakeholders who were randomly selected and 99 key informants from selected sites along the Kenyan coast.

Appraisals were followed by two community meetings: one at Funzi Island, with representatives from the south coast, and another at Robinson Island, with representatives from the north coast area. The stakeholders included fishermen, local women group representatives, government officers (mainly from the Fisheries Department, KWS and Forest Department), NGO representatives, fish dealers, business people and farmers. The main objective of the consultative meetings was to gather detailed spatial as well as temporal data through a participatory process and harmonize the information gathered during the preliminary stages. During the consultative meetings, site-specific participatory maps, seasonal calendars, trendlines and threats were developed. Site-specific community resource maps were later merged to produce two composites; one for the south coast area from Gazi to Jimbo and one for the north coast area from Vipingo to Robinson Island. The maps contained spatial information on the location of marine resources important to local livelihoods. They showed the main turtle nesting and foraging habitats (seagrass beds and coral reefs), turtle sighting, turtle nesting grounds and mangrove areas (Map 14.1-14.2, pp.204-205).

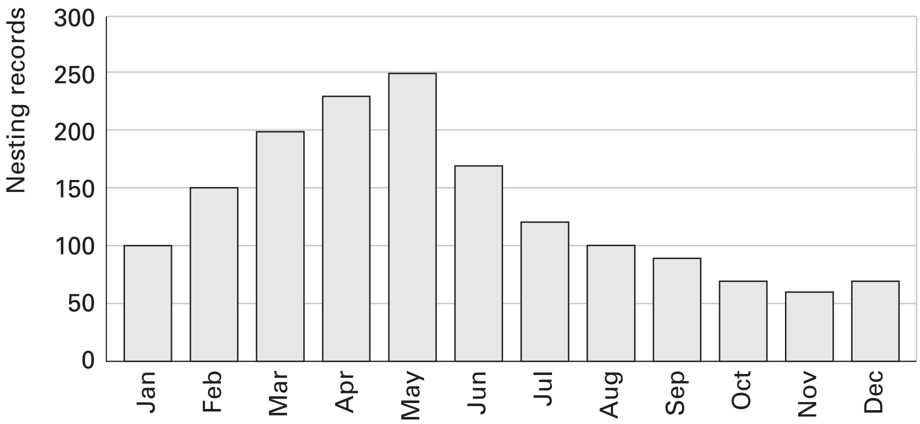
Participants ranked threats and management problems, prioritised conservation action and developed a community action plan to address threats to their resources. The 1960s and 1990s were used as base years (with score 100) for the north and south coast sites respectively to account for ecological differences between sites and to standardize community response.

Triangulation was employed in order to test the accuracy of the information obtained through meetings and patrols. Triangulation involved literature review based on published works and interpretation of topographic maps on marine resources.

Results

Seasonal calendars indicated the ways in which local people interacted with marine resources on an annual basis. The highest levels of interaction were reported during the north-east monsoon (NEM) when there is intensive fishing activity although fishing continues within the creeks and sheltered bays (especially within the Lamu archipelago) during the south-east monsoon (SEM). Eighty-five percent of the respondents indicated that the highest numbers of turtle mortalities are recorded during the NEM. Increased sea turtle nesting and sightings were reported during the SEM in areas with important sea turtle foraging habitats and fishing grounds. This information compares well with nesting data collected by KESCOM between 1997 and 2004 (Figure 14.1).

Figure 14.1 Seasonal nesting activity of sea turtles in Kenya, 1997-2004. (Data pooled for all years and sites; KESCOM 2005)



Other economic activities reported during the interviews included fishing, mangrove harvesting, farming, businesses and palm wine tapping. While fishing is highly influenced by monsoon wind patterns, the societal roles and responsibilities are gender based with men being engaged almost exclusively in the activities mentioned.

Threats to sea turtles

The threats to turtles that were identified by respondents relate to fisheries, coastal development, over-exploitation (subsistence as well as commercial use), population and industrial growth. Fishing methods were generally thought to directly impact on sea turtles as well as marine habitats. The use of dynamite, gillnets, shark nets and purse seines were thought to be responsible for incidental capture in all sites except Vanga. In shrimp trawling areas such as Ungwana Bay, trawlers were mentioned during the consultative meetings as contributing to turtle mortalities.

Apart from direct threats to sea turtles, respondents also mentioned threats to sea turtle habitats. Beach seining and octopus (lobster) fishing were identified as leading threats to coral reefs in Takaungu-Kilifi, Malindi-Ngomeni and Funzi-Bodo areas. The use of poison was reported as occurring in the Gazi-Msambweni area and is common with migrant fishers from Pemba Island in Tanzania.

Near Ngomeni, a massive expanse of mangrove forests has been cleared to pave the way for salt manufacturing activities. Massive beach erosion was reportedly witnessed in the area having resulted in the submersion of a Kenya Navy Camp. According to one respondent, the tidal regime has been altered by the construction of salt pans leading to increased coastal erosion in adjacent areas. The group from Malindi-Ngomeni identified trawling as the major threat to seagrass (an important sea turtle habitat) in their area. Participants from the other areas did not think that seagrass beds were threatened although they indicated that seagrass coverage had declined due to the impact of fisheries.

Ranking tables were constructed of the perceptions about threats to sea turtles and their habitats at the different sites. Respondents in Takaungu-Kilifi and Vipingo reported the same trends and therefore their responses have been grouped together (Table 14.1a). Respondents in Malindi-Ngomeni did not mention threats to turtles but rather to corals, seagrass, mangroves and fish stocks. The team made no effort to further unify the information from the different communities. For instance, respondents from Gazi-Msambweni (Table 14.1b) and Funzi-Bodo (Table 14.1c) indicated that threats to turtles relate to bycatch and incidental capture respectively while respondents from Takaungu-

Table 14.1 Pairwise ranking of threats to sea turtles by study site

a) Takaungu-Kilifi and Vipingo

Threats	Ac	Ep	Tc	score	rank
Ac		Ac	Ac	3	1
Ep			Tc	2	2
Tc				1	3

b) Gazi-Msambweni

Threats	Po	Bc	Md	Cd	score	rank
Po		Po	Po	Po	3	1
Bc			Bc	Bc	2	2
Md				Md	1	3
Cd					0	4

c) Funzi-Bodo

Threats	Et	Ic	score	rank
Et		Et	1	1
Ic			0	2

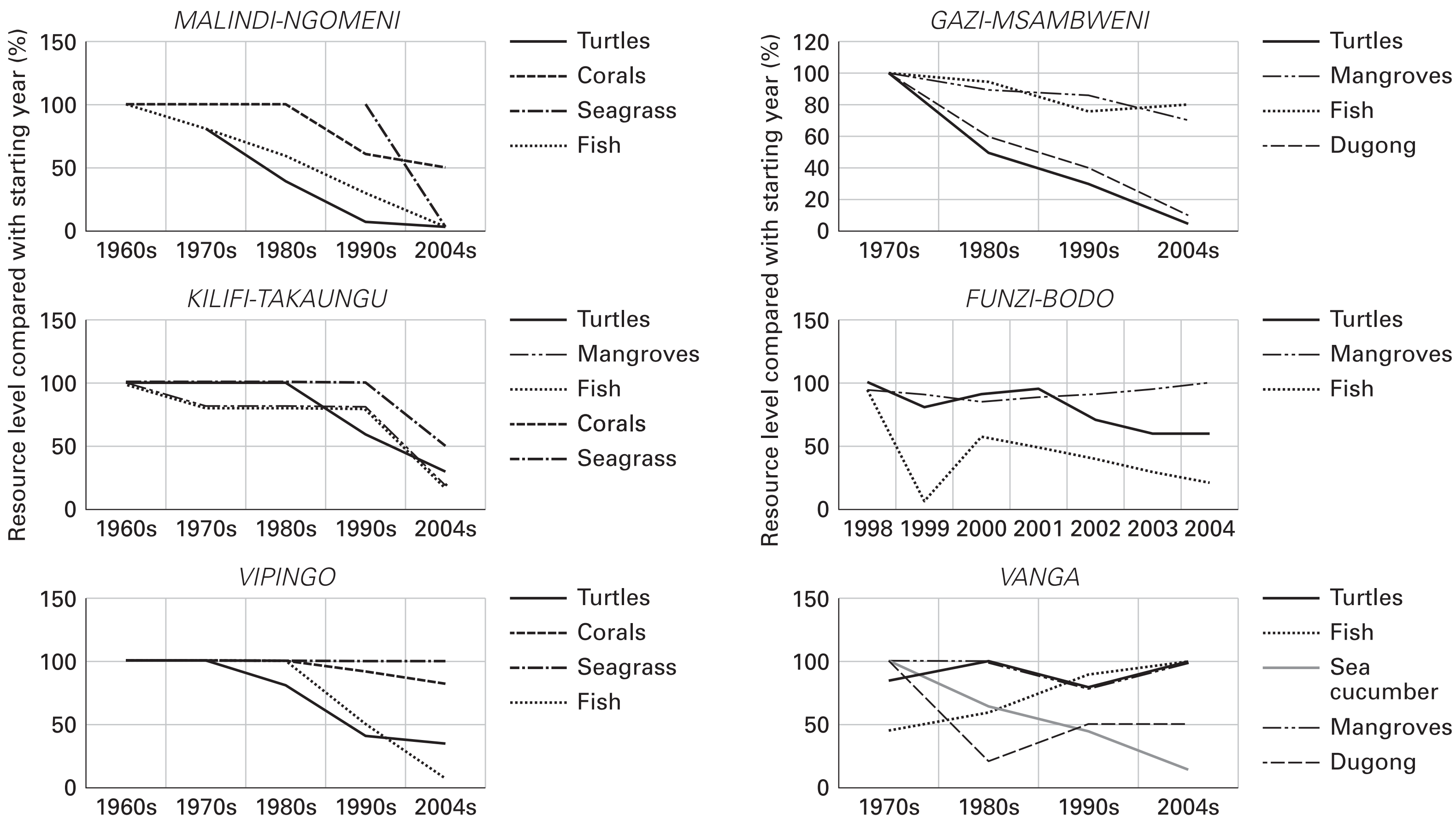
d) Vanga

Threats	Et	Ep	Bd	Es	score	rank
Et		Et	Et	Et	3	1
Ep			Ep	Ep	2	2
Bd				Bd	1	3
Es					0	4

Legend

Ac	Accidental capture	Ep	Egg poaching	Md	Medicinal
Bd	Beach decline	Es	Engine sound	Po	Poison
Bc	Bycatch	Et	Eating	Tc	Turtle consumption
Cd	Coastal development	Ic	Incidental capture		

Figure 14.2 Resource trend lines developed by local communities for Malindi-Ngomeni, Kilifi-Takaungu, Vipingo, Gazi-Msambweni, Funzi-Bodo and Vanga.



Kilifi mentioned accidental capture. In Vanga sea turtle meat eating was mentioned as a threat (Table 14.1d) while in Takaungu-Kilifi and Vipingo turtle consumption was mentioned. The results of the pair-wise rankings show that local consumption of sea turtle meat, poison and accidental catch were among the causes of marine turtle population decline in Kenya. The preference of local consumption of sea turtle meat over egg poaching or vice versa depends on the ease of access and the possibilities to evade rangers or fisheries officers (pers. observation). Coastal development did not rank high as a threat to sea turtles probably because there are comparatively few structures near the coastline in Gazi and Msambweni areas.

Interviews administered to selected contact persons and government officials revealed a similar appreciation of the threats to sea turtles and other marine resources in Kenya. Overharvesting was cited by 82% of the respondents as hampering efforts to ensure the sustainability of sea turtles and other marine resources. Seventy-eight percent of the respondents ranked fisheries as the leading threat to sea turtles and other marine resources in Kenya. Illegal activities such as poaching of turtle products and use of destructive fishing gear were other threats mentioned.

Lax enforcement of legislation, low levels of awareness, lack of adequate capacity on the part of government institutions and lack of willingness among some local communities in turtle conservation were cited as the main obstacles which account for the failure to adequately address threats to marine resources. This understanding was also found among 56% respondents representing government officials, NGOs and researchers.

Trendlines

In simulating perceived resource trends, participants considered threats and conservation problems identified during the ranking process. Six marine resource trend scenarios were developed for Malindi-Ngomeni, Takaungu-Kilifi, Vipingo, Gazi-Msambweni, Funzi-Bodo and Vanga respectively (Figure 14.2).

Sea turtles, coral reefs, seagrass beds and mangroves were all perceived to have declined over the years. The reef system in Malindi was judged to have been stable between the ‘60s and the ‘80s but to have degraded in quality by about 50% in 2004. In Takaungu-Kilifi, corals and seagrass beds were noticeably impacted by human activities from the ‘90s degrading to a similar percentage as that of Malindi-Ngomeni by the end of 2004. The degradation of seagrass beds in these areas was cited due to the proliferation of sea urchins and was perceived as lowering fisheries productivity. Representatives from Malindi-Ngomeni indicated a drastic decline of seagrasses since the 1990s but could not remember trends in previous years.

Vipingo was cited as one of the areas where the productivity of the reef system had been greatly impacted upon by artisanal fisheries. Its fisheries potential was thought to have declined to about 33% from the 1960s. Beach seining and use of poison were cited as the leading causes of coral mortality in this area.
Results on mangroves indicated that they are the only ecosystem which the local people do not perceive as having significantly degraded over the years especially in Gazi-Msambweni and Funzi-Bodo. Fish and mangroves in Takaungu-Kilifi were judged to have declined by less than 25% of their original value between 1990 and 2004.

Community action
The PRA process culminated in the development of a *Community Action Plan* (CAP). The CAP proposes ways to mitigate the threats and problems identified by local communities and respondents. Eight (8) broad areas were listed as undermining conservation efforts in many areas along the Kenyan coast namely legislation and policy framework, impact of fisheries, illegal harvesting, coral harvesting, mangrove degradation, natural predation, pollution and coastal development.

Discussion

In Kenya, like elsewhere in the world, it has been practically impossible to conserve sea turtles without direct involvement and participation of local communities (Ghimire & Pimbert 1997; Frazier 1998; Lelo 2000; Nzuki *et al.* 2004) and fisherfolk. A number of surveys and analyses (Wamukoya & Mbendo 1995; Wamukoya *et al.* 1997; Mueni & Mwangi 2001; Okemwa *et al.* 2004) conducted between 1994 and 2004 also revealed that 85% of sea turtle mortality cases reported are directly attributed to human activity with fishing accounting for over 50% of the total. In addition, local people poached about 30% (Nzuki *et al.* 2004) of all the nests laid (this figure is based on reported cases only and therefore may be an underestimate). In addition, the methods used in the exploitation of fish have a direct impact on sea turtles as well as marine habitats (Wamukoya *et al.* 1997). The present study showed that overexploitation of sea turtles and poor harvesting of marine resources were among the lead causes of turtle decline.

Other studies have indicated a decline in mangrove coverage of 7% leading to a decline in macroinvertebrate diversity and also changes in soil, physical and chemical characteristics (Karanja 1998). This study did not undertake soil, physical and chemical analysis, however the decline in mangroves could have an impact on sea turtle diversity due to important ecological role played by mangroves in protecting sea turtle habitats. Trawling was identified as the major threat to seagrass beds in the Malindi-Ngomeni area. This contributed to the increased conflict between trawler operators and artisanal fishermen in the area. Elsewhere, seagrass beds were not thought to be threatened although their coverage was thought to be declining.

Interviews administered to selected contact persons and government officials revealed a similar appreciation of the threats to marine resources in Kenya. Overharvesting was cited as hampering efforts to ensure the sustainability of marine and coastal resources. Fish stocks and mangroves have been reported in many parts of Kenya as being overexploited. Several overfished reef systems have also been reported (Obura 2001). The problem of resource overexploitation is further compounded by the use of unsustainable fishing methods such as beach seining, use of poison and prawn trawling. The perceptions among the respondents compare well with the programme areas listed under the *Indian Ocean and South East Asia (IOSEA) Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats* (UNEP 2001).

Resource trend analysis for six sites, showed that sea turtles have declined by between 25-75%, except in Vanga. Other marine resources including dugongs were also shown to have declined. The local communities attributed this to habitat degradation occasioned by destructive methods of fishing, demand for trade and consumption of marine turtle products and growth of coastal population and tourism infrastructure over the years. This is supported by a 1997 marine mammal survey (Wamukoya *et al.* 1997) and the recently compiled Western Indian Ocean (WIO) region dugong status report (WWF 2004). Poaching and habitat destruction were cited as the leading causes for their decline.

Data collected by the Coral Reef Conservation Project (CRCP) in 2004 on reef systems in Kenya indicated a decline in percent coral cover in the early and late '90s and a steady recovery for the period after the 1998 coral bleaching event. Fished reefs in Kenya such as Vipingo, Kanamai and Diani-Chale have continued to record reduced marine biodiversity due to degradation (McClanahan & Mangi 2004). This supports the claim by the participants that in Vipingo, the reef system has been greatly impacted upon by artisanal fisheries, its productivity declining to about 33% of its original value. Beach seining and use of poison were cited as the leading causes of coral mortality in this area.

The survey also showed that local people regarded the conservation and management of marine resources as a government responsibility with no obligation on their part but at the same time registered their willingness to participate in resource management and conservation if this had positive impacts on their livelihoods.

Conclusion

The study showed that the level of awareness and understanding of the value of coastal and marine resources to local livelihoods was still very low. The absence of direct benefits accruing from conservation activities was a limiting factor in local people's willingness to conserve and manage sea turtles and their habitats. However, local communities indicated willingness to invest in appropriate fishing gear if the cooperative movement targeting coastal fishermen could be revamped so that they could access credit facilities.

Local perceptions also supported the view that sea turtles are important indicators of ecosystem health and they are an important flagship species that can be used to promote the overall conservation and management of marine resources in Kenya. As such, the participatory approach to the conservation and management of sea turtles and their habitats in Kenya needs to be institutionalized. Key stakeholders should be involved throughout entire project cycles, through forums, actual participation in activities and major decision making processes. Long-term measures in the conservation and management of sea turtles should be based on scientific research that takes into consideration the socio-economic and socio-cultural dimensions underlying the conservation and management of marine resources.

Alternative income opportunities are not only essential for the conservation of marine and coastal resources but for the overall development of the coastal communities. An education initiative backed by a scientific knowledge of the social, cultural and economic aspects is necessary and should be tailored to clearly demonstrate to local people why conservation of marine resources and their habitats is important to their livelihoods. In essence, a Participatory and Integrated Development Approach (PIDA) is needed to manage marine resources in Kenya.

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Summary

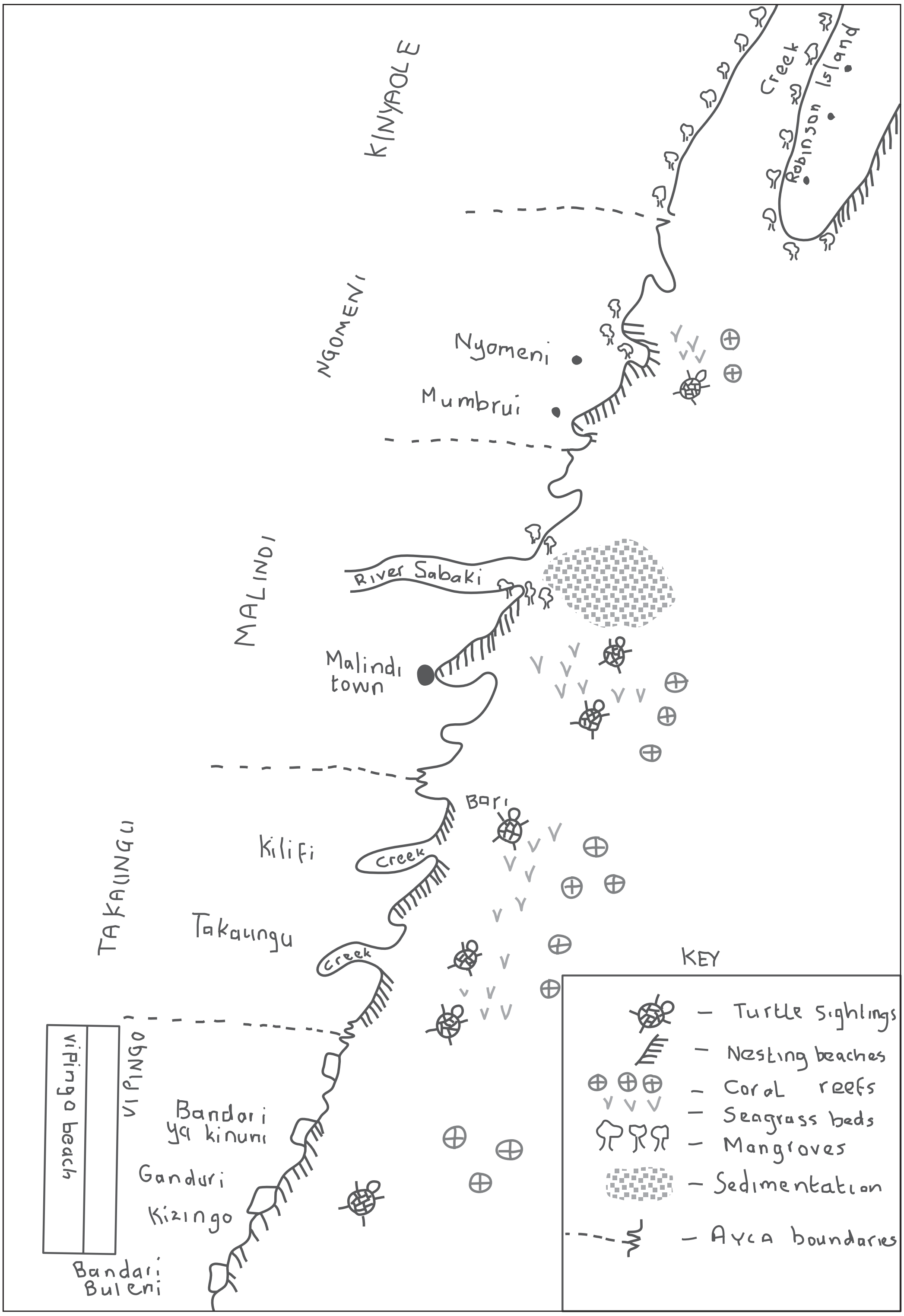
Information on perception, trends, status and major conservation issues relating to sea turtles in Kenya was collected between November 2003 and December 2004 among 23 communities along the 600 km long Kenyan coast. The objective was to determine major conservation issues and identify solutions.

The survey employed participatory rural appraisal (PRA) methods including transect walks, observation, resource mapping, problem visualizations, seasonal calendars, time lines, resource prevalence trend lines and structured interviews. Data was analysed through ranking and scoring.

Respondents indicated a steady decline of 25-75% of the sea turtle populations in six sites since the early ‘80s. Overall, marine fisheries were identified as a leading cause of marine turtle strandings on Kenyan beaches accounting for over 50% of reported cases. Over 90% of the participants indicated willingness to conserve sea turtles by using appropriate fishing gear but cited lack of capital outlay to purchase the recommended gear.

Recommendations included further research to better understand the socio-economic and socio-cultural dimensions underlying the conservation and management of marine resources as well as adopting a participatory and integrated development approach in the management of marine resources in Kenya.

Map 14.1 A participatory map of the Jimbo-Gazi area developed by a community consultative meeting held in January 2004 (not drawn to scale)



Map 14.2 A participatory map of the Vipingo-Robinson Island area developed by a community consultative meeting held in February 2004 (not drawn to scale)

Rehabilitation and Coastal Processes

15

Planning and evaluating performance of ecosystem restoration projects – the case of Bamburi limestone quarry

Paula Kahumbu[1]

Introduction

Land is essential – we depend on it for our survival and we modify it by using it in order to obtain our needs. As a result, land degradation is now one of the most serious economic threats in the developing countries where it affects the security of water and land productivity and plays a key role in exacerbating poverty, insecurity and entire economies (Brown 1997). To combat the problem, many African countries have recently enacted environmental legislation to protect the environment and make the polluters pay, however, the authorities are generally unable to enforce this legislation as they have not defined how restoration should be conducted, nor how completion will be evaluated. The need for common tools for management is therefore important to guide any rehabilitation programme. The most basic mistake often made is failure to agree on the definition of what the endpoint is. If this could be negotiated and agreed on in a rational manner, it would enable a company to walk away from a site once it is completely restored. Knowing what the end point targets are allows for a structured approach in rehabilitation planning. The manager will be able to make decisions regarding how to direct the re-assembly of any ecosystem in order to achieve compliance in the most efficient manner. Because of the budgetary implications of rehabilitation (costs of management and rewards for completion), the duration of the rehabil-

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itation process is important. Management decisions include extent of assisted succession, the sequence of species introductions, and degree of management intervention.

Planning for rehabilitation should ideally be initiated before any land change actually occurs. Mining companies need to know what needs to be done, how much it will cost and how long it will take to rehabilitate degraded or mined sites. This is necessary in order to effectively plan and budget for mine closure and post mining activities as budgetary accruals for rehabilitation need to be taking place during the mineral extraction. The answers are not simple and require much background information and experience. One of the most impressive restoration programmes is in Australia where Alcoa Alumina has been rehabilitating bauxite mines in South-Western Australia since the 1970's. They define targets for restoring the biodiversity of natural Jarrah forests based on consultations and agreements with stakeholders who were key opponents to the mining practices due to concern about the impacts on the natural environment and its services (Alcoa 2003). Alcoa has invested in decades of research into understanding natural systems and improving rehabilitation methods and, in the 1990's, re-established 80% of the natural Jarrah forest species within 18 months of mine closure. Like Bamburi in East Africa, Alcoa is considered the industry leader in rehabilitation of mine sites and has global recognition for setting the benchmarks.

The most cost effective approach is to take advantage of nature's free services in restoring natural repair processes. In some sites, natural succession processes can restore forest structure in a few years, however, this is rare and in most places, the natural rate of succession is quite prolonged (Brown & Lugo 1994; Vieira & Scariot 2006). Relying on natural succession could be risky, it may not always proceed along expected trajectories and the process can be arrested in an undesired state (Chapman & Chapman 1999). This can be due to the lack of propagules of desired species (McClanahan 1986), continued disturbances such as fire, inhospitable abiotic conditions such as light, humidity, pH, and nutrients, and biotic factors such as predation, disease, and invasive species (Brokaw 1985; Putz & Canham 1992). This means that active management is usually necessary to drive succession along a trajectory towards a desired natural forest state (Alcoa 2003). One of the greatest challenges in restoring natural forests on degraded or mined lands therefore, is having a good understanding of the complex interactions between biotic and abiotic components of natural ecosystems. Of particular interest is the importance of biodiversity in ecosystem functioning and health and how this affects the quantity and quality of ecosystem services (Harris & Hobbs 2006; Loreau *et al.* 2002; Tuxill 1999).

The International Mines and Minerals Council (ICMM) suggests a simple approach of planning for biodiversity recovery after mine closure (ICMM 2006). The ICMM proposes that rehabilitation targets should include biodiversity and ecosystem health that should be incorporated into the planning and assessment methodology for monitoring and evaluation. The pre-mining biodiversity should be evaluated and the overall rehabilitation objective should ensure that regulatory requirements are met, and opportunities for re-establishing biodiversity or conservation enhancement are realized during closure, planning, and implementation. The views of stakeholders and technical constraints on propagation of some species should be considered in the rehabilitation plan to avoid raising false expectations amongst stakeholders (Cipollini *et al.* 2005).

It is generally recognized that the purpose of restoration is reversing negative impacts on ecosystems in order to achieve sustainable development (Harris & Diggelen 2006). Restoration of biodiversity and ecosystem services emerged as key objectives in post mining efforts at the 1992 Earth Summit of the Convention on Biological Diversity. The International Council on Mines and Minerals (ICMM) emphasizes the need for the integration of biodiversity into the mining cycle (ICMM 2006) and the challenge therefore is to define methods of assessing rehabilitation success in order to guide planning and for decision support (Reynolds & Hessburg 2005).

This study examined the rehabilitation success of one company that has been rehabilitating former limestone quarries for 35 years in Bamburi, Mombasa, to create functioning natural ecosystems (Map A, p.2). Like many early rehabilitation efforts, initial planning did not define completion criteria. We therefore examined the progress towards restoring forest structure, species composition and soil function by comparing the results of restoration against a nearby native coastal forest that could represent a reference or target system in terms of diversity, structure and functions. We compared the relative success of re-establishing forest diversity under three different planting treatments, and examined the role of giant millipedes in soil formation processes.

Study area

Bamburi Cement Company operates several limestone quarries in East Africa. Quarries are handed over for restoration as flat barren rocky landscapes. There are no waste heaps or toxicity effects nor initial rehabilitation of limestone quarries. Though the pre-quarrying condition of the Bamburi quarry was degraded bushlands, rehabilitation aimed to recreate the original coastal forest, which are highly threatened and fragmented across the Kenyan coast.

Conditions in recently exhausted limestone quarries limit plant growth mainly due to physical attributes (rock hardness, access to water, wind, heat, albido) and chemical (salinity) characteristics. The initial stages of rehabilitation must therefore ameliorate the physical and soil environments to allow successional precursors or pioneer species to become established. The ground was broken up by a bulldozer and pioneer species planted at 2x2 m intervals. There was no soil or overburden applied. Early tests with 24 species found only 2 pioneer trees were capable of surviving the open quarry conditions in Bamburi: *Casuarina equisetifolia* and *Conocarpus lancifolius*. These two fast growing trees created a rapid ground cover and altered the humidity, light and wind conditions. Moreover, these species are nitrogen fixers and thus initiated the process of restoring soil structure and nutrients.

Method

Field data were collected in April 2006. Three 10x10 m plots were established in the four planting treatments of 35 years of age: The pioneer species set up in the four treatments were *Casuarina* only, *Casuarina* and *Conocarpus*, *Conocarpus* only, and *Casuarina* with species enrichment. Plots were also established on two natural reference sites, limestone reserves which comprise degraded bushland, and a natural coral rag forest in Kuruwitu, Vipingo, 25 km north of Mombasa. The Kuruwitu site was selected from a privately owned 20 ha forest that has largely been undisturbed for the last 50 years. This forest is utilized for spiritual and non-destructive purposes. Illegal hunting in the past may have eliminated most of the large mammals save baboons and other primates, and limited harvesting of shrubs and deadwood takes place from time to time. The forest is a remnant of the original coastal coral rag forest that once lined the East African coast .

Within each plot, data were gathered on vegetation community composition and structure, soil and litter depth, abundance and diversity of undergrowth invertebrates using 3x10 m sweep nets, the presence of ungulate signs throughout the plot and number of millipedes in 1x10 m searches of leaf litter. The forest composition and structure was characterised by identifying species and measuring the diameter at breast height (DBH) of trees > 2 cm within a 10 m radius of the centre of the plot. Seedlings were identified and counted in three 1x1 m quadrates in each of the 10x10 m plots. The presence and population sizes of the red-legged millipedes *Epibolus pulchripes* were recorded in the same sites, and their diet preferences examined in controlled feeding experiments.

Results

Forest structure and composition

The planted forests were generally tall compared to the pre-quarrying sites and natural forest at Kuruwitu, which had a canopy height of only 1.5 m and 11.9 m respectively (Table 15.1). The density of trees and basal area was highest in the planted forests where densities were similar to initial planting densities of 2,500 per ha, and slightly higher than the natural forest. Although the planted forests had a larger standing biomass than the original bush or the natural forest at Kuruwitu, planted forests were generally depauperate, having an average of 9.5 species, even after years of enrichment planting.

Table 15.1 Some characteristics of forest structure in Bamburi quarries after 35 years of rehabilitation compared to pre-quarry conditions and a natural forest

Treatment*	Ht (m)	Density (# stems >2.5 cm per ha)	Basal area (m^2/ha)	Species richness (per ha)	Total # of species
Pre-quarry bush	1.5	500	6	5	5
Casuarina	15.8	2,300	20	2	4
Conocarpus	16.4	1,500	17	3	5
Casuarina and *Conocarpus*	18.7	2,500	16	5	12
Casuarina interplanted	15.8	3,500	15	7	17
Natural forest	11.9	1,900	19	13	21

* 3 plots of 10x10m per treatment

There was variation in the number of species between treatments, the *Casuarina* interplanted treatment had the most number of species (17) while the monoculture of *Casuarina* or *Conocarpus* had only 4 or 5 species (respectively) after 35 years. Few species had arrived naturally into the planted forests – most notably was the invasive exotic species Neem (*Azadirachta indica*) which was prevalent in all treatments but not at the natural reference sites. *Conocarpus* did not self establish in the pioneer forest. Few *Ficus sycomorus*, a native keystone fig species, occurred in the rehabilitated forests. *Casuarina* had become self established in *Conocarpus* plantations but *Conocarpus* did not easily self propagate (Appendix 15.1). Few canopy tree species were represented as seedlings in the undergrowth of any of the treatments or the reference site.

Soil formation under different treatments was generally similar in all rehabilitated forests with depths of between 4 and 6 cm compared to 2.5 cm in the pre-quarried sites and 12 cm in the natural forest (Table 15.2). Soil depth in the bushland quarry reserves was thin possibly caused by previous disturbances.

Table 15.2 The average soil depth, leaf litter depth and millipede density in Bamburi quarries after 35 years of rehabilitation compared to pre-quarry conditions and a natural forest at Kuruwitu

Treatment*	Soil depth (cm)	Leaf litter depth (cm)	Millipede density (per ha)
Pre-quarrying bush	2.8	5.1	3,000
Casuarina	4.0	3.2	33,000-60,000
Conocarpus	6.2	4.3	25,000-43,000
Casuarina and *Conocarpus*	5.0	4.6	35,000-70,000
Casuarina interplanted	5.0	3.6	75,000
Natural forest	11.8	1.3	5,000

* 3 plots of 10x10m per treatment

Leaf litter depth, which contributes to soil formation was greatest in the bush, and similar in all the planted treatments where it was, on average, three times greater than in the natural forest. The red-legged millipede densities were generally high in all treatments (25,000-75,000 per ha.) compared to the natural forest, but quite variable in the different treatments, the greatest density was found in the interplanted *Casuarina* forest. These animals occurred in the pre-quarried bushland but in densities that were an order of magnitude less.

Millipedes ranged in size from 4 cm to 16 cm and averaged 10.5 g in weight (Table 15.3). Preliminary feeding experiments over a 5-day period revealed that when given the choice of two plant species, the red-legged millipede preferred to consume *Conocarpus* (0.4 g per day) to *Casuarina* (0.25 g per day). This amounts to consumption of approximately 2% of the body weight of Casuarina needles consumed per day vs. 3.8% of *Conocarpus* consumed. Observations revealed that the millipedes chopped up the *Casuarina* needles into tiny pieces during the night, and did not consume all of them. Some sex specific differences were also documented and the millipedes were also observed to consume large quantities of soil (1.5-3 g per day; Jaeger 2006) as well as bark, animal dung, and fallen fruit (Kahumbu pers. obs.)

Table 15.3 Size characteristics of adult millipedes (*Epibolus pulchripes*) in the Bamburi quarries

	Length (cm)	Weight (g)
Sample size	44	44
Mean	10.1	10.5
Range	4.1-15.2	1.1-23.8
Max	15.2	23.8
95% CI	0.95	2.12

Leaf litter fall rates over a 5 day period revealed that 54 kg of *Casuarina* needles fall per hectare, compared to 1 of *Conocarpus* and 70 kg in the mixed *Casuarina* and *Conocarpus* forest.

Discussion

These preliminary results are limited by the small sample sizes, however this is the first analysis of changes in forest structure, composition and processes in the different treatment plots in limestone quarries in East Africa and some interesting insights were revealed that could be useful for restoration management and also lead to more in-depth studies.

Forest structure and composition

In comparison to the pre-quarrying site condition, the effects of 35 years of rehabilitation were impressive. The forests were much taller than the reference site, which falls within the range of other coastal forests (8-22.2 m; Lowe & Clarke 2000). Timber basal area was two to three times greater in the planted forest than pre-quarrying bush land and similar to forests elsewhere along the coast (Lowe & Clarke 2000). Compared to the natural forest at Kuruwitu, post-mining planted forests generally had a greater biomass of timber but a low species diversity and dominance of a few species, as well as a simple canopy structure (see Appendix 15.1 for species distribution in different treatments).

The results indicate that 35 years of rehabilitation is inadequate to reestablish the native biodiversity as the natural processes of diversification were very slow. We suggest that either the propagules of native species were absent, or were unable to become established under monodominant stands (see Appendix 15.2 for species of seedlings present in the understory of each treatment). Even where native species have been introduced, the total species richness had increased significantly but densities still remained low compared to natural forest and natural dispersal was limited. The study revealed that the neem tree (*Azadirachta indica*) is an aggressive invasive that naturally established in every post-mining treatment but was hardly present in the natural forest. Further research and experiments need to be conducted to evaluate the impact of this invasive and to find natural mechanisms to promote natural dispersal of indigenous species that could contribute to more effective enrichment of these forests.

Forest processes

Leaf litter depth was greatest in the pre-quarried bushland where the fewest millipedes occurred and soil was also thinnest suggesting low litter turnover rates. Litter turnover was most rapid in the rehabilitated sites where rates of leaf litter fall were greater than in the natural forest. In these sites high millipede densities suggest that these invertebrates can consume between 12 and 22% of the daily leaf fall of *Casuarina* needles. In the *Conocarpus* forests, millipede densities are slightly lower than in *Casuarina* plantations, but high consumption rates of *Conocarpus* leaves suggest that the millepedes can consume the entire leaf litter fall. In mixed forests the density of these organisms were lower still but their preference for indigenous species such as *Milicia excelsa*, *Ficus sycomorus*, *Sorindea madagascariensis*, mangrove ferns and *Terminalia catappa* suggests that they can consume between 22 and 44% of leaf litter fall.

From the sheer numbers and biomass of millipedes (315-735 kg/ha) this study suggests that their foraging activities contribute significantly to nutrient turnover in every rehabilitated treatment while a diversity of other organisms including crickets and beetles play a more important role in natural forests. The low density of millipedes in the natural forest at Kuruwitu suggests that these organisms are adapted to early pioneer habitats and may not do well in developed habitats due to competition, predation or other factors. It should be noted that these studies were conducted during the rainy season when millipedes were visible and active and more long-term studies will be necessary to determine average trends throughout the year. Further investigations and more long-term studies of these important organisms could aid in understanding factors affecting the site preferences of millipedes and how this affects the rate of soil rehabilitation in post mining sites.

This preliminary study indicates that the pre-quarrying bushlands represent previously degraded landscapes and therefore do not adequately represent rehabilitation targets. The natural forest at Kuruwitu however, should be described in terms of structure, composition and function to identify rehabilitation targets that would lead to the restoration of natural forest processes. Further research will be necessary to better define the target for species composition in order to restore guilds and niches, and functional groups of species.

It is evident from this study that further management intervention will be necessary in Bamburi to accelerate the natural succession pathways in order to restore native forest biodiversity. This could include continued enrichment planting, and the removal of invasive species such as the neem tree, and mechanisms to attract natural seed dispersers such as birds, primates, small omnivores, herbivores, rodents and bats. This process is important in order to create a rich mix of leaf litter that will attract a diversity of decomposers thus improving the habitats for millipedes, creating habitats for other decomposers and accelerating the soil formation process. The continued monitoring and comparison of the rehabilitated forests and a reference site with a naturally diverse forest will contribute significantly to the body of knowledge on tropical ecosystem restoration.

Conclusion

Clear biodiversity objectives for rehabilitation of any degraded mining areas including Bamburi Quarries are essential if we are to effectively evaluate success towards reaching a desired endpoint. We recommend adopting a structured approach to planning using a nearby natural forest as a reference for forest biodiversity and structure objectives. Both the reference and rehabilitation sites should be continuously monitored in order to incorporate reference variation when assessing performance. Continued enrichment with indigenous species will be necessary at the rehabilitation sites as natural processes are too slow. Earlier and more frequent introductions are suggested, as well as an emphasis on species that attract seed dispersing animals.

We believe that the current paucity of rehabilitation efforts in Africa is due to lack of incentives. Governments should encourage companies to accelerate the rehabilitation rate by using active management practices in degraded industrial sites by setting clear targets, enforcing penalties and by offering incentives to companies that go beyond the simple bare minimum but achieve success in restoring biodiversity and ecosystem services (Egan 2004). Bamburi Cement can play an important role in Africa by formalizing the rehabilitation processes, defining clear targets, conducting regular monitoring and reporting, and maintaining a research and development programme to continually progress the science and practice of rehabilitation of natural forest in exhausted quarries. The principles of restoring quarries are transferable to other sites that would have enormous benefit to the Lafarge Group, the owner of Bamburi Cement and other mining sites in Africa.

Finally, Bamburi Cement Ltd, can also considerably enhance conservation of coastal forests through conservation offsets to protect remaining important forest fragments. This will be necessary to protect future reservoirs of species and as knowledge banks for planning, implementation and monitoring of rehabilitation activities.

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Summary

Assessment of rehabilitation success of post-mining landscapes is a recent field of ecology necessitated by the growing global awareness of negative impacts of mining and need for legislative compliance. The Bamburi Cement Company has made rehabilitation a natural part of the business process and for the last 35 years has been rehabilitating exhausted quarries in Mombasa, Kenya. It is generally acknowledged that the project has been successful and Bamburi's man-made forested ecosystems are celebrated as showcases of rehabilitation. The goals of quarry rehabilitation by Bamburi are to re-create self-sustaining tropical forests typical of the Kenya coast but how can we measure how well we are doing? We conducted surveys comparing vegetation characteristics after 35 years in three different planting treatments with a

natural coastal forest which we proposed could be the end point or reference. After 35 years of rehabilitation, the forests were tall in stature with high rates of nutrient turnover but were structurally simple compared to the native coastal forest. Biodiversity was lower than in the natural forest though enrichment planting can correct this. Where introductions have been ongoing, species richness was 61% of the native forest. Low rates of natural introductions and establishment indicated that continued active enrichment planting will be required for some time, as well as the active removal of aggressive invasive species such as the neem (*Azadirachta indica*). Soil formation processes were active and the most important arthropod responsible for nutrient turnover was the red legged millipede (*Epibolus pulchripes*) which was estimated to consume between 22 and 44% of the annual leaf fall.

Appendix 15.1 The total number of trees in forests under different treatments (*Casuarina*, *Conocarpus* and both species as well as bush and natural forest plots)

Tree species	Bush	*Casuarina*	*Conocarpus*	*Casuarina* and *Conocarpus*	*Casuarina* interplanted	Natural forest
Adenanthera pavonina			1			
Albizia saman				1		
Alchornea laxiflora					3	1
Antidesma venosum	1					
Berchemum sp.						1
Cassia singueana	1					
Casuarina equisetifolia		43	3	11	43	
Cissus olveri				1		1
Cissus rotundifolia				1		
Cordia monoica	1					
Cordyla Africana					1	
Conocarpus lancifolius			48	11	6	
Crabia b.						4
Cussonia zimmermanni						1
Derris indica					1	
Derris trifoliata					2	
Drypetes natalensis					1	
Ficus sycomorus				1		1
Grewia densa						3
Grewia glandilosa	1					
Grewia sp.						1
Grewia truncate						1
Grewia vaughanni						2
Gyrocarpus americanus					1	2
Harrisonia abyssinica					1	
Hoslundia opposita		2				
Kigelia Africana					2	
Lannea schweinfurthii						1
Lannea welwitschii		1				2
Lecaniodiscus fraxinifolius				2	1	
Lepisanthes senegalensis					1	
Markhamia zanzibarica						3
Meyna tetraphylla				3		
Milicia excelsa					1	
Millettea usaramensis						1
Mimosa						1
Neem		18	16	31	36	2
Newtonia hildebrandtii					1	
Ochna thomasiana				1		
Parkia filicordia					2	
Thevetia peruviana			2	1		
Trichilia emetica					1	2
Uvaria accuminata	1			1		
Other 1						3
Other 2						4
Other 3						1
Total no. of species found	5	4	5	12	17	21

Appendix 15.2 The number of seedlings of different species in plots under different treatments (*Casuarina*, *Conocarpus* and both species as well as bush and natural forest plots)

Seedling species	Bush	*Casuarina*	*Conocarpus*	*Casuarina* and *Conocarpus*	*Casuarina* interplanted	Natural forest
Alchornea laxiflora					2	3
Allophyllus pervellei				1		
Allophyllus rubifolius	1					
Amophophalus	1					
Cocos nucifera					1	
Cucurbitaceae	1					2
Cyphostemma hildebrandtii			1	1		3
Dalechampia scandens	1	2				
Delonix regia						1
Derris trifiolata					2	
Drypetes reticulates						1
Ecbolium auriculate				1	6	
Enteropogon macrostachys	3	1				
Flueogea virosa		1				1
Grewia spp	1					
Gyrocarpus americanus						1
Haplocoeclum inoploeum						1
Hibiscus macrantha	1					
Lecaniodiscus fraxinifolius		1		1		
Luceana lecocephala		3				
Meyna tetraphylla				2		
Mimosa spp.						1
Neem	1	9	7	5	5	2
Parquetina nigrescens		1	3		2	
Phylanthus reticulates	1	5				
Polysphaeria multiflora						1
Ricinus cuminis	1	2				
Rynchosia sp.		1				
Synalepsis kirkii				1	2	
Thevetia peruviana			1			
Tiny liana						1
Tragia furialis					1	
Uvaria accuminata	2			3		
Total no. species found	11	10	4	8	8	12

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Tick species, distribution, and control in rehabilitated quarries in Bamburi, Mombasa

Sharon Okanga[1]

Introduction

Lafarge Eco Systems Ltd (LES) in Mombasa specializes in the restoration of tropical ecosystems and their sustainable management. As a subsidiary of Bamburi Cement Company, LES rehabilitates spent quarries to restore them back as much as possible to their previous natural state before mining, or to create a profitable end-use for the quarry. Successful examples of quarries rehabilitated by LES include the Haller Park and the Forest Trails. Haller Park is a nature park open to the public, with a rich biodiversity of enclosed and free-ranging wildlife. The Forest Trails is an extensive tract of forest also rich in biodiversity, but used mainly as a recreational site for jogging and cycling, and it also has a children's playground.

The quarries provide opportunity for the interaction of human and wildlife populations at close quarters. In such a scenario, it is important to be vigilant and aware of the implications of such a close interface, particularly with regard to parasitic organisms. Ticks act as the vectors for several diseases of significant socio-economic importance in both livestock and wildlife (Uilenberg 1995; Okello-Onen *et al.* 1999). In addition, with the emergence of new human infections that are transmitted by ticks (Parola & Raoult 2001) comes the need for increased vigilance of tick densities, distribution and control. Monitoring tick

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population dynamics is particularly important in areas such as Haller Park and Forest Trails, where opportunity arises for the exchange of zoonoses between wildlife and humans (Hoogstraal 1981).

This study aims to determine tick species richness and general tick density patterns on LES premises. Current and potential measures of tick control are also discussed.

Study site

The study took place in an area of approximately 450 hectares within LES premises. The premises are located in Bamburi, 10 km north-west of Mombasa; they stretch parallel to the coastline for 5 km and are situated 1-2 km inland (Map A, p.2). The premises are owned by Kenya's largest cement producing company, Bamburi Cement Ltd., subsidiary of Lafarge Cement (East Africa), which initiated the quarry rehabilitation programme in 1971. The study was conducted in two locations consisting of rehabilitated quarries: South Quarry and North Quarry.

The South Quarry is approximately 150 hectares in size. It consists of the Haller Park and quarry reserve land (land that has not yet been mined). The Haller Park occurs in an area of the quarry that is spent, fully rehabilitated and is now a forest and wetlands ecosystem and a popular tourist attraction. The reserve land consists of open primary grasslands and bare coral rag with sparse bush vegetation. A portion of reserve land is mined each year, after which rehabilitation is started. Large animals found in South Quarry include the semi-domestic herds of oryx and eland, waterbucks, giraffes, bushbucks, duikers, bushpigs and Aldabran tortoises. These animals are free to wander around in the grasslands and the quarry reserve land.

The North Quarry (Forest Trails) is approximately 300 hectares in size. Most of the quarry has been rehabilitated into a recreational wetland forest interspersed with jogging and cycling trails, and with open grasslands in the north-eastern area. A herd of semi-domesticated oryx and eland, together with wild bushbucks, duikers and wild bushpigs also occur in the North Quarry. There are no waterbucks, giraffe or Aldabran tortoises.

Method

The study was conducted over a period of 12 months, from February 2005 to February 2006. Within each location, several sites were selected and the physical characteristics of the sites are described in Table 16.1.

Tick dragging (Daniels *et al.* 2000) was conducted on a monthly basis by the researcher and two LES staff members as part of the wildlife health program at

Table 16.1 Summary of sample sites, number of samples and physical characteristics

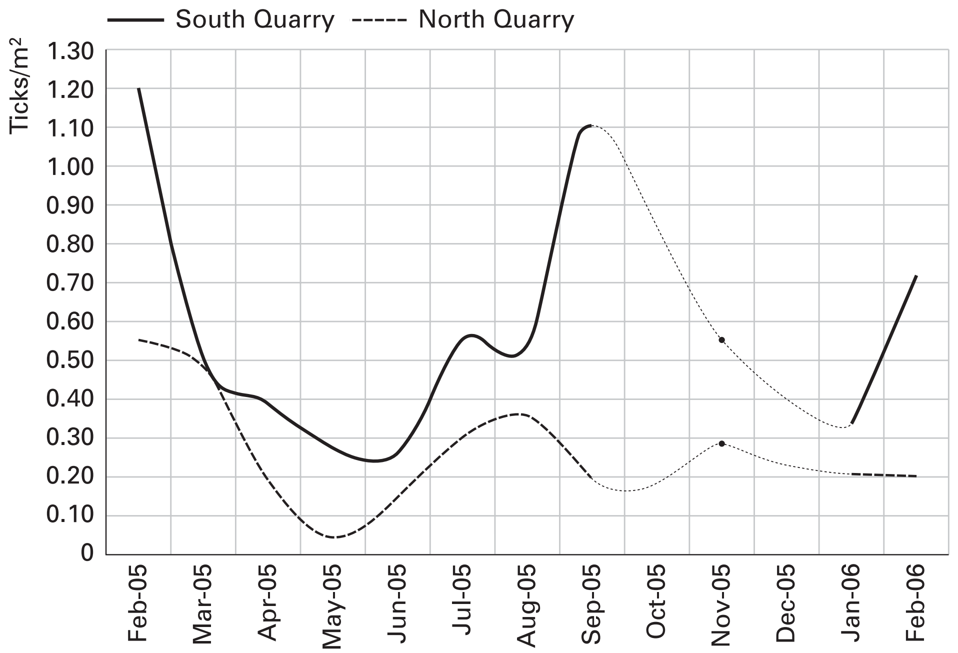
	Sites	# drags	Characteristics
SOUTH QUARRY	Ziwa la Ngombe	10	Primary grassland on black cotton soil grassland interspersed with doumpalms. The main grazing site in South Quarry and it occurs on reserve land.
	Bare Ground (SQ BG)	10	Open spacious quarry reserve land consisting of coral rag base with sparse bush vegetation.
	New Quarry	10	Spent quarry under rehabilitation. Consists of 2-3 year old *Casuarina* forest interspersed with ponds and small grasslands.
	Main Gate	8	Area just outside Haller Park containing the car park and arrival area. Consists of a grassy lawn area with dust roads facilitating visitor traffic.
	Snake Park	2	Grassy patch located in the centre of the Snake Park in Haller Park. Contains four small tortoise species.
	Reception (SQ Reception)	7	The main area for receiving visitors into Haller Park. Consists of grassy lawn interspersed with various tree and palm species.
	Fish Farm	3	Small grassy area behind the Fish Farm bordering the road leading into the quarry reserve land (South Quarry bare ground).
	Boma (SQ Boma)	10	Oryx and eland boma in South Quarry; occurs on reserve land and consists of coastal scrub vegetation.
NORTH QUARRY	Reception (NQ Reception)	5	Area around Butterfly Pavilion in North Quarry consisting mainly of grass lawns, visitor reception and car park.
	Maweni	10	Primary grassland with black cotton soil found on reserve land; main grazing site for oryx and elands
	Great Lake	8	Secondary grassland with sand/clay soil; occurs in spent and rehabilitated quarry land
	Boma (NQ Boma)	10	Enclosure in which eland and oryx in North Quarry are kept at night; consists mainly of scrub and bush vegetation
	Western Waterbodies	10	Secondary *Casuarina* forest interspersed with waterbodies of varying sizes; occur in spent and rehabilitated quarry

LES. A 1x1 m^2 flannel cloth was dragged along the ground for a maximum distance of 30 m or less. Dragging was repeated a maximum of 10 times or less, with the number of drags varying according to the size of the location. Due to absences and logistical problems, no dragging was conducted in October 2005 and December 2005. Similarly the areas of SQ new quarry and SQ bare ground have no data for May and June 2005, and Maweni has no data for August 2005.

Ticks attached to the flannel cloth were counted and put in 10% formalin for preservation and identification. Ticks collected were sent to the International Centre of Insect Physiology and Ecology (ICIPE) for identification.

As part of tick control procedures, Ziwa la Ngombe was burned in March and September 2005. Similarly dipping was ongoing throughout the study period. Elands were treated with pour-on acaricides Bayticol® and Spoton® on a monthly basis, while oryx and giraffes were treated once every 2-3 months. Aldabran tortoises and the Snake Park tortoises were treated with Frontline® spray every 3 months; treatment of the tortoises was started in March 2005.

Figure 16.1 Tick densities (mean monthly number/m^2) pooled for sample sites in Bamburi North and Bamburi South quarries from Feb. 2005 to Feb. 2006. (No samples were taken in Oct. and Dec.)



Results

Eight tick species were collected over the course of the study. The tick species were *Amblyomma hebraeum*, *A. sparsum*, *A. nuttalli*, *A. gemma*, *Rhipicephalus pulchellus*, *R. pravus*, *Hyalomma marginatum rufipes* and *Boophilus decoloratus*. All the species occurred in the South Quarry, whereas only *R. pulchellus*, *R. pravus* and *B. decoloratus* were found present in the North Quarry.

Tick densities exhibited a fluctuating pattern throughout the study period in both North and South Quarry (Figure 16.1). Both locations exhibited similar tick density trends, with rises and falls in density at similar time periods during the year.

In South Quarry, tick densities above 2 ticks/m^2 occurred in the Snake Park, Ziwa la Ngombe and the SQ boma (Appendix 16.1). The Snake Park exhibited the highest variation in tick densities (s.d.=5.65), and densities were initially high, but gradually reduced over the study period. Ziwa la Ngombe also exhibited a large variation in tick density (s.d.=4.22). Variation in density was minimal within other locations and no significant variation occurred in tick densities between or within South Quarry sites ($p>.05$).

Tick densities in North Quarry (Appendix 16.2) were generally much lower than densities in South Quarry, although this difference was not significant ($p>0.05$). Minimal variation in tick density occurred within sites, but a significant variation in tick density was found between sites ($p<0.01$), with the North Quarry oryx/eland boma and the Maweni grassland exhibiting the highest tick densities for North Quarry.

Discussion and conclusion

The higher tick densities that were found in South Quarry compared to North Quarry is most likely related to the wider variety of animals found in the South Quarry. This has been seen in previous studies where positive correlations between tick density and host density patterns occurred (Krasnov *et al.* 2001). Among the South Quarry sites with higher tick densities, Ziwa la Ngombe and South Quarry bare ground tend to have a higher volume of animal traffic compared to other South Quarry sites. Additionally Ziwa la Ngombe and South Quarry New Quarry were favoured by waterbucks. The waterbucks were not treated for ticks and this seems to encourage tick proliferation in these areas. It is recommended that the waterbucks be included in the tick treatment program for large ungulates. In addition it is proposed that further studies should look into animal dispersal patterns and movement in South Quarry in relation to tick density.

The Snake Park showed high tick densities initially, which reduced over the course of the study. The reduction is most likely linked to acaricidal treatment of the tortoises in the Snake Park, as tick densities began to fall soon after the treatment program started (March 2005). Ziwa la Ngombe also exhibited a reduction in tick densities after burning in March and September 2005.

North Quarry results showed two sites (Western waterbodies and Reception NQ) had almost no ticks during the period of study, whereas two sites (Maweni and Boma NQ) exhibited the highest tick densities. The significant variation in tick densities in North Quarry supports the finding that wildlife dispersal patterns exert an influence on tick distributions (Ginsberg & Zhioua 1999). Similarly a narrower choice of hosts in North Quarry also may have influenced tick species richness, as there are no giraffes, waterbucks or Aldabran tortoises in North Quarry.

Although there was no significant variation between monthly tick densities, the similar density trends seen in both quarries indicate that seasonal factors of temperature and rainfall may influence tick densities, as has been observed in similar tick studies carried out in the Kenyan coastal region (Randolph 1999). Further information on the effect of such seasonal factors on tick densities will contribute to more efficient tick control practices. However, despite the emergence of a particular tick density trend over the course of the study, findings from previous studies imply that tick population densities are subject to annual variations (Daniels *et al.* 2000). Hence regular monitoring of tick densities is an important part of efficient tick control. Monitoring may also provide guidance regarding other aspects of wildlife management such as wildlife dispersal patterns.

The tick control measures that were employed including burning and acaricidal use resulted in a reduction in tick density in the locations that were applied. Although acaricidal treatment is effective, biological tick control through the use of tick predators (Mwangi *et al.* 1991), despite its restricted application has more potential for sustainability, and is firmly advocated as an important aspect of wildlife and ecosystem management.

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Summary

Ticks are acknowledged as significant disease vectors with socio-economic impacts in the management of both domestic and wild animals. The rich wildlife diversity found at Bamburi Quarry, managed by Lafarge Eco Systems (LES), encourages the presence and proliferation of ticks on LES premises. As a popular attraction for tourists and locals to visit, LES has high potential for the occurrence of tick-borne diseases and the development of new exchange patterns of pathogens between hosts. Tick control is an important aspect of wildlife management practices in LES, and also contributes towards more efficient ecosystem management. Tick densities were surveyed by dragging a towel along the ground in two different locations (South Quarry and North Quarry). Mean densities were computed by dividing the number of ticks collected by the total distance dragged. Tick densities were significantly higher in South Quarry than North Quarry. No significant difference was found between densities either between months, or between locations while current methods of tick control for the premises including burning and use of acaricid reduced tick densities, biological control using tick predators was recommended because of its potential for sustainability.

Appendix 16.1 South Quarry; Mean tick densities by month (mean number of ticks/m^2 (s.d.))

Month	New quarry	Ziwa la Ngombe	Bare ground	Main gate	Snake park	SQ Reception	Fish farm	SQ Boma
Feb ’05	0.19 (0.004)	1.82 (0.16)	0.17 (0.07)	0.23 (0.12)	5.91 (0.58)	0.70 (0.1)	0.13 (0.002)	0.45 (0.04)
Mar ’05	0.03 (0.02)	0.24 (0.14)	0.06 (0.04)	0.02 (0.04)	3.10 (0.30)	0.10 (0.02)	0.10 (0.02)	0.29 (0.02)
Apr ’05	0.21 (0.01)	0.48 (0.04)	0.40 (0.04)	0.21 (0.02)	0.29 (0.12)	0.28 (0.02)	0.70 (0.06)	0.50 (0.04)
May ’05	-	0.05 (0.06)	-	0.21 (0.18)	0.88 (0.18)	0.32 (0.19)	0.12 (0.014)	0.52 (0.08)
Jun ’05	-	0.25 (0.2)	-	0.23 (0.08)	0.40 (0)	0.17 (0.08)	0.39 (0.04)	0.65 (0.10)
Jul ’05	1.14 (0.08)	0.43 (0.17)	0.48 (0.06)	0.22 (0.18)	0.12 (0.20)	0.15 (0.05)	1.00 (0.10)	0.86 (0.09)
Aug ’05	0.30 (0.02)	1.20 (0.10)	1.56 (0.14)	0.38 (0.04)	0.10 (0)	0.20 (0.10)	0.35 (0.04)	0.18 (0.01)
Sep ’05	0.47 (0.06)	3.35 (0.30)	0.47 (0.05)	0.79 (0.19)	0.23 (0.12)	0.21 (0.10)	0.60 (0.08)	2.73 (0.28)
Oct ’05*	-	-	-	-	-	-	-	-
Nov ’05	0.60 (0.08)	0.09 (0.08)	0.11 (0.04)	0.70 (0.08)	0.33 (0.26)	0.46 (0.17)	0.76 (0.07)	1.40 (0.12)
Dec ’05*	-	-	-	-	-	-	-	-
Jan ’06	0.31 (0.24)	1.35 (0.20)	0.06 (0.38)	0.17 (0.10)	0.05 (0.07)	0.18 (0.52)	0.02 (0.03)	0.50 (0.05)
Feb ’06	0.19 (0.16)	0.57 (0.05)	0.32 (0.02)	1.44 (0.13)	0.54 (0.30)	1.06 (0.13)	1.26 (0.16)	0.35 (0.026)

* Samples were not taken in October and December 2005.

Appendix 16.2 North Quarry; Mean tick densities by month (mean number of ticks/m^2 (s.d.))

Month	Western waterbodies	NQ Reception	Great lake	NQ Boma	Maweni
Feb ’05	0	0	0.02 (0.12)	1.16 (3.12)	1.58 (4.62)
Mar ’05	0	0	0.01 (0.06)	0.90 (1.81)	1.50 (1.38)
Apr ’05	0	0	0.01 (0.001)	0.51 (0.27)	0.43 (0.23)
May ’05	0.005 (2.65)	0	0.01 (0.03)	0.08 (0.17)	0.15 (0.12)
Jun ’05	0	0	0.01 (0.004)	0.37 (0.20)	0.39 (0.26)
Jul ’05	0	0	0.06 (0.37)	0.44 (0.72)	1.04 (2.08)
Aug ’05	0	0	0.11 (0.03)	1.67 (1.36)	-
Sep ’05	0	0	0.01 (0.03)	0.56 (0.32)	0.41 (0.85)
Oct ’05*	-	-	-	-	-
Nov ’05	0	0	0.39 (0.20)	0.44 (0.29)	0.60 (0.22)
Dec ’05*	-	-	-	-	-
Jan ’06	0	0	0.19 (0.19)	0.31 (0.13)	0.55 (0.21)
Feb ’06	0	0	0.28 (0.20)	0.27 (0.23)	0.43 (0.42)

* Samples were not taken in October and December 2005.

17

Interaction between hydrography and tides of an ebb-dominated shallow water estuary – the Tudor Creek

M.M. Nguli[1], L. Rydberg[2], U. Cederlöf [3] & D. Kirugara[4]

Introduction

Studies of hydrography and tides in tropical shallow water ecosystems of the Western Indian Ocean are rare.[5] In Kenya, data from the Kilindini Harbour (Mombasa) tide gauge was investigated by Pugh (1979). Nguli (1994) and Odido (1994) studied tides and currents in Tudor Creek, just north of Mombasa, and Magori (1997) did similar investigations in Mtwapa Creek further north (Map 17.1). Analyses of salinities, temperatures and currents were done by Norconsult in the creeks surrounding Mombasa (Anon. 1975) and by Kitheka in Gazi Bay (Kitheka 1997) and in Mida Creek, Kilindini Harbour (Mwache Creek) and Tana River estuary (Kitheka 1998; Kitheka *et al.* 2002, 2005). However, with the exception of Pugh (1979) and Magori (1997) none of these studies evaluated tides or tidal circulation. Recently, Nguli (2006) gave an overview of the hydrography of the Kenyan creeks and the adjoining coastal waters, presenting more comprehensive data series on salinities, temperatures, currents and sea levels from three Kenyan creeks (Gazi Bay, Tudor and Kilifi Creeks). These data can be used for further investigations.

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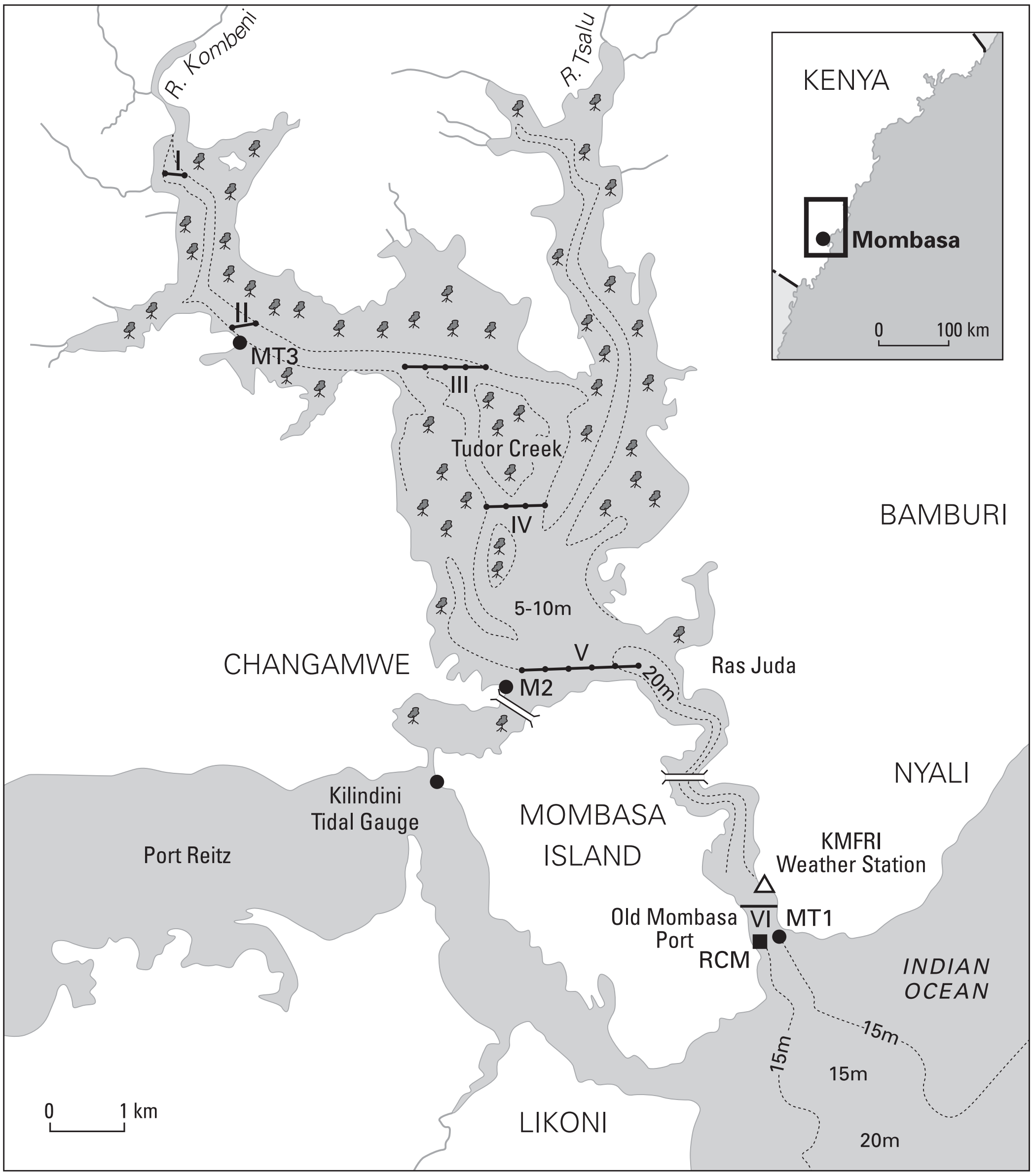
5 For a popular description of tides and tidal analysis, see e.g. Tobisson *et al.* (1998).



Map 17.1 Tudor Creek with positions of measuring instruments: Tide gauges (MT1, M2, MT3), current meter (RCM), salinity and temperature (Sections I-VI), surface water salinity and temperature (KMFRI)

Nguli *et al.* (2006) used temperature and salinity data from hydrographic surveys in Tudor Creek in order to estimate water exchange based on average gradients, and heat and fresh-water fluxes, respectively. The maximum temperature difference between the creek basin and the ocean was 1.54^0C, during the north-east monsoon (December-March), and the minimum was 0.49^0C during the inter-monsoon long rains (April-May). The corresponding salinity differences, on the other hand, maximized during the long rains, with 2.59 psu lower salinity in the basin compared to the ocean. During the north-east monsoon, on the other hand, the salinity was 0.26 psu higher than in the ocean, due to excess evaporation. These horizontal temperature (and salinity) variations exert some influence on inlet hydrography and currents. During low and high water, when the tidal currents are weak, the inlet waters may tend to stratify. Less dense (i.e. warmer and fresher) water from the creek will flow on top, while heavier (colder and saltier) water from the ocean will sink underneath. Stratification in turn will affect the inlet flow conditions and create flow resistance through what is called baroclinic wave drag (i.e. Stigebrandt 1999).

In this paper we examined the tides of Tudor Creek, based on three parallel series of tide gauge observations from different parts of the creek during a period of 25 days. The results were compared to current and salinity measurements from the inlet. Funnelling, ebb dominance and baroclinic wave drag were features discussed in order to elucidate the appearance of the tide and its relationship to currents and salinity-temperature variability.

Table 17.1 Volumes and areas of Tudor Creek (including the inlet) at different stages of the tide, based on evaluations from sea charts and Admiralty Tide Tables. (The mean depth is similar because the relative importance of the deep inlet is increasing during low water)

	MHWS*	MHWN*	MLWN*	MLWS*
Sea level (datum ref, m)	3.5	2.4	1.3	0.3
Surface area (km^2)	24	14	11	7.5
Volume ($x10^6m^3$)	95	68	54	41
Mean depth (m)	5	5	5	5.5

* MHWS/MLWS = Mean High/Low Water Spring
MHWN/MLWN= Mean High/Low Water Neap

Study site

The Tudor Creek constitutes the northern branch of the waters surrounding Mombasa Island (Map 17.1). The creek has two seasonal rivers, Kombeni and Tsalu, draining an area of 550 km^2 and a single sinuous inlet with a mean depth of about 20 m. The tidal range at Kilindini Harbour on the southern side of Mombasa Island is 3.2 m at spring and 1.1 m at neap (Admiralty Tide Tables). Outside the entrance to Tudor Creek, there is a 2-3 km wide opening surrounded by fringing reefs. The sill depth vs. the ocean in this area is 14 m at Mean Low Water Spring (MLWS).

The inlet is connected to a shallow inner basin, which is fringed by mangroves and mudflats. The basin has an area of 6.25 km^2 at MLWS and 22.3 km^2 at Mean High Water Spring (MHWS). The sea surface area of the inlet varies from 1.25 km^2 at MLWS to 1.7 km^2 at MHWS (Table 17.1). Mangrove forests occupy some 8 km^2 (Map 17.1).

Method

Hydrographic sampling, using a direct reading salinity-temperature sensor (Aanderaa 3210; accuracy 0.1 psu, 0.1^0 C), was carried out between 1994 and 1997. Data from a total of 21 surveys, covering all seasons, were obtained. The sampling sections (I-VI) are shown in Map 17.1.

From October 2 to 26, 1998, tidal observations, with three tide gauges working simultaneously at Stns MT1, M2 and MT3 (Map 17.1), were conducted. The instruments, of type MicroTide (Coastal Leasing) measure sea level and temperature with an accuracy of 1.5 cm and 0.1^0 C, respectively. Velocity measurements from the inlet (at Stn RCM) were obtained during a much earlier period, from 12 January-9 February 1993. A current meter of type SD-6000 (Sensordata) was deployed at mid-depth (10 m). The accuracy of this instrument is 2 cms^{-1} for velocity and 5^0 for direction. Sea level, temperatures and velocities were measured in 5-min intervals.

A weather mast was erected at Stn KMFRI from 14 June-28 August 1996. During this period, sea surface temperature and salinity were measured, using a salinity-temperature sensor (Aanderaa 3210; see above) connected to the weather mast. Data were sampled at 20 min intervals.

Data analysis included harmonic analysis of tides and temperature data, using programs designed in Matlab.

Results

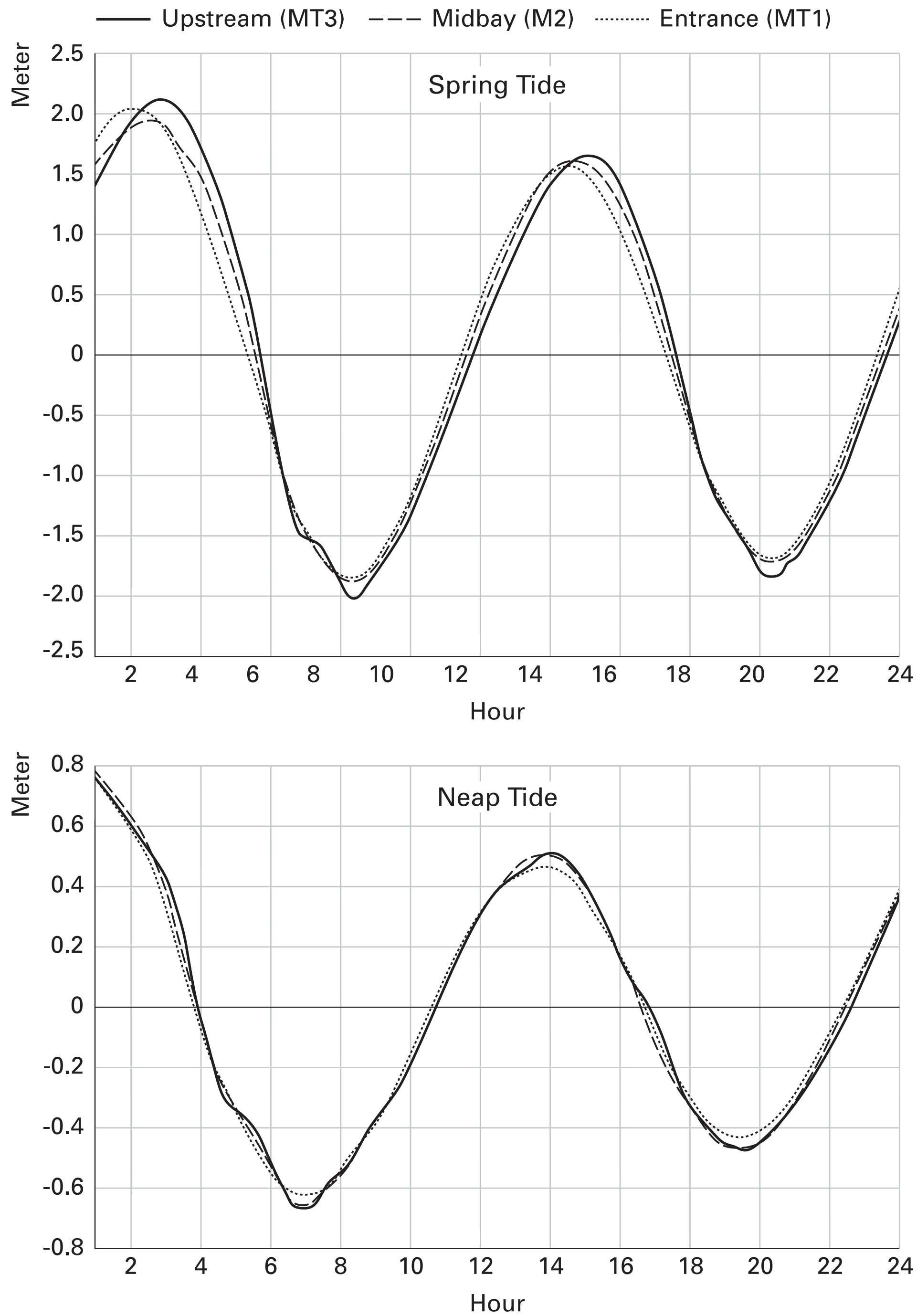
Sea level and water temperatures

Harmonic analysis was carried out on the sea level data. In this exercise, fourteen components were employed, including the fortnightly M_f and six shallow water tides. Amplitudes and phase angles for the principal components, i.e. the semi-diurnal (M_2, S_2, N_2 and K_2) and the diurnal (O_1 and K_1) are shown in Table 17.2. The results by Pugh (1979), based on a one year long series from the tide gauge in Kilindini Harbour (see Map 17.1), are shown for comparison. Table 17.3 presents data on various tidal parameters, such as tidal ranges and the form factor, derived from Table 17.2 data. The Mombasa tide was semi-diurnal, with a form factor of 0.21 (Table 17.3).The largest component was the semi-diurnal M_2 with an amplitude of about 1.1 m (Table 17.2), and with a small increase from the entrance towards the head of the creek. This increase is counteracted by a decrease in S_2, averaging about 0.5 m. The spring tidal range, $2(M_2+S_2)$ therefore was similar at all three stations, including Kilindini (3.14-3.16 m; Table 17.3), whereas the neap tidal range, $2(M_2-S_2)$ varied from 1.09-1.32 m. The amplitudes obtained by Pugh (1979) for Kilindini Harbour feature just marginal deviations. For M_2, there was an increase of the phase angle from 32^0 to 38^0 from the entrance (Stn MT1) to the head (Stn MT3), indicating an average 12 min delay between these stations. The shallow water tidal components, M_4 and others (not shown here) were measured because we expected a different behaviour of the tide towards the head, compared to the inlet area of the creek. Tidal component M_4 and MS_4 were most prominent in the upstream end of the creek, at Stn MT3, indicating a tidal asymmetry. However, the amplitudes were small, with a maximum of 7 cm.

Table 17.2 Amplitudes (m) and phases (0) for six principal tidal components based on harmonic analysis of sea level and temperature (^{0}C) data from Stns MT1, M2 and MT3. Results from Kilindini Harbour based on a 1-yr series are inserted for comparison (Pugh 1979)

Tidal comp.		MT1		M2		MT3		Kilindini
Tidal component	Period (hrs)	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase	Amplitude
M2	12.42	1.062	32	1.097	35	1.117	38	1.055
S2	12.00	0.519	138	0.487	137	0.457	141	0.521
N2	12.66	0.212	-49	0.213	-44	0.214	-40	0.201
K2	11.97	0.082	-164	0.143	-153	0.179	-161	0.139
K1	23.93	0.224	-84	0.226	-76	0.237	-78	0.191
O1	25.84	0.102	57	0.097	60	0.099	64	0.113
Name	Period	Temp.		Temp.		Temp.		
M2	12.42	0.154		0.040		0.102		-
S2	12.00	0.086		0.006		0.112		-
S1	24.00	0.113		0.118		0.289		-
Mf	327.86	0.050		0.150		0.165		-

Figure 17.1 Tidal sea levels of Tudor Creek at spring and neap tide. (The figures indicate larger range upstream, due to funneling, and substantial ebb dominance, with longer flood than ebb periods).



Temperature data from the tide gauges were also subjected to harmonic analysis, using fewer components. Temperature amplitudes for some major components including the 24-h diurnal S_1 and the fortnightly M_f are shown in Table 17.2 (lower part). As expected the diurnal solar component, with day heating and night cooling dominated the short term temperature variation, particularly in the shallow upper reaches of the creek, i.e. at Stn MT3. Among the common tidal components, M_2 had the largest amplitude. It was more pronounced at the inlet (Stn MT1) and in the upper reaches (Stn MT3) where the currents were stronger, than it was in the basin, at Stn M2. In addition, there was a large temperature amplitude in the fortnightly tide (M_f), which occurred because the water exchange was at least twice as strong during spring compared to during neap (Nguli *et al.* 2006). This indicated that the temperature gradients were twice as large during neap than they were during spring, and that the difference gave rise to the fortnightly tide, which appears stronger in the basin (Stn M2) and at the head.

Table 17.3 Tidal characteristics based on harmonic analysis of sea level data from Stn MT1, M2 and MT3. Results from Kilindini Harbor are inserted (Pugh 1979)

Parameter	Formulae	MT1	M2	MT3	Kilindini
Form factor	$(K_1+O_1)/(M_2+S_2)$	0.206	0.204	0.213	0.193
Mean tidal range	$2.2M_2$	2.336	2.413	2.46	2.32
Spring tidal range	$2(M_2+S_2)$	3.162	3.168	3.148	3.15
Neap tidal range	$2(M_2-S_2)$	1.086	1.220	1.320	1.07
Tropical range	$2(K_1+O_1)$	0.652	0.646	0.672	0.61
Equatorial range	$2(K_1-O_1)$	0.244	0.258	0.276	0.13

Tidal variations in detail

The tidal series from Tudor Creek had several interesting features, which were not immediately obvious from the harmonic analysis. This is clearly seen from Figure 17.1, showing details of the sea level at spring and neap, respectively. During neap tides, the difference in phase between the entrance (Stn MT1) and the head (Stn MT3) was negligible. During spring, on the other hand, there was an almost 1 h phase lag between high water at the entrance and at the head, while the phase lag was zero at low water. All three stations featured ebb dominance, although it was most pronounced at Stn MT3, where the ebb period was about 5.5 h and the flood period was almost 7.0 h, similar at neap and at spring. Ebb dominance, which is different from flood dominance means shorter ebb tides, but larger ebb velocities (e.g. Shetye & Gouveia 1992).

A spectacular feature of Figure 17.1, in addition was the rapidly falling sea level at Stn MT3, which was suddenly slowed for a short period of time, at about 1 h before low tide. This odd feature appeared in all data, both at spring and neap tide. The reason for this sudden slow-down, was most likely an effect of baroclinic wave drag (Stigebrandt 1999), which developed in the inlet. As aforementioned, stratification appears during most of the year (Nguli 2006).

Baroclinic wave drag implies that tidal energy is used to lift heavier water from deeper levels in the inlet towards the surface. The process takes place both during in- and outflow but is likely to be more continuous during inflow, whereby the flood period is extended. Figure 17.1 also showed that the range was slightly higher upstream than at the inlet: During spring, the difference in range was 20 cm (3.91m - MT1, 4.13 m – MT3), but during neap, ranges were similar. The reason for the increase in range was probably topographic, due to funnelling in the upper part of the creek. The difference was clearly seen in the mean and neap tidal range, but not in the spring range (Table 17.3).

Inlet tidal currents

Data from the tide gauges were used to calculate entrance volume fluxes. For this purpose we simply employed sea level data from Stn MT1 to calculate the tidal velocity $u_t=A_h(dh/dt)$. The instantaneous volume flux $Q_t=u_tA_v$ was calculated accordingly. Peak flood and ebb volume fluxes are shown in Table 17.4. The peak spring mean volume fluxes were ~ 2400 m^3s^{-1} and the peak neap fluxes were ~ 600 m^3s^{-1}, whereas the maximum fluxes were 50% larger.

Table 17.4 Mean flood and ebb volume fluxes, at peak spring and neap, respectively including duration of ebb and flood at Stn MT1. Maximum fluxes (for maximum velocities) are about 50% larger.

	Spring (m^3s^{-1})	Neap (m^3s^{-1})	Duration (hrs)
Flood	2354	589	6.33
Ebb	2451	613	6.08

The current measurements carried out in the centre of the inlet, at Stn RCM indicated maximum ebb velocities of 60-70 cms^{-1} and maximum flood velocities of 50-55 cms^{-1}, at spring. The mean flood period was 6.33 h and the ebb period was 6.08 h for the 1-month period of observations (Nguli 2006). At neap, the velocities were small, typically 10-20 cms^{-1}, with more shifting directions. Given a cross-section area of about 6000 m^2, the mean volume flux at peak spring is 2400 m^3s^{-1}, thus similar to the estimate from the tide gauge (Table 17.4).

However, the more important result was that the current measurements indicated ebb dominance, although not as strong as in the tide gauge data. This is reasonable as the velocity data were from another period, and the degree of ebb dominance depends on the strength of the stratification.

Short term salinity variations

High resolution records of sea surface salinities and temperatures were obtained with a salinity-temperature sensor placed at Stn KMFRI (Map 17.1). Measurements started from June 18, 1996, and continued for several months, although the salinity sensor stopped working after a month because of fouling. During this period, at the end of the long rains, the salinity in the ocean was at its lowest (34.8 psu) but higher than in the Tudor Creek basin area (32 psu; Nguli *et al.* 2006). Thus, the semidiurnal tide created a surface salinity range of 0.5-1 psu in the inlet, larger during spring tide than during neap. The difference in range was even more obvious in the temperature record, from 0.3^{0}C during neap to 0.8^{0}C during spring.

Discussion

Simultaneous sea level and temperature observations from three tide gauge stations in Tudor Creek were used to investigate 1) tidal variations within the creek 2) relationship between creek tides and inlet velocities (and salinities) and 3) efficiency of tidal mixing based on tide gauge temperature data. Harmonic analysis showed an average spring tidal range of 3.16 m, with very small differences between the stations (1 cm; Table 17.3). Neap tidal range, on the other hand varied from 1.09 m at the entrance (Stn MT1) to 1.32 m at the head (Stn MT3). The average phase lag for M_2, between MT1 and MT3 was 12 min (Table 17.2). A comparison of ranges and phases at Stn MT1 with Kilindini Harbor data (Tables 17.2-3), showed good agreement.

However, more detailed studies of the tide gauge data indicated other features (Figure 17.1), which were not apparent from harmonic analysis. These include for example a strong ebb dominance. At Stn MT3 the flood period was 1.5 h longer than the ebb period. At Stn MT1, the current meter and tide gauge data indicated differences of 0.5 and 0.3 h, respectively. Maximum ebb velocities were accordingly somewhat larger, compared to flood velocities. We hypothesized the prolonged flood tide to be a result of baroclinic wave drag (caused by inlet stratification), which is assymetric, for topographic reasons, and more efficient during flood than during ebb. For 30 min during ebb (see Figure 17.1), there are also indications of a baroclinic control. However, because stratification varies throughout the year, the strength of the ebb dominance will vary, accordingly. Fronts with horizontal temperature and salinity gradients appeared in the inlet at Stn KMFRI (from June-August 1996), corroborating the wave drag hypothesis. However, measurements simultaneous with the tide gauge observations are missing, and therefore our hypothesis is still somewhat speculative.

Harmonic analysis performed on the tide gauge temperature data showed very clear evidences of differences in tidal exchange between different sites and during neap and spring. Distinct amplitudes appear both in the semi-diurnal and in the fortnightly tide (Table 17.2). With parallel data on sea surface heat fluxes, temperature data could be used to calculate exchange coefficients with high accuracy (Nguli *et al*. 2006).

Conclusion

The tidal data from Tudor Creek are shown to be of high quality. There is virtually no difference in spring tidal range between the different sites, whereas the neap tidal range increases towards the head. The average M_2 phase lag between the inlet and the uppermost station is 12 min, largest during spring. Ebb periods are longer than flood periods (0.3-1.5 h; with maximum at the head), indicating an ebb dominance. We hypothesized that this is caused by baroclinic wave drag, due to stratification in the deep inlet combined with the particular topography. To evaluate this hypothesis, simultaneous observations of creek tides and inlet salinities and temperatures are needed. Such observations should be carried out at the end of the south-east monsoon (August-September) and at the end of the long rains season (May-June), when horizontal density gradients are smallest and largest, respectively. Parallel observations of sea surface heat fluxes would make it possible to determine tidal exchange coefficients within the creek.

Acknowledgements

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Summary

Tropical shallow water ecosystems on the East African coast are characterized by semi-enclosed inner basins with muddy-peripheral lagoons and mangrove-fringed small creeks. The inner basins are connected to the ocean by one or several tidal channels that determine the hydrography of the creek waters. Seasonal river discharge may turn them into estuaries, albeit for short periods during monsoon rains. This paper investigates hydrography and currents in relation to the tidal characteristics of Tudor Creek, Kenya. Tudor Creek has a single deep channel, connecting it to the Indian Ocean. Tides and temperatures were observed for a period of 25 days, using tide gauges placed in the upper and middle reaches of the creek, respectively and at the oceanic side of the inlet. Salinity was measured near the surface in the outer part of inlet channel, and a current meter was placed at mid-depth. Harmonic analysis showed dominance of the semi-diurnal tides. Neap and spring tidal ranges were 1.09-1.32 m and 3.14-3.16 m, respectively. The temperature differences between the creek and the ocean were large enough to create intermittent stratification in the inlet, the strength of which was directly related to the tides. Inlet stratification, in turn, was the likely reason for baroclinic wave drag and an ebb dominant tide. Baroclinic wave drag prolonged the flood tide and created some outstanding features on the tidal curve. Ebb periods were shorter than flood periods (0.3-1.5 h), while maximum ebb velocities were accordingly somewhat larger; 60-70 cms^{-1}, compared to 50-55 cms^{-1} during flood.

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