A study of fish community structure and distribution in the River Sabaki estuary, Kenya

By

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Declaration

This thesis is my original work and has not been presented for a degree in any other university.

Signed.. Date 14/4/2004

Kimakwa Edward Wafula

This thesis has been submitted for examination with our approval as University supervisors.

Signed:.. Date 14 April 2004

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Signed:.. Date 04 March 2005

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LIST OF ABBREVIATIONS AND ACRONYMS

CBD	Convention on Biological Diversity
Chl-a	Chlorophyll a
Cm	Centimetres
CORDIO	Coral Reef Degradation in the Indian Ocean
CPUE	Catch per Unit of Effort
DPM	Directorate of Personnel Management
EACC	East African Coastal Current
EEZ	Exclusive Economic Zone
EFN	Education for Nature
FAO	Food and Agriculture Organization of the United Nations
FD	Fisheries Department
Fig.	Figure
GEF	Global Environment Facility
ITCZ	Inter-Tropical Convergence Zone
IUCN	World Conservation Union
KEMFRI	Kenya Marine and Fisheries Research Institute
Km	Kilometres
Km^2	Square kilometres
Ksh.	Kenya Shilling
L	Litre
Ln	Natural Logarithm
m	Metres
m^3	Cubic metres
mg	Milligram
MSY	Maximum Sustainable Yield
mt	Metric tons
NEM	North-eastern Monsoon
NMK	National Museums of Kenya
^oC	Degrees centigrade
ppt	parts per thousand
R^2	Coefficient of determination
SEACAM	Secretariat for Eastern African Coastal Area Management
SEM	South-eastern Monsoon
TSS	Total Suspended Sediments
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Scientific & Cultural Organization
USA	United States of America
V	Volume
WRI	World Resources Institute
WWF	World Wildlife Fund for Nature

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DEDICATION

To my beloved wife Ruth for her moral support and encouragement, and our lovely children, Sammy and Mercy, for their patience especially when I was away at the Kenyan coast.

ABSTRACT

Fish was sampled within the Sabaki River estuary for a period of 6 months (January to June 2003) on monthly basis, during the last quarter of the lunar cycle (neap tide) at low water tide. The physico-chemical parameters investigated included rainfall, temperature, salinity, water transparency, total suspended sediments (TSS) and chlorophyll a (Chl-a) concentrations. The broad objective of this study was to investigate environmental gradients and how they influence seasonal and spatial variation in fish community structure and distribution in the River Sabaki estuary. This was tested against the hypothesis that estuarine hydrodynamics significantly influenced fish communities at the estuary and adjacent coastal waters. The study area was divided in to 5 zones designated SBK0, SBK1, SBK2, SBK3 and SBK4, based on salinity gradient. Each stratum was sampled independently and data pooled to give overall results. Data on rainfall was obtained from Malindi meteorological station, a standard mercury thermometer was used to measure temperature, salinity was determined using a hand held refractometer and a 30 cm diameter secchi disk was used to estimate water transparency. Total suspended sediments (TSS) concentration in the water was determined using gravimetric methods as described by Strickland *et. al.* (1972) and Mudroch and Macknight (1994). Water samples were filtered through oven-dried and pre-weighed GF/C glass micro-fibre filters. The filters and sample were dried to a constant weight. The dry weight of TSS was then estimated. Chlorophyll a (Chl – a) concentration in the water samples was determined using spectrophotometric method as described by Parsons *et. al.* (1989). Water samples were passed through GF/F glass micro-fibre filters. The filters were placed in stoppered glass tubes and centrifuged in 10 ml 90% Acetone (Analyzer grade). The supernatant was decanted and extinctions measured in 650 *nm*, 664 *nm*, 647 *nm* and 630 *nm* wavelengths using a zeroed spectrophotometer. Fish samples were collected by seining using nets of 10 mm and 20 mm knot –knot mesh sizes, measuring 2 m deep and 45 m long. Two hauls of 15 minutes each were made at each sampling station. Fish collected was identified to species level where possible. Multivariate analysis of variance (MANOVA), multiple regression analysis, F- test, t-test, Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) were performed on the data sets to test for any significant differences between the parameters. Results showed that January to March were dry. Rainfall peaked in May (22.1 mm). March recorded the highest mean water temperature, 36.5 °C while highest mean air temperature was in April, 34.04 °C. Salinity gradient was observed. SBK0 recorded the highest mean salinity levels, 4.43 ‰, significantly differing from others ($P < 0.05$). The difference in spatial variation in TSS was not significant ($P > 0.2$). Highest amount of TSS was recorded in the Mid stations, 0.334 mg/l – 0.335 mg/l. Mean TSS concentration between the dry and wet seasons was significantly different ($t = 0.208$, $F = 4.87$, $P < 0.05$). May recorded highest TSS levels, 0.52 mg/l while lowest in March, 0.063 mg/l. Highest amounts of Chl–a was recorded in June, 226.4 mg/l and lowest was in March, 29.33 mg/l. The difference in spatial variation in Chl-a was significant. SBK1 had the highest levels, 107 mg/l. A total of 10,807 individuals of fish and crustaceans were caught in the sample. This represented 35 species, 25 families and 7 orders of fish; and 6 species, 3 families and 1 order of crustaceans. *Arius africanus* was the most dominant species, contributing 38.9% of the fish sampled, closely followed by *Valamugil buchanani* and *Mugil cephalus* with 14.9% and 14.6%, respectively. The difference in the number of fish species caught during the dry and wet season was significant (F = 49.3, t = 5.2). An average of 13 species were observed in the dry season compared to 26 in the wet season. High species richness was experienced in the fresh water and marine zones, 29 and 26, respectively. The brackish zones recorded 17 – 20 species. Fish catch rates significantly varied between the dry and wet seasons (F = 38.4, t = 4.82). March recorded the highest catch rates, 245.4 g/hr while lowest in May, 26.8 g/hr. Fish abundance varied among sites. Fish was more abundant in SBK0, 259.17 g/hr and lowest in SBK4, 60.44 g/hr. Fish catch rates negatively correlated with rainfall (R^2 = 0.26) and TSS concentrations (R^2 = 0.85), and positively correlating with water transparency (R^2 = 0.88) and salinity (R^2 = 0.346). Based on the similarity in sharing freshwater and seawater gradient, fish communities in the estuary can be classified as fresh water, sedentary and migrants. Monte Carlo Permutation test show that physico-chemical parameters investigated contributed to 50% of the observed variation in the fish community structure in this estuary. Water temperature, rainfall, TSS and water transparency accounted for most of the observed variations, 42%. The study reveals that fish assemblages in this estuary resulted from spatial and temporal variations in hydrodynamics exhibiting a gradient of physical and biological factors from adjacent open sea waters and upstream. Therefore it can be concluded that estuarine hydrodynamics significantly influenced fish community structure and distribution in the estuary and adjacent coastal waters.

Key words: Estuary, environment, fish, community, structure, species, distribution, conservation

CHAPTER ONE

1.0 INTRODUCTION

The Kenyan coastline is approximately 640 Km long with a continental shelf area of about 8,500 Km^2. While most of the shelf area in Kenya lies within 3-8 km, it extends to 64 Km in the northern bank and Ungwana Bay. Reefs are typified by a fringing reef located 100-2000 m from the shore (Obura, 1995). Reefs to the southern region consist mostly patch or rock Islands that are frequently circular (McClanahan & Arthur, 2001). Kenya has a vast area of 12 nautical miles of territorial waters and 200 nautical miles of the Exclusive Economic Zone (EEZ) whose resources are least exploited (Fisheries Department, 2002).

The coastal zone occupies a relatively small part of the oceans but contains complex habitats, including low lying river plains, estuaries and deltas, lagoons and creeks, beaches, salt marshes, rocky shores, mangroves, drowned shelves, shelf edges and parts of continental slopes. Coastal zone is, "the intertidal and subtidal areas above the continental shelf (up to a depth of 200 m) and adjacent land area up to 100 Km inland from the coast", (WRI, 2000). The Secretariat for Eastern African Coastal Area Management (SEACAM, 1999) defines a coastal zone as, "the interface between land and ocean, and encompasses the shoreline and components of the adjacent ocean and terrestrial environment". In the context of this study, therefore, a coastal zone is defined as the area from the EEZ towards the land to the inner edge of the coastal plain where the influences of tides are replaced by continental hydrological processes.

Coastal areas form a critical interface between terrestrial and marine ecosystems. They control anthropogenic and terrestrial fluxes and fates of physico-chemical and biological products to and from the open ocean (Heip *et. al.*, 1995). About 40% of the world's population lives within 100 Km of coastline, an area accounting for about 22% of the landmass (WRI, 2000). Oceans on the other hand cover 70% of the planet Earth.

Coastal ecosystems in Kenya are of prime importance to economic growth and conservation. Marine parks and reserves protect marine life, and are therefore important for biodiversity conservation (World Wildlife Fund (WWF), 2001; Kemf *et. al.*, 2001; UNEP, 1984; WRI, 2000; IUCN, 1992; Richmond, 1997). They also generate revenue for local population and the country (Heip *et. al.*, 1995; WRI, 2000), through park entry fees, boat operators, hoteliers, sale of handicrafts to tourists, sport fishing and surfing.

The system of reefs and sea grass beds on the Kenyan shore is interrupted in a number of places by rivers, especially the Tana and Galana-Sabaki. These two major rivers originate on the volcanic highlands around Mount Kenya and Aberdare Ranges (Whitehead, 1960).

It is widely recognized that estuaries are ecologically important as indispensable nursery, feeding and breeding sites as well as refugia for diverse marine and fresh water species (WRI, 2000; SEACAM, 1999). An estuary is " the transition zone along which the quality of water changes from that of fresh water, characteristic of inland river water, to that of saline water characteristic of open sea water" (Wilson *et. al.*, 1985). It has also been defined as, "a semi-enclosed coastal body of water, which has a free connection with the open sea and within which seawater, is measurably diluted with fresh water derived from land drainage" (Day *et. al.*, 1989). It can be visualized as an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors; a marine or lower estuary with free connection to the open sea; a middle estuary subject to strong salt and fresh water mixing; and an upper or fluvial zone, characterized by fresh water but subject to daily tidal action. The limits between these sectors are variable, and subject to constant changes in the river discharge (Day *et. al.*, 1989). Therefore, in this study, the estuary is defined as a semi-enclosed coastal body of water having a free connection with the open sea and fresh water derived from land drainage in which sea water is measurably diluted with fresh water (adapted from Day *et. al.*, 1989)

This thesis describes research work undertaken in the Sabaki River estuary, Malindi, Kenya, between October 2002 and June 2003. The broad objective of this study was to investigate environmental gradients and how they influence seasonal and spatial variation in fish community structure and distribution in the River Sabaki estuary. Krebs (1999) defines a community as, "a group of populations of plants and animals in a given place". Begon *et. al.* (1996) describes a community as, " an assemblage of species or populations which occur together in space and time". Southwood (1978) described a community as, "an organized body of individuals in a specified location". A community from these three definitions is made up of interacting individuals within defined boundaries.

Ecological surveys of this nature characteristically collect relative information. In other words, they can only detect change in an ecological community if prior data exists. In this study, sites, seasons and physico-chemical parameters were used as a basis for comparison and a means of detecting change in the estuarine fish communities. Any differences observed were attributed to above factors but this data cannot claim that they were the only causes of the observed differences in the fish species composition, community structure and distribution. Such conclusive statements would require data collected over a longer time, which proved difficult due to lack of resources. However, in the context of the present study, the data do provide a comprehensive assessment of the fish assemblages at the Sabaki estuary, illustrating some of the major ecological and environmental factors influencing their structure, relative abundance and distribution.

The findings of this study will contribute to better understanding of factors influencing estuarine fish diversity and production in Kenya with a view to ensuring their sustainable utilization, management and conservation. Further, the study will also provide essential information for further research.

1.1 PROBLEM STATEMENT

The Sabaki River estuary and the adjacent coastal ecosystems are important for biodiversity conservation and socio-economic development. However, they are highly threatened by both natural and anthropogenic factors such as siltation, pollution, eutrophication, use of illegal fishing methods, unsustainable utilization and physical developments (McClanahan & Obura, 1995; McClanahan, 1988). Furthermore, data on marine fish stock is inadequate.

Various land-based sources of pollution and activities affecting marine environment have been identified (FAO, 2000). However, interactions between the offshore and coastal areas, and the impact of seasonal changes on these interactions are unknown. For instance, the effects of siltation on marine and coastal biodiversity in Kenya is least studied (Heip *et. al.,* 1995; Obura, 1995)

Availability of information and data on the distribution of habitat types are lacking for most areas except for coral reefs and mangroves (WRI, 2000). The ichthyofauna of the Sabaki estuary and adjacent coastal waters is also poorly studied (IUCN, 1992; De Vos *et. al*., 2000). Our knowledge of the fish community occurring in the Sabaki estuary is still rudimentary.

1.2 LITERATURE REVIEW

1.2.1 Ecological and socio-economic importance of coastal ecosystems

Estuaries are highly variable ecosystems where environmental gradients such as salinity, turbidity, temperature, water currents and dissolved oxygen fluctuate both in time and space (Whitefield, 1992).

Estuaries are breeding grounds for many marine species, namely the sea turtles, fish, crustaceans and other invertebrates such as lobsters and oysters (WWF, 2001). They are also home for migratory birds and wildlife. WWF (2001) further reports that inshore waters of Eastern African Marine Eco-region (EAME) support about 1,000 different sea weeds, several hundreds of sponge species, over 200 coral species, more than 3,000 species of mollusks (oysters, cockles, mussels and clams), over 300 species of crabs, at least 50 species of starfishes, over 100 species of sea cucumbers and more than 1,500 species of fish. WWF further reports that 15% of the eastern Africa marine fish is endemic to the region.

The Malindi and Watamu Marine Parks and Reserves are important conservation areas for marine life and biodiversity (McClanahan & Shafir, 1990; McClanahan & Mutere, 1994; McClanahan & Obura, 1995). They also generate income for local communities and the country. The effects of protection are not just restricted to the abundance of big commercial fishes but also include a number of other non-commercial aspects of the reef ecology.

The contribution of fish and fishery products to protein consumed globally has been recognized. Statistics show that fish and fishery products contribute a significant proportion of the total dietary animal protein requirements (Kenya Fisheries Department, 2002). Williams (1996) reports that fish provides about 19% of animal protein requirement. FAO (1999) indicate that global catch of marine fishery appears to have reached a plateau of about 90 Million metric tons per year in the 1990s and this trend is likely to continue. Williams (1996) observed that global fish supply is increasingly becoming scarce. Over 60% of the world's major fish stocks are depleted or overexploited (Williams, 1996). McGinn (1998a) estimates that 11 of the world's 15 major fishing grounds have reached or exceeded maximum sustainable yields (MSY).

According to the statistics from Fisheries Department (2002), Kenya's fish production has fluctuated between 25,000 Metric tons – 200,000 Metric tons in the years 1967 – 2000, respectively. In the year 2000, about 202, 639 Metric tons of fish valued Ksh.7, 963,768,000 to fishermen were landed. Lake Victoria contributed over 95%, while only 2.3% came from marine waters. In 1998, the total marine catch reached 6,332 Metric tons valued at Ksh.318, 608, 000 to fishers. The catches dropped to 5,271 Metric tons valued Ksh.315, 437,000 in 1999. This further dropped to 4,763 Metric tons valued Ksh.284, 198,000 in the year 2000. The decline in fish catches in the past few years have been associated with several factors, namely, decline in nutrient levels (Kenya Fisheries Department, 2000), over exploitation, habitat degradation (WRI, 2000; Kenya Fisheries Department, 2002).

Malindi area is rich in marine fishery (Kenya Fisheries Department, 2002). Shrimps and prawns is highly valued commercial fishery. The fishery, mainly artisanal, supports a considerable number of fishermen who rely on fishing for their livelihood security. Currently, there are about 1200 fishermen in Malindi District (Kenya Fisheries Department, 2002). They employ different types of fishing gears; gillnets, cast nets, shark nets, hand lines, long lines and local traps. Sardines form an important fishery among the coastal people. Fisheries statistics from the area indicate that sardines contributed about 8% of marine fish landings while mullets and milkfish contributed 7.5% and 1.3%, respectively (Kenya Fisheries Department, 1999).

As human population grows, fisheries production from natural sources will continue to decline. This is because of the need to exploit more resources to meet the increased human population demand, which may result to depletion of resources if done unsustainably. Aquaculture has been viewed as an alternative. McGin (1998b) reports that farmed fish production increased from 12.4 Million tons in 1990 to 23 Million tons in 1996 globally, however, this trend is not the same for Kenya. Aquaculture in Kenya is not well developed, contributes less than 1% of the national fish production (Kenya Fisheries Department, 2002).

1.2.2 Land-based activities affecting coastal habitats

Marine pollution, eutrophication (inshore and offshore), sedimentation and silting of coastal ecosystems are identified as major ecological drawbacks in marine biodiversity conservation (UNESCO, 1992; WRI, 2000).

East African coast and other countries within the Western Indian Ocean region are cited for the increasing damage to the coastal environments, resulting from poor land use practices in the drainage basins of coastal rivers (Obura, 1995).

The catchment areas for Sabaki River are characterized by high rainfall, dense human population and intensive agriculture. Livestock keeping is an important economic activity in the arid and semi-arid lands (ASALS). Therefore, intensive cultivation, vegetation clearing and livestock grazing (Obura, 1995; Katwijk *et. al*., 1993) make the soil more vulnerable to erosion. Destruction of mangrove forests has increased riverbank erosion leading to widening of the river channel (Giesen *et. al*., 1984). The total amount of terrigenous material has increased considerably (Giesen *et. al*., 1984; Keech, 1980) since the 1960s.

The Sabaki River discharges a considerable amount of sediments in to the Indian Ocean, with estimated annual deposition of 58,000 tons before 1960 (Watermeyer *et. al*., 1981). The discharge rate may amount to 5,000 m^3/s during the rainy season and 20 m^3/s in the dry period (Delft Hydraulics, 1970). Kitheka (2002) reported daily sediment loading ranging from 5.3 to 8,771 tons/day, peaking in May with an average of 140,000 tons/day in the Malindi – Ungwana Bay. Water flow is intermittent with flooding becoming a common occurrence. The silt load and subsequent discharge to the sea will continue to increase year in, year out. Kenya is characterized by seasonal, usually unpredictable and erratic rainfall in the ASALs (Tiffen. *et. al*., 1994). Blom (1985) reported that silt together with agrochemicals, is carried in river runoff to inshore environments.

Disruption of coastal and marine ecosystems through siltation is envisaged to cause a slump in the tourism and fishery sector and deprive local people of their livelihood. The effects of sedimentation or silt on the reefs are visible, through the expansion of the sea-grass beds and reduction of the corals near the mouth of Sabaki River at Malindi. In Malindi area, beaches have been expanded but with dirty muddy sediments (Waning & Hafkenscheid, 1983; Giesen & Van der Kerkhof, 1984; Samoilys, 1988; IUCN, 1992).

Obura (1995) studied the effects of sediments on coral recruitment within the Malindi-Watamu ecosystem and showed that sediments had negative effects on the corals although the species were affected differently. Lewis *et. al.* (1998) conducted a similar study at Taa Reef, Tanzania, and found that sediment levels played a significant role in coral recruitment. They further showed that sedimentation rates were negatively correlated to water transparency. According to Oyieke and Oyugi (2001) and McClanahan and Obura (1995) death of corals occurred due to global warming and siltation, subsequently leading to coral bleaching phenomenon. IUCN (1992) further reports that sediments smother corals, obscure light and hinder the settling of coral larvae.

Coral reef ecosystems are rich in marine life (Souter *et. al.*; 2000). While studying the effect of marine protected areas on the adjacent coral fisheries, McClanahan and Arthur (2001) reported that silt discharged to the sea had impacted negatively on the ecology of these habitats.

The effect of siltation on marine and coastal biodiversity in Kenya is least studied (Heip *et. al*., 1995; Obura, 1995) and there exist a lot of information gaps (WRI, 2000). Unsustainable land use and poor soil conservation practices in the hinterland have been identified as the major causes of siltation (McClanahan & Obura, 1995). At present there is very little data on river discharge of sediments to the sea (Lasserre, 1992; Obura, 1995; FAO, 1999).

1.2.3 Factors influencing the distribution of marine organisms

Bayne (1985) underscores the need for detailed knowledge in understanding the range and distribution of species as influenced by different environmental stressors. Availability of information and data on the distribution of habitat types are lacking for most areas except for coral reefs and mangroves (WRI, 2000). Lasserre (1992) identified four principle gradients of species distribution, namely, depth, salinity, nutrient and latitude. In several coastal regions, marine organisms encountered local gradients of decreasing or increasing salinity. However, Lasserre (1992) reports that for most groups of organisms, the pattern is simply not known because of lack of comparative data.

Studies of seasonality in the biological systems have been restricted to planktonic systems, benthic algae, rocky shores and marine fisheries (McClanahan, 1988). McClanahan (1988) further notes that the data available on factors affecting distribution of fish communities and coastal ecosystems is inadequate. Very little work has been done towards understanding the estuarine fish communities and seasonality in the tropics (Day *et. al*., 1989). Wakwabi (1981) reports that identification of marine/coastal fish species has not been successful due to lack of proper taxonomic features, especially where only colouration has been used as the major distinguishing feature.

Lasserre (1992) observes that assessment of marine and coastal biodiversity has been neglected. He notes that estuaries and other brackish habitats typically have low species diversity, however, they are highly productive. They support dense populations of some species. There are potential colonizing organisms that are highly adaptive to estuarine environment.

The fishery of the Sabaki estuary is poorly studied (IUCN, 1992; De Vos *et. al.*, 2000) apart from some work done by Whitehead (1960) who described some of the species inhabiting the Lower Athi-Sabaki River. These studies, however, overlooked the ecological factors and related attributes on the fishery. Obura (1995) and Katwijik *et. al.* (1993) studied the effects of River Sabaki sediments on the adjacent corals. These studies revealed that sediments smothered corals, obscured light, and prevented the settling of coral larvae. The extent of injury varied among species. Ohowa (1997) investigated nutrient fluxes in the Sabaki estuary. These studies showed that concentration of nitrates, orthophosphates and silicates exhibited a linear decrease with increasing salinity.

Wahby and Bishara (1981), studied the effect of siltation of the Nile River, and established that silt aggregated at the mouth spreading hundreds of kilometers from the point of discharge. The River Nile is considered the chief source of sediments to the Mediterranean Sea where about 57 million tons are deposited annually (Shukry, 1950). Bishara's study showed that phytoplankton production increased by about 3 - 8 times in the deeper waters. The construction of the Aswan High Dam led to less water discharge into the Mediterranean Sea resulting in the reduction in sardine fish production. Total catch from the Mediterranean area decreased from 37, 832.2 tons in 1962 (before dam construction) to 13, 586.3 tons (after dam construction). FAO (1995) reported that those mostly affected were the *Sardinella spp* and shrimp catches. The composition of fish catch changed after the construction of the Aswan Dam (FAO, 1995; Wahby & Bishara, 1981). There was enrichment in fish species, which consisted of the neritics mixed with deep-sea species and some Red Sea migrants. The rise in salinity allowed a shift in the neritic habitat closer to the coast and created more favourable conditions for the Red Sea species. Species such as *Scomberomorus commerson, Sphyraena chrysotaenia* and *Leiognathus klunzingeri* extended nearer to the coast (Al-Kholy & El-Wakeel, 1975). The other species whose abundance reduced included the sardines (Clupeidae), mullets (Mugilidae), sole (Cynoclossidae), morone (Muraenidae) and sciaena (Sciaenidae).

Direct relations between river discharge and fishery yields in estuarine environments have been demonstrated in a number of studies. Day *et. al.* (1989) reported the existence of a strong correlation between river discharge and commercial fish landings in the estuaries of Mexican Gulf, a phenomenon also described in the San Francisco Bay (Rozengurt & Herz, 1985). A positive correlation between discharge and fish landings was found by Sutcliffe (1972) in the Gulf of St. Lawrence. Grimes and Finucane (1991) suggested that accumulation of food (mainly zooplanktons) along the Mississippi plume front could be a factor favouring food intake and growth

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The biogeographic patterns of marine flora and fauna are the product of geological history of oceans and continents (Lasserre, 1992). They give an illustration of interactive and interdependent processes. The interrelationships are necessary for the survival of individual species and populations of coastal and marine life.

While studying the distribution of marine echinoderms and decapods, O'Hara and Poore (2000) established that species composition varied with latitude and longitude. They also observed that the area of continental shelf or average species range size did not affect species richness. The investigations were limited to the shallow-waters (0-100 m) marine waters off Southern Australia. This area lacked major rivers and, consequently, the carbonate sediments covered most of the continental shelves. The study described the shallow- water marine biota of Southern Australia to be endemic.

Rijkswaterstaat (1985) reports that studies conducted at the EMS Dollard estuary in the Netherlands showed a strong relationship between fish species distribution and the composition, and structure of sediments, the mean salinity, salinity fluctuations and the level of sediments, food availability, influence of currents and waves as well as oxygen concentrations. Species under investigation, mainly meiobenthos, representing the major taxa of nematodes, copepods, oligochaeta, turbellaria, ostracoda and harpacticoid. The study further observed that the effect of lower silt concentration resulted in an increase in primary production. Consequently, this led to higher biomass of the pelagic diatoms but not the flagellates. Effects on the other groups were small with the exception of the mesozooplankton. Higher production of detritus was seen to be an indirect effect of the sedimentation process brought about by the mortality of phytoplankton and or excretion. These increased the export of organic carbon to the sea. On the other hand benthic suspension feeders were stimulated by the lower silt content of the water. The study, therefore, concluded that inorganic particulate matter concentration (silt) in the estuary had a strong influence on the fish community.

Baretta and Ruardij (1988) explained that silt influenced biological systems of the EMS estuary in three major ways. First, they serve as carriers of particulate carbon, second, the amount of silt determines the light penetration into the water thus influencing primary production, and, third, it modifies the food uptake of benthic suspension feeders.

Riddle (1985) conducted a study on the Wyre estuary, in Lancashire in the United Kingdom. The survey consisted of sampling five fixed stations between the Wyre Light and Shard Bridges. At each sampling time, instruments were used to measure current velocity and direction, salinity, temperature, dissolved oxygen and pH. Additionally, water samples were taken for analysis to determine dissolved oxygen and nutrients. The survey covered tidal ranges from neaps to spring and a wide range of fresh water flows. The study results recorded salinity difference from surface to bottom as 0.1‰. Low dissolved oxygen levels were recorded in the middle reaches of the estuary. The scope of the study was limited to effluent discharge as an environmental stress factor and was particularly applied in modelling. This did not consider the biological processes.

Middleburg *et. al.* (1995) showed that nutrient concentration for coastal sediments was very low. The study conducted at Gazi Bay, Kenya, showed that ammonia ranged from 3-390 *u*m, nitrate from 1-50 *u*m, nitrite from <0.1 *u*m to 2.3 *u*m, and Phosphate from <0.05 *u*m to 1 *u*m. Further, the results indicated that the major components, sulphate and chloride, showed considerable variability related to salinity fluctuations, ranging from 12 *u*m to 68 *u*m and 210 *u*m to 1125 *u*m, respectively.

Mangrove forests have significant effects on the sediments. Middleburg *et. al.* (1995) found that the forests regulate Carbon dioxide fluxes, sediment grain sizes, sedimentary organic carbon, nitrogen and phosphorous contents, and pore water characteristics. The study further revealed that mangroves affected the acid - base balance of mangrove sediments. Mangroves can acidify the sediments through the oxygen translocation from their leaves to roots and subsequently leaking to the sediments.

Habitat degradation unless checked will have adverse ecological and economic implications to biodiversity, fisheries and tourism. These sectors are crucial to the economy of Kenya and the eastern Africa region. Therefore, the proposed study will make a solid contribution to the current local, national, regional and international initiatives towards conservation and sustainable management of coastal ecosystems in Kenya.

1.3 JUSTIFICATION

Coastal ecosystems, including estuaries are important for ecological and socio-economic values, namely the Malindi-Watamu Marine Parks and Reserves (McClanahan & Shafir, 1990; McClanahan & Obura, 1995; McClanahan & Mutere, 1994). Ungwana and Malindi bays provide fishing grounds, supporting over 1,200 fishermen (Fisheries Department, 2002).

Lack of information on coastal and marine fisheries resources makes it difficult in planning for their effective management. Knowledge on the status of fish stocks, catch rates, species composition as well as their distribution is crucial for developing effective strategies for their sustainable exploitation and management.

Although Whitehead (1960) described some of the species inhabiting the Lower Athi-Sabaki River, this work, however, was only limited to species listing. It overlooked the ecological factors and related attributes on the fishery. Environmental parameters influence the occurrence, abundance and survival of different species in a given habitat.

The effects of habitat degradation will have ecological and economic consequences in terms of biodiversity loss, decline in fishery and the collapse of the tourism industry. These sectors are crucial to the economy of Kenya and the eastern Africa region. This, therefore, underscored the need for detailed knowledge in understanding the range and distribution of fish species as influenced by different environmental factors.

Therefore, the proposed study will make a contribution to the ichthyological knowledge and inventory of fish species occurring in the estuary and adjacent coastal waters. The data gathered will enhance information base for policy formulation and development of effective strategies for sustainable utilization and conservation of fisheries.

1.4 HYPOTHESIS

The study sought to test the hypothesis that estuarine hydrodynamics influenced fish communities at the estuary and adjacent coastal waters.

1.5 STUDY OBJECTIVES

1.5.1 Broad objective

The broad objective of the study was to provide evidence that estuarine environmental gradients alter spatial/seasonal distribution, composition and abundance of fish at the River Sabaki estuary and adjacent coastal waters.

1.5.2 Specific objectives

Specific objectives of the study were to;

i) Characterize seasonal variation of the physico-chemical properties of water within the Sabaki River estuary and its adjacent marine areas.

ii) Identify the ichthyofauna of the River Sabaki estuary and adjacent coastal waters.

iii) Investigate the effect of biotic and abiotic factors on fish species distribution, composition and relative abundance in the estuary.

CHAPTER TWO

2.0 MATERIALS AND METHODS

2.1 Study area

The study was limited to the Sabaki River estuary, about 10 Km, north of Malindi town and about 130 Km north of Mombasa Island (Fig. 1). The estuary is situated within latitudes 3^{o} 06'S and 40^{o} 05'E. The estuary is relatively short extending about 2.4 Km upstream. The estuary bottom is basically composed of silt and mud indicating high level of deposition. It is a shallow water body, about 1.5 m deep on average.

The Sabaki River (commonly referred to as Athi/Galana/Sabaki) originates on the eastern slopes of the Aberdare Mountains and northern slopes of Mount Kilimanjaro, with a catchment area of about 70,000 Km^2 . The river runs over 500 Km and discharges its waters in to the Indian Ocean, about 10 km north of Malindi town (Ohowa, 1997).

The upper system of the river drains hilly areas characterized by high rainfall. The lower course (Galana/Sabaki) traverses arid and semi-arid lands (ASALS) characterized by scarce, unpredictable and erratic rainfall. The Tsavo River, a major tributary of the Sabaki drains a permanent spring deriving its waters from rainfall on Chyulu Hills and snowmelt on Mount Kilimanjaro. River discharge at the mouth varies with seasons. Flash floods are a common phenomenon during the rainy seasons, particularly from inland drainage. The weather elements combine to give the study area a hot arid and semi arid climate.

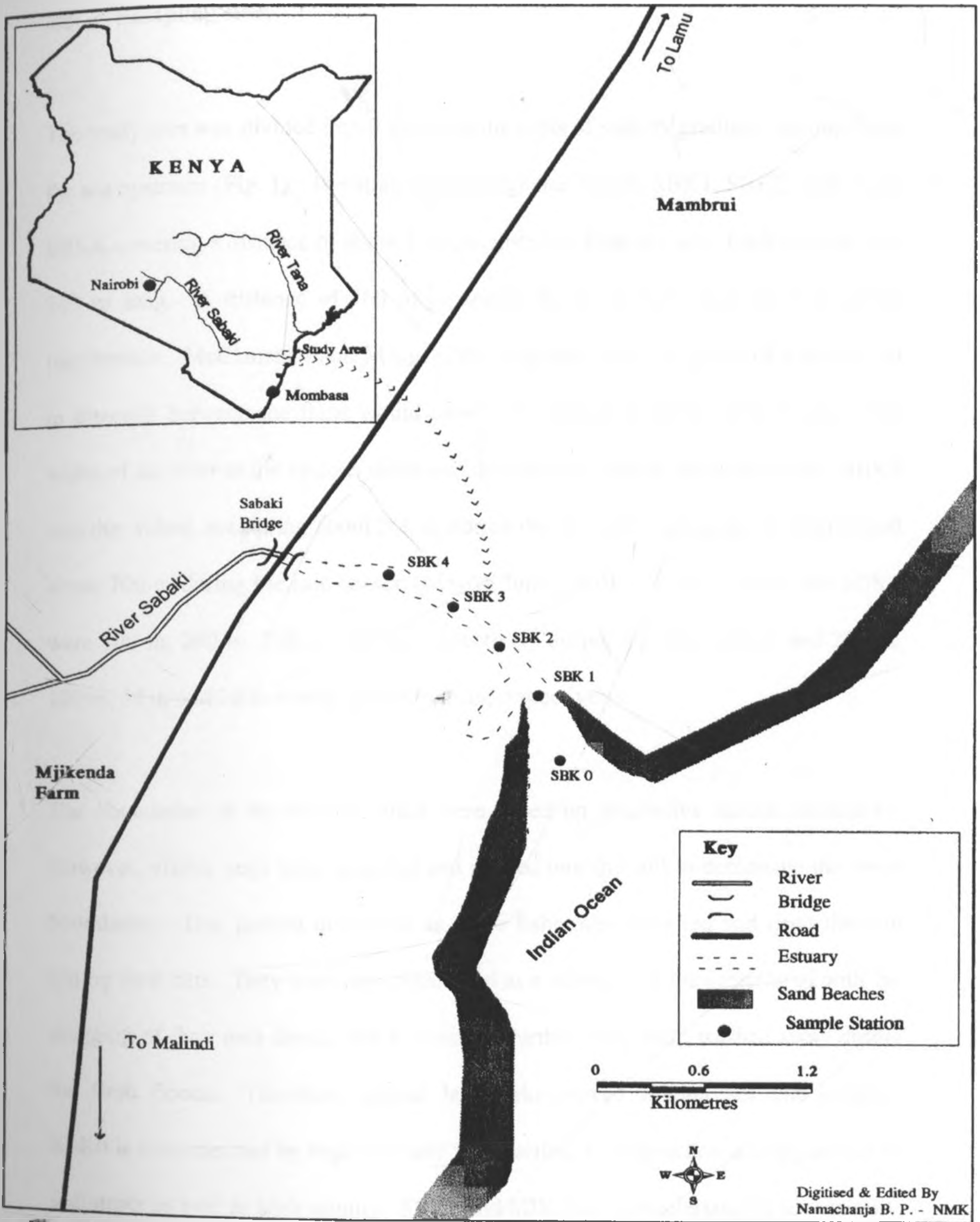

Fig. 1: Location of Stations sampled in Sabaki River estuary, Stations SBK0 to SBK4 depending on spatial salinity variations.

2.2 Sampling sites

The study area was divided into 5 zones on the basis of salinity gradient, starting from the sea upstream (Fig. 1). The strata were designated SBK0, SBK1, SBK2, SBK3 and SBK4, covering a distance of about 1.5 Km upstream from the sea. Each stratum was 200 m long. A distance of 100 m separated the strata from each other to avoid interference. McClanahan and Mangi (2000) reported that a distance of less than 60 m intervals between the traps would cause interference between them (traps). The width of the river at the various strata was determined using a measuring rope. SBK0 was the widest, measuring about 200 m during the dry season (January to March) and about 700 m during the rain season (May to June). SBK1, SBK2, SBK3 and SBK4 were 500 m, 200 m, 200 m, 100 m, respectively during the rain season, and 200 m, 100 m, 50 m and 20 m during the dry season, respectively.

The boundaries of the various strata were based on distinctive natural landmarks. However, visible pegs were prepared and pushed into the soil to demarcate the strata boundaries. This proved unreliable as some fishermen uprooted and used them in setting their nets. They were also considered as a nuisance as they interfered with the dragging of their nets during beach seining. Further, they were washed away during the flash floods. Therefore, natural landmarks proved suitable for this purpose. SBK0 is characterized by high seawater wave action, re-suspension and deposition of sediments as well as high salinity. SBK1 and SBK2 are characterized by low salinity, less wave action and re-suspension and deposition of sediments. SBK3 and SBK4 were generally of zero salinity with high rate of river water flow, transport and river based turbulence.

2.3 Study design and sampling procedure

Stratified random sampling formed the study design. The strata were sampled as separate entities and results from each stratum combined to give overall results. Stratification was aimed at reducing variability in the population samples thus increasing the precision of results. Water samples for determination of total suspended sediments (TSS) and Chlorophyll a (Chl-a) content were collected randomly from 3 sampling sites designated as western (W), central (C) and eastern (E) parts of the river within each stratum. Fish sampling was done using beach seining with the assistance of 3 fishermen. Throughout the study period, same fishing gears, methods, time and duration was observed. This standardized fishing survey was adopted in order to reduce variability in the population samples.

Samples were collected on a monthly basis for a total of 8 months. October and November 2002 were used for methodology testing and review. Real sampling was conducted from the month of January 2003 through to June 2003. Samples were collected 4 days consecutively in each month during the last quarter of the lunar cycle (neaps) at low tide.

2.4 Data collection

2.4.1 Rainfall

Monthly data on rainfall was obtained from Malindi Meteorological Station.

2.4.2 Temperature measurement

A standard mercury thermometer was used to measure both air and surface water temperature. Surface water temperature was measured by drawing water in a 20 - litre bucket, then a thermometer suspended at a depth approximately 10 cm below the surface for a period of at least 30 seconds (to stabilize), and quickly hoisted to the surface and readings taken to the nearest 0.5 °C.

2.4.3 Salinity

Salinity was determined using a hand held refractometer calibrated for salinity range 0 ‰ – 100 ‰. The equipment was zeroed using distilled water before any measurements were taken by dispensing 3-5 drops of distilled water on the refractometer using a 300 ml wash bottle. After zeroing, 3- 5 drops water samples were dispensed on to the refractometer using a dropper. Readings were taken to the nearest unit per mille.

2.4.4 Determination of Total Suspend Sediments (TSS)

Total suspended sediments (TSS) in the water samples was determined using gravimetric methods as described by Strickland *et.al.* (1972), and Mudroch and Macknight (1994).

Water samples for determining TSS were collected from a depth of between 30 cm and 50 cm of the water column using 5-litre black plastic containers. The water samples were transported to the laboratory for filtration using oven dried and pre-weighed glass-microfibre (GF/C) filters. The filters were oven dried at 80 °C for about an hour and cooled in a desiccator containing dry gel to a constant weight. Each filter was removed fast enough from the desiccator to avoid absorbing moisture from the environment, weighed using an electrobalance, wrapped in a numbered aluminium foil and stored in a small plastic box.

Oven-dried and pre-weighed GF/C filter was placed on the base-plate of the filtering apparatus and filter funnel assembled. Using a litre-measuring cylinder, suitable volume of vigorously shaken water samples were filtered through the filter. Vigorous shaking of the water samples ensured that all sediments were kept in a uniform suspension. The vacuum pump provided the required suction. The funnel top was removed while still applying suction to remove water. The source of vacuum was disconnected and filters carefully removed using a pair of flat-bladed forceps. Two filters per every sampling session were reserved as blank corrections. They went through all the processes as described except that distilled water rather than sample water was passed through them.

The filters were folded in half, gently returned in their respective numbered aluminium foils and preserved in a refrigerator until all the samples had been filtered.

The filters and their respective samples were placed on a pre-weighed crucible and dried to a constant weight in an oven. The dry weight of the TSS was obtained using the following equation:

$$TSS\ (mg/l) = \frac{W_2 - W_1 + X}{V}$$

Where,

V is the volume of water filtered in litres,

W_1 is the weight of the pre-weighed filter before filtration,

W_2 is the weight of filter plus dry sample, and,

X is the blank correction.

Monthly values for TSS were computed to provide a basis for comparison.

2.4.5 Water Transparency

A circular, 30 cm diameter, smooth white secchi disk was used to estimate water transparency. The seccchi disk was attached to a nylon rope with some weight at its tip. The weight was to facilitate vertical movement of the disc and to minimize tapering of the rope. This was to minimize errors in the readings. The disc was gradually lowered in the water column down to a point just when it became invisible to the eye. The corresponding point on the rope just at the water surface was marked and measurements taken using a measuring tape.

2.4.6 Determination of chlorophyll *a* (Chl-a)

Chlorophyll *a* in the water samples was determined using spectrophotometric method as described by Parsons *et. al.* (1989). Water samples for determining chlorophyll *a* concentration (a standard measurement used to estimate biomass or standing stock of phytoplankton) were collected from a depth of between 30 cm and 50 cm of water column using 5- litre black plastic containers.

The water samples were taken to the laboratory for filtration in dim light to reduce the chances of photosynthesis. Glass-microfibre (GF/F) filter was placed on the base-plate of the filtering apparatus and filter funnel assembled. Using a litre-measuring cylinder, suitable volume of water samples were filtered through the filters. The vacuum pump provided the necessary suction. Three to five drops of Magnesium Carbonate ($MgCo_3$) (1 gm of $MgCo_3$ dissolved in 100 ml distilled water) were added to the water using a 100 ml wash bottle as it was being filtered to prevent acidity on the filter. The funnel top was removed while still applying suction to remove water. The source of vacuum was disconnected and glass-microfibre filter carefully removed using a pair of flat-bladed forceps. The filters were folded in half, gently placed in labelled aluminium foils and preserved in a refrigerator at -20 °C.

The filters were preserved in the refrigerator until all the samples had been filtered. The filters were then placed in stoppered centrifuge glass tubes with 10 ml of 90% acetone (analyser grade) and thoroughly shaken to dissolve. Similarly, two glass tubes were filled with 90% acetone for blanks and two blank filters added and shaken to dissolve. The sample and blank were allowed to stand overnight in a dark refrigerator. The contents of each tube were centrifuged at 6000 rpm at room temperature for 5-10 minutes. The samples were left to stand for at least an hour to allow settling of any particulate matter. The supernatant was decanted into a 10 cm path length spectrophotometer cuvette and the extinctions measured at different wavelengths; 750 *nm*, 664 *nm*, 647 *nm* and 630 *nm* using a zeroed spectrophotometer. Each extinction was corrected for a small turbidity blank by subtracting the 750 *nm* from 664 *nm*, 647 *nm* and 630 *nm* absorptions.

Chlorophyll *a* expressed as milligrams (mg) of dry weight per m^3 was determined using the following equation;

$$\text{Chlorophyll } a\ (Ca) = 11.85\ E_{664} - 1.54\ E_{647} - 0.08\ E_{630}$$

$$\text{Mg Chlorophyll/m}^3 = \frac{Ca \times v}{V}$$

Where;

E is the absorbance at different wavelengths obtained above (corrected for 750 *nm* reading),

Ca is the amount of chlorophyll *a* in mg/m^3 ($ug/l = mg/m^3$),

v is volume of acetone used in ml, and,

V is the volume of water filtered in litres.

Chlorophyll *a* content in the water samples was computed monthly for each station to allow for comparison between them.

2.4.7 Fish sampling

Fish samples were collected by beach seining and catch landed on available suitable banks. Two sizes of nets were used alternately at each site. The smaller net measured 2 m deep and 45 m long, with a mesh size of 10 mm knot to knot. The larger net was 2 m deep and 45 m long with a mesh size of 20 mm knot to knot. This improved on the catchability of fish with different size ranges. The choice of the gear types was based on experimental trials prior to the sampling programme and also the ease of use.

To standardize fishing effort between each station, three operators fished continuously for 15 minutes and then landed the catch on suitable banks. A second haul taking 15 minutes was made. Therefore, at each site, 2 hauls of 15 minutes each were conducted and total fish caught was placed in appropriately marked and labelled polythene paper bags. At a few sites, where water flow rate was high, especially in the month of May, samples were collected for duration of over 30 minutes, particularly in stations SBK1 and SBK2 and results corrected by a factor of 2, to express catch effort per hour.

Fish were sorted and identified to species level where possible using various identification keys/guides (Smith & Heemstra, 1995; Richmond (eds), 1997; Eccles, 1992; Lieske & Myers, 2001) and representative individuals photographed. The total and fork length of all the fish in each sample was measured on a fish measuring board. The approximate weight of each un-gutted fish in the sample was determined using a weighing spring balance to the nearest gram.

Some individuals of each species were prepared as voucher specimens. Individuals that could not be identified on site and/or voucher specimens were fixed in 10% formalin for 7 days and later transferred to 70% alcohol for storage. Further identification of specimens was done at the National Museums of Kenya, Ichthyology Department (Nairobi).

Crustaceans were also caught, particularly the prawns. Occasionally mangrove crabs were trapped.

The data gathered was used to compute the number of fish species collected, catch per unit of effort (CPUE), length distribution, and production by wet weight to give an indication of relative abundance, species diversity, spatial and seasonal distribution patterns of fish.

2.5 Treatment of Data

2.5.1 Fish catches

Conventionally, fish catch rate is expressed per hour. Since fish were sampled for 30 minutes per every station, the results were corrected by a factor of 2 to determine catch effort (CPUE), which was taken as an index of availability.

Fish species diversity at each sampling station was measured using the Shannon-Wiener function (Krebs, 1999), which is expressed as;

$$H^1 \quad = \quad -\Sigma\,(pi)(Log_e Pi)$$

Where;

H^1 is index of species diversity,

e is 2.71828 (base of natural logs)

Pi is the proportion of total sample belonging to *i*th species.

In using the Shannon-wiener diversity index, the following assumptions were made; firstly, the probability of each individual being caught in the fishing net remained constant throughout the experiment, and secondly, all individuals had the same probability of being trapped.

The total length and individual weight data were used to plot weight/ length relationship curves and size distributions. These could be used as a measure of growth, separation of sexes and classification of age groups in fish. The weight/ length relationships were determined for fish species where adequate data had been collected. The relationship was calculated using the following formula;

$$W = aL^{b} \quad \text{(cubic or power curve)}$$

Or $\ln W = \ln a + b \ln L$ (power curve transformed in to linear form by use of natural logarithms)

Where;

W is total body weight (g)

L is total Length (cm)

a is a constant

b is the exponent

A value of 3 for the exponent b indicated symmetric or isometric growth whereas a value other than 3 indicated asymmetric or allometric growth (King, 1995).

2.5.2 Statistical analyses

Experimental data were analysed using both simple descriptive statistics and where appropriate parametric or non-parametric statistical procedures.

Multivariate analysis of variance (MANOVA) using *Statistica* programme was performed to test for any significant differences in the parameters on both temporal and spatial scales. Effects of the explanatory variables in regression analysis were separated through multivariate tests. Post MANOVA tests (Monte Carlo permutation test and Scheffe test) were done to isolate variables, which significantly contributed to the observed variations. Non – parametric test was performed to show any significant difference in the means of biological variables. Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) using CANOCO version 4.0 programme were performed to test for the association between environmental variables and distribution of fish species.

Pearson correlation coefficient was calculated to establish relationship between pairs of variables from small sample sizes. t and F tests were performed on the data to test for significant differences between the derived means and variances of both physico-chemical parameters and fish samples in wet and dry seasons.

The differences were considered significant at $P < 0.05$ or at 95% Confidence Level.

CHAPTER THREE

3.0 RESULTS

3.1 Physico-chemical parameters

3.1.1 Rainfall

The mean monthly rainfall recorded in Malindi District during this study showed that January and February were dry (Figure 2). Some light rains were experienced in March during the inter-monsoon period. Heavy rains were realized in April, peaking in May where a mean rainfall of 22.1 mm was recorded. A slight drop in rainfall was observed in June. The rainfall regime followed a monsoon pattern. Significant differences in rainfall was observed between the months of January, February and March, and April and May ($P<0.05$). However, the difference in rainfall amount between January, February and June was not significant ($P>0.05$)

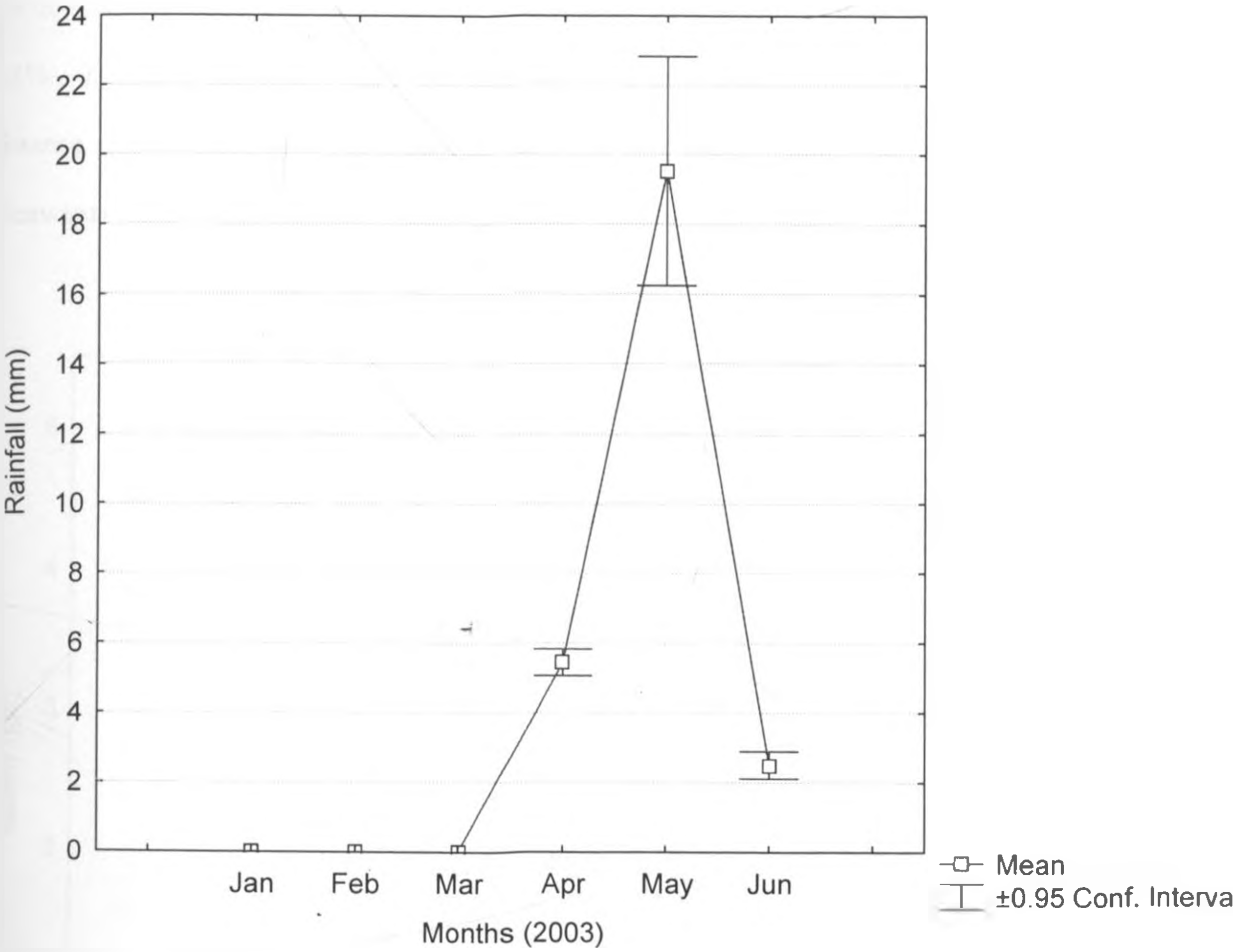

Fig. 2. Mean monthly rainfall in Malindi District during the study

3.1.2 Salinity

Spatial variation in mean salinity is depicted in Figure 3. Highest mean salinity of 4.4‰ was registered at SBK0, closely followed by SBK1 with a mean salinity of 1.5‰. Lowest mean salinity of 0‰ was recorded at SBK4. Salinity decreased with distance upstream away from the sea. Salinity was highly significant at SBK0 (Seaward) while insignificant at SBK2, SBK3 and SBK4.

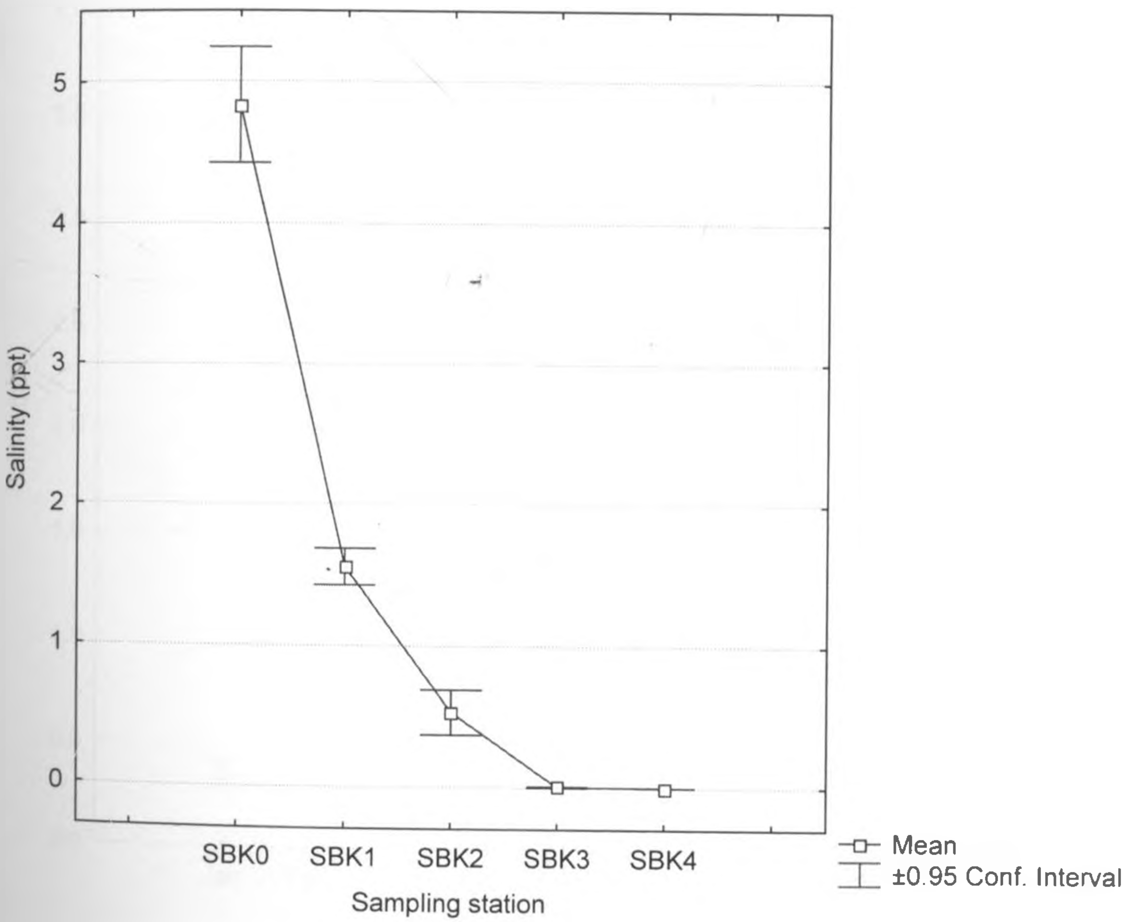

Fig.3. Spatial variation in salinity during the period of study

Temporal variation in salinity is shown in Figure 4. January and February experienced low salinity levels with a sharp increase noted in March. A high variability in salinity was observed in April, as can be seen from very high standard deviation. A slight decline was noted in May but gradually increased in June. Salinity reflected rainfall and monsoon patterns. The results indicate that salinity significantly varied between January, February and April ($P < 0.02$). The difference in salinity between the months of March, May and June was not significant ($P > 0.5$)

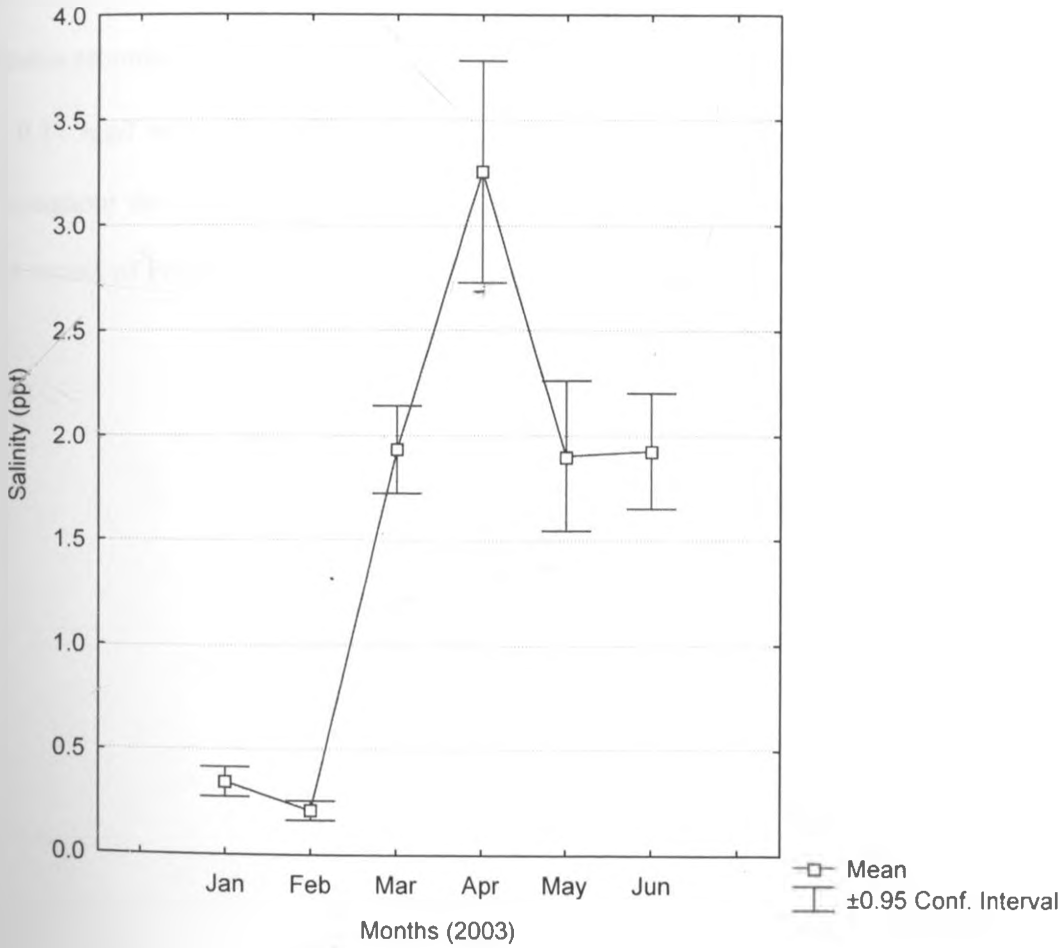

Fig. 4. Temporal variations in salinity within the estuary

3.1.3 Total Suspended Sediments (TSS)

Temporal variations in total suspended sediments (TSS) are shown in Figure 5. TSS concentration progressively increased from the month of January to February, averaging 0.27 ± 0.02 mg/l and 0.33 ± 0.03 mg/l, respectively. A steep decline in the TSS was recorded in March, 0.064 ± 0.02 mg/l, coinciding with inter-monsoon period. A steady increase in TSS was experienced in April, 0.32 ± 0.1 mg/l peaking in May, 0.54 ± 0.2 mg/l and slightly declining to 0.5 ± 0.08 mg/l in June. The dry season recorded lower mean TSS concentration of 0.22 ± 0.12 mg/l compared to 0.42 ± 0.17 mg/l in the wet season. Monthly TSS concentration was highly significant throughout the study period ($P < 0.05$). However, the difference in TSS amounts in the month of February and April was not significant ($P > 0.2$)

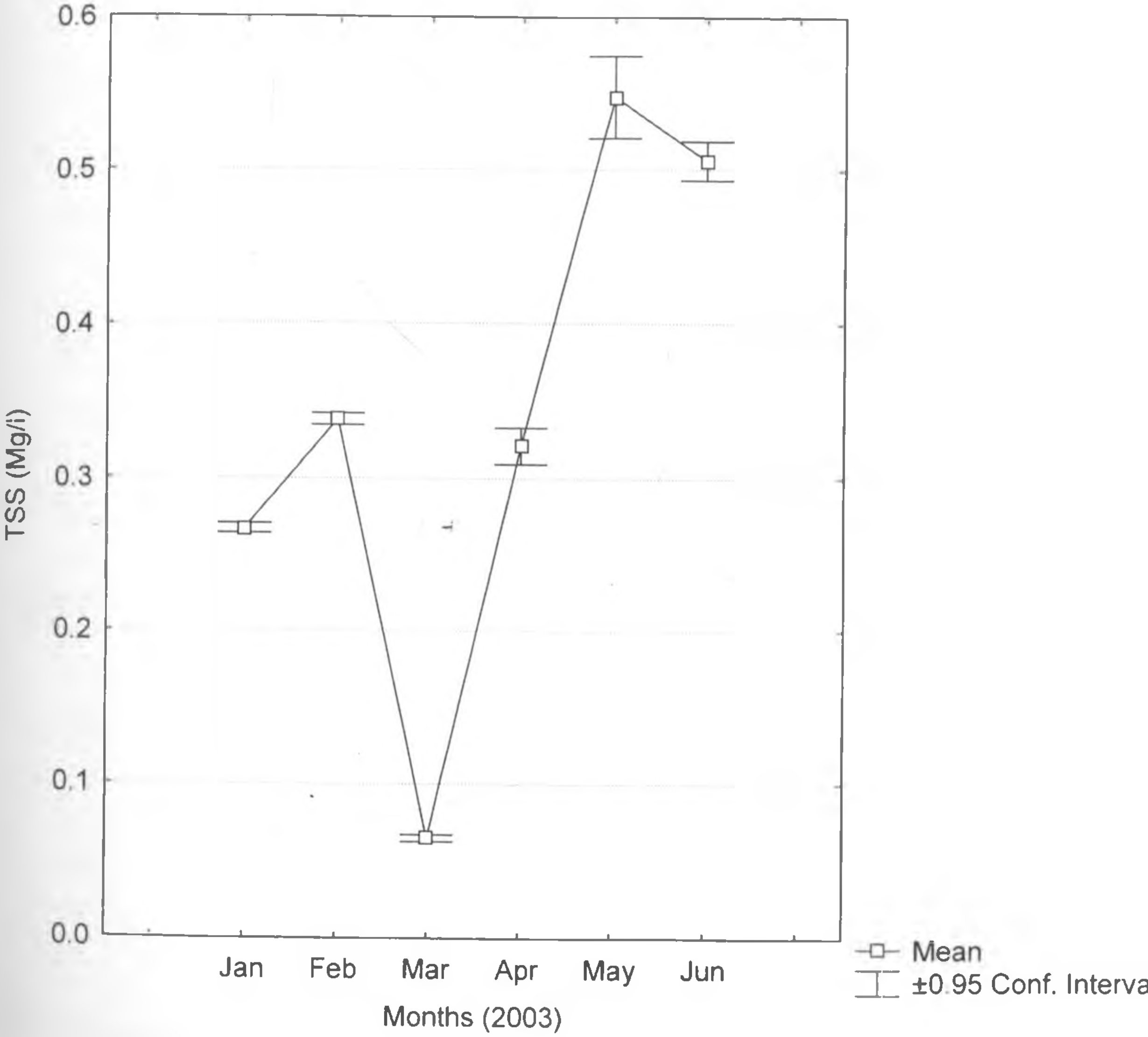

Fig.5. Temporal variation in TSS supply in the Sabaki estuary

Figure 6 depicts temporal relationship between TSS concentrations and amount of rainfall. Lowest TSS amount was recorded in March, 0.063 g/l, peaking in May, 0.52 g/l. TSS supply increased with increase in the amount of rainfall.

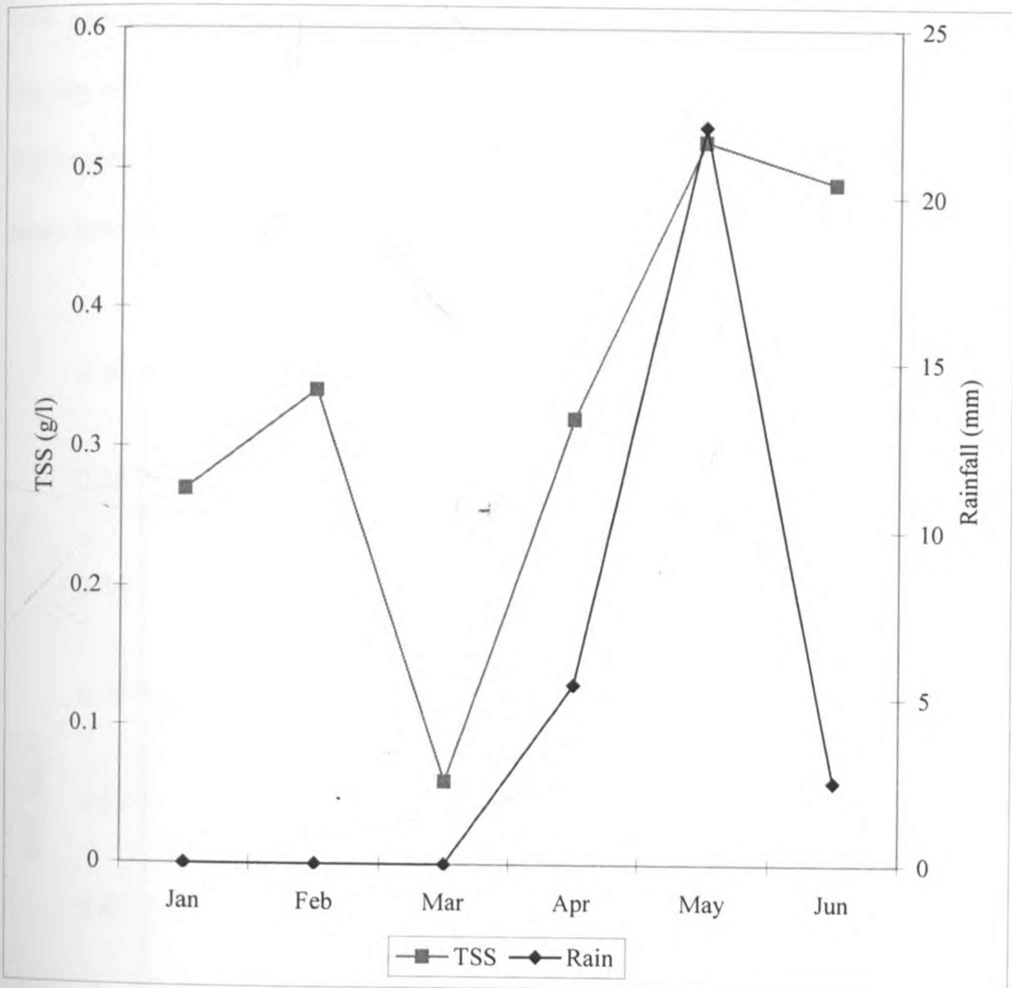

Fig. 6. Temporal relationship between TSS concentrations and amount of rainfall

Spatial variation in TSS concentration in the estuary is depicted in Figure 7. The variations within stations were low. Highest mean TSS concentration was 0.333 mg/l recorded at SBK4. SBK2 and SBK0 registered 0.331 mg/l and 0.323 mg/l, respectively. 0.305 mg/l TSS was noted at SBK3 while SBK1 recorded the lowest, 0.301 mg/l. No significant difference was observed in station to station variation in TSS concentrations (P > 0.2). However, there was a significant difference between the dry and wet seasons (t = 0.208, F = 4.87, P < 0.05). TSS supply in the estuary was influenced by seasonal changes in river discharge, influx of terrigenous materials from terrestrial sources, tides and estuarine circulation.

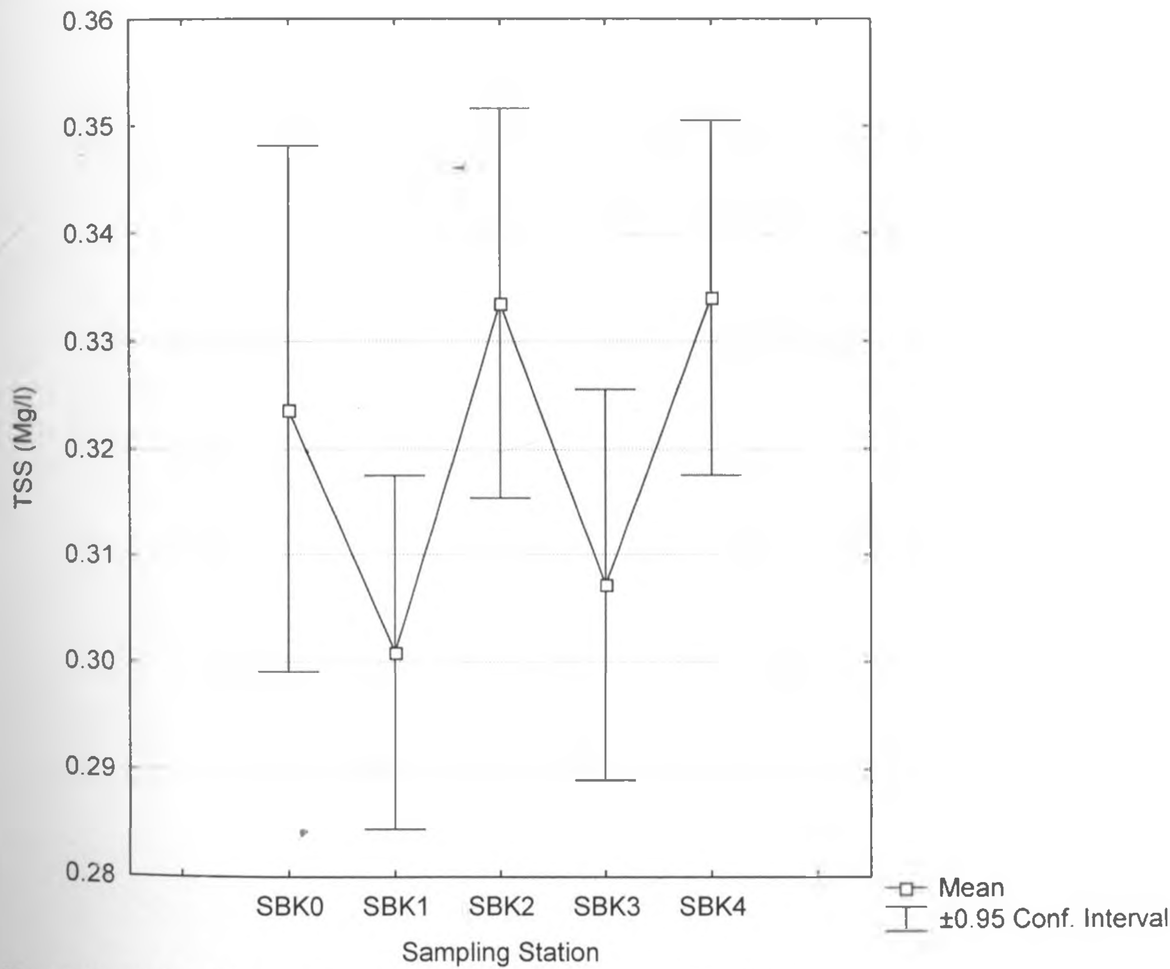

Fig. 7. Spatial variation in TSS concentration in the Sabaki estuary

3.1.4 Water transparency/visibility

Variation in water transparency at the sampling stations is shown in Figure 8. Maximum mean visibility value attained was 7.7 cm at SBK0. This was closely followed by SBK1 with a mean visibility of 6.9 cm. Lowest visibility of 4.5 cm was noted at SBK4. Visibility improved with distance towards the sea. The difference in visibility between SBK0 and SBK1 was not significant ($P > 0.08$). Significant difference in visibility was observed between stations SBK0 and SBK1 (seaward) and SBK2, SBK3 and SBK4 ($P < 0.05$). Visibility was not significantly different between stations SBK2, SBK3 and SBK4 ($p > 0.2$)

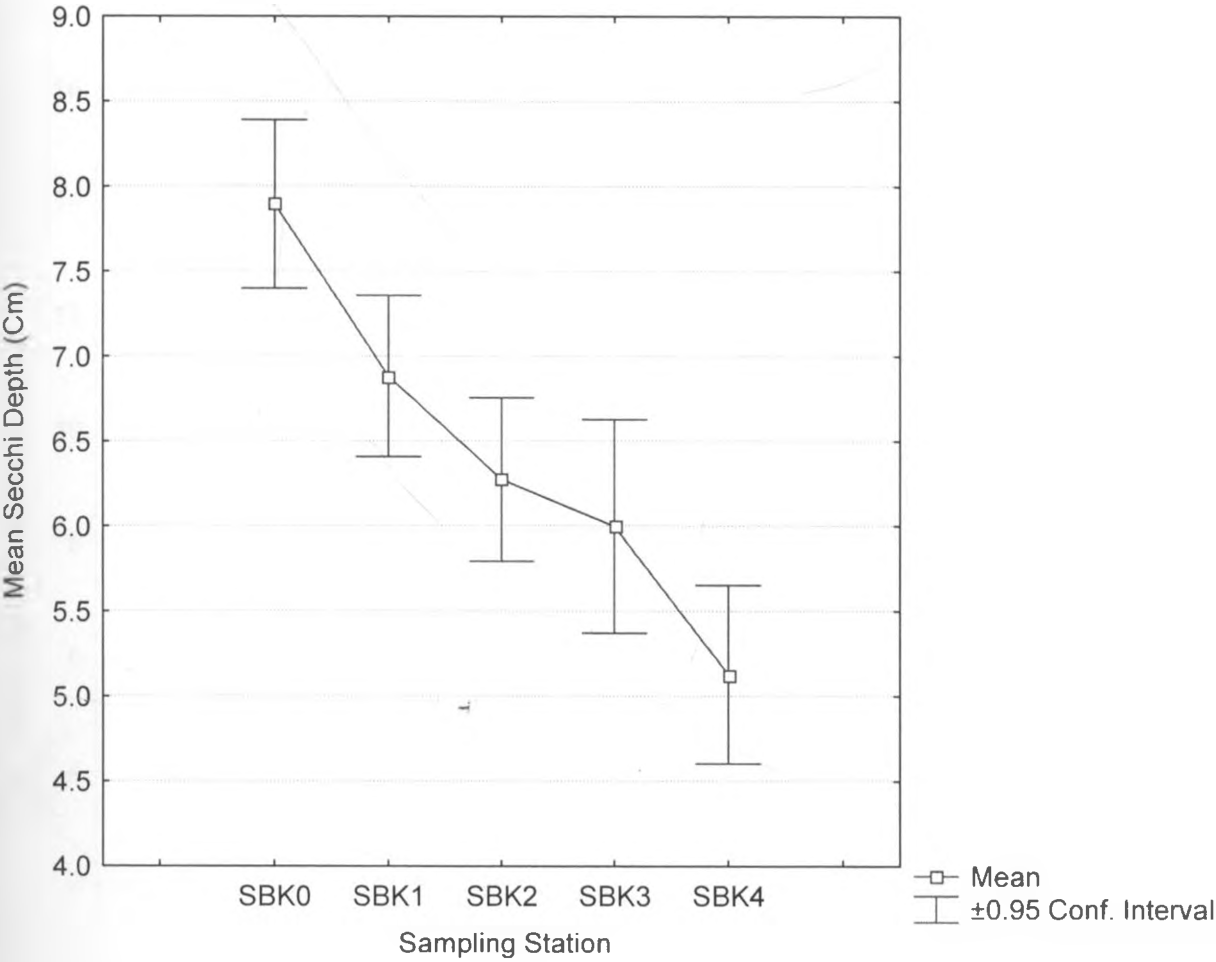

Fig. 8. Spatial variations in visibility

Temporal variation in visibility is depicted in Figure 9. January recorded a mean visibility of 6.9 cm, which slightly declined to 4.2 cm in February. Maximum mean visibility of 14.6 cm was noted in March. A sharp drop in visibility was experienced in April with onset of the long rains. Visibility was at its minimum in May where a mean of 1.5 cm was recorded. A general improvement in visibility was observed in

June. Visibility was influenced by the rains, river discharge, TSS supply and oceanographic processes. Monthly variations in visibility was highly significant ($P < 0.05$)

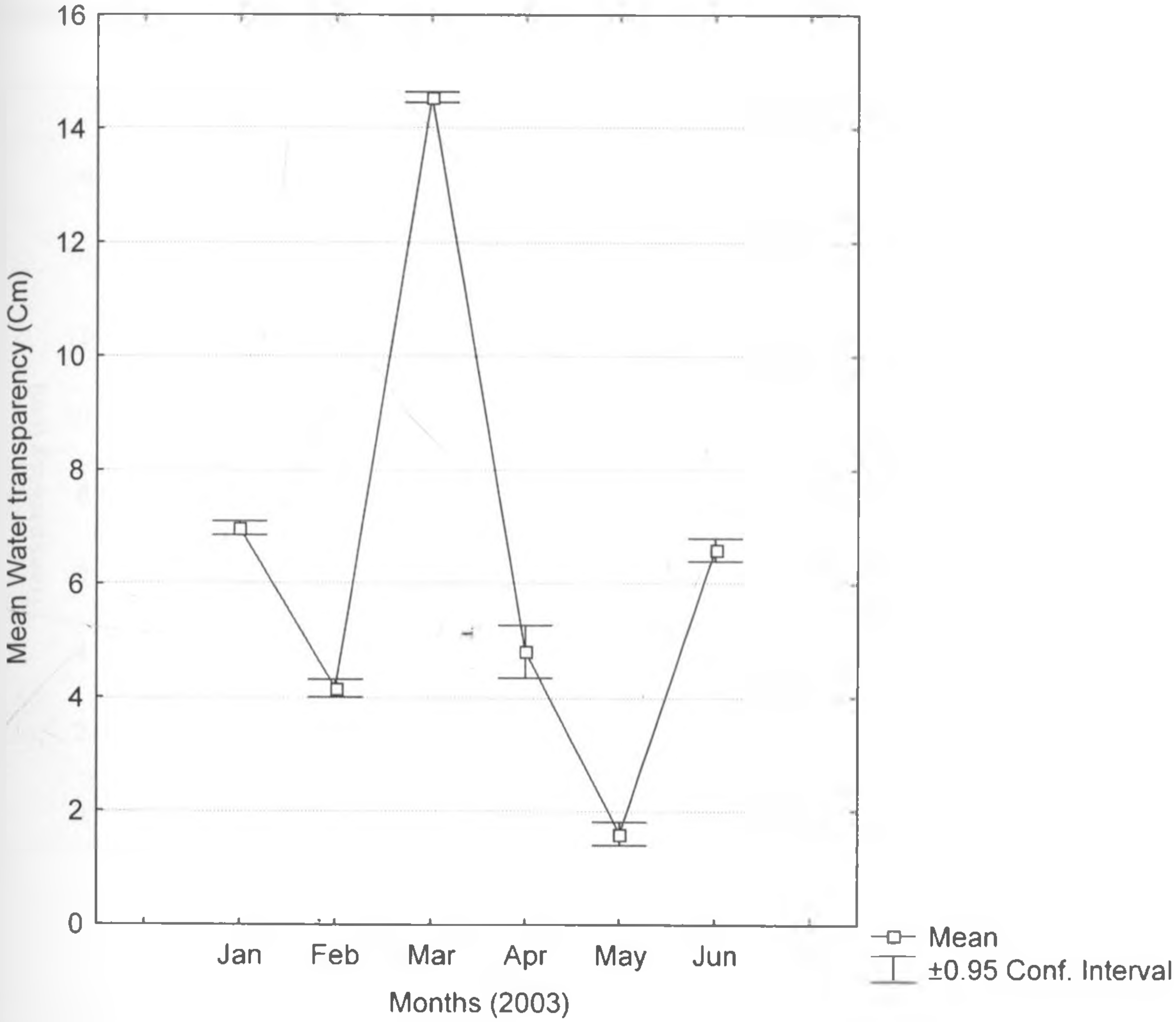

Fig. 9. Temporal variations in visibility

Figure 10 shows temporal relationship between transparency and TSS. There was a strong inverse relationship between transparency and TSS concentration with a correlation coefficient of 0.80. The higher the concentration of TSS the lower the transparency.

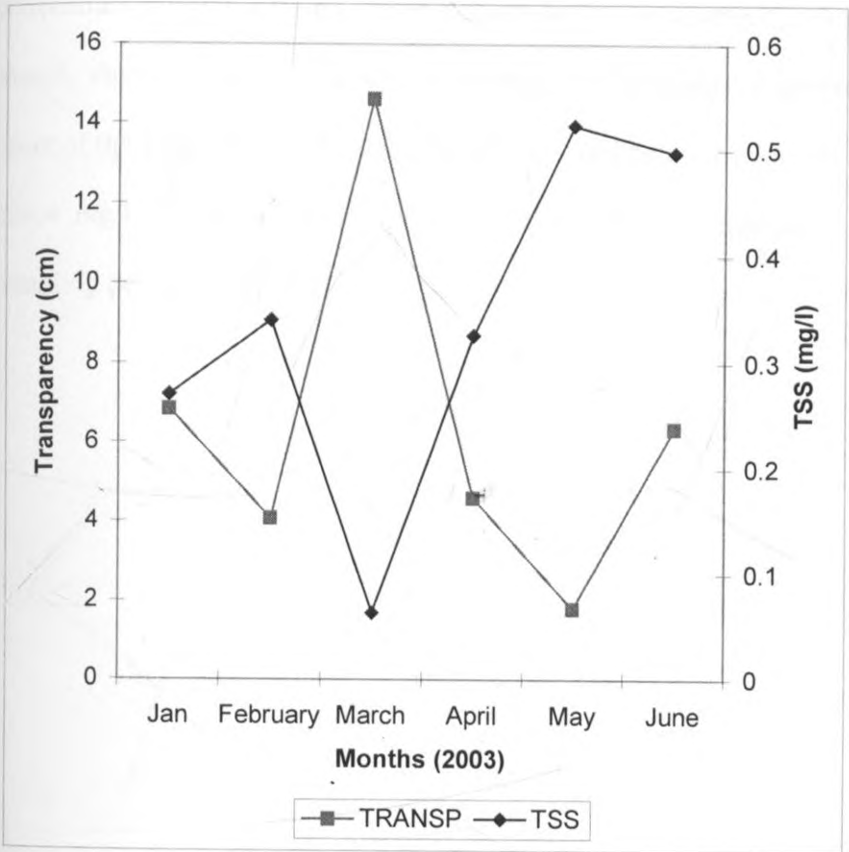

Fig. 10. Temporal relationship between transparency and TSS

3.1.5 Chlorophyll a (Chl-a) Concentration

Temporal variation in Chlorophyll a is shown in Figure 11. Chl-a was somewhat less variable in January and February where mean concentrations of 114.7 mg/l and 138.6 mg/l were recorded, respectively. Lowest level of Chl-a was realized in March, when concentration was 29.3 mg/l. After a sharp decline in chlorophyll a in the month of March, there followed a logarithmic increase in Chlorophyll a immediately after the onset of the long rains, averaging 35.8 mg/l in April before peaking in June, averaging 226.4 mg/l. Chlorophyll a concentration was highly significant throughout the sampling period ($P < 0.05$)

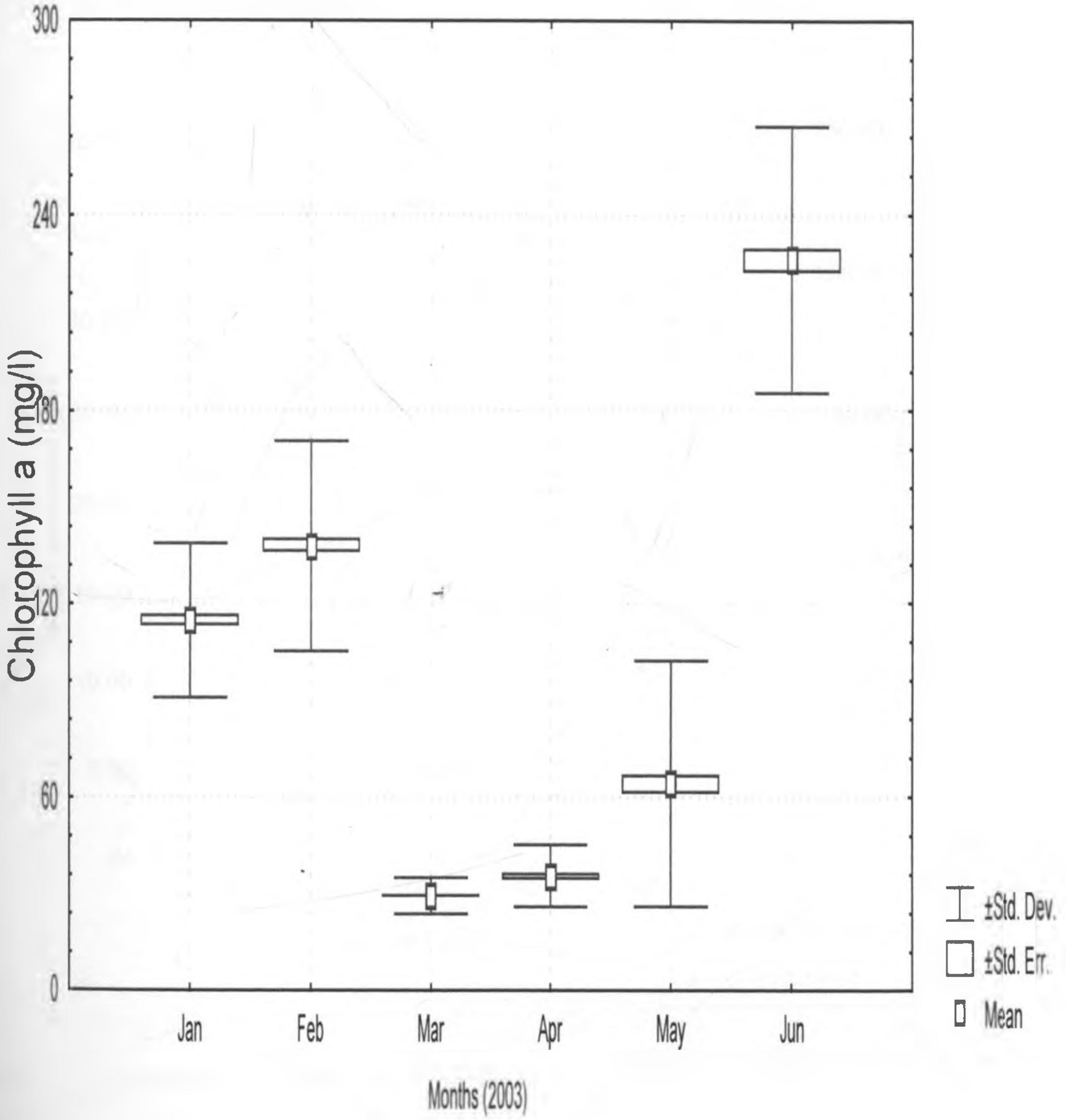

Fig.11. Temporal variations in chlorophyll a production

Temporal relationship between chlorophyll a and water temperature is depicted in Figure 12. The amount of chlorophyll a correlated negatively with water temperatures, correlation coefficient of 0.36. High water temperatures resulted to a declined production of chlorophyll a.

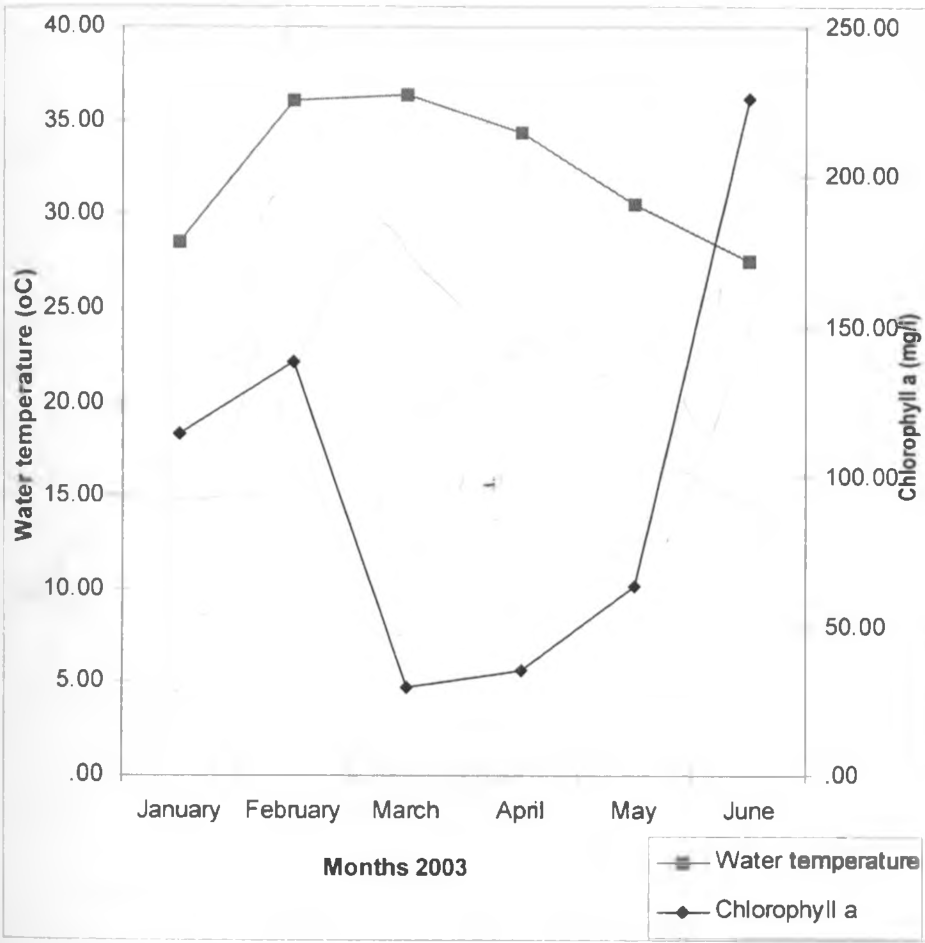

Fig. 12. Temporal relationship between water temperature and chlorophyll a concentration

Figure 13 denotes temporal relationship between chlorophyll a content and total suspended sediments. A positive correlation coefficient of 0.40 was attained between chlorophyll a and TSS. Increased sediments resulted to an increase in the production of chlorophyll. However, this may not be an effect - causal relationship.

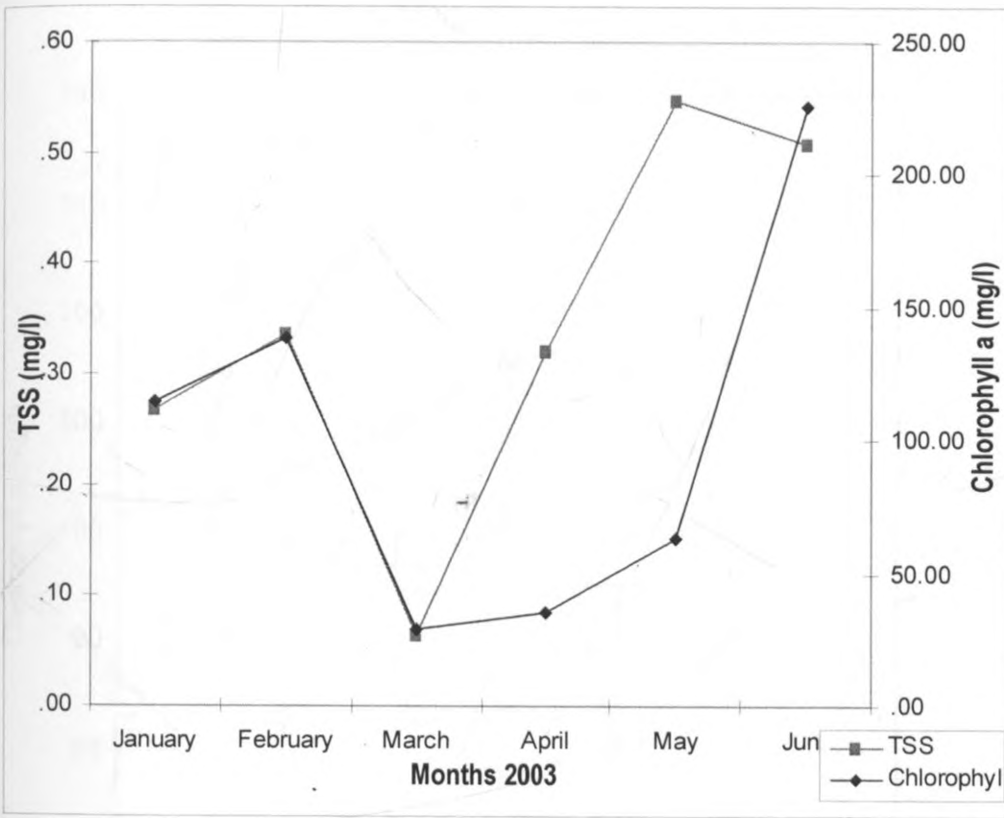

Fig.13. Temporal relationship between total suspended sediments (TSS) and Chlorophyll a

Spatial variation in Chl-a is depicted in Figure 14. There was little variation in Chl-a production among the sampling stations. Middle stations, SBK1 and SBK2 generally recorded higher Chl-a concentration ranging from 101.1 mg/l to 98.5 mg/l, respectively. This was attributed to river flow and estuarine circulation. Spatial variation in chlorophyll a was not significant (P > 0.06).

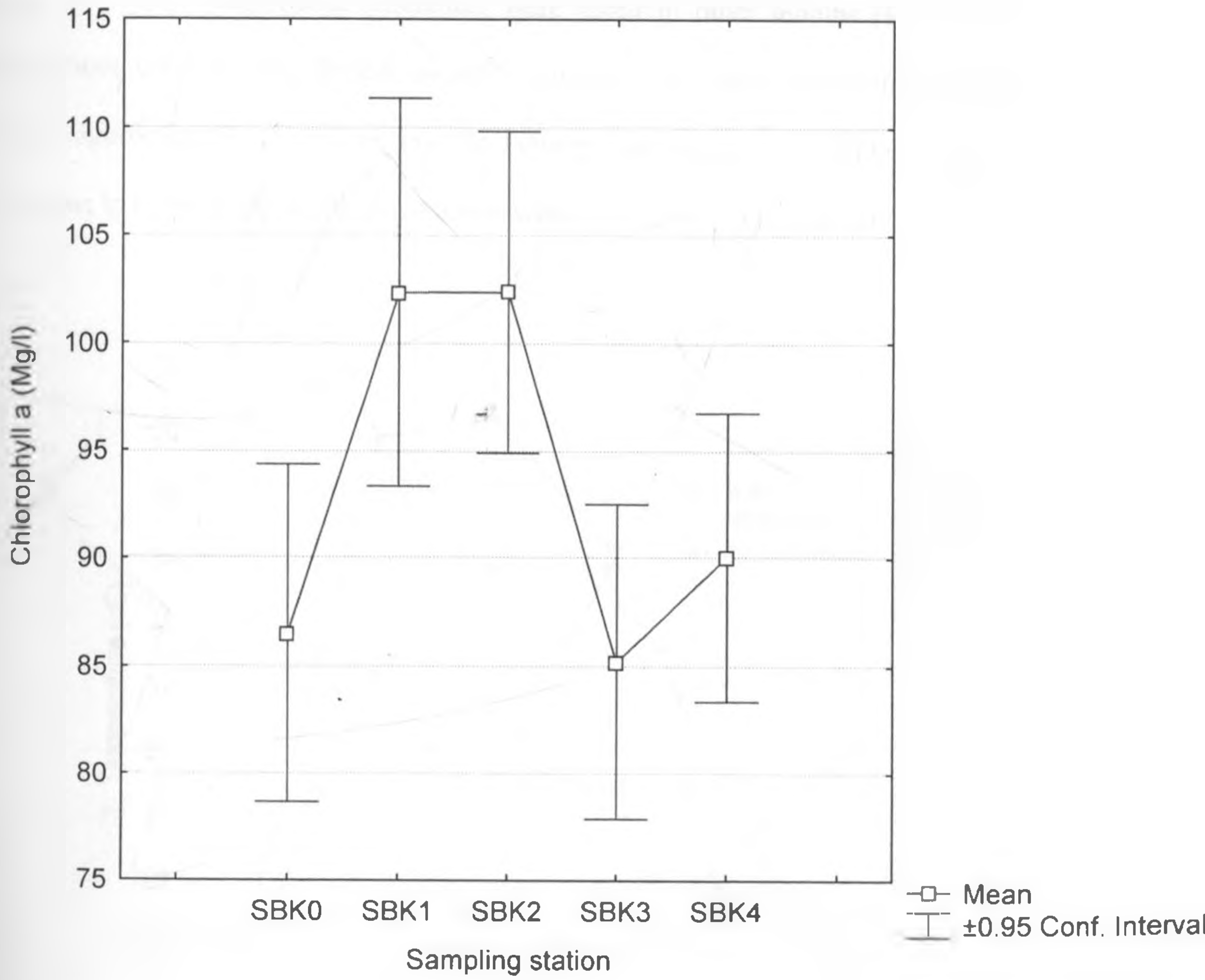

Fig.14. Spatial variations in chlorophyll a concentrations at the Sabaki estuary during the study period.

3.1.6 Temperatures

The temporal variation in both air and water temperatures at the Sabaki estuary during the study period is shown in Figure 15. The highest mean water temperatures were recorded in March, 36.3°C while air temperature was highest in April with 34°C. No significant differences in air temperature were observed in the months of March and April ($P > 0.7$). Significant differences were noted in other months ($P < 0.05$). Throughout the sampling period, monthly variations in water temperatures were highly significant ($P < 0.05$) except for January and March ($P > 0.11$). Spatial variations in either air or water temperatures were not significant ($P > 0.05$)

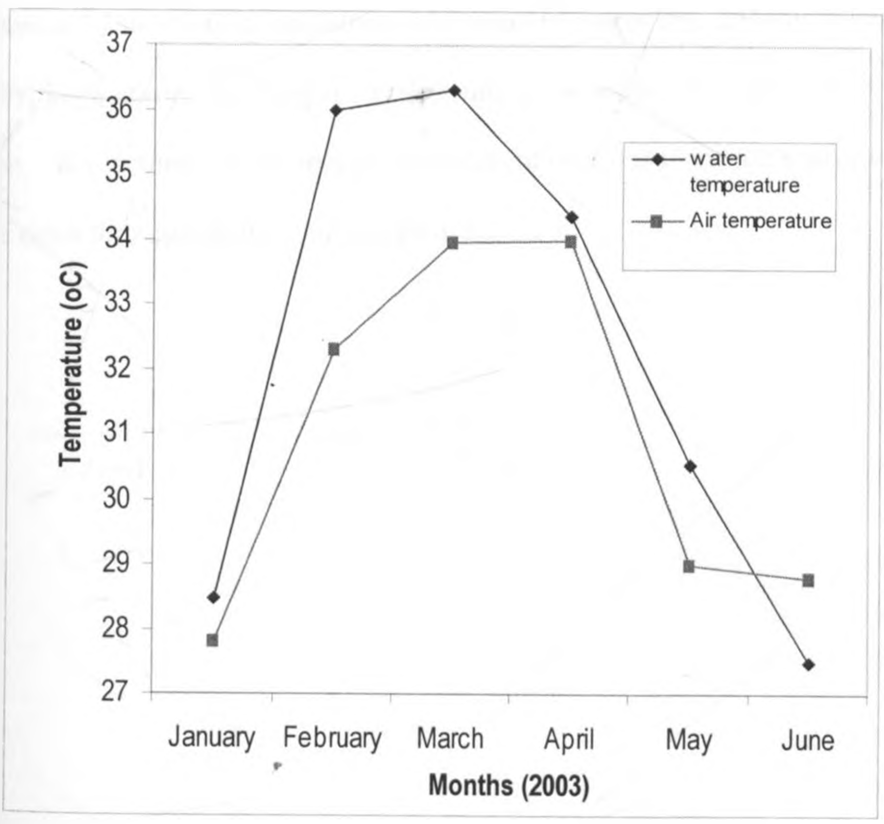

Fig.15. Temporal variations in water and air temperatures during the study period

3.2 Fish community structure and distribution

3.2.1 Species composition and dominance

A total of 10,807 individuals of both fish and crustaceans were caught, representing 35 species, 21 families and 7 orders of finfish as well as 6 species, 2 families and 1 order of the crustaceans (Table 1). *Arius africanus* dominated the catch, accounting for 38.8% of the individuals caught. *Valamugil buchanani* was second in dominance, contributing 14.9% of the sample population followed by *Mugil cephalus* comprising 14.6% of the total number of individuals caught in the sample. Members of the genus *Caranx* showed considerable presence in the estuary, contributing 6.3% while *Apogon sangiensis* 3.3%. Single individuals of *Synodontis serpentis*, *Lobotes surinamensis*, *Gerres filamentosus* and *Barbus oxyrhynchus* were caught once and only during wet season. While some of the species were caught occasionally, others were consistent in the catch throughout the sampling period.

Table 1. A summary of fish species occurring in the Sabaki estuary on a temporal scale

No.	Scientific Name	Common Name	Family	Order	Jan	Feb	Mar	Apr	May	Jun	Total	% of Total
1	*Apogon sangiensis*	Sangi cardinalfish	Apoginidae	Perciformes	10	114	86	142	5	4	361	3.33925
2	*Arius africanus*	African Sea catfish	Ariidae	Siluriformes	12	263	3749	84	74	21	4203	38.87775
3	*Awaous aeneofuscus*	Freshwater goby	Gobiidae	Perciformes	0	0	0	0	4	0	4	0.037
4	*Barbus oxyrhynchus*	Pangani barb	Cyprinidae	Cypriniformes	0	0	0	0	1	0	1	0.00925
5	*Carangoides spp*	Trevallys	Carangidae	Perciformes	0	0	0	0	22	41	63	0.58275
6	*Caranx spp*	Jacks	Carangidae	Perciformes	18	440	138	93	0	0	689	6.37325
7	*Chanos chanos*	Milkfish	Chanidae	Gonorynchiformes	0	0	0	0	2	5	7	0.06475
8	*Clarias gariepinus*	Catfish	Clariidae	Siluriformes	31	0	0	12	0	0	43	0.39775
9	*Glossogobius biocellatus*	Sleepy goby	Gobiidae	Perciformes	0	0	0	2	0	1	3	0.02775
10	*Glossogobius giuris*	Tank goby	Gobiidae	Perciformes	0	0	0	1	2	0	3	0.02775
11	*Cynoglossus zanzibarensis*	Zanzibar tonguesole	Cynoglossidae	Perciformes	0	0	0	0	5	3	8	0.074
12	*Gerres filamentosus*	Whipfin silver-biddy	Gerridae	Perciformes	0	0	0	0	1	0	1	0.00925
13	*Herklostsichthys quadrimaculatus*	Gold spot herring	Clupeidae	Clupeiformes	0	0	0	1	5	48	54	0.4995
14	*Hyporhamphus affinis*	Insular halfbeak	Hemiraphidae	Beloniformes	0	0	0	3	0	0	3	0.02775
15	*Johnius dussumieri*	Small kob	Sciaenidae	Perciformes	0	0	0	0	14	9	23	0.21275
16	*Leiognathus equulus*	Common slipmouth	Leiognathidae	Perciformes	0	0	0	0	11	7	18	0.1665
17	*Lethrinus mahsena*	Sky emperor	Lethrinidae	Perciformes	0	0	0	0	1	3	4	0.037
18	*Liza macrolepis*	Large scale mullet	Mugilidae	Perciformes	143	322	479	268	15	12	1239	11.46075
19	*Lobotes surinamensis*	Triple tail	Lobotidae	Perciformes	0	0	0	0	1	0	1	0.00925
20	*Lutjanus fulviflammus*	Black-spot snapper	Lutjanidae	Perciformes	0	0	0	2	1	0	3	0.02775
21	*Macrobrachium rude*	Furry-armed river	Palaemonidae	Decapoda	0	0	21	0	0	0	21	0.19425

		shrimp										
22	*Macrobrachium spp*	Fresh water shrimp	Palaemonidae	Decapoda	0	0	0	0	3	2	5	0.04625
23	*Megalops cyprinoides*	Indo-Pacific tarpon	Megalopidae	Elopiformes	0	0	0	1	0	5	6	0.0555
24	*Mugil cephalus*	Flathead mullet	Mugilidae	Perciformes	185	553	536	236	49	20	1579	14.60575
25	*Oreochromis mossambicus*	Mozambique tilapia	Cichlidae	Perciformes	0	0	1	0	23	6	30	0.2775
26	*Oreochromis spirulus spirulus*	Sabaki tilapia	Cichlidae	Perciformes	29	0	0	7	30	8	74	0.6845
27	*Pellona ditchela*	Indian pellona	Clupeidae	Clupeiformes	0	1	3	12	28	56	100	0.925
28	*Penaeus indicus*	White shrimp	Penaeidae	Decapoda	25	59	3	101	6	0	194	1.7945
29	*Penaeus monodon*	Giant tiger prawn	Penaeidae	Decapoda	16	54	3	54	8	6	141	1.30425
30	*Penaeus semisulcatus*	Tiger prawn	Penaeidae	Decapoda	5	24	1	20	0	1	51	0.47175
31	*Periophthalmus sobrinus*	Mudskipper	Gobiidae	Perciformes	0	0	0	0	2	0	2	0.0185
32	*Scylla serrata*	Mangrove crab	Portunidae	Decapoda	0	0	0	1	0	0	1	0.00925
33	*Schilbe intermedius*	Butter catfish	Schilbidae	Siluriformes	0	0	0	2	0	5	7	0.06475
34	*Siginus rivulatus*	Rivulated rabbitfish	Siganidae	Perciformes	0	0	0	0	0	3	3	0.02775
35	*Sillago sihama*		Sillagidae	Perciformes	5	2	0	14	1	2	24	0.222
36	*Stenogobius kenyae*	Africa river goby	Gobiidae	Perciformes	0	0	2	2	3	0	7	0.06475
37	*Synodontis serpentis*	Tana squeaker	Mochokidae	Perciformes	0	0	0	0	0	1	1	0.00925
38	*Terapon jarbua*	Crescent-banded grunter	Teraponidae	Perciformes	0	7	1	93	29	57	187	1.72975
39	*Thryssa setirostris*	Longjaw glassnose	Engraulidae	Clupeiformes	0	0	0	0	1	19	20	0.185
40	*Valamugil buchanani*	Blue-tail mullet	Mugilidae	Perciformes	181	533	560	300	26	12	1612	14.911
41	*Yongeichthys nebulosus*	Shadow goby	Gobiidae	Perciformes	0	0	0	0	11	0	11	0.10175
Total					**660**	**2372**	**5583**	**1451**	**384**	**357**	**10807**	**99.96475**

3.2.2 Fish abundance

Fish abundance was determined in terms of relative numbers and catch per unit of effort (CPUE).

3.2.2.1 Relative numbers

Fish abundance at each sampling site in the estuary is depicted in Figure 16. The mean number of individuals ranged from 16.67 to 3.3 from SBK0 through to SBK4, respectively. Fish was more abundant at SBK0 where 54.6% of the fish was caught. SBK0 had a high variability of fish caught. On the contrary, SBK4 registered a relatively low number of individuals, 9.7%. Fish abundance significantly varied between SBK0 and other sites ($P < 0.05$). However, variations in fish abundance between SBK1, SBK2, SBK3 and SBK4 were not significant ($P > 0.9$)

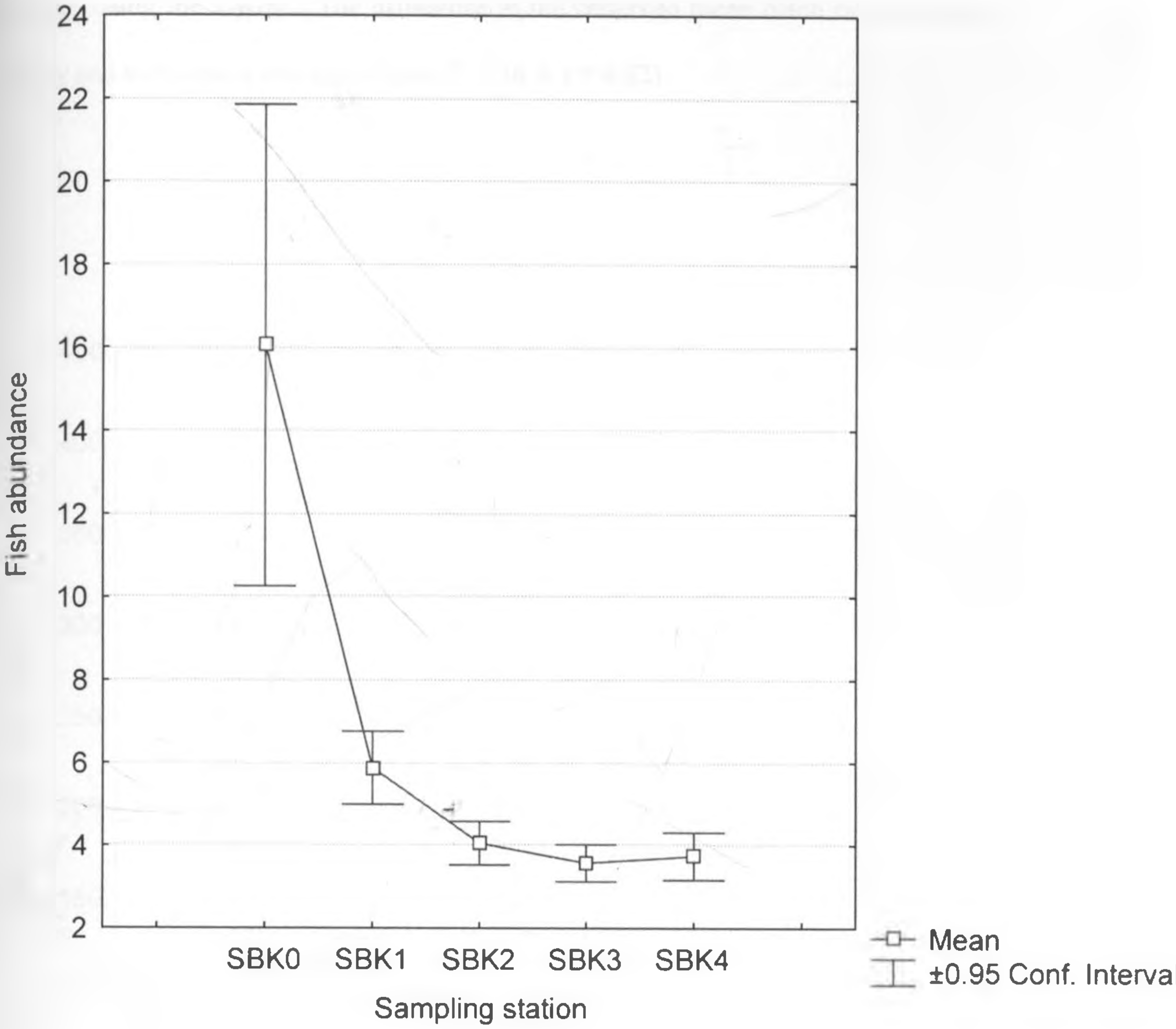

Fig.16. Spatial variation in fish abundance

3.2.2.2 Catch per Unit of Effort (CPUE)

A total of 191.9 Kg of fish was realized in this study. Figure 17 shows the temporal variation in fish catch rates., More fish was caught during the dry season than the wet season. In this period, CPUE of 0.186 Kghr^{-1} was attained. Fish catches declined in the rain season, where mean CPUE of 0.074 Kghr^{-1} was recorded. Monthly catches indicated that March had the highest CPUE of .0.245 Kghr^{-1} compared to 0.07 Kghr^{-1}

in June, being the lowest. The difference in the observed mean catch rates between the dry and wet season was significant (F = 38.4, t = 4.82)

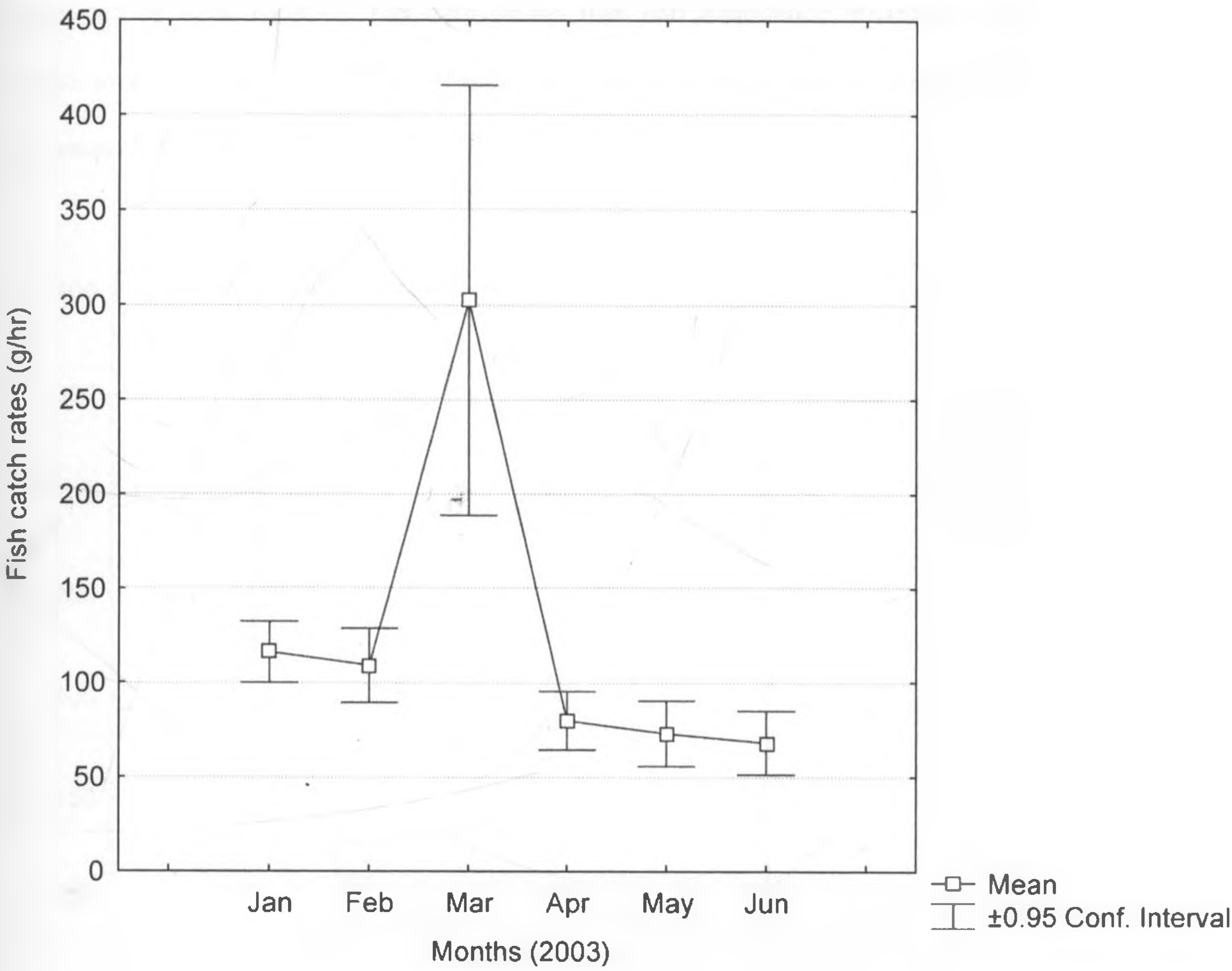

Fig.17. Temporal variation in fish catch rates at the Sabaki estuary

Spatial variation in CPUE is shown in Figure 18. Fish was more abundant in seaward stations. 54.7% of the individuals were caught at SBK0. SBK1 contributed 16.4% of the fish caught while SBK3 had the lowest, accounting for 7.7% of the total catch.

A mean catch rate of 0.259 $Kghr^{-1}$ was realized at SBK0, while SBK4 recorded the lowest rate of 0.06 $Kghr^{-1}$. The data shows that fish abundance decreased with distance away from the sea. SBK0 significantly varied with other sites in terms of fish catch rates ($P < 0.05$)

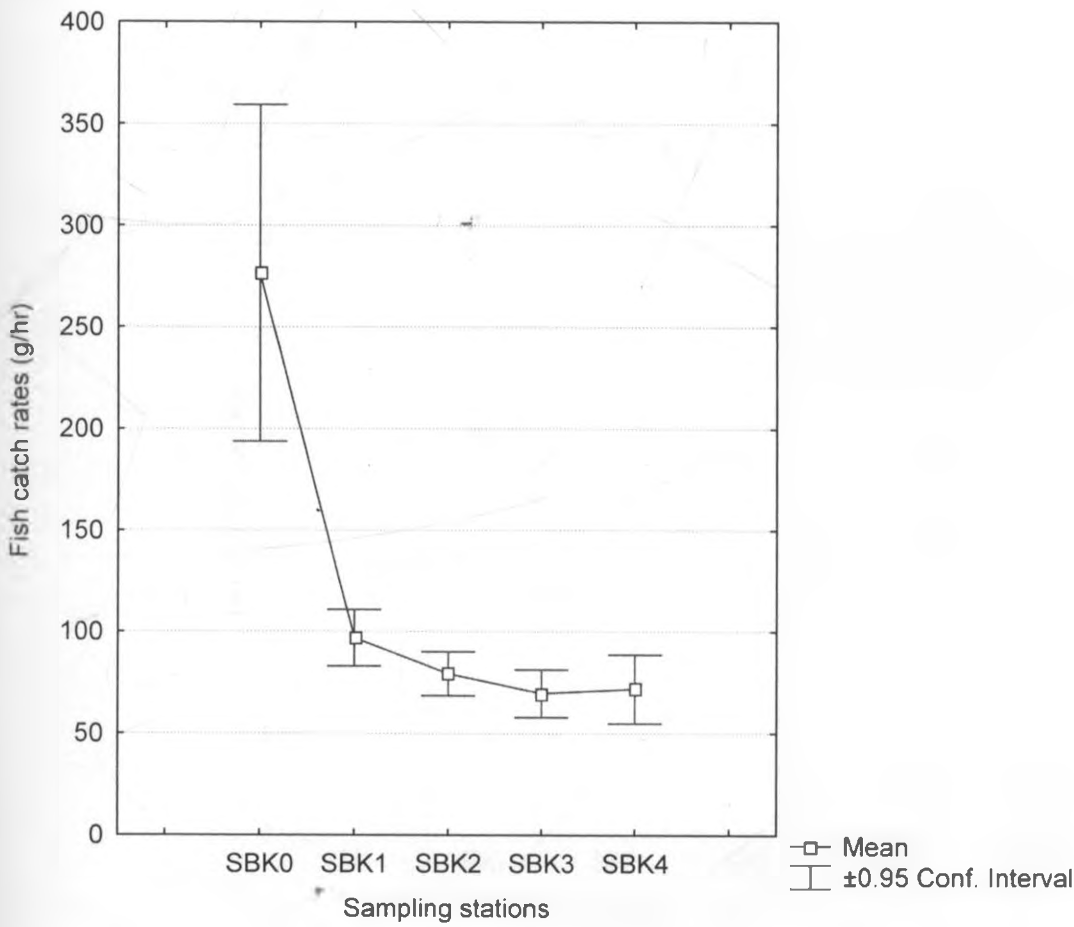

Fig.18. Spatial variation in fish catch rates

3.2.3 Species richness

Figure 19 shows variation in species richness of fish and crustaceans caught in the various sampling stations in the estuary during the study. SBK4 had the highest species richness, recording 29, and closely followed by SBK0 with 26 species. Middle stations had a near stable number of species ranging between 17 and 20. Overall, there were 41 species. The stations located upstream and seaward, SBK4 and SBK0, respectively, recorded high number of fish species. This was attributed to the influx of riverine species from upstream waters to SBK4, and species of oceanic origin to SBK0.

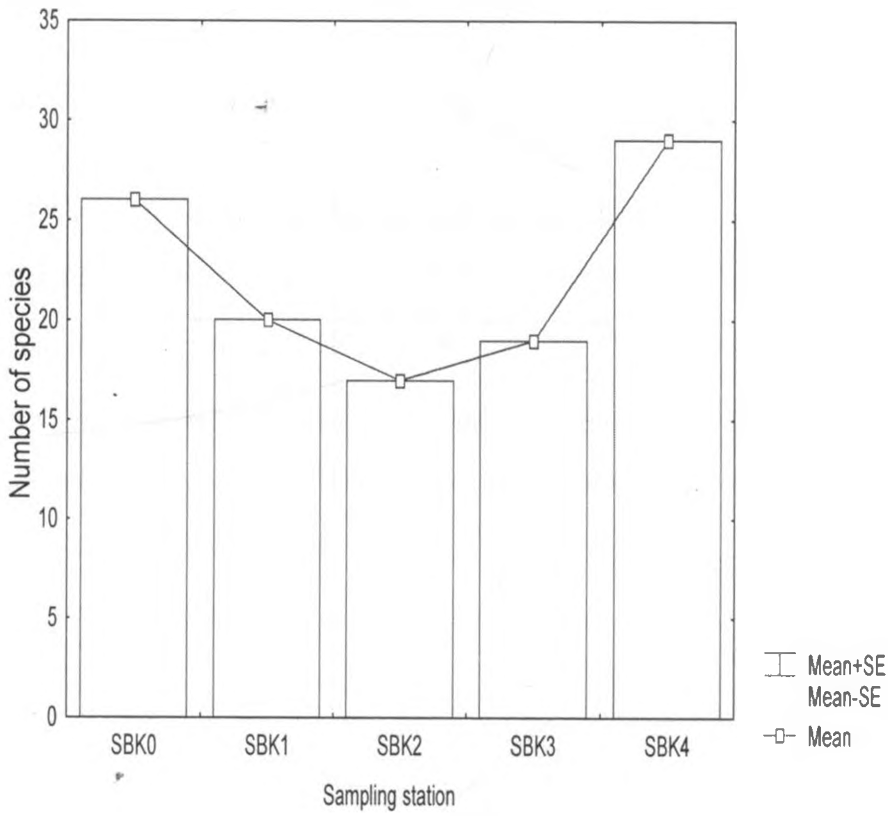

Fig. 19. Spatial variations in species richness at the River Sabaki estuary

Temporal distribution of fish species in the River Sabaki estuary is shown in Table 1 above. A total of 35 species of fish and 6 species of crustaceans were caught in this study. More species of fish and crustaceans were realized in the wet season compared to the dry period. For instance, an average of 13 species were caught in the dry season whereas 26 in the wet season. The difference in the number of fish species caught in the dry and wet seasons was significant ($F = 49.3$, $t = 5.21$). This suggested that seasonal variation in the species distribution of estuarine fishes was associated with temporal changes in environmental factors.

3.2.4 Species diversity

Shannon – wiener species diversity index for the fish and crustaceans sampled is shown in Figure 20.

Species diversity was low in seaward stations, unlike species richness. Upstream station recorded the highest species diversity with 2.61 species compared to 1.3 species at the oceanic station. Species diversity increased with distance away from the sea. Overall analysis indicates that the Sabaki estuary has a species diversity of 20. This figure could be an underestimation due to technicality involved in the sampling.

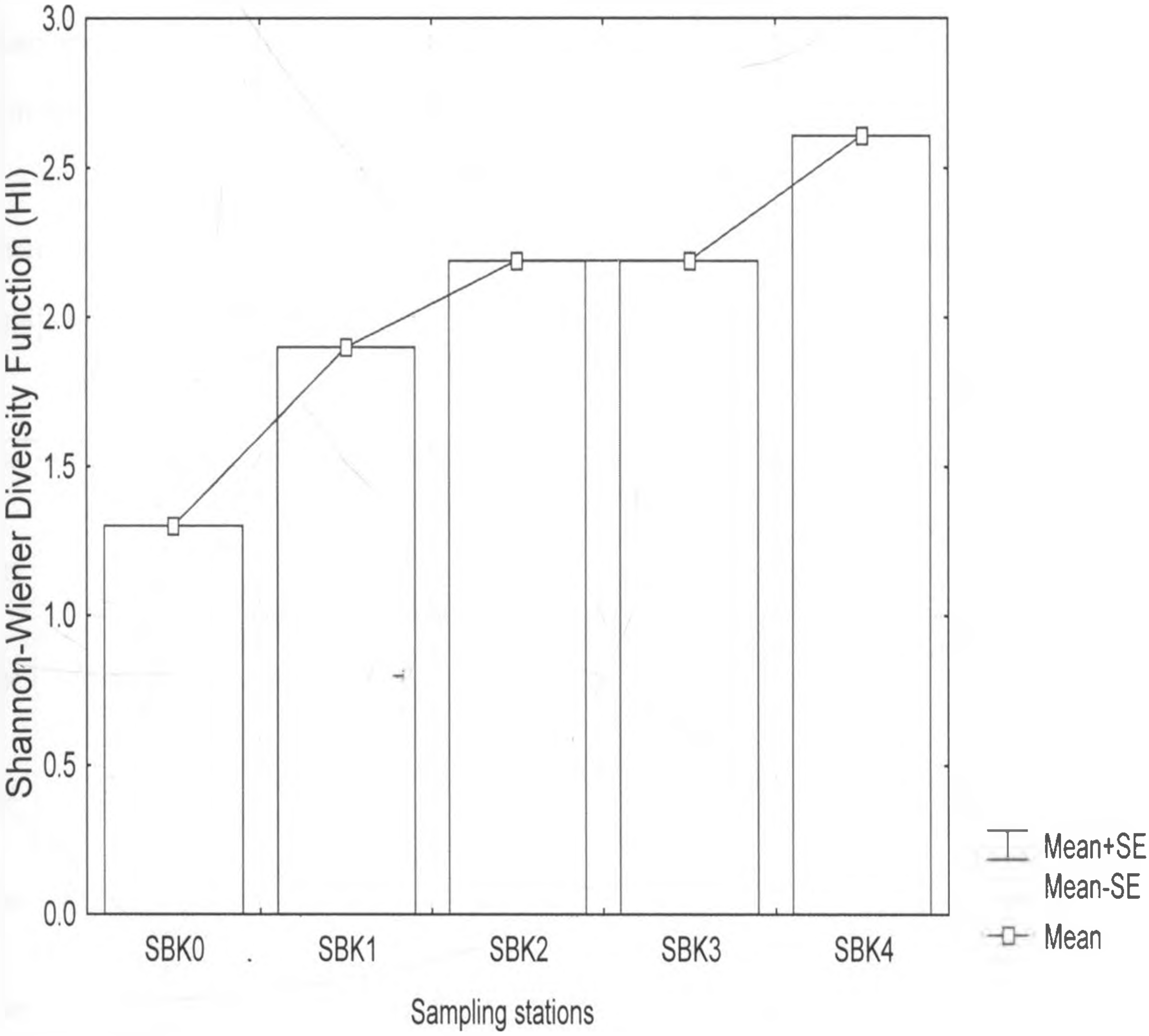

Fig .20. Spatial variation in fish species diversity

3.2.5 Size composition

Mean total length of fish caught during the sampling period is shown in Figure 21. Maximum length of fish caught was 42.0 cm. This was a cyprinid, *Megalops cyprinoides*. The shortest fish recorded was a newly hatched *Arius africanus*, which measured 0.5 cm. The results indicate that most of the fish trapped were in the size range of 5.0 – 10 cm. Individuals of size range, 0.5 –10 cm accounted for 93.6% of the total fish caught in this study. This data suggests that most of the fish caught in the estuary were juveniles. This was further confirmed by comparing the sizes of fish caught in the sample with their respective sizes at maturity.

The difference in the observed mean sizes of fish between the dry and wet seasons was significant (F=30.7, t= 3.3).

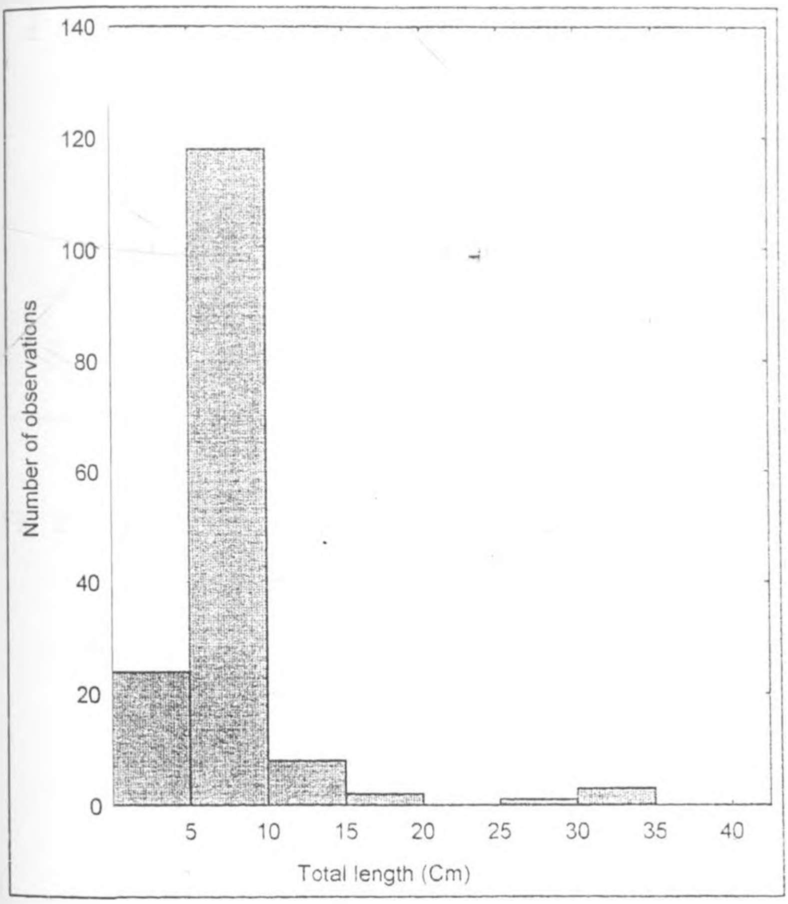

Fig. 21(a). Length frequency distribution for *Arius africanus*

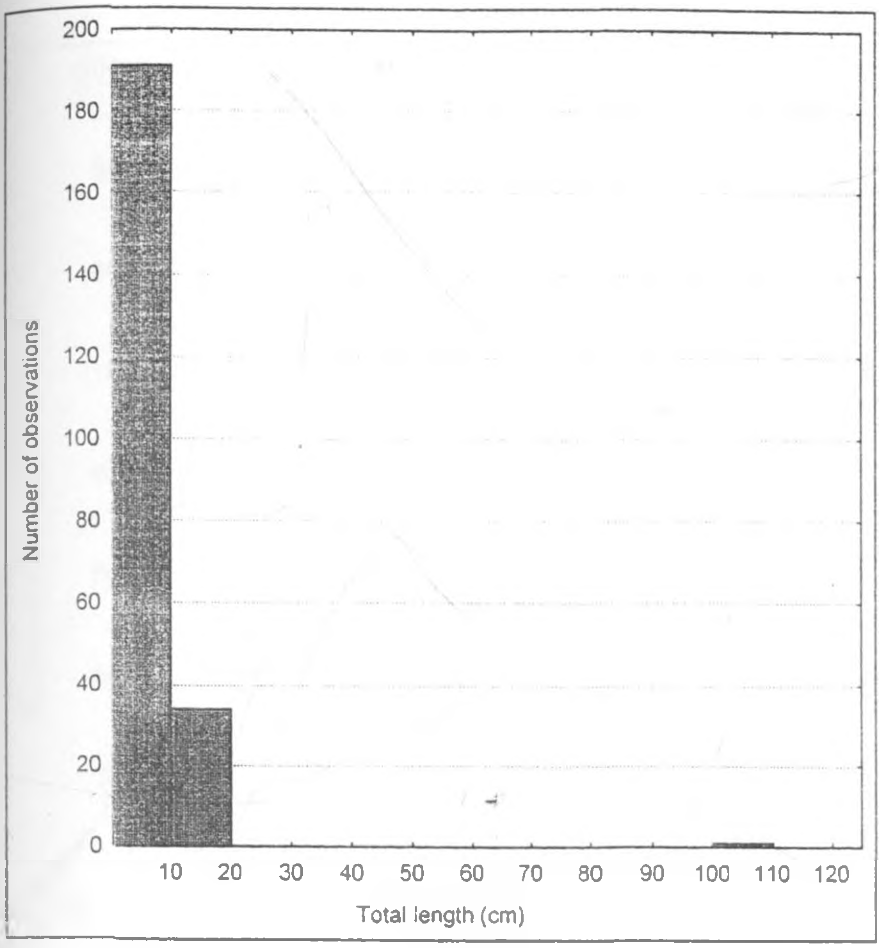

Fig. 21 (b). Length frequency distribution for *Valamugil buchanani*

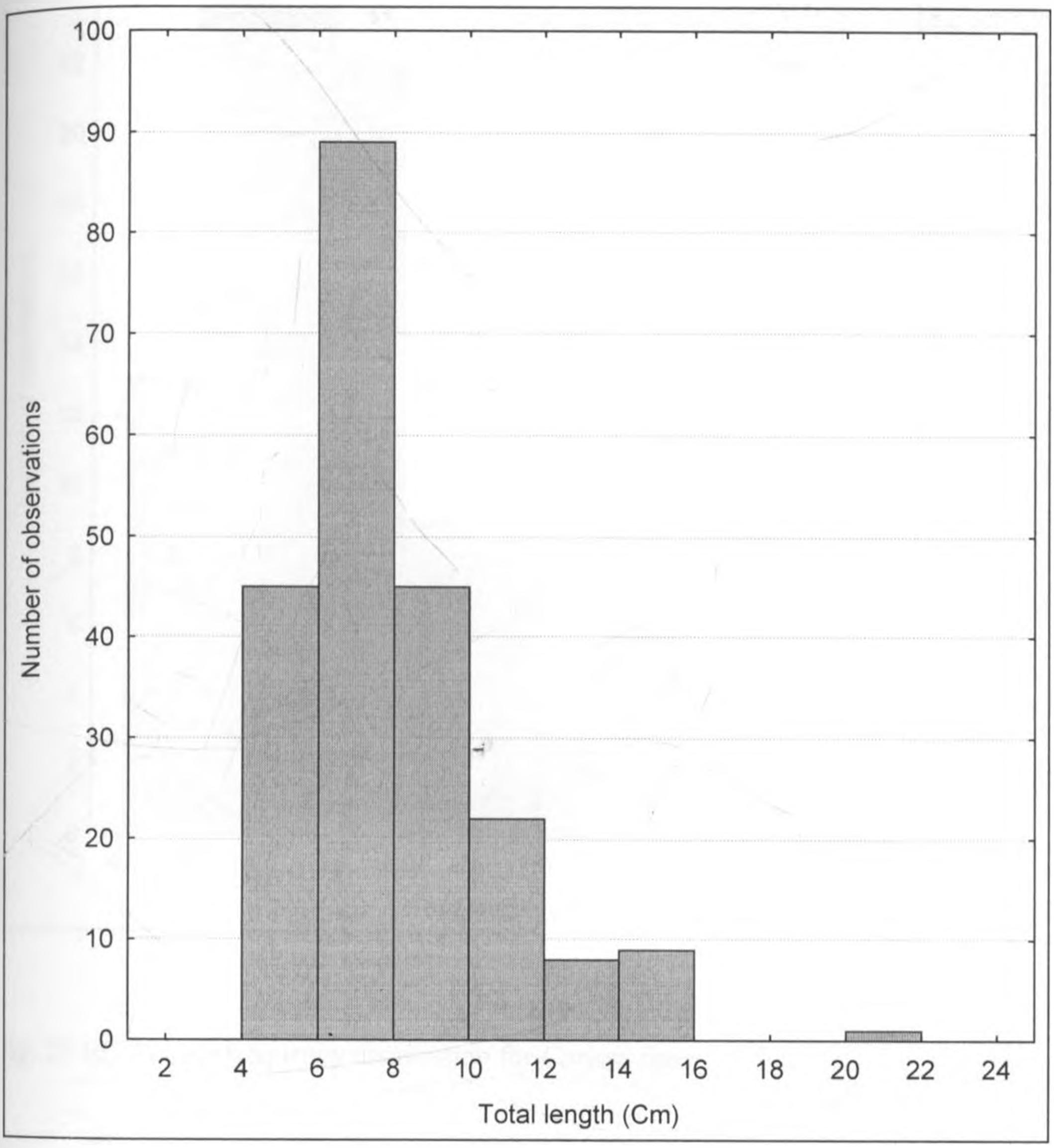

Fig. 21 (c). Length frequency distribution for *Liza macrolepis*

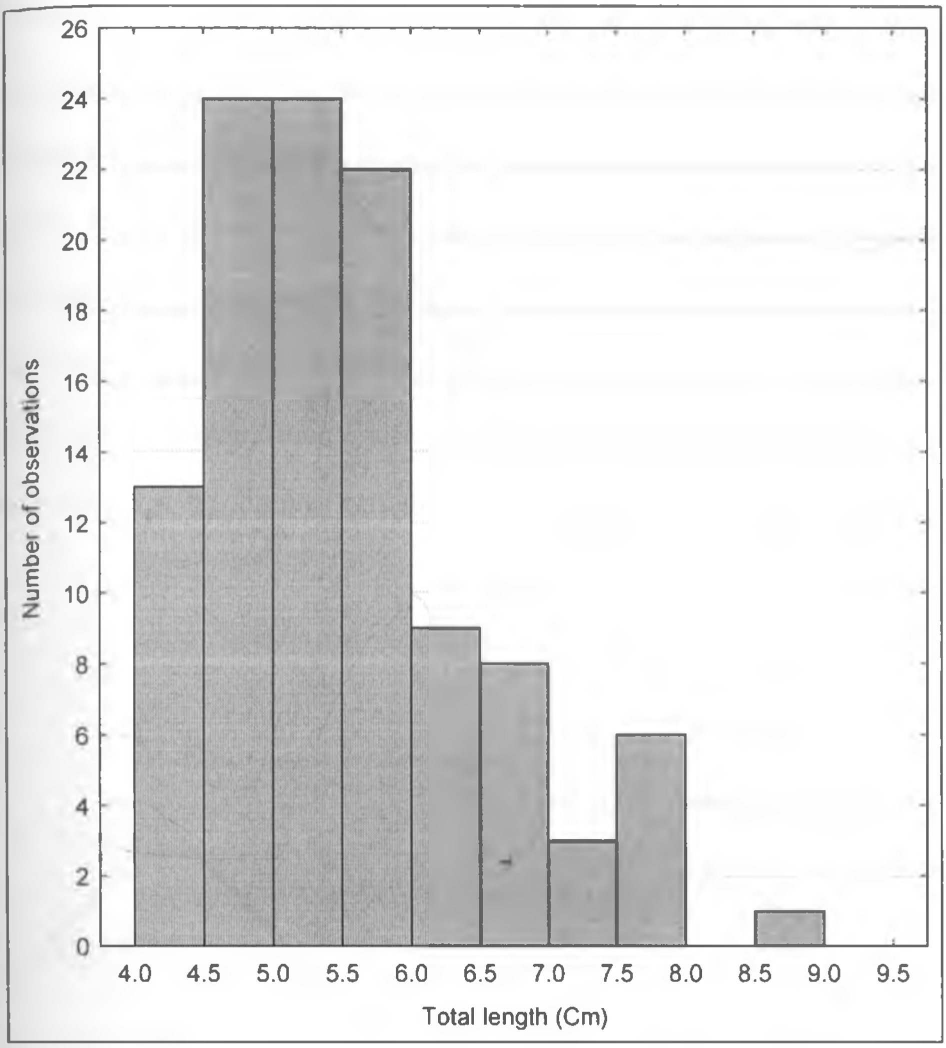

Fig. 21 (d). Length frequency distribution for *Caranx spp*

Variations in size with distance away from the sea in some selected fish species is depicted in Figures 22 - 25. The choice of species for this analysis was based on their occurrence in all the sampling stations as well as considerable contribution to total catch. The results indicated that small sized individuals of *Apogon sangiensis* (R^2 = 0.96) and *Terapon jarbua* (R^2 = 0.7) preferred less saline upstream waters. This was also noticed in the family of *Mugilidae*, although weak (R^2 = 0.31 – 0.4). R^2, a coefficient of determination indicating the contribution of the effect of distance away from the sea in the observed variation.

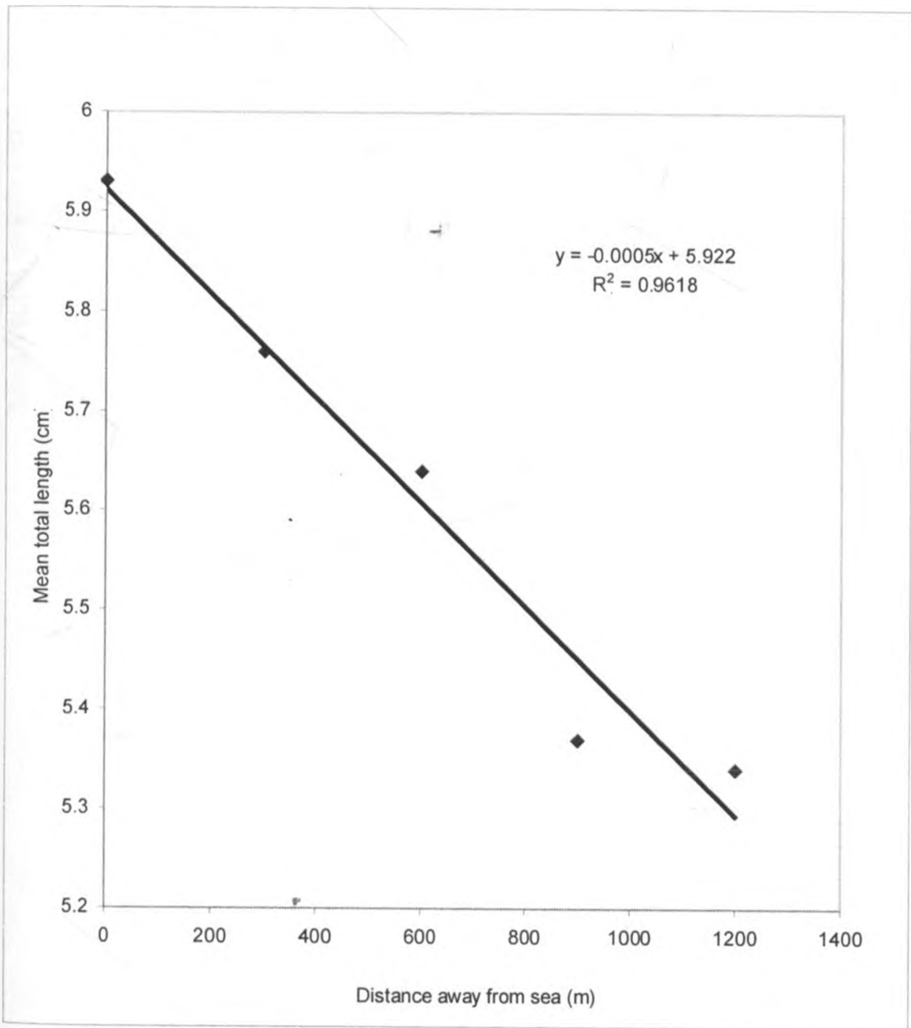

Fig.22. Spatial variation in size distribution among *Apogon sangiensis*

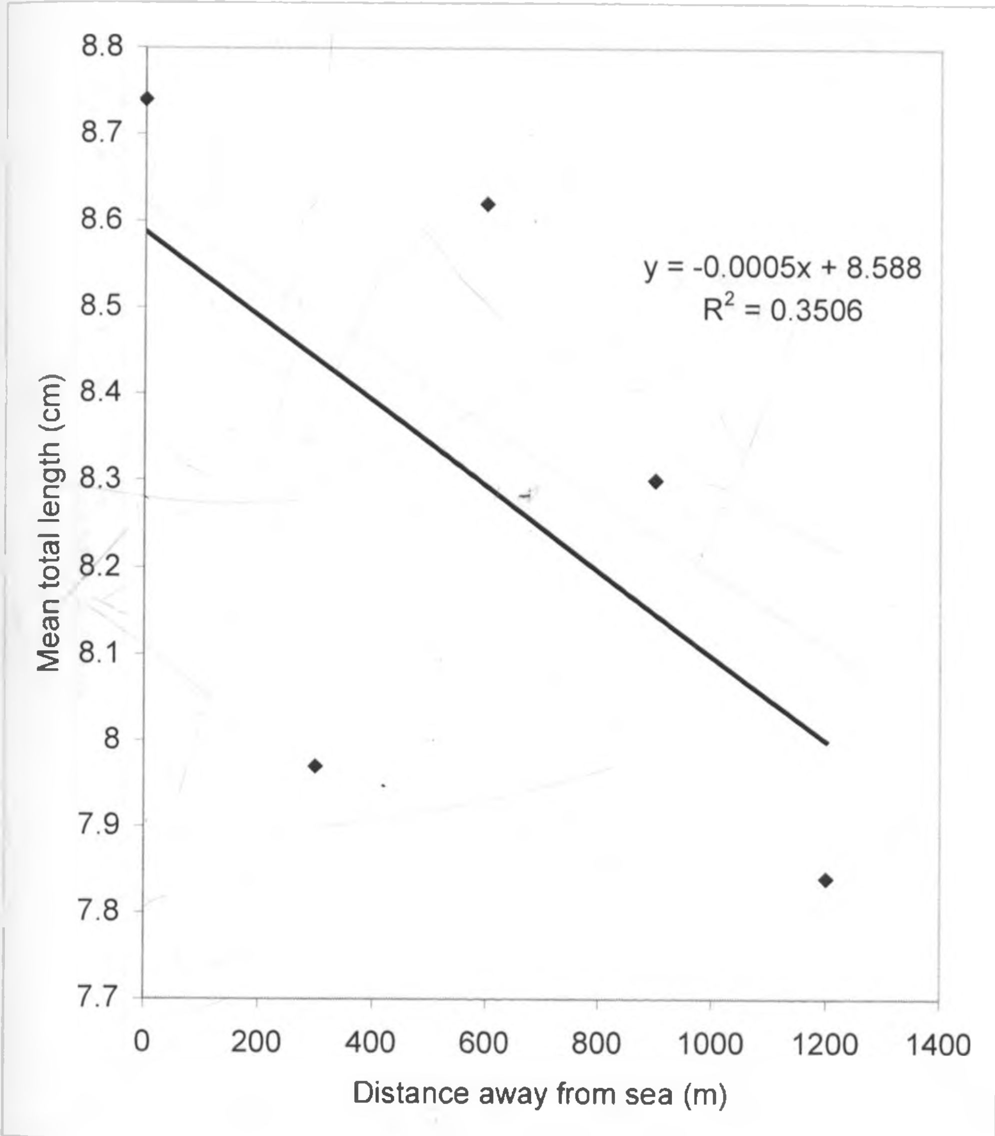

Fig .23. Spatial variation in size distribution among *Liza macrolepis*

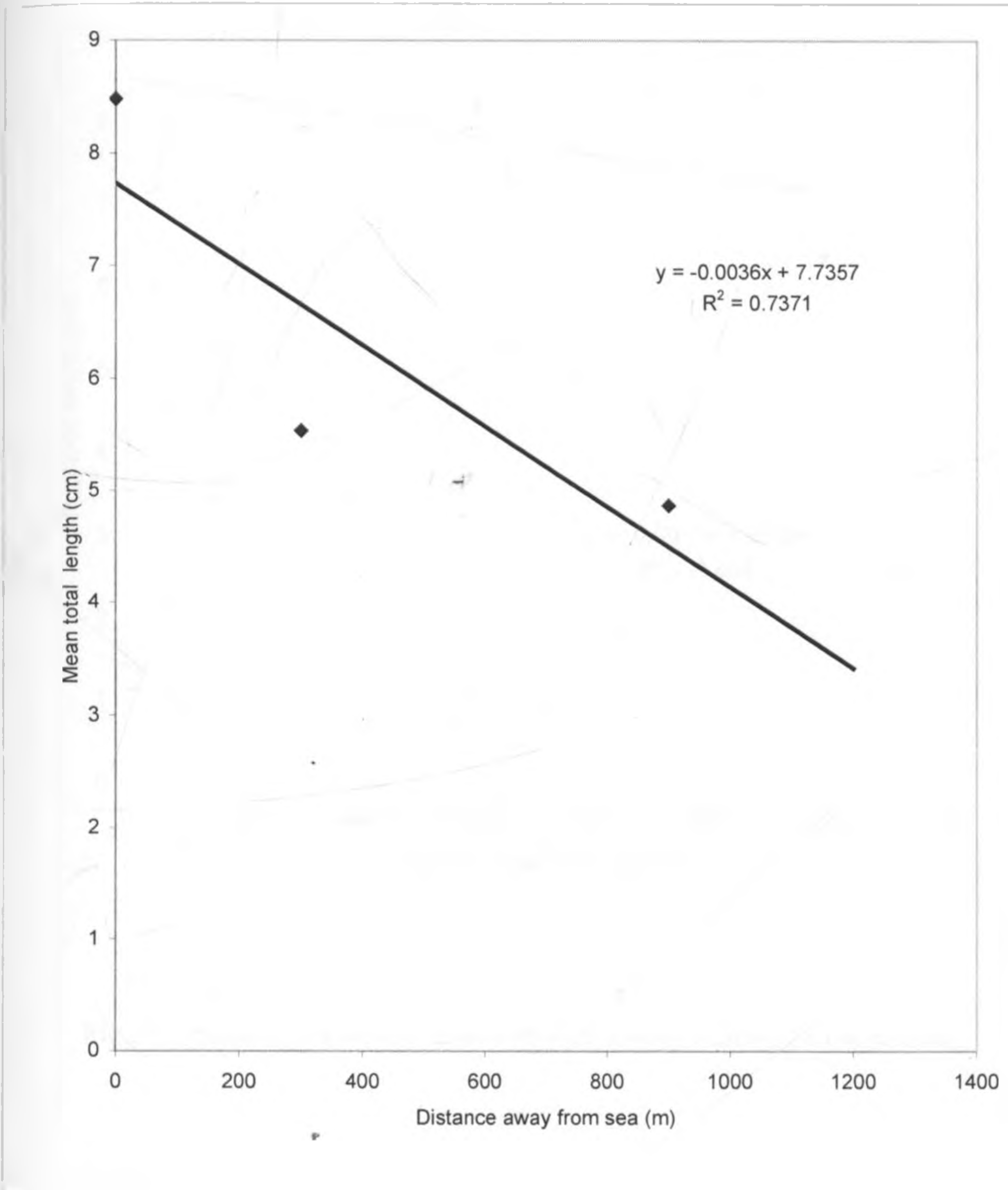

Fig.24. Spatial variation in size distribution among *Terapon jarbua*

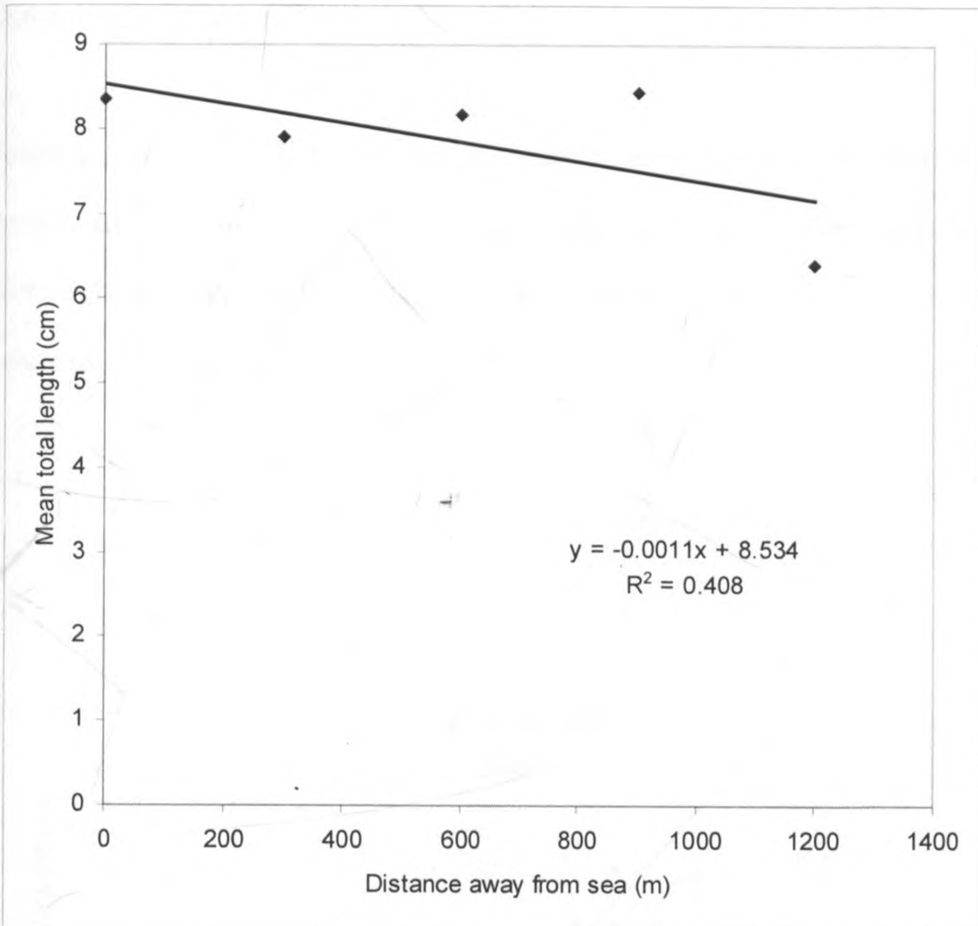

Fig.25. Spatial variation in size distribution among *Valamugil buchanani*

3.2.6. Weight – Length relationships of selected fish species

The weight-length relationships for some of the numerically abundant species are shown, respectively, as follows;

3.2.6.1 Apogon sangiensis

Weight-length relationship for *Apogon sangiensis* is shown in Figure 26. There was a strong relationship between weight and length with a coefficient of determination, R^2 = 0.85. The b value, 0.48 is not close to 3, thus indicating that none isometric growth in the species.

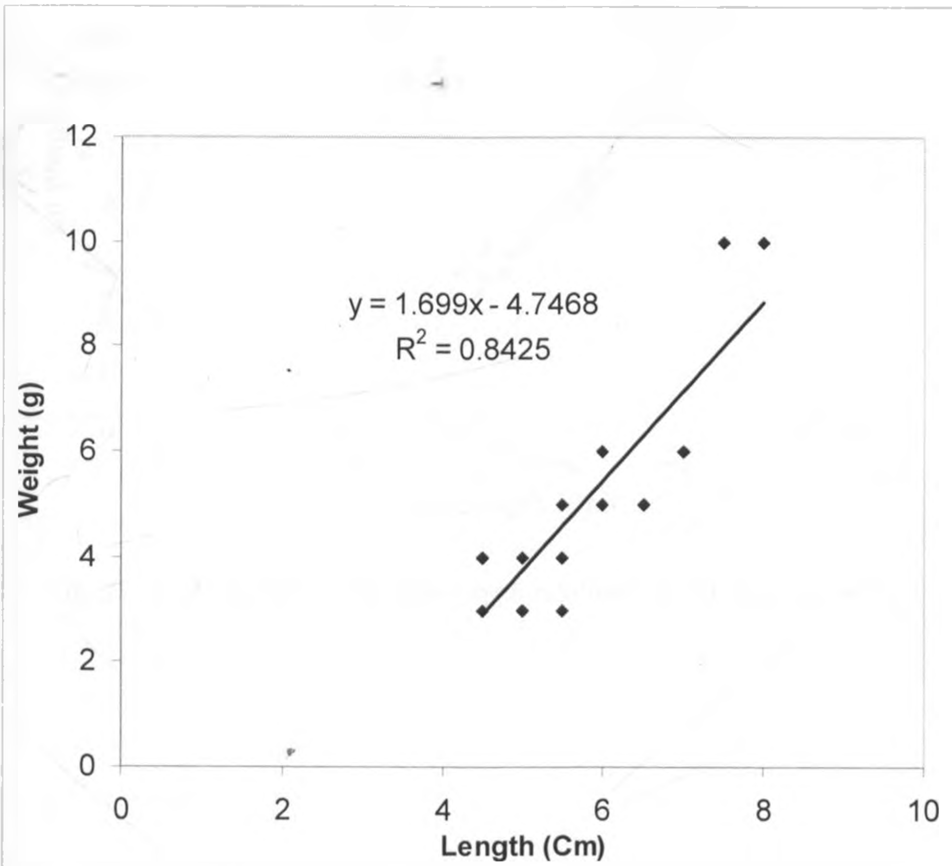

Fig. 26. Weight-length relationship for *Apogon sangiensis*

3.2.6.2 Liza macrolepis

Weight-length relationship for *Liza macrolepis* is depicted in Figure 27 (a). There was significant relationship between weight and length, however, growth was not isometric.

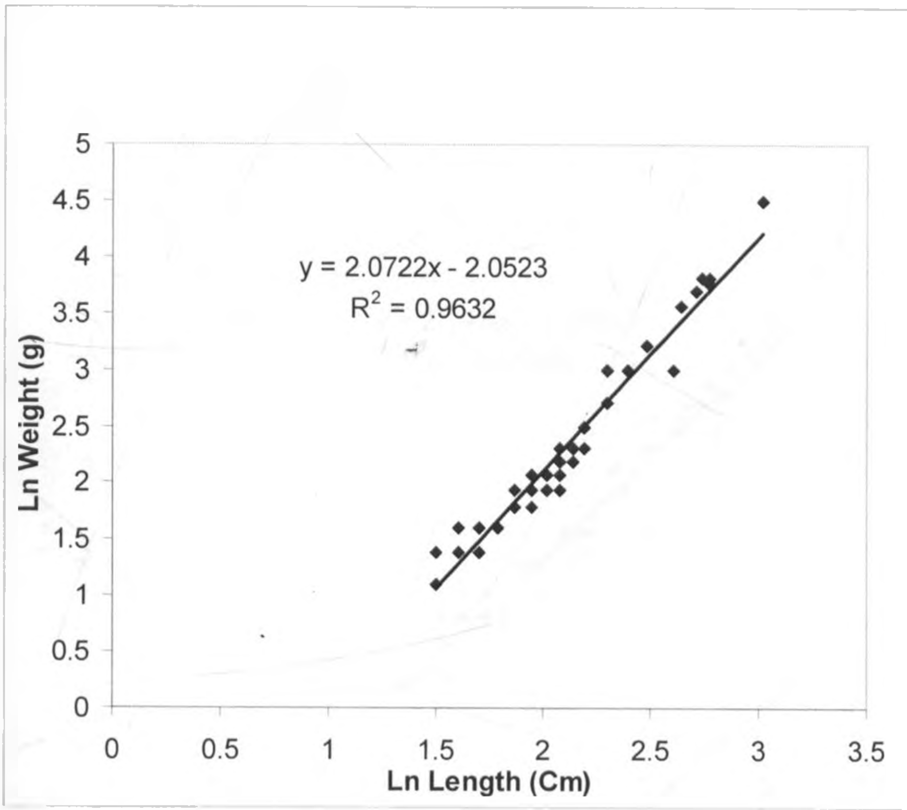

Fig .27 (a). Transformed Weight-length relationship for *Liza macrolepis*

3.2.6.3 Mugil cephalus

Weight-length relationship for *Mugil cephalus* is shown in Figure 27 (b). There was a strong relationship between weight and length as depicted by the coefficient of determination, $R^2 = 0.95$. Growth in this species is not isometric.

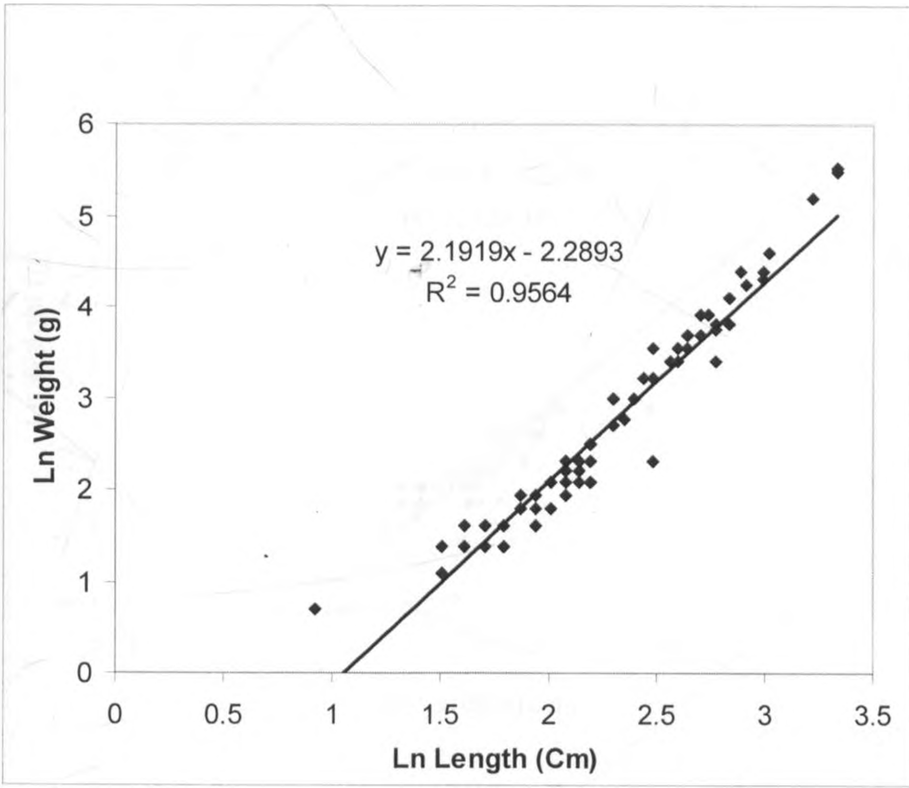

Fig.27 (b). Transformed Weight-length relationship for *Mugil cephalus*

3.2.6.4 Arius africanus

Weight-length relationship for *Arius africanus* is shown in Figure 27 (c). Relationship between weight and length is very strong as indicated by a high coefficient of determination, $R^2 = 0.84$. Growth, however, is not isometric.

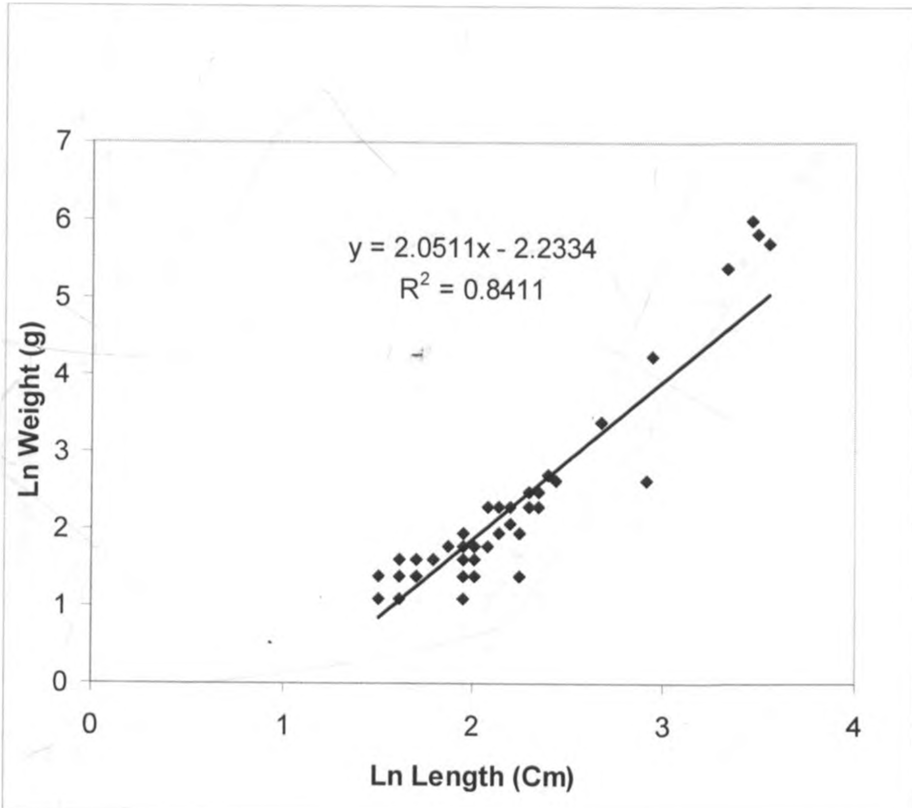

Fig.27(c). Transformed Weight-length relationship for *Arius africanus*

3.2.6.5 Valamugil buchanani

Weight-length relationship for *Valamugil buchanani* is depicted in Figure 27 (d). This shows a strong relationship between weight and length as indicated by the coefficient of determination, $R^2 = 0.96$. However, growth is not isometric.

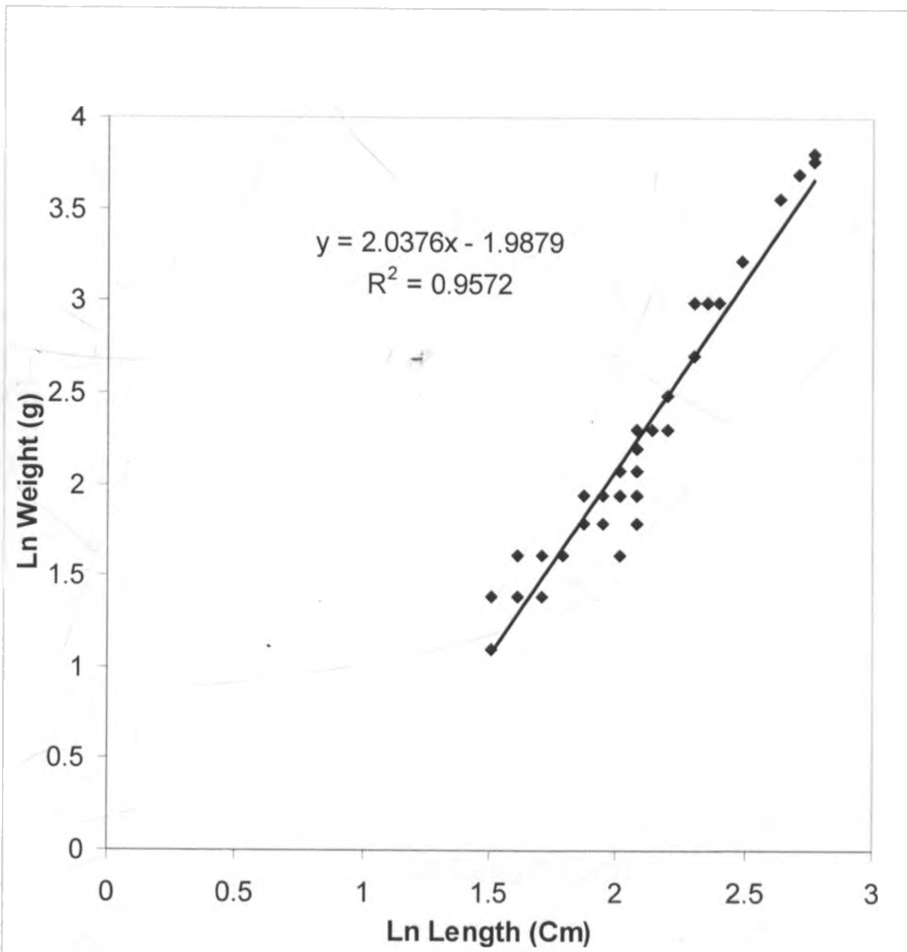

Fig .27 (d). Transformed Weight-length relationship for *Valamugil buchanani*

3.2.6.6 Carangoides spp

Weight-length relationship for *Carangoides spp* is shown in Figure 27 (e). This depicts a strong relationship between weight and length as indicated by a high correlation coefficient of determination, R^2 = 0.90. However, the growth is not isometric.

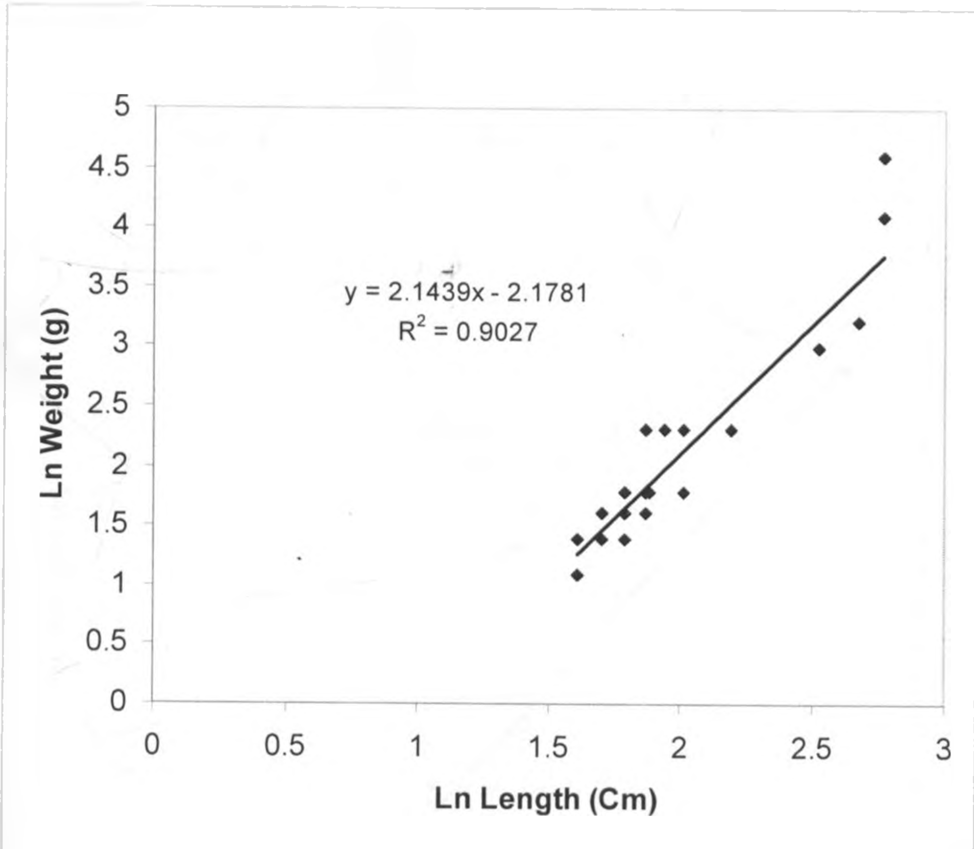

Fig. 27 (e). Transformed Weight-length relationship for *Carangoides spp*

3.2.6.7 Clarias gariepinus

Weight-length relationship for *Clarias gariepinus* is shown in Figure 27 (f). There is a highly significant relationship between weight and length as indicated by the coefficient of determination, R^2 = 0.97. The data shows that this growth was not isometric.

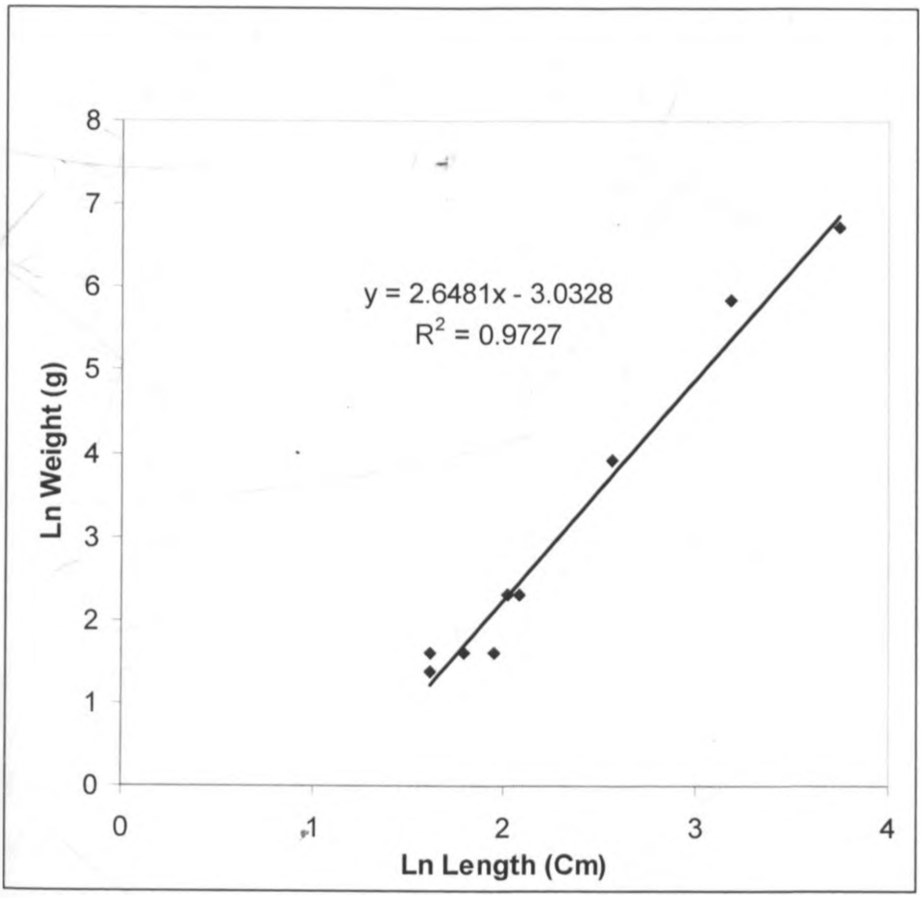

Fig. 27 (f). Transformed Weight-length relationship for *Clarias gariepinus*

3.2.6.8 Oreochromis spirulus spirulus

Figure 27 (g) shows the weight-length relationship for *Oreochromis spirulus spirulus.* The data indicates a strong relationship between weight and length as depicted by a coefficient of determination, $R^2 = 0.90$. Growth is not isometric.

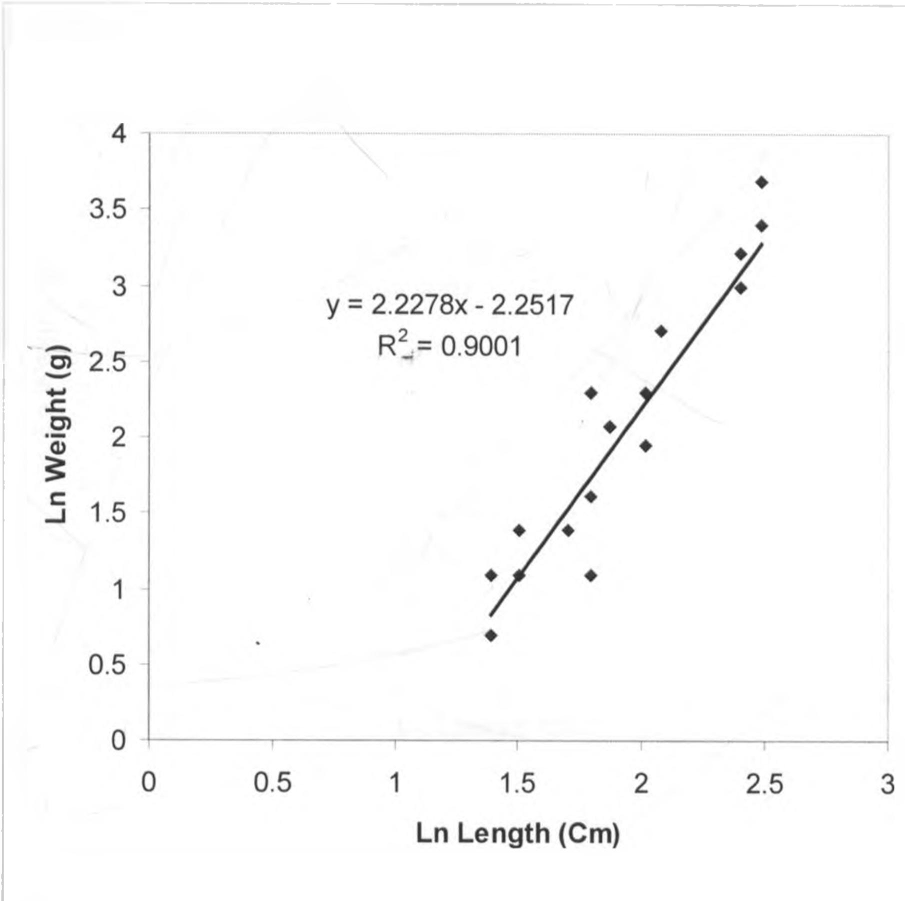

Fig. 27 (g). Transformed Weight-length relationship for

Oreochromis spirulus spirulus

3.2.6.9 Terapon jarbua

Figure 27 (h) shows the weight-length relationship for *Terapon jarbua.* The data indicates a strong relationship between weight and length as depicted by a coefficient of determination, $R^2 = 0.92$. However, the growth is not isometric.

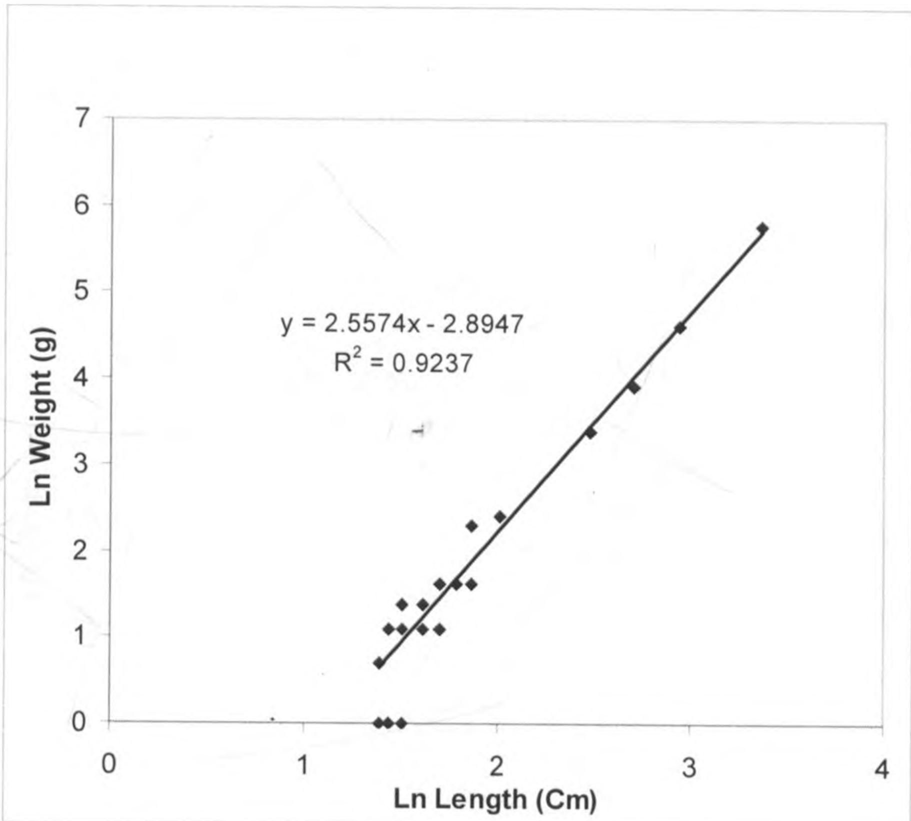

Fig. 27 (h). Transformed Weight-length relationship for *Terapon jarbua*

3.2.6.10 Penaeus monodon

Weight-length relationship for *Penaeus monodon* is shown in Figure 27 (i). There is significant relationship between weight and length as depicted by a coefficient of determination, $R^2 = 0.76$. There is no isometric growth

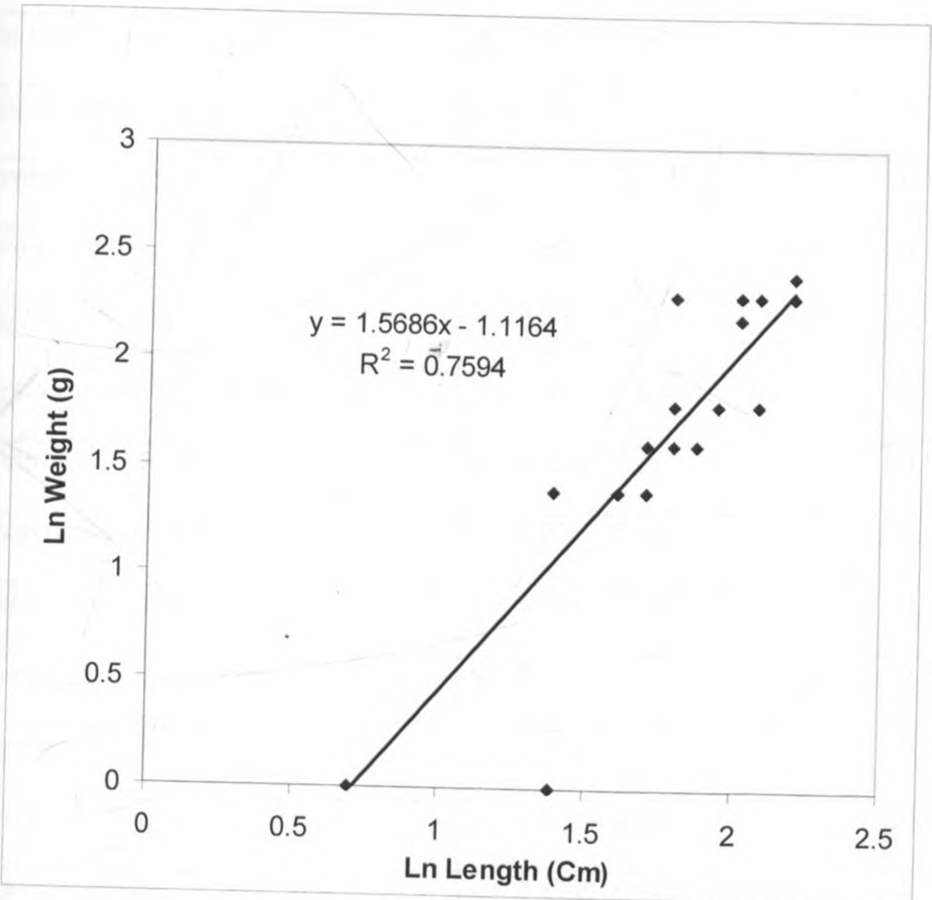

Fig. 27. Transformed Weight-length relationship for *Penaeus monodon (i)*

Table 2. A summary of weight-length relationships for various fish species for comparison

Species	**Descriptive Equation**	**R^2 Value**
Arius africanus	y = 2.05x – 2.23	0.84
Mugil cephalus	y = 2.19x – 2.29	0.96
Valamugil buchanani	y = 2.03x – 1.99	0.96
Liza macrolepis	y = 2.07x – 2.05	0.96
*Apogon sangiensis**	$y = 2.66x^{0.48}$	0.85
Carangoides spp	y = 2.14x – 2.17	0.90
Caranx spp	y = 1.82x – 1.5	0.61
Clarias gariepinus	y = 2.64 – 3.03	0.97
Herklostsichthys quadrimaculatus	y = 1.81x - 1.82	0.73
Johnius dussumieri	y = 2.28x – 2.26	0.88
Leiognathus equulus	y = 2.23x – 2.06	0.96
Oreochromis mossambicus	y = 1.81x – 1.69	0.75
Oreochromis spirulus spirulus	y = 2.22x – 2.25	0.90
Pellona ditchela	y = 2.02x – 2.03	0.79
Terapon jarbua	y = 2.56x – 2.89	0.92
Penaeus indicus	y = 0.99x – 0.06	0.34
Penaeus monodon	y = 1.57x – 1.11	0.76

* Data not transformed for direct plot gave a linear relationship

Relationship between environmental parameters and fish species distribution are shown by Canonical Correspondence Analysis (CCA) biplot in Figure 28. There is a clear pattern of fish species assemblages in relation to different environmental variables within the Sabaki estuary.

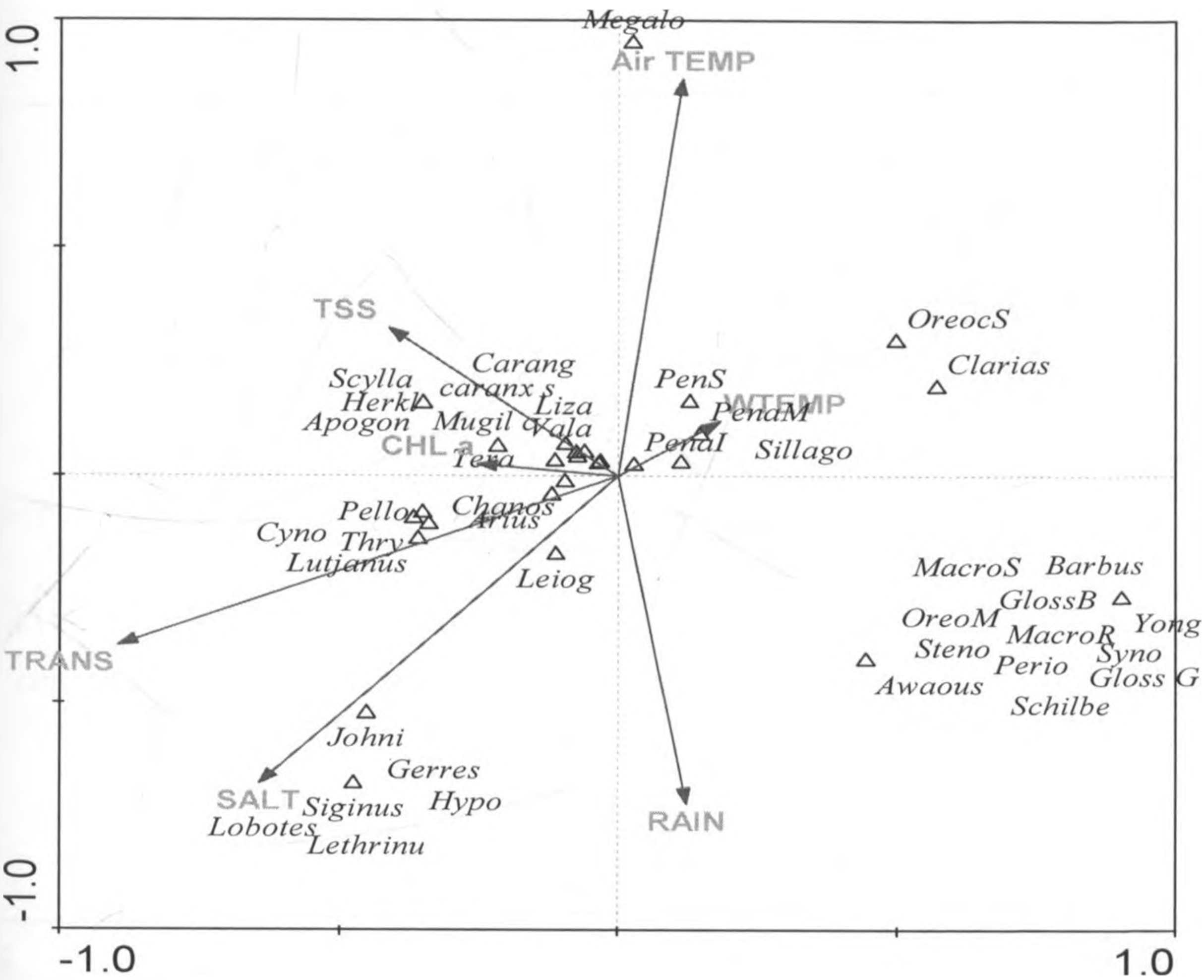

Fig.28. A CCA Biplot showing the association between fish species and environmental variables.

Figure 29. A PCA ordination diagram shows the aggregation of fish species in different sites. Fish species are more abundant at SBK0 and SBK4. SBK0 and SBK4 are negatively correlated. SBK0 are mainly marine. SBK4 fresh water while the SBK1, SBK2 and SBK3 are brackish zones.

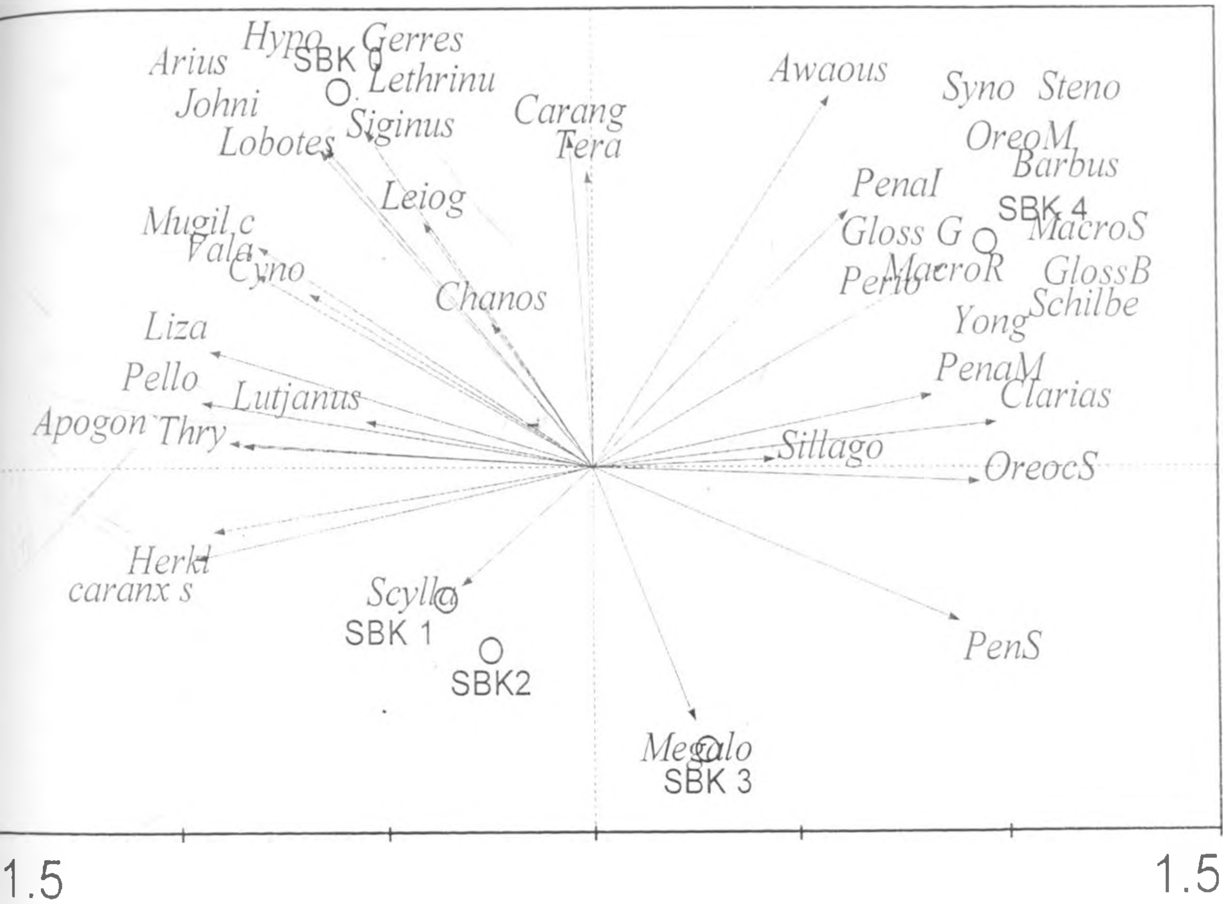

Fig. 29. A PCA Ordination diagram showing the association of different species with different sites.

3.3 Component Interactions

Results of the correlation analysis for the various parameters monitored by this study are shown in Table 3. The number of individuals of fish and crustaceans caught positively correlated with water transparency, water temperature, air temperature and salinity with correlation coefficients of 0.180, 0.153, 0.125 and 0.089, respectively. There was a positive correlation between total weight of the catch, and catch per unit of effort (CPUE) with total length, water transparency, water temperature, air temperature and salinity whose respective correlation coefficients were 0.125, 0.165, 0.109, 0.069 and 0.102.

Variation in fish catch with visibility is shown in Figure 30. Fish catch increased with improvement in visibility. Highest CPUE (245 g/hr) corresponded with maximum visibility of 14.6 cm.

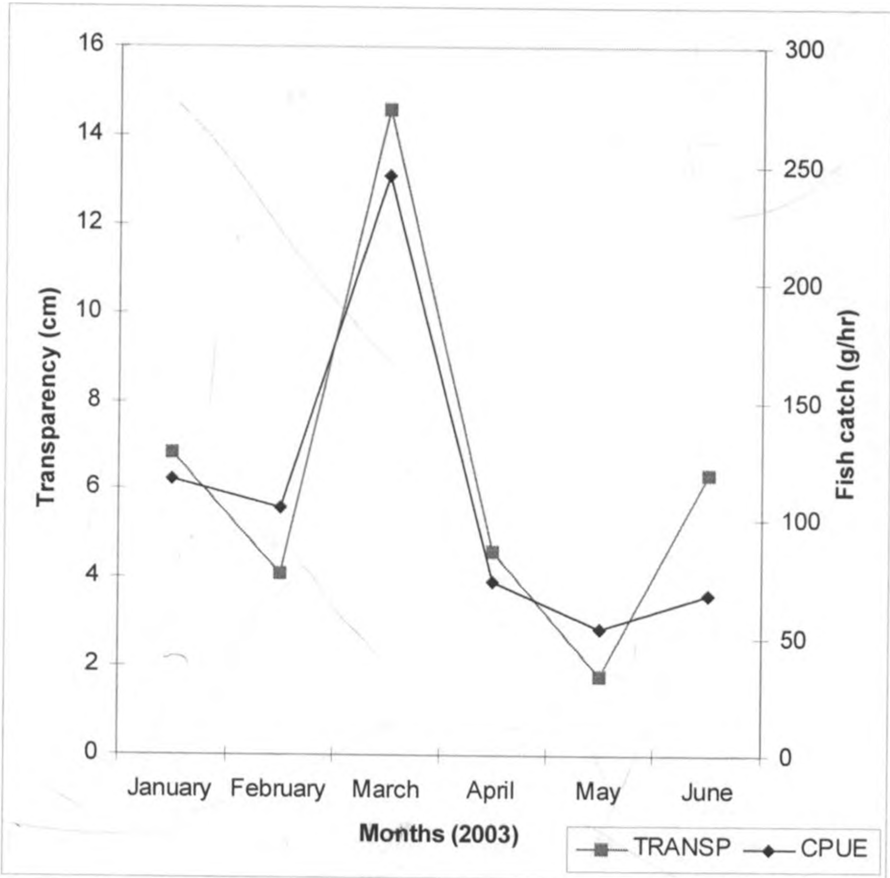

Fig. 30. Temporal variation in fish catch rates with transparency

A negative relationship was noted between total weight, and CPUE with rainfall, total suspended sediments and chlorophyll. Figure 31 shows temporal variation of fish catch (CPUE) with TSS concentration. Fish catch reduced with increase in TSS supply.

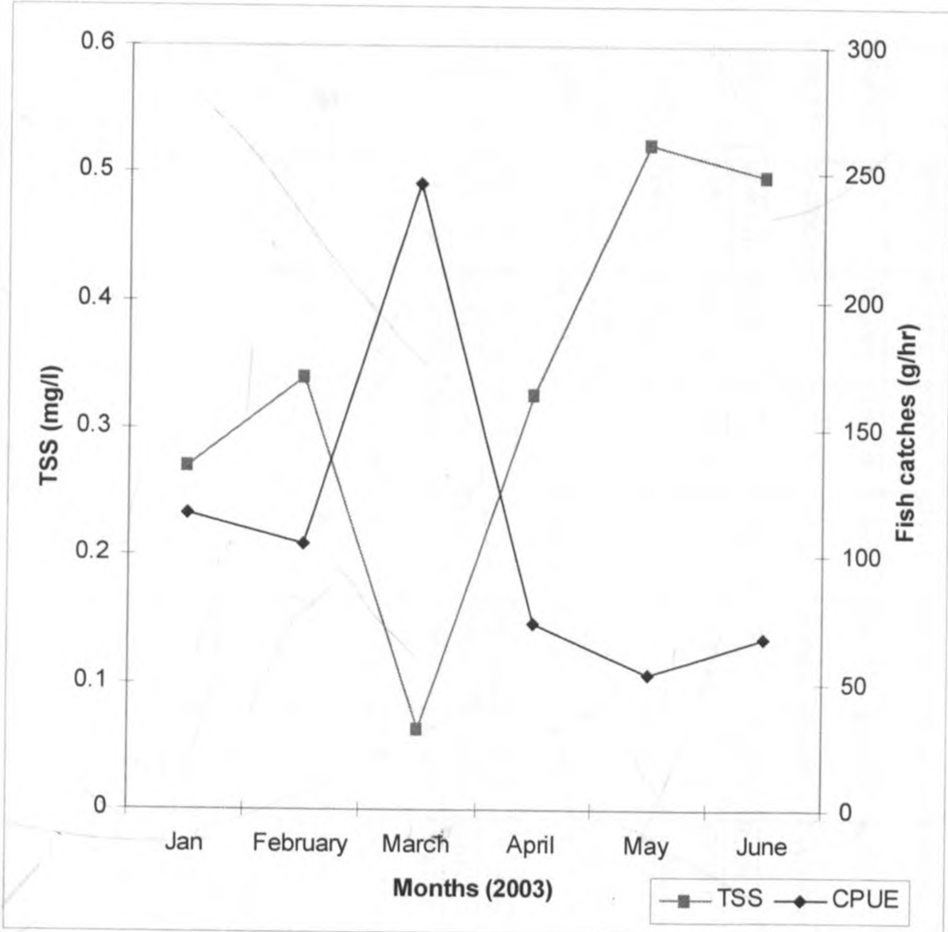

Fig. 31. Temporal relationship between TSS and CPUE

It was noted that the weight of each individual fish and crustacean in the sample had a strong and positive relationship with length. Correlation coefficients of 0.5 were recorded for fork length (FL) whereas 0.78 for total length (TL).

The results of the correlation analyses showed that environmental factors related with the biotic communities in the estuary.

Table 3. Correlation matrix

Correlations are significant at p < .05000														
N=1485 (Case wise deletion of missing data)														
	Species	Population	Weight of individuals	Total weight	CPUE	Fork length	Total length	Rainfall	Transparency	Water temp.	Air temp.	TSS	Chl-a	Salinity
Species	1	-0.06628	0.133767	-0.04452	-0.04452	-0.14513	0.142695	0.09049	-0.18424	-0.28063	-0.28735	0.405488	0.290138	0.054167
Population	-0.06628	1	-0.04625	0.926639	0.926639	0.003431	-0.03861	-0.05855	0.180208	0.153281	0.125016	-0.17145	-0.08743	0.089957
Weight of individuals	0.133767	-0.04625	1	0.12386	0.12386	0.504925	0.7873	-0.0307	-0.09256	-0.13804	-0.16966	0.164057	0.042565	0.052452
Total weight	-0.04452	0.926639	0.12386	1	1	0.118633	0.124908	-0.06945	0.165012	0.109684	0.06983	-0.13728	-0.06991	0.102891
CPUE	-0.04452	0.926639	0.12386	1	1	0.118633	0.124908	-0.06945	0.165012	0.109684	0.06983	-0.13728	-0.06991	0.102891
Fork length	-0.14513	0.003431	0.504925	0.118633	0.118633	1	0.710512	-0.04824	0.035961	-0.15241	-0.19383	0.046495	0.054296	0.069629
Total length	0.142695	-0.03861	0.7873	0.124908	0.124908	0.710512	1	-0.03243	-0.07977	-0.28523	-0.36778	0.200562	0.118519	0.06085
Rainfall	0.09049	-0.05855	-0.0307	-0.06945	-0.06945	-0.04824	-0.03243	1	-0.3242	-0.11423	-0.15812	0.390955	-0.07788	0.033478
Transparency	-0.18424	0.180208	-0.09256	0.165012	0.165012	0.035961	-0.07977	-0.3242	1	0.154624	0.271812	-0.80055	-0.21682	0.341168
Water temp.	-0.28063	0.153281	-0.13804	0.109684	0.109684	-0.15241	-0.28523	-0.11423	0.154624	1	0.636925	-0.32503	-0.35971	0.00148
Air temp.	-0.28735	0.125016	-0.16966	0.06983	0.06983	-0.19383	-0.36778	-0.15812	0.271812	0.636925	1	-0.45308	-0.54676	0.163508
TSS	0.405488	-0.17145	0.164057	-0.13728	-0.13728	0.046495	0.200562	0.390955	-0.80055	-0.32503	-0.45308	1	0.403541	-0.13122
Chl-a	0.290138	-0.08743	0.042565	-0.06991	-0.06991	0.054296	0.118519	-0.07788	-0.21682	-0.35971	-0.54676	0.403541	1	-0.19895
Salinity	0.054167	0.089957	0.052452	0.102891	0.102891	0.069629	0.06085	0.033478	0.341168	0.00148	0.163508	-0.13122	-0.19895	1

Multiple regression analysis results, with fish catch rates as a dependent variable is shown in Tables 4. The data indicates that water temperature, transparency and salinity significantly influenced fish catches in the estuary.

Table 4. Regression Summary for Dependent Variable: Fish catch rates (CPUE)

$R= .20094892$ $R^2= .04038047$ Adjusted $R^2= .03583251$						
$F(7,1477)=8.8788$ $p<.00000$ Std.Error of estimate: 413.26						
		St. Err.		St. Err.		
	BETA	of BETA	B	of B	t(1477)	p-level
Intercept			46.85441	194.1767	0.241298	0.809358
Rainfall	-0.03193	0.029098	-1.29714	1.182136	-1.09728	0.272697
Transparency	0.137036	0.048845	12.44954	4.437477	2.805545	0.005089
Water temp.	0.124641	0.03349	11.1097	2.98505	3.72178	0.000205
Air temp.	-0.07303	0.038479	-11.7167	6.173472	-1.89791	0.057903
TSS	0.01299	0.053067	31.17936	127.3791	0.244776	0.806664
Chl-a	-0.03015	0.033471	-0.18313	0.203273	-0.90089	0.367794
Salinity	0.064669	0.029413	9.447606	4.297021	2.198641	**0.028058**

Results of regression analysis, with fish species as a dependent variable are shown in Table 5. The data indicates that rain, water transparency, water temperature and chlorophyll a significantly influenced fish communities.

Table 5. Regression Summary for Dependent Variable: Fish species

R= .49170167 R^2= .24177053 Adjusted R^2= .23817703						
F(7,1477)=67.280 p<0.0000 Std.Error of estimate: 8.0037						
		St. Err.		St. Err.		
	BETA	of BETA	B	of B	t(1477)	p-level
Intercept			99.05346	3.760652	26.33944	0
Rainfall	-0.05855	0.025865	-0.05183	0.022895	-2.26369	0.023738
Transparency	0.303582	0.043418	0.600909	0.085941	6.992082	4.09E-12
Water temp.	-0.10885	0.029769	-0.21139	0.057812	-3.65654	0.000265
Air temp.	0.000944	0.034204	0.003301	0.119563	0.027612	0.977975
TSS	0.612416	0.047171	32.02815	2.466972	12.98278	1.41E-36
Chl-a	0.07515	0.029752	0.009944	0.003937	2.525855	0.011646
Salinity	0.047875	0.026145	0.152386	0.083221	1.831101	0.067287

Results of the Monte Carlo permutation test are shown in Table 6. The results show that all the environmental parameters investigated contributed 50% of the observed variation in fish community structure and distribution in the estuary. Water temperature, rainfall, total suspended sediments (TSS) and water transparency respectively are the most important factors, accounting for 42% of the observed variance.

Table 6. A summary of Monte Carlo permutation test showing variables with extreme influence on fish communities in the Sabaki estuary during the period of study

Environmental variable 7 added to model				
Variance explained by the variables selected: .42				
" " " all variables : .50				
N Name Extra fit				
5 Transparency .07				
4 TSS .07				
3 RAIN .07				
2 Water Temperature .07				

CHAPTER FOUR

4.0 DISCUSSION AND CONCLUSIONS

4.1 DISCUSSION

4.1.1 Physico-chemical parameters

The Sabaki estuary is spatially and temporally dynamic, exhibiting a gradient of physical and biological factors from adjacent open seawaters, mouth and upstream. These factors include salinity, water transparency, temperature, suspended sediments, chlorophyll a and fishery.

The climate and oceanographic conditions are under the influence of monsoon winds (McClanahan, 1988; Katwijk *et. al.*, 1993) driven by the north-south movement of the Inter-tropical Convergence Zone (ITCZ). Significant differences in rainfall are observed between January to March and April to June. Rainfall peaked in May where a mean of 22.5 mm was experienced (Fig.2). Rainfall is bimodal, long rains occurring from April through to July and short rains from October to December (Obura, 1995).

The rainy seasons are under the influence of monsoon winds, south-easterly (SEM) and north-easterly (NEM), and the transitional period (inter-monsoon). The NEM season, locally referred to as Kaskazi occurs between November and March while the SEM season, Kusi is present in April to October.

The monsoon seasons and the transitional period have different sets of environmental characteristics (Obura, 1995). The SEM season is usually associated with strong winds causing high water column mixing resulting in cooler temperatures, reduced phytoplanktons and zooplankton abundance (due to mixing below the photic zone), increasing transparency and higher benthic algal biomass. Transport of water is towards the north at the coastal areas. Strong winds operating together with the East African Coastal Current (EACC) results in large water waves and rough sea conditions. The Inter-monsoon period experiences overhead passage of the ITCZ, consequently calm weather with subsequent commencement of rain seasons (short rains in November and long rains in April). Temperature increase, terrestrial runoff and river discharge are some of the attributes of the monsoon change. The following features are characteristic of NEM season; light winds allowing water column stratification, and resulting in warmer temperatures, higher phytoplankton and zooplankton abundance, reduced transparency and lower benthic algal biomass. Inshore currents are directed southwards along the coast and the EACC is slowed down by the opposing winds and northerly obstruction by the Somali current (Obura, 1995, Katwijk *et. al.*, 1993).

Salinity values, both temporal and spatial, remained low throughout the study period. Maximum mean salinity experienced was 4.4‰. Whitehead (1960) reported similar values where overall salinity in the estuary rarely exceeded 5‰. There was a salinity gradient between the various sampling stations. Salinity increased with distance towards the sea (Fig. 3). The difference in salinity between SBK0 and SBK1 was not significant ($P = 0$). There was no significant difference in salinity between SBK2, SBK3 and SBK4 ($P > 0.05$). Kitheka (2002) observed similar trends where most of the zones in the estuary experienced riverine conditions at low water tide. SBK0 and SBK1 are heavily influenced by the open seawaters through tide. A sustained increase in salinity particularly for seaward zones was associated with tidal influences and estuarine circulation causing mixing of fresh riverine water with high saline seawaters.

The general trend of salinity in the estuary followed the rainfall and monsoon patterns. Salinity significantly varied between January, February and April ($P < 0.02$). The difference in salinity between the months of March, May and June was not significant ($P > 0.05$). Low river discharge, lack of or low rainfall and high air temperatures contributed to high salinities experienced in March and to some extent April (Fig. 4). A slight drop in salinity in June was due to the enhanced long rains, high river discharge, and high cloud cover.

Temporal variation in total suspended sediments (TSS) in the estuarine system indicated a marked seasonal pattern (Fig. 5). TSS concentration was highly significant through the sampling period ($P < 0.05$). However, the difference in TSS amounts in the months of February and April was not significant ($P > 0.2$). Mean TSS concentration between the dry and wet seasons was significant ($t = 0.0208$, $F = 4.87$, $P < 0.05$). TSS supply in the estuary positively correlated with the amount of rainfall (Fig. 6). TSS amount was generally low during the dry season and high in the wet season. Similar findings were reported in Kitheka (2002). Lowest levels were recorded in March, which coincided with the inter-monsoon change (transition), characterized by calm weather (Obura, 1995). The pulse effect caused by intense rainfall and high river discharge, during the wet season (April to May) was responsible for the increase in TSS concentration in the water column.

Variation in TSS supply between the sampling stations was not significant ($P > 0.2$). High TSS amounts were recorded upstream and mid portions of the estuary (Fig. 7). This was attributed to the presence of relatively finer riverine sediments from terrestrial sources with very low settling velocities and residence period. The pulse effect also contributed to spatial variation in TSS supply. However, this was gradually dissipated along the estuary (seawards) due to high deposition of sediments through flocculation resulting in low mean TSS concentration. River borne sediments flocculated on entering high salinity seaward waters in the estuarine environment. This increased their settling velocities, thus greatly lowering sediment levels, especially during the neaps at low tides. High TSS amounts, especially in SBK0 in the months of April and May was associated with estuarine circulation, which caused re-suspension of bottom sediments.

The dynamics of suspended sediments in the estuary and adjacent environment was strongly associated with rainfall, river discharge, tidal influences and salinity. Highly turbid Sabaki waters mainly comprised of soil particles from terrestrial sources, detritus and algal bloom (Giesen *et. al*., 1984).

Water transparency (visibility) varied both in time and space. The difference in visibility between SBK0 and SBK1 was not significant ($P > 0.08$). SBK0 and SBK1 (Seaward) significantly differed with other stations ($P < 0.05$). Visibility improved seaward with flocculation (Fig. 8). These results compares with Mwangi (2002) who reported that water transparency improved with distance towards the sea. Giesen *et. al.* (1984) and Obura (1995) reported that the turbid Sabaki waters reduced visibility to near zero in the Malindi Bay during the northeastern monsoon season.

Temporal variation in visibility was significant ($P < 0.05$). These variations were strongly associated with temporal pattern of terrestrial water influx and river discharge to the estuary from the River Sabaki catchment. Visibility was high during the dry period (peaking in March) when the water was calm, river discharge less and temperature high (Fig. 9). There was a strong inverse relationship between visibility and TSS concentrations. High concentration of TSS resulted in reduction of visibility (Fig. 10). Minimum visibility was observed in May during the long rains when high river discharge brought in silt-laden waters into the estuary.

Chlorophyll a production varied on a temporal scale (Fig.11). The difference in chlorophyll a concentration are significant throughout the sampling period ($P < 0.05$). Highest amounts of chlorophyll a was recorded in the month of June while lowest in March. Low levels of chlorophyll a production experienced in January through to March could be attributed to the presence of a thermocline due to the increase in air temperatures, especially in March (Fig. 12). The low river discharge became a predominant process of nutrient input to the estuarine system. The calm weather and presence of thermocline limited the riverine nutrient input and mixing within the water column. Sustained primary production required a continuous availability of nutrients especially nitrates, phosphates and silicates (Ohowa, 1997). Temperature might have also had a direct influence on the phytoplankton production. Goldman (1979) showed that optimum temperature for some coastal phytoplankton species all fell in the range of 20 °C to 25 °C.

Primary production increased logarithmically with sustained increase in rainfall in the Month of May through to June. Mwangi (2002) reported that Chlorophyll a production in the Malindi – Ungwana Bay was significantly higher during the wet season than the dry season. High chlorophyll a production could be associated with the absence of thermal stratification and the pulse effect caused by intense rainfall. The absence of thermal stratification facilitated vertical transport and convective movements in the estuary hence sustained supply of nutrients through resuspension of sediments (Schallenberg and Burns, 2004). High river discharge played an important role in nutrient supply. During the rain period, the nutrient dynamics seemed to be controlled by allochthonous inputs brought into the estruary by the Sabaki river and terrestrial surface runoff (Schallenberg and Burns, 2004; Ohowa , 1997). This phenomenon is supported by the fact that high TSS supply positively correlated with chlorophyll a concentrations (Fig. 13) and the amount of rainfall.

An increase in turbidity as indicated by visibility resulted to low primary production. High river discharge during the long rains caused water to be more turbid, reducing light penetration necessary for photosynthesis, especially in the month of April and May.

There was little spatial variation in chlorophyll a production (Fig. 14) and it did not significantly vary between the stations ($P > 0.06$). Highest chlorophyll a concentrations occurred in the mid estuary. This was associated with river flow effects and tidal influences. With increase in river flow, a portion of the phytoplanktons was transported downstream. On the other hand, seawater counteracted this downward movement of the riverine transported phtyoplanktons through tidal influences, consequently concentrating them in the mid estuary.

The mid portions of the estuary at low water tide had relatively longer retention time and the influence of advective processes was low. This also accounts for high Chl-a concentrations in the mid estuary. Similar results have been reported by other studies. Filardo and Dunstan (1985) found peak chlorophyll a concentrations occurring in the brackish regions of the James River estuary, but some of this was transported downstream with increase in river flows. In northern San Francisco Bay, gravitational circulations tended to concentrate chlorophylls in the oligohaline reaches (Cloern *et. al.*, 1983).

Other factors which might have also contributed to the observed variation in chl-a production included grazing effects of zooplankton and benthic macrofauna. Herbivory significantly reduces phytoplanktons ((Day *et. al.*, 1989; McClanahan, 1988).

Temporal variations in temperature were small with March being the hottest month (Fig. 15). The difference in air temperature between the months of March and April were not significant ($P > 0.7$). This period coincided with the inter-monsoon change characterized by high temperatures. Significant differences were noted in the temporal variations in water temperatures ($P < 0.05$), except for January and March ($P > 0.11$).

The northeastern (NEM) season was slightly hotter than the southeastern (SEM) season, with mean water temperatures of 33.99 ^{o}C and 31.6 ^{o}C respectively. During the same period, air temperatures were 31.59 ^{o}C and 31.37 ^{o}C for NEM and SEM respectively. Temperature patterns are under the influence of monsoon winds, south-easterly (SEM) and north-easterly (NEM).

Spatial differences in temperature were not significant ($P > 0.05$). There was no surface water temperature gradient from upstream seawards. The effect of Sabaki River on water temperature was not significant.

4.1.2 Fish community structure and distribution

A total of 10,807 individuals of both fish and crustaceans were caught. This represented 35 species, 25 families and 7 orders of fish as well as 6 species, 3 families and 1 order of the crustaceans (Table 1). *Arius africanus* dominated the catch, accounting for 38.9% of the individuals caught. This was closely followed by members of the family *Mugilidae*, which accounted for over 30% of the fish caught. *Valamugil buchanani* was second in dominance, contributing 14.9% of the sample population followed by *Mugil cephalus* comprising 14.6% of the total number of individuals caught in the sample. The genus *Caranx* showed considerable presence in the estuary, contributing 6.3% while *Apogon sangiensis* 3.4%. Single individuals of *Synodontis serpentis*, *Lobotes surinamensis*, *Gerres filamentosus* and *Barbus oxyrhynchus* were caught once and only during wet season. While some of the species were caught occasionally, others were consistent in the catch throughout the sampling period.

Fish species composition followed a pattern of hydrological variations between the dry and the wet season, and the corresponding mobility of the brackish zone.
River discharge was low during the dry season, permitting the presence of marine fish species at juvenile or adult stages to the upper part of the estuary mostly for feeding purposes. The temporal modification of the estuarine conditions allowed an incursion of marine based species such as *Leiognathus equulus, Lobotes surinamenis, Gerres filamentosus, Lethrinus mahsena, Carangoides spp, Siganus rivulatus* and *Lutjanus spp* in the estuary.

There was a general deficit of riverine fish species such as *Oreochromis spirulus spirulus, Oreochromis mossambicus, Schilbe intermedius, Synodontis serpentis* and *Barbus oxyrhynchus* , during the dry season within the estuary. This was compensated for by the presence of a number of marine species; *Arius africanus, Mugil cephalus, Liza macrolepis, Valamugil buchanani, Apogon sangiensis, Herklostsichthys quadrimaculatus, Caranx spp,* and *Sillago sihama* whose incursions into the estuarine system were not limited by the presence of a brackish zone nor by the possible competition with freshwater species. For these species present in all the sites, factors, which were beyond the scope of this study, might have determined their occurrence.

Spatial variation in fish abundance was evident (Fig. 16). Fish abundance significantly varied between SBK0 and other sites ($P < 0.05$). There was no significant difference in the variation of fish abundance from SBK2, SBK3 and SBK4 ($P > 0.9$). Fish were more abundant in the lower part of the estuary, which was greatly influenced by the sea. Similar observations were reported in the Gambia estuary (FAO, 1995). The abundance in fish decreased with distance away from the sea. The size and type of fish species could be attributed to this observation. Large sized individuals of marine origin were more abundant at SBK0. The data on spatial size distribution give an indication of the relationship between number of individual fish and or species assemblages and habitat complexity (Talbot *et.al.*, 1978).

Fish distribution also varied on a temporal scale (Table.1). Fish was more abundant during the dry season compared to the wet season. For instance a total of 5,583 individuals were caught in the sample in March, compared to 1,451 in April. This is associated with fish catchability and hydrodynamics within the estuary.

Fish catch rates varied with months (Fig.17). Variation in catch per unit effort (CPUE) between the dry and wet seasons was significant ($F = 38.4$, $t = 4.82$). Fish catchability reduced with increase in rainfall. More fish catches were recorded in the dry season compared to the wet season. For instance 137.5 Kg of fish were caught during the dry season compared to 48.6 Kg in the wet season. Highest fish catches were recorded in the month of March. During the dry period, fish catchability was high because of the low river discharge, calm water condition and high fish density. Water occupied a relatively smaller portion of the estuary, resulting to high fish density. The calm water also made it easy to manoeuvre the net during the fishing operations. During the wet season, the conditions changed significantly, the sea condition was rough, discharge from Sabaki River became very high, coupled with silt-laden terrestrial surface runoff, particularly from upland areas. Catchability reduced with increase in river discharge. More fish were distributed over a large expanse of water during the wet season. Manoeuvring of the fishing gear also became difficult. These factors considerably reduced fish catchability.

Fish catches significantly varied between SBK0 and other stations. More fish catches were realized at SBK0. Lowest fish catches were at SBK4. Fish catches increased with distance towards the sea (Fig. 18).

Species richness is here defined as the number of species encountered in the community (Krebs, 1999; Kent & Coker, 1998). Spatial variation in fish species richness was evident (Fig.19). Upstream waters recorded the highest number of species followed by seaward areas. Middle portions of the estuary had near constant number of species. This was attributed to the influx of riverine species from upstream waters to SBK4, and species of oceanic origin to SBK0.

Fish species richness in the estuary followed a seasonal pattern (Table 1). Significant differences were observed in the number of fish species caught during the wet and dry seasons ($F = 49.3$, $t = 5.2$). There were more fish species during the wet season compared to the dry period. For instance, an average of 13 species were caught in the dry season compared to 26 in the wet season. These suggest that seasonal variation in the distribution of estuarine fish species was strongly associated with temporal changes in the environmental factors. Overall, there were 41 species encountered in this study. These results compare with a study conducted in the Tana River delta where a total of 30 species were observed (Devos *et al.*, 2002)

Species diversity as estimated by the Shannon – Wiener index, increased with distance away from the sea (Fig.20). Upstream station recorded the highest species diversity with 13.59 species compared to 3.67 species at the oceanic station. This was attributed to a temporary influx of marine species to the estuary. Overall, the Sabaki estuary had a species diversity of 20. This figure could be an underestimation due to technicality involved in the sampling, especially in the wet season, when river discharge was high and fishing became difficult. Fish catchability also reduced considerably.

Most of the fish caught in the estuary were in the size group, 0.5 – 10 cm (Figs. 21 a - d). This size group accounted for 93% of the fish caught in the sample. The results show that most fish inhabiting the estuary represented juveniles of the respective species. For instance average sizes at maturity for some of the species, namely; *Chanos chanos* (180 cm), *Arius africanus* (45 cm), *Mugil cephalus (*60 cm*), Liza macrolepis* (35 cm), *Clarias gariepinus* (150 cm), *Oreochromis mossambicus* (40 cm), and *Valamugil buchanani* (100). There respective mean sizes caught in this study are; 17.1 cm, 45 cm, 9.0 cm, 8.3 cm, 10.5 cm, 5.5 cm, 8.0 cm, respectively. This observation confirms with Day *et. al.* (1989) who reported that many fish species are found in estuaries during their juvenile stages.

Analysis of spatial distribution in fish sizes (Figs. 22 – 25) indicated that mall sized individuals of *Apogon sangiensis* and *Terapon jarbua* were found in the low saline headwaters. The effect of distance contributed 96% ($R^2 = 0.96$) of the observed variation in the mean total length of *Apogon sangiensis* and 70% ($R^2 = 0.7$) in *Terapon jarbua*. This suggests that low salinity water was more favourable for juveniles. Some studies have shown that low salinity water portions of many estuaries receive fish eggs, larvae and young from fresh water, estuarine and marine spawners (Day *et. al.*, 1989).

Weight-length relationships indicated positive linear correlation (Figs. 26, 27 a – i). The weight of an individual fish positively correlated with its length. However, increase in weight was not proportional to the increase in length, indicating non-isometric growth (Table 2). Weight –length relationships gave an indication of type of fish species. This could also be used for sexing, aging and estimating condition factor of fish. However, in this study it was not possible to sex the fish sampled because most of them were juveniles.

Canonical Correspondence Analysis (CCA) biplot (Fig. 28) shows a clear pattern of fish species assemblages in relation to environmental parameters. There is an emergence of various grouping of fish associated with environmental conditions. For instance, groups associated with high salinity; namely, *Siginus sp., Lobotes surinamensis, Gerres filamentosus*. Those associated with high sediment load included, *Caranx spp, Mugil cephalus, Liza macrolepis* and *Valamugil buchanani*. The occurrence of *Schilbe intermedius*, *Macrobrachum spp* and gobbies was closely linked to rainfall.

From these data, fish species occurring in the estuary can be easily grouped into three main categories based on the similarity in sharing freshwater/ seawater gradient (Fig.29). These three groups are; fresh water, sedentary and migrants fish species.

Fresh water species are those inhabiting the upper reaches of the estuary with less saline water. These fish species spawn in freshwater and spend at least part of their lifecycle in the estuary. These include among others; *Yongeichthys nebulosus, Synodontis serpentis,* *Glossogobius giuris, Glossogobius biocellatus, Stenogobius kenyae (*Gobbies*), Clarias gariepinus, Barbus oxyrhynchus, Megalops cyprinoids, Schilbe intermedius, Oreochromis spirulus spirulus, Oreochromis mossambicus* and *Synodontis serpentis.*

The sedentary species are euryhaline estuarine or coastal species capable of breeding either in the sea or estuary. Sometimes are referred to as estuarine spawners. They either spend their entire life in the estuary or move in to spawn. This group is well represented by *Arius africanus*. The species spends part of its lifecycle in near shore coastal waters, but are estuarine dependent.

The migrant species are sea spawners, sometimes referred to as "estuarine dependent". They spend part of their development in the estuary with successive migrations between the freshwater and sea. Among this group include *Mugill cephalus, Liza macrolepis, Valamugil buchanani, Terapon jarbua, Cynoglossus zanzibarensis, Lutjanus spp, Siginus rivulatus, Lethrinus mahsena, Hyporhamphus affinis, Gerres filamentosus, Lobotes surinamensis, Johnius dussumieri,* and the crustaceans. These species usually spawn in the near shore coastal waters. The larvae and or eggs move into the estuary through tidal influences and two-layered estuarine circulation. The juveniles spend a few weeks to several years in the estuary before moving offshore in the adult feeding grounds. For instance juveniles of the family *Mugilidae* enter the estuary in large schools during the rain season and remain there for about a year feeding on detritus and filamentous algae (Day *et. al*., 1989). The adults leave the estuary and enter the sea to spawn. Once again the estuarine ecosystem is invaded by large schools of small individuals, which are the product of the spawning of the previous year. Knowledge of the migration habits of these species is essential for their sustainable exploitation and management.

These seasonal migrations of species between the two adjacent ecosystems contributed to the permanent presence of some fish communities such as the *Mugil cephalus, Liza macrolepis, Valamugil buchanani, Arius africanus* and *Apogon sangiensis.*

4.1.3 Component Interactions

There is clear evidence from this study of an obvious relationship between estuarine environmental gradients and fish community structure and distribution. Correlation analyses (Table 3) showed that environmental factors strongly correlated with the biotic communities in the estuary. For instance fish abundance positively correlated with water transparency, water temperature and salinity. There was a positive correlation between fish catches with water transparency, water temperature, air temperature and salinity. Fish catch rates improved with transparency (Fig. 30) and inversely varied with TSS concentrations (Fig. 31). Other studies have also shown that sedimentation has a negative influence on fish community structure and distribution (Henley *et. al.*, 2000). Sawyer *et. al*, (2004) reported that TSS had a negative relationship with species richness and diversity.

Regression analysis results show that water temperature and transparency had a significant influence on fish catches (Table 4). Fish species occurring in the estuary are dependent on chlorophyll a concentrations, rain and water temperature (Table 5)

Monte Carlo permutation test indicated that all the environmental variables studied contributed 50% of the observed variance in fish community structure and distribution (Table 6). Water temperature, rainfall, TSS and water transparency were the most important, contributing 42% of the observed variation. Clearly, these environmental factors were not the only causes of the observed differences in the fish species composition, community structure and distribution. Such conclusive statements would require data collected over a relatively longer time. Results from the various statistical tests suggests that there are other important factors, which were not considered by this study, that may have had some considerable influence on the fish communities in this estuary.

Other factors which may have contributed to the observed variance include, light, nutrients, physical transport processes, cloud cover, wind energy, radiation, predation of eggs, interspecific/intraspecific competition, and herbivory (Day *et. al.*1989; McClanahan,1988), depth, pH and dissolved Oxygen (Storey and Williams, 2004).

The results of this study provide a comprehensive assessment of the status of fish assemblages at the Sabaki estuary. The study demonstrates that fish distribution and species composition in the estuary shifted seasonally according to temporal changes in water physico-chemical parameters. However, this should be taken as preliminary. From this study, it can be concluded that the hypothesis that estuarine hydrodynamics in the Sabaki estuary influenced fish communities at the estuary and adjacent coastal waters is true, hence accepted.

4.2 CONCLUSIONS AND RECOMMENDATIONS

It can be concluded that the Sabaki River and seasonal climatic changes influence the estuarine ecosystem. The weather elements combine to give the study area a hot arid and semi arid climate. Fish species diversity, richness, composition, relative abundance and distribution within the estuary follow environmental gradients, which change seasonally.

In this study, a total of 10,807 individuals of both fish and crustaceans were caught. This represented 35 species, 25 families and 7 orders of fish as well as 3 families and 1 order of the crustaceans. The fish community structure and distribution in the estuary results from the penetration of marine species upstream and riverine species downstream, regulated by river discharge and oceanographic processes. Fish populations are characterized by a big reduction in catch per unit effort upstream. Fish are more abundant in the lower part of the estuary, which is greatly influenced by the sea. There is more fish during the dry season compared to the wet season. The catchability of fish was favourable during the dry period and low river discharge.

Different fish species utilize the estuary on a temporal scale for various purposes, namely, feeding, breeding and refuge. However, a few species are permanent residents. Over 93% of the fish inhabiting the estuary are juveniles of both marine and fresh water species. This indicates the importance of Sabaki estuary as a breeding and nursery ground hence need for its conservation.

The following recommendations therefore can be deduced from this study;

In order to follow further development in the pysico-chemical and biotic factors in the River Sabaki estuary, to investigate their influence on fish community structure and distribution, and establish a causal relationship, a follow up study is necessary. Such a study needs to encompass where possible most of biological, meteorological, physical and chemical parameters monitored over a relatively longer period of time.

There is inadequate information on some of the fish species in fresh, brackish and marine waters in the tropics. Hence, there is a need for further studies and taxonomic work in this field.

River Sabaki continues to discharge a considerable amounts of sediment to the estuary and adjacent coastal waters. The exact effects of these sediments on fish ecology, particularly reproduction requires special attention.

Some considerable work has been done to understand the seasonality of coastal and marine ecosystems. However, this has been mainly undertaken in temperate regions. Eastern Africa region, particularly the Sabaki estuary provides good opportunities and potential for research in understanding seasonality in the tropics.

The River Sabaki estuary supports considerable number of diverse water birds. Their impact on the fish community structure, abundance and distribution has not been studied. Relationship between estuarine avifauna and ichthyofauna need to be investigated.

Kenya's Fisheries Department has for a long time collected data on fisheries. These need to be analysed and improved for statistical purposes. This would provide useful information and highlight knowledge gaps for further research necessary for developing effective strategies for environmental quality monitoring and sustainable utilization of coastal/marine fisheries resources.

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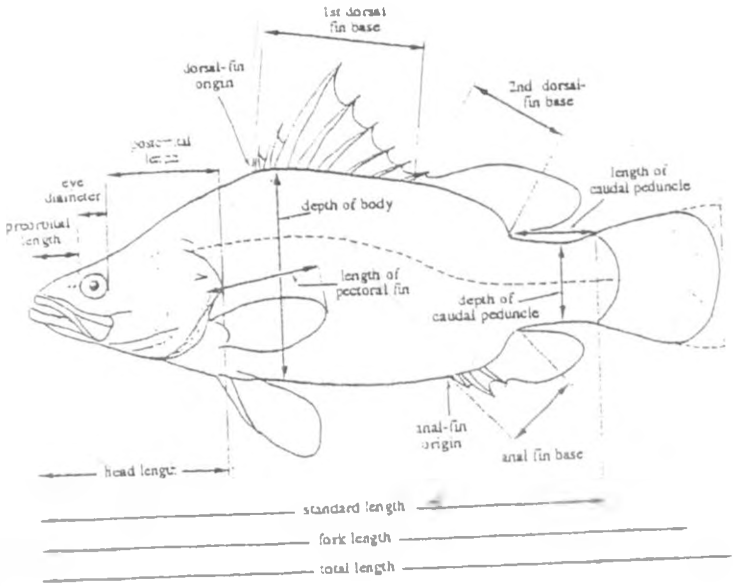
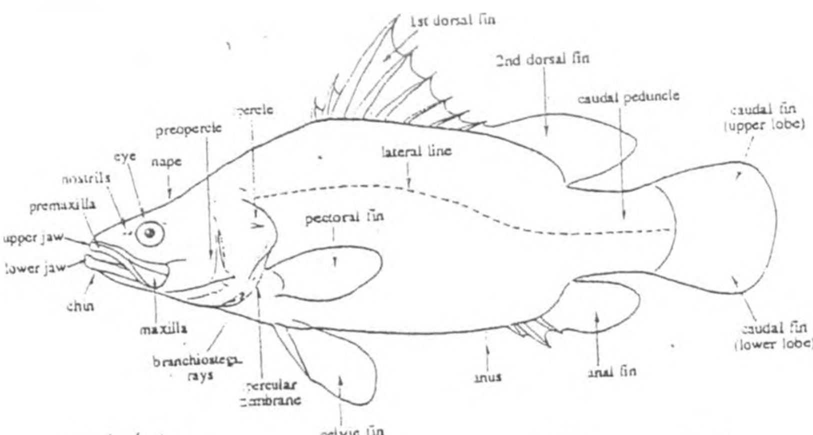
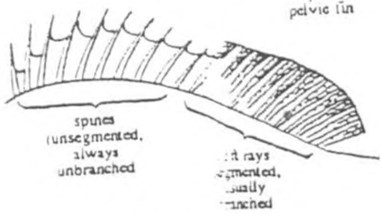
APPENDICES

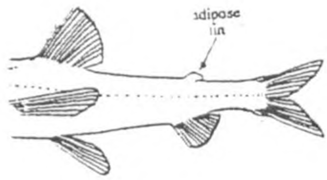
APPENDIX 1: FISH TAXONOMIC FEATURES USED IN MEASUREMENTS AND IDENTIFICATION







example of a continous dorsal fin of a spiny-rayed fish



adipose fin (not supported by rays)

APPENDIX II: TIME FRAME AND SAMPLING PLAN

Year	2002					2003								
Month	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Activity														
Project Identification	X													
Project Preparation and identification of collaborators	X	X												
Preliminary Investigation and methodology refining		X												
Field based data collection and laboratory analysis			X	X	-	X	X	X	X	X	X			
Data Organization											X	X		
Data Analysis												X	X	
Report writing													X	
Submission														X