Mangrove linkages to coral reef and seagrass ecosystem services in Mombasa and Takaungu, Kenya

Participatory Modelling Frameworks to Understand Wellbeing Trade-offs in Coastal Ecosystem Services:
Mangrove sub-component

Bosire J. O., Okemwa G., Ochiewo J.

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EXECUTIVE SUMMARY

The main objective of this work was to document mangroves linkages to coral reef/seagrass ecosystem services between Mombasa and Takaungu, Kenya especially in supporting fisheries productivity. According to the most recent estimates, mangroves globally cover about 15.2 million ha straddling coastlines in 123 tropical and subtropical countries. Of these, about 1 million ha are in the Western Indian Ocean region with Kenya having about 54,000 ha. Mangroves are among some of the most productive and biologically important ecosystems of the world because they provide important and unique ecosystem goods and services to humanity and coastal and marine systems. Many coastal communities depend on mangrove wood products for timber, poles and fuel-wood. The forests help stabilize shorelines and reduce the devastating impact of natural disasters such as tsunamis and hurricanes. In the context of climate change, mangroves, could sequester approximately 22.8 million metric tons of carbon each year. Covering only 0.1% of the earth's continental surface, the forests account for 11% of the total input of terrestrial carbon into the ocean and 10% of the terrestrial dissolved organic carbon (DOC) exported to the ocean. The forests act as a sink of pollutants, trap sediments and strip land based nutrients which could otherwise threaten adjacent ecosystems (e.g. seagrasses and coral reefs). The role of mangroves in supporting fisheries productivity although not clearly understood is widely appreciated. The overlap of fish species between coral reefs, seagrass beds and mangroves indicate strong linkages between the three ecosystems, with the greatest diversity being associated with coral reefs. It has also been observed that mangroves strongly influenced the community structure of fish on neighbouring coral reefs. In addition, the biomass of several commercially important species more than doubled when adult habitat was connected to mangroves demonstrating the strong functional linkage between tropical coastal ecosystems. Sustainable management of mangroves will require an ecosystem based management (EBM) approach which links mangroves with seagrass, coral reefs and upstream contiguous ecosystems. Instead of managing mangroves as single-use resource, they should be managed as multiple-use resources for fisheries, coastal protection, carbon sequestration and the traditional provision of wood products.

Participatory modelling of wellbeing tradeoffs in coastal Kenya (P-Mowtick, REF: NE/I00324X/1*) is funded by the Ecosystem Services for Poverty Alleviation (ESPA) programme. ESPA aims to deliver high quality and cutting-edge research that will produce improved understanding of how ecosystems function, the services they provide, the full value of these services, and their potential role in achieving sustainable poverty reduction. ESPA research provides the evidence and tools to enable decision makers and end users to manage ecosystems sustainably and in a way that contributes to poverty reduction. See www.espa.ac.uk for more details. For more information on the P-Mowtick project see: www.espa.ac.uk/projects/ne-i00324x-1/further-information-and-project-documents*

The ESPA programme is funded by the Department for International Development (DFID), the Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC), as part of the UK's Living with Environmental Change Programme (LWEC).

TERMS OF REFERENCE

This work was undertaken under the auspices of the main Project on "Participatory Modelling Frameworks to Understand Wellbeing Trade-offs in Coastal Ecosystem Services" and specifically reviewed "Mangroves linkages to coral reef/seagrass ecosystem services between Mombasa and Takaungu, Kenya". Since it was a desktop study, Mombasa mangroves are majorly dealt with while works on fisheries and socio-economics have been quoted from other parts of Kenya and the world. Since it is a review, some of the TORs below may not have been exhaustively dealt with. Below are the TORs for this work:

1. Standard descriptions of the mangroves within the study area (area, location, biomass, productivity, type, species etc).
2. Knowledge of trends (e.g., abundance, area, productivity, species composition) in these mangroves and possible future trajectories.
3. Summary of major ecosystem service provision (particularly fisheries) from these mangroves (with references where available) including activities numbers and types of people involved (where possible gender, where they live etc) species groups, any indications of trends/level of exploitation (e.g., annual catch preferrably by species/groups and by types of fishing gears used)
4. Any knowledge of reef/seagrass - mangrove link organisms present (i.e. what is known for these mangroves in terms of species which provide trophic, reproductive or other linkages between the mangrove and adjacent reef habitat). The following data estimated for each fish or invertebrate species with linkages, with indications of sources and level of certainty: Species or name, average size (length and weight), functional group or diet, main habitat (Reef, seagrass, mangrove), alternate habitat. Characterisation of their movement (e.g. juveniles in mangroves, adults in seagrasses or primarily a reef species which occasionally feed in mangroves at high tide [timing of the movement] etc). Type of activity (only of interest if it involves permanent transport of biomass across reef/mangrove boundary), Migration, foraging, other degree of dependence on Mangroves (facultative or obligate (e.g. proportion of time spent in mangroves, proportion of recruitment related to mangroves, relative amount of food obtained from mangroves etc.). If Migration, Biomass (in kg of fish per km^2 of habitat) or number of fish (per km2 of habitat) or percentage of fish population migrating (not returning) per day If foraging. Biomass (in kg of fish per km2 of habitat) or number of fish (per km^2 of habitat) or percentage of fish population that goes foraging per day. If other, give descriptive and quantitative details: Location/Area where this is known to occur, or All Indication of the relevance/significance of their role in generation of any of the ES. If life stages are particularly relevant because different habits.
5. Estimate of the import/export of zooplankton, phytoplankton, and Particulate Organic Matter and Dissolved Organic Matter.
6. Summary of current understanding about any other physical or social linkages between mangrove, reef and seagrass systems within the study area. All the information should be fully referenced making it clear what knowledge is specifically known for these mangroves and what is drawn from general scientific knowledge from research in Kenya or elsewhere. Where information is not available or uncertain this should be clearly indicated.

CHAPTER 1. MOMBASA MANGROVE ECOSYSTEMS

1.0. INTRODUCTION

1.1 Distribution

Mangroves are coastal forests found in sheltered estuaries and along river banks and lagoons in 124 tropical and subtropical countries and areas, mainly growing on soft substrates (FAO 2007). They are distributed in the inter-tidal region between the sea and land between approximately 30° N and 30° S latitude (Giri et. al.,2010) Their global distribution is believed to be delimited by major ocean currents and the 20° C isotherm of seawater in winter and are typically distributed from mean sea level to highest spring tide (Alongi, 2009). The current estimate of mangrove forests of the world is less than half of what it once was (Spalding et al., 1997; Spiers, 1999) and much of what remains is in a degraded condition (Giri et. al.,2010).

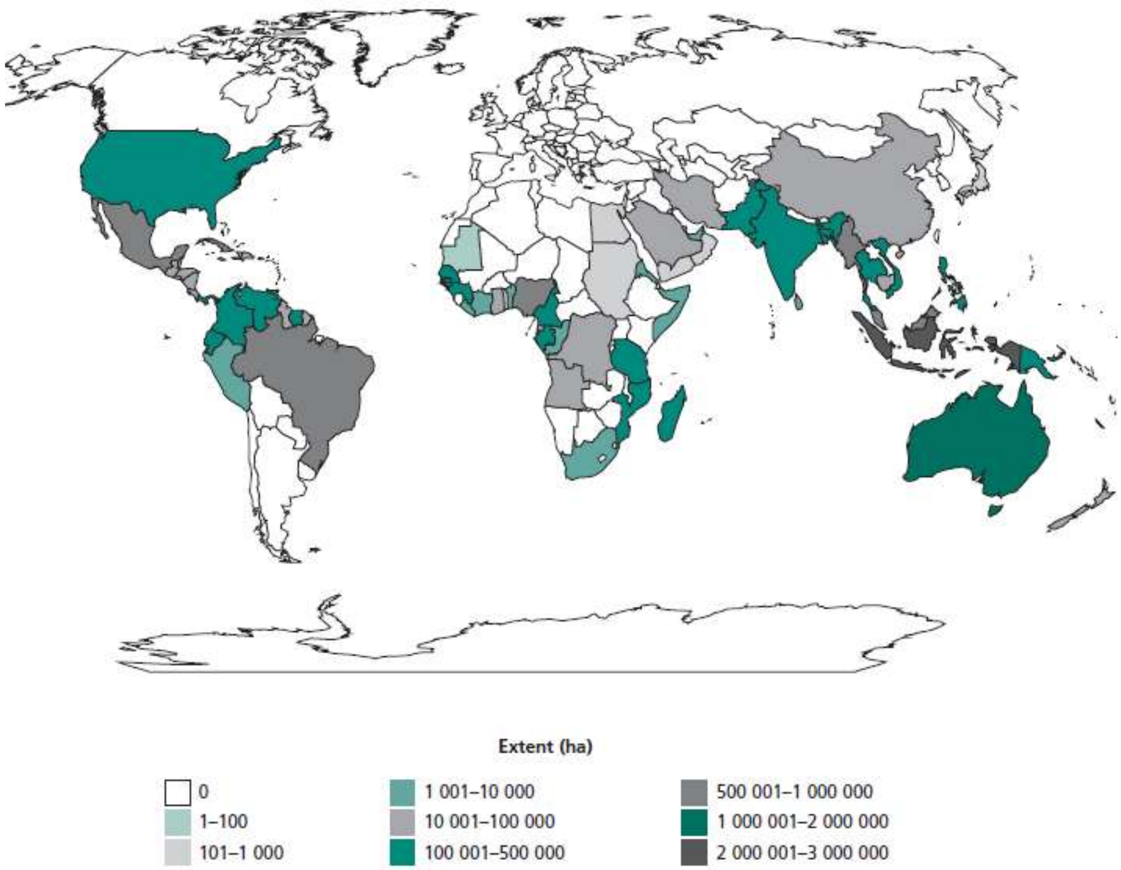

Figure 1. Mangrove distribution worldwide (FAO 2007).

There are 9 orders, 20 families, 27 genera and roughly 70 species of mangroves (Spalding et al. 1997, Alongi, 2002). A study by Giri et. al., 2010 estimated that the total mangrove forest area of the world in 2000 was 137,760 km^2 with the largest extent of mangroves found in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). The total mangrove area accounts for 0.7% of total tropical forests of the world.

Table 1: The 15 most mangrove-rich countries and their cumulative percentages (FAO 2007).

SN	Country	Area (ha)	% of global total	Cumulative %	Region
1	Indonesia	3,112,989	22.6	22.6	Asia
2	Australia	977,975	7.1	29.7	Oceania
3	Brazil	962,683	7.0	36.7	South America
4	Mexico	741,917	5.4	42.1	North and Central America
5	Nigeria	653,669	4.7	46.8	Africa
6	Malaysia	505,386	3.7	50.5	Asia
7	Myanmar (Burma)	494,584	3.6	54.1	Asia
8	Papua New Guinea	480,121	3.5	57.6	Oceania
9	Bangladesh	436,570	3.2	60.8	Asia
10	Cuba	421,538	3.1	63.9	North and Central America
11	India	368,276	2.7	66.6	Asia
12	Guinea Bissau	338,652	2.5	69.1	Africa
13	Mozambique	318,851	2.3	71.4	Africa
14	Madagascar	278,078	2.0	73.4	Africa
15	Philippines	263,137	1.9	75.3	Asia

Although mangroves are able to grow under unique conditions of sand, peat, rock and coral, the most extensive and luxiuriant forests are often associated with muddy soils usually found along deltaic Coasts, in lagoons and along estuarine environments (Saenger 2002).The morphorlogical architecture of mangroves enables them to modify the local wave climate and some of them can therefore grow out from sheltered environments to medium-high energy environments. Climatic conditions also play a critical role in determining mangrove distribution (Bosire 2006).

Figure 2. Lush mangrove forest at Tudor Creek Mombasa, Kenya

Mangroves are under constant flux due to both natural (e.g. erosion, aggradations) and anthropogenic forces. In the last three decades, forest losses because of anthropogenic factors have increased significantly (Giri et. al. 2010). The remaining mangrove forests are under immense pressure from clear-cutting, land-use change, hydrological alterations, chemical spill and climate change (Blasco et al., 2001). In the future, sea-level rise could be the biggest threat to mangrove ecosystems (Giri et. al. 2010).

1.2 Importance of Mangroves

Mangrove forest ecosystems fulfil a number of important functions and provide a wide range of services. They are among some of the most productive and biologically important ecosystems of the world because they provide important and unique ecosystem goods and services to human society and coastal and marine systems (FAO 2007). The forests help stabilize shorelines and reduce the devastating impact of natural disasters such as tsunamis and hurricanes. They also provide breeding and nursing grounds for marine and pelagic species, and food, medicine, fuel and building materials for local communities (Giri et al. 2010). Mangroves, including associated soils, could sequester approximately 22.8 million metric tons of carbon each year. Covering only 0.1% of the earth's continental surface, the forests account for 11% of the total input of terrestrial carbon into the ocean (Jennerjahn & Ittekot, 2002) and 10% of the terrestrial dissolved organic carbon (DOC) exported to the ocean (Dittmar et al., 2006). The rapid disappearance and degradation of mangroves could have negative consequences for transfer of materials into the marine systems and influence the atmospheric composition and climate.

Mangroves support the conservation of biological diversity by providing habitats, spawning grounds, nurseries and nutrients for a number of animals. These include several endangered species and range from reptiles (e.g. crocodiles, iguanas and snakes) and amphibians to mammals (tigers – including the famous *Panthera tigris tigris,* the Royal Bengal tiger – deer, otters, manatees and dolphins) and birds (herons, egrets, pelicans and eagles). A wide range of commercial and non-commercial fish and shellfish also depends on these coastal forests. Mangrove organic productivity (Odum and Heald, 1972) has been suggested to support near shore fisheries production (Lee, 1999).Mangrove ecosystems are also used for aquaculture, both as open-water estuarine mariculture (e.g. oysters and mussels) and as pond culture (mainly for shrimps).

SUMMARY
Mangrove uses – wood and non-wood forest products
Fuel (Fuelwood**,** Charcoal)
Construction (Timber, scaffolding**,** Heavy construction**,** Railway sleepers**,** Mining props**,** Boat-building**,** Dock pilings**,** Beams and poles**,** Flooring, panelling**,** Thatch or matting**,** Fence posts, chipboard)
Fishing (Fishing stakes**,** Fishing boats**,** Wood for smoking fish**,** Tannin for nets/lines**,** Fish-attracting shelters)
Textile, leather (Synthetic fibres (rayon)**,** Dye for cloth**,** Tannin for leather preservation)
Other natural products (Fish, Crustaceans Honey Wax Birds Mammals Reptiles Other fauna)
Food, drugs and beverages (Sugar, Alcohol, Cooking oil**,** Vinegar**,** Tea substitute**,** Fermented drinks**,** Dessert topping**,** Condiments (bark)**,** Sweetmeats (propagules)**,** Vegetables (fruit/leaves)
Agriculture (Fodder)
Household items (Glue, Hairdressing oil**,** Tool handles**,** Rice mortar**,** Toys**,** Match sticks**,** Incense)
Other forest products (Packing boxes**,** Wood for smoking sheet rubber**,** Medicines)
Paper products (Paper – various)
Source: Modified from FAO, 1994

The increasing popularity of ecotourism activities also represents a potentially valuable and sustainable source of income for many local populations (UNEP- WCMC, 2006), especially where the forests are easy accessible. Through the construction of mangrove boardwalks, visits to mangroves have become an emerging alternative livelihood to mangrove dependent communities (Bosire, 2006).

Mangroves also help protect coral reefs, sea-grass beds and shipping lanes by entrapping upland runoff sediments. This is a key function in preventing and reducing coastal erosion and provides nearby communities with protection against the effects of wind, waves and water currents. In the aftermath of the 2004 Indian Ocean tsunami, the protective role of mangroves and other coastal forests and trees received considerable attention, both in the press and in academic circles (FAO 2007). Many local communities use designated locations in mangrove forests as sacred shrines where tree extraction is forbidden (UNEP-WCMC, 2006; pers obs).

1.3 Threats to Mangroves

The world has lost around 3.6 million hectares (ha) of mangroves since 1980, equivalent to an alarming 20 percent loss of total mangrove area according to (FAO, 2007, Giri *et.al*., 2010) recent. The total mangrove area has declined from 18.8 million ha in 1980 to 15.2 million ha in 2005, according to the report by FAO, 2007. Increasing human population with a subsequent demand for food production, industrial and urban development compounded with limited appreciation of the true value of mangroves by policy makers, have compromised mangrove conservation leading to widespread degradation (Field 1996). Direct and indirect human activities degrading terrestrial ecosystems are similarly affecting mangrove forests (Bosire, 2006).

Although accurate data on mangrove loss in different regions of the world is not available, the information accessible suggests that Asia and Latin America have suffered the highest losses mainly due to intensive shrimp farming (Dahdouh-Guebas et. al. 2005). Unfortunately, the world's most expansive and well developed mangroves are located in these regions, which raises questions on the global sustainability of these spatially limited and unique forests. Studies on external resources required to support these intensive shrimp farms indicates that shrimp farming ranks as one of the most resource-intensive food production systems, thus characterizing it as an ecologically unsustainable throughput system (Larsson et al. 1994, Kautsky et al. 1997). The tragedy of this conversion besides environmental degradation is the fact that mangroves which are multiple-use resources are turned into unsustainable single-use enterprises. Though some mangrove biodiversity components may persist, they nevertheless get run down and ecosystem conversions generally lead to a net loss of goods and services.

Other causes of widespread mangrove degradation include: reclamation for expansion of residential houses, tourist installations and agriculture; commercial or artisanal extraction of wood for timber, fuelwood, poles, freshwater diversion (Kairo et al. 2002, Farnsworth and Ellison 1997, Dahdouh-Guebas et al. 2005). A direct relation has also been found between the level of GDP and the area of mangroves remaining across countries (Barbier and Cox 2003). Overall globally, shrimp farming and agriculture have been identified as the leading causative factors in mangrove degradation (Barbier and Cox 2003). In Kenya, extraction of wood for use as industrial fuel-wood (Kairo 1995a) was the major cause of mangrove degradation in the study site (Gazi Bay).Unfortunately, the extent of degradation by these various causes in the Kenyan situation has not been quantified but is only evident from expansive bare areas. Recent estimates indicate that mangrove loss in Kenya since 1992 is about 20% (Kirui et al. 2011) and the highest degradation rates have been recorded in Tudor (86%) and Mwache Creek mangroves (46%) over this period (unpublished data).

The consequences of mangrove degradation are varied ranging from lack of wood for timber, poles, fuel-wood (Kairo 1995); reduced fishery productivity within mangroves and in nearshore waters; and loss of mangrove associated biodiversity (Bosire et al. 2004, Crona and Ronnback 2005); coastal erosion (Dahdouh-Guebas et al. 2004) and loss of human lives and property during catastrophic oceanic events like the tsunami (Dahdouh-Guebas et al. 2004). Loss of mangroves also causes salt water intrusion and deterioration of groundwater quality depended on by the local people, as well as the disappearance of sediment and nutrient filtering capacity of mangroves (UNEP-WCMC 2006). This can have deleterious effects on adjacent ecosystem (seagrasses and coral reefs) which may be smothered by allochthonous sediments or experience eutrophication due to an overload of land-based nutrients (Valiela and Cole 2002 in UNEP-WCMC 2006).

Mangroves play an important role in the global carbon cycle and it has been estimated that a loss of 35% of the world's mangroves over the last two decades (Valiela et al. 2001 in UNEPWCMC 2006) has resulted in the release of large quantities of stored carbon, further aggravating the global warming phenomenon. Ecosystems that can no longer provide their full ecosystem goods and services have a social and economic "cost" to humanity, which can be felt even in areas far away from the degraded ecosystem (UNEPWCMC 2006). Overall, it is the local people who suffer most due to a shortage of wood products, compromised food security, water quality and loss of protection against catastrophic sea events

Figure 3. Mangrove degradation due to anthropogenic activities in Tudor Creek. Kenya

There has, however, been a slowdown in the rate of mangrove loss: from some 187 000 ha destroyed annually in the 1980s to 102 000 ha a year between 2000 and 2005, reflecting an increased awareness of the value of mangrove ecosystems Most countries have now banned the conversion of mangroves for aquaculture and they assess the impact on the environment before using mangrove areas for other purposes (Bosire, 2006). This has lead to better protection and management of mangroves in some countries. Countries need to engage in a more effective conservation and sustainable management of the world's mangroves and other wetland ecosystems.

2.0 SITE DESCRIPTION

This review was supposed to cover the mangroves of Mombasa and Takaungu (Kilifi). Since it was meant to be a desktop review, only the mangroves of Mombasa (Tudor and Mwache Creeks) are covered for which information from our team's work.

2.1 Tudor Creek

Tudor creek, 39̊ 35'E and 04̊ 02'S (Figure 4) bounds Mombasa Island on the northwest and extends some 10 km inland. The creek has two main seasonal rivers, Kombeni and Tsalu, draining an area of 550 km^2 (450 and 100 km^2 respectively) with average freshwater discharge estimated at 0.9 m^3s^{-1} during the inter-monsoon long rains (Nguli, 2006). It has a single narrow sinuous inlet with a mean depth of 20 m, that broadens out further inland to a central relatively shallow basin (5m) fringed by a well developed mangrove forest mainly composed of *R. mucronata*, *A. marina* and *S. alba*. (Mohammed *et. al.* 2008) The basin has an area of 6.37 km^2 at low water spring and 22.35 km^2 at high water spring. Mangrove forests occupy 8 km^2 of the creek.

The floristic composition of mangroves of Tudor creek has been described by SPEK (1992). There is no obvious zonation displayed by the dominant mangrove species in Tudor creek. *A. marina.* occupies the landward zone, whereas mostly *R. mucronata* mosaic covers the middle zone. Wherever present, *S. Alba* occupies the seaward margin, but is replaced by tall *A. marina* and *R. mucronata* along small creeks. The forest resembles the fringing mangroves described by Lugo and Snedaker (1974), with strong inward tidal current during the flood tides which reverses during ebb tides, attaining maximum tide velocities of 0.6–0.7 m s-1 (Nguli 2006), and the dense, well-developed prop roots that accumulate large stocks of debris, with a spring tidal range of 3.5 m and a neap tidal range of 1.1–1.3 m. The mangroves of Tudor creek are separated naturally by two main tidal creeks, Kombeni and Tsalu, 4.5 and 3 km long respectively cutting through the mangroves connecting to the upstream rivers (Fig. 4).

The Tudor creek mangrove system has been exposed to raw sewage intensively for more than a decade. The sewage runs through the mangrove forest in canals and is discharged into the Tudor creek waters mainly from Mikindani, Tudor and the Old Town settlements. The mangroves are periodically dozed with sewage every tidal cycle, with the loading exponentially reducing with distance from source (PUMPSEA, 2007). Sediments of Tudor creek are predominantly muddy and some parts are covered with sand. The land surrounding the creek beyond Mombasa Island is mainly agricultural, largely small-holdings and coconut plantations with rough grazing land further inland, while the immediate slopes bordering the mangrove creek are being intensively cleared of vegetation to create space for informal settlements and subsistence farming.

2.2 Mwache Creek

Mwache Creek (S $04^0$3.01' & E $39.06^0$38.06') is located on the upper part of the Port Reitz, 20 km Northwest of Mombasa city. It is one of the two main creeks in Mombasa (Kitheka, 2000). The total area of the wetland is approximately 1,576 ha with about 70% of the surface area being covered with mangroves (Bosire, 2010). The creek has both basin and riverine mangroves and a distinct mangrove-fringed channel in the lower sections. The five species of mangroves in Mwache display a zonation pattern typical of mangroves in Eastern Africa. The seaward side is occupied by *Sonneratia-Rhizophora*-giant *Avicennia* community, the mid zone by *Rhizophora-Ceriops*, followed by dwarf *Avicennia* on the landward side.

Poor land use practices in the hinterland have increased sediment loads into the mangrove forest leading to siltation of breathing roots of the trees and eventual death of the system (Kitheka et. al., 2002). Between 1983 and 1993 Mombasa port and surrounding waters experienced 39,680 tons of oil spills that affected mangroves of Port Reitz and Makupa creeks. Spot assessments in some impacted site within Mwache Creek area have indicated limited post-impact recovery of mangroves (Kitheka et al., 2002, Bosire *et al*. 2008). Clearing of mangrove trees to create access routes to shorelines and pave way for physical developments is another challenge faced in the area with plans underway for the construction of a by-pass through the area. This may cause changes in sea currents and encourage erosion of the shoreline.

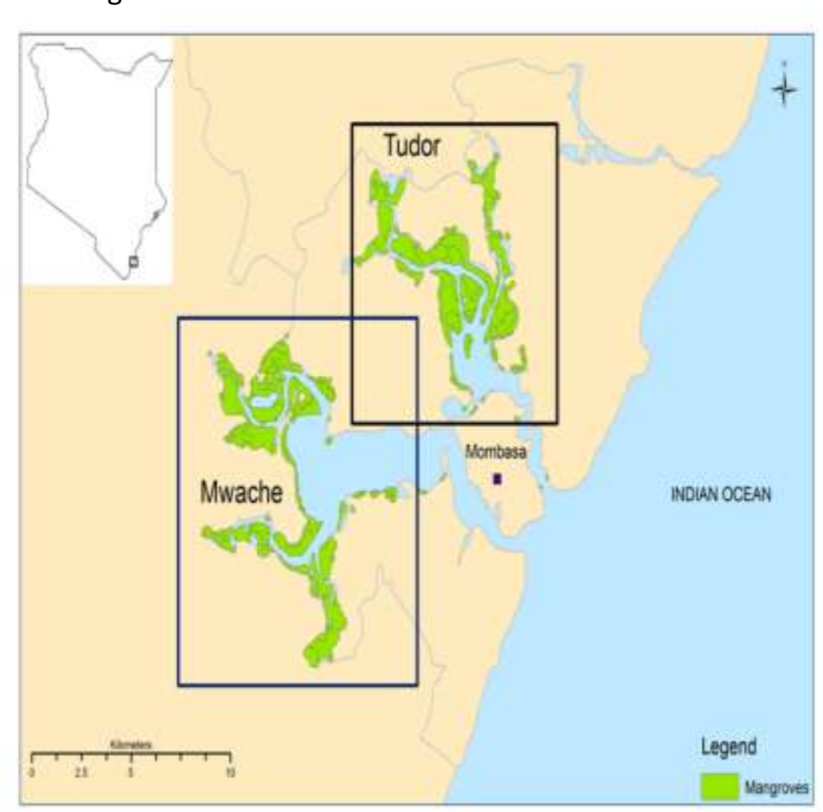

Figure 4. A map of mangroves in Tudor and Mwache Creeks

2.3 Climate

The climate of Mombasa is influenced by the semi annual passage of the inter-tropical convergence zone (ITCZ) and the monsoons. The North Easterly Monsoon (NEM) occurs from December to March, and the South Easterly monsoon from May to October. Most of the rainfall occurs between the monsoons when convention is enhanced. The mean annual rainfall is 1,038 mm with the months of April, May and June recording the maximum. Average annual temperatures for the two seasons are 23.9° C and 28.5° C respectively.

The areas are generally sunny throughout the year. The average numbers of daily sunshine hours are 8.4 in July and 8.9 in February, October and November. Annual evaporation is around 1800 mm and this is considered to be higher than the normal annual total rainfall and thus a freshwater deficit in dry seasons in the basin. Evaporation increases from a low of 138mm in July to 221mm in March. Sea surface temperature and salinity vary with the monsoon season. The highest temperatures of 28-29^{0}C occur following the Northeast Monsoon in the months of March and April. On the other hand, the lowest sea surface temperature occurs in August and September with a minimum of 24^{0}C. Relative humidity is comparatively high all the year round, reaching its peak during the wet months of April to July. However, there is a marked diurnal change where it is around 60-70% during the afternoon, rising to 92-94% during the night and in the early morning (Aura *et al.,* 2010).

3.0 SPECIES COMPOSITION, VEGETATION STRUCTURE AND REGENERATION

3.1 Species Composition

The structural characteristics of the mangroves of Tudor creek are given in Table 2. The creek has six mangrove species with *R. mucronata* and *A. marina* being the principal species.

Table 2: Structural attributes of the mangrove forest in Tudor creek (Mohammed et. al. 2008)

	Species	Height (m)	BA (m^2 ha^{-1})	Density (ha^{-1})	Relative			IV	Rank	CI
					Density	Dominance	Frequency			
Kombeni	*A. marina*	7.98 ± 2.94	7.07	143.40	11.34	43.43	24.53	79.30	2	4.38
	B. gymnorrhiza[a]	4.09 ± 0.86	0.15	16.98	1.34	0.91	5.66	7.91	5	
	C. tagal	2.62 ± 1.05	0.16	54.72	4.33	1.00	10.38	15.70	4	
	R. mucronata	3.61 ± 2.10	5.91	904.72	71.57	36.31	62.26	170.14	1	
	S. alba	5.22 ± 2.41	2.99	144.34	11.42	18.36	12.26	42.04	3	
Tsalu	*A. marina*	6.23 ± 3.30	5.89	167.74	14.60	60.69	25.00	100.29	2	2.60
	B. gymnorrhiza	3.82 ± 1.72	0.17	29.84	2.60	1.71	8.06	12.37	4	
	C. tagal	2.30 ± 0.55	0.58	175.81	15.30	5.99	29.84	51.13	3	
	R. mucronata	3.00 ± 1.06	2.58	750.00	65.26	26.57	83.87	175.70	1	
	S. alba	5.09 ± 2.09	0.39	20.97	1.82	4.00	3.39	9.21	5	
	X. granatum	3.83 ± 0.68	0.10	4.84	0.42	1.05	1.61	3.08	6	

[a] *Bruguiera gymnorrhiza* (L.) Lam

In Mwache Creek, five species of mangroves were observed in the adult tree canopy at the study area with R. *mucronata* being dominant, followed by *A. marina*.

Table 3: Stand structure of mangroves in Mwache (mean ± se)

Species	Density (stems/ha)	Height (m)	Basal area (M2/ha)	Relative values (%) Dom	Den	Freq	I.V (%)	C.I
A. marina	111	6.9±2.4	4.1±2.3	19	6	17	42	21
B. gymnorrhiza	63	4.1±1.0	0.3±0.3	1	3	3	8.1	
C. tagal	33	2.7±0.3	0.1±0.1	0	2	10	12.1	
R. mucronata	1633	5.3±1.4	16.1±2.6	76	87	60	223.6	
S. alba	33	6.8±1.6	0.5±0.3	2.4	1.8	10	14.2	
Mean		**5.5±1.3**	**4.2±2.1**					
Total	**1840**			**100**	**100**	**100**	**300**	

3.2 Vegetation Structure

Table 3 gives vegetation inventories for Tudor creek mangroves. There were 1,264 stems ha^{-1} of mangroves in Kombeni, out of which, 71.57% were *R. mucronata*, 11.42% *S. alba* and 11.34% *A. Marina.* While there was 1,301 stems ha^{-1} of mangroves in Tsalu, of which 57.66% were *R. mucronata*, 13.52% *C. tagal* and 11.34% *X. granatum*. The variation in complexity index between Kombeni and Tsalu is evident (table 2) with Kombeni recording a higher index than Tsalu. Mwache creek had 1,840 stems ha^{-1} constituting of 89% *R. mucronata.* Mwache creek had a higher complexity index (21) indicating higher structural complexity than Tudor creek, which agrees with cover change analysis results where Tudor creek was found to have lost 86% of its mangroves between 1992 and 2009, while Mwache creek lost 46% over the same period (unpublished). These losses are the highest recorded in the country with the national loss in mangrove having been estimated to be 20% (Kirui et al. 2011). This loss is attributed primarily to severe anthropogenic pressure, because the forests are peri-urban and thus adjacent to highly populated communities.

3.3 Regeneration

Significant differences in juvenile densities were observed across Tudor creek. On average the juvenile densities were in the range 21,905–33,965 ha^{-1}, with R. *mucronata* representing approximately 45–75% of the total juveniles (Table 4). Very few saplings were observed for S*. alba*. The equivalent regeneration ratios i.e. RCI:RCII:RCIII were 4:1:1 for Kombeni and 1:1:2 for Tsalu. The regeneration ratios are not within the range of effective stocking rate 6:3:1 for saplings described by Chong (1988). However, Tudor creek mangroves can still be considered potentially of good regeneration capacity taking into account the seedling densities.

Table 4: Juveniles density (Saplings ha^{-1}) in Tudor Creek (Mohammed *et. al.* 2008).

Site	Species	RCI 0–40 cm	RCII 40.1–150 cm	RCIII 150.1–300 cm	Total ha^{-1}
Kombeni	*A. marina*	17,080 (99.70)	37 (0.22)	15 (0.09)	17,132 (50.46)
	B. gymnorrhiza	60 (33.90)	81 (45.76)	37 (20.90)	177 (0.52)
	C. tagal	271 (25.78)	411 (39.11)	368 (35.01)	1,051 (3.10)
	R. mucronata	4,357 (27.94)	4,802 (30.80)	6,432 (41.25)	15,592 (45.92)
	S. alba	–	–	1	1 (0.00)
	X. granatum	–	–	–	– (0.01)
	Total ha^{-1}	21,768 (64.11)	5,331 (15.70)	6,853 (20.18)	33,953
Tsalu	*A. marina*	2,234 (93.28)	78 (3.26)	82 (3.42)	2,395 (11.09)
	B. gymnorrhiza	318 (81.54)	47 (12.05)	25 (6.41)	390 (1.81)
	C. tagal	1,251 (38.15)	870 (26.53)	1,158 (35.32)	3,279 (15.18)
	R. mucronata	3,713 (23.95)	4,066 (26.22)	7,725 (49.82)	15,505 (71.77)
	S. alba	–	–	–	–
	X. granatum	34 (91.89)	2 (5.41)	–	37 (0.17)
	Total ha^{-1}	7,550 (34.95)	5,064 (23.44)	8,991 (41.62)	21,605

Mwache creek (Table 5had a juvenile density of 16,489 ha-1 constituting of 92% *R. mucronata.* The ratio of RCI:RCII:RCIII was 4:3:2. The juvenile densities of both creeks suggest that they have high potential to naturally regenerate if the prevailing anthropogenic pressure is reduced. Where natural regeneration will be impeded, human intervention can be applied to support the process.

Table 5. Density (no ha^{-1}) of juveniles at Mwache Creek.

Species	Juveniles/ha				
	RC1	RC11	RC111	Total	%
A. marina	733	22	0	756	5
B. gymnorihza	61	17	6	83	1
C. tagal	150	78	122	350	2
R. mucronata	6,094	4,989	4,194	15,278	93
S. alba	0	0	22	22	0
Total	**7,039(43)**	**5,105(31)**	**4,344(26)**	**16,489**	100

4.0 DISCUSSION

4.1 Forest Cover

The major factors that seem to fuel the forest cover changes in Tudor creek range from unregulated harvesting, a high population and demand for wood products and siltation (Mohammed et al., 2008). Siltation is considered an important factor in mangrove ecology (Hutchings and Saenger, 1987; Ellison, 1998). This is mainly due to their location on low-lying continental coastlines, where sediments supply is regarded as "essential substrate accretion‟, and is important in buffering against erosion and the perceived sea level rise (Ellison, 1998).

The sedimentation rates that occurred during the single ENSO event are unknown, but studies from the neighbouring Mwache creek, estimates a 1.4m deposition of terrigenous sediments in the middle section of the creek, and 0.2m deposition in the outer edges during the same period, causing significant mortalities of mangroves (Kitheka et al., 2002). No recovery has occurred in some of these areas 11 years after the siltation event (personal observation). A similar scenario might have occurred in Tudor creek, with variable spatial patterns (Mohammed et. al., 2008). This may have caused high mangrove mortalities, resulting in the emergence of the extended open areas. The report by Mohammed et. al (2008) presents a hypothesis that, these openings altered edaphic conditions, including higher soil salinities and temperatures, particularly in the less frequently inundated areas, altering species distributions. Prevailing conditions after the changes may have favoured the establishment of *A. marina*, characteristically the most salt tolerant of all the mangrove species, identified as a pioneering species (Osborne and Berjak, 1997), producing the highest number of propagules and high success rates in colonising open substrates (Thampanya et al., 2006), with root initiation and subsequent establishment hardly hampered by extreme saline conditions

The mangroves of Tudor creek are not prestine, and are recipient of significant anthropogenic pressure, Anthropogenic influences such as indiscriminate and unregulated harvesting, raw industrial and domestic sewage pollution and enhanced siltation have had accumulated effects on the structure and regeneration of the forest, which is characterised by high density of stumps and a dominant crooked tree form (Mohammed et. al., 2008). However, the impacts of raw domestic sewage cannot be proven from current observations, but studies indicate enhanced mangrove growth rates (Feller et al. 2003), with no apparent negative effects (Wong et al. 1997).

Vegetation structure at the impacted site of Mwache creek was severely impoverished as reflected from the very low stand density of 179 trees ha^{-1} as compared to 820 trees ha^{-1} at the less impacted site. Other structural attributes (mean height, basal area and dbh) emphasized this observation (Bosire et. al. 2012. Unpublished). The high density of stumps suggests that the site had reasonably high tree density pre-impact thus confirming the severity of the mangrove die-back after the massive sedimentation as earlier mentioned. The overall stand density of 1,640 stems ha^{-1}, suggest the forest can be sustainably exploited. However the structural attributes reported here for Mwache creek are much lower than those of mangrove stands in other parts of the country. For instance mangroves of the northern part of Kenya in Lamu (stand density of 2,075 to 2,142 stems ha^{-1}, basal area of 24.5-46.97 m^2 ha^{-1}, and canopy height of 16-26.5 m; (Kairo et al., 2001) are much more developed than the mangroves of both Mwache and Tudor creeks.

4.2 Regeneration

Natural regeneration was observed all over Tudor creek, with *R. mucronata* seedlings and saplings dominating, while A. marina seedlings were abundant, with low density of saplings, implying high mortality of seedlings and/or saplings resulting in low recruitments into successive regeneration classes. *C. tagal, B. gymnorrhiza* and *X. granatum* had very low regeneration levels, with S. alba having particularly low regeneration, with the adults visibly impacted by insects, and in some areas suffering die backs, a fact reported in 1992 (SPEK 1992) and observed in the field as well. Observations indicate regeneration based on the ''direct replacement'' model, with species replaced by members of the same species as reflected by stand composition, but establishment and survival is diminished due to site spatial and temporal heterogeneity introduced by canopy gap formation and siltation (Flower and Imbert 2006). On average, twelve parent trees (standards) are required per ha to serve as seed sources for regeneration (FAO, 1994). The two creeks had a higher density of parent trees than this and thus suggest high potential for propagule supply. Normally a minimum of 2,500 seedlings per ha are required to qualify natural regeneration as being sufficient (Srivastava and Ball, 1984). Both creeks had reasonably high juvenile densities, suggesting that with improved management (especially reduction of anthropogenic pressure), the forest can naturally restock itself sufficiently.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The mangroves of Mombasa, though stressed, are not irreversibly degraded. However, stand densities and basal areas were lower than for Rhizophoraceae dominated forests along the Kenyan coast (Gazi bay, 8–24 m2 ha-1, 1,130–2,571 stems ha-1; Kairo 2001; Bosire et al. 2003; Mida creek and Ngomeni, 24.05– 46.97 m2 ha-1, 2,075–2,142 stems ha-1: Kairo et al. 2002; Bundotich 2007) Within Mombasa, natural disturbances are either relatively small or rare, leaving anthropogenic disturbances as the principal threat, with direct needs by the people, lacking a consistent harvesting plan, resulting in a haphazard spatial distribution of different size classes, with a highly selective graphical frequency distribution. These anthropogenic pressures can be reduced through effective community engagement by formation of Community Forest Associations (CFA) and also provision of alternative livelihood options.

5.2 Recommendations

1. Management ought to focus on the anthropogenic element. Harvesting should be regulated through zoning of the forest coupled with a harvesting regime that includes replanting and closed periods, allowing for forest regeneration and growth. This will regulate canopy gap sizes, as intermediate level of gap creation may be optimal for long-term stand stability (Duke 2001).
2. To add value to peri-urban mangroves, management for multiple uses as opposed to single (forestry) products (Ronnback 1999;Nagelkerken et al. 2008), is desirable.
3. Establishment of 'environmental' forests (no cut zones) for protection of migratory birds and other fauna for eco-tourism and subsistence, coupled with an integrated land use plan, which shall regulate causes of pollution and siltation and involve local communities in management. This will serve to boost the ecosystem resilience in the long-run.
4. Provision of alternative livelihoods will reduce pressure on the mangrove forests and thus allow natural regeneration.

CHAPTER 2. MANGROVES FISHERIES IN KENYA

2.1 Introduction

A large number of fish species utilise mangrove areas as larvae, juveniles, or adults and are captured by subsistence, commercial and recreational fishermen along the Kenyan coast. In Kenya, coral reef associated fisheries are estimated to constitute about 80% of marine fish production. The fish fauna however overlap considerably between coral reefs, seagrass beds and mangroves indicating strong linkages between the three ecosystems, with the greatest diversity being associated with coral reefs.

Notably, reef associated fish form a high proportion of the species found in mangrove fringed areas. Little et al (1988) recorded 86 species belonging to 43 families using a beach seine in Tudor creek and established Gobiidae and Gerridae as the dominant families. In Gazi bay, Kimani et al (1999) recorded 128 fish species belonging to 50 families using beach seines in Gazi bay and found Gerreidae, Atherinidae and Clupeidae as the most abundant accounting for 78.5% of the total catches. Crona and Ronnback (2007) identified 49 taxa and 34 families using stake nets and found five species/taxa accounted for approximately 70% of the total number captured. Studies conducted by Huxham et al (2004), also established the same fish families as most abundant in Gazi bay. However, they recorded only 12 species in the mangroves of which 7 were not previously recorded. In Kilifi creek, Oyugi (2005) recorded 95 species belonging to 45 families and found Signathidae and Leiognathidae to dominate using gillnets, handnets and castnets. Studies conducted in Ungwana bay (Mirera et al 2010) and Mtwapa creek (Mavuti et al 2004) have also reported similar families and species however with different densities. The studies support the existence of a distinct community of fish species that are closely associated with mangroves and species that migrate freely between the creeks, seagrass beds, sandflats and coral reefs. Only one species, the crepuscular feeder *Sphaeraemia orbicularis* (Apogonidae) has been established to be strictly mangrove associated.

*M*angroves also provide important nursery areas for many commercially important shrimp and crab species (crustaceans). Crona and Ronnback (2005) identified 19 species of shrimp/taxa dominated by penaeid shrimps which made up 66% of the total abundance including *Peneaus japonicas*, *P. indicus*, *P semisulcatus*, *Metapenaeus monoceros,* followed by macrobrachium spp (16%), *Acetes* sp (6%) and other carideans (11%). Mud crab populations are typically associated with mangroves and are abundant in estuaries and mangrove swamps along the Kenyan coast at some stage in their life cycle (Muthiga, 1986; Onyango, 2002). Mud crabs (Scylla serrata) are harvested for subsistence throughout their range along the Kenyan coast, and are the focus of small to moderate scale commercial fisheries. They are commonly found within the mangrove habitat, on mudflats or inside mangroves while larger crabs are found in mangrove channels, near the shore or in burrows (Hill et al., 1982).

2.2 Ecosystem Functioning

Mangroves at the Kenyan coast mainly occur as fringing vegetation along coastal lagoons and creeks. Mangroves have been cited as providing important nursery, shelter and feeding habitats for a wide array of fish, crustaceans and molluscs utilized in commercial and subsistence fisheries. Capture fisheries production is therefore believed to constitute the major value of marketed products from an unexploited mangrove forest (Hamilton et al., 1989). A summary of the fish species found in mangrove fringed habitats and the associated ecosystem function is shown in Table 1.

2.2.1 Role of mangroves as nursery grounds

Mangroves support coral reef fish both directly by providing nursery habitat and indirectly as part of an ecosystem of connected habitats that include seagrasses and coral reefs. As documented by Ronnback (1999), the larvae and juveniles of many coral reef fish and shellfish species utilise mangroves and seagrass beds as nursery grounds, after which they permanently emigrate to other ecosystems as adults or subadults (Ogden and Gladfelder, 1983; Parrish, 1989). Mangroves might be expected to have negligible influence on reef fish communities as the juvenile fish can inhabit alternative habitats and fish populations may be regulated by other limiting factors such as larval supply or fishing (Mumby et al 2004). Contrary to this, studies have demonstrated that mangroves are unexpectedly important, serving as an intermediate nursery habitat that may increase the survivorship and recruitment success of commercially valuable species harvested in other ecosystems, such as coral reefs and pelagic zones (Parrish 1989, Mumby et. al 2004).

Mangroves strongly influenced the community structure of fish on neighbouring coral reefs in the Caribbean (Mumby et al, 2004). In addition, the biomass of several commercially important species more than doubled when adult habitat was connected to mangroves demonstrating the strong functional linkage between tropical coastal ecosystems. In Kenya, Kimani et al (1996) established that mangroves and seagrass beds functioned as nurseries for the juvenile coral reef fishes. Among the coral reef associated species observed, 69% were juveniles of which 32% also occurred as adults. Crona (2007) found high densities of juvenile fish species of importance to local subsistence fisheries (e.g. *Lethrinus harak*, *Siganus canaliculatus*). Additionally, they found that 7 of the 10 most abundant juvenile fish families captured in seagrasses were of commercial importance while 6 of the 10 species were in higher abundance in seagrasses associated with mangroves, indicating that mangrove habitat is important to the majority of juvenile seagrass associated fish species.

Mangroves are also utilized by mudcrabs which settle out from the plankton and continue to adult stage when they move out for spawning in deep waters (Walton et al., 2006). However, utilisation of the mangrove ecosystem by the different mud crab size classes varies widely from intertidal mudflats (low and high tides), along the shore or channels (low tides), in the mangrove basal roots (high tides) and in mangrove holes (low tides) (Mirera 2012). Post larval and juvenile life stages of penaeid shrimps were also found in the mangroves of Gazi bay (Crona and Ronnback 2005).

2.2.2 Role of mangroves as refuge and feeding grounds

Mangroves provide important refuge and feeding grounds for fish and invertebrates and this role cannot be underestimated. Two related hypotheses have been proposed in relation to this ecosystem function (Huxham et al 2004):

1) <u>The predator refuge hypothesis</u>: this suggests that prey species avoid predators by migrating into mangroves during periods of tidal inundation to take advantage of the structural complexity provided by the roots and pneumatophores and the high turbidity which aids in restricting the

efficiency of predator movement and vision (Abrahams and Kattenfield, 1997). The young and small sized fish (Wakwabi 1999) and shrimps (Crona, 2005) especially concentrate in Rhizophora and Avicennia stands, to feed and hide from predators (Wakwabi 1999). Verweij (2006) was able to clarify that the presence of structure, food and shade significantly contributed to the attractiveness of mangroves and seagrass beds to juvenile reef fish.

2) The feeding hypothesis: this suggest that the fish migrate to the mangrove creeks and fringes to feed on the concentrations of juveniles and other benthic macrofauna (Wakwabi, 1999), indicating that the fish could be benefiting from mangrove productivity without necessarily entering the mangrove area; hence resulting in a carbon transfer to the adjacent seagrass beds (Laegdsgaard and Johnson, 2001). Nyunja et al (2009) found that the most dominant carbon sources for fish were mainly derived from the seagrass beds and their associated epiphytic community, and possibly macroalgae. Mangrove-derived organic matter contributed only marginally to the overall fish food web as fishes from the mangrove creeks had distinctly lower $\delta^{13}C$ signatures compared to those collected in the adjacent seagrass indicating that mangrove habitats are used more distinctly as sheltering and feeding zones for the fishes collected, with minimal degree of exchange within the fish communities despite their regular movement.

Table 1: Summary of coral reef fish families and ecosystem functions in coastal Kenya. Data summerised from Gazi and Ungwana bay, Kenya (Kimani *et al* 1996; Wakwabi 1999, Oyugi *et al.* 2005, Crona, and Ronnback 2007; Nyunja *et al* 2009; Mirera *et al* 2010). NB: the presence of juveniles indicates a potential nursery function, presence of adults as either feeding or breeding, while presence of both indicates both a nursery and feeding function.

Family	**Species**	**Nursery**	**Feeding**	**Breeding**
Acanthuridae	*Acanthurus lineolatus, Naso brevirostris*	√ (s)	√ (s)	C
Acropomatidae	*Acropoma japonica, Acropoma hyalosoma*		√ (m,s)	C
Apogonidae	*Apogon lateralis, A. fraenatus, A. nigripes, A. cookie, A. cyanosoma, Cheilodipterus quingquelineatus, C. lineatus, Fowleria aurita, Archamia furcata*		√ (S)	
Apolectidae	*Apolectus niger*	√ (m)	√ (m)	C
Atherinidae	*Atherinomorus lacunosus, A. duodecimalis,*	√ (m,s)	√(m,s)	√ (m,s)
Belondinae	*Tylosurus acus, T. crocodilus*	√ (m)	√ (m)	C
Bothidae	*Bothus manchus, B. pantherinus*	√ (m,s)	√ (m,s)	C
Carangidae	*Caranx ignobilis, Trachinotus blochii, Scomberoides tol, Caranx sexfasciatus*	√ (s)	√ (s)	C
Clupeidae	*Sardinella gibbosa, S. mellanura, Spratelloides delicates, Pellona ditchella, Herklotsichthys quadrimaculatus, Macrura kelee*	√ (m)	√ (m)	offshore
Elopidae	*Elops machnata√*	√ (m)		C
Epiphidae	*Platax pinnatus, P. teira, P. orbicularis*			C
Fistularidae	*Fistularia petimba*	√ (m,s)	√(m,s)	C
Gerreidae	*Gerres oyena, G. filamentosus, G. poeti*	√(m,s)	√(m,s)	C
Haemulidae	*Plectorhinchus gaterinus. P. flavomaculatus*	√ (s)	√ (s)	C
Hemiramphidae	*Hemiramphus far, Zenarchopterus dispar*	√ (m)	√ (m)	C
Labridae	*Cheilio inermis, Stethojulis strigiventer, Cheilinus trilobatus, C. diagrammus*	√ (s)	√ (s,m)	C
Lethrinidae	*Lethrinus harak, L. semicinctus, L. nebulosus, L. lentjan*	√ (m,s)	√(m,s)	C
Leiognathidae	*Leiognathus elongates, L. fasciatus, L. equulus*	√ (m)	√ (m)	C
Lutjanidae	*Lutjanus fulviflamma, L. ehrenbergii, L. argentimaculatus.*	√ (m,s)	√ (m,s)	C

	L sanguineus			
Monacanthidae	*Aleturus scriptus, Paramonacanthus barnadi*		√ (s)	C
Monodactylidae	*Monodactylus argenteius, M. falciformis*	√ (m)	√ (m)	C
Mugillidae	*Valamugil seheli, Mugil cephalus*	√ (m)	√ (m)	offshore
Mullidae	*Parupeneus barberinus, P.i ndicus, P. cinnabarinus, Upeneus tragula*	√ (m,s)	√ (m,s)	C
Ostraciidae	*Lactoria cornuta*	√ (s)	√ (s)	offshore
Plotosidae	*Plotosus lineatus*		√ (m,s)	C
Pomacentridae	*Dascyllus carneus, D. trimaculatus*	√ (s)		C
Tetraodontidae	*Chelonodon laticeps, Arothron immaculatus*	√ (s)	√ (s)	C
Terapontidae	*Terapon jarbua, T. theraps, Pelates quadrilineatus*	√ (m,s)	√ (m,s)	C
Scaridae	*Scarus tricolor, Leptoscarus vaigiensis*	√ (m,s)	√ (m,s)	C
Scorpaenidae	*Pterois miles, Parascorpaena mossambica*	√ (m)	√ (m)	C
Siganidae	*Siganus sutor,S. stellatus,S. canaliculatus*	√ (m,s)	√ (m,s)	C
Sillaginidae	*Sillago sihama*	√ (m)	√ (m)	C
Sphyraenidae	*Sphyraena barracuda, S. jello*	√ (m,s)	√ (m,s)	C

Key: m = mangrove, s = seagrass, c = coral reef, √ = present as nursery or feeding function

2.3 Ecosystem linkages with coral reefs

Evidence of the connectivity between juvenile and adult habitats has been demonstrated by the faunal similarities between mangroves and seagrasses. De Troch et al (1996) established that some fish species within the mangroves were also found within nearby seagrass beds suggesting that many species of fish use mangroves for either feeding or shelter on a daily basis. Based on the data summary shown in Table 2, approximately 98% coral reef associated species have been documented in the mangroves, seagrass beds at Gazi as juveniles and adults. Carnivores represent 62% of the species, omnivores 22% and herbivores 7%. Carnivores were found distributed abundantly outside the mangrove-seagrass beds, herbivores on the seagrass beds while omnivores in the mangrove creek and towards the reef (Wakwabi 1999).

2.4 Characterisation of migration between ecosystems and trophic organisation

The different life history stages of fish (egg, larvae, juvenile and adult) are often in distinctly different environments, requiring distinct resources and different ecological processes. Seasonality in spawning has been established for a number of coral reef fish in Kenya (Nzioka, 1979). Some coral reef associated species undertake seasonal migrations to aggregate in offshore areas where they undergo broadcast usually in the outer reef crest and channels leading through the reef (Johannes 1979). Their eggs and larvae then drift back into shallower waters to settle within seagrass beds and mangroves creek habitats (Johannes 1979, Little et al, 1988).

Spawning migrations have been recognized as adaptive strategies for efficient utilization of the associated habitats as this ensures that the larvae are spawned in areas where the currents favor their ultimate return to shallow nursery grounds thereby increasing their chances of recruiting to parent populations (Johannes 1978). In Kenya, evidence of spawning aggregations has been documented for the following families; Serranidae, Lethrinidae, Lutjanidae, Siganidae, Haemulidae and Scaridae (Samoilys et al 2004). Some of the species documented to aggregate have also been documented in mangroves, which is evidence of fish migration into mangroves. Thus, the whole process of reproduction/spawning (on reefs), larval settlement in mangroves and seagrass beds as juveniles, and sub adults moving back to the reef, forms the basis of the habitat connectivity between these three ecosystems (Kimirei 2012). Dispersal of pelagic larval stages of key coral reef fish documented in mangroves have also been documented in Malindi and Watamu MPA and Reserves) and in Mida creek (Mwaluma et al 2011). The dominant species included Apogonidae (*Apogon* sp., *Archarmia* sp.), Carangidae *(Caranx* sp*., Gnathadon speciosus*, *Carangoides* sp.), Labridae and Pomacentridae (*Abudefduf* sp.).

Some (economically important) species including fish and mud crabs have adopted a life strategy whereby they migrate from the coral reefs to seagrass beds and mangroves as they mature (Kimirei, 2012) indicating ontogenic habitat shifts. The shift in habitats from the adjacent coral reefs establishes a strong connectivity and energy transfer between the three ecosystems (Wakwabi, 1999). Stable isotopes ratios analysis of ^{18}O, ^{16}O and ^{13}C and ^{12}C from fish otoliths as an indicator of fish migration was attempted by Huxham et al (2007. Although the method was not found useful due to species specific differences in carbon metabolism; the observed changes in δ^{13}C isotope signatures between life stages within a species was identified as a potential indicator in tracing fish migration patterns. Two species, *Lethrinus harak* and *Lutjannus fulviflamma* exhibited such significant changes in migration patterns based on their isotope signatures.

Table 2. Summary of key coral reef fish (with linkages) showing their mean size, diet and main habitats. (Species in bold undertake spawning aggregations/migrations in Kenyas offshore waters as documented by Samoilys et al (2004). Species found in seagrasses shown in Appendix I.

Species	**Source**	**Average size (cm)**	**Diet** (DeTroch et al 1998, Wakwabi, 1999	**Main habitat** (Wakwabi 1999, Nzioka 1979	**Alternate habitat** (Kimani et al 1996, De Troch et al 1996,Wakwabi et al 1999, Crona & Ronnbeck 2007, Huxham et al 2007)
Acanthuridae					
Acanthurus lineolatus	Kimani et al., 1996	4.8 -16.0	Macro-detritivores	Reef	Seagrass
Naso brevirostris			Macro-detritivores	Reef	Seagrass
Acropomatidae					
Acropoma hyalosoma	Kimani et al., 1996	4 - 13.2	Planktivores	Pelagic	Mangrove
Acropoma japonica	Ntiba et al 1993 1993	6.06	Planktivores	Pelagic	Mangrove
Apogonidae					
Apogon lateralis	Kimani et al., 1996	7.2 -7.6	Pisci-invertivores	Reef	Seagrass
Apogon fraenatus	Ntiba et al 1993 1993	8.7	Pisci-invertivores	Reef	Seagrass
Apogon nigripes	Ntiba et al 1993 1993	7.1	Pisci-invertivores	Reef	Mangroves
Apogon cookii	Ntiba et al 1993 1993	9.95	Pisci-invertivores	Reef	Seagrass
Cheilodipterus quingquelineatus	Nyunja et al 2009		Pisci-invertivores	Reef	Seagrass
Cheilodipterus lineatus	Ntiba et al 1993 1993	8.37	Pisci-invertivores	Reef	Seagrass
Fowleria aurita	Kimani et al., 1996	7.5	Pisci-invertivores	Reef	Mangroves
Archamia furcata	Nyunja et al 2009		Pisci-invertivores	Reef	Seagrass
Atherinidae					
Atherinomorus lacunosus	Kimani et al 1996, Crona & Ronnbeck 2007	7.49	Planktivores	Reef	Sandy shallows magroves
Atherinomorus duodecimalis	Kimani et al.	4.0 - 9.5	Planktivores	Reef	Sandy shallows, mangroves
Bothidae					
Bothus manchus	Kimani et al., 1996	13.5	Planktivores	Reef	Seagrass
Bothus pantherinus	Ntiba et al 1993 1993	8.7	Planktivores	Reef	Seagrass
Carangidae					
Caranx ignobilis	Kimani et al., 1996	1.66	Pisci-invertivores	Reef	Seagrass
Trachinotus blochii	Ntiba et al 1993 1993	12.4	Pisci-invertivores	Reef	Seagrass
Scomberoides tol	Ntiba et al 1993 1993	4.71	Pisci-invertivores	Reef	Seagrass
Scomberoides commersonnianus	Huxham et al 2007		Pisci-invertivores	Reef	Seagrass
Caranx sexfasciatus	Wakwabi 1999	12.3	Pisci-invertivores	Reef	Seagrass
Clupeidae					
Sardinella gibbosa	Ntiba et al 1993 1993	12.3	Planktivores	Reef	Mangrove

Spratelloides delicatus	Ntiba et al 1993 1993	6.16	Planktivores	Reef	Mangrove
Pellona ditchella	Ntiba et al 1993 1993	8.6	Planktivores	Reef	Mangrove
Herklotsichthys quadrimaculatus	Kimani et al., 1996	6.63	Pisci-invertivores	Reef	Mangrove
Fistularidae					
Fistularia petimba	Kimani et al., 1996	5.7 - 42.8	Piscivores	Reef	Seagrass
Gerreidae					
Gerres oyena	Kimani et al., 1996; Crona & Ronnebeck 2007	8.98		Reef	Mangrove
Gerres filamentosus	Kimani et al., 1996	12.2	Planktivores	Reef	Mangrove
Gerres poeti	Kimani et al., 1996	7.8	Planktivores	Reef	Mangrove
Hemirhamidae			Planktivores		
Hemiramphus far	Kimani et al., 1996	27.9-28.2		Reef	Mangrove
Zenarchopterus dispar	Kimani et al., 1996	5.9-16.7	Macro-invertivores	Reef	Mangrove
Lethrinidae			Planktivores		
Lethrinus harak	Kimani et al., 1996; Crona & Ronnebeck 2007	7.44		Reef	Mangrove
Lethrinus ehrenbergi	Huxham et al 2007		Macro-invertivores	Reef	Mangrove
Lethrinus semicinctus	Kimani et al., 1996	4.3 - 6.9	Macro-invertivores	Reef	Mangrove
Lethrinus nebulosus	Kimani et al., 1996	8.7	Macro-invertivores	Reef	Mangrove
Lethrinus lentjan	Kimani et al., 1996	7.7	Macro-invertivores	Reef	Seagrass
Lutjanidae			Macro-invertivores		
Lutjanus fulviflamma	Kimani et al., 1996; Crona &Ronnebeck 2007	8.18		Reef	Seagrass/mangrove
Lutjanus ehrenbergii	Kimani et al., 1996, Haxhum et al 2007	6.63	Pisci-invertivores	Reef	Mangrove
Lutjanus argentimaculatus	Nyunja et al 2009	37.4	Pisci-invertivores	Reef	Mangrove
Monodactylidae			Pisci-invertivores		
Monodactylus argenteius	Kimani et al., 1996	3.3-13.2		Reef	Mangrove
Monodactlylus falciformis	Kimani et al., 1996	11.78	Planktivores	Reef	Mangrove
Mugillidae			Pisci-invertivores		
Valamugil seheli	Haxhum et al 2007, Nyunja et al 2009	14.4		Mangrove	Seagrass
Mugil cephalus	Haxhum et al 2007Nyunja	14.4	Planktivores	Mangrove	Seagrass

	et al 2009				
Mullidae			Macro-invertivores		
Parupeneus barberinus	Kimani et al., 1996	6.3	Macro-invertivores	Reef	Seagrass/Mangrove
Parupeneus indicus	Ntiba et al 1993 1993 1993	13.8	Macro-invertivores	Reef	Seagrass/Mangrove
Upeneus tragula	Ntiba et al 1993 1993	9.58	Macro-invertivores	Reef	Seagrass/Mangrove
Parupeneus cinnabarinus	Ntiba et al 1993 1993	10.9	Macro-invertivores	Reef	Seagrass/Mangrove
Ostraciidae			Macro-invertivores		
Lactoria cornuta	Kimani et al., 1996	4.8 - 24.5		Reef	Seagrass
Plotosidae			Macro-invertivores		
Plotosus lineatus	Kimani et al., 1996	21.7	Macro-invertivores	Reef	Mangrove
Scaridae			Pisci-invertivores		
Scarus tricolor	Kimani et al., 1996	9.24		Reef	
Leptoscarus vaigiensis	Kimani et al., 1996	5.2	Scrapervators	Reef	Seagrass beds/ mangroves
Scorpaenidae			Scrapervators		
Pterois miles	Kimani et al., 1996	12		Reef	Seagrass/Mangrove
Parascorpaena mossambica	Kimani et al., 1996	7.78	Piscivores	Reef	Mangrove
Siganidae			Piscivores		
Siganus sutor	Kimani et al., 1996	6.18		Reef	Seagrass/mangroves
Siganus stellatus	Kimani et al., 1996	4.7 - 10.6	Macro-grazers	Reef	Seagrass
Siganus canaliculatus	Kimani et al., 1996		Macro-grazers	Reef	Seagrass
Sigillidae			Macro-grazers		
Sillago sihama	Kimani et al., 1996; Crona &Ronnebeck 2007	18.5		Reef	Sandy shallows, mangroves
Sphyraenidae			Macro-invertivores		
Sphyraena barracuda	Kimani et al., 1996; Crona & Ronnebeck 2007	21.1	Macro-invertivores	Reef	Mangroves
Sphyraena jello	Kimani et al., 1996; Crona & Ronnebeck 2007	12	Piscivores	Reef	Mangroves
Synodontidae			Piscivores		
Synodus variegatus	Ntiba et al 1993	10			
Saurida undosquamis	Kimani et al., 1996; Crona &Ronnebeck 2007	10.7	Pisci-invertivores	Reef	Sandy shallows
Saurida gracilis	Kimani et al., 1996	14.35	Pisci-invertivores	Reef	Sandy shallows
Terapontidae			Pisci-invertivores		

Terapon jarbua	Kimani et al., 1996	6.97		Reef	Sandy shallows
Terapon theraps	Kimani et al., 1996	6.8	Macro-invertivores	Reef	Sandy shallows
Pelates quadrilineatus	Ntiba et al 1993	4.6	Macro-invertivores	Reef	Sandy shallows
Tetraodontidae			Pisci-invertivores		
Chelonodon laticeps	Kimani et al., 1996	19.35		Reef	Seagrass/Mangrove
Arothron immaculatus	Kimani et al., 1996	18.4	Macro-invertivores	Reef	Seagrass/Mangrove
Belonidae			Macro-invertivores		
Tylosurus acus	Kimani et al., 1996; Crona &Ronnebeck 2007	28.75		Reef	Mangroves
Tylosurus crocodilus	Kimani et al., 1996; Crona &Ronnebeck 2007		Pisci-invertivores	Reef	Mangroves
Epiphidae		30.6	Pisci-invertivores		
Platax pinnatus	Ntiba et al 1993	8.39		Reef	Seagrass/Mangrove
Platax teira	Ntiba et al 1993	5	Pisci-invertivores	Reef	Seagrass/Mangrove
Platax orbicularis	Ntiba et al 1993	5.5	Pisci-invertivores	Reef	Seagrass/Mangrove
Labridae			Pisci-invertivores		
Cheilio inermis	Kimani et al., 1996	14.4		Reef	Mangrove
Stethojulis strigiventer	Kimani et al., 1996	6.7	Pisci-invertivores	Reef	Seagrass
Cheilinus trilobatus	Wakwabi 1999		Macro-invertivores	Reef	Seagrass
Cheilinus diagrammus	Wakwabi 1999		Macro-invertivores	Reef	Seagrass
Leiognathidae			Pisci-invertivores		
Leiognathus elongatus	Kimani et al., 1996	1.6		Reef	Mangrove
Leiognathus fasciatus	Kimani et al., 1996	9	Micro-grazers	Reef	Mangrove
Leiognathus equulus	Kimani et al., 1996	3.7 - 9.5	Pisci-invertivores	Reef	Mangrove
Monacanthidae			Pisci-invertivores		
Aleturus scriptus	Kimani et al., 1996	14.5		Reef	Seagrass
Paramonacanthus barnadi	Kimani et al., 1996	9.31	Micro-grazers	Reef	Seagrass
Pomacentridae			Macro-invertivores		
Dascyllus carneus	Kimani et al., 1996	3.65	Macro-invertivores	Reef	Seagrass
Dascyllus trimaculatus	Kimani et al., 1996	8.01	Planktivores	Reef	Seagrass
Haemulidae			Planktivores		
Plectorhinchus gaterinus	Kimani et al., 1996	6.5 -16.7		Reef	Seagrass
Plectorhinchus flavomaculatus			Macro-invertivores	Reef	Seagrass

Table 3: Biomass of fish in Tudor mangrove creek (numbers/ km^2 /day) as caught by beam trawl May 1995- April 1996 (Wakwabi and Mees,1999)

Month (1995-96)	**Total numbers/30 m^2**	**Total numbers/ m^2 /day**	**Total numbers/ km^2 /day**
May	78.5	2.6	2617
June	16.9	0.6	563
July	64.0	2.1	2133
August	16.0	0.5	533
September	68.0	2.3	2267
October	119.4	4.0	3980
November	76.8	2.6	2560
December	62.5	2.1	2083
January	77.5	2.6	2583
February	123.6	4.1	4120
March	70.4	2.3	2347
April	28.0	0.9	933

2.5 Fish Biomass

In Kenya, fish biomass in mangrove creeks (Table 3 above) varies immensely with seasons along the coast with generally higher biomass being recorded during the Northeast monsoon as compared to the Southeast monsoon season. The northeast monsoon period is between November –M arch while the southeast monsoon is from April- October (McClanahan 1988).

Table 4: Biomass of fish in Gazi mangrove creek (numbers/ km^2/day) as caught by beam trawl December 1994 To September 1996 (Wakwabi and Mees, 1999)

Month (1995-96)	Total numbers/30 m^2	Total numbers/ m^2 /day	Total numbers/ km^2 /day
December	78.5	2.6	2617
January	105.2	3.5	3507
February	90	3.0	3000
March	113	3.8	3767
April	210.9	7.0	7030
May	58.4	1.9	1947
June	43.7	1.5	1457
July	21.5	0.7	717
August	98.3	3.3	3277
September	55.9	1.9	1863
October	27.4	0.9	913
November	47.6	1.6	1587
December	21.9	0.7	730
January	13.4	0.4	447
February	23.4	0.8	780
March	17.4	0.6	580
April	29.4	1.0	980
May	8.1	0.3	270
June	228	7.6	7600
July	156	5.2	5200
August	182	6.1	6067
September	23.5	0.8	783

2.6 Catch composition in artisanal fisheries

Artisanal fisheries in Kenya use various gears including hand lines, traps, gill nets, seine nets and spear guns. These gears harvest many species and may be employed from shore to the outer reef edge in waters seldom deeper than 5 m at low tide (McClanahan & Kaunda-Arara 1996), usually from small boats and throughout the year. The main fish families caught in this fishery are seagrass and coral reef-associated species reflecting where fishing is focused (McClanahan and Mangi, 2001). Previous studies have shown that a significant portion of the catch from lagoonal reefs also comes from fish migrating in from deeper offshore areas (McClanahan & Mangi 2000).

Sixty four fish families have been recorded as captured in artisanal fishing gears along the Kenyan coast (Maina et al, 2008). The families Siganidae, Scaridae (mainly *Leptoscarus vaigiensis*) and Lethrinidae dominate artisanal landings accounting for 60.6% of the landings at the southcoast. The three families are seagrass and coral reef associated with a small number of species contributing largely to the total captures (Figure 1, McClanahan and Mangi (2001).

Catch rates are characterized by high variability, as catch is affected by local site characteristics, gear use patterns in the area, seasonal and spatial patterns in fish abundance and factors that affect catchability (See appendix II and III). Cast nets and ring nets record the highest catch rates (9.4 kg/man/trip) while juya, nyavu ya kutega, mkondzo and kimia kigumi and juya recorded the lowest (<3 kg/man/trip).

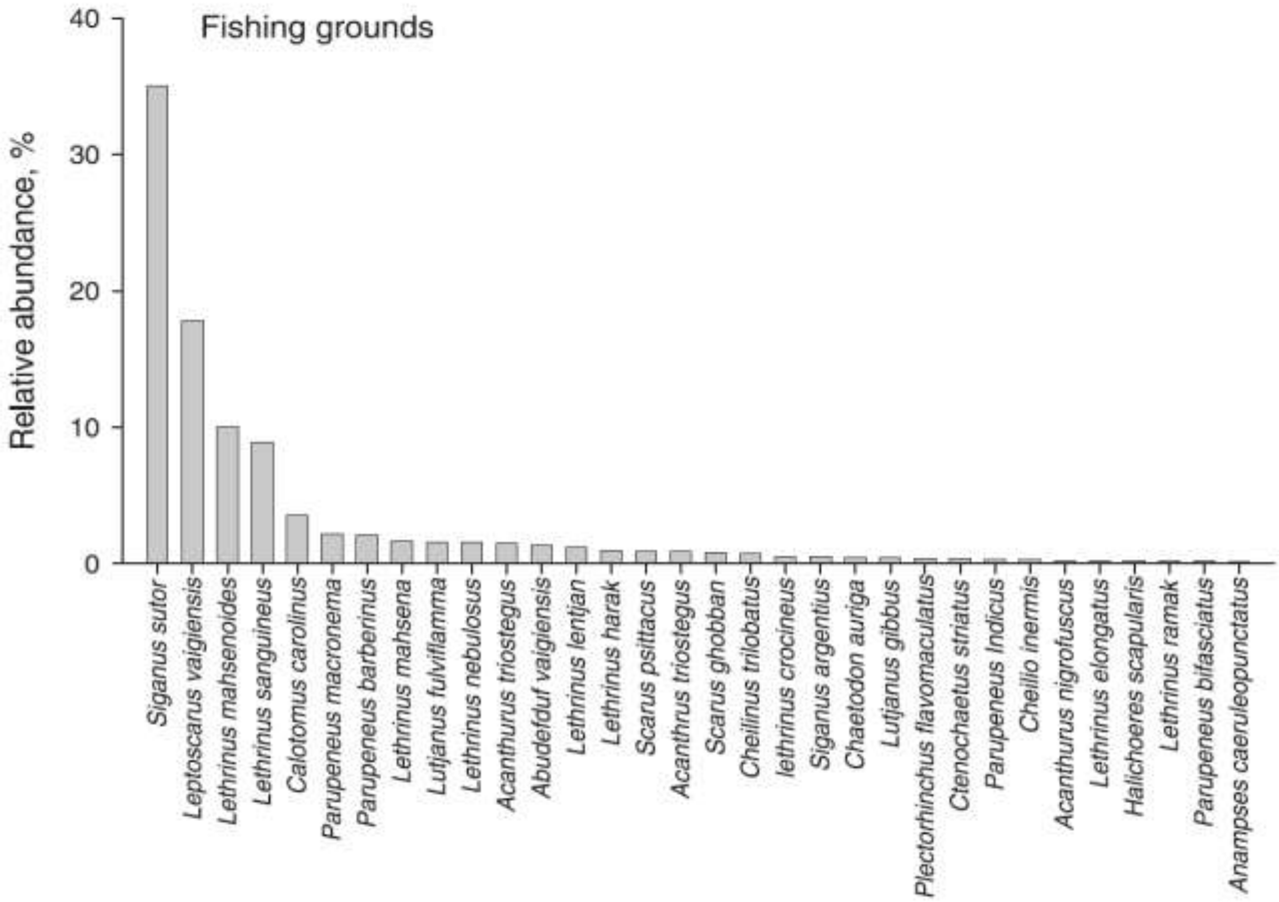

Figure 2.1. Relative abundance of fish captured in trap catches (Source: McClanahan et al 2010)

In summary, there are inter-linkages between the different critical habitats (coral reefs, seagrasses and mangroves) and these inter-linkages support fishery productivity in different ways, some of which may not be exactly clear. The role of mangroves in supporting fisheries either as nursery ground, feeding or for refugia seems to be strongly supported from different studies. While there is great variability in catches from different areas dependent on site productivity, gear, effort and season, the role of mangroves and associated ecosystems in supporting fishery productivity is not disputed.

CHAPTER 3: SOCIAL LINKAGES BETWEEN CRITICAL COASTAL ECOSYSTEMS AND CONTRIBUTION TO LIVELIHOODS OF COMMUNITIES

3.1 Coastal population

The available and most detailed information on the characteristics of the human population along the coast of Kenya is from the national population and housing census of 2009. The national population census is conducted after every ten years to provide detailed information on the size, distribution, composition and other social and economic characteristics of the population which are necessary for the implementation of development agenda (Republic of Kenya 2010). An analysis of population statistics from the last five national census reports shows that the human population in the coast of Kenya has experienced a steady growth since 1969 (Figure 1). The growth has been rapid with the population rising from 944,082 people in the year 1969 to 3,325,307 people in the year 2009.

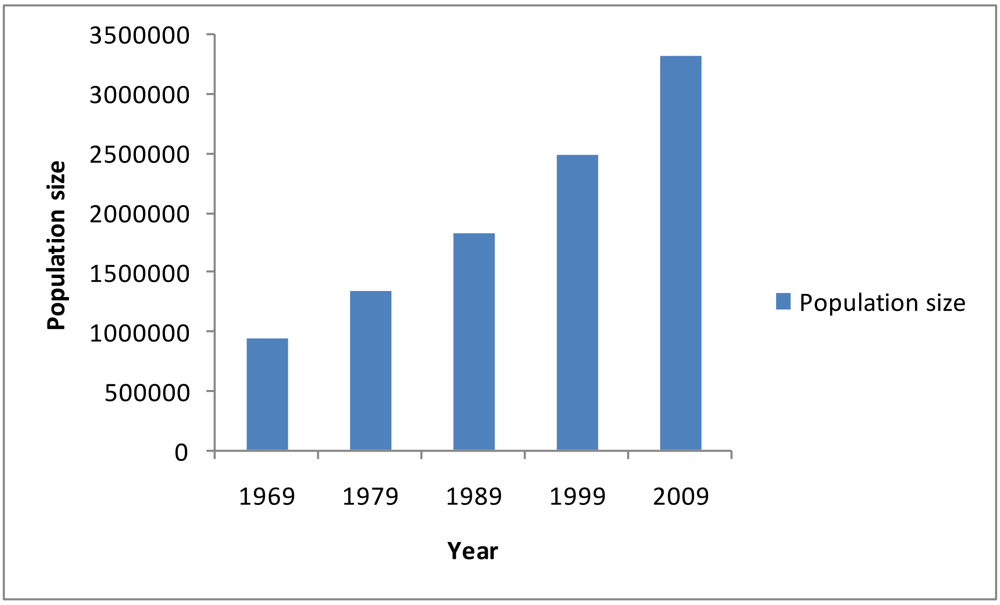

Figure 3.1: Trends in coastal population since 1969

Population size and density on the coast of Kenya varies from place to place with the urban centres having the highest density, resulting from rural-urban migration. There are seven urban centres in the coast of Kenya with Mombasa being the largest. Mombasa which consists of both Mombasa and Kilindini districts has the highest population density and a total population of 939,370 people (Republic of Kenya 2010) that accounts for 28% of the coastal population. Other important urban centres in the coast that host about 22% of the population include Malindi, Kilifi, Kwale, Lamu, Voi and Ukunda. It is estimated that about 50% of the coastal population live in rural areas. As population grows, population pressure and loopholes in resource management have led to over-exploitation of inshore (shallow water) fisheries, degradation of mangrove areas, shoreline changes and cultural erosion.

Apart from the influence of rural-urban migration, distribution of the population in the coast region is influenced by rainfall, altitude, agro-ecological area, and administrative policies through which a number of settlement schemes have been created (Hoorweg *et al*. 2000).

Due to location of most of the country's coastal urban centres in the vicinity of estuaries, mangrove swamps and coral lagoons, the rapid growth in population places significant pressure on the coastal environment and its resources. For example, in Lamu County population density is higher in areas that depend mainly on fisheries and other marine resources for livelihoods and income. This implies that population pressure impacts more heavily on fisheries and other marine resources than on terrestrial resources. Overall, the female population slightly exceeds the male population especially in the rural areas but the situation is different in Mombasa city where the male population exceeds the female population. Furthermore, the Coast Province has an annual population growth rate of 2.9% (Republic of Kenya 2010). Although this rate shows a slight drop compared to 3.1% in 1989 and 1999 it still implies that the coast experiences a rapid population growth.

The inhabitants of the coast of Kenya are culturally diverse with the largest indigenous ethnic groups being the Mijikenda. The Mijikenda consists of nine sub-tribes namely: Giriama, Digo, Rabai, Duruma, Kauma, Chonyi, Kambe, Ribe, and Jibana. Other coastal ethnic groups are: Taita, Pokomo, Bajuni, Orma, Sagala, Swahili, Boni and Watha. Each of these ethnic groups has a distinct culture. The historical long distance trade and the recent developments in tourism development, shipping and harbor activities and commerce provide opportunities for livelihoods, employment and leisure and have attracted a multiplicity of ethnic and racial groups to the coast of Kenya. In addition, artisanal fisheries and agriculture are major sources of livelihoods particularly in the rural areas. Table 1 shows the distribution of population by districts in the coast of Kenya.

Table 3.1. Demographic characteristics of the thirteen districts in the coast of Kenya in 2010 (Republic of Kenya 2010)

District	Male	Female	Total	Density
Mombasa	268,038	255,145	523,183	4,144
Kilindini	218,886	197,301	416,187	4,493
Kwale	74,323	77,655	151,978	147
Kinango	99,369	110,191	209,560	52
Msambweni	142,305	146,088	288,393	89
Kilifi	218,486	237,811	456,297	116
Kaloleni	120,359	132,565	252,924	284
Malindi	196,681	203,833	400,514	51
Tana River	71,153	72,258	143,411	6
Tana Delta	48,700	47,964	96,664	6
Lamu	53,045	48,494	101,539	16
Taita	110,315	106,677	216,992	16
Taveta	35,019	32,646	67,665	19
TOTAL	**1,656,679**	**1,668,628**	**3,325,307**	**40**

3.2 Social linkages between coastal ecosystems and community livelihoods

The coastal ecosystems being considered here are mangroves, coral reefs and seagrasses. Traditionally, the Kenyan coastal communities have depended on fisheries and mangrove exploitation for their livelihoods and income.

Studies have shown that there is a complex linkage between mangrove forests and the local community. Zorini et al. (2004) through a participatory approach designed to evaluate the relationships between mangroves and human activities and the use of multi-criterion analysis to identify management solutions, established that at the family and village level, the linkage involves a family's knowledge of natural resources, its cultural background and the opportunities to satisfy basic needs. At an institutional level, it involves various institutions and the rules that control the exploitation of mangroves. The real challenge is in increasing the knowledge of these elements and the causal relationships among them.

The mangrove forest of Mida creek, north of Takaungu, provides goods and services which supports the welfare of the local community. According to Zorini et al. (2004) there is a clear division of mangrove uses on the basis of age and gender within the local community. The children catch small crabs and fish for self-consumption at low tide in the shallow inlets within the forest. Women go to the mangrove mainly for firewood. Men engage in artisanal fishing, which is dependent on the mangrove, coral reef and seagrass ecosystems. The artisanal fishing is carried out in the coral reef, seagrass and mangrove areas. Men also engage in mangrove cutting for building wood. Another study which involved four communities within peri-urban areas of East Africa by Crona et al. (2009) established that the local communities are involved in extraction of forest or marine products in, or in close vicinity of, the adjacent mangroves although what products, and to what extent, is determined partly by cultural and economic preferences.

There is a well-established demand for mangrove products at the study site and these mangrove products are an essential source of income for the families. The cutting of building poles and fuelwood from the mangrove forests generate quick cash and are characterized by a low degree of seasonality, a satisfactory income level and great income security, both against the difficulty of putting the product on the market and against the risk of production loss (Zorini et al., 2004). Unfortunately, the rate of exploitation of mangroves is ecologically unsustainable and the mangrove ecosystems are threatened by over-exploitation. However, prohibiting the local community from exploiting the mangrove products, especially where there is high human pressure requires provision of attractive alternatives or else the level of compliance remains low since the local community may opt to poaching for the same products. Without an alternative source of income, the population cannot afford to satisfy basic needs, such as food, shelter, clothing, medical care and education (school fees).

Existing policies and legislations restrict local communities from cutting mangrove trees for commercial purposes. This has often led to discontent because licenses to cut mangroves are granted to dealers, who often are not original inhabitants of the area. It is the licensed dealers (licensees) that carry out the operations of cutting, transportation and sale of mangrove wood. The Kenya Forest Services, the agency responsible for the management of all forests in the country, allows the local inhabitants to cut firewood only for their own needs. It is also appreciated that if mangrove exploitation is not controlled, over-exploitation my lead to disastrous consequences. In fact, it has been observed (Ochiewo pers com) that illegal mangrove cutting supplements the income to some poor households. Legally, the local communities have been cutting the mangrove wood as a supplementary source of income; often on the request of traders. The amount of building wood harvested in one year from the Mida creek mangroves was estimated at around 2,650 m , corresponding to 37,400 US$ (Zorini et al. 2004). The main economic activities that generate income to the communities living around the mangrove forest at Mida creek are summarized in figure 2 below.

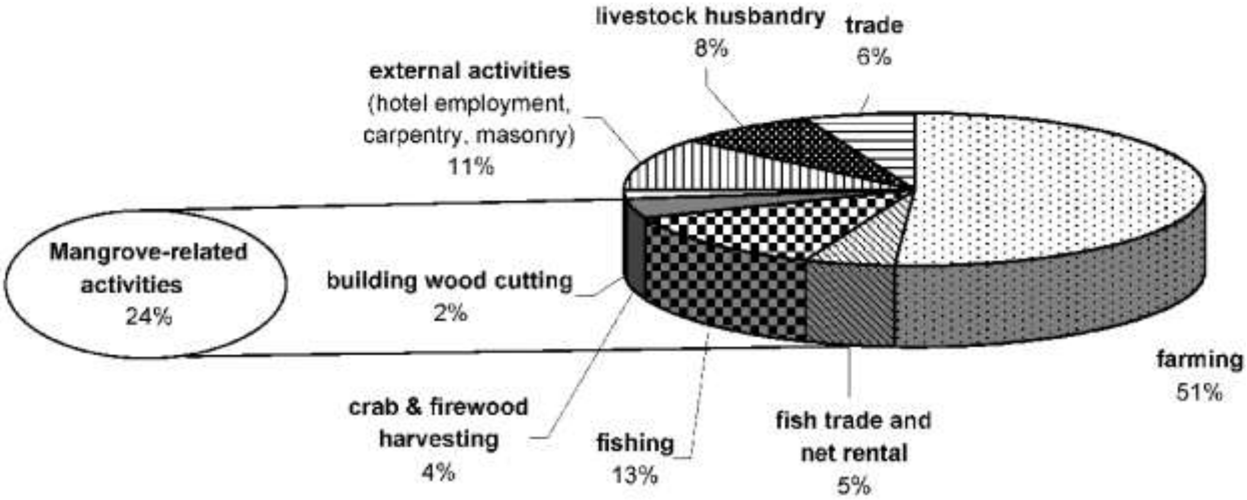

Figure 3.2. Composition of annual income of the local community at Mida Creek based on results of the participatory appraisal (Source: Zorini et al. 2004)

In Mida Creek, the local people identified the introduction of an extra head of dairy cattle as one of the possible alternative sources of income. However, due to the long time required to organize and set up dairy farming, the cutting of building poles and fuel wood from the mangrove forests is still preferred.

The local community has a deep knowledge of the functioning of the mangrove ecosystem. It is aware that the presence of fish, crabs and molluscs in the creek and adjacent lagoons is directly linked to the health of the mangrove ecosystem. This awareness also led the communities to become involved in mangrove conservation initiatives, managed by the communities themselves. An active community-based mangrove conservation group, the Mida Creek Community Conservation Group, is presently undertaking a project that has integrated mangrove conservation, mud crab fattening and ecotourism. The fishermen from the Mida Creek have also demonstrated a unique understanding of the ecological characteristics of the mangroves. They have for example supported the efforts of scientists to understand these ecological conditions.

The alternative sources of income that are identified above would not modify the existing resource relationship patterns with regard to children and women. These alternatives would only provide alternative sources of income to the local communities so as to reduce the pressure on the mangroves.

When conditions allow it, the population itself could be the main protector of the mangroves and the most enthusiastic promoter of economically sound sustainable management plans. These plans should be based on sustainable utilization of mangrove resources and promotion of alternative sources of income and employment. The Forest Act 2005 now empowers communities to actively participate in forest conservation by the formation of Community Forest Associations (CFAs).

3.3 Social linkages between coral reef and seagrass ecosystems and community livelihoods

The inshore fishery is mainly carried out within the coral reef and seagrass systems and exploited by artisanal fishers who use simple fishing crafts and gears. A study of the changing fisheries practices in the south coast of Kenya established that fishing has traditionally been a male occupation while women play a key role in fish marketing and distribution (Ochiewo 2004). The most commonly used fishing gears include gillnet, shark nets, hook and line, beach seine, spear gun and traditional traps especially the basket traps (McClanahan *et al*. 2005; McClanahan & Mangi 2004; Ochiewo 2004). The artisanal fishing in the inshore waters is labour-intensive providing employment and livelihood to thousands of households. Over 10,000 fishers are directly engaged in artisanal fishing in the Kenyan coast (Ochiewo 2004; Fisheries Department 2007; 2009). The artisanal fishers land at least 95% of the marine catch and over 60,000 coastal people depend on these fisheries (UNEP 2006). Fishing effort has increased with increase in the number of artisanal fishers over the years. Increase in the number of artisanal fishers has been caused by rapid population growth at the coast and lack of alternative employment opportunities for the young school leavers.

It has been observed that the Kenyan inshore fishery now shows signs of over-exploitation (Ochiewo 2004) with yields from the lagoonal reef fisheries declining (McClanahan & Mangi 2001). The decline in yield has been attributed to increase in fishing effort and competition for dwindling fish stocks in the inshore waters (Glaesel 2000; McClanahan *et al*. 1997, McClanahan & Mangi 2004). It has also been observed that the application of destructive fishing techniques within the inshore waters has also contributed to the decline in yield and some fishing methods that were introduced in the past few decades, such as trawling, use of seine nets and spear guns are disapproved by traditional fisheries elders (McClanahan *et al.* 1997, McClanahan & Mangi 2004) and have been a source of conflicts. There is a widespread perception that some fishing methods such as trawling, use of seine nets and spear guns degrade the fishing grounds.

The increased application of fishing methods that are considered destructive is partly attributed to decline in application of traditional rules in the management of fisheries resources. A community's traditional rules influence the management of marine resources that support livelihoods. Consequently, for a long time, fishing effort was regulated by the presence of traditional rules such as restrictive taboos and technological constraints. It has been observed that the areas where the traditional rules that regulated fishing effort have broken down are more exposed to destructive fishing techniques and their fishery conditions have badly deteriorated (McClanahan et al. 1997; McClanahan et al. 2008; Cinner & Aswani 2007; Cinner et al. 2009).

Emerging trends such as the increased influence of migrant fishers who have no incentive to protect and conserve fishing grounds which are far from their ancestral homes and the rapid spread of fishing methods such as beach seines and ring nets, that are destructive to the fishing grounds but appear to be more efficient and employ many people who lack their own fishing gears, have contributed towards the break-down of customary rules and institutions. The artisanal fishers have tended to adopt the fishing techniques and life styles that have been introduced by the migrant fishers.

Figure 3.3 below summarizes the social linkages between mangroves, coral and seagrass systems and contributions to livelihoods of communities.

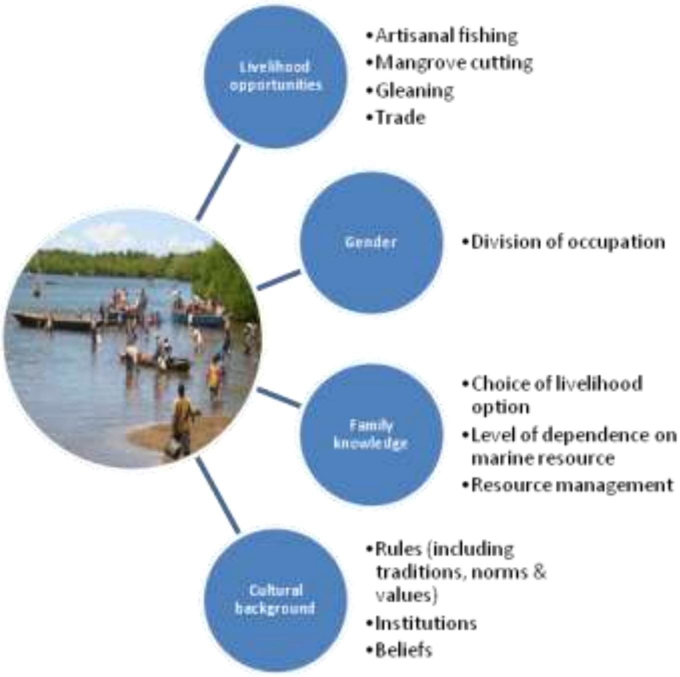

Figure 3.3. Social linkages between mangroves, reef and seagrass systems in the coast of Kenya

CHAPTER 4. CONCLUSION

There is plenty of information which supports the linkages between fisheries and the main critical tropical coastal habitats i.e. mangroves, seagrasses and coral reefs. Evidence of the connectivity between juvenile and adult habitats has been demonstrated by the faunal similarities between mangroves and seagrasses. De Troch et al (1996) established that some fish species within the mangroves were also found within nearby seagrass beds suggesting that many species of fish use mangroves for either feeding or shelter on a daily basis. Based on the data summary shown in Table 2 (Chapter 2), approximately 98% coral reef associated species have been documented in the mangroves and seagrass beds at Gazi as juveniles and adults. A large number of fish species utilise mangrove areas as larvae, juveniles, or adults and are captured by subsistence, commercial and recreational fishermen along the Kenyan coast. In Kenya, coral reef associated fisheries are estimated to constitute about 80% of marine fish production. The overlap of fish species between coral reefs, seagrass beds and mangroves indicate strong linkages between the three ecosystems, with the greatest diversity being associated with coral reefs. It has also been observed elsewhere in the Caribbean that mangroves strongly influenced the community structure of fish on neighbouring coral reefs (Mumby et al, 2004). In addition, the biomass of several commercially important species more than doubled when adult habitat was connected to mangroves demonstrating the strong functional linkage between tropical coastal ecosystems.

Some (economically important) species including fish and mud crabs have adopted a life strategy whereby they migrate from the coral reefs to seagrass beds and mangroves as they mature (Kimirei, 2012) indicating ontogenic habitat shifts. The shift in habitats from the adjacent coral reefs establishes a strong connectivity and energy transfer between the three ecosystems (Wakwabi, 1999). The different life history stages of fish (egg, larvae, juvenile and adult) are often in distinctly different environments, requiring distinct resources and different ecological processes. Seasonality in spawning has been established for a number of coral reef fish in Kenya (Nzioka, 1979). Some coral reef associated species undertake seasonal migrations to aggregate in offshore areas where they undergo broadcast usually in the outer reef crest and channels leading through the reef (Johannes 1979). Their eggs and larvae then drift back into shallower waters to settle within seagrass beds and mangroves creek habitats (Johannes 1979, Little et al, 1988).

The above ecosystem services provided by mangroves and related ecosystems, suggest that fisheries productivity is highly dependent on the integrity of these ecosystems. According to the most recent estimates, mangroves globally cover about 15.2 million ha straddling coastlines in 123 tropical and subtropical countries (Spalding et al. 2010). Of these, about 1 million ha are in the western Indian Ocean region (FAO 2007) with Kenya having about 54,000 ha. However, the decline of these spatially limited ecosystems due to multiple global and local pressures is increasing (Aksornkoae et al., 1993; MacKinnon 1997, Valiela et al. 2001; FAO 2007, Gilman et al. 2008), thus rapidly altering the composition, structure and function of these ecosystems and their capacity to provide ecosystem services essential for the livelihoods of people in most tropical countries (Kairo 2002, Bosire et al. 2004, Mumby et al. 2004, Dahdouh-Guebas et al. 2005, Duke et al. 2007). Deforestation rates of between 1-2% per year have been reported thus precipitating a global loss of 30-50% of mangrove cover over the last half century majorly due to overharvesting and land conversion (Alongi 2002, Duke et al. 2007, Giri et al. 2010). Kenya has lost an average of 20% mangrove cover in the last three decades with some mangrove areas loosing as high as 86% of the cover over the same period.

Ecosystems that can no longer provide their full ecosystem goods and services have a social and economic “cost” to humanity, particularly at local scales where people suffer most due to a shortage of wood products, compromised food security, water quality and loss of protection against catastrophic sea events although the impact can be felt even in areas far away from the degraded ecosystem (UNEP-WCMC 2006). In Thailand, the welfare losses associated with the impacts of mangrove degradation on coastal communities were estimated to be around US$27,264 to US$35,921 ha^{-1} (Sathirathai and Barbier 2001).

Sustainable management of mangroves will require an ecosystem based management (EBM) approach which links mangroves with seagrass, coral reefs and upstream contiguous ecosystems. Instead of managing mangroves as single-use resource, they should be managed as multiple-use resources for fisheries, coastal protection, carbon sequestration and the traditional provision of wood products.

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APPENDICES

Appendix I: Fish Species Identified in Seagrass beds (Gazi)

The number of individuals caught per species (N), their minimal (min) and maximal (max) length, the modal length class (mode) and the maximal recorded length (L_∞). All lengths in millimeter. Source: De Troch et al (1999)

Family	Species	N	min	max	mode	mean	L_∞
Clupeidae	*Herklotsichthys quadrimaculatus*	226	44	105	70-73	64	140
Engraulidae	*Stolephorus indicus*	128	25	113	40-45	63	150
Plotosidae	*Plotosus lineatus*	88	165	257	220-230	217	320
Synodontidae	*Synodus variegatus*	6	55	89	55-65	70	220
	Saurida gracilis	1	–	–	–	51	200
Atherinidae	*Atherinomorus duodecimalis*	627	20	54	33-35	38	90-100
Belonidae	*Tylosurus crocodilus crocodilus*	3	290	317	290-320	306	1250
	Ablennes hians	8	–	–	–	–	1200
Hemiramphidae	*Hyporhamphus affinis*	6	170	214	190-210	193	260
Aulostomidae	*Aulostomus chinensis*	1	–	–	–	194	500
Fistulariidae	*Fistularia commersonii*	45	140	347	170-180	220	1500
Syngnathidae	*Hippichthys cyanospilos*	1	–	–	–	83	160
	Syngnathoides biaculeatus	10	125	213	120-130	164	290
	Trachyrhamphus bicoarctatus	2	301	351	–	326	390
Solenostomidae	*Solenostomus cyanopterus*	4	66	94	60-70	77	170
Centriscidae	*Aeoliscus punctulatus*	1	–	–	–	95	150
Scorpaenidae	*Pterois miles*	6	35	145	70-80	79	310
	Parascorpaena mossambica	12	18	53	20-30	33	100
	Dendrochirus brachypterus	2	32	34	–	33	150
	Sebastapistes strongia	7	29	61	40-45	46	60
Platycephalidae	*Platycephalus indicus*	1	–	–	–	400	1000
Dactylopteridae	*Dactyloptena orientalis*	1	–	–	–	115	380
Serranidae	*Epinephelus* spec.	1	–	–	–	107	800-900
Teraponidae	*Pelates quadrilineatus*	2	45	46	–	46	240
Apogonidae	*Cheilodipterus quinquelineatus*	6	35	50	30-40	46	120
	Apogon thermalis	221	28	55	31-32	33	80
	Fowleria aurita	98	15	55	20-25	25	90
Lutjanidae	*Lutjanus fulviflamma*	45	75	107	90-95	90	300
	Lutjanus argentimaculatus	85	20	120	40-45	59	1000

Appendix II: Catch per unit effort by gear type (Source: Maina et al 2008)

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

Appendix III: Catch composition (Kg/Day) at various monitored landing sites along the Kenyan coast (Source: Maina et al 2008)

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