

**THE EFFECTS OF MANGROVE HABITAT DEGRADATION ON
FISH ABUNDANCE AND DIVERSITY IN UNGWANA BAY,
KENYA**

BY

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DECLARATION AND RECOMMENDATION

This thesis is my original work and has not been presented for the award of a degree in any University or institution of learning.

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DEDICATION

This thesis is dedicated to my dear parents, my wife and child who have great interest in nature conservation.

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ABSTRACT

The inability to acknowledge the indirect economic importance of ecosystem goods and services generated by mangroves (ecological and physical values) is a major driving force behind mangrove degradation. Disturbances and degradation of mangrove ecosystem by human activities such as clear-cutting are increasing. To maintain a balanced ecosystem and sustainable resource use, it is essential to identify the impact such activities have on the ecosystem. Fish and sediment fauna are the natural resources that are affected by disturbances in the mangrove ecosystem. The objectives of this study were to describe fish assemblage and determine fish density in forested and un-forested mangrove habitats. Eight microhabitats each 36m² inside the forested and un-forested mangrove sites at Ngomeni were sampled in spring tides using stake nets. Half of the forested and un-forested sites had either muddy or sandy substratum. Plankton and benthos were sampled using plankton net and plastic corer respectively. The mean density of fish ranged from 0.10 fish m⁻² to 2.67 fish m⁻² while biomass ranged from 0.26 fish m⁻² to 10.89 fish m⁻² in both forested and un-forested habitats. The data was analyzed to find out if there was any significant difference using ANOVA and means were separated with post hoc test at $p < 0.05$. There were significant differences in fish densities with respect to substratum type indicating that the fish community preferred muddy bottom forested sites to sandy bottom forested sites. Significantly higher fish abundance, biomass and mean length were observed in forested habitats compared to un-forested habitats. The un-forested sites showed significantly low density of fauna (copepods, polychaetes, nematodes) in the sediments compared to forested sites. Muddy substratum sites had the highest fauna density compared to hard substratum ones. The copepods and nematodes were a major component of fish diet and they were also the principal fauna in sediments and water. Based on the findings of this study, abundance, composition, density, biomass and diversity of fish and fauna were higher in muddy substratum sites compared to sand ones, consequently in forested than un-forested sites.

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DEFINITION OF TERMS

Mangrove degradation: Degeneration of mangrove forests which is caused by human activities.

Un-forested: Are mangrove ecosystems where all mangrove trees have been removed.

Forested: Are mangrove ecosystems where mangrove tree stands exist.

Tide: The cyclic rise and fall of sea level caused by the gravitational pull of the sun and moon. There are usually two high tides and two low tides in each lunar day.

Spring tide: High or low tide that occur at or just after new moon and full moon when the tide generating force of the sun acts in the same direction as that of the moon, reinforcing it and causing the greatest rise and fall in tidal level.

Neap tide: High or low tide that occur at the first or last quarter of the moon when the tide-generating forces of the sun and moon oppose each other and produce the smallest rise and fall in tidal level.

Abundance: Number/weight of fish caught during sampling process.

Density/Biomass: Number/weight of fish caught during sampling per unit area.

Stomach fullness index: The degree of fullness of the fish stomach

Percent frequency of occurrence: Number of guts having common food item in the stomach

Percent numerical abundance: Is the percentage of each food item in the stomach contents

Muddy (soft) substrate: Is the substrate with a high percentage of clay and silt compared to its sand composition. It is sticky when wet and difficult to walk in due to sinking effect.

Sandy (hard) substrate: Is the substrate with a high percentage of sand particles compared to clay and silt. It is rough when felt by hand and has no stickiness when wet.

LIST OF ABBREVIATIONS

| | |
|--------|---|
| F | Forested |
| UF | Un-forested |
| MASMA | Marine Science for Management of (WIOMSA) |
| WIOMSA | Western Indian Ocean Marine Science Association |
| KMFRI | Kenya Marine and Fisheries Research Institute |
| NEM | North East Monsoon |
| SEM | South East Monsoon |
| CDA | Coast Development Authority |
| CORDIO | Coral Reef Degradation in the Indian Ocean |
| FAO | Food and Agriculture Organisation of United Nations |
| F.I | Stomach fullness index |
| EACC | East African Coastal Current |
| WWF | World Wide Fund for Nature |
| ANOVA | Analysis of variance |

CHAPTER ONE

1.0 INTRODUCTION

The coastal environment of Kenya contains important marine habitats; including mangroves, coral reefs and sea grass beds. These habitats provide essential nursery beds, feeding areas and shelter for a large variety of marine biota. However these habitats are always degraded leading to decreased fish and other marine animals which are dependent on them.

Mangrove forests are salt-tolerant tidal swamp forests found along tropical and subtropical coastlines, usually in sheltered bays, lagoons and estuaries (Ronnback, 2001). Mangrove vegetation is taken as a tropical equivalent of the temperate salt marsh and these forests signify gentler shores as opposed to shores ending into rocky cliffs. Since their root systems are regularly flooded by saline water, very few species of woody plants are able to survive under such physiological conditions. Mangrove ecosystems are diverse and include several environmental components including terrestrial, freshwater, marine, and estuarine systems. The mangrove swamps are flooded at high tide and drained at low tide. Several species of mangrove trees are in some areas clearly zoned between the upper shore and the mid-eulitoral zone while others are scattered all over the intertidal zone (Ruwa, 1993). Mangrove forests along the Kenya coast covers about 53,000 ha with the largest stands occurring in the Lamu area and the Vanga-Funzi coastal system.

The mangrove forests are vital economically and ecologically as a natural resource and as protection to the environment. Both aspects cannot be separated without causing damage to the area. Economically, mangrove wood is a source of fuel wood, poles and roofing while roots and leaves have medicinal value. The ecological role of mangroves is challenging and range from nursery and feeding habitat to complex ecosystem services like water quality maintenance and carbon export (Ronnback, 2001). In due respect mangrove tree formations contribute to the marine food web through their production of detritus and also commercially important species of marine animals (crabs, fish and shrimps) are known to spend at least part of their life cycle here (FAO, 1983).

Mangroves develop ecosystems by trapping terrestrial sediments, litter and nutrients to build platforms using their root systems, which then generate nutrients for growth. Such mechanism cleans the water environment making it suitable for the establishment of other near-shore ecosystems such as sea grass beds and coral reefs. Organic materials from mangrove forests are pumped into the aquatic system as leaves, twigs, flower buds and detritus. These materials then enter in sequence through the detritus feeders (Shell fish, and invertebrates), primary and secondary consumers (Bell *et. al.*, 1984; Well, 1990). Mangrove forests therefore form nutrient rich environments, which promote a variety of food chains, and hence function as feeding and nursery grounds to many species of fish, prawns and crabs. Various components of this food web are harvested by the coastal human population (Kapetsky, 1985).

Mangrove forests are important nursery areas, feeding grounds and permanent residence for prawns and fish including many species of commercial importance (Robertson and Duke, 1987; Morton, 1990; Vance *et. al.*, 1996; Ronnback, *et al.*, 1999, 2001). Work done by Robertson and Duke (1987) in Australia showed that post-larval juveniles and small adult fish were significantly more abundant in the mangrove forest habitat than the un-forested habitats. As a consequence of the high productivity of the mangrove system and associated epi-fauna and benthic fauna, marine fisheries are correspondingly high in mangrove fringed coastal lagoons and estuaries (Wakwabi, 1999). According to Ronnback (2001), each hectare (ha) of mangrove ecosystem has potential to generate 1.0-11.8 tons fisheries catch per year with a market value of US dollar 900-12,400 in developing countries. Such productivity is much higher than 10-370 kg/ha/year proposed for coral reef (Alcala, 1988).

Also by migrating into mangrove forests when the trees are inundated by tides, prey species can avoid predators. This could be due to the structural complexity provided by the above ground parts of mangrove trees like aerial roots, trunks and branches that are submerged at high tide reduce predator efficiency by impeding movement or restricting predator vision (Vance *et. al.*, 1996; Ronnback, *et al.*, 1999; Pessanha and Araujo, 2003). Similarly, high turbidity within mangroves may also reduce predator efficiency (Mees *et al.*, 1999).

Despite the important role played by mangrove forests in fisheries production, they are being destroyed for the immediate tangible benefits: woodchip production, aquaculture, housing, firewood, export posts, tourism and other uses. The high level destruction of

mangrove forest for large scale prawn farming especially in Asia has lead to declined buffering ability to large scale wave action. In due respect such areas are highly exposed to intense calamities like Tsunami. It is therefore critical for the future management of mangrove forests that we understand clearly the relationships between fish, prawns and mangroves and exactly why mangroves are important aquatic ecosystems.

Research on the role of mangroves to fisheries has tended to concentrate on studies showing that the juveniles of many *penaeid* prawns and fish are caught near mangrove habitats and studies that have related the size of offshore catches of prawns and fish to the extent of coastal mangrove forest habitat (Robertson and Blaber, 1992). In Fiji and India, approximately 60% of the commercially important coastal fish species are directly associated with mangrove environments (Ronnback, 2001). Studies done by Ronnback (1999) in the Philippines revealed, 21 fish families in the mangroves among which 18 families were economically important. The contribution of mangrove related species to total fisheries catch is 67% in Eastern Australia (Hamilton and Snedaker, 1984) and 49% of the demersal fish resources in the Southern Malacca strait. The contribution of subsistence fisheries to total catch supported by mangroves has been estimated at 10-20% in Sarawak, 56% in Fiji and 90% in Kosrae (Ronnback, 2001). Mangrove forests were also found to be important nursery areas in studies done in Australia (Robertson and Duke 1987). However most of these studies have been carried out in rivers and creeks adjacent to mangrove forest themselves (Sasekumar *et.al.*, 1992). Therefore little is known of how mobile aquatic animals such as prawns and fish

move into the mangrove forests. Hence need to determine population density of fish within the mangrove forest.

Like other mangrove forests in the world, the mangroves of Kenya play a significant role in maintaining the productivity of the coastal fishery resources. Apart from studies carried out in Tudor creek (Little *et. al.*, 1988) and Gazi bay (Huxham *et. al.*, 2004, Kimani *et. al.*, 1996; Wakwabi, 1999) the role of mangrove swamps in the ecology of marine fisheries has not received enough attention in Kenya. At Gazi a total of 109 fish species belonging to 44 families were identified as being associated with mangroves. Out of these, 78.5% comprised Gerreidae, Atherinidae and Clupeidae families. Huxham *et.al.*, 2004 recorded more species richness in forested than un-forested mangrove sites while the densities were similar. No similar studies have been conducted at Ungwana bay to compare fish population density, biomass and species richness in forested and un-forested mangrove habitats despite Ungwana bay being the basket of Kenya's marine fisheries. Further there is lack of information on the relationship of fish caught in relation to mangrove dwelling fish species, hence the need for these research.

1. 1 Overall objective

To compare fish assemblage, in forested and un-forested mangrove ecosystems at Ungwana bay.

1.2 Specific Objectives

1. Identify fish species composition in un-forested and forested mangrove habitats.
2. Determine fish population density in un-forested and forested mangrove habitats.

3. Determine if type of bottom substrate influences fish population density in un-forested and forested mangrove habitats.
4. Compare prey availability in un-forested and forested mangrove habitats.

1.3 Scientific Hypotheses

- 1.0 Ho. Fish species composition in un-forested and forested mangrove habitats is not different.
- 2.0 Ho. Fish population density in forested and un-forested mangrove habitats is similar.
- 3.0 Ho. Bottom substrate does not influence fish population density.
- 4.0 Ho. Prey item in un-forested mangrove habitats is not different from that in forested mangrove habitats.

1.4 Problem Statement

Mangrove ecosystems are ecologically important for providing feeding areas for larger marine species like snappers, and shelter for marine creatures (molluscs, crustaceans and fish), nurseries for fish, pollutant recycling and nutrient recycling (Hamilton and Snedarker, 1984; Ronnback, 2001; Sasekumar *et.al.*, 1992). However, information on this is missing in many parts of Kenya, therefore the need for the present research.

Due to lack of adequate information on the relationship between their ecology and fishery production, mangrove forests are exploited/converted to other land uses such as; timber production, building, fire wood, mariculture, and medicine (Saenger *et al.*, 1983; Primavera, 1993; Kairo *et.al.*, 2001a).

Such unsustainable utilization of mangrove forests leads to ecosystem degradation as reflected in Ungwana bay and other areas. In due course, nutrient flow is affected, consequently declining primary and secondary production. Such impacts reduce fish prey abundance, hibernation potential and nursery suitability of mangrove forest habitat. In combination, the above shortfalls lead to negative change in fish species composition, density and population structure. Overall fish production is drastically reduced and hence negatively impacting the livelihoods of the coastal communities. In recognition of the importance of the mangrove habitat in coastal areas and the environmental threats faced, the research was set up to demonstrate impact of degradation on fish production.

1.5 Justification of the Study

Mangrove forests are economically, ecologically and environmentally vital in the world (Kapetsky, 1985; FAO, 1988) even though scientific support of such information is lacking in Kenya's Ungwana bay. By interfering with the nutrient link, energy flow in the ecosystem is thwarted and hence low fish production.

A number of food products are harvested directly within the mangrove forests through hunting, gathering and fishing operations (Ronnback, 2001). Fisheries production constitutes the major value of marketed resources from unexploited mangrove ecosystems. It is estimated that each hectare of mangrove forest can generate fisheries catch of the range 1.0-11.8tons/year (Ronnback, 2001). Robertson and Duke (1987) found mangroves in Northern Australia to contain 4 -10 times higher fish abundance compared to adjacent sea grass habitats however such information has not been well

documented for Kenyan mangroves and Ungwana bay in particular. In addition the value of mangroves to fishery is about 5 times higher than when same mangroves are converted to wood products (Ronnback, 2001).

Despite such understanding, destruction of these ecosystems still continues. Depletion of this ecosystem has been facilitated by poor understanding of their ecological importance with respect to fisheries assemblage and production (Ronnback, *et al.*, 1999). Adequate knowledge on the significance of mangrove forest in fishery production lacks in the region. Such aspect has led to reduction in fishery production in the Ungwana bay due to mangrove degradation. As a result there is a threat of declining food security.

The present study, sampled fish from discrete forested and un-forested mangrove habitats, using stake nets, modifying the methodology used by Vance *et. al.*,(1996) and Huxham *et. al.*, (2004). Zooplanktons and Meiofauna (benthos) in each habitat were also identified and related to the fish feeding habits. The study aimed at increasing the scientific knowledge of fish species assemblage in forested and un-forested mangrove ecosystem, and the role mangrove forests play in determining fish population densities in order to advice on the proper management of these habitats for improved livelihoods of the local communities.

1.6 Limitations of the study

A number of limitations hindered the present research in one way or another. Some sampled sites had very strong waves that completely teared the old stake nets therefore

delaying the sampling process however such was resolved by using only new stake nets in those sites. Some fish lost their original colour as a result of preservation hence making it difficult to identify them effectively to the lowest taxa level once in the laboratory (therefore making them to be identified only to the family level). The logistics for sampling overnight made the work difficult because some areas were only accessible by boat which could occasionally get entangled in the fishing gill nets therefore leading to long time on sea and conflict with the fishermen.

CHAPTER TWO

2.0 LITERATURE REVIEW

Fisheries play a vital role in support of local livelihoods along the coast of Kenya, where almost the entire fishery is artisanal. The Kenyan coastal fishermen are approximated at about 5,000 of which 4,000 are artisanal and the rest industrial (UNEP, 2001). In Kenya practically all the capture fishery is carried out inshore, around coral reefs, mangrove creeks, and over sea grass beds. These biotopes offer vital environments for spawning, nursery, feeding and shelter for various fishes (UNEP, 2001). The biotopes therefore form a vital resource base for the coastal fisheries, meaning that degradation of the ecosystems is a major threat to the fisheries.

The mangrove ecosystems are important ecologically for providing feeding areas for larger marine species like snappers, and shelter for marine creatures (molluscs, crustaceans and fish), nurseries for fish, pollutant recycling and nutrient recycling among others (Hamilton and Snedaker, 1984; Kimani *et.al.*, 1996; Ronnback, 2000, and Sasekumar *et.al.*, 1992). Ecological services of mangrove ecosystems are key features that sustain economic activities in coastal areas through out the tropics. In addition a range of direct and indirect natural resources from mangroves are vital to subsistence economies and provide a base to local and national economies (Semesi, 1998).

Relatively small-scale modifications to the physical structure of tropical and subtropical mangrove forests such as; foot paths, removal of pneumatophores among others can lead to significant effects on the diversity and abundance of macro benthic organisms in

these habitats (Skilleter and Warren, 1999). Such modifications have the potential to cause cascading effects at higher trophic levels with deterioration in the value of these habitats as nursery and feeding grounds. Therefore efforts aimed at conservation of these estuarine environments must focus on the prevention or reduction of modifications to the physical structure and integrity of the system, rather than just on the prevention of loss of entire patches of habitat (Skilleter and Warren, 1999).

Mangrove forests have been subjected to widespread deforestation during the last decades. More than 50% of the world's mangroves have been removed (World Resource Institute, 1996; Spalding *et al.*, 1997, FAO, 2003), and for the Asia-Pacific region an annual deforestation rate of 1% is considered to be a conservative measure (Ong, 1995). For example, the Philippines lost 67% of their mangroves from 1951 to 1988, of which the development of shrimp and fish mariculture ponds accounted for approximately half of the loss (Primavera, 1993). Other direct impacts of mangrove loss include over exploitation of forest resources by local communities, and conversion into large-scale development activities such as agriculture, forestry, salt extraction, urban development and infrastructure. In addition, indirect degradation of mangrove system includes upstream diversion of fresh water flows, and deterioration of water quality caused by pollutants and nutrients (Saenger *et al.*, 1983; Semesi, 1998).

In the world today, there has been increasing awareness that mangrove ecosystems provide free of charge many valuable ecological services like protection against floods, hurricanes, reduction of shoreline and riverbank erosion, maintenance of biodiversity among others (Ronnback *et al.*, 1999). This is without forgetting their importance in

reducing the effect of Tsunamis in coastal areas. These services are key features that sustain economic activities in coastal areas throughout the tropics. In addition a range of direct and indirect natural resources from mangroves are vital to subsistence economies and provide a base to local and national economies (Semesi, 1998). The economic role of mangroves in supporting coastal fisheries is documented for various mangroves in the world. For example it is estimated that as much as 90% of the U.S. commercial catch and 70% of the recreation catch in the Gulf of Mexico, is made up of fin and shell fish species that spend all or a vital part of their life history in estuarine areas, where mangrove forms an important part of the habitat, (Odum and Heald, 1975). The relationship between mangrove forest surface area and fishery yield has been demonstrated by MacNae (1974) for the Western Indian Ocean, Martosubroto and Naamin (1977) for Indonesia, Stoner (1986) for Puerto Rico, Robertson and Duke (1987) for Australia, Sesakumar *et al.*, (1992), for Malaysia and Krishnamurthy *et al.*, (1981) for India. Further the ecological economic valuation of mangroves in fisheries production has been documented by Ronnback (2001).

The major driving force behind massive mangrove deforestation is underestimation of the economic value of mangrove ecosystems (Ronnback *et al.* 1999; Barbier, 1994). Some cost-benefit analyses done for instance have been shown to underestimate the economic value of mangrove-fisheries with upto two orders of magnitude (Ronnback *et al.*, 1999, Ronnback , 2000; Ronnback and Primavera, 2000). In part, this trend of under valuation is due to the difficulty involved in placing monetary value on mangrove goods and services that are; not traded or marketed and thus do not have a directly observable value, and harvested or enjoyed outside the mangrove ecosystem and

therefore not readily acknowledged as generated by this system (Barbier, 1994). Lack of ecological knowledge among valuers is another important determinant to the undervaluation of mangroves (Ronnback, 2001). Thus the reason why mangroves are considered as wastelands and are therefore prime candidates for conversion into alternative uses like shrimp mariculture, which generate direct marketable products.

2.1 Mangroves and fisheries

Indigenous people have exploited the biota of mangrove waters for centuries, and fish and shrimp are still one of the major products harvested from the habitats (Saenger *et al.*, 1983). Mangrove forests are characterised by high abundance of fish, crustaceans and molluscs (Ronnback *et al.*, 1999). Few fish species are permanent residents in mangroves, but numerous marine species use mangroves as nursery grounds (Robertson and Blabber, 1992). There is a high-supposed connection between mangrove forests and juvenile nekton that is the basis of argument for conservation of mangrove forests among others (Hatcher *et al.*, 1989).

The mangroves, seagrass beds and shallow coral reef (0 to 3m deep) are the main nursery biotope for juveniles of many fish species. Mangroves and sea grass beds have been found to have high abundance of juvenile fishes because these biotopes often cover extensive areas and may intercept planktonic fish larvae more effectively than the coral reef (Parrish, 1989; Little *et al.*, 1988). The presence of mangroves greatly increases the residence time of the water, which is particularly prominent in the upper reaches of flat, wide mangrove forests with high-complexity waterways (Wolanski and Ridd, 1986). This reflects the need for extensive and wide mangrove forests in retaining

immigrating young stages of fish and invertebrates of direct and indirect importance to fisheries and aquaculture (Ronnback *et al.*, 1999). Also the biotopes are often located at a distance from the coral reef or from offshore waters and are therefore less frequented by predators. For most fish species, the juveniles were found in shallow water biotopes and the large and adult fish on the (deeper) coral reef.

Various studies have revealed that fish are dependent on mangrove forests as nurseries (Thayer *et al.*, 1987; Robertson and Duke, 1987, and Morton, 1990). The habitats harbour higher densities of juvenile fishes than adjacent habitats and that most fish species, which use mangroves as juveniles, spawn outside estuaries. The high densities of fish and dependence of certain species on tropical estuaries that contain large mangrove forests is associated to the turbid waters of the habitat. Turbid waters reduce the effectiveness of large predators on fish (Blaber and Blaber, 1980; Cyrus and Blaber, 1992). In addition, (Blaber *et al.*, 1985 and Blaber, 1987) observed greater abundance of piscivorous fish species in mangroves that receive no run-off from the land, and therefore have much clearer waters. This means that the predation rate is high and hence the habitat is unsuitable as nursery. It has been demonstrated that many juveniles prefer shallow waters of high turbidity and absence of turbulence, perhaps because they are linked to areas of high productivity and also enhance escape from predators inclusive less energy needed to manoeuvre in the gentle waters by the younger fish (Blaber, 1981; Ronnback 2001). Adults of the same species occur mainly in clearer offshore waters. Robertson and Duke (1987) showed highly significant differences in the densities and communities of fishes between mangrove and other near shore habitats that are immediately adjacent to each other and have no differences in

turbidity. Therefore indicating that, factors other than turbidity may influence mangrove fish density.

Robertson *et al.*, (1988) indicated in Australia that mangrove habitats have an order of magnitude greater density of the preferred zooplankton prey of fish during the late dry-mid wet season recruitment period of fishes than in the middle of the dry season. However, Natewathana and Tantichodok (1984) found out that benthic food resources for fish are not more abundant in mangrove forests than in adjacent bare sand and mud habitats or sea grass beds. Meaning that, feeding is not the primary reason for more fish density in mangrove forests.

Daniel and Robertson (1990) observed a highly significant relationship between mangrove detritus and fish densities and biomass in mangrove creeks. Prop roots, pneumatophores, fallen logs and branches in mangrove forests and the snags caused by such debris in mangrove creeks provide structural complexity and increased shelter from predators (Thayer *et al.*, 1987; Ronnback, 2001). In Sri Lanka, local fishermen improve their catches in lagoons that were once surrounded by mangroves by creating thickets of dead mangrove sticks on the lagoon floor (Blabber and Milton, 1990; Robertson and Duke, 1990a).

A study done by Kimani *et al.*, (1996) at Gazi bay, showed that 63% of the fish species captured were juveniles while 44% were associated with coral reefs. The abundant families of the fish caught in the mangrove forest were those commercially sought for by fishermen in the area (Kimani *et al.*, 1996; Wakwabi, 1999). Also Wakwabi (1999)

found out that fish caught in mangroves fed or obtained their food from the mangrove areas. This implies that feeding is one of the factors that make fish to move into mangroves. Huxham *et al.*, (2004) compared fish communities between forested and un-forested habitats at Gazi. The results indicated low densities in both forested and un-forested habitats, which were attributed to be site specific and most probably the effect of mangrove reforestation which has been highly practised in Gazi bay after high degradation levels in the area. Therefore implying that ecosystem recovery has not attained the level at which there can be significant differences between forested and un-forested sites.

The food chain model in mangrove forests suggested that the principal flow of energy was along the path of: mangrove leaf litter →saprophytic community→detritus consumers (detritivores and omnivores) → lower carnivores → higher carnivores (Odum and Heald, 1975). Most leaf litter was thought to be flushed into mangrove waterways, where microbial decomposition occurred before the nutrients are released into offshore waters (Odum and Heald, 1975). Research has indicated that large proportion of the leaf and other litter reaching the floor of mangrove forests is consumed by crabs and prawns or buried underground by crabs (Robertson, 1986; Odum and Heald, 1975). Consumption and retention of litter within mangrove forests by crab populations has profound effects on pathways of energy and carbon flow within the forests which tend to be a store from where nutrients are supplied to the aquatic environment (Robertson, 1991). Primary production estimates in mangrove forests justify how litter processing and retention by crabs conserve significant amount of nitrogen within the mangrove forest (Robertson *et al.*, 1992). The cycling of

phosphorus through mangrove food webs is presumably similar to that in other aquatic systems. At the base of pelagic and benthic food webs, 'a microbial loop' exists in which interactions among bacteria, micro algae and nanoprotozoans and larger protists facilitate net release of phosphorus into the water column (Alongi *et al.*, 1992).

Robertson *et al.*, (1988) showed that there was an order of magnitude higher density of zooplankton in mangrove habitats in tropical Australia than in the waters of an adjacent embayment, some 10 kilometres from their mangrove sampling sites. Higher abundance and diversity of phytoplankton and primary production has been noted in mangrove forest habitats compared to non-forest habitats. Mangrove forests have high nutrient values therefore high chlorophyll-a (Robertson and Blaber, 1992). In addition to the trees themselves, seedlings, algae and other periphyton also contribute to the primary productivity of mangrove ecosystems. High abundance of planktons ensures sufficient food supply for the filter feeding fish, hence stable food web and high fish production.

In his studies, Kondalarao (1983) found high densities of meiofauna in the mangrove forest. He found very high abundances in surface sediments dominated by nematodes. In Malaysia, Sasekumar (1981) found that nematodes dominated the meiofauna followed by copepods and oligocheates. High densities of meiofauna were also noted in mud banks adjoining mangroves in India (Krishnamurthy *et al.*, 1984). Meiofauna are mainly found within the top 10cm of substrate in mangrove ecosystem. However, plant derived tannins in combination with other factors account for low meiofauna density in mangrove forests (Alongi, 1987b) but the meiofauna have developed special

adaptations to survive such harsh conditions (Nicholas *et al.*, 1987). The meiofauna are an important food source for larger organisms found in the mangrove forests like; prawns and fish (Krishnamurthy *et al.*, 1984; Sasekumar, 1981).

2.2 Feeding Habits

Studying fish stomach contents as a means to assess their diets is like tracing information from destroyed archive records. The difficulty can be surmounting when one has to decide between what was really valuable food and that accidentally ingested (Berg, 1979 and Hyslop, 1980). Consequently, 'a microbial loop' exists in which interactions among bacteria, micro algae and nanoprotozoans, protozoan and larger protists facilitate net release of nutrients into the water column and some may be available as fish food but difficult to notice due their quick digestion in the fish stomach while others are too small and need advance machines for identification (Mavuti *et al.*, 2004; Alongi *et al.*, 1992).

In nature, fish feed on a great diversity of food items such as phytoplankton, zooplanktons, benthic and non-benthic invertebrates, benthic deposits, other fish and aquatic macrophytes that are deemed to be plenty in mangrove ecosystems. The knowledge on the types of natural foods for fish is important in formulating the dietary needs of species, as well as ascertaining whether the population age structure in the fishery is in proper relation to the food resources available to it (Getabu, 1994).

Studies done at Gazi mangroves indicate that 44 fish species were dominant in the catches, which were distinguished into 3 trophic guilds based on dietary diversity;

planktivores, benthivores and piscivores (Wakwabi, 1999). Planktivores had low stomach fullness index, diet was not diverse and mainly composed of harpacticoid and calanoid copepods and Brachyuran zoea and megalopae. Benthivores had low stomach fullness index but a little bit higher than those observed for the planktivores, mainly feed on small epi- and hyper benthic prey, diet was diverse and dominated by amphipoda, tunaidacea and mysidacea. Piscivores were characterised by much higher stomach fullness index, less diverse diet and dominant items in the food spectrum of post larval fishes and large nektonic invertebrates (amphipods, mysids, shrimps and crabs) (Wakwabi, 1999). All the food items were found to be abundant within the same mangrove forest.

It is important to note that mangrove forests influence primary productivity in their habitats hence increase prey availability, fish diversity, density and abundance consequently making them important in determining the livelihoods of the coastal communities; which is the basis of this research.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

3.1.1 Geographical location

The study was carried out at Ungwana Bay located 150km north of Mombasa town. The bay is situated in the northern banks of Kenya coast, stretching from the mouth of R. Sabaki in the South to Kipini at the Tana River delta, to the north (Fig. 1). It lies between latitudes $2^{\circ} 50'$ and $3^{\circ} 10'$ South and Longitudes $40^{\circ} 00'$ and $40^{\circ} 20'$ West. The bay has a length of 100 km along the coast and the straight distance from south to north of the bay is 60 km. The total surface area is approximated at $1,200 \text{ km}^2$ making it the largest bay in Kenya. The bay is shallow with a wide continental shelf whose extent ranges between 15 and 60 km. The mean depth at high tide is 12 m at 1.5 nautical miles and 18.0 m at 6.0 nautical miles. The depth increases rapidly to 100 m after 7 nautical miles. Figure 1 shows the designated sampling points within Ungwana bay as detailed in the sampling design. Like other coastal areas in Kenya, Ungwana bay experiences high and low tides separated by six-hour interval. Tides are either magnified or reduced depending on the gravitational pull by the moon and the sun thus leading to neap and spring tides.

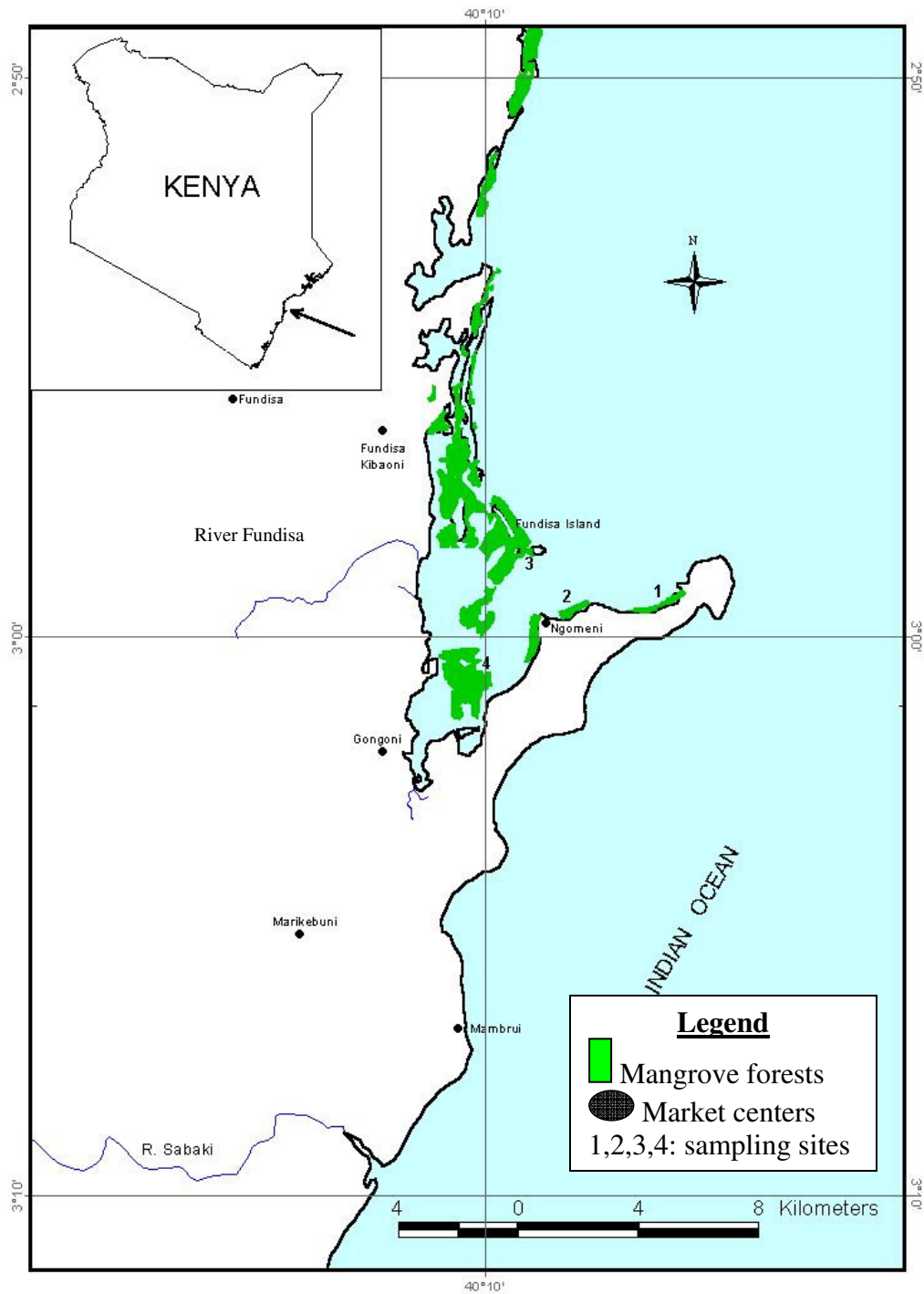


Figure 1: Study Area (Source, KMFRI-2001)

3.1.2 Climate

Ungwana bay experiences tropical climate influenced by the monsoon winds with two distinct periods. The Northeast Monsoon (NEM) (Kaskazi) blows from September to February, which brings hot and calm weather. The Southeast Monsoon (SEM) (Kusi) blows from March to August and is characterised by strong winds, cool temperatures and rough seas. Rainy seasons occur between the Monsoon periods with long rains occurring from March to July while short rains from October to December. Mean rainfall ranges from 508 mm to 1150 mm per year. Highest average wind speed is recorded between 9.3-9.8 knots and the speed increase during the morning and drops during the nights. Annual mean temperature ranges from 28-32°C (Figure 2).

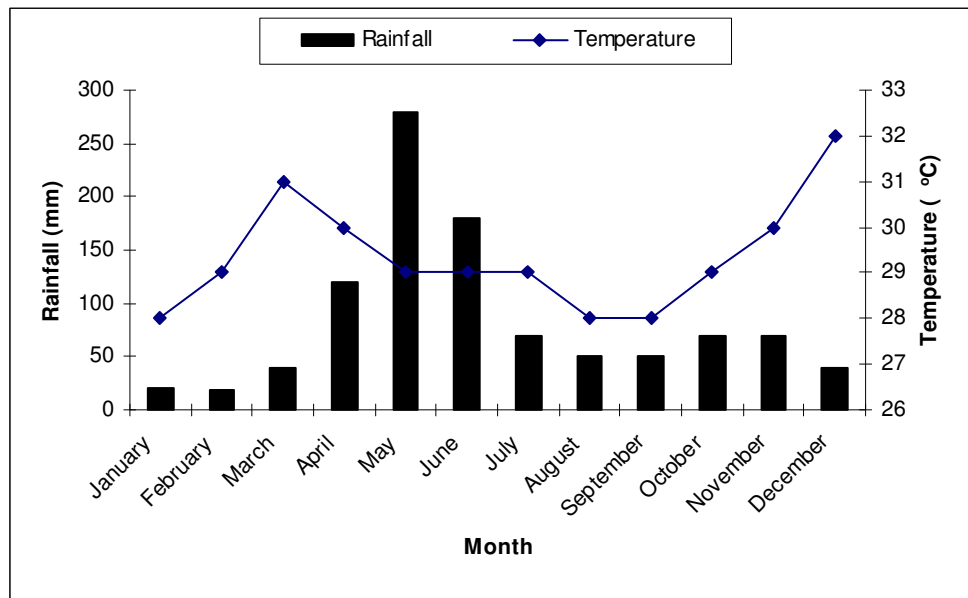


Figure 2: Mean Rainfall and Temperature distribution at the study site (source- Jaetzold and Smidt, 1976).

During SEM, the north-flowing East African Coastal Current (EACC) is intensified particularly at the upper zone of the water column (McClanahan, 1988). During NEM, the EACC is weakened and is tuned out to the sea when it meets the south flowing Somali currents at latitude between 0° and 1°S . The meeting of EACC and Somalia currents causes upwellings along the Somali coast, which are among the most extensive in the world (Figure 3). The upwellings are responsible for the increased marine fish productivity in the northern Kenyan coast (Brakel, 1982). The high productivity of the surface waters during the NEM in northern Kenya is not reflected in higher organic matter in sediments. This is because the shelf is narrow and offshore currents are strong. The organic matter is probably not recycled but transported and deposited into the sea.

The differences in currents, rainfall, up and down welling, water temperature and nutrients cause a north-south divide between the marine ecosystems (Baars *et al.*, 1991). The south coast is with low-nutrient water and hence low fish productivity (Ohowa *et al.*, 1997; Woitchik *et al.*, 1997). Northern Kenya has cooler nutrient rich water and greater predominance of planktonic productivity that triggers high fish production at Kiunga and Tana River delta.

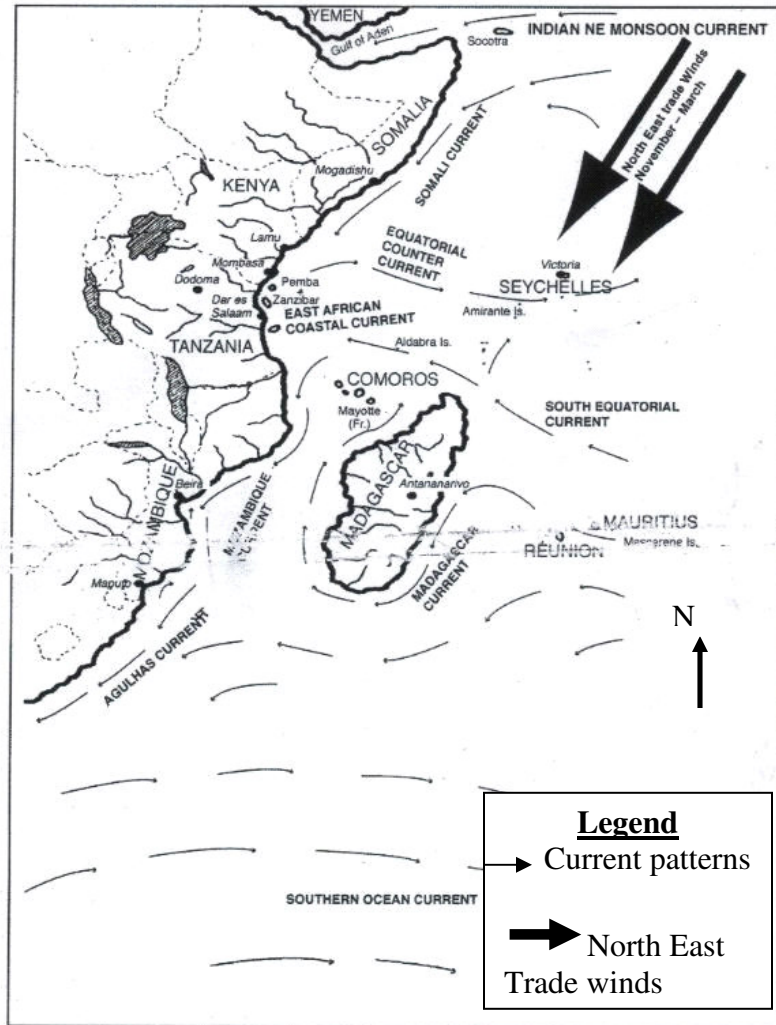


Figure 3: Current patterns and North East Trade Winds (Source: Linden and Lundin, 1996): Scale: 1: 500,000

3.1.3 Topography and Drainage

Rivers extending into the coastal zone exhibit a high degree of seasonal variability. Only two major rivers draining into the Indian Ocean are permanent, the Tana and Sabaki. The Tana originates on the slopes of Mt. Kenya and Aberdare Ranges then extends for 700 km to the sea. It has a catchment area of 132,000 km². The Sabaki River has its origin as Athi River in the central highlands around Nairobi. When joined by the Tsavo River in the lower basin the river is known as Galana. The river is known

as Sabaki when it drains into the sea. The entire Athi- Galana system extends for 390 km to the sea and drains 70,000 km² (Brakel, 1984). River Tana has an annual discharge of 4.7×10^9 m³ while the Sabaki has a discharge of 1.3×10^9 m³ per year (Angweny, 1980). The estuarine region of Tana delta formed by the river Tana and its tributaries and that of river Sabaki are rich in alluvial deposition. Along with this, high tidal amplitude ranging from 1.0 to 4.0 m, gentle gradient topography and influx of large quantities of fresh water for a long period of time provides an ideal condition for development of mangrove forest in Ungwana Bay. The sediments within the continental shelf are mainly composed of sand and clay/mud.

3.1.4 Biodiversity

All the nine species of mangroves recorded in Kenya (Kokwaro, 1985) are found in Ungwana bay. Ungwana mangroves harbour the highest population of *Heritiera littoralis* and *Xylocarpus granutum* rising as high as 27m, which are nearly on a verge of extinction in other parts of Kenya: Because of these Ungwana Bay may be considered an important centre for mangrove genetic conservation in Kenya. The mangroves of Ungwana have recently been designated as an eco-region of global importance (WWF, 2001; Kairo and Kivyatu, 2000). However a major threat of mangrove wetland degradation is their conversion to areas of aquaculture (60 ha of mariculture at Ngomeni -Kenya), increased coastal development, over exploitation, siltation (3 million tons of sediment/yr from Tana river and 2 million tons/yr from river Sabaki), drying of riverbeds, salt extraction (9,500 ha of salt works at Ngomeni) and farming activities like rice farming (Kairo, 2001, Abuodha and Kairo, 2001, Kairo *et al.*, 2001).

Other aquatic flora recorded in the area includes: Sea grass beds, algae and various phytoplankton communities. The terrestrial trees found in the study area comprise; *Acacia* spp, Neem and pine trees including thickets and bushes.

Animals found in the region are quite diverse, ranging from aquatic dwelling ones to terrestrial species. Example of aquatic mammals includes crocodiles, hippopotamus and a variety of snake species. Also different types of crabs like (mud crab-*Scylla serrata*), marine families *chelonia* (sea turtles) and *cetaceans* (whales) have been recorded moving up and down the bay. The zooplanktons and invertebrates are also abundant in this region. Molluscs like Green snail, *Terebralia pallustris* and pearl oysters are also present.

The examples of dominant terrestrial mammals here include; Colobus monkeys, Velvet monkeys, baboons, mongoose, buffaloes, bush pigs and gazelles among others. Major birds within the region are, Banded Snake Eagle, Spotted Ground Thrush, Fisher's Turaco, and Plain backed sunbird among other important bird species.

3.1.6 Socio-economic

Main ethnic groups living in the villages along the coastal areas are the Swahilis of mixed origin (Mijikenda, Bajunis among others) who are mainly Muslims (Kairo, 2001). Within the study area, the Giriama and Bajunis are predominant. Fishing and subsistence farming are the primary occupation of the villages living along the study area. Fishing forms the main and traditional activity carried out by the communities to

maintain their livelihoods. The fishing activity here is mainly artisanal and involves use of low cost vessels and gears such as outrigger canoes, basic fishing lines and hooks, basket traps, spears, small nets and one or two man boats. This is mainly aimed at obtaining fish for family use and sell to the local markets. Fishing occurs along the mangrove creeks and it involves finfish and shellfish. However shellfish fishery is at times mechanized, targeting export market. Due to increased mangrove deforestation, the catch/landings of artisanal fishers may decrease over time.

Marine fish landing in Kenya is mainly made up of demersal fish, which account for 36% of the total fish catch. The commonest demersal fish families landed are the scavengers (Lethrinidae) and rabbit fish (Siganidae) each of which contribute some 20% of the demersal fish catch, while parrotfish (Scaridae) and snapper (Lujanidae) are the next common and contribute between 6 and 8%. Sharks and rays make up 21% of the landings with pelagic species accounting for less than 15%, prawn fishery less than 10% and molluscs 2.5% (Odido, 1998).

Other economic activities that are regarded as secondary occupations include: salt harvesting and mangrove harvesting. The main use of mangrove products is building and export of poles. Mangrove harvesting is a male dominated activity (Kairo, 2001). The main farming activities in the region are; rice farming, coconut farming and pastoralism. Most of this region has mainly sandy soils characterised by sand dunes. In some areas where alluvial soils exist, subsistence farming is carried out, however, with a very poor attitude. All these activities affect the bay and mangrove degradation in one way or another.

3.2 Sampling Techniques

3.2.1 Stake Net sampling

It is difficult to use traditional methods of fishing, such as trawling and seining, within mangrove forests. For this reason, the majority of studies on mangrove fish communities have caught fish in the habitats immediately adjacent to the mangrove forest, or in mangrove creeks. One danger of sampling adjacent to the mangrove forest is that small-scale habitat differences may have larger effects on fish communities. Quantitative sampling inside mangroves can be achieved using stake nets (Vance *et al.*, 1996 and Ronnback, 2001, Huxham *et al.*, 2004). This method encloses a known area, and therefore allows quantitative comparisons between sites differing in location and habitat. Stake nets were used to sample fish as detailed in (Vance *et al.*, 1996; Huxham *et al.*, 2004) however in a modified way.

A mosquito net 36m long by 2.7m wide was used to enclose an area of 36 m² in the forested and un-forested habitats within the designated study sites (1, 2, 3, 4), Table 1. The nets were set during low spring. For the case of forested sites, nets were set in or near *Sonneratia alba* and *Rhizophora mucronata* mangroves that are found seawards in lowest tide regions. Within the mangrove forest, a rectangular path was cleared off prop roots and pneumatophores. The net was deployed at low tide along the cleared path and the chain buried in the sediment and held in place with mud. Net was rolled down to the level of the sediments and left until high tide (high water); when the water level was at least chest high. At high water, the top of the net was lifted onto wooden stakes, tied at 3m intervals, such that the net was above the water level (Figure 4). At low tide the net was checked and any fish caught were put in plastic bags, labelled, fixed with 5%

formalin and transported to the laboratory at KMFRI where they were stored in a freezer for later analysis.

Table 1: Organisation of sampling design and site description of the study area

| Sites/Description | Forested/ soft | Forested/h ard | Un-forested/soft | Un-forested/hard |
|-------------------|-------------------|-------------------|------------------|------------------|
| Site 1 | | X | | X |
| Site 2 | X | | X | |
| Site 3 | | X | | X |
| Site 4 | X | | X | |

X - Sampling site description

Hard- Sandy substratum

Soft- Muddy substratum

3.2.2 Categorisation of substrate

Substrate in each sampling site was classified as soft/hard depending on the percentage of sand/silt and how sticky it was when wet. Sieve analysis was used for grain size determination to separate the substrate into sand and silt according to Hankanson and Jansson, (1983). Sieves ranging from 500 micrometer to 38 micrometers were stacked with the finest sieve at the bottom and a lid on top. The samples were weighed and then poured to the top sieve, lid placed and shaken by mechanical shaker for 10 minutes. The various fractions of the sample in different sieves were then collected and weighed by digital balance. After grain separation, the composition of grain sizes

(categorisation) was described by using the Shephard (1954) triangle. The silty and sticky substrate when wet was referred to as soft while the sand and non-sticky when wet was termed hard.

3.2.3 Sediment sampling

The corer technique was used as described by Hankanson and Jansson (1983) where by a plastic corer of 6.4 cm diameter was used to sample to a depth of 5 cm because only the top meiofauna was targeted. Core sampling was done in the area covered by the fish sample nets. This was done before any disturbance was caused on the sediments. Two replicates were obtained from each sampling station. The samples were put in plastic bags, labelled, fixed with 5% formalin and taken to the laboratory for meiofauna identification.

3.2.4 Plankton sampling

Sampling was done using plankton net of size 335 micrometers during high tide (the net size was chosen being the most appropriate for plankton sampling). Plankton sampling was carried out at sites where stake nets were set. The nets were towed on the water surface for 10 minutes to obtain the plankton sample. The obtained sample was concentrated using a sieve of same size so as to fit into 100ml-sample bottle. Samples were fixed with 5% formalin and taken to the laboratory for zooplankton analysis. Three replicates from each sampling point were obtained per one sampling time.

3.3 Laboratory analysis

3.3.1 Fish samples

In the laboratory fish were identified to species level using principal identification keys by Smith and Heemstra (1986); Fischer and Bianchi (1984); and Bianchi (1985). They

were then counted and the standard length recorded for each specimen to the nearest mm using a measuring board. The fresh weight of the fish caught was measured to the nearest grams using a weighing balance. Length and weight of fish is important in fish biology as it generates information on composition, growth and production. Growth stage of fish was assessed by opening the fish stomach using a dissecting kit and maturity of gonads observed. Each specimen was assigned to a maturity stage (larvae, post larvae, Juveniles, sub-adults or adults) based on their structural and textural features such as size, colour, shape and texture following the protocols of Ntiba and Jaccarini (1990). Individuals in the dominant size classes of ten most abundant and characteristic species were selected for analysis of stomach contents. At least five specimens per species were selected for the study from the ten identified fish species in each sampling time. The fish were weighed, then opened and their guts carefully severed from oesophagus to the last part of the intestine. Each gut was opened and the contents removed carefully and weighed in grams using a digital analytical balance, after which they were emptied into a Petri dish with water and stained with Bengal indicator. Staining was necessary for the organisms to take up the pink colour for easy identification examination under a light microscope. All items present in the gut were identified to the lowest possible taxa and counted. For those items partially digested, heads were identified and counted. Three mathematical models were applied to determine the food and feeding habits of these fishes (Hyness, 1950).

The intensity of feeding was studied by determining the degree of fullness of the stomach (Getabu, 1994; Hynes, 1950).

$$FI = \frac{\text{Weight of ingested food}}{\text{Weight of fish}} \times 100 \quad (1)$$

Where FI = Fullness Index

Diet composition was calculated as a percentage of each food item in the stomach contents and expressed as numerical abundance (N %).

$$N \% = \frac{\text{Number of individuals of prey item}}{\text{Total number of ingested prey}} \times 100 \quad (2)$$

The number of guts with common food items were grouped and the percentage frequency of occurrence (%F) of each food item in the stomach calculated.

$$\% F = \frac{\text{Number of stomachs with prey item}}{\text{Total number of stomachs with food}} \times 100 \quad (3)$$

3.3.2 Sediment samples

The faunal organisms less than 1mm and more than 63-micrometer size (meiofauna) were targeted for the study. The sediment was washed through a sieve of 1mm size and 63-micrometer size respectively. Sample retained by 63-micrometer sieve was transferred into sample bottles, fixed with 5 % formalin and stained with Rose Bengal

indicator to enable fauna take up the brown colour and thus ready for identification under electronic microscope according to the key provided by (Smith, 1977).

3.3.3 Water samples

Plankton samples in the water column were stained with Bengal indicator to enable easy identification and observed under a light microscope for zooplankton identification using key by Smith (1977).

3.4 EXPERIMENTAL DESIGN AND DATA ANALYSIS

3.4.1 Experimental design

Randomised Complete Block Design (RCBD) was used in the study, where by the blocking was based on forested mangrove habitats and un-forested habitats. Sampling was randomised within the blocks. Table 1 illustrates in detail the sampling design that was used for this research. Sampling was done between 2003 and 2004 during spring tide both in Northeast Monsoon and Southeast Monsoon seasons. For each sampling time at least four replicates were made for each site thus giving a total of 32 fish samples from all sites in one month.

The four sampling sites at Ngomeni differed in their degree of shelter from prevailing winds and hence in the wave strength. Site 1 and 3 were exposed to the open sea and experienced relatively strong waves unlike sites 2 and 4 that were sheltered from the strong wave influence. The sheltered sites (2 and 4) had soft (muddy) bottom substrate while the unsheltered sites (1 and 3) had hard (sandy) bottom substrate. Forested sites had higher percentage organic matter (2.9 – 5.7 %) than the un-forested sites (1.2 – 3.7

%) while the muddy substratum sites had high organic matter (2.0 – 5.7 %) than sandy substratum ones (1.2 -3.4 %) .

The sampled areas in the mangrove forest were dominated mainly by *Sonneratia alba* and a few *Rhizophora mucronata* stands since they are the ones found offshore in the study area. There was a distance of between forty to eighty metres from one sampling point to the other to instil effective replication and stake nets were shifted after every one sampling time. Sampling stations in un-forested sites had to be at least 60 m away from the mangrove forest while sampling was done simultaneously in paired forested and un-forested to avoid interaction effect and allow for comparison of samples (Figure 4). Sampling was done at every spring high tide through out the 24-hour clock system in all the sampling sites at each sampling period.



Figure 4: Raised stake net at spring low tide in un-forested mangrove habitat

3.4.2. Data Analysis

Logarithmic transformations ($\log_{10}(x+1)$) of fish abundance (number and weight) data were performed to meet assumptions of normality and homogeneity for statistical tests. Consequently, data was tested for normality using Shapiro-Wilks test and homogeneity using Levine test (STATISTICA 6.0). Fish density was calculated based on number of fish per unit area and biomass from fish per unit area. Analysis of Variance (ANOVA) was used to compare fish densities within and among habitats and seasonal variations in fish abundance. Cluster Analysis was used to test for similarity of fish assemblage in the various sites. Species richness index (H) and Shannon Wiener diversity index (D) were calculated based on sampling sites. Prey items in the environment and fish stomach were analysed by calculating frequency of occurrence, abundance percentages and prey density/m³.

$$D = S - 1/\log_{10}N \quad (4)$$

Where S is the number of species in the sample and N is the sample size.

$$H = n \log n - \sum (\varnothing \log \varnothing) / N \quad (5)$$

Where n is the number of species in a sample, \varnothing is the number of individuals in a species and N is the total number of individuals in a sample.

CHAPTER FOUR

4.0 RESULTS

4.1: Fish diversity, abundance, density, composition, and seasonality

4.1.1 Species diversity and similarity

Forested Site 2 showed greatest species richness (19 *spp*) with respect to sampling times while un-forested site 3 had the lowest species richness (8 *spp*) Figures 5. Fish species varied greatly in sites depending on bottom substrate types and presence or absence of mangrove. Forested sites with soft bottom substrate had higher species richness index at site 4 with (3.854 ± 2.303) and lowest at site 3 with (0.417 ± 0.317). Un-forested sites had higher species richness indices in soft substrate sites compared to hard bottom substrate sites (Table 2). Diversity index of Shannon Wiener also showed significant differences between forested and un-forested sites. Soft bottom substrate sites had higher species diversity compared to hard bottom substrate sites (Table 2).

Grouping fish catches into clusters at the species level yielded three distinct groups. Site 2 showed no similarity with other sites. Samples from site 2 were separated at the first level. The first and second group represents fish caught from sandy bottom substrate while the last group consists of samples from soft bottom substrate. Soft bottom substrate sites had similar species grouping that were less linked to the hard bottom substrate types. Soft bottom substrate sites showed very close species association. Hard bottom substrate sites also had close association of species (Figure 6).

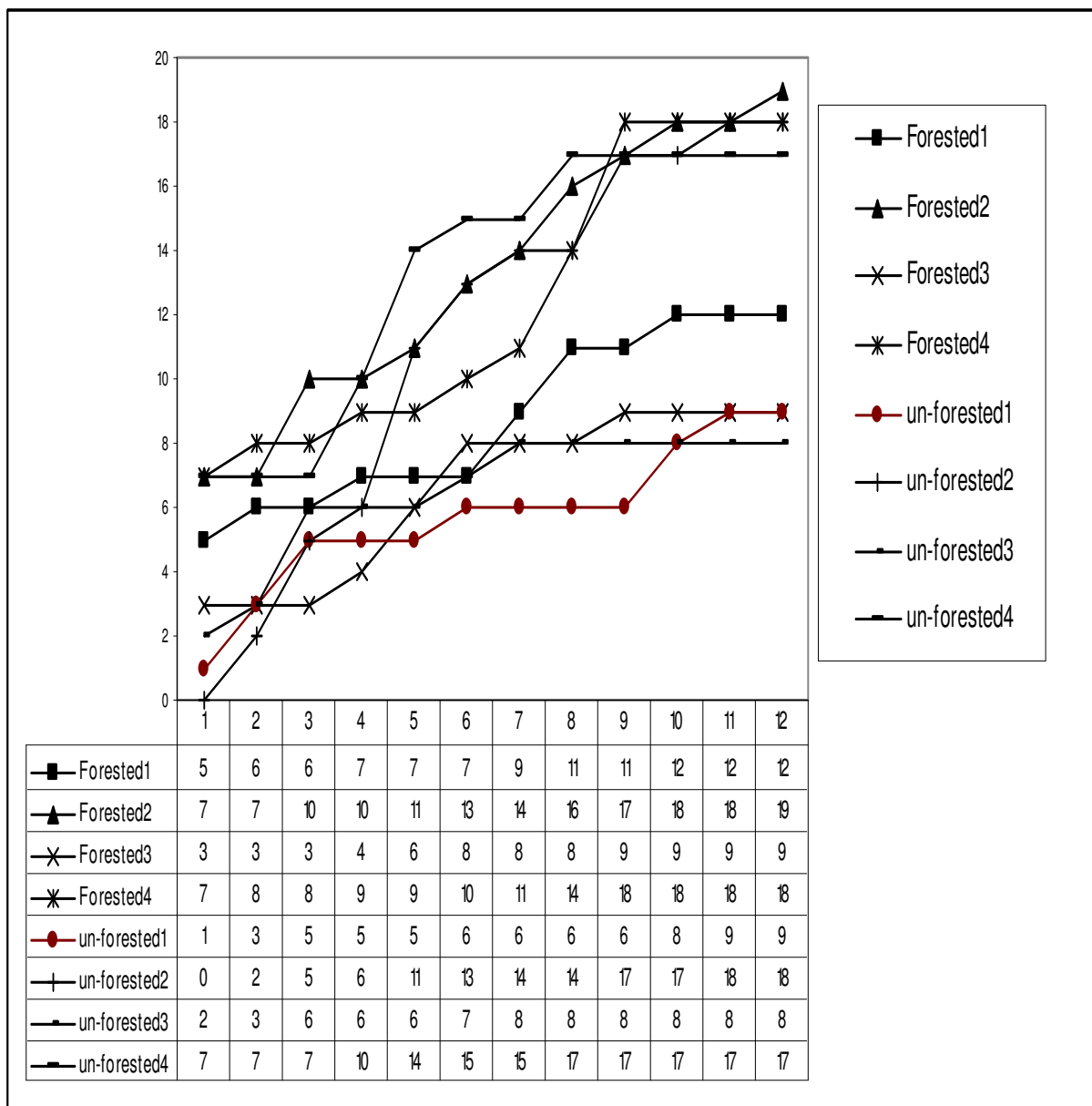


Figure 5: Cumulative increase in the number of fish species per site with respect to increase in the number of samples.

Table 2: Fish Species Richness Index and Shannon Wiener Diversity Index.

| Sites | Species richness index (D) | Shannon Wiener index (H) |
|-----------|----------------------------|-----------------------------|
| Site 1 F | 1.087± 0.985 ^a | 0.275±1.054 ^a |
| Site 1 UF | 0.207±1.488 ^a | 0.09203±0.4669 ^a |
| Site 2 F | 2.876±1.896 ^b | 1.0456±0.998 ^a |
| Site 2 UF | 3.741±2.10 ^c | 1.9100±1.9094 ^b |
| Site 3 F | 0.417±0.317 ^a | 0.2154±0.189 ^a |
| Site 3 UF | 1.521±2.04 ^b | 0.6929±1.4615 ^a |
| Site 4 F | 3.854±2.303 ^c | 1.627±1.411 ^b |
| Site 4 UF | 5.108±1.525 ^c | 2.275±1.256 ^b |

Means followed by different superscripts (^{a, b, c}) differ statistically at p<0.05.
 ± Standard deviation

Site 1 forested and un-forested had the lowest species similarity (17.5 %) while the highest species similarity (37 %) on site 4. Sites 2 and 4 showed higher linkage distance than sites 1 and 3 indicating that bottom substrate may influence species similarity. Site 4 showed the strongest species similarity (57.5 %) while Site 1 and 3 had the lowest species similarity (34.8 %).

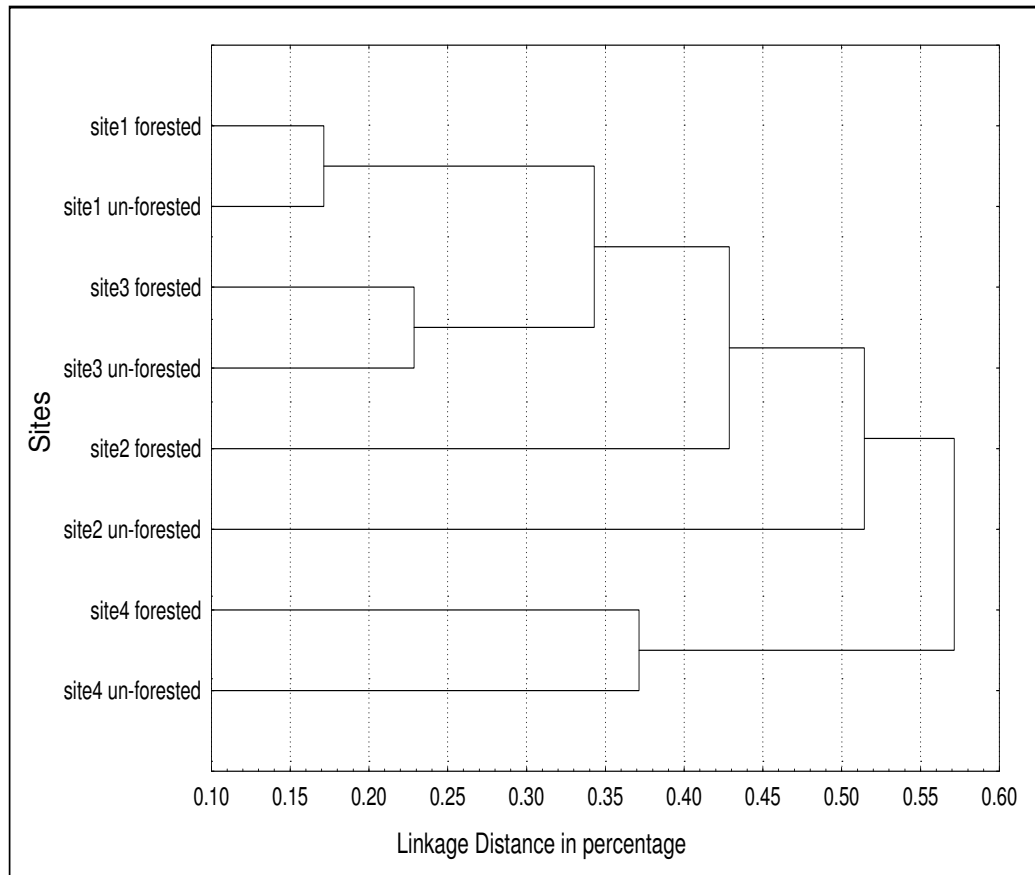


Figure 6: Dichotomy (Cluster) diagram for fish species similarity in the sampling sites.

A total of 18 species occurred in site 4 (forested and un-forested) where 15 species were common in the forested and un-forested sites. In site 2 (forested and un-forested), 24 species were observed and 12 species were common in both forested and un-forested sites. Fifteen species occurred in site 1 but only 6 species were common in the two microhabitats while 11 species were recorded in site 3 but 5 species were common (Table 3).

Table 3: Fish species percentage abundance per site in the forested and un-forested habitats

| species | site1 | site1 | site2 | site2 | site3 | site3 | site4 | site4 |
|--|-------|-------|-------|-------|-------|-------|-------|-------|
| | F | UF | F | UF | F | UF | F | UF |
| | % | % | % | % | % | % | % | % |
| <i>Acanthopagrus berda</i> ^a | 0 | 0 | 0 | 0 | 1.9 | 0.6 | 0 | 0 |
| <i>Anchoviella commersonii</i> | 36 | 15.2 | 50 | 17.3 | 0 | 0 | 4.7 | 3.9 |
| <i>Apogon hyalosoma</i> | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| <i>Apolectus niger</i> | 0 | 0 | 0 | 0 | 7.5 | 0 | 0 | 0 |
| <i>Arothon immaculatus</i> ^a | 0 | 0 | 0 | 0 | 3.8 | 0 | 0.3 | 0.04 |
| <i>Atherinidae spp.</i> | 0 | 0 | 0.1 | 0.8 | 0 | 0 | 0 | 0 |
| <i>Atherinomomus lacunosus</i> ^a | 0 | 0 | 0 | 0 | 41.5 | 1.2 | 1.5 | 0.1 |
| <i>Bothus pantherinus</i> | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| <i>Caranx ignobilis</i> ^a | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Elops saurus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 0.3 |
| <i>Epinephelus tauvina</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 |
| <i>Gaza minuta</i> | 0 | 0 | 0 | 13.9 | 0 | 0 | 0 | 0 |
| <i>Gerres oyena</i> | 2.4 | 9 | 1.97 | 12.2 | 13.2 | 49.7 | 0.3 | 0.32 |
| <i>Gerres punctatus</i> ^a | 2.4 | 3 | 2.07 | 0 | 0 | 0.6 | 0.3 | 0 |
| <i>Hermirhamphus far</i> | 0.8 | 3 | 0 | 0.4 | 0 | 1.8 | 1.2 | 0.14 |
| <i>Leognathus equula</i> ^a | 1.6 | 0 | 0.21 | 21.9 | 0 | 8.6 | 5.9 | 13.2 |
| <i>Lethrinus harak</i> ^a | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| <i>Lutjanus fululflamma</i> ^a | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Macruwa kelee</i> | 1.6 | 6 | 0 | 0 | 0 | 0 | 0.6 | 0.1 |
| <i>Mugil cephalus</i> ^a | 0.8 | 0 | 12.6 | 1.7 | 0 | 0 | 0.3 | 0.1 |
| <i>Pellona ditchella</i> ^a | 0 | 3 | 1.87 | 0.4 | 0 | 0 | 7.7 | 73.1 |
| <i>platyphalus crocodysis</i> ^a | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| <i>Pomadysis birocularis</i> | 0 | 0 | 0.3 | 0 | 0 | 0 | 0 | 0 |
| <i>Pomadysis maculatum</i> ^a | 0 | 0 | 0 | 1.3 | 0 | 0 | 0.6 | 0.07 |
| <i>Pomadysis multimaculatum</i> ^a | 0 | 0 | 0 | 0.4 | 0 | 0 | 0 | 0 |
| <i>Dasyatis pastinacus</i> | 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Sardinella melanura</i> | 0 | 0 | 18.7 | 1.3 | 0 | 0 | 63.4 | 7.2 |
| <i>Sardinella spp.</i> | 0 | 0 | 0.21 | 0 | 0 | 0 | 0 | 0 |
| <i>Secutor insidiator</i> | 0 | 0 | 0.42 | 0.4 | 7.5 | 1.2 | 11.8 | 0.43 |
| <i>Silago sihama</i> ^a | 44.8 | 54.6 | 9.6 | 13.5 | 22.6 | 36.2 | 0.3 | 0.4 |
| <i>Sphyaena jello</i> ^a | 0 | 0 | 0.21 | 0.4 | 0 | 0 | 0 | 0 |
| <i>Saurida undosquamis</i> | 4.8 | 0 | 1.2 | 0.8 | 0 | 0 | 0 | 0 |
| <i>Therapon jarbua</i> ^a | 3.2 | 0 | 0.1 | 3.4 | 1.9 | 0 | 0 | 0 |
| <i>Thrissocles malabaricus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 |
| <i>upenaus sulphurus</i> ^a | 0.8 | 0 | 0 | 9.7 | 0 | 0 | 0.3 | 0.2 |

^a Indicate fish species that were abundantly captured by artisanal fishermen in the area.

4.1.2 Fish abundance

The fish abundance by numbers ranged from 3.08 ± 2.74 in un-forested site 1 to 80.1 ± 125.5 in site 2 forest. However abundance in forested site 2 had the highest standard deviation (125.5) indicating the wide variation of fish abundance per sample. Generally forested sites had higher fish abundance compared to un-forested sites. Fish abundance was also greater on soft substrate habitats (Figure 7).

Mean fish wet weight ranged from 7.88 ± 6.19 g/36m² in Un-forested site 1 to 326.75 ± 293.36 g/36m² in forested site 2 (Figure 7). Higher fish wet weight was recorded in forested soft substratum habitats than all the other habitats with the lowest being in un-forested hard substratum habitats. Forested habitats had generally higher biomass than un-forested habitats.

Spatial comparisons revealed that overall abundance of fish changed between sites. The abundance was higher at sites 2 forested and 4 un-forested. Significant differences were recorded for number of fish ($F= 4.10$, $P<0.0007$) and wet weight ($F = 5.60$, $P<0.0016$).

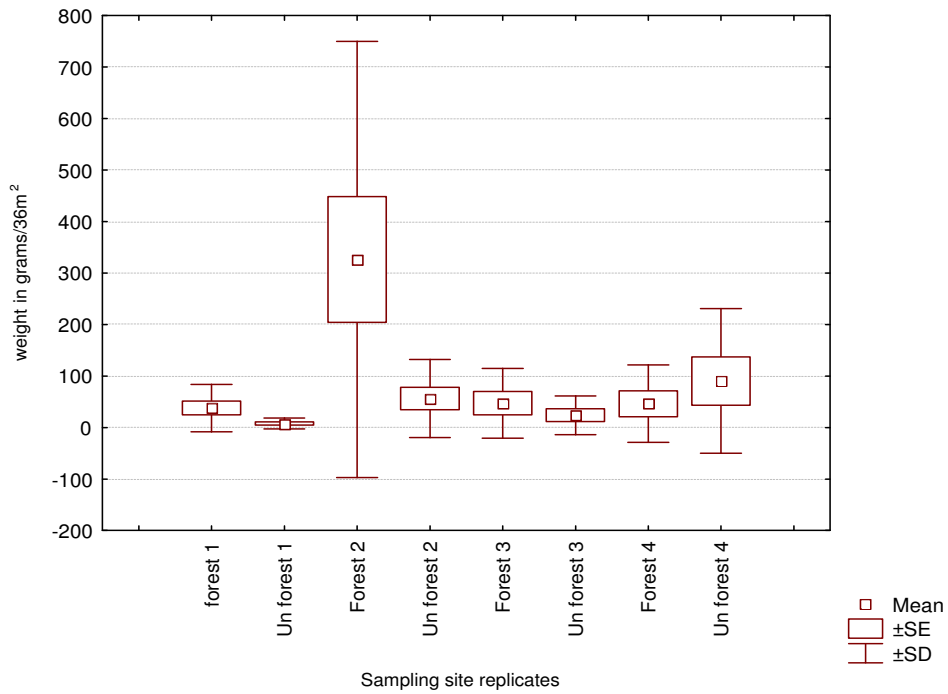
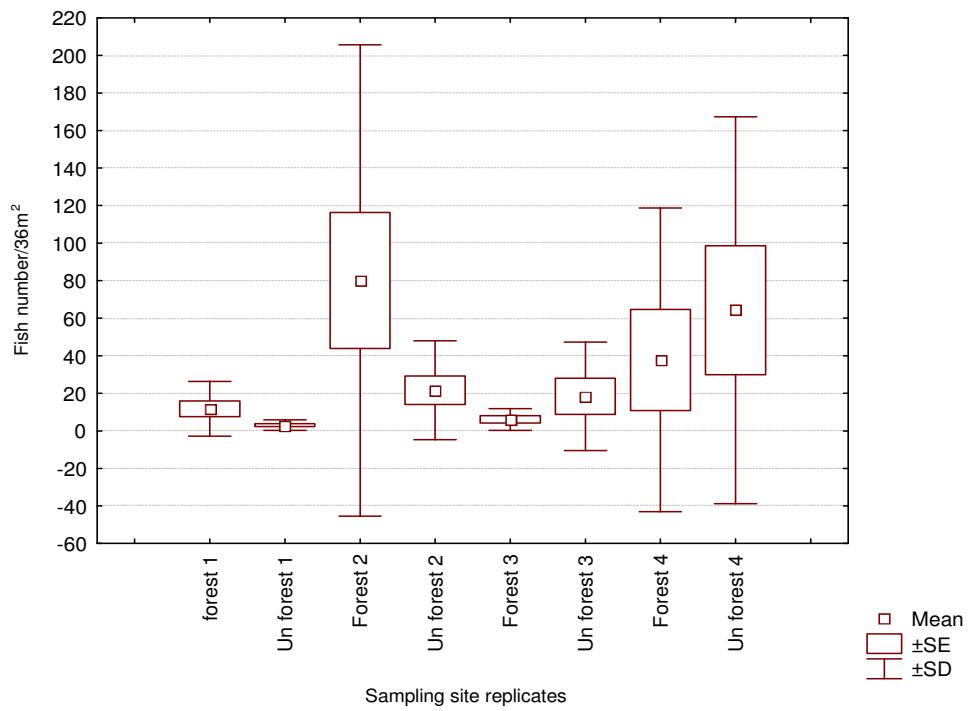


Figure 7: Mean fish numbers and wet weight per 36 m² for the replicates study sites

4.1.3 Fish density

Density was calculated as number of fish / m² and biomass as weight (g) of fish / m² in all the study sites. Mean fish density varied from 0.10 ± 0.09 fish/m² in un-forested site 1 to 2.67 ± 4.18 fish/m² in forested site 2 (Table 4). Fish density was higher in the soft-forested sites compared to that in the hard forested and un-forested sites. Biomass followed the same trend as that of numbers with Site 2 forested having the highest biomass (10.89 ± 8.78 g/m²) and un-forested site 1 the lowest (0.26 ± 0.17 g/m²).

Table 4: Mean fish density, abundance and length including ANOVA results

| Sites | Density (fish/m ²) | Biomass (g/m ²) | Mean Length (cm) |
|-----------|--------------------------------|-----------------------------|-----------------------|
| Site 1 F | 0.39±0.36 ^a | 1.26±1.15 ^c | 7.33±2.7 ^a |
| Site 1 UF | 0.10±0.09 ^a | 0.26±0.17 ^a | 6.56±2.3 ^a |
| Site 2 F | 2.67±2.13 ^b | 10.89±8.78 ^b | 7.74±5.3 ^a |
| Site 2 UF | 0.72±0.69 ^c | 1.88±1.64 ^c | 6.13±2.4 ^a |
| Site 3 F | 0.20±0.19 ^a | 1.57±1.26 ^c | 9.03±6.2 ^b |
| Site 3 UF | 0.61±0.90 ^c | 0.79±0.68 ^a | 6.30±4.5 ^a |
| Site 4 F | 1.26±2.29 ^c | 1.55±1.23 ^c | 6.21±2.8 ^a |
| Site 4 UF | 2.14±3.43 ^b | 3.01±4.68 ^b | 6.44±6.9 ^a |

Means followed by different superscripts (^{a, b, c}) differ statistically at p<0.05
± Standard deviation

4.1.4 Species composition

A total of 4676 fishes from 35 species representing 24 families were recorded during the sampling period. Gonad classification indicated 71.4% of fish were juveniles. The fish caught had total length varying from 1.0 cm to 48.5 cm however most fish were within 2.5 - 4.5 cm (Table 5) indicating that most fish were juveniles in their early stages of development. Forested site 3 recorded a significant difference in the mean fish length (9.03 ± 6.23) from all the other sites.

From table 5, the three most abundant species by numbers accounting for 71 % of the total fish number sampled are; *Pellona ditchella* (44.16 %), *Anchoviella commersonii* (14.91 %) and *Sardinella melanura* (12.75 %). These species also yielded more biomass accounting for 44 % of the total fish weight. This biomass was contributed by, *Pellona ditchella* (15.34 %), *Anchoviella commersonii* (18.44 %) and *Sardinella melanura* (6.07 %) Table 5.

Species composition varied spatially with abundance depending on the site. *Silago sihama* (44.8 %) was dominant in forested site 1, *Secutor insidiator* (54.55 %) un-forested site 1, *Anchoviella commersonii* (50.0 %) forested site 2, *Leognathus equula* (21.9%) un-forested site 2, *Atherinomomus lacunosus* (41.5 %) forested site 3, *Gerres oyena* (49.7 %) un-forested site 3, *Sardinella melanura* (63.4 %) forested site 4 and *Pellona ditchella* (73.1 %) un-forested site 4 with (Table 6). Thirty one out of 35 fish species compiled from the study sites occurred in forested sites. Among the 31 species 17 that accounted for 65.27 % abundance in the forested samples also occurred in the catches of artisanal fishermen in the area (Table 3).

Table 5: Family, species abundance, biomass, length range and stage of maturity of all fish caught during the whole Sampling period.

| Family/Species | Abundance | | Biomass | | Total length(cm) | | Maturity |
|---------------------------------|-----------|-------|---------|-------|------------------|------|----------|
| | n | % | wgt | % | min | max | |
| Apogonidae | | | | | | | |
| <i>Apogon hyalosoma</i> | 1 | 0.02 | 5.9 | 0.07 | 7.1 | 7.1 | j |
| Apolectidae | | | | | | | |
| <i>Apolectus niger</i> | 4 | 0.09 | 61.4 | 0.68 | 7.8 | 10.5 | j/m |
| Atherinidae | | | | | | | |
| <i>Atherinomomus lacunosus</i> | 32 | 0.68 | 39.02 | 0.43 | 2.0 | 7.3 | j |
| <i>Atherinidae spp</i> | 3 | 0.06 | 21.5 | 0.24 | 5.4 | 6.7 | j |
| Bothidae | | | | | | | |
| <i>Bothus pantherinus</i> | 1 | 0.02 | 98.4 | 1.09 | 22.1 | 22.1 | m |
| Carangidae | | | | | | | |
| <i>Caranx ignobilis</i> | 1 | 0.02 | 8.21 | 0.09 | 7.8 | 7.8 | j |
| Clupeidae | | | | | | | |
| <i>Pellona ditchella</i> | 2065 | 44.16 | 1380.1 | 15.34 | 3.2 | 8.9 | j |
| <i>Macruwa kelee</i> | 9 | 0.19 | 16.3 | 0.18 | 5.3 | 8.5 | j |
| <i>Sardinella spp</i> | 2 | 0.04 | 8.1 | 0.09 | 7.1 | 8.0 | j |
| <i>Sardinella melanura</i> | 596 | 12.75 | 546.2 | 6.07 | 2.2 | 8.9 | j/m |
| Dasyatidae | | | | | | | |
| <i>Dasyatis pastinacus</i> | 1 | 0.02 | 103.6 | 1.15 | 25.3 | 25.3 | m |
| Engraulidae | | | | | | | |
| <i>Ancheviella commersonii</i> | 697 | 14.91 | 1659.21 | 18.44 | 2.0 | 10.8 | j/m |
| <i>Thrissocles malabaricus</i> | 10 | 0.21 | 17 | 0.19 | 6.2 | 8.0 | j |
| Gerridae | | | | | | | |
| <i>Gerres oyena</i> | 152 | 3.25 | 204.39 | 2.27 | 1.8 | 10.2 | j |
| <i>Gerres panctatus</i> | 26 | 0.56 | 11.3 | 1.31 | 4.2 | 10.9 | j |
| Hermirhamphidae | | | | | | | |
| <i>Hermirhamphus far</i> | 14 | 0.3 | 56.67 | 0.63 | 5.2 | 18.6 | j |
| Leiognathidae | | | | | | | |
| <i>Leognathus equula</i> | 456 | 9.75 | 572.42 | 6.36 | 1.5 | 14.6 | j/m |
| <i>Gaza minuta</i> | 33 | 0.71 | 33.5 | 0.37 | 4.1 | 6.0 | j |
| <i>Secutor insidiator</i> | 63 | 1.35 | 72.55 | 0.81 | 2.0 | 8.2 | j |
| Lenthrinidae | | | | | | | |
| <i>Lenthrinus harak</i> | 1 | 0.02 | 132.1 | 1.47 | 19.5 | 19.5 | m |
| Lutjanidae | | | | | | | |
| <i>Lutjanus fulviflamma</i> | 1 | 0.02 | 32.1 | 0.36 | 11.2 | 11.2 | j |
| Mugilidae | | | | | | | |
| <i>Mugil cephalus</i> | 130 | 2.78 | 273.22 | 3.04 | 2.5 | 16.2 | j/m |
| <i>Elops saurus</i> | 10 | 0.21 | 3.5 | 0.04 | 4.4 | 5.7 | j |
| Mullidae | | | | | | | |
| <i>Upeneus sulphurus</i> | 31 | 0.66 | 235.81 | 2.62 | 6.5 | 9.8 | j/m |
| Platycephalidae | | | | | | | |
| <i>Platycephalus crocodysis</i> | 1 | 0.02 | 0.5 | 0.01 | 4.0 | 4.0 | j |
| Pomadasyidae | | | | | | | |
| <i>Pomadysis birocularis</i> | 3 | 0.06 | 10.54 | 0.12 | 5.3 | 6.7 | j |
| <i>Pomadysis maculatum</i> | 7 | 0.15 | 17.6 | 0.2 | 6.7 | 8.7 | j |
| <i>Pomadysis multi-maculata</i> | 1 | 0.02 | 2.01 | 0.02 | 5.3 | 5.3 | |
| Serranidae | | | | | | | |
| <i>Epinephelus tauvina</i> | 1 | 0.02 | 1777.3 | 19.75 | 48.5 | 48.5 | m |
| Sillaginidae | | | | | | | |
| <i>Silago sihama</i> | 281 | 6.01 | 914.27 | 10.16 | 1.0 | 15.5 | j/m |
| Sparidae | | | | | | | |
| <i>Acanthopagrus berda</i> | 2 | 0.04 | 169.5 | 1.88 | 6.4 | 21.1 | m |
| Sphyraenidae | | | | | | | |
| <i>Sphyraena jello</i> | 3 | 0.06 | 288.5 | 3.21 | 4.7 | 33.4 | j/m |
| Synodontidae | | | | | | | |
| <i>Saurida undosquamis</i> | 20 | 0.43 | 23.35 | 0.26 | 2.0 | 4.9 | j |
| Tetraodontidae | | | | | | | |
| <i>Arothron immaculatus</i> | 4 | 0.04 | 34.51 | 0.38 | 1.9 | 9.1 | j/m |
| Theraponidae | | | | | | | |
| <i>Therapon jarbua</i> | 14 | 0.3 | 61.33 | 0.68 | 2.0 | 12.8 | j |

j – Juvenile

m - Mature

Forested site 2 showed greatest abundance and species richness (19 spp) than all the other sites (Table 6). Most species contributed minimal to the total number of fish since they had one or two fish, therefore representing less than 0.4 % of the total fish numbers (Table 5). Fish biomass also showed differences that were dependent on habitat variability and length of fish caught. Larger fish contributed greatly to biomass even though less abundant for example *Epinephelus tauvina* contributed 45.63% in biomass to un-forested site 4 while its abundance contribution was 0.04% (Table 5).

Clupeidae family contributed the highest number of species (4) while Leiognathidae and Pomadasysidae had the second largest with 3 species each (Table 5). The three families contributed; 44.39 %, 11.81 % and 0.23 % respectively of the total abundance of fish collected. Seventeen families were represented by one species each, among which only the Sillaginidae were represented by more than 1% of the total number of fish collected during the entire sampling period.

Table 6: Percentage biomass contribution by species in the forested and un-forested habitats

| species | site1 | site1 | site2 | site2 | site3 | site3 | site4 | site4 |
|---------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | F | UF | F | UF | F | Uf | F | UF |
| | % | % | % | % | % | % | % | % |
| <i>Acanthopagrus berda</i> | 0 | 0 | 0 | 0 | 38.72 | 2.95 | 0 | 0 |
| <i>Anchoviella commersonii</i> | 30.83 | 7.70 | 44.53 | 11.16 | 0 | 0 | 8.04 | 1.91 |
| <i>Apogon hyalosoma</i> | 0 | 0 | 0.19 | 0 | 0 | 0 | 0 | 0 |
| <i>Apolectus niger</i> | 0 | 0 | 0 | 0 | 14.54 | 0 | 0 | 0 |
| <i>Arothon immaculatus</i> | 0 | 0 | 0 | 0 | 8.15 | 0 | 0.03 | 0 |
| <i>Atherinidae spp.</i> | 0 | 0 | 0.32 | 2.07 | 0 | 0 | 0 | 0 |
| <i>Atherinomomus lacunosus</i> | 0 | 0 | 0 | 0 | 4.13 | 1.96 | 2.38 | 0.24 |
| <i>Bothus pantherinus</i> | 0 | 0 | 3.25 | 0 | 0 | 0 | 0 | 0 |
| <i>Caranx ignobilis</i> | 0 | 9.36 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Elops saurus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0.07 |
| <i>Epinephelus tauvina</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45.63 |
| <i>Gaza minuta</i> | 0 | 0 | 0 | 5.92 | 0 | 0 | 0 | 0 |
| <i>Gerres oyena</i> | 1.90 | 10.20 | 1.34 | 5.32 | 14.54 | 16.48 | 0.07 | 0.54 |
| <i>Gerres panctatus</i> | 6.43 | 5.70 | 2.27 | 0 | 0 | 5.11 | 1.61 | 0 |
| <i>Hermirhamphus far</i> | 0.85 | 1.94 | 0 | 1.52 | 0 | 18.40 | 1.44 | 0 |
| <i>Leognathus equula</i> | 9.50 | 0 | 0.16 | 12.55 | 0 | 33.57 | 2.75 | 9.66 |
| <i>Lethrinus harak</i> | 0 | 0 | 4.36 | 0 | 0 | 0 | 0 | 0 |
| <i>Lutjanus fulviflamma</i> | 0 | 36.60 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Macruwa kelee</i> | 0.52 | 1.71 | 0 | 0 | 0 | 0 | 1.41 | 0.20 |
| <i>Mugil cephalus</i> | 0.61 | 0 | 7.98 | 1.38 | 0 | 0 | 5.91 | 0 |
| <i>Pellona ditchella</i> | 0 | 0.34 | 0.92 | 1.04 | 0 | 0 | 3.73 | 34.22 |
| <i>platyphalus crocodysis</i> | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| <i>Pomadysis birocularis</i> | 0 | 0 | 0.35 | 0 | 0 | 0 | 0 | 0 |
| <i>Pomadysis maculatum</i> | 0 | 0 | 0 | 3.04 | 0 | 0 | 0.11 | 0 |
| <i>Pomadysis multimaculatum</i> | 0 | 0 | 0 | 0.35 | 0 | 0 | 0 | 0 |
| <i>Dasyatis pastinacus</i> | 23.29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Sardinella melanura</i> | 0 | 0 | 4.98 | 0.21 | 0 | 0 | 59.13 | 4.83 |
| <i>Sardinella spp.</i> | 0 | 0 | 0.27 | 0 | 0 | 0 | 0 | 0 |
| <i>Secutor insidiator</i> | 0 | 0 | 0.78 | 0.34 | 0.29 | 7.17 | 6.31 | 0.24 |
| <i>Silago sihama</i> | 21.84 | 26.44 | 17.78 | 18.24 | 11.82 | 14.37 | 5.68 | 1.36 |
| <i>Sphyraena jello</i> | 0 | 0 | 9.36 | 0.83 | 0 | 0 | 0 | 0 |
| <i>Saurida undosquamis</i> | 0.53 | 0 | 0.65 | 0.23 | 0 | 0 | 0 | 0 |
| <i>Therapon jarbua</i> | 1.06 | 0 | 0.49 | 1.54 | 7.82 | 0 | 0 | 0 |
| <i>Thrissocles malabaricus</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.44 |
| <i>upenaus sulphurus</i> | 2.65 | 0 | 0 | 34.27 | 0 | 0 | 1.15 | 0.67 |

4.1.5 Seasonal variation

Fish abundance varied greatly depending on season. Higher abundance was noted during the NEM season than the SEM season in the forested and un-forested sites. The highest number of fish was recorded in forested site 2 during the NEM season, followed by un-forested site 4 during NEM season. The lowest abundance was observed in un-forested site 1 during SEM season (Figure 8).

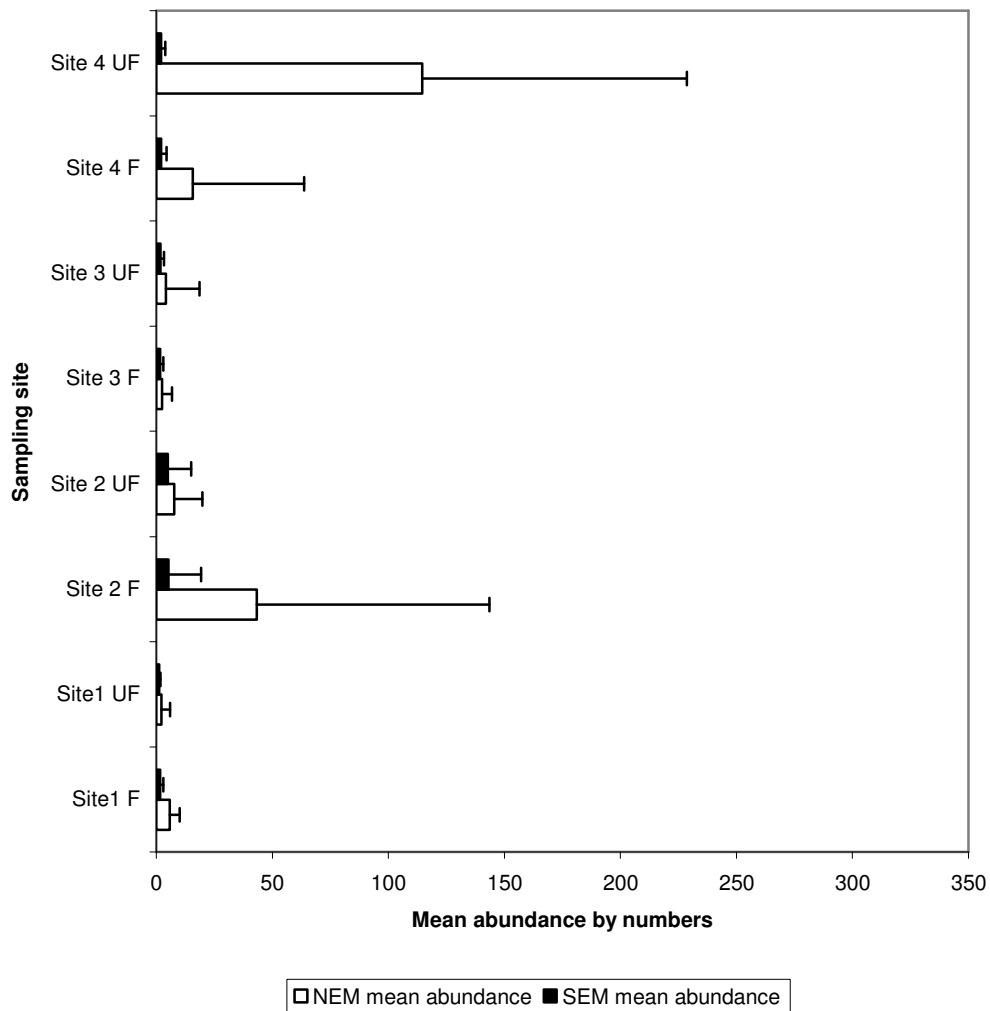


Figure 8: Mean abundance of fish during the northeast monsoon and southeast monsoon.

The number of fish species showed slight variations depending on season in the forested and un-forested sites during the study period (Appendix 1). The un-forested sites recorded 24 fish species during North East Monsoon (NEM) while 14 species were recorded in the un-forested sites during South East Monsoon (SEM). In the forested sites 22 fish species were recorded during the SEM and 20 during the NEM (Table 7). However forested sites had 11 species, which did not appear in the un-forested compared to 5 species, which were observed in the un-forested but not in the forested. In general, the most abundant species were common in all sites and seasons.

Pellona ditchella had the highest percentage (65.4 %) in the un-forested during NEM season, while *Anchoviella commersonii* topped the un-forested during the SEM with 39.5 %. In the forested, *Anchoviella commersonii* was the highest with 35.97 % during NEM season and consequently in the SEM with 41.67 %.

The abundance of fish between the two seasons was significantly different at $p < 0.05$ and $F = 7.40$. NEM had the highest mean abundance of 61.40 while SEM had 7.29. Forested and un-forested habitats had also significantly different fish abundances. Mean abundance in the forested sites was 8.18 and 65.05 during the SEM and NEM respectively while un-forested sites mean abundance was; SEM = 6.41 and NEM = 57.76 (Table 8).

Table 7: Fish species abundance during the North East Monsoon and South East Monsoon in the forested and un-forested.

| species | NEM(UF) | | SEM(UF) | | NEM(F) | | SEM(F) | |
|---------------------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| | Abundance | | Abundance | | Abundance | | Abundance | |
| | n | % | n | % | n | % | n | % |
| <i>Pellona ditchella</i> | 2019 | 65.40 | 2 | 1.92 | 22 | 1.69 | 22 | 12.22 |
| <i>Leognathus equula</i> | 417 | 13.51 | 15 | 14.42 | 13 | 1.00 | 11 | 6.11 |
| <i>Sardinella melanura</i> | 201 | 6.51 | — | — | 395 | 30.36 | — | — |
| <i>Gerres oyena</i> | 113 | 3.66 | 9 | 8.65 | 23 | 1.77 | 7 | 3.89 |
| <i>Anchoviella commersonii</i> | 112 | 3.63 | 39 | 37.50 | 468 | 35.97 | 75 | 41.67 |
| <i>Silago sihama</i> | 109 | 3.53 | 10 | 9.62 | 152 | 11.68 | 10 | 5.56 |
| <i>Gaza minuta</i> | 33 | 1.07 | — | — | — | — | — | — |
| <i>upenaus sulphurus</i> | 29 | 0.94 | — | — | 2 | 0.15 | — | — |
| <i>Secutor insidiator</i> | 12 | 0.39 | 3 | 2.88 | 44 | 3.38 | 4 | 2.22 |
| <i>Thrissocles malabaricus</i> | 10 | 0.32 | — | — | — | — | — | — |
| <i>Therapon jarbua</i> | 8 | 0.26 | — | — | 2 | 0.15 | 4 | 2.22 |
| <i>Mugil cephalus</i> | 5 | 0.16 | 2 | 1.92 | 118 | 9.07 | 5 | 2.78 |
| <i>Pomadysis maculatum</i> | 5 | 0.16 | — | — | 2 | 0.15 | — | — |
| <i>Atherinomomus lacunosus</i> | 2 | 0.06 | 3 | 2.88 | 19 | 1.46 | 8 | 4.44 |
| <i>Atherinidae spp.</i> | 2 | 0.06 | — | — | 1 | 0.08 | — | — |
| <i>Gerres punctatus</i> | 1 | 0.03 | 1 | 0.96 | 17 | 1.31 | 7 | 3.89 |
| <i>Hermirhamphus far</i> | 1 | 0.03 | 8 | 7.69 | — | — | 5 | 2.78 |
| <i>Macruwa kelee</i> | 1 | 0.03 | 2 | 1.92 | — | — | 4 | 2.22 |
| <i>Sphyaena jello</i> | 1 | 0.03 | — | — | 2 | 0.15 | — | — |
| <i>Caranx ignobilis</i> | 1 | 0.03 | — | — | — | — | — | — |
| <i>Acanthopagrus berda</i> | 1 | 0.03 | — | — | — | — | 1 | 0.56 |
| <i>Arothron immaculatus</i> | 1 | 0.03 | — | — | 2 | 0.15 | 1 | 0.56 |
| <i>Pomadysis multimaculatum</i> | 1 | 0.03 | — | — | — | — | — | — |
| <i>Epinephelus tauvina</i> | 1 | 0.03 | — | — | — | — | — | — |
| <i>Elops saurus</i> | — | — | 7 | 6.73 | — | — | 3 | 1.67 |
| <i>Saurida undosquamis</i> | — | — | 2 | 1.92 | 14 | 1.08 | 4 | 2.22 |
| <i>Lintianus fulufamma</i> | — | — | 1 | 0.96 | — | — | — | — |
| <i>Pomadysis birocularis</i> | — | — | — | — | 3 | 0.23 | — | — |
| <i>Sardinella spp.</i> | — | — | — | — | 1 | 0.08 | 1 | 0.56 |
| <i>Lethrinus harak</i> | — | — | — | — | 1 | 0.08 | — | — |
| <i>Apolectus niger</i> | — | — | — | — | — | — | 4 | 2.22 |
| <i>Ray fish</i> | — | — | — | — | — | — | 1 | 0.56 |
| <i>platyphalus crocodysis</i> | — | — | — | — | — | — | 1 | 0.56 |
| <i>Bothus pantherinus</i> | — | — | — | — | — | — | 1 | 0.56 |
| <i>Apogon hyalosoma</i> | — | — | — | — | — | — | 1 | 0.56 |

n Number of fish

NEM North east Monsoon

SEM South East Monsoon

Table 8: Means and ANOVA results of fish abundance in the forested and un-forested habitats in the two seasons

| Sites/ seasons | Mean total numbers | F-value | p-value |
|-------------------|----------------------------|---------|---------|
| Forested (SEM) | 8.18 ± 4.56 ^a | | |
| Forested (NEM) | 65.05 ± 32.78 ^b | 2.48 | <0.05 |
| Un-forested (NEM) | 57.76 ± 46.92 ^b | | |
| Un-forested (SEM) | 6.41 ± 3.75 ^a | | |

Means followed by different superscripts (^{a, b}) differ statistically at p<0.05

4. 2 Stomach Contents

4. 2.1 Food composition and feeding

Occurrence of different food items ingested by the ten selected species is shown in (Figure 9). *Mugil cephalus* had only one identifiable prey item (copepods) in the stomach despite having the second highest stomach fullness index (FI) of (6.73 %). Copepods were most eaten by almost all the fish species apart from *Gerres panctatus* that ate more nematodes (52.9 %). Gastropods were only identified in *Gaza minuta* (0.33 %). *Atherinimomus lacunosus* had only two prey items in the stomach (Aurelia spp 5.56 % and copepods (94.4 %) therefore showing the lowest diversity of prey together with *Mugil cephalus*. *Silago sihama* showed the highest percentage of decapods (45.9 %) in the stomach indicating that it is a piscivore.

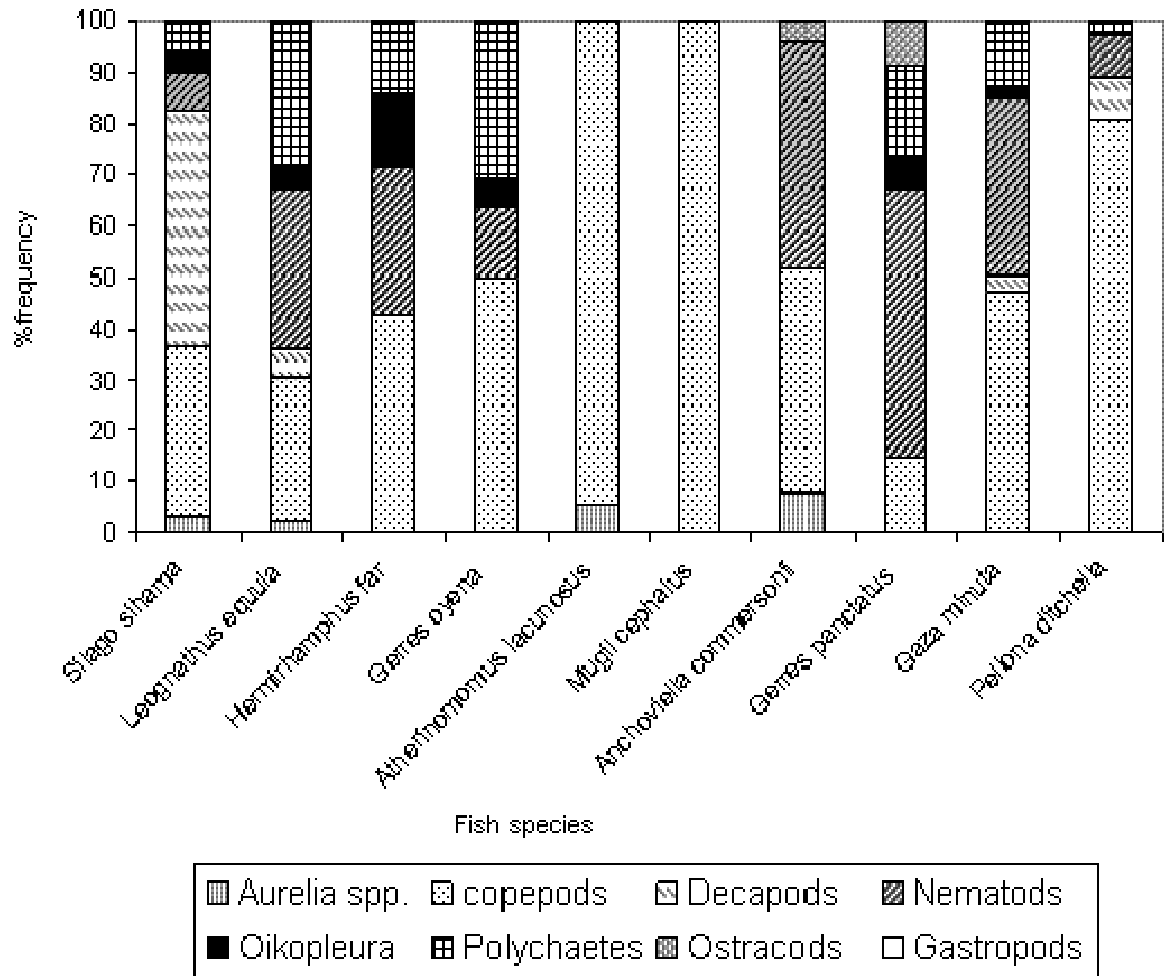


Figure 9: Proportion of prey items in the guts of fish sampled from the mangrove ecosystem

Gaza minuta had the highest stomach fullness index 7.74 % among the ten fish species, followed by *Mugil cephalus* with 6.73 % therefore indicating high intensity of feeding. The least stomach fullness index was noted in *Gerres punctatus* 1.38 % followed by *Gerres oyena* 2.51 % and *Silago sihama* 2.52 % (Figure 10).

From Figures 9 and 10, the ten fish species can be classified as planktivores (*Hermirhamphus far*, *Atherinomomus lacunosus* and *Mugil cephalus*), benthivores (*Gerres panctatus*, *Anchoviella commersonii*, and *Gerres oyena*), and piscivores (*Gaza minuta*, *Silago sihama*, *Pellona ditchella* and *Leognathus equula*).

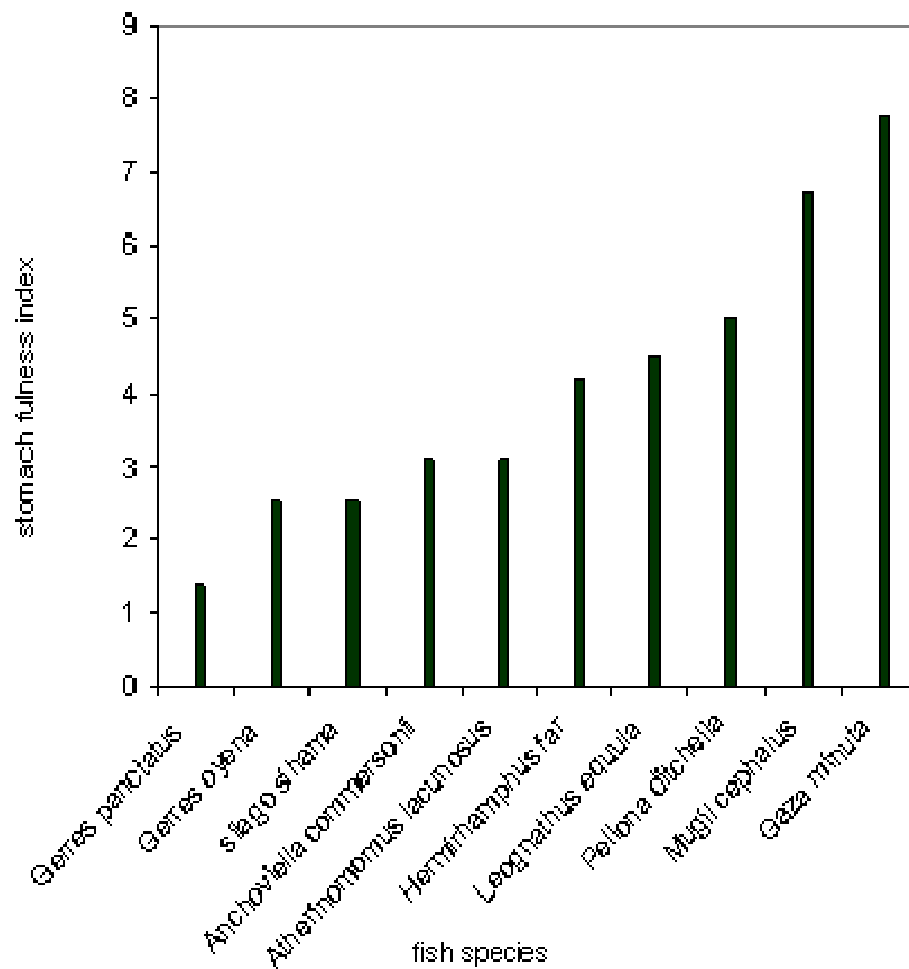


Figure 10: An overview of the stomach fullness index (FI) of fish caught in the mangrove ecosystem studied.

Percentage Frequency of Occurrence of prey items in all the 100 observed guts is shown in Figure 11. Copepods had the highest percentage (70 %) followed by nematodes (58 %) while the lowest occurrence was in Gastropods (2.0 %). Diet composition of prey items in the fish stomachs was also highest for copepods (45.16 %) and lowest for Gastropods (0.14 %) Figure 12. In this respect it implies that fish will be abundant in sites with high supply of the main food items (copepods, nematodes, polychaetes and decapods). Meaning that sites with less abundant prey items will make fish use a lot of energy to search for the same, therefore forcing them to abandon such sites. However most fish are opportunistic foragers. Fish feeding and food habits have been related to productivity of the marine ecosystem, which is determined by physical and chemical factors like organic matter.

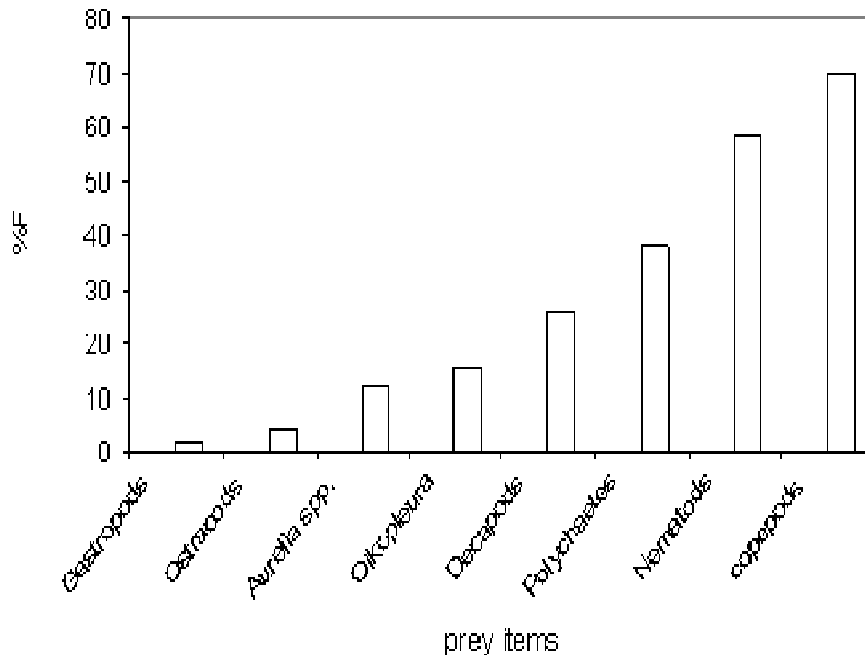


Figure 11: Percentage frequency of occurrence (%F) of each prey item in the fish stomachs

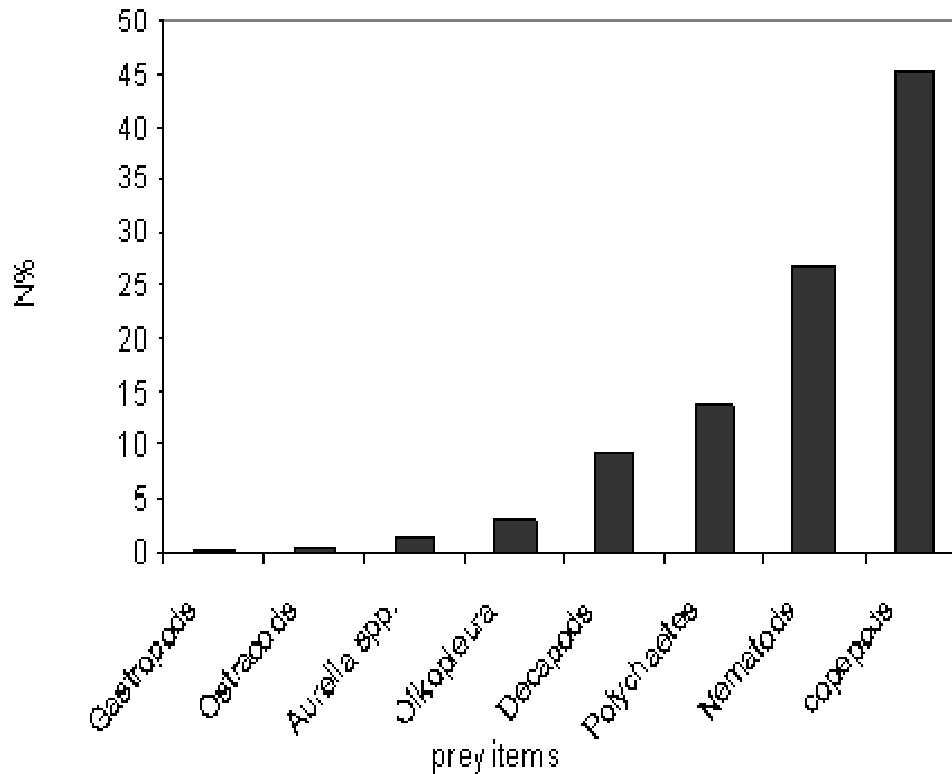


Figure 12: Diet composition of fish species analyzed for gut contents expressed as numerical abundance (N %).

4.3 Prey items

4.3.1 Water

In all the study sites, copepods showed the highest percentage as; 66.2 % in forested site 2 and lowest 23.2 % in forested site 4 (Appendix 2). Therefore, explaining the reason for fish abundance in the two sites respectively. Copepods were the most significant prey item in water followed by nematodes, polychaetes and oikopleura. Nematodes were highest in un-forested site 1, which also had the lowest fish abundance. Suggesting that fish do not necessarily visit sites only for feeding but for combined effects (breeding and escape). There was a high diversity of prey items in

water however some occurred in one or two places with very low percentage abundance such as bipinnaria 0.3 % only in un-forested site 4, foraminifera 2.1 % and 2.5 % in forested site 2 and un-forested site 2 respectively. Forested sites showed a higher percentage abundance of all the prey items observed which concurs with fish abundance. Figure 13 shows the percentage abundance of the prey items in the fish stomach as observed in water. The copepods contribute the highest percentage in all sites with the highest being in forested site 2 (74 %) that also had the highest fish density. In most prey items there is no clear boundary between their abundance in soft forested and un-forested with respect to hard forested and un-forested (Appendix 2).

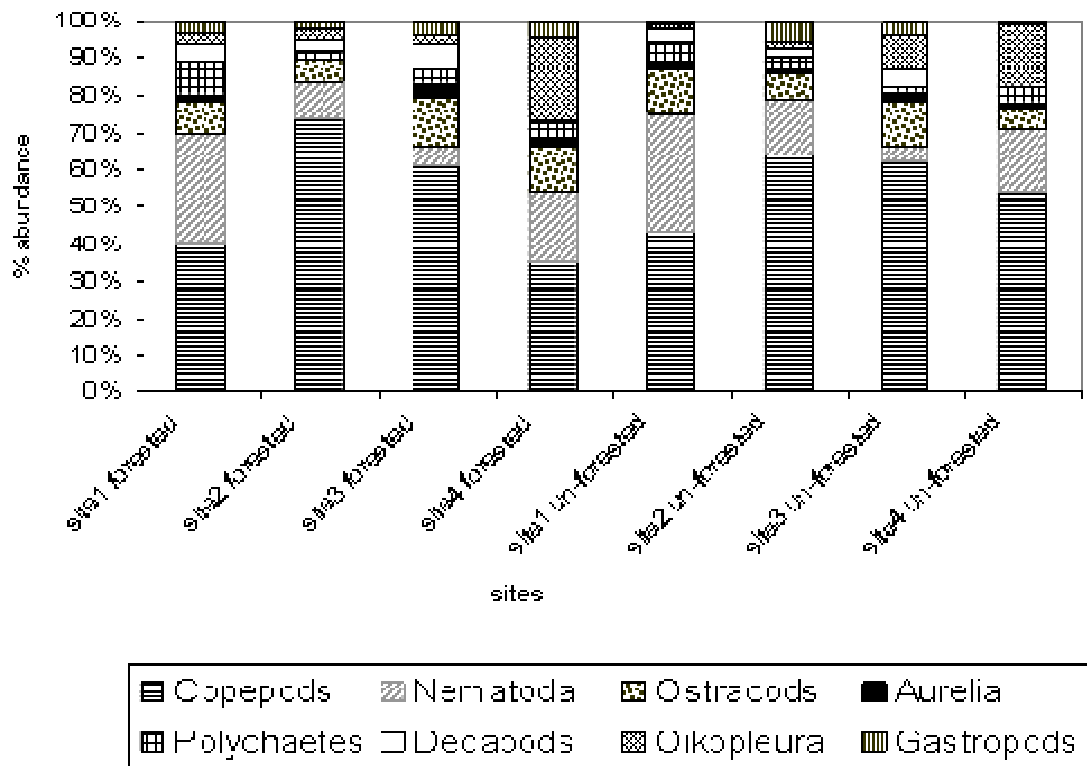


Figure 13: Abundance of prey items in fish stomach as reflected in the water environment of the study sites

4. 3.2 Sediments

The most abundant prey item was Nematodes in forested site 3 (54.7 %) which was also least in un-forested site 1 (16.8 %). Second most abundant prey item was polychaetes (45.2 %) in forested site 1 and lowest (13.4 %) in un-forested site 3. These observations indicate a smaller presence of prey items in forested than un-forested sites. This was also associated with a greater density of fish (appendix 3).

The summary of the prey items identified at different sediments is shown in figure 4. Gastropods were not identified in the sediments although present in water and therefore their low contribution in the fish stomachs contents. The diversity of the prey items was low in the sediments in relation with that observed in water. The results are evident that more contribution of fish prey is made by water mainly for none bottom feeders.

Soft-forested sites 2 and 4 have high abundance of nematodes and polychaetes compared to other sites (Appendix 3). Similar results are reflected in the soft un-forested sites 2 and 4 in relation to the hard forested and un-forested sites 1 and 3. Such results are also repeated for fish densities in the respective sites.

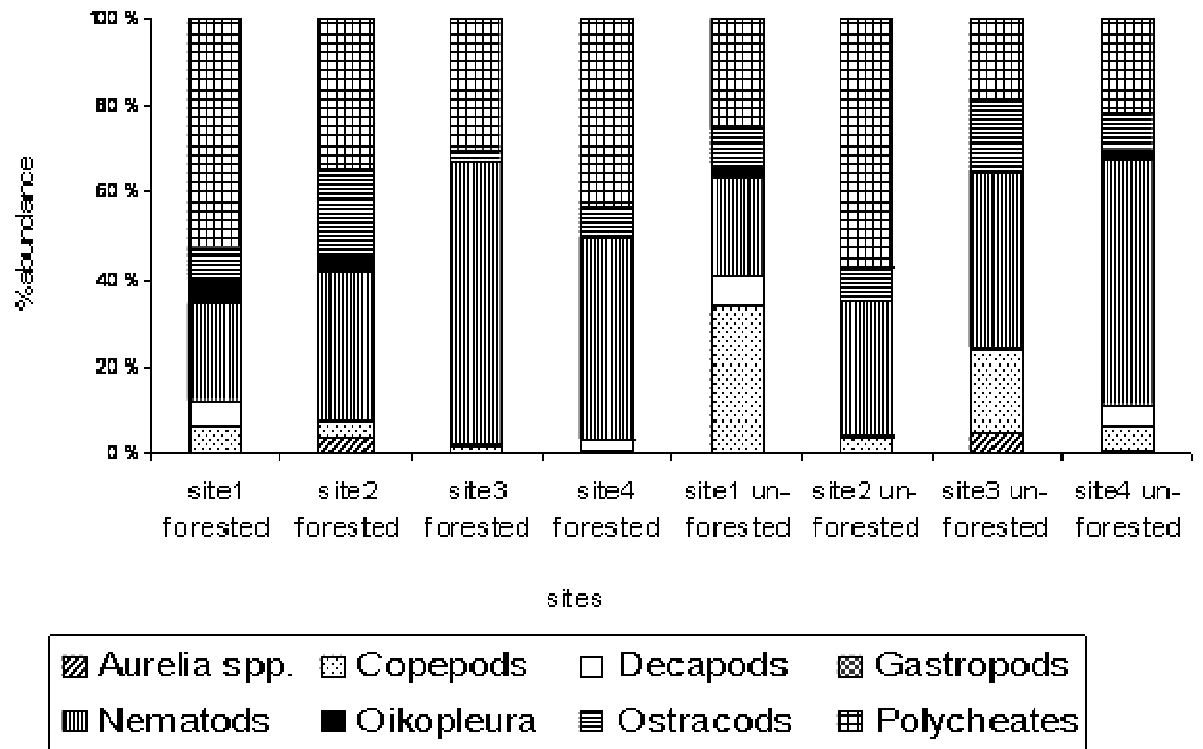


Figure14: Percentage abundance of prey items in fish stomach as reflected in the sediments of the study sites

The summary of meiofauna density in sediments is shown in Table 9 below. There were significant differences in density of meiofauna depending on substratum type. All forested sites had higher prey density that un-forested ones apart from site 4 where the results were inverted. In addition site 4 had the highest prey density compared to all the other sites while site 1 un-forested had the least prey density.

Table 9: Effect of mangrove forest cover and substratum type on meiofauna density (Individuals/m²)

| <i>Site</i> | <i>Density (Individuals/m²)</i> |
|--------------------|--|
| Site 1 forest | 2.73 ± 1.80 ^b |
| Site 1 un-forested | 1.07 ± 0.93 ^a |
| Site 2 forest | 4.00 ± 3.74 ^c |
| Site 2 un-forested | 2.91 ± 2.40 ^b |
| Site 3 forest | 3.92 ± 2.89 ^c |
| Site 3 un-forested | 2.49 ± 2.13 ^b |
| Site 4 forest | 3.78 ± 3.21 ^c |
| Site 4 un-forested | 5.29 ± 4.33 ^d |

Means followed by different superscripts (^{a, b, c, d}) differ statistically at p<0.05
 ± Standard deviation

CHAPTER FIVE

5.0 DISCUSSION

5.1: Fish diversity, abundance, density, composition, and seasonality

The number of fish species were highest in forested site 2 compared to all the other forested and un-forested sites. All forested sites had higher species richness than un-forested ones. Soft bottom substrate sites showed relatively higher species richness than the hard bottom substrate. This is explained by the more diverse microhabitats provided by mangrove forests and soft substratum (Ronnback *et al.*, 1999). Studies done by Robertson and Duke (1987) and Little *et al.*, (1988) indicated that although many species are represented in mangrove forest ecosystems, few are abundant. Site 4 forested and un-forested with soft bottom had the highest fish diversity. The results indicate that apart from the mangrove forest, bottom substrate also has a role in determining fish species diversity. This is because the soft substrates have a higher ability to retain nutrients than hard sandy substrates and therefore maintain a high meiofauna and macro-infauna that form a good source of food for the fish (Alongi, 1991). Further data on zooplankton abundance indicate that the distribution pattern of filter feeders is due to a higher abundance of zooplanktons in mangrove forests (Alongi, 1991). The copepods fed on by the fish were most abundant in mangrove forest habitats than un-forested ones.

There were noticeable differences in the fish assemblage in the eight study sites as indicated by species abundance. The mangrove forest sites were used more by the fish community unlike the un-forested sites. Higher fish abundance was recorded in

mangrove forests than un-forested sites. Similarly the bottom substrate types influenced fish abundance. The soft (muddy) bottom substrate was highly favoured by fish. The observation was associated with retention of litter within the mangrove forest that creates a food web base on detritus (Odum and Heald, 1975, Robertson *et al.*, 1992). In addition, the aspect of refuge from predation provided by shallow waters, high water turbidity, soft mud (suitable for burrowing) and the habitat complexity resulting from prop roots, pneumatophores and mangrove forest debris favour the sites as fish habitat. The importance of structural complexity in reducing predator efficiency is evident in the fish abundance results of the present study. However, the role of shelter function is species specific and depends upon the behaviour of the prey and the efficiency of the predator (Primavera, 1995). The long residence time of water in mangrove forest physically retains immigrating larvae and juveniles (Chong *et al.*, 1996) and thus supports fisheries production.

All the sites with calm waters had soft (muddy) substrate while those with strong waves had hard (sandy) bottom substrate. Fish abundance was higher in calm water sites. Calm waters in the mangrove forest (Blaber and Whitefield, 1978) reduce energy spent by the young fish to swim in the mangroves. Soft bottom substrate has high holding capacity for nutrients therefore supporting high primary production and fish prey abundance (Pessanha and Araujo, 2003). These characteristics favoured high fish abundance in the mangrove forests.

A high number of juvenile fish were recorded in all the forested sites compared to the un-forested sites indicating that most fish that visit mangrove forests are juveniles

possibly to feed or escape predation. However the mean length of fish caught was less than 10 cm in both forested and un-forested sites. This may be associated with depletion of the resource as a result of indiscriminate fishing and degradation of mangroves that act as nursery areas. Garcia and Viera (1997) compared fish assemblages of juveniles in Patos lagoon estuary, Brazil, and found that some species were more abundant in mangrove forest areas and others in un-vegetated areas. Romer (1990) similarly reported that in three beaches in the Algoa Bay, South Africa, 16 species were common at all sites. He attributed variations to a biotic variables, mainly wave influence. In some systems there is a strong tidal influence, with more species being present at low tide and higher abundance of dominant species at high tide (Gibson *et al.*, 1996). The effect of tide position did not appear an important environmental constraint for fish assemblages in the current study because they are sheltered areas and tides are not strong to have an effect on fish distribution.

Soft bottom substrate habitats showed higher fish density than the hard bottom substrate. Densities were higher among forest habitats than in un-forested habitats. Small fishes could gain predatory protection inside soft bottom substrate mangrove forest as indicated by their density. Un-forested site 4 had the highest density followed by forested site 2 which all have soft bottom substrate. The mean density of fish among the soft bottom forest was about twice that of hard bottom un-forested unlike hard bottom forested. Consequently, presence of mangrove forests had influence on determining fish density. The shift of fish abundance in site 4 where un-forested habitat had more than forested was mostly because one big sample of *Pellona ditchella* and one large *E. tauvina* were caught during the sampling process. Huxham *et. al.*, (2004) at

Gazi bay obtained higher fish abundance in un-forested mangrove sites which he associated to site specific conditions and mangrove reforestation after indiscriminate deforestation.

The abundance of benthic animals particularly (nematodes) shows a relative correlation between their occurrence and that of juvenile fish in the study site. Eight out of ten fish species analysed consumed nematodes. Abundance of nematodes was higher in the soft substrate mangrove forests compared to hard substrate mangrove sites.

Previous studies done in various parts of the world in mangrove forests recorded different fish densities (Table 10):

Table 10: Comparison of mangrove fish density studies done in different mangrove ecosystems in the world with the current study.

| Study site | Fish density (fish/m²) | Source |
|----------------------|---|-------------------------------|
| Ungwana bay | Forest: 0.20±0.19 - 2.67±2.13 Un-forest: 0.10±0.09 - 2.14±3.43 | Present study |
| Florida-USA | 8.0 | Thayer <i>et al.</i> , 1987 |
| Queensland-Australia | 0.27±0.14 | Morton, 1990 |
| Queensland-Australia | 3.5±2.4 | Robertson and Duke, 1990 |
| Florida-USA, | 5.9 | Sheridan, 1992 |
| Queensland-Australia | 0.04±0.01 | Halliday and Young, 1996 |
| Queensland-Australia | 0.83 | Vance <i>et al.</i> , 1996 |
| Luzon-Philippines | 5.1±2.0 | Ronnback <i>et al.</i> , 1999 |
| Gazi bay-Kenya | 0.21 | Huxham <i>et al.</i> , 2004 |

The density documented by Thayer *et al.*, (1987) and biomass by Morton (1990) was the highest recorded in any estuarine habitat. Studies done at Gazi bay (Huxham *et al.*, 2004) recorded the lowest fish densities in forested and un-forested mangrove habitats. In using method 1 (A 100-m-long X 3-m-wide net, of mesh size 18mm-enclosing an area of 625m²), he found mean density of 0.004 fish/ m² in forested habitats and 0.014 fish/ m² in cleared habitats while by using method 2 (two 24-m (+1m overlap to seal-long nets –mesh size 1mm-enclosing an area of 36m²), he obtained 0.21 fish/ m² and

0.25 fish/ m² respectively. In comparison with studies in literature, the results of the present study are relatively high in both forested and un-forested sites which can be associated to the thick mangrove forest in the bay and hence high productivity of the system.

In the present study a total of 29 species belonging to 20 families were identified as being associated to the mangrove forest while only 27 species were found in the un-forested sites. The difference in fish species richness is associated to the uniqueness of the habitats where by mangrove forest ecosystems have high nutrient supply and good protection for young fish against predation (Mangrove roots) than un-forested ecosystems. In studies done at Gazi Bay, 109 species of fish belonging to 44 families were identified as mangrove associated (Kimani *et al.*, 1996) while Huxham *et. al.*, (2004) in the same bay, obtained 30 species in total, 12 of which were found exclusively in forested habitats and 10 of which in cleared habitats. Little *et al.*, (1988) in Tudor creek found 83 fish species associated to the mangrove forest which could be associated to sampling method, time of sampling and site characteristics.

The strong difference's in species diversity in the study sites are associated to different factors; Studies done at Gazi bay by Kimani *et al.*, (1996) showed high diversity of fish but 37% of the fish caught were associated to coral reef so was 19.5% of those captured in Tudor creek. Further some samples at Gazi bay were taken close to sea grass beds hence had a poor representative of mangrove fish. Consequently the high diversity of fish in Gazi bay and Tudor creek unlike in the present study may be attributed to high deforestation rate of mangrove forest therefore changing the colonisation structure of

fish or differences in fishing density/ characteristics of sampling site. This might have eliminated the commercially viable fish species from the Gazi mangroves resulting in colonisation by less palatable species in large numbers. However, in the present study mangrove deforestation is at a lower scale, therefore the reason for low diversity but high abundance of commercially important fish species. This implies that mangrove degradation may lead to species diversity while vital species to the fisher community are decreased and hence ecosystem structure is changed.

Changes in the fish assemblages in the study sites were evident from differences in composition and abundance between the sites. The most dominant fish was *Pellona ditchella* with 44.16%, mainly found in site 2 and 4, followed by *Anchoviella commersonii* found in all sites apart from site 3. Huxham *et. al.*, (2004) found the most abundant species in mangrove forest to be *Atherina afra* although found only in two large catches and *Gerres oyena* in cleared sites but was frequent in samples. The presence of these two species in the present study indicates a strong link to the soft bottom substrate than the aspect of mangrove forest coverage. This is possibly as a result of high prey availability in the soft bottom substrates inclusive hibernation capabilities (Blaber and Blaber, 1980; Blaber, 1981; Cyrus and Blaber, 1987; Ronnback *et al.*, 1999). The results indicate high diversity of species in forested habitats compared to the un-forested ones. However the highest diversity is noted in the forested habitat with soft bottom substrates.

High organic matter in the mangroves seems to favour increasing primary and secondary production in the area since some fish species feed mainly on small benthic

organisms (Krishnamurthy *et al.*, 1984). The fish species also get in the mangrove forest, protection against predators, followed by low transparencies (Blaber and Blaber, 1980). Large piscivorous fishes are restricted to deeper waters; during the present study *E. tauvina* was captured in one of the sampling site. Absence of such big predators from the relatively shallow sampling sites may have attracted the high density of fish in the forested sites.

Differences in fish assemblage were observed between the sites with bottom substrate habitats having similar species equally with hard bottom sites. The fish species similarity folded along bottom substrate types irrespective of the degree of forest coverage. Site 1 and 3 showed strong species similarity with respect with their bottom substrate types (hard/sandy). Site 2 and 4 had a high similarity of species, which concur with the degree of bottom substrate characteristics (soft/silty). However only three assemblages are distinct in the study sites; Site 1 (1st grouping), site 3 (2nd grouping), then site 4 (3rd grouping) while site 2 tend to take sides with both of the two groupings. With respect to that, it implies that bottom substrate has a big role in determining species diversity rather than mangrove forest coverage.

Studies carried out by Mlay *et al.*, (2001) on sandy and muddy shores in Dar es Salaam showed that muddy shores had higher organic matter content than sandy shores. The muddy shores were also found to have highest species diversity, density and biomass of fauna. This was associated to their ability to retain water and therefore protect organisms from desiccation. Such results tie well with the present study where there is a higher density of fish and benthos in soft bottom sites than hard bottom substrate sites.

The utilization of the surf zones by large numbers of juvenile fish is certainly due to the presence of rich food resources in the form of zooplankton and the protection provided by the shallowness, turbidity and turbulence of these areas (Lasiak, 1986).

Study done by Pessanha and Araujo (2003) at Sepetiba bay-Brazil showed that muddy beaches play an important role as recruitment areas and rearing ground for some fish species unlike sandy beaches. This was linked with high organic loads in such areas, which favour increasing primary and secondary production, inclusive protection from predators due to low transparencies. It was found that a number of species were mostly associated with muddy beaches while others were linked to the sandy beaches. According to Clark *et al* (1996), transparency and the presence of emergent rock on the shore are good indicators of spatial variations in the surf zone fish community structure. In addition, transparency may have been acting as a proxy for other factors not measured at that time like food availability. However the present study has dealt with the aspect of food availability, which has been seen to be relatively abundant and diverse in soft bottom substrate sites compared to hard substrate sites. Hence implying that fish clusters are well linked with substrate types rather than the mangrove forest cover and indicating that fish diversity may be comparable between sites (sites 1, 3 and forested 2 have similar fish species).

The family Gobiidae dominated samples from mangrove estuaries with a soft substratum in the Solomon Islands (Blaber and Milton, 1990), Gerreidae, Clupeidae and Atherinidae dominated the Gazi fish community (Kimani *et al.*, 1996; Huxham *et al.*, 2004), in Tudor creek family Gobiidae dominated followed by Gerreidae and

Clupeidae (Little et al., 1988) .The present study was dominated by family Clupeidae that contributed 58.14% of the total fish sampled. The family Engraulidae dominated samples from the forested habitats while family Sillaginidae dominated those from un-forested habitats. This is explained through the fact that Bays normally present a variety of habitats at shoreline, which define the type of fish assemblages that inhabit these areas, and variations among sites inside a Bay are greater than variations among different bays in tropical zones. The changing features of these habitats and the mobility of juvenile fish greatly influence the composition of the fish assemblages. Changes in certain physical variables such as the degree of wave exposure, sediment particle size and turbidity have a strong influence on the relative abundance of certain species and may alter the composition and species richness of fish assemblages (Hillman *et al.*, 1977).

The coastal waters of Kenya are influenced by two alternating seasons; namely, the southerly and northerly monsoons (Newell, 1957; Brakel, 1982). Circulation of coastal waters of East Africa is strongly influenced by these winds. Increases in fish abundance and biomass in all sites (forested and un-forested) occurred in North East Monsoon (NEM) season (Appendix 1). The same situation applies to the number of species recorded during the two seasons. These observations might be attributable to migration of small calm-water species (Day *et al.*, 1981) into the creek from rough offshore waters. The NEM season is characterised by low temperatures, low salinity, weak up welling and short rains in November and December. Therefore these are some of the attributes, which favour fish abundance in the bay understudy as it is situated in northern Kenya unlike the SEM (Wiese *et al.*, 1994). In addition northern Kenya coast

has nutrient rich water and greater predominance of planktonic productivity (Brakel, 1982; Baars *et al.*, 1991). The SEM is also characterised by high temperatures, high salinity, strong up-welling and high mixing capability which leads to nutrient mixing thus a likelihood of more fish (Wiese *et al.*, 1994). However the south coast is dominated by coral reefs and benthic productivity associated with low nutrient water (Ohowa *et al.*, 1997; Woitchik *et al.*, 1997). Nyaga (unpublished report) indicate more fish in the south coast during SEM than NEM season. Therefore implying that NEM season winds increase fish in the North Coast while SEM winds increase fish production in South Coast respectively.

5.2: Food and feeding habits

The study of fish stomach contents is a common way of investigating the food web in marine biological communities. Food availability is recognised as the main factor regulating growth, abundance and migration patterns of fish. However fewer studies have been done on the use of feeding habits as an indicator of habitat variability in the western Indian Ocean region (Nyunja *et al.*, 2002). Fish feeding and food habits have been related to productivity of the marine ecosystem, which is determined by physical and chemical factors. These factors are derived from anthropogenic activities like deforestation of mangrove forests and bottom substrate change.

From the results on stomach analysis of the ten species observed (*S. sihama*, *L. equula*, *H. far*, *G. oyena*, *A. lacunosus*, *M. ditchella*, *A. commersonii*, *G. panctatus*, and *G. minuta*) it can be deduced that copepods constitute the most abundant food item. Despite the fact that polychaetes are larger and do constitute one of the food items, their

occurrence is very low, probably due to their main occurrence in sediments other than water column. The ten fish species are both planktivores and benthivores, hence they were able to utilise the available food resource adequately resulting in very high fullness indices compared to those obtained at Mtwapa creek and Wasini channel (Nyunja *et al.*, 2002). Benthic organisms tend to be larger in size than planktonic organisms. Fish feeding on a larger portion of benthic organisms tend to have a high stomach fullness index than those feeding mostly on planktonic organisms (Nyunja *et al.*, 2002). These appear to concur with two species (*L. equula* and *G. minuta*) in present study. Wakwabi (1999) indicated that stomach fullness indices closely reflected seasonal changes in feeding. However most fish fed with some rhythm (Sawara and Azuma, 1992) therefore it was not possible to fully identify the feeding cycles. The stomach fullness index was associated with high water transparency that made it easier for both species, which are mainly visual feeders (Major 1977) to locate their prey. It has been noted that visual predators pursue the prey item that appears largest at the start of the search (O, Brien *et al.*, 1976). High transparency is as a result of low water turbulence because the area is sheltered.

Nematodes are the second most important food item however it does not occur in all the ten fish species. This suggests that it is only preferred when there is no alternative feed. Gastropods were only identified in *Gaza minuta* with a very small percentage, suggesting that it was probably ingested accidentally with other food material.

At Ngomeni where this study was conducted, the copepods had a higher percentage frequency of occurrence and abundance than all the other prey items. Indicating that,

fish were selecting more copepods than the other prey items. The overall dominance of copepods in the stomach contents of the ten fish species was attributed to the relative abundance of copepods in the environment.

Tropical fish in coastal water are acknowledged to be generalists, as they have to cope with a seasonally changing environment (Lowe McConnell, 1991). The present study shows that the investigated fishes foraged on a wide variety of organisms with a high level of inter- and intraspecific dietary overlaps. Most fish species employed rather opportunistic feeding strategies, taking wide prey spectra. Prey diversification has somewhat diffuse competition within the species (Austen *et al.*, 1994).

Opportunistic feeders have versatile diets and feeding behaviour. They can take preys that are not in their usual diets, and can also feed from habitats strange to their normal foraging grounds. Larkin (1956) observed that many fish species have a relatively wide tolerance to habitat types, flexibility in feeding habits, and generally share many resources in their environment with several other species. Most fish are therefore general feeders taking advantage of the available resources but not compromising the costs/benefits of the diet (Gerking, 1994). According to Diamond (1978), a species may have a greater range of diet or foraging techniques in the absence of competition. The above observations clearly show that habitat variability can affect predator behaviour as well as prey availability resulting in habitat specific foraging strategies.

Clupeids have long been recognised as opportunistic foragers that feed on suitable food as encountered (Koslow, 1981; James, 1988). This habit results in flexible feeding

cycles that depend on local conditions. Laboratory and field data indicate that intermediate microphages (*S. gibbosa* and *A. lacunosus*) display a high degree of opportunism in fulfilling their dietary requirements (Koslow, 1981). They are energy maximisers, capable of alternating their feeding strategies to use the available trophic spectrum efficiently. It has been commonly recognised that the diets of these fish reflect the composition of the ambient plankton communities (Koslow 1981, James 1988, 1987). From the foregoing, it can be concluded that the ten species under investigation are generalists and opportunistic feeders.

5.3: Prey items

Water planktonic samples were dominated by copepod in all sites with the highest percentage abundance noted in site 2. Higher abundances were evident in soft substrate bottoms than the hard bottom substrate sites. Second in rank were the nematodes followed by polychaetes. Temporal variations in distribution and abundance of marine fish species is influenced both by changes in structural complexity of the mangrove forest habitats and by the variations in recruitment of planktonic larvae. Ley *et al.*, (1999) found out that rooty mangrove areas provide refugia and food to juvenile and adult fish. Since the copepods and nematodes are the main food items in the fish stomachs it is evident that the fish were visiting the habitats for feeding purposes in addition to other benefits. Site 2 forest had the highest fish density and biomass equally with copepod abundance. Therefore there is an indication of a strong relationship between fish and prey abundance. Studies done elsewhere indicate that differences in productivity and food availability between habitats as a result of presence or absence of

mangrove vegetation influences the distribution and feeding activities of fish (Robertson and Duke, 1987).

Unlike water samples, sediment samples from all sites were dominated by nematodes and followed by polychaetes. Copepods were relatively less abundant in all study sites. No gastropods were identified in the sediments. Forested and un-forested soft bottom sites seemed to have equitable distribution of the main fish prey items indicating that substrate type influence prey abundance. The density of meiofauna was significantly high in forested sites with soft substratum. This was seen to tally well with the fish density from the sites (site 4 un-forested had the highest fish density and prey density while site one un-forested had the least fish density and prey density). Alongi (1991) found high density of meiofauna (polychaetes and nematodes) in intertidal mudbanks. The high nematode and polychaete abundance in the sediments signify their importance in the fish stomach and hence fish abundance in the sites. More fish density and biomass was obtained in the soft bottom forested mangrove sites which links well with the availability of prey items. Studies done indicate that extensive mangrove vegetation and mud banks surround Mtwapa creek creating micro-habitats that support dense populations of micro and macro-fauna at both benthic (Ruwa, 1990) and Planktonic levels (Osore, 1994). One notable attribute of mangroves is high net primary productivity compared to other aquatic ecosystems. This production results in high leaf and litter fall that forms the basis for the detritus food web for microbes, molluscs, crabs and fish. They also bind roots and sediments creating a stable habitat for burrowing organisms. In this regard mangrove forests are considered important in fishery production due to rich planktonic and benthic food supply.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Young fish utilize mangrove forests during high tides therefore requiring extensive mangrove cover for high fisheries production. This is supported by the high density of small-sized fish community in the mangrove forest habitat unlike their un-forested counterparts. Hence an extensive mangrove cover is necessary as feeding, nursery and protection sites for fish and hence fisheries protection.

Soft bottom mangrove substrates support high fish density and biomass unlike the hard bottom substrate. Soft bottom substrate is postulated to hold high nutrient levels to support primary and secondary production and also reduce vision of predators. Combination of forest and soft substratum provided the highest fish density and diversity while the un-forested and hard substratum had the least fish diversity and biomass. Since organic matter levels tend to influence sediment composition and type, it is logical that mangrove forest coverage has a big role to play in determining sediment type and hence fish abundance.

Assemblage of fish species is influenced by substratum type rather than mangrove forest coverage. There was a high similarity of fish species in forested and un-forested sites with same substratum type unlike in sites with different substrates and both having forest cover.

The substratum type influence abundance of prey items where by soft substratum have highest prey abundance than hard substratum ones. There was greater variation of prey items diversity and density with substratum type rather than forest coverage (same substrate type hard similar prey abundance and diversity).

Fish species utilised the partial and nutritional resources of the environment variably. Utilization of the detritus by some fish like *Gerres spp* allowed them to take advantage of an abundant food resource in the benthic zone while minimising competition with planktivores and piscivores. Spatial and temporal differences in the prey items consumed, shows how habitat variability, and therefore food availability affects the food types consumed by the fish.

6.2 RECOMMENDATIONS

Holistic mangrove ecosystem utilization policy should be developed to ensure sustainable fishery production in our oceans. Keen interest and management attention to be given to mud substrate mangrove ecosystem since they support a high abundance and diversity of marine fishery as evidenced from the present study. In due respect mangrove conservation be given a key approach so as to maintain high fish recruitment and hence catches. This is necessary because mangrove forest cover is directly proportional to fish abundance/productivity.

Reafforestation of mangrove forests is vital in degraded areas to restore the original ecosystem that is necessary for fisheries production. The mangrove forest coverage will increase fish species diversity and abundance.

I recommend more work related to the present one to be carried out in order: (1) To have the exact picture of the productivity of Ungwana bay fisheries in relation to mangrove forest productivity (2) To come up with a value of how much fish can be associated to one hectare of mangroves in Kenya and investigation of how far fish caught in mangrove forest move offshore.

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8.0 APPENDICES

Appendix 1: Species abundance (n) in the forested (F) and un-forested (UF) for the eight sampling sites (1,2,3 ,4) during South East Monsoon (SEM) and North East Monsoon (NEM).

| species | SEM | NEM | SEM | NEM | SEM | NEM | SEM | NEM | NEM | SEM | NEM | SEM | NEM | SEM | NEM | SEM | NEM |
|---------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|-----|
| | site1UF (n) | site1UF (n) | site2UF (n) | site2UF (n) | site3UF (n) | site3UF (n) | site4UF (n) | site4UF (n) | site1F (n) | site1F (n) | site2F (n) | site2F (n) | site3F (n) | site3F (n) | site4F (n) | site4F (n) | |
| <i>Acanthopagrus berda</i> | — | — | — | — | — | 1 | — | — | — | — | — | — | — | — | 1 | — | — |
| <i>Anchoiella commersonii</i> | 3 | 2 | 39 | 2 | — | — | — | 108 | 39 | 6 | 416 | 66 | — | — | 13 | 3 | — |
| <i>Apogon hyalosoma</i> | — | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — |
| <i>Apogon niger</i> | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 4 | — | — |
| <i>Arthon immaculatus</i> | — | — | — | — | — | — | — | 1 | — | — | — | — | 1 | 1 | 1 | — | — |
| <i>Atherinidae spp.</i> | — | — | — | 2 | — | — | — | — | — | — | 1 | — | — | — | — | — | — |
| <i>Atherinonotus laucosus</i> | — | — | — | — | — | 2 | 3 | — | — | — | — | — | 19 | 3 | — | — | 5 |
| <i>Bathus pantherinus</i> | — | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — |
| <i>Caranx ignobilis</i> | — | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| <i>Dasyatis pastinacus</i> | — | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — |
| <i>Elaps saurus</i> | — | — | — | — | — | — | 7 | — | — | — | — | — | — | — | — | — | 3 |
| <i>Epinephelus taumina</i> | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — | — | — | — |
| <i>Gaza minuta</i> | — | — | — | 33 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| <i>Gerres oyna</i> | — | 3 | 4 | 25 | 5 | 72 | — | 9 | 3 | — | 19 | — | — | 7 | 1 | — | — |
| <i>Gerres pandatus</i> | — | 1 | — | — | 1 | — | — | — | 2 | 1 | 15 | 5 | — | — | — | — | 1 |
| <i>Hemirhamphus far</i> | 1 | — | — | 1 | 3 | — | 4 | — | — | 1 | — | — | — | — | — | — | 4 |
| <i>Leognathus equula</i> | — | — | 10 | 42 | 5 | 2 | — | 366 | 2 | — | 2 | — | — | — | — | 9 | 11 |
| <i>Lethrinus hark</i> | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — | — |
| <i>Lutjanus fulvimanus</i> | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| <i>Macrurus kelee</i> | 2 | — | — | — | — | — | 2 | 1 | — | 2 | — | — | — | — | — | — | 2 |
| <i>Mugi cephalus</i> | — | — | — | 4 | — | — | 2 | 1 | — | 1 | 118 | 3 | — | — | — | — | 1 |
| <i>Pellona dtichella</i> | — | 1 | 1 | — | — | — | 1 | 2018 | — | — | — | 18 | — | — | — | 22 | 4 |
| <i>platyphalus crocodylus</i> | — | — | — | — | — | — | — | — | — | — | — | 1 | — | — | — | — | — |
| <i>Pomadasys bicocularis</i> | — | — | — | — | — | — | — | — | — | — | 3 | — | — | — | — | — | — |
| <i>Pomadasys maculatum</i> | — | — | — | 3 | — | — | — | 2 | — | — | — | — | — | — | — | 2 | — |
| <i>Pomadasys multimaculatum</i> | — | — | — | 1 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| <i>Sardinella melanura</i> | — | — | — | 3 | — | — | — | 198 | — | — | 180 | — | — | — | — | 215 | — |
| <i>Sardinella spp.</i> | — | — | — | — | — | — | — | — | — | — | 1 | 1 | — | — | — | — | — |
| <i>Saurida unobscuamnis</i> | — | — | 2 | — | — | — | — | — | 6 | — | 8 | 4 | — | — | — | — | — |
| <i>Scutor insidator</i> | — | — | 1 | — | 2 | — | — | 12 | — | — | — | 4 | 4 | — | 40 | — | — |
| <i>Slago sihana</i> | 1 | 17 | 5 | 27 | 1 | 2 | 3 | 7 | 51 | 5 | 92 | 1 | 9 | 3 | — | — | 1 |
| <i>Sphyrana jello</i> | — | — | — | 1 | — | — | — | — | — | — | 2 | — | — | — | — | — | — |
| <i>Therapon jarbua</i> | — | — | — | 8 | — | — | — | — | — | 4 | 1 | — | 1 | — | — | — | — |
| <i>Thriassodes malabaricus</i> | — | — | — | — | — | — | — | 10 | — | — | — | — | — | — | — | — | — |
| <i>upeneus sulphurus</i> | — | — | — | 23 | — | — | — | 6 | 1 | — | — | — | — | — | — | 1 | — |

Appendix 2: Percentage abundance of Zooplanktons in the water from the eight study sites (1,2,3,4 –forested and un-forested).

| Zooplanktons | site1 forested | site2 forested | site3 forested | site4 forested | site1 unforested | site2 unforested | site3 unforested | site4 unforested |
|--------------|----------------|----------------|----------------|----------------|------------------|------------------|------------------|------------------|
| Copepods | 324 | 662 | 579 | 232 | 328 | 528 | 58 | 428 |
| Haracariidae | 169 | 04 | 09 | 14.7 | 20 | 04 | 39 | 1.7 |
| Nematoda | 233 | 9 | 46 | 12 | 24.7 | 122 | 39 | 133 |
| Ostracods | 68 | 53 | 128 | 82 | 87 | 55 | 11.4 | 48 |
| Obelia | 1.7 | 04 | 0 | 182 | 1.7 | 0 | 1.1 | 181 |
| Aurelia | 14 | 02 | 37 | 1.4 | 1.2 | 1.1 | 21 | 1 |
| Polychaetes | 7.1 | 2 | 28 | 24 | 48 | 25 | 1.4 | 35 |
| Auricularia | 1.9 | 63 | 37 | 0.9 | 1.2 | 10.1 | 1.6 | 0.2 |
| Decapods | 35 | 23 | 68 | 0.4 | 26 | 1.9 | 39 | 0.1 |
| Clapcleura | 25 | 29 | 22 | 14.5 | 0.8 | 1.7 | 89 | 129 |
| Tubellaria | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 0 | 0.5 |
| Gastropods | 27 | 2 | 39 | 31 | 0.9 | 4.6 | 36 | 0.9 |
| Diddium | 0 | 1 | 0.8 | 0.4 | 0 | 4.6 | 0 | 0.2 |
| Foraminifera | 0 | 21 | 0 | 0 | 0 | 25 | 0 | 0 |
| Elpimaria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 |

Appendix 3: Percentage abundance of Meiofauna in sediments from the eight study sites (1,2,3,4 –forested and un-forested).

| Meiofauna | site1 forested | site2 forested | site3 forested | site4 forested | site1 unforested | site2 unforested | site3 unforested | site4 unforested |
|--------------|----------------|----------------|----------------|----------------|------------------|------------------|------------------|------------------|
| Copepods | 58 | 28 | 1.4 | 0.4 | 253 | 27 | 134 | 4.7 |
| Amphipods | 7.1 | 158 | 11.6 | 1.1 | 253 | 11.3 | 81 | 28 |
| Polychaetes | 452 | 231 | 253 | 359 | 189 | 426 | 134 | 168 |
| Nematods | 187 | 231 | 54.7 | 389 | 168 | 23 | 29 | 44.5 |
| Ostracods | 58 | 136 | 24 | 56 | 63 | 59 | 121 | 65 |
| Clapcleura | 52 | 26 | 0 | 0.7 | 21 | 0 | 0 | 1.4 |
| Oligochaetes | 65 | 11.4 | 38 | 127 | 0 | 132 | 199 | 149 |
| Bryozoa | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aureliaspp | 0 | 26 | 0 | 0 | 0 | 0 | 36 | 0.5 |
| Decapods | 45 | 0 | 0.5 | 22 | 53 | 0.5 | 0.7 | 33 |
| Obelia | 1.3 | 1.5 | 0 | 1.9 | 0 | 0.7 | 0 | 33 |
| Foraminifera | 0 | 0 | 0.3 | 0.6 | 0 | 0 | 0 | 1.4 |