THE BIOLOGY OF THE MULLETS (PISCES: MUGILIDAE) FROM KILIFI, A TROPICAL MANGROVE CREEK ON THE KENYA COAST.

By

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DECLARATION

I, the undersigned, do hereby declare that this thesis is my original work and has not been presented for any academic degree in any other university.

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We confirm that the candidate, under our supervision, carried out work reported in this thesis and it has been submitted for examination for the degree of Doctor of Philosophy of the University of Nairobi with our approval as University supervisors.

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DEDICATION

This work is dedicated to Mzee **Mathayo Obuolo**.

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ABSTRACT

The mullet form a major component of marine finfish fishery and investigations were carried out to study the biology of mullet *in situ* at Kilifi creek on the Kenya coast. The mullet, commonly known as *Mkizi* are fin fishes of the family Mugilidae, are estuarine fishes, inhabiting the tropics and temperate regions, harvested for food and roe hence play an important role in commercial fisheries. In Kenya, coastal aquaculture has considerable potential as a source of economic return and if well planned and managed and the mullet have a considerable potential for culture.

The first component of the study covered the diversity of fishery organisms at Kilifi creek. The second component concentrated on the species composition and distribution of Mugilidae from which the most available species were identified. The third and fourth components dealt with population parameters and reproduction of two Mugilidae species, *Mugil cephalus* Linnaeus, 1758; *Valamugil buchanani* Bleeker, 1853 as potential candidates for culture.

Eight sampling sites were identified within Kilifi creek from which water was obtained for analysis of the physico–chemical parameters; temperature, dissolved oxygen, salinity, Depth, water transparency and inorganic phosphate and nitrate). Fishing was carried out from a canoe using monofilament gillnets (50.8, 63.5 and 76.2 mm mesh sizes) and/or a nylon cast net (19.1 mm mesh size, 7.6m^2). All fishery organisms obtained were identified and counted.

Chapter three presents the results of the biodiversity of fishery organisms. Both crabs and prawns were present at Kidundu, Kombeni and Rare but the prawns (*Penaeus indicus* (H. Milne Edwards, 1837), *Penaeus monodon* (Fabricius, 1798) were absent from Sea Horse and Nkoma while the crabs *Portunus pelagicus* (Linnaeus 1766) and *Scylla serrata* (Forsskal, 1755) were present throughout the study period and at all sites except Konjora.

Fish species of Konjora, Rare and Kombeni were distinctly different from those at Fumbini, Kidundu, Mazioni, Sea Horse and Nkoma and it was also observed that fin fish species composition of the study area shows a spatial distribution from the creek mouth to the freshwater end and that most members are marine immigrants visiting the area specifically to feed.

Chapter four presents the results of species composition and distribution of Mugilidae within the creek. The species obtained were *Mugil cephalus* Linnaeus, 1758; *Valamugil buchanani* Bleeker, 1853; *Liza vaigiensis* Quoy and Gaimard, 1825 and *Myxus capensis* Valenciennes, 1836 but the most common species were *M. cephalus* and *V. buchanani.* The distribution of *M. cephalus* and *V. buchanani* showed no specific pattern related to seasons. Kruskal-Wallis test indicated significant variation in distribution between study sites ($H = 22.35$; d.f. = 7; $N = 100$; $P = 0.0022$). Mugilidae distribution is bimodal with a peak at class sizes 5.5 – 10.4 cm and 40.5 – 45.4 cm total length (TL). There was no significant correlation between Mugilidae and phosphates, nitrates, dissolved oxygen, temperature and depth at each site respectively. When all sites were grouped, Spearman rank order correlations were significant between Mugilidae and salinity ($P = 0.01$); dissolved oxygen ($P = 0.03$); temperature ($P = 0.04$); depth ($P = 0.00$) and transparency ($P = 0.005$) but not significant with nitrates ($P = 0.74$) and phosphates ($P = 0.38$). The juveniles (5.5 – 15.4 cm) formed high percentage of *M. cephalus* and *V. buchanani* at Kidundu and Kombeni.

Population parameters are presented in chapter five. Negative allometric growth was observed in both *M. cephalus* [males (Log_{10} W = 1.7458 + 2.8659 Log_{10} L); females (Log_{10} W = 1.7972 + 2.8954 Log_{10} L)] and *V. buchanani* [males (Log_{10} W = 1.7648 + 2.8924 Log_{10} L); females (Log_{10} W = 1.7787 + 2.9034 Log_{10} L)] respectively. The relative condition factors in *M. cephalus* were observed to be higher during the NE monsoons in both sexes but in *V. buchanani* the relative condition factors showed no relation to seasons and no major difference between males and females. In *M. cephalus* females, the value of asymptotic length L_∞ (51.48 cm) is higher in females than in males (48.3 cm) but in *V. buchanani* males, the value of asymptotic length L_∞ (42.88 cm) is

higher than in females (41.75 cm). In *M. cephalus* the overall sex ratio was 1: 0.42 males to females, a significant deviation from the expected 1:1 ($\chi^2 = 124.65$; d.f. = 1; $P < 0.05$). The variance test of homogeneity of the binomial distribution of the sex ratio showed a highly significant difference in the monthly samples ($\chi^2 = 75.173$; d.f. = 23; $P < 0.05$). Comparison of the overall mean sizes of males and females in different size classes showed no significant difference between the sexes ($t = 1.913$; d.f. = 9; $P > 0.05$). In *V. buchanani*, the variance test of homogeneity of the binomial distribution of the sex ratio showed significant difference in the monthly samples ($\chi^2 = 50.49$; d.f. = 23; $P < 0.05$) but the overall sex ratio did not differ from the expected 1:1 ($\chi^2 = 0.328$; d.f. = 1; $P > 0.05$). Comparison between the overall mean sizes of males and females in different class sizes also showed no significant difference between the sexes ($t = -0.275$; d.f. = 7; $P > 0.05$).

Reproduction of *M. cephalus* and *V. buchanani* is reported in chapter six. The size at first maturity was 20.8 and 25.2 cm TL in males and females of *M. cephalus*. In *V. buchanani*, the size at first maturity was 20.7 and 24.4 cm TL in males and females respectively. Gonadal maturity stages above stage one were present throughout, indicating that *M. cephalus* and *V. buchanani* reproduce continuously. Variation in mean monthly GSI confirms that in Kilifi, *M. cephalus* reproduce throughout the year but in both sexes of *V. buchanani,* GSI indices were low with no seasonal relationship. In *M. cephalus* the highest fecundity of 13.2×10^6 oocytes was recorded in a 45.5 cm TL fish, weighing 1085.4 g but the mean fecundity from 75 females, ranging between 10.1 and 50.7 cm TL, was 5.2×10^6 oocytes. There was a positive relationship between fecundity and TL and gonad weight respectively. In *V. buchanani* the highest fecundity was 2.5×10^6 oocytes in a female 39 cm TL and weighing 616 g, but the mean fecundity was 1.1×10^6 oocytes in 15 specimens ranging from 15.9 to 39 cm TL. There is also a positive relationship between fecundity and TL and gonad weight respectively.

The results presented in this thesis were extensively discussed and compared to those from Mugilidae in other areas of the world.

This data fills the scientific gap in Mugilidae biology and also provides suggestions to be used by fisheries managers protect important nursery sites at Kilifi for sustainability and conservation of these fisheries resources for posterity.

CHAPTER ONE

1.0 General introduction

1.1 Mugilidae

The family Mugilidae belongs to the finfish order Perciformes and are commonly known as mullets. The order Perciformes is the largest with 148 families, 1,496 genera and 9,293 species (Wootton, 1998). They are found in both temperate and tropical waters of the world but in any particular region only a few species may occur. The species *Mugil cephalus* Linnaeus 1758 is widely distributed between latitudes 42° North and South of the equator (Thomson, 1966). The eastern coast of Africa is known to have at least 15 species (Thomson & Luther, 1984) of which the common genera include *Valamugil, Myxus, Mugil, Liza* and the rare genus *Crenimugil* (Whitfield, 2005).

Mugilidae play are important ecologically being food for piscivorous fish and diving birds besides supporting fisheries because they are euryhaline, thriving in a wide range of salinities from 0 – 113 ‰ though they spawn at sea (Thomson, 1966). Some are marine fishes ascending into freshwater, therefore estuarine and diadromous. Due to their euryhalinity, they are stocked in brackish water coastal lagoons and are raised in commercial fresh water ponds to improve fish yields and have also been introduced into freshwater lakes and reservoirs to improve water quality and to create new fisheries (Cardona, 2000, Thomson, 1966).

The Mugilidae are a major component of the Kenyan marine fishery and is one of the most harvested pelagic fish among cavalla jacks, barracudas and tuna, all of which are

oceanic in origin (Annual Reports, 1980 – 2008). Mugilidae are estuarine dependent and are cultured in other parts of the world. In Kenya, its catch has fluctuated considerably since 1998 (Table 1) in all the coastal districts as indicated below.

Table 1: Mugilidae distribution at the Kenyan coastal districts. (Values in Metric Tonnes, Zero value means production is less than a tonne; Source: Fisheries Department, Kenya).

District	Lamu	Tana River	Malindi	Kilifi	Mombasa	Kwale	Total
1998	36	1	10	21	16	30	104
1999	43	0	28	10	19	44	144
2000	59	1	54	13	21	33	181
2001	85	0	24	18	20	50	197
2002	61	3	26	34	17	23	164
2003	93	4	24	11	19	37	188
2004	119	3	41	16	15	42	237
2005	110	2	47	14	17	58	248
2006	96	4	45	20	16	41	222
2007	45	4	56	29	16	51	201
2008	82	7	29	23	15	80	236

1.2 Literature review

Because Mugilidae occurs in a wide area covering both the tropics and the temperate regions, research investigations have been carried out in most regions and nearly all species under a variety of research areas have been documented as shown in the sections that follow.

1.2.1 Systematics and distribution

The family has proliferated greatly in the Indo-Pacific region where there are 10 genera and 49 species compared to two genera and six species in the North-East Atlantic, three genera and nine species in South-East Atlantic and three genera and five species in the east Pacific (Thomson, 1966). Nine species of mullet occur in the West Central Atlantic ocean and occur in the sea, estuaries, brackish bays, inlets and lagoons with sand or mud bottoms and some even migrate into fresh water (http://www.sms.si.edu, 2008). Jacot (1920) observed that because of unreliability of single characters in species determination and of the possible difference in colouration of adult and young in Mugilidae, a study of the variation of specific characters are necessary. At Hoogly estuary, Joglekar and Rao (1967) described the systematics of mullets using morphometric and meristic characteristics and identified *Mugil parsia* (Hamilton), *Mugil cunnesius* (Valenciennes), *Mugil cephalus*, Linnaeus and *Mugil tade* (Forskal). Herzberg and Pasteur (1975) identified mullets in Israel using disc electrophoresis and reported that the electropherograms of muscle myogen of the investigated mugilids are characteristic for each species while Anderson (1982) constructed an identification key for British grey mullets using physical characteristics and gel-electrophoresis.

Chubb *et al.* (1981) reported that *M. cephalus* and *Adrichetta forsteri* (Valenciennes) occur extensively in the coastal and estuarine waters of Australia where the two species comprise a substantial portion of the commercial and amateur estuarine fishery. Three Mugilidae *Liza argentea, M. cephalus* and *Myxus elongatus* were identified at Shellharbour beach in Australia (Griffiths, 2001). At Solomon Island estuaries, *Liza melinoptera, Liza surviridis, Valamugil seheli* and *Liza vaigiensis* were recorded present (Blaber & Milton, 1990) and thirteen Mugilidae species have been reported from Thailand estuaries (Vidthayanon & Premcharoen, 2002). Mugilidae species *Liza affinis, Liza alata, Liza macrolepis, Liza subviridis, Valamugil cunnesius* and *Mugil cephalus* have been reported at Chuwei mangroves and Chiku lagoon in Taiwan (Kuo et al., 2001, Lin & Shao, 1999).

Thomson and Luther (1984) reported 15 species in the Western Indian Ocean region but along the Natal coast of south east Africa, 12 species of Mugilidae have been identified (Blaber, 1976, Whitfield, 2005) and this diversity has been related to all year round availability of detritus and their euryhalinity (Mbande *et al.*, 2005). Thomson (1963) described taxonomy and external morphology of *M. cephalus* in Australia.

Akin et al. (2005) reported seven Mugilidae species at Koycegiz lagoon in Turkey while Pombo et al. (2002) also reported seven Mugilidae species at Ria de Aveiro estuarine lagoon in Portugal. *Chelon labrosus* and *Liza aurata* have been reported by La Mesa and Vacchi (1999) at Ustica Island Marine reserve and *Mugil cephalus* from Minorca Island

(Mediterranean sea) (Cardona, 2000). On the south Texas coast, *M. cephalus* was reported in all major surveys of the estuarine and coastal fauna and was found in all shallow marine and estuarine habitats ranging from open beaches to fresh water and to hypersaline water of over 80 ‰ (Moore, 1976). From Mexico, Raz-Guz-man and Huidobro (2002) reported *M. cephalus, Mugil curema* and *Mugil liza* at Laguna de Madre and *Mugil curema* at Laguna Salinas del Padre. Along the Kenyan coast reported Mugilidae species at Gazi are *Valamugil seheli, Liza macrolepis* (Van der Velde *et al.*, 1995) and at Kilifi creek, *Crenimugil crenilabis, Valamugil buchanani* and *Valamugil seheli* (Oyugi, 2005).

1.2.2 Food and feeding

The mullet feed by sucking up the surface layer of the substrate or by grazing on submerged rock and plant surfaces. Thomson (1966) observed that they ingested large quantities of inorganic particles together with food items, whose function is to act as a grinding paste in the degradation of plant cell walls in the pyloric portion of the stomach. Blaber (1976) observed that the small centric and pinnate diatoms found in the stomachs of Mugilidae are epiphytes which have been either chemically or physically removed from ingested filamentous algae or macrophytes. All species of Mugilidae are initially plankton feeders (Thomson, 1966), the change in the diet from planktonic feeding to ingestion of micro benthos takes place in estuaries which provide suitable conditions for this change (Blaber & Whitfield, 1977). Wells (1984) reported that grey mullet fed all the year despite temperatures ranging from 7 – 26 °C and their diet included a wide range of algal species, macrophyte detritus, inorganic particles and occasionally the snail.

In *M. cephalus*, Collins (1981) reported peak feeding intensity at midday in Florida as also observed by De Silva and Wijeyaratne (1977) with lack of feeding at night but Blaber (1976) reported a peak feeding intensity at 18.00 hours with feeding continuing throughout the night. *L. macrolepis* and *L. dumerili* feed predominantly during daylight hours but *L. macrolepis* ceases feeding at night while *L. dumerili* continue feeding but at a lower intensity (Blaber, 1976).

Zismann et al. (1976) reported that copepods were the most important food items in the gut contents of grey mullets at all times of the year and at sizes ranging between 4.27 – 22.88 mm TL. However as they increase in size and approach the beaches, estuaries and lagoons, their feeding pattern changes to a variety of phytoplankton and zooplankton organisms. Eggold and Motta (1992) established that *M. cephalus* undergoes an ontogenetic shift in diet because fish of 20 - 30 mm Standard Length (SL) ingest small amounts of sand, large amounts of organic matter and diatoms. At 30 - 40 mm SL, they ingest more sand, less organic matter, no zooplankton but more species of diatoms hence a transition from browsing to grazing. At 40 - 100 mm SL, they are characterized by greater ingestion of sand and diatom species and less ingestion of organic matter. The fact that mullet of all classes feed on the benthos and ingest large amounts of organic matter supports the concept that detritus is an important source of food for the mullet. The observed changes in feeding behaviour from browsing to grazing did not occur due to changes in feeding locations because both feeding locations and intra-habitats were similar. Morphological measurements such as inter-raker distances, inter-spine distances,

gill raker lengths, intestinal length and mouth width and height appeared not to contribute to the shift. De Silva and Wijeyaratne (1977) noted that studies on food and feeding habits for polycultural practices is well known to fish culturists and in *M. cephalus* (20 – 55 mm TL), diatoms, green algae and blue green algae account for 90 % of the total diet.

At Guadalquivir estuary (Spain), Baldo and Drake (2002) reported two major trophic guilds i.e., a zooplankton feeding and hyperbenthos feeding. Though fish communities differ between estuaries, the basic trophic structure is similar, with the fishes being either generalist feeders or opportunists. Copepods were the preferred prey in the zooplankton guild being consumed mainly by Clupeiformes and mullets. The mysids dominated the hyperbenthic community and were abundant in spring and summer although the diet of the studied fishes showed low diversity. Baldo and Drake also reported ontogenic shift for the mullets *Liza ramada* and *Liza saliens*. *Rhinomugil corsula* at river Yamuna are iliophagus and omnivorous in their feeding habits consuming both fresh and decaying plant matter from the iliotrophic layer of the substratum but seasonal variations and maturity stages affect intensity of feeding (Khan & Fatima, 1994).

Melville and Connolly (2005) observed that traditional methods such as stomach contents analysis cannot separate the roles of the many different components in detritivores therefore isotope analysis is effective and useful. They reported that the detritivores, *Liza argentea, M. cephalus, Myxus elongatus* and *Valamugil georgii* obtain their carbon from transported and/or epiphytic algae material.

1.2.3 Nutritive value

Mullet is abundant in tropical and sub-tropical areas, is heavily fished in Kenya (Annual Reports, 1980 - 2005) and in the Far East countries of Hawaii, Japan, China and Philippines where it is heavily fished and farmed (Iversen, 1968b). Iversen also quoted an early writer Rachel Carson who described the mullet as flavourful and oily with nut-like flavour hence a highly rated food. Thomson (1966) reported that besides being sold fresh and smoked, its roe is highly valued.

Lytle and Lytle (1994) observed that natural populations of fishes contain fatty acids and other nutritional components that are highly variable. The chemical composition of fish is known to be dependent on size and change with ontogenesis and in addition, the quality and quantity of food (Perera & De Silva, 1978). Lytle and Lytle analysed fatty acid variability of *M. cephalus* and spot mullet (*Leiostomus xanthurus*). Their observation was that each constituent fatty acid as well as fatty acid class varies in individuals within a species of marine fish even when all environmental and physiological factors are minimized. *M. cephalus* showed greater variability in fatty acid composition and lipid content than *L. xanthurus* and the diet is the primary cause of these variations.

Perera and De Silva (1978) reported a higher percentage of protein, total lipid and a lower moisture content and carbohydrate that the reared young mullet had than wild fish. They attributed the high lipid content to the high calorific diet presented in excess of their requirements and lipid deposition influenced by the quality of food. Protein values were also high because of excess food and the relatively inactive life in confined spaces of the

rearing tanks. The lower moisture content was associated with development and growth typical for periods of cell division while low levels of carbohydrate suggest no storage because it is utilized for energy sources.

1.2.4 Growth

Growth is the measurable increase of an organic system, produced by its assimilation of materials obtained from its environment (Von Bertalanffy, 1938). Growth patterns and rates are known to be sensitive to biotic and abiotic stresses but provide a basis for theoretical and practical insight into the nature of functional adaptations and population dynamics. Growth rate information also adds to a more complete understanding of energy budget allocations in response to natural environmental stimuli at different times of the year (Cech & Wohlschlag, 1975).

Cech and Wohlschlag established two major periods of slow growth in *M. cephalus* from scale analysis. The slowest growth occurred during late autumn (November) and winter (December) months and also during summer (July) in the Northern Hemisphere. They correlated summer growth depression with changes in food assimilation and biochemical metabolic pathways, hence, significant effects on assessment of biological production. Chubb *et al.* (1981) observed very rapid growth in two species of the mullet, *M. cephalus* and *Adrichetta forsteri* at Swan-Avon river system (Australia). They explained that the rapid growth was related partly to stable nature of the estuary because water movement due to tidal action was small, fresh water discharge was confined to restricted periods during winter (July) and salinities exhibited no marked fluctuations between spring and

autumn. Growth and age structure are essential features in the study of fish populations (Weatherly & Rogers, 1978). Thomson (1966) reported that in sub-tropical and temperate waters, growth of mullet ceases in mid winter but reaches its maximum at mid-summer but in tropical waters no regular formation of annuli occurs.

Knowledge of the size at first maturity is important in the determination of the minimum legal size that may be needed to secure potential reproductive stocks (Shine, 1990). The age at maturity of *M. cephalus* has been estimated to range from one to eight years, the mode being three years while the size at sexual maturity has been given variously as 23 to 41 cm outside the tropics (Thomson, 1966). The age at first maturity in *Liza aurata*, has been reported to be one year in both sexes (Hotos et al., 2000, Ilkyaz et al., 2006) and in *Crenimugil labrosus* it is nine years in males and 11 years in females (Kennedy & Fitzmaurice, 1969).

The length-weight relationships have been used to estimate growth, provide information on the condition of fish but is very useful in fisheries research because they allow use of length or weight in stock assessment models, the estimation of biomass from length observations and are useful for between region comparisons of life histories of certain species (Dulcic & Glamuzina, 2006, Giarrizzo et al., 2006, Ibanez & Gallardo-Cabello, 2004, Verdiell-Cubedo et al., 2006). Kraiem et al. (2001) used the length-weight to express condition factors of *Liza ramada* in different ecological regions of Mediterranean Sea.

Condition factor is often used as a measure of the plumpness, fatness or "well being" of a fish and it varies with age group, sex, season, habitat and reproductive state (Bagenal and Tesch, 1978). Differences in the value of condition between populations frequently yield insight into the circumstances of their lives e.g., with regard to food supply and timing and duration of the breeding cycle, therefore the value of condition factor to fishery science is considerable (Weatherly & Rogers, 1978).

1.2.5 Reproduction

Thomson (1966) reported that the mullet are heterosexual with occasional abnormalities such as hermaphroditism and malformation of ovaries but gonads are large with very high fecundities. Hermaphroditism was reported in the thinlip *Liza ramada* from Homa lagoon in the Aegian sea (Bayhan & Acarli, 2006). The mullet eggs are round, transparent, non-adhesive with a large yellowish oil globule and therefore, are buoyant. Essential factors for successful incubation included high dissolved oxygen, minimum temperature variation (20 – 24 ° C) and gentle movement of water (Liao, 1975). Although mullets grow successfully in fresh and brackish water ponds, accumulation of large quantities of a potent androgen in the ovary inhibits the release of ovulating hormones (Eckstein, 1975). The mullets are known to have spawning seasons (Hotos et al., 2000) and research on the reproductive studies of *Liza aurata* (Risso) in Greece showed that Gonadosomatic Index (GSI) was highest in September for both sexes but the level was maintained from August to November. Hence, it was inferred that the spawning period extends through these months but takes place in the sea. First maturation occurred at the first year (age

1+) for both sexes and they comprised the greatest portion of spawners with absolute fecundity of 80,000 while a 7th year fish (age 7+) had a maximum fecundity of 1,410,000.

The population structures of Mugilidae vary in different parts of the world (Cardona, 1999b, Moura & Gordo, 2000, Samad & Abbas, 1999). The spawning season for Mugilidae of the Mediterranean population ranges from July to December (Aizen et al., 2005, Hotos et al., 2000), Gulf of Mexico from September to February (Ibanez & Benitez, 2004), in Taiwan from December to January (Chang et al., 2000) and in Kuwaiti waters from December to February (Abou-Seedo & Dadzie, 2004). Ibanez (1993) observed that changes in reproductive behaviour enables closely related species to coexist within the same environment. Spawning in *M. cephalus* took place for seven months between March and September in Swan-Avon river system in western Australia with *Adrichetta forsteri* and *M. cephalus* individuals spawning at different times (Chubb *et al.*, 1981). In the Tanshui estuary, *M. cephalus* juveniles reached the estuary approximately 40 days after hatching estimated to have occurred between October to February (Abraham et al., 1999, Chang et al., 2000).

In nature mullet spawns in seawater but can grow and thrive in lower salinity water (Aizen et al., 2005, Ibanez & Gallardo-Cabello, 2004, Thomson, 1963). The apparent spawning site is on the surface of deep water making the eggs and young susceptible to the vagaries of water movement. The fry enter estuaries at a size between 17 and 25 mm, and at 50 mm the third anal spine becomes apparent, the adipose eyelid starts to form,

hence this is taken as the age of adolescence as only growth is to be achieved before reaching maturity (Thomson, 1966).

Mullets do not breed in confinements of freshwater and brackish water ponds. Eckstein, (1975) suggested that in *Mugil capito* Cuvier and Valenciennes, accumulation of large quantities of a potent androgen in the ovary of mullet confined to freshwater inhibits the release of ovulating hormone, causing infertility. The culture of mullets in many countries is based on obtaining the necessary fry by seining as they migrate into lagoons and ponds. Natural causes or pollution can be responsible for a bad spawning season and therefore lead to inadequate quantities of naturally produced fry (Oren, 1975).

Being able to manipulate endocrine control of fish reproduction is critical to the development of hatchery technology. Lee *et al.* (1996) examined the effectiveness of chronic release hormone implants for stimulating testicular and ovarian maturation in *M. cephalus*. They observed a significant increase in milt production up to 11 months in males implanted with 10 mg Methyltestosterone (MT) capsules. In females with 200 μg Luteinizing hormone releasing hormone (LHRH), there was an increase in additional clutch of oocytes during the spawning season. The results of these implants provide a means for mullet hatcheries to increase brood stock performance. Comprehensive embryonic development have been described by Abraham *et. al.* (1999). Aizen *et al.* (2005) reported that combined treatment of Gonadotropin releasing hormone (GnRH) and domperidon (Dom) was more potent in inducing ovulation and spawning as compared to GnRH alone.

1.2.6 Aquaculture

Aquatic environments constitute one of the sources of proteins required to meet nutritional needs of the globally increasing human population, hence there is continuous harvesting of aquatic resources besides production of fish which outweighs beef, sheep and poultry meat (FAO, 1992a in Williams 1996). Williams (1996) observed that global fish supply is becoming scarce and more subject to human influences and will only be ameliorated by better management of fishery resources, improved aquaculture production, better use of resources and interventions to improve equity. Globally, capture fisheries landings (excluding plants and mammals have stabilized at around 92.8 ± 2.1 Million tonnes (mean ± SD) since 1994, fluctuating from a high of 95.7 million tonnes in 2000 to alow of 90.5 million tonnes in 2003 (Tacon & Metian, 2009).

Contributions from aquaculture to world fisheries became increasingly significant after 1975 and by 1990, accounted for approximately 14.5 million metric tonnes, out of which 10 million metric tonnes were from marine. In 1998, aquaculture contributed 39.4 million metric tonnes and marine waters accounted for 20.7 million metric tonnes (FAO, 2000). Coastal aquaculture has become a major contributor to estuarine fish harvests and its role continues to increase in importance (Houde & Rutherford, 1993). Thomson (1966) reported that pond cultivation of mullet is carried out in several Mediterranean countries, South East Asia, Japan and Hawaii, though experimental work has been carried out in the U.S.A., Israel and Korea. The mullets are the primary crop in parts of India but form secondary crop in countries like France, Japan and Italy. In the fishponds of Hong

Kong, the mullet are reared with Asiatic carps. The rearing of the mullet takes place in brackish water in most places but in India they are farmed in fresh water ponds.

The mullet possesses several characteristics desirable in a fish for pond culture such as high quality of flesh; extreme salinity tolerance; wide temperature tolerance and low position on the food chain. Mullets also respond well to inexpensive methods of fertilization and readily accept supplemental food (Bardach et al., 1972a). *Mugil parsia* (Hamilton) is cultivated in brackish water in deltaic West Bengal. Its fry ranging from 12 - 20 mm length enter the impoundments with tidal flux and grow in captivity. Ghosh *et al.* (1972) established that the fry upon entry into the brackish water, change from a diet of diatoms into zooplankton especially *Daphnia*, *Brachionus* and *Cypris*. The fry achieved the fastest growth with a combined diet of zooplankton and phytoplankton. Tamaru *et al.* (1994) reported that the added benefit for the use of background phytoplankton in the larval culture process included an indirect effect on larval growth and survival by maintaining the rotifers and alteration of environmental parameters such as light improved larval survival and growth in commercial production.

Eggs and larvae are more vulnerable to environmental stresses than juveniles and adults. The knowledge on salinity and oxygen tolerances of eggs and larvae is essential to both ecologist and aquaculturist. Sylivester *et al.* (1975) reported that the optimal salinity for eggs of *M. cephalus* lies within the range of 30 - 32 ‰ while of larvae between 26 - 28 ‰, therefore, larvae are adapted to estuarine existence. The eggs survive above mean oxygen level of 5.0 parts per million (ppm) while for larvae rearing 5.4 ppm oxygen level

is required. Spawning, therefore, occurred under conditions of oxygen super saturation. In Israel, *M. cephalus, Mugil capito* and *Mugil auratus* are used in polyculture with common carp. The advanced fry are obtained from Mediterranean estuaries and reared alone in fertilized ponds to the second year before stocking. Sampaio *et al* (2001) reported that it is advisable to work with intermediate densities of 3-5mullet/L in order to optimize facilities though growth will not be the best but larger numbers of fingerlings are produced. They noted that a higher water exchange rate should be employed to eliminate metabolites and improve water quality, providing conditions for better results in terms of growth and survival.

In the culture of captive mullets, Eckstein (1975) reported that accumulation of a large quantity of a potent androgen in the ovary of mullet confined to fresh water inhibits the release of ovulating hormone. Kuo et al. (1974) suggested that growth of oocytes is accelerated by injection of pituitary gonadotropin doses increasing from 0.12 to 3.4 µg/g body weight and a decrease in water temperature also assists in oocyte development.

Nash and Kuo (1975) enumerated some of the problems impeding mass propagation of grey mullet as size of the larvae because the eggs are much smaller and the larvae have shorter yolk utilization periods and larval foods smaller than nauplius of *Artemia salina* and with adequate nutritional value to sustain life and establish growth; induced spawning technique accelerates final development of oocytes thus lowering the quality of the individual oocytes which are inferior to those developing naturally; artificial diets from both natural and synthesized material have been tried with limited success because

most have the disadvantage of increased fouling in the rearing containers; the effect of salinity on larval development and survival is more significant because there is a distinct advantage in changing salinity at some time during development between hatching and metamorphosis; incubation times for both egg incubation and larval development is temperature dependent and finally bacterial infection in rearing tanks.

Oren, (1975) noted that aquaculture is practised in countries with surplus water and land but there is need to conserve fresh water, hence need to change to mariculture, therefore the coastal waters, lagoons, marshes estuaries and bays should be made into more intensive protein producing areas and in the process address universal problems of food security and employment.

In Kenya, mariculture is practised at the coast on a very small scale and culture organisms include prawns, oysters and seaweeds. There are no developed facilities for marine fin fish culture and Mugilidae have high prospects of culture at the coast (Annual report, 2008).

1.2.7 Diseases

O'Shea et al. (2006) devised the wrap method to accurately determine the surface area of a fish because parasitic infections show an increase in infection intensity with an increase in host size due to the larger surface area available for settlement. Diseases and parasites play a very significant detrimental role in aquaculture hence is a major barrier to the expansion of aquaculture industry (Paperna, 1975). *Mugil cephalus* is one of the most

important commercial fishes in the U.S.A. where there is an increase in the use of the mullet in aquaculture. Parasites common on and in mullet include trematodes, copepods and fungi (Thomson, 1966). Paperna (1975) recorded gill protozoa, Myxosporidia, Monogenea, Digenea, Metacercariae, Nematoda, Cestoda, Acanthocephala, Copepoda, Isopoda and Hirudinea from mullets in the Eastern Mediterranean Sea, Northern Red Sea, Black Sea and the Gulf of Mexico. Wild mullet fingerlings are infected with parasites that contribute to high mortalities in rearing ponds and also create problems in polyculture. Rawson (1976) identified three species of Monogenea, which infected the mullet on the gills and the body surface. He observed that the mullets have a seasonal pattern of abundance, reproduction and growth, hence temperature was the most important environmental factor because Monogenean population increased during warm weather due to increase in rates of oviposition and embryonic development at temperatures of 30 ^{o}C.

Kruger *et al.* (1998) identified female specimens of the copepod *Mugilicola smithae* on the gills of four mullet species *Liza alata, Liza macrolepis, Myxus capensis and Valamugil seheli* which are specifically estuarine fishes.

1.2.8 Pollution influence

Lead toxicity was studied in grey mullet *Mugil auratus* Risso, with a view of its detection in and clinical treatment of people exposed to this metal (Krajnovic-Ozretic & Ozretic, 1980). They reported that satisfactory ALA-D activity test is satisfactory for assessing lead contamination in fishes. It is more sensitive and easier to perform than direct

determinations of lead concentrations in the blood. The accumulation of lead in mullets produces anaemia but Zinc is very effective in restoring the ALA-D activity of the exposed mullets to lead.

Bhagwant and Elahee (2002) reported the presence of mucous in the ballooning dilatations of gill filaments they deduced were an ion trap to concentrate trace elements from water. They attributed such lesions to the sediment-borne contaminants after noting the presence of white blood cells, which indicated inflammatory reaction. They related these pronounced gill lesions to the presence of toxicants in they bay that are detrimental to fish health.

From the above review it is clear that only presence of Mugilidae have been documented at the Kenyan coast where fisheries statistics indicate their harvesting (Annual Reports, 1980 – 2008) but research work on the family has been done elsewhere in the world. Over-exploitation and environmental pressures on fish stocks in many of the world's natural fisheries threaten food security in much of the developing world. Few people will be dependent on capture fisheries because commercial fishers operating more efficient gear will dominate. Many people will participate in aquaculture hence it is becoming increasingly important but it must be intensified significantly and sustainably (Williams, 1996). Houde and Rutherford (1993) observed that aquaculture production of estuarine dependent species has added significant supplements to wild fishery harvests. It is also recognized that estuaries are highly productive with respect to fisheries resources and that fishery productivity and yields are related to relatively high primary production supported

by high nutrient inputs. Mariculture although practiced in many countries of the Far East, is not developed in Kenya.

1.3 Description of the Kenyan coastline

The Kenyan coastline is approximately 640 km long and forms part of the western border of Indian Ocean consisting of 12 nautical miles of territorial waters and the Exclusive Economic Zone extending 200 nautical miles seawards. It lies within the tropical zone extending from Kiunga (Somalian border) at 1° 41' S to Vanga (Tanzanian border) at 4° 40'S and runs in a southwesterly direction (Kokwaro, 1985, UNEP, 1998). The area of the continental shelf to a depth of 200 m is approximately 8,500 km^2 and lies within eight kilometers offshore except in the northern bank and Ungwana bay where it extends to 64 km (UNEP, 1998). A continuous fringing coral reef runs parallel to the coast extending to approximately 45 m depth and at a distance of 500 m to two kilometres from the shore except where river systems enter the sea creating conditions of low salinity and high turbidity which limit coral growth. (Annual Report, 2005).

This coast lies in the hot tropical region where the weather is influenced by the monsoon winds of the Indian Ocean (Kokwaro, 1985). Climate and weather systems on the Kenyan coast are dominated by large-scale pressure systems of the Western Indian Ocean and the two monsoon periods. From October to early March, the North East Monsoons (NEM) dominates the coast and is comparatively dry and hot. From April to September, the South Easterly Monsoons (SEM) dominates and the weather is associated with strong winds and is rainy with cooler temperatures (UNEP, 1998).

The Kenyan marine waters support a wide variety of finfish species grouped as pelagics (king fish, barracuda, mullets, queen fish etc) and demersals (rabbit fish, snapper, rock cod, scavenger etc); crustaceans (prawns, lobsters, crabs); echinoderms (sea cucumbers) and molluscs (squids, oysters, octopus etc). All crustaceans belong to the class Malacostraca, subclass Eucarida and order Decapoda. The swimming crustaceans, prawns are in suborder Natantia, infra-order Penaeidea while crawling crustaceans, crabs are in the suborder Reptantia, infra-order Brachyura (King, 1995).

Crustaceans are an important source of food for humans and animals besides being of economic importance to humans and forming part of the food chains of marine systems (Kyomo, 1999). Along the Kenyan coast, crustaceans of importance are prawns and crabs caught from mangrove areas while lobsters are caught on the continental slope beyond the reef by divers (Annual Report, 2005). At Ungwana bay, a Penaeid prawn trawl fishery established harvests *Panaeus indicus, Metapenaeus monoceros* and *Penaeus monodon* as important species along the Kenyan coast (UNEP, 1998). These fishery organisms are commercially exploited therefore, support the economy and livelihoods of the coastal residents (Annual Report, 2005).

Marine fishery in Kenya is predominantly small scale and artisanal. It's productivity is constrained by the narrow continental shelf, low productivity waters and seasonality (Matthes, 1974, McClanahan, 1988). The Ministry of Fisheries carries out monitoring of fisheries in Kenyan waters. Approximately 12,077 artisanal fishers harvest over 90 % of marine catch using 2,687 crafts, which include 319 motorized, the rest are dugout canoes

using paddles, outrigger canoes and dhows using sail. They also employ the use of simple gears such as cast net, hand net and traditional traps especially *malemma* and *uzio* within bays and estuaries (Annual report, 2008). Artisanal fisheries play an important role in fish production hence responsible for the bulk of marine fish catches in Kenya (UNEP, 1998).

Marine finfish species offering good prospects for mariculture at the Kenyan coast having been tried elsewhere are Milkfish (*Chanos chanos)* (Bardach *et al.*, 1972b), Rabbitfish (Siganidae) (Ben-Tuvia et al., 1973, Von Westernhagen, 1973) and Mullet (Mugilidae) (Bardach et al., 1972a, Milne, 1979). The general biology of these fishes are known but information on local characteristics of the milkfish and the mullet is quite scanty (Sivalingam, 1981). In Kenya, the mullets and milkfish form an important component of marine pelagic fishery while rabbitfishes are demersal (Annual Report, 2007). Milkfish and rabbit fishes are herbivorous but their salinity and temperature tolerance is much lower than that of mullets (Iversen, 1968a). Mullets are herbivorous, feeding by taking detrital or other organic matter from the bottom or by grazing off epiphytic and filamentous algae, are euryhaline (> 80 ‰), eurythermal (8 – 30 °C), have rapid growth and hardy (Iversen, 1968b, Thomson, 1966). Mariculture is undeveloped in Kenya and has been limited to brackish water ponds and artisanal shrimp and oyster cultivation on experimental scale. Coastal aquaculture has considerable potential as a source of economic return and if well planned and managed. The mullet have a considerable potential for culture (UNEP, 1998). It is with the aim of mariculture, that research on Mugilidae was carried out to establish growth and reproduction *in situ*.

The Kenyan coastline (Figure 1) is characterized by open inland lagoons systems such as Mida, Kilifi, Mtwapa and Tudor creeks and several small river estuaries with many entrances to the sea separated by islands such as Chale, Lamu and Funzi. Conditions for establishing mariculture farms in the areas mentioned above include favourable soils which can retain adequate level of water, suitable tidal range which in Kenya is three to four metres and availability of seed for stocking. Three types of mariculture for various organisms could be utilized: a). Pond culture in cleared mangrove area and/or land behind mangroves, b). Suspension culture i.e., cage and raft in sheltered waterways of sufficient depth and c). Rack culture in the shallow intertidal areas. Pond culture has been carried out at Ngomeni and Mtwapa where prawns (*Penaeus monodon*) have been successfully cultured. Rack culture has been used in oyster culture (*Crassostrea cucullata*) at Gazi and Shirazi (UNEP, 1998). Wild seeds could be used for stocking established mariculture farms because juvenile stages of both finfish and shellfish are abundant throughout the year (Sivalingam, 1981). Williams (1996) was more concerned with global fish supply, which are becoming scarce and more subject to human influences but will only be improved by better management of fishery resources. She further noted that aquatic resources make up 19 % of the total animal protein consumed and also provide environmental cultural values and services. Williams and Corral (1999) observed that monitoring has a key role to play in all aspects of fisheries management including those related to sustainable management of the resource. This project was undertaken to establish the distribution and biology of two Mugilidae species *Mugil cephalus* and *Valamugil buchanani* at Kilifi creek on the Kenyan north coast.

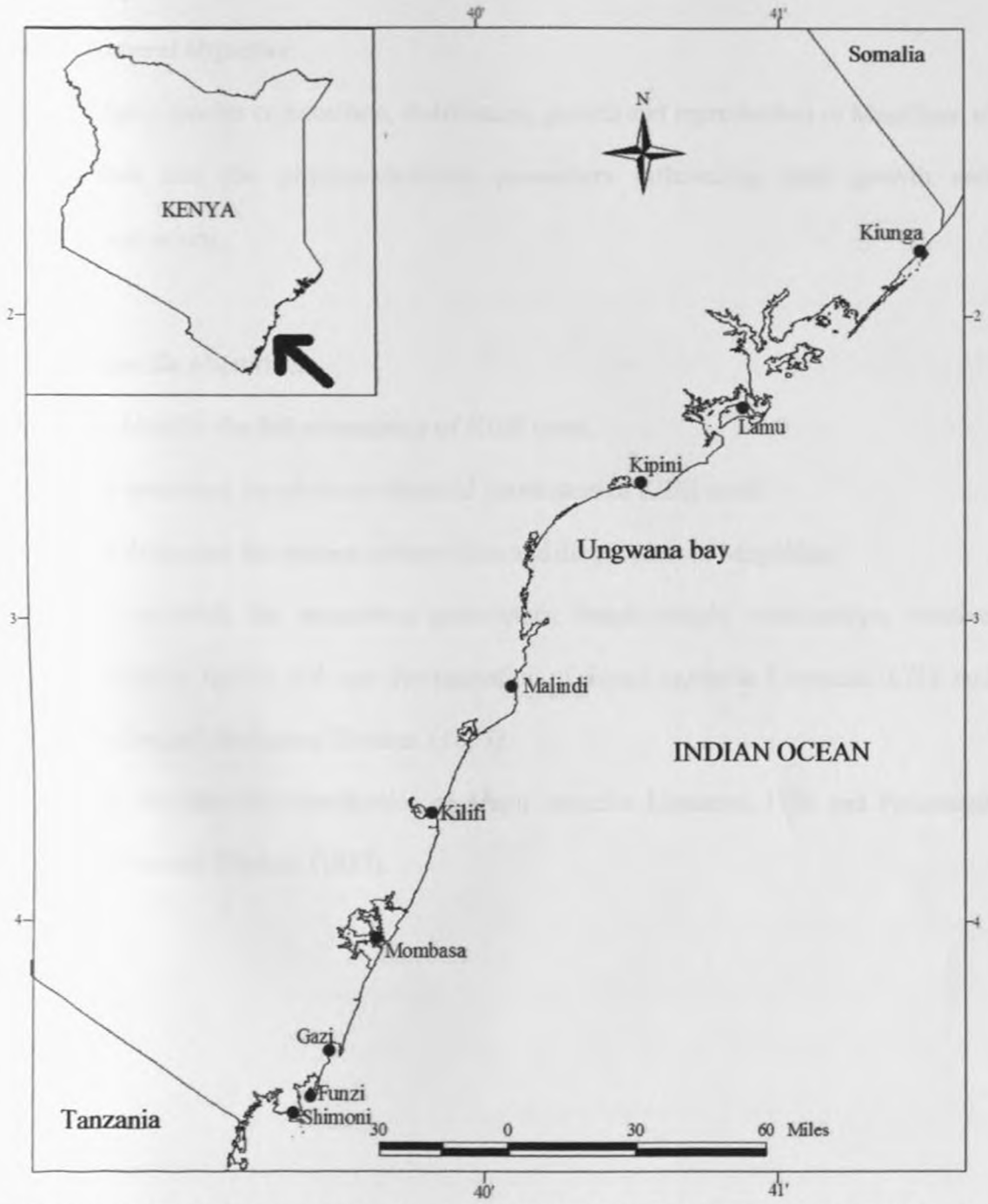


Figure 1: Map of Kenya coast showing inland lagoons, bays and creeks (Source: KMFRI).

1.4 Objectives

1.4.1 General objective

To investigate species composition, distribution, growth and reproduction of Mugilidae at Kilifi creek and the physico-chemical parameters influencing their growth and reproduction *in situ*.

1.4.2 Specific objectives

a). To identify the fish community of Kilifi creek.

b). To determine the physico-chemical parameters of Kilifi creek.

c). To determine the species composition and distribution of Mugilidae.

d). To establish the population parameters: length-weight relationships, relative condition factors and age determination of *Mugil cephalus* Linnaeus, 1758 and *Valamugil buchanani* Bleeker, (1857).

e). To elucidate the reproduction of *Mugil cephalus* Linnaeus, 1758 and *Valamugil buchanani* Bleeker, (1857).

CHAPTER TWO

2.0 General Materials and Methods

2.1 Study area

Kilifi creek (39° 50'E and 3° 38'S) (Figure 2 overleaf) is located approximately 55 km north of Mombasa Island on the Kenyan coast. The deepest part of the creek is approximately 38 m at the creek entrance and a distance of about 4 km (approximately 500 m wide) separates the ocean from an open water area known as Bahari ya Wali. The entire area of Kilifi creek covers approximately 22.4 km^2 (Ong'anda, 2008). The western side of the creek is extensively covered with mangrove trees of different species. There are two main water channels winding in between the mangrove forest. The southern arm is shorter and has no permanent stream inlet while the northern arm is longer with two permanent streams, Ndzovuni and Rare, which join up forming the Konjora channel that leads to Bahari ya Wali. These rivers originate at about 300 metres above sea level on the western side of the Nyika plateau. Kilifi creek has an estimated mangrove area of 360 ha (Kokwaro, 1985). The northern arm has *Avicennia marina* (Forsskal, 1907); *Rhizophora mucronata* (Lamarck, 1804); *Sonneratia alba* (Smith, 1891) and *Xylocarpus granatum* (Koenig, 1784) while the mangrove species within southern arm include *Ceriops tagal* (Perrottet) C. B. Robinson, 1908; *Rhizophora mucronata; Avicennia marina* and *Sonneratia alba.* These mangrove species are mixed with no defined zonation, however, a linear transition was observed towards the streams. Along the northern arm at Fumbini, *Avicennia marina, Rhizophora mucronata*, *Sonneratia alba* species are mixed but from Konjora *Xylocarpus granatum* dominates along the channel into Rare stream.

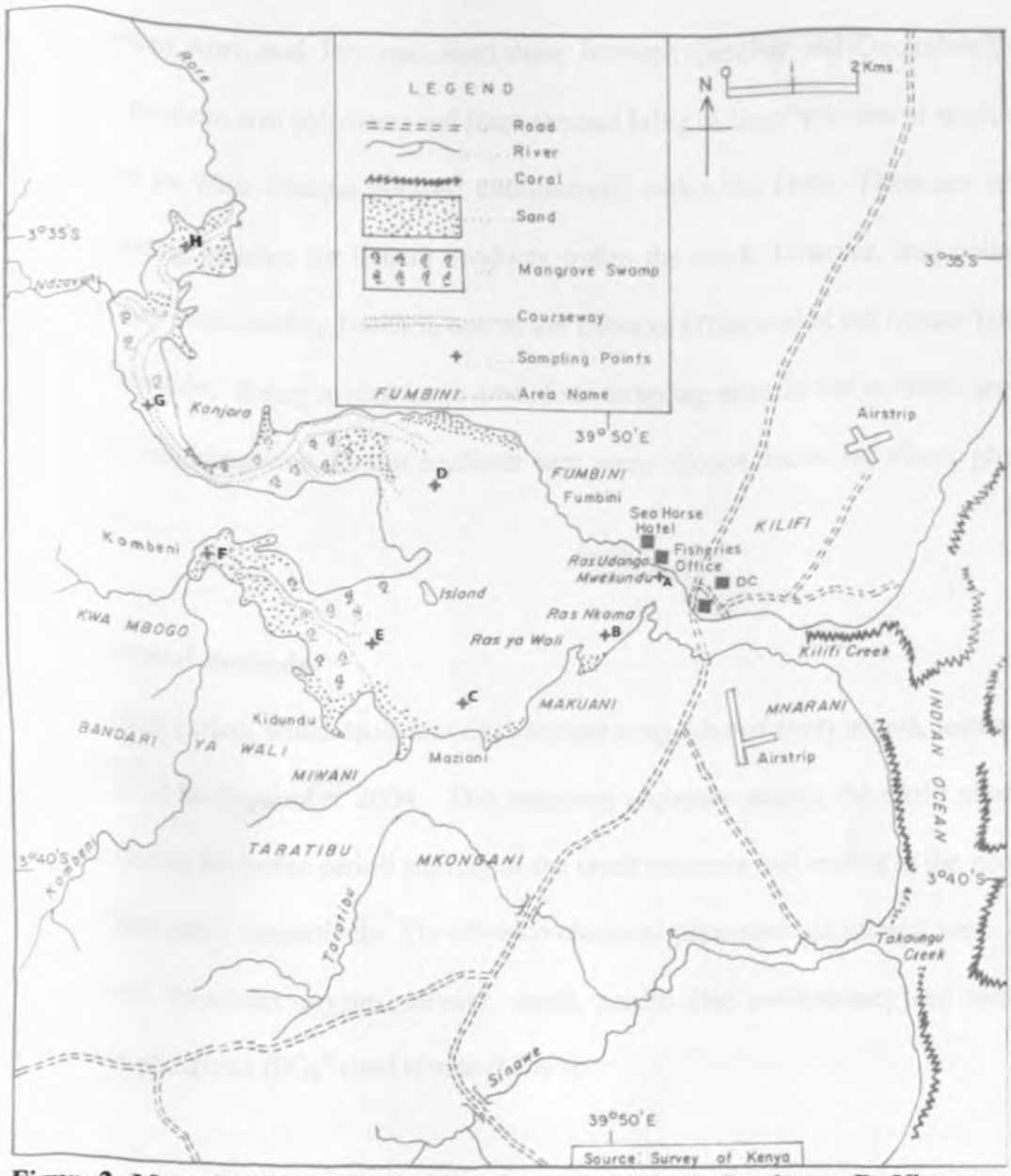


Figure 2: Map of Kilifi creek showing the study sites, A- Sea horse, B- Nkoma, C- Mazioni, D- Fumbini, E- Kidundu, F- Kombeni, G- Konjora, H- Rare.

In the southern arm, *Rhizophora mucronata, Avicennia marina* and *Sonneratia alba* are mixed at Kidundu but into the channel up to Kombeni, *Ceriops tagal* dominates. In both areas, *Avicennia marina* and *Sonneratia alba* are in areas with salinities of approximately 35 ‰ but *Ceriops tagal* is found in hypersaline areas of Kombeni while *Xylocarpus*

granatum is in the hypo-saline area towards Rare. There are two rainfall seasons, the long rains between April and July and short rains between October and December during which the northern arm Ndzovuni and Rare streams bring in large volumes of fresh water into Bahari ya Wali. Fishing goes on continuously within the creek. There are several smaller landing beaches for fishery products within the creek, however, data collection occurs in two main landing beaches, one at the fisheries office and at the former ferry on the opposite side. Being a very large area, four sampling sites in the northern arm and other four sampling sites in the southern arm were chosen based on visual physical differences.

2.2 General methods

The sampling period, which took four days around neap tides of every month, lasted from October 2002 to September 2004. The sampling sequence among the study sites was constant during the entire period starting at the creek entrance and ending in the northern and southern arms, respectively. The physico-chemical parameters of interest were water temperature, dissolved oxygen, salinity, depth, secchi disc transparency and nutrients (inorganic phosphate (PO_4^{3-}) and nitrate (NO_3^-)).

At each site, a scoop bucket (5 litres) was placed 10 cm below the water surface and after acclimatization period of 10 minutes, surface water was obtained. A graduated string attached to an improvised bottom water sampler (3 litres) was used to obtain water from the bottom region at each sampling site after recording its depth. The bottom water sampler was allowed an adjustment period of 20 minutes, bottom water was obtained.

Each site was sampled twice every month and means of surface and bottom water for each physico-chemical parameter was calculated.

Fishing was carried out at each sampling site during the day using a canoe towed by a motorboat with an outboard engine because of the long distances between sites. Cast net (19.1 mm mesh size, 7.6 m^2) and gill nets (50.8, 63.5 and 76.2 mm mesh sizes, 166 cm depth and 100 m long each) were used for fishing.

2.3 The physico-chemical parameters of Kilifi creek.

2.3.1 Water temperature

Both surface and bottom water was obtained and their temperature recorded immediately using an ordinary mercury thermometer (50 °C).

2.3.2 Dissolved oxygen

Dissolved oxygen concentration was determined using the Winkler Method of 1888 (Grasshoff, 1972). Fill 250 ml glass stoppered biological oxygen demand (BOD) bottles gently with both surface and bottom water respectively. To fix the samples, 1.5 ml of both Manganese (II) Chloride and Alkaline Iodide solution were added respectively at the bottom of the stoppered BOD bottles and shaken vigorously for one minute. The precipitate was allowed to settle and the BOD bottles were then kept in a dark container and transported to the laboratory. In the laboratory, 1 ml Concentrated Sulphuric acid was added to the BOD bottles and allowed to stand for 30 minutes. Then 50 ml of the contents were pipetted into four different Erlenmeyer flasks, which had been rinsed with

distilled water. The liberated iodine was titrated with 0.01 N sodium thiosulphate in bright light, 3 drops of starch solution was added before the disappearance of the yellow iodide colour and titrated to end point. Dissolved oxygen concentration was calculated using the formula:

$$O_2\ mg\ l^{-1} = \frac{(ml\ titrant \times Normality\ of\ thiosulphate \times 8000)}{Vol.of\ sample\ titrated \times \{(Vol.of\ BOD\ bottle - Vol.of\ reagents\ added) / Vol.of\ BOD\ bottle\}}$$

2.3.3 Salinity

A hand held Atago refractometer was used to estimate salinity at all study sites. The units used were parts per thousand (‰).

2.3.4 Transparency

This was determined using a Secchi disc fitted with weights to aid sinking. The disc had a calibrated string, which was used to estimate Secchi depth in metres. At the sampling site, the disc was lowered into water and the depth of disappearance or appearance, when lifted, was taken as the level of transparency.

2.3.5 Depth of water

The calibrated string attached to the bottom water sampler fitted with weights to aid sinking was used to estimate the depth of water at the study sites.

2.3.6 Nutrient analysis

At each site, water was obtained 10 cm below the surface using a scoop bucket and from the bottom, using an improvised bottom water sampler. Approximately 270 ml was placed in a plastic container (Polyethylene bottles), a drop of chloroform added and then deep-frozen at 4 °C awaiting analysis in the Laboratory. This water was then used in analysis for inorganic Phosphate and Nitrates in both surface and bottom water as described by Grasshoff, (1972) and Parsons et al, (1984).

2.3.6.1 Inorganic Phosphate

The water samples were allowed to de-freeze in the laboratory. 100 ml water sample was pipetted into 100 ml glass bottles, 10 ml of mixed reagents added, bottles closed and mixed thoroughly. The components of mixed reagents were:

i). Ammonium Molybdate solution 100 ml

ii). Sulphuric acid 250 ml

iii). Ascorbic acid solution 100 ml

iv). Potassium antimonyl-tartrate solution 50 ml

The samples were then allowed to stand for two hours at room temperature. Analysis was done using (Technicon Auto Analyzer II System) where the extinction of the solution was measured in 1 cm cell at 885 nm against distilled water using single beam UV-Spectrophotometer. The reagent blank value was subtracted from the measured extinction and multiplied with a proportionality factor obtained from the calibration curve. To establish the calibration curve, the reagent blank value was subtracted from the measured extinction and multiplied with a proportionality factor obtained from the

calibration curve. Calibration was done using 0.816 g of anhydrous potassium dihydrogen phosphate dissolved in 1000 ml distilled water and 1 ml chloroform added. Five standards (0.8, 1.6, 2.4, 3.2, 4 ml) of phosphate solution were prepared and made up with 100 ml of distilled water, served as Blank reagents. 10 ml of mixed reagents were added and extinction measured in 1 cm cell at 885 nm.

2.3.6.2 Nitrate

The water samples were allowed to de-freeze in the laboratory. In 100 ml of filtered seawater sample in a 125 ml Erlenmeyer flask, 2 ml of concentrated Ammonium chloride was added and thoroughly mixed. The copper coated cadmium fillings reducer was filled with 40 ml of this mixture and after a preliminary run off of 40 ml, the reducer was filled again with 30 ml of this mixture and the effluent collected in 50 ml Erlenmeyer flask. This volume was adjusted to 25 ml by draining off with a needle. 0.5 ml sulphanilamide solution was added, mixed and after five minutes, 0.5 ml of ethylenediamine dihydrochloride solution was added, mixed thoroughly. After two hours, the extinction of the dye formed was measured in a single beam UV-spectrophotometer at wavelength 543 nm (Technicon Auto Analyzer II System). For a comparison sample, the filtered water sample, but without reduction was used. To establish the calibration curve, known quantities of standard nitrate solution (1.02 g potassium nitrate in 1000 ml distilled water) were added to the synthetic seawater (310 g sodium chloride, 100 g magnesium sulphate and 0.5 g sodium bicarbonate in 100 ml distilled water) with low nitrate content and the sample extinction measured at wavelength 543 nm.

2.4 Treatment of samples

2.4.1 Identification and classification of fish community of Kilifi creek.

After fishing, as described in the general methods (section 2.2), the fishes obtained were taxonomically classified using:

i). Smith's Sea Fishes (Smith & Heemstra, 1986).

ii). Biology and Ecology of Fishes in Southern African Estuaries (Whitfield, 1998).

iii). FAO Species Identification Sheets for fishery purposes (Thomson & Luther, 1984).

iv). Field guide to freshwater fishes of Tanzania (Eccles, 1992).

v). Fish resources in Kenyan marine fisheries (Government of Kenya Unpublished, 2003).

vi). Superclass Pisces (Esseen & Richmond, 1997).

The fin fish obtained were classified into orders, families and species where possible. The data obtained used in chapter three and four of this thesis.

2.4.2 Identification and measurements of Mugilidae

All Mugilidae obtained were taken to the laboratory fresh and for each fish, the following was recorded:

i). Total length (cm) using a fish measuring board (to the nearest 1 mm).

ii). Total weight of the ungutted fish (to the nearest 0.1 g) using a triple beam balance (Ohaus capacity 2610g).

iii). The fish was then dissected for identification of sexes and gonads removed and preserved in Bouin's solution for histological studies and Gilson's fluid for fecundity studies.

The data obtained was used in chapter four and five of this thesis.

2.5 The physico-chemical parameters of study sites

The identified study sites (Figure 2, page 27) were chosen because of various characteristics and locations as described below. Magellan 2000 GPS was used to give the geographical positions. The physico-chemical parameters results (Table 2) are given in summarized form to show the variation of these factors at the study sites.

2.5.1 Sea Horse

This study site was located around the Sea Horse hotel (Plate 1), GPS position (39° 50' 12 sec E; 03° 37' 39 sec S). The site was deep (8.67 m) with high mean secchi depth transparency (2.92 m) hence suitable for boating activities by hotel patrons as well as artisanal fishing. There was a small island with exposed rock boulders, which was usually covered by water during high spring tides but exposed during low tides. It was at the entrance of Bahari ya Wali. A few *Avicennia marina* (Forsskal, 1907) and *Rhizophora mucronata* (Lamarck, 1804) trees were scattered on clean white sandy beach with underlying mud. (1 cm: 3m)

Plate 1: Sea Horse sampling site (A – *R. mucronata*, B – *A. marina*, C – Small Island. Photograph by Sigana, 2004).

2.5.2 Fumbini

Fumbini (Plate 2) was approximately 3.5 Km away from Sea Horse in front of a large mangrove island next to an extensive area of mudflat always exposed during low tides. Its GPS position was (39°48' 48 sec E; 03° 37' 15 sec S). Seaweeds, submerged during low tides and covering the mudflat, provided a unique ecosystem for various organisms. The main seaweed species were *Enteromorpha ramulosa* and *Chaetomorpha crassa* that formed a dense luxuriant growth especially in channels never exposed at low tide. Two deep channels at extreme ends, joined up to form Konjora behind Fumbini from the mangrove Island. The large mangrove Island had mainly *Sonneratia alba* (Smith, 1891) mixed with *Rhizophora mucronata* species on the seaward side. But on the leeward side of the island were scattered *A. marina*. The beach area was muddy with germinating seedlings of *S. alba* and R. *mucronata*.

Plate 2: Fumbini sampling site at low tide (A – *S. alba*, B – Mudflat covered with seaweeds. Photograph by Sigana, 2004).

2.5.3 Konjora

Konjora (Plate 3), GPS position, (39° 46' 34 sec E; 03° 36' 14 sec S) was approximately 5.75 Km from Fumbini within a deep meandering channel whose width varied between 20 to 50 m, the deepest point approximately 6 m. At the edge of the channel was a fringing stand, mainly of *R. mucronata* mixed with *A. marina,* on the depositional side of the channel and *A. marina* with scattered *Xylocarpus granatum* (Koenig, 1784) and *Bruguiera gymnorrhiza* (Linnaeus) Savatier, 1798 on the erosional side above the banks. The channel led water from the union of Ndzovuni and Rare streams and a decrease in its width and depth was noted just after Konjora.

Plate 3: Konjora channel lined with *A. marina* mangrove trees (A). (Photograph by Sigana, 2004).

2.5.4 Rare

Rare (Plate 4) was the furthest site leading into Rare fresh water stream within the northern arm of the creek, GPS position (39° 46' 46 sec E; 03° 35' 37 sec S). This channel is narrow, width not more than 10 m and a mean depth of 2.22 m. Along the fringes were interspersed species of *A. marina, R. mucronata* and *X. granatum* mangrove trees. *S. alba* was a rare occurrence.

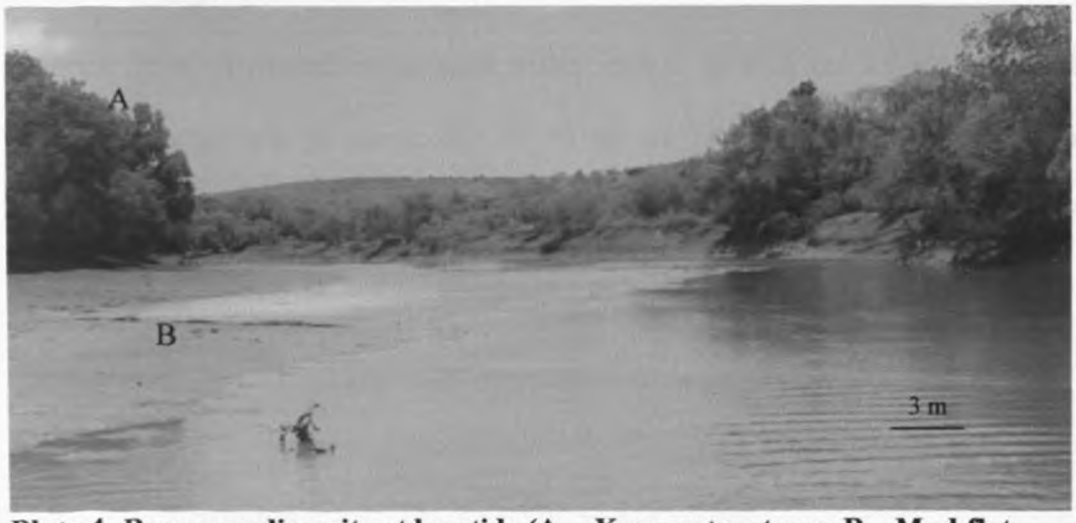


Plate 4: Rare sampling site at low tide (A – *X. granatum* trees, B – Mud flat within the channel. (Photograph by Sigana, 2004).

2.5.5 Nkoma

Nkoma (Plate 5) was on the southern part of the creek opposite Sea horse also at the entrance, GPS position (39° 49' 58 sec E; 03° 38' 09 sec S). There were no mangrove trees next to the cliff slope but within an embayment were scattered and mixed species of *Bruguiera gymnorrhiza*, *R. mucronata*, *A. marina* and *C. tagal.*

Plate 5: Nkoma sampling site (A – Mixture of Mangroves species, B – Cliff face). (Photo by Sigana 2004).

2.5.6 Mazioni

Mazioni (Plate 6) was an embayment within Bahari ya Wali but 2½ Km from Nkoma GPS position (39° 49' 07 sec E; 03° 38' 43 sec S). The beach had fringing mangroves with mixed *R. mucronata* and *A. marina* species. The benthic area was muddy, with a depth range between 2.77 and 4.7 m.

Plate 6: Mazioni sampling site (A – *Avicennia marina*). (Photograph by Sigana, 2004).

2.5.7 Kidundu

Kidundu (Plate 7) was located behind a mangrove Island with mixed species of *A. marina, S. alba* and *R. mucronata.* Its GPS position was (39° 48' 23 sec E; 03° 38' 16 sec S) and was approximately 2 km from Mazioni. It has a large mud flat always exposed at spring low tides next to a luxurious mangrove stand of mixed *S. alba, R. mucronata*, and *A. marina*. There were scattered seaweed areas within the mudflat. The southern part of the site is approximately 3 m deep and never exposed at low tide. The depth range at Kidundu was between 1.34 and 2.84 m. From this site a shallow channel, less than 10 m wide and less than one metre deep brings in water from Kombeni stream as it narrows ahead. At the fringes were mangrove stands of mixed *R. mucronata, S. alba*, and *A. marina.*

Plate 7: Kidundu sampling site, southern part (B), northern part (C) and entrance into Kombeni channel (A). (Photograph by Sigana, 2004).

2.5.8 Kombeni

Kombeni (Plate 8) was less three metres wide and very shallow with GPS position (39° 47' 19 sec E; 03° 37' 34 sec S) and was 3½ km from Kidundu. At the muddy fringes were mainly *C. tagal* on the erosional side of the channel and a mixture of *R. mucronata* and *A. marina* on the depositional side of the channel.

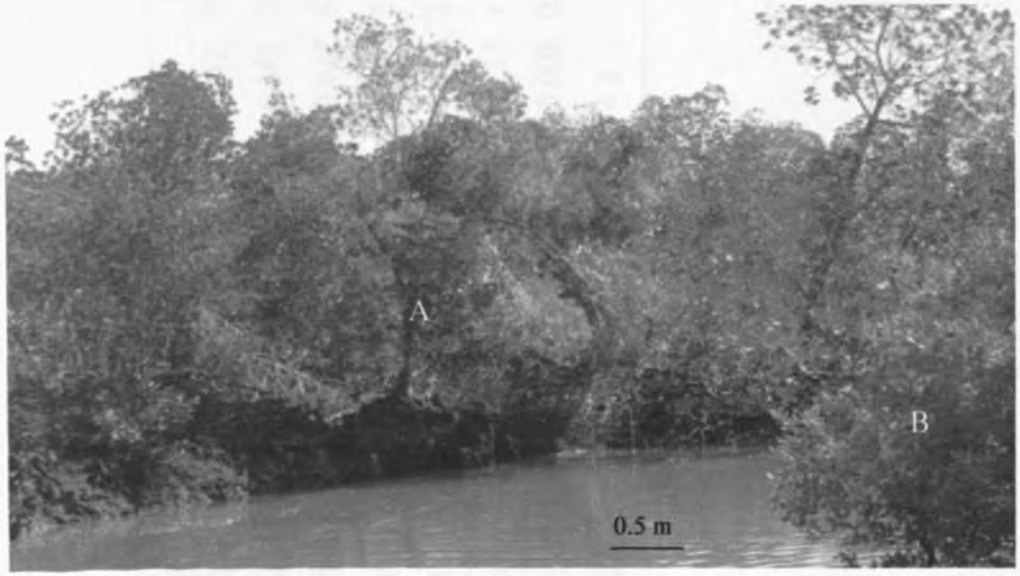


Plate 8: Canopy of *Ceriops tagal* (A) and *A. marina* (B) almost closes the channel at Kombeni sampling site. (Photograph by Sigana, 2004).

Table 2: Means of Physico-chemical parameters and finfish at the study sites (± = SE; n=

Parameters	Sea horse	Nkoma	Mazioni	Fumbini	Kidundu	Ko
Phosphates (μM)	0.65±0.029	0.72±0.036	0.63±0.023	0.7±0.032	0.58±0.021	1.06
Nitrate (μM)	1.37±0.055	1.27±0.038	1.21±0.045	1.28±0.047	1.32±0.048	1.49
Dissolved Oxygen (mg/l)	6.50±0.024	6.29±0.018	6.24±0.017	6.34±0.027	6.19±0.021	5.32
Temperature (° C)	28.0±0.061	28.2±0.062	28.6±0.073	28.4 ±0.07	27.8±0.073	30.1
Salinity (‰)	35.2±0.058	35.2±0.059	35.5±0.072	35.3±0.076	35.5±0.062	37.
Depth (m)	8.67±0.08	8.05±0.08	3.76±0.021	1.61±0.013	1.96±0.017	1.37
Secchi transparency (m)	2.92±0.029	2.55±0.033	1.57±0.015	1.21±0.008	0.95±0.009	0.43
Fish (mean No.)	34 ± 2	32 ± 1	12 ± 1	52 ± 2	41 ± 1	1

The physico-chemical parameter with the largest mean variation (Table 2) was nitrates being highest at Rare and lowest at Mazioni. The mean phosphate concentration was high at Rare but low at Kidundu. The variation in means among sites was, however, low in salinity, temperature and dissolved oxygen. Both Sea Horse and Nkoma were the deepest sites and also with the highest secchi transparency. F-test was carried out to establish if there was significant difference in the physico-chemical parameters during the North East Monsoon and South East Monsoon seasons. Significant difference was observed in phosphate concentration and water temperature ($F_{1,184} = 22.51$, $P=0.00$; $F_{1,184} = 48.06$, $P = 0.00$) respectively while no significant difference was observed in nitrates, dissolved oxygen, salinity, secchi transparency and depth ($F_{1,184} = 0.71$, $P = 0.4$; $F_{1,184} = 0.88$, $P = 0.35$; $F_{1,184} = 0.10$, $P = 0.74$; $F_{1,184} = 1.20$, $P = 0.27$ and $F_{1,184} = 1.16$, $P = 0.028$) respectively. These variations were comparable to those from other parts of the Kenyan coast (Ohowa et al., 1997, Uku & Bjork, 2001, Uku & Kitheka, 2002) indicating that the Kenyan coast is still pristine. These sites were also chosen to establish how far and which species of Mugilidae utilize which areas.

CHAPTER THREE

3.0 Diversity of fishery organisms at Kilifi creek

3.1 Introduction

Estuaries, coastal embayments and shallow inshore habitats are recognized as productive systems used by fishes and invertebrates as nursery areas. Estuarine habitats are nutrient traps that support high primary productivity promoting high secondary productivity. This high biomasses of secondary consumers provide economic opportunities in terms of fishery yields (Houde & Rutherford, 1993). These habitats have also been recognized as important zones for breeding of many fish species because of their large number of different habitats, great food resources and low incidence of predators (Cruz-Escalona *et al.*, 2000).

The estuaries are ecologically important in that they are a highly indispensable nursery ground for numerous marine species of commercial value and home for migratory birds and other wildlife besides stabilizing the coastline by acting as a buffer against pollutants and wastes (Barletta et al., 2005, Loneragan et al., 1987, Raz-Guzman & Huidobro, 2002). Houde and Rutherford, (1993) attributed the high yields of fish from estuaries to high primary production levels, the availability of nutrients to sustain the high productivity, the proximity of estuaries and their harvestable resources to fishing ports. Estuaries are however, highly unpredictable ecosystems in which conditions such as salinity, temperature, turbidity, water currents and dissolved oxygen fluctuate rapidly, both spatially and temporally. Despite the instability, composition of fish species was relatively stable with predictable patterns of abundance and distribution in Southern

African estuarine systems (Whitfield, 1994). Several studies have documented variability in the abundance of populations in shallow marine areas. The main aim of these studies is to provide estimates of natural rate of change in abundance for a variety of species at a range of spatial scales. Such information is essential in order to be able to assess the effect of any future disturbance caused by humans (Worthington *et al.*, 1995).

Community structures in open lagoons and estuaries are affected by various physico-chemical parameters such as salinity, temperature and distance from the estuary mouth (Loneragan *et al.*, 1987). Hatcher et al. (1989) observed that environmental destruction due to pollution and over-exploitation, is proceeding at an accelerating rate in well monitored areas of shallow marine tropics, hence the most vulnerable and most frequently disturbed of these habitats occur in sheltered estuaries. Garcia et al.(Garcia *et al.*, 2001) reported that the shallow water fish assemblage of Patos lagoon (Brazil) showed different species composition and recruitment patterns of dominant species during La Nina and El Nino. At Peel–Harvey estuary in Australia, salinity was positively correlated with number of species, density and biomass (Loneragan *et al.*, 1986).

At Solomon Islands (Pacific ocean) different fish species were reported at different mangrove estuaries based on substrata and tree species (Blaber & Milton, 1990). Estuaries are usually characterized by a longitudinal distribution pattern of fish species, for example, in South Africa, 15 species were captured at the Great fish river estuary, with *Pomadasys commersonnii* being the most abundant in the small seine net fish assemblage, due to lower salinity (Ter Morshuizen *et al.*, 1996). At shell harbour lagoon

(Australia), 27 species were caught out of which two were transients, 14 marine, seven residents and four freshwater but the assemblage did not vary because both marine and resident fishes were under less osmoregulatory stress (Griffiths, 2001). Whitfield and Elliott (2002) concluded that the conceptual and qualitative understanding of changes within estuarine fish assemblages is good but quantitative understanding is poor.

Mangroves are not always associated with truly estuarine conditions and for many of the mangrove areas on the tropical East African coast, salinity may remain close to 35 ‰ for much of the year. As a result, fish community may be different from that in a truly estuarine mangrove system (McNae, 1968). Detailed studies of the fish communities associated with tropical mangroves are few, despite the accepted importance of these areas as nursery grounds for commercially important species and their increasing misuse by man. Such misuse includes timber extraction, clearance for aquaculture practices and overexploitation of the juvenile fish stocks (Ong, 1982).

Abuodha and Kairo (2001) extensively documented human induced stresses on mangrove swamps along the Kenyan coast. Studies on composition, abundance and seasonal distribution of fish fauna has been carried out in different aquatic ecosystems in various parts of the world (Garcia et al., 2001, Jowett & Richardson, 1996, Pombo et al., 2002, Potter et al., 2001, Sutton & Hopkins, 1996, Travers & Potter, 2002, Whitfield et al., 1989) amongst others. Other researchers have focused on abundance and species composition of ichthyoplankton (Harris et al., 1999, Melville-Smith & Baird, 1980). Scientific reports on fish community in the Kenya marine waters, have been documented

for Gazi bay (Kimani et al., 1996, Van der Valde et al., 1995, Wakwabi, 1999); Tudor creek (Little et al., 1988); Kilifi creek (Oyugi, 2005), Kilifi reef (Nzioka, 1985) and Diani reef (Obura, 2001).

The Kenyan coast extends through four latitudes south of the Equator, hence creeks, bays and estuaries have different physico-chemical characteristics. In the tropical and subtropical estuaries, both physical and biological factors determine the diversity of fishes and the similarities between fish communities of estuaries far apart. Many fish species operate at or close to their physiological limits as indicated by a large array of specializations due to anthropogenic influences (Blaber, 2002). These habitats have a direct influence on the food resources, distribution, abundance, growth, survival and behaviour of the fishes present (Whitfield, 1994). Because estuaries are nursery areas for juvenile fish, there is a complexity of fish movements between estuaries and marine environments (Melville-Smith and Baird, 1980). Most fish found in estuaries and coastal lagoons use these areas for feeding and growth since these areas provide protection from predators and ensure high food availability for a number of marine species in tropical regions (Little *et. al.,* 1988). These regions are also spawning grounds for fin fishes and shell fishes (Vidthayanon & Premcharoen, 2002). Whitfield (1994) noted that the structure of an estuarine fish community depends on both biotic and abiotic factors, such as salinity, temperature, turbidity and dissolved oxygen concentration. Zoogeography also plays a major role in determining which species are available for recruitment into a particular estuary, generally, tropical and sub-tropical estuaries have a higher species

diversity than temperate systems due to the richer ichthyofaunal associated with rivers and marine habitats nearer the equator Blaber (1981) in (Whitfield, 1994).

Kilifi creek is relatively pristine with no industrial development in areas surrounding it apart from few tourist hotels. This study identifies the fish community of kilifi creek focusing on:

1). Exploring whether the different habitats within the creek contributes to variation in composition and distribution of fishery organisms hence, the fisheries production.

2). Whether the assemblage of fishery organisms at Kilifi is similar to those estuaries within the Indo-Pacific region.

3.2 Methodology

All fishery organisms obtained at each study site were identified taxonomically as described in section 2.4.1.

Data analysis

To facilitate comparison of the fish communities, Bray-Curtis clustering was carried out using the PRIMER (Plymouth Routines In Marine Ecological Research) package to examine fish assemblages between study sites. Diversity indices were calculated for each sampling site using the Primer software (Clarke & Warwick, 2001) as indicated below.

A). The species richness index for each sampling site was determined using Margalef's species richness (1958) formula (Krebs, 1978):

$$R = S - 1/\ln N$$

i.e., S = number of species, N = Total number of specimens.

B). Simpson's index of diversity, 1949 (Krebs, 1978) was calculated using the formula:

$$D = 1 - \sum(p_i)^2$$

i.e., D = Simpson's index of diversity, p_i = proportion of individuals of species 1 in the community.

C). A test of Pielou's evenness (J) was then carried out using the formula ((Zar, 1996)):

$$J = (H/Hmax)$$

i.e., Hmax = log n. This index describes distribution of individuals.

Principal Components Analysis (PCA) was tested to map the distribution of study sites based on physico-chemical parameters and fish composition. STATISTICA software from StatSoft was used to relate physico-chemical parameters to seasons and other diversity indices and multiple correlations (SPSS software) used to establish variations between the physico-chemical parameters and fish.

3.3 Results

3.3.1 Seasonal distribution of fishery organisms

Trends of fishery organisms at Kilifi creek are shown in Figures 3 and 4. Catches of finfishes and prawns were high during the North East Monsoons (October – March) of each year and low during the South East Monsoons (April – September). The peaks in the first year of study were higher than the peaks in the second year. Prawn catch peaks occurred around February of every year, although the second peak was small. Finfish landing was high during the North East Monsoons and low during the South East Monsoons. Crabs (Figure 4) were caught throughout the study period although the total

numbers were low. *P. pelagicus* were numerous between March and July of the first year but in the second year, their numbers fluctuated during the same period. *P. pelagicus* was not caught in four months only during the study period. *S. serrata* had only one peak in the first year of study but with the numbers kept fluctuating in the second year but were never caught in seven months during study.

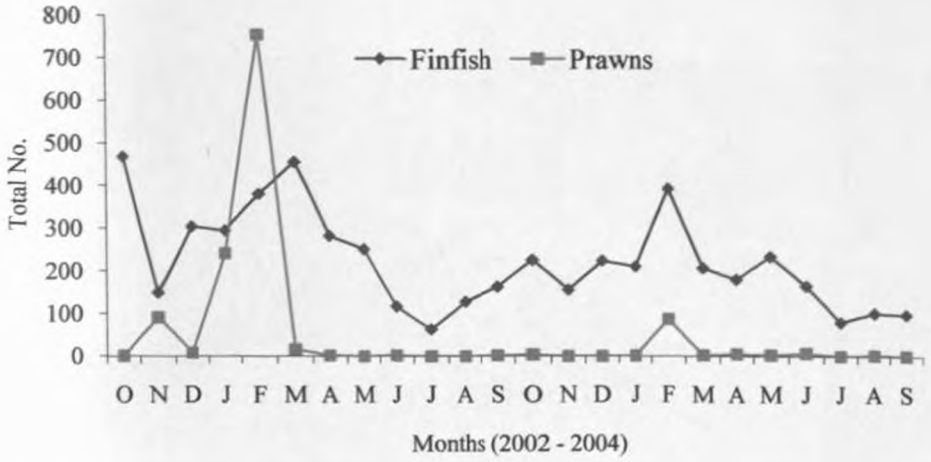


Figure 3: Fin fish and prawns obtained during the study period.

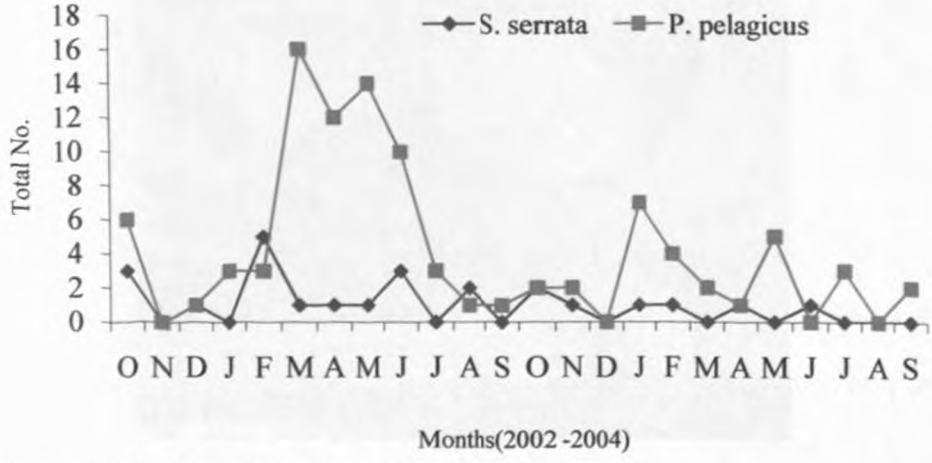


Figure 4: Crab species obtained during the study.

3.3.1.1 Composition and spatial distribution of crustaceans

During the current study the prawn species caught were *Penaeus indicus* (H. Milne Edwards, 1837) and *Penaeus monodon* (Fabricius, 1798), while crab species were *Portunus pelagicus* (Linnaeus, 1766) and *Scylla serrata* (Forsskal, 1755).

Plate 9: *Penaeus indicus* from Kilifi creek, Kenya (Photograph by Sigana, 2004).

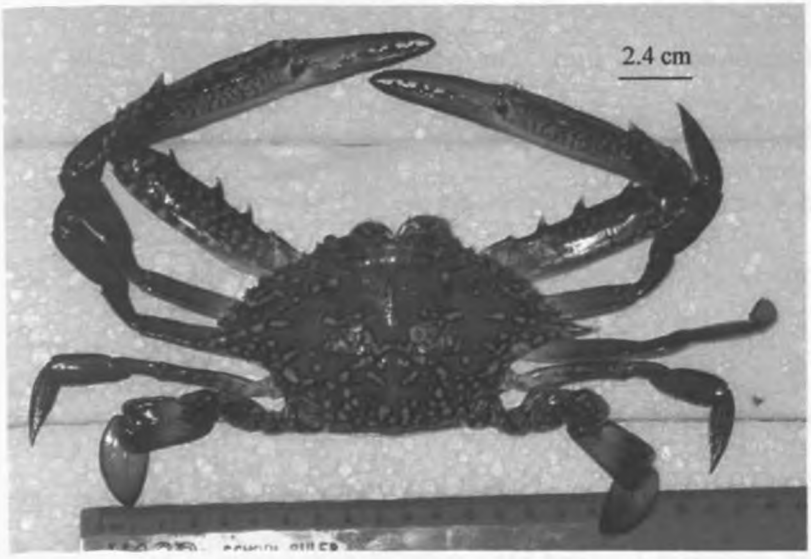


Plate 10: *Portunus pelagicus* from Kilifi creek, Kenya (Photograph by Sigana, 2004).

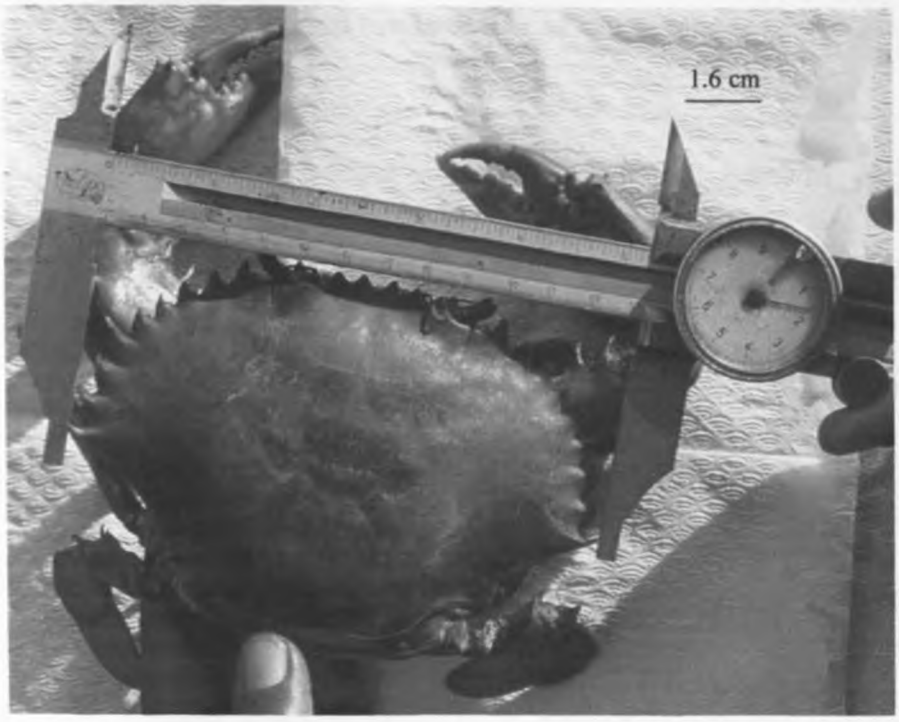


Plate 11: *Scylla serrata* from Kilifi creek, Kenya (Photograph by Sigana, 2004).

Though a site-specific variation in total numbers was observed, all crustaceans were present at Kidundu, Kombeni and Rare (Table 3). Specifically, *Penaeus indicus* was abundant at Kidundu, Rare and Mazioni. The actual total catches in number, of *Penaeus monodon* were low with only 13 being recorded at Kombeni and none was caught at the other five sites. However, it is worth noting that the prawns were not caught at Sea horse and Nkoma, possibly because those are deep sites and prawns are detritivores.

Though occurring in low numbers, the crabs were present throughout the study period and at all the sites except for Konjora. *Portunus pelagicus* were abundant at Fumbini, Kidundu and Mazioni than in other sites because it prefers deep water and carnivorous while Rare recorded highest number of *Scylla serrata* because it is a detritivore.

Table 3: Distribution and total number of crustaceans collected at study sites within Kilifi creek.

Sites	Sea horse	Nkoma	Mazioni	Kidundu	Kombeni	Fumbini	Konjora	Rare	Total
Penaeus indicus	0	0	85	845	5	1	1	356	1293
Penaeus monodon	0	0	0	3	13	0	0	4	20
Scylla serrata	2	4	2	3	4	3	0	6	24
Portunus pelagicus	5	6	20	23	1	39	0	4	98
Total	7	10	107	874	23	43	1	370	1435

3.3.1.2 Distribution and composition of fin fishes at the study sites

Figure 5 overleaf shows the Bray-Curtis similarity dendrogram of Kilifi fin fishes. These results indicate that both Sea Horse and Nkoma had the highest fin fish similarity (67.7 %) followed by Fumbini and Kidundu (65.9 %) then Konjora and Kombeni (63 %). The lowest similarity (48.2 %) was observed between the fresh water stream sites within the mangroves and Bahari ya Wali.

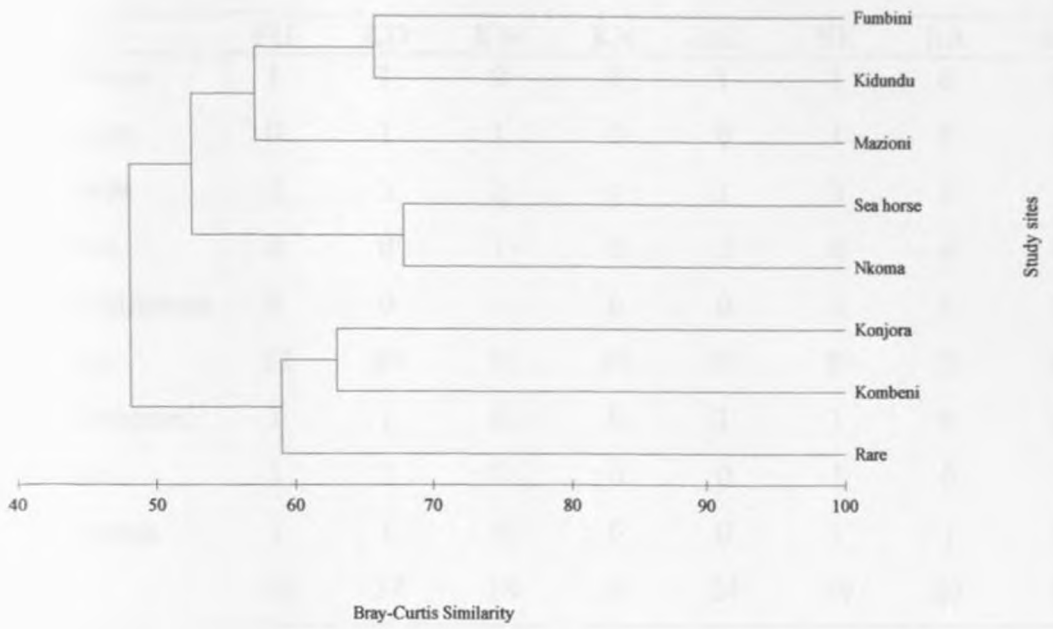


Figure 5: Bray-Curtis similarity dendrogram showing classification of the fin fish species collected from Kilifi creek.

From the 5332 finfishes obtained, nine orders, 38 families and 63 species were identified at Kilifi. Nkoma had the highest total number of fish species, the least being recorded at Konjora (Table 4). The order Perciformes had over 50 species distributed at various sites with a maximum of over 31 species at Sea horse. Fish species of Konjora, Rare and Kombeni were distinctly different from those at Fumbini, Kidundu, Mazioni, Sea horse and Nkoma. In the open lagoon area, Sea horse and Nkoma were distinct from the other sites since these were the deep sites within the study area, Nkoma had the largest total number of species but Fumbini had the highest number of fishes caught. Fumbini and Kidundu had extensive mudflats exposed during low tides while Mazioni was permanently under water.

Table 4: Fin fish distribution by order and species number recorded at each study site (FU- Fumbini, KD- Kidundu, KM- Kombeni, KN- Konjora, MZ- Mazioni, NK- Nkoma, RA- Rare, SH-Sea horse).

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

Table 5 shows the percentages and totals of the most common 10 species at the study area. *Leiognathus equula* (Forsskal, 1775) had the highest percentage followed by the family Mugilidae (species of *M. cephalus* and *V. buchanani*) and *Gerres filamentosus* (Cuvier, 1829). Table 6 shows *Pomadasys multimaculatum* (Playfair, 1866) common at all sites except Nkoma and Kidundu. The dominant species by number at each site are either Mugilidae or *Leiognathus equula* or *Gerres filamentosus* all belonging to order Perciformes. Sea Horse had only four orders but the order Perciformes had the largest number of species (in 28 families) hence contributing to the diversity indices observed. Konjora only recorded two orders hence low diversity indices, observed. The mean number of species was significantly higher at Sea horse, Nkoma, Fumbini and Kidundu and lower at the remaining sites.

Table 5: Percent composition of most common finfish species collected from all sites during the study period.

Species	Total	% (Composition)
Leiognathus equula	1228	23.03
Mugilidae	1165	21.84
Gerres filamentosus	632	11.85
Pomadasys multimaculatum	474	8.89
Caranx papuensis	211	3.96
Leiognathus leuciscus	185	3.47
Gerres oyena	180	3.38
Pellona ditchella	169	3.17
Ulua mentalis	123	2.31
Thryssa vitrirostris	114	2.14

Table 6: The total numbers of dominant species (pooled numbers in brackets) at each site.

Sites	First position	Second position	Third position
Sea horse	*L. equula* (295)	*L. leusciscus* (103)	*P. multimaculatum* (56)
Nkoma	*L. equula* (226)	*G. filamentosus* (105)	*G. oyena* (64)
Mazioni	*G. filamentosus* (89)	*P. ditchella* (50)	Mugilidae (37)
Fumbini	Mugilidae (445)	*P. multimaculatum*(275)	*G. filamentosus* (217)
Kidundu	Mugilidae (325)	*L. equula* (193)	*G. filamentosus* (129)
Kombeni	Mugilidae (181)	*L. equula* (72)	*P. multimaculatum* (48)
Konjora	Mugilidae (37)	*L. equula* (28)	*P. multimaculatum* (27)
Rare	*L. equula (297)*	Mugilidae (100)	*P. multimaculatum* (75)

3.3.2 Fin fish diversity indices

During the first year, all the monthly diversity indices were high at all sites but a sharp decrease was observed towards the end of the second year. This was probably because of climatic change. F-test showed no significant differences between North and South East

Monsoon seasons when Margalef's species richness index ($F_{1,178}$ = 0.022; P = 0.882); Simpson's diversity index ($F_{1,178}$ = 0.57; P = 0.45) and Pielou's evenness ($F_{1,178}$ = 3.882; P = 0.05) were compared.

3.3.2.1 Margalef's species richness index

This index is a measure of the number of species present for a given number of individuals and is sensitive to seasonal influx of migratory species. Sea Horse had a coral island while Nkoma was located at the base of a cliff. Rare, Konjora and Kombeni were at the extreme ends with incoming freshwater streams of the northern and southern arms. Figure 6 shows that the mean species richness was highest at Sea horse (2.2) followed by Kidundu (2.1) then Nkoma (1.8) and was lowest at Konjora (1.1). The study area had high mean species richness at all sites, which was above 1.0.

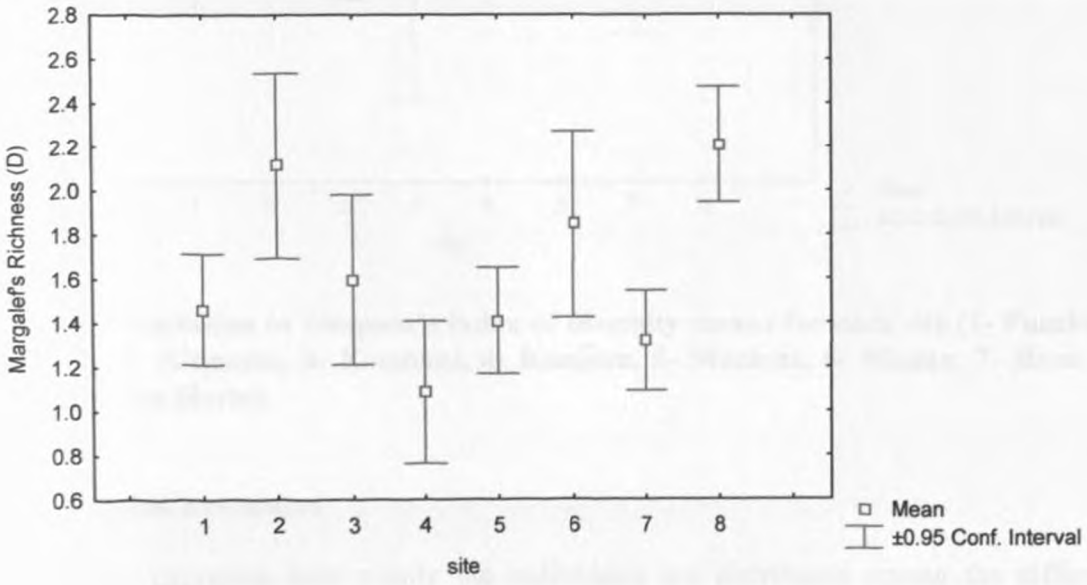


Figure 6: Variation in Margalef's Species richness index means for each site (1- Fumbini. 2- Kidundu, 3- Kombeni, 4- Konjora, 5- Mazioni, 6- Nkoma, 7- Rare, 8- Sea Horse).

3.3.2.2 Simpson's diversity index

This index gives relatively little weight to the rare species and more weight to the common species in describing the community structure. It has a natural interpretation as the probability that any two individual from the sample chosen at random, are from the same species. It is also a dominance index. Simpson's diversity index (Figure 7) was above 0.5 at all sites, being highest at Sea horse (0.76) followed by Mazioni (0.75) and Kidundu (0.73) but lowest at Konjora (0.56).

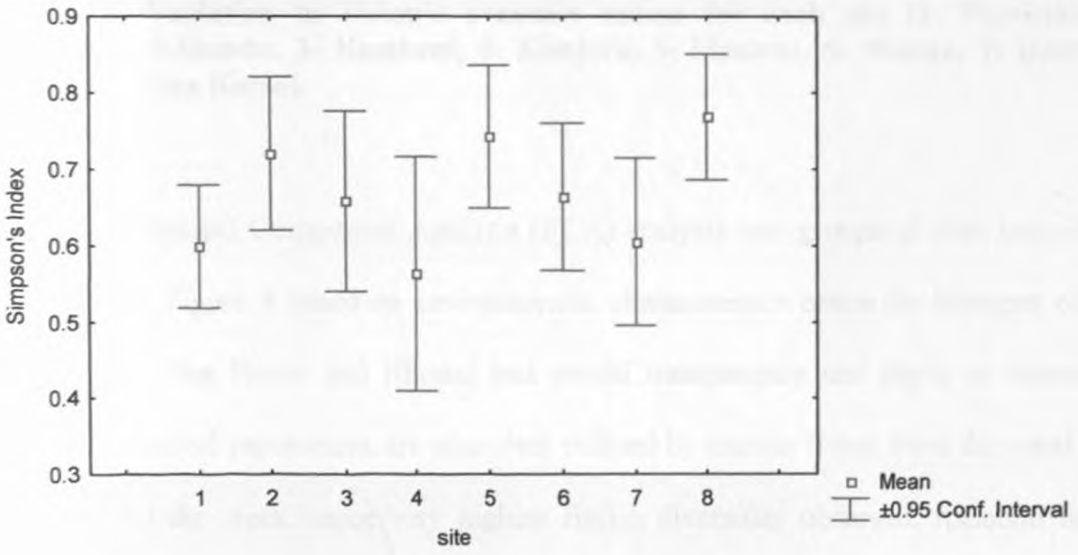


Figure 7: Variation in Simpson's index of diversity means for each site (1- Fumbini. 2- Kidundu, 3- Kombeni, 4- Konjora, 5- Mazioni, 6- Nkoma, 7- Rare, 8- Sea Horse).

3.3.2.3 Pielou's evenness

This index expresses how evenly the individuals are distributed among the different species. The maximum evenness that can be achieved is one. Mean Pielou's evenness was highest at Mazioni (0.90) and lowest at Fumbini (0.68), (Figure 8 overleaf), though the mean evenness values were high at all sites (above 0.65).

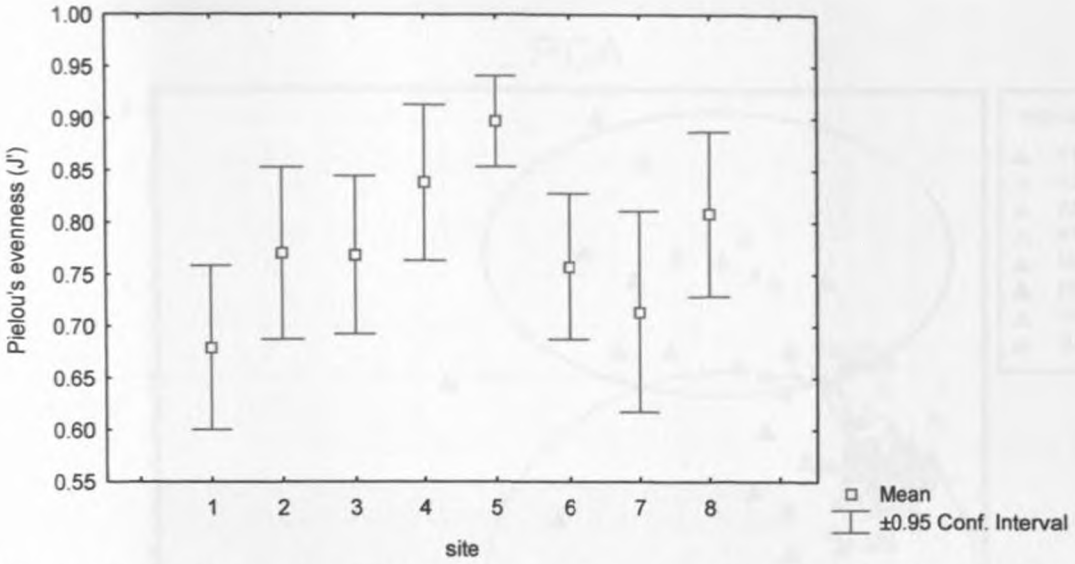


Figure 8: Variation in Pielou's evenness means for each site (1- Fumbini. 2- Kidundu, 3- Kombeni, 4- Konjora, 5- Mazioni, 6- Nkoma, 7- Rare, 8- Sea Horse).

From the Principal Component Analysis (PCA) analysis two groups of sites have been identified in Figure 9 based on environmental characteristics hence the biotopes of the study area. Sea Horse and Nkoma had secchi transparency and depth as important physico-chemical parameters, are also sites utilized by marine fishes from the coral reef area beyond the creek hence very highest finfish diversities observed. Kidundu had a large area with mudflat without seaweeds while Fumbini, Kombeni, Mazioni, Rare and Konjora are all grouped together because they are generally shallow with slightly varying physico-chemical parameters. The most utilized areas by fish were Fumbini and Kidundu with Konjora being the least utilized site (Table 2).

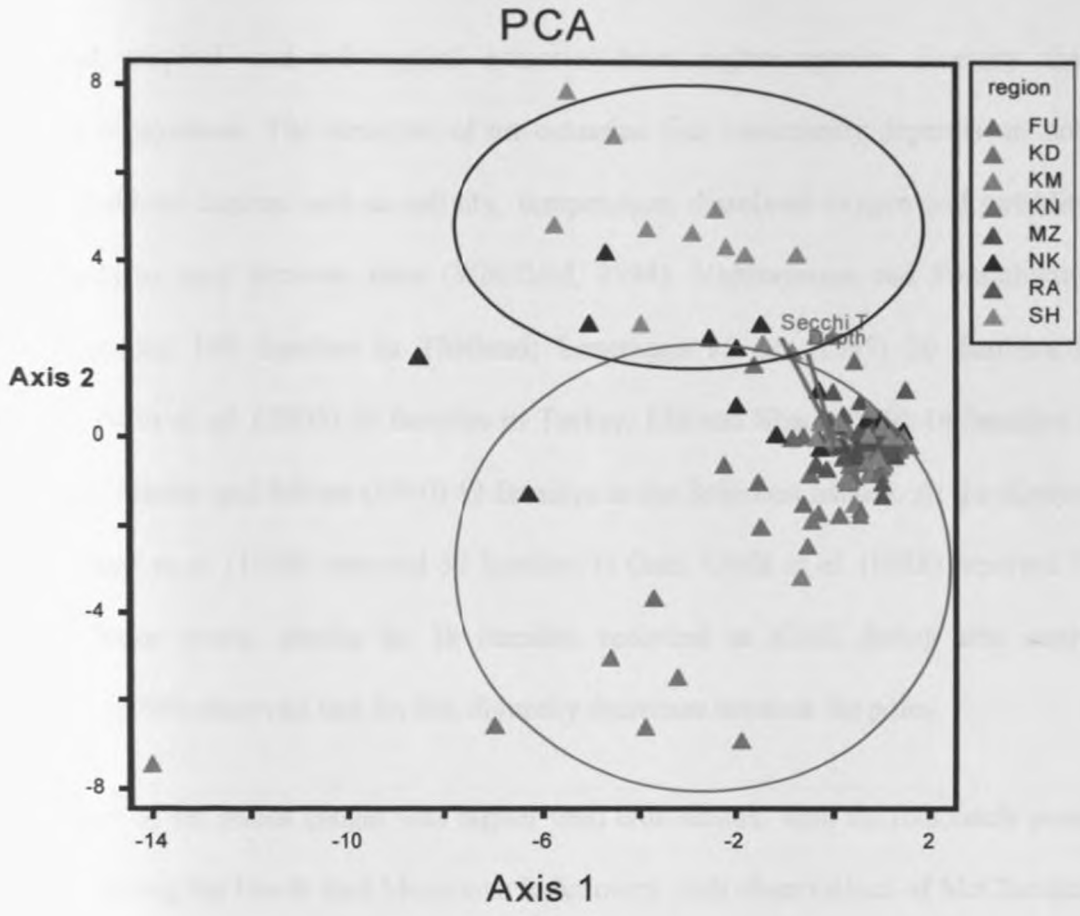


Figure 9: 2-dimensional Principal Component Analysis results showing grouping of the study sites (FU-Fumbini, KD-Kiundu, KM-Kombeni, KN-Konjora, MZ- Mazioni, NK-Nkoma, RA- Rare and SH-Sea horse), (Axis 1 and 2 show the ordination of sites about zero).

3.4 Discussion

In general, tropical and sub-tropical estuaries have higher species diversity than temperate ecosystems. The structure of an estuarine fish community depends on both biotic and abiotic factors such as salinity, temperature, dissolved oxygen and turbidity, which tends to vary between sites (Whitfield, 1994). Vidthayanon and Premcharoen (2002) recorded 199 families in Thailand; Loneragan *et. al.* (1987) 26 families in Australia; Akin *et. al.* (2005) 29 families in Turkey; Lin and Shao (1999) 14 families in Taiwan and Blaber and Milton (1990) 42 families in the Solomon Islands. At the Kenyan coast, Kimani et al. (1996) reported 50 families in Gazi; Little et al. (1988) reported 38 families Tudor creek, similar to 38 families recorded at Kilifi during this study. Whitfield, (1994) observed that fin fish diversity decreases towards the poles.

The number of fin fishes caught was higher than crustaceans, with fin fish catch peaks occurring during the North East Monsoons in harmony with observations of McClanahan (1988). Species composition indicates how preferred habitats differ by species (Jung & Houde, 2003) hence the spatial distribution observed. Kombeni, Rare and Konjora were riverine sites hence similar inhabitants. The remaining sites were within Bahari ya Wali lagoon with oceanic characteristics therefore similar fish species, however, Sea horse and Nkoma (deep sites) were markedly different from Fumbini, Kidundu and Mazioni. Within the same area, Mazioni being deeper is again having fishes slightly different from Fumbini and Kidundu.

Whitfield (2005) categorized the major fish group utilizing estuaries and during this study, the highest numbers of species caught were marine immigrants. The order

Perciformes had the largest number of species and also determined the diversity indices. Hatcher *et. al.* (1989) observed that the community structure in tropical areas differ from temperate areas in that their species diversity and diversity within genera are higher, species distribution is patchier and population size smaller. Nkoma recorded the highest number of species during the study period, the least being Rare that concurs with the findings of Gatwicke and Speight (2005) that complex marine habitats support a greater number of fish species than less complex ones. The diversity indices in aquatic microcosms are controlled by a combination of history, biotic and abiotic factors but abiotic variables mostly influence biodiversity (Therriault & Kolasa, 1999). During this study, both Clupeiformes and Perciformes utilized all the study sites, other orders were found at specific sites and not others indicating either spatial or temporal distribution. Species composition indicates how preferred habitats differ by species (Jung & Houde, 2003), and this is shown by the similarity dendrogram, hence spatial distribution observed. Almost all study sites were utilized by similar species hence high Margalef's species richness, Simpson's diversity index and Pielou's evenness.

Among the parameters affecting fish community at Kilifi, dissolved oxygen, temperature and salinity had the least variations and concurred with observations of McClanahan (1988) that these are not limiting factors affecting fish Community. It can also be observed that the areas most utilized by fish were Fumbini and Kidundu with large mean catches followed by Sea horse and Nkoma. The least utilized areas were Mazioni and Konjora. A combination of various parameters influenced fish distribution within the study sites. The most outstanding physico-chemical factors were secchi transparency and

depth at Sea horse and Nkoma. Phosphate concentration was outstanding factor at Rare, Kombeni and Mazioni and to a small extent at Sea horse and Nkoma. Nitrate concentration was outstanding factor at Rare while dissolved oxygen and temperature were more or less uniform at all sites. These physico-chemical parameters were optimum at Fumbini and Kidundu where fish mean number was highest but variations in these factors at Konjora contributed to low mean number observed. Rare had the lowest salinity while Kombeni was hypersaline. This confirms spatial distribution related to salinity changes similar to the observations of Ter Morshuizen *et al.,* (1996) at the Great fish river in South Africa and Akin *et al.,* (2005) at Koycegiz Lagoon – Estuary.

The diversity indices in aquatic microcosms are controlled by a combination of historic, biotic and abiotic factors but abiotic variables mostly influence biodiversity (Therriault & Kolasa, 1999). Sea horse had four orders but the order Perciformes had the largest number of species hence contributing to the high species richness while Konjora recorded two orders hence the low species richness. The mean number of species was significantly higher at Sea horse, Nkoma, Fumbini and Kidundu and lower at the remaining sites. It can be clearly observed that the species number decreased significantly from Bahari ya Wali towards the fresh water end, a spatial distribution observed by Loneragan *et al.,* (1986). Diversity indices are used in attempts to establish the seasonal patterns of fish in estuarine habitats (Van den Broek, 1979). While Akin *et al.,* (2005) reported that physiological tolerances of organisms to the dominant gradient determine the frame of the community structure, this study shows the use of various biotopes within the study area that most marine immigrants visit specifically to feed. Moore (1978) reported that

the species composition of the community and especially the appearance of indicator species tell investigators more about the ecological conditions than any numerical index.

Global climate change is impacting estuarine fish and fisheries by effects ranging from changes in metabolic rates to changes in fish behavioural patterns. Future impacts on distribution and abundance of fishes associated with small temperature change will also affect human communities harvesting these stocks (Roessig et al., 2004). Vidthayanon and Premcharoen (2002) mentioned that some estuarine fish species in Thailand are indicator species sensitive to environmental change and their disappearance from an ecosystem is important while Williams and Corral (1999) reported that monitoring has a key role to play in all aspects of fisheries management including those related to sustainable management of the resource. In Kenya, only 7.4 % of total annual fishery production comes from marine waters and the factors constraining this fishery include narrow continental shelf, strong South East monsoon winds hazardous to canoes and the fact that the East African coast has low productivity due to nutrient deficient coastal currents, oceanic in origin (UNEP, 1998).

Despite the relatively high number of species, fish species in Kilifi was composed of a few dominant species only. Quinn (1980) observed that this is a common feature of bay, inshore and estuarine fish assemblages in both temperate and sub-tropical environments. At Kilifi, seven species comprise approximately over 70% of the total number, a situation similar to Tudor creek (Little et al., 1988). Among species of importance at Kilifi creek are the Mugilidae (21.8 %) and Haemulidae (8.9 %) (*Pomadasys multimaculatum*).

Mugilidae play an important role in the fisheries and aquaculture in tropical and subtropical regions of the world (Blel *et al.*, 2008).

Studies on variability in abundance of populations provide estimates of natural rates of change in the abundance for a variety of fish species at a range of spatial scales (Worthington et al., 1995). Aquaculture is becoming increasingly important but it must be intensified significantly and sustainably (Williams, 1996). Along the Kenya coast, the four finfish species offering good prospects for culture are Milk fish (*Chanos chanos*), Mullet (Mugilidae), Rabbit fish (Siganidae) and Tilapia (UNEP, 1998). As step towards mariculture of fin fishes in future in Kenya, Matthes (1974) suggested *Chanos chanos* (milkfish), *Tachysurus dussumeri* (catfish) and Mugilidae as the likely candidates. Suitable sites for mariculture are plentiful especially around estuaries, (Matthes, 1974) but food requirements and supply have to be studied because fry are found in large concentrations at suitable periods, hence necessitate determination of the breeding seasons for different fish species. It is on the basis of mariculture that this study is undertaken *in situ*.

From this research study, it can be concluded that the species composition of the study area shows a spatial distribution from the creek mouth to the freshwater end since fish species of Konjora, Rare and Kombeni were distinctly different from those at Fumbini, Kidundu, Mazioni, Sea horse and Nkoma (all within Bahari ya Wali). It also shows the use of various biotopes within the study site and that most members are marine immigrants visiting the area specifically to feed. The sites within the streams had high

mean concentrations of nutrients but variations in other parameters were not high (Personal observation). Within this creek, Fumbini and Kidundu were utilized most by fishery organisms, especially Mugilidae and therefore require conservation by fisheries managers. The study also provides baseline data for future comparisons in marine coastal ecosystems, however further research work to study feeding habits of each species needs to be carried out to discern the importance of each study site in fisheries and the possibility of Mugilidae culture at this study area because of their contribution to aquaculture worldwide.

CHAPTER FOUR

4.0 Species composition and distribution of Mugilidae

4.1 Introduction

Several studies have been conducted along the Kenya coast on the biology of various marine fin fish such as *Leptoscarus vaigiensis* (Mwatha, 1997), *Scolopsis bimaculatus* (Nzioka, 1981), *Lethrinus harak* (Kulmiye, 1997) and *Siganus sutor* (De Souza, 1988, Ntiba, 1986). Marine fin fish species whose culture has been tried in other parts of the world include Rabbit fish, milkfish and the mullet. The biology of Rabbit fish (Siganidae) is adequately documented in Kenya (De Souza, 1988, Ntiba, 1986, Ntiba & Jaccarini, 1990). The general biology of the milkfish (Iversen, 1968a) and the mullet (Iversen, 1968b, Thomson, 1963) is known but information on the characteristics of Kenyan species is quite scanty (Sivalingam, 1989). Most aspects of the biology of *M. cephalus* have been widely studied due to the importance of Mugilidae in fisheries and as forage for predatory fishes (Collins, 1981). Studies on Mugilidae have been carried out throughout the world in various aspects such as general ecology and distribution (Iversen, 1968b, Moore, 1974), reproduction (Abou-Seedo & Dadzie, 2004, Chubb et al., 1981, Mathew et al., 2000, Moore, 1974, Odum, 1970, Samad & Abbas, 1999, Thomson, 1966) and feeding (Cardona, 1999b, Eggold & Motta, 1992, Ghosh et al., 1972, Khan & Fatima, 1994).

The form of the Mugilidae makes them distinct from other related groups, but a high degree of intra-family shape similarity causes problems in discriminating between species (Grant & Spain, 1975). The family Mugilidae comprises about 100 species found all over

the world. There are at least 15 species on the Western Indian Ocean coast of which the common genera include *Crenimugil* Schultz, 1946, *Valamugil* Smith, 1948, *Myxus* Gunther, 1861, *Mugil* Linnaeus, 1758 and *Liza* Jordan and Swain, 1884. Mugilidae are known to spawn in the sea but shoal in shallow water, they vary in size depending on species and within the Western Indian Ocean region, a species *Mugil cephalus* (Linnaeus, 1758) attains a maximum size of 90 cm and a common size of 35 cm (Thomson & Luther, 1984).

Mugilidae comprise a large proportion of the inshore fisheries of the world and they occupy a relatively low position in the food web and as a result are efficient secondary producers of protein besides being euryhaline and can be readily cultured under artificial conditions (Grant & Spain, 1975). The present study aims to extend information about species composition and seasonal distribution of Mugilidae *in situ* as one of the commercial fish family in enhancing its management at Kilifi creek.

4.2.1 Methodology

All Mugilidae obtained at each study site were treated as described in section 2.4.2. Taxonomic identification was carried out using Keys listed in section 2.4.1 and confirmed by fisheries research officers based at Kenya Marine and Fisheries Research Institute, Mombasa.

4.2.1 Data analysis

Mugilidae seasonal distribution pattern was related to both North East Monsoon and South East Monsoon periods. The non-parametric Kruskal-Wallis test was used to relate Mugilidae spatial distribution by sites and total length class sizes. To establish the physico-chemical parameters influencing Mugilidae distribution, Statistica version 6 programme was used in carrying Spearman's multiple correlations.

4.3 Results

4.3.1 Species composition and seasonal distribution

The Mugilidae species obtained at Kilifi were *Mugil cephalus* Linnaeus, 1758 (Plate 12); *Valamugil buchanani* (Bleeker, 1853) (Plate 13); *Liza vaigiensis* Quoy and Gaimard, 1825 (Plate 14) and *Myxus capensis* Valenciennes, 1836 (Plate 15), which represented the genera *Mugil, Valamugil, Liza* and *Myxus,* respectively. The species with the highest total numbers during the study period were *M. cephalus* (765) and *V. buchanani* (390) from all sites. *M. capensis* (9), the fresh water mullet and *L. vaigiensis* (1) caught at Rare and Fumbini respectively, were rare species.

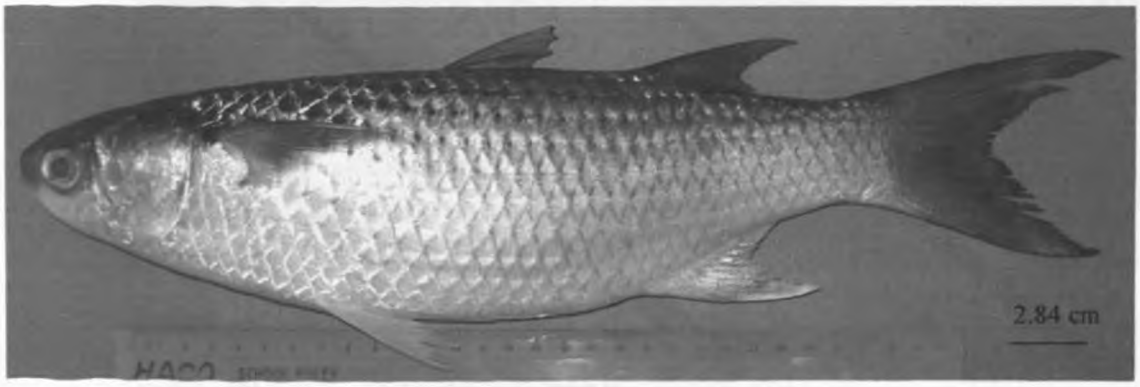


Plate 12: *Mugil cephalus* from Kilifi creek, Kenya. (NB: Has deep forked tailfin, large scales and pointed pectoral fins. Commonly known as *Mkizi*). (Photograph by Sigana, 2004).

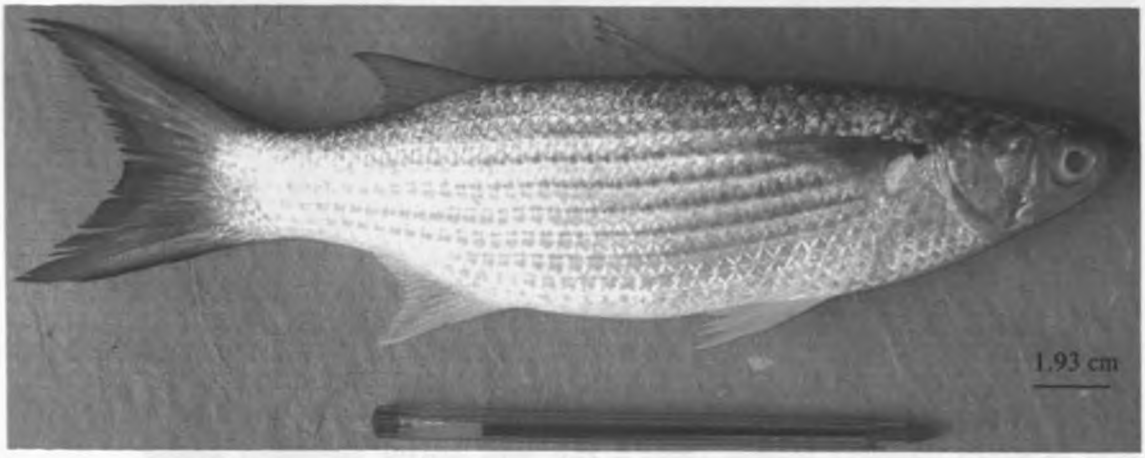


Plate 13: ***Valamugil buchanani*** **from Kilifi creek, Kenya. (NB: Has a deep forked tailfin, smaller scales and has silvery body. Commonly known as** ***Kalizi*****). (Photograph by Sigana, 2004).**

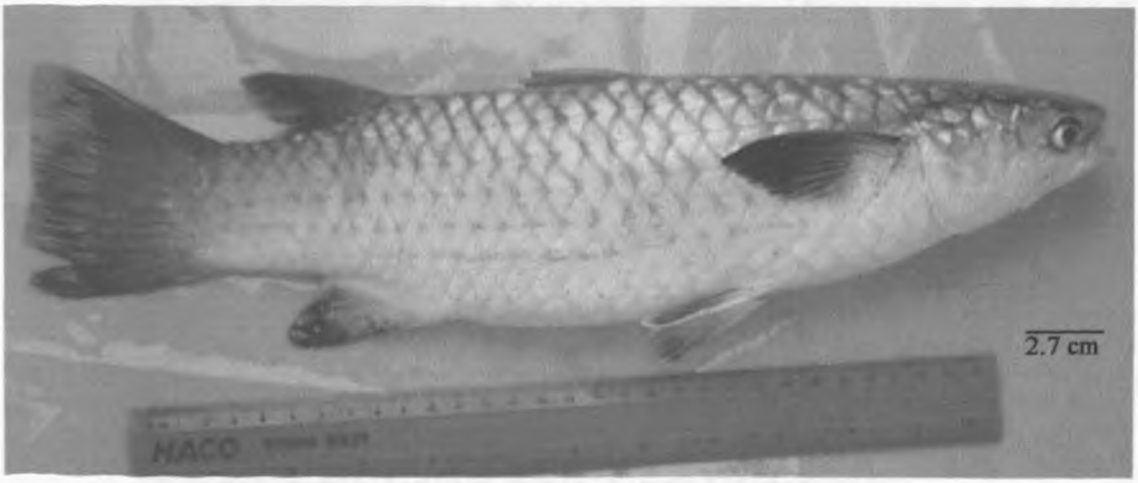


Plate 14: ***Liza vaigiensis*** **from Kilifi creek, Kenya. (NB: Has a squaretail with large scales and a short almost rounded pectoral fin. Commonly known as** ***Junda koko*****). (Photograph by Sigana, 2004).**

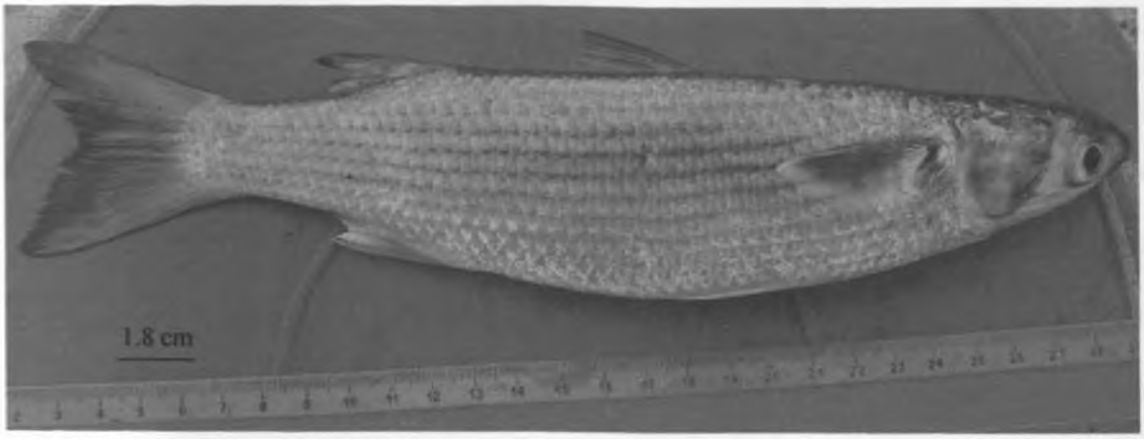


Plate 15: *Myxus capensis* from Kilifi creek, Kenya. (NB: Scales are small in size, tailfin shallowly forked and has a short almost rounded pectoral fin). (Photograph by Sigana, 2004).

The distribution of *M. cephalus* and *V. buchanani* showed no specific pattern related to North East Monsoon (October – March) and South East Monsoon (April – September) seasons as shown in Figure 10. There was a decrease in the total numbers of *M. cephalus* in the catch during the NEM season of the second year, however, both *M. cephalus* and *V. buchanani* were always present in the monthly samples. *Liza vaigiensis* was caught only in April while *Myxus capensis* was caught in September of the first year.

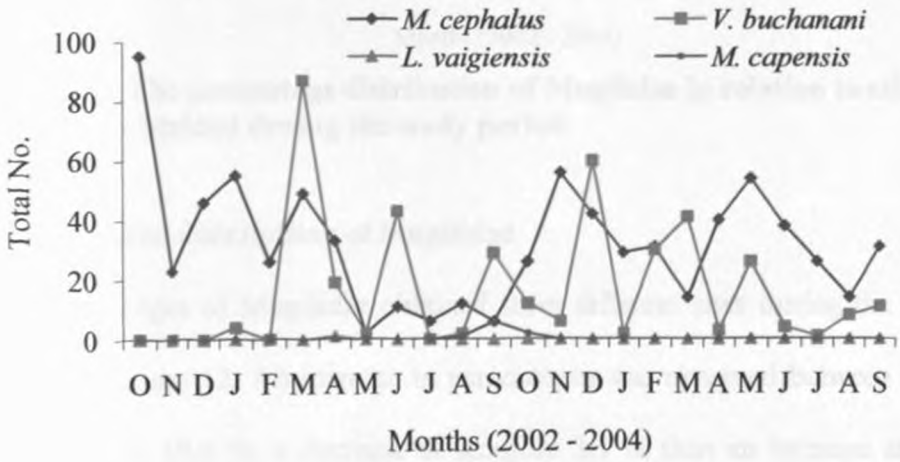


Figure 10: The monthly total numbers of each species of Mugilidae obtained during the study period, (Pooled data used).

Figure 11 shows that Mugilidae were caught throughout the sampling period with no specific abundance pattern but the percentage in the catch decreased significantly during the South East Monsoons (April – September). Percentages of other fin fishes displayed high peaks during the North East Monsoons (October – March) and a decrease during the South East Monsoons. Mugilidae were caught throughout within Kilifi during the sampling period with no specific seasonal variation pattern but the percentage of the catch from each site decreased significantly during the South East Monsoons (April – September).

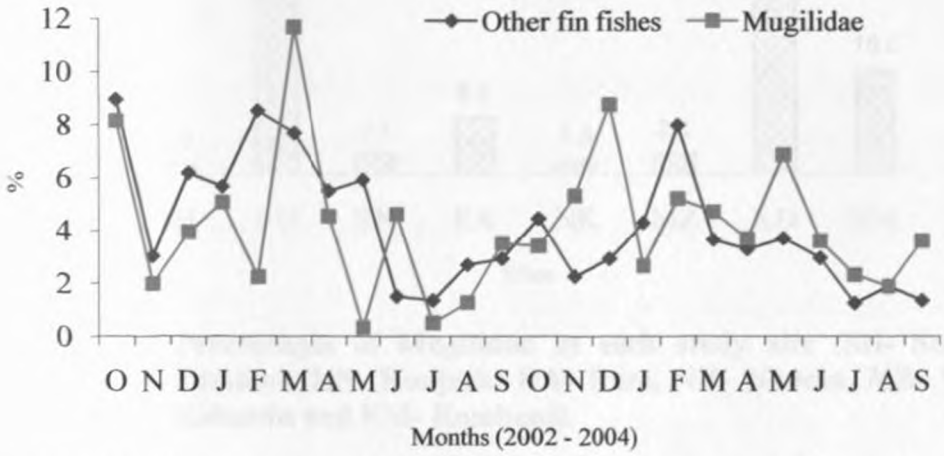


Figure 11: The percentage distribution of Mugilidae in relation to other fin fishes obtained during the study period.

4.3.2 Spatial distribution of Mugilidae

The percentages of Mugilidae obtained from different sites during the study period are shown in Figure 12. An increase in percentages was observed between Sea horse 1.5 % and Fumbini 39.0 %, a decrease at Konjora 3.1 % then an increase at Rare 8.5 %. A similar pattern is also observed where Nkoma had 1.8 % followed by Mazioni 3.1 %, Kidundu 27.5 % and a decrease at Kombeni 15.5 %. Kruskal-Wallis test indicated

significant variation in distribution between study sites (H = 22.35; d.f. = 7; N = 100; P = 0.0022). Turkey HSD test showed that Fumbini was significantly different from Mazioni and Sea Horse while Kombeni differed significantly from Mazioni only ($P < 0.05$). Table 7 reveals that high percentages of *M. cephalus* were present in all study sites while high percentages of *V. buchanani* were at Nkoma, Rare and Fumbini. Fumbini and Rare recorded three species each but other sites had only two species.

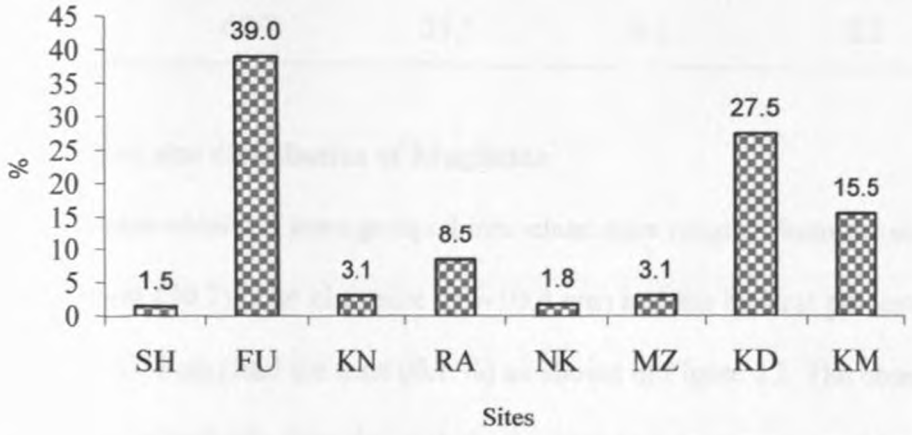


Figure 12: Percentages of Mugilidae at each study site (SH- Sea horse, FU- Fumbini, KN- Konjora, RA- Rare, NK- Nkoma, MZ- Mazioni, KD- Kidundu and KM- Kombeni).

Table 7: Percentages of Mugilidae species obtained at each study site.

Sites	*Mugil cephalus*	*V. buchanani*	*Liza vaigiensis*	*Myxus capensis*	*Total %*
Sea horse	94.4	5.6	0.0	0.0	100
Fumbini	58.4	41.4	0.2	0.0	100
Konjora	80.6	19.4	0.0	0.0	100
Rare	41.4	49.5	0.0	9.1	100
Nkoma	47.6	52.4	0.0	0.0	100
Mazioni	83.3	16.7	0.0	0.0	100
Kidundu	60.3	39.7	0.0	0.0	100
Kombeni	99.4	0.6	0.0	0.0	100
Total	65.7	33.5	0.1	0.7	100

4.3.3 Class size distribution of Mugilidae

All Mugilidae obtained were grouped into class sizes ranging from the smallest (5.7 cm) to the largest (50.7). The class size (5.5-10.4 cm) had the highest percentage while class size (50.4-55.4 cm) had the least (0.1 %) as shown in Figure 13. The observed Mugilidae distribution is basically bimodal with the highest peak at class sizes 5.5 – 10.4 cm and a smaller peak at 40.5 – 45.4 cm indicating continuous breeding in a species.

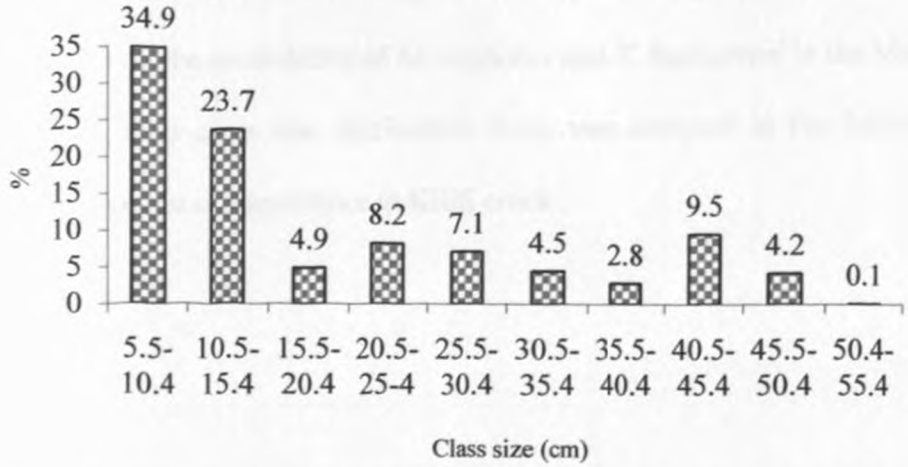


Figure 13: Percentage distribution of Mugilidae class sizes at Kilifi.

Figure 14 shows the distribution of Mugilidae by mean TL per site. Sea Horse, Nkoma and Mazioni had largest mean TL (36.28 cm, 36.56 cm and 38.27 cm, respectively) represented by the largest circles. Kidundu and Kombeni had the smallest mean TL of 12.02 cm and 9.8 cm respectively being represented by the smallest circle. Fumbini and Konjora fish mean TL were 26.24 cm and 27.29 cm, while at Rare fish mean TL were 16.25 cm and are represented by circles with intermediate sizes respectively. Mugilidae mean TL size ranges varied at the sites; Sea Horse 25.3 – 47.1; Nkoma 22.1 – 47.5; Mazioni 7.6 – 49.9; Fumbini 7.1 – 50.7; Konjora 8.4 – 47.7; Rare 7.1 – 48.6; Kidundu 7.7 – 45.6 and Kombeni 5.7 – 16.1 cm, respectively. Juveniles except for Sea Horse and Nkoma, mainly utilize most of these sites.

As shown in Table 8, the males of *M. cephalus* were more numerous in the catch up to class size 20.4 cm, the largest being in class size 45.5 - 50.4 cm. Female *M. cephalus* were also numerous in smaller class sizes and the largest size in class size 50.5 – 55.4 cm. Females of *V. buchanani* also numerous in the smaller class sizes up to 20.4 cm compared to the males but the largest of this species were males in class size 40.5 – 45.4 cm. Based on the availability of *M. cephalus* and *V. buchanani* in the Mugilidae samples (Table 8), their class size distribution study was analysed in the following part of the thesis as species of importance at Kilifi creek.

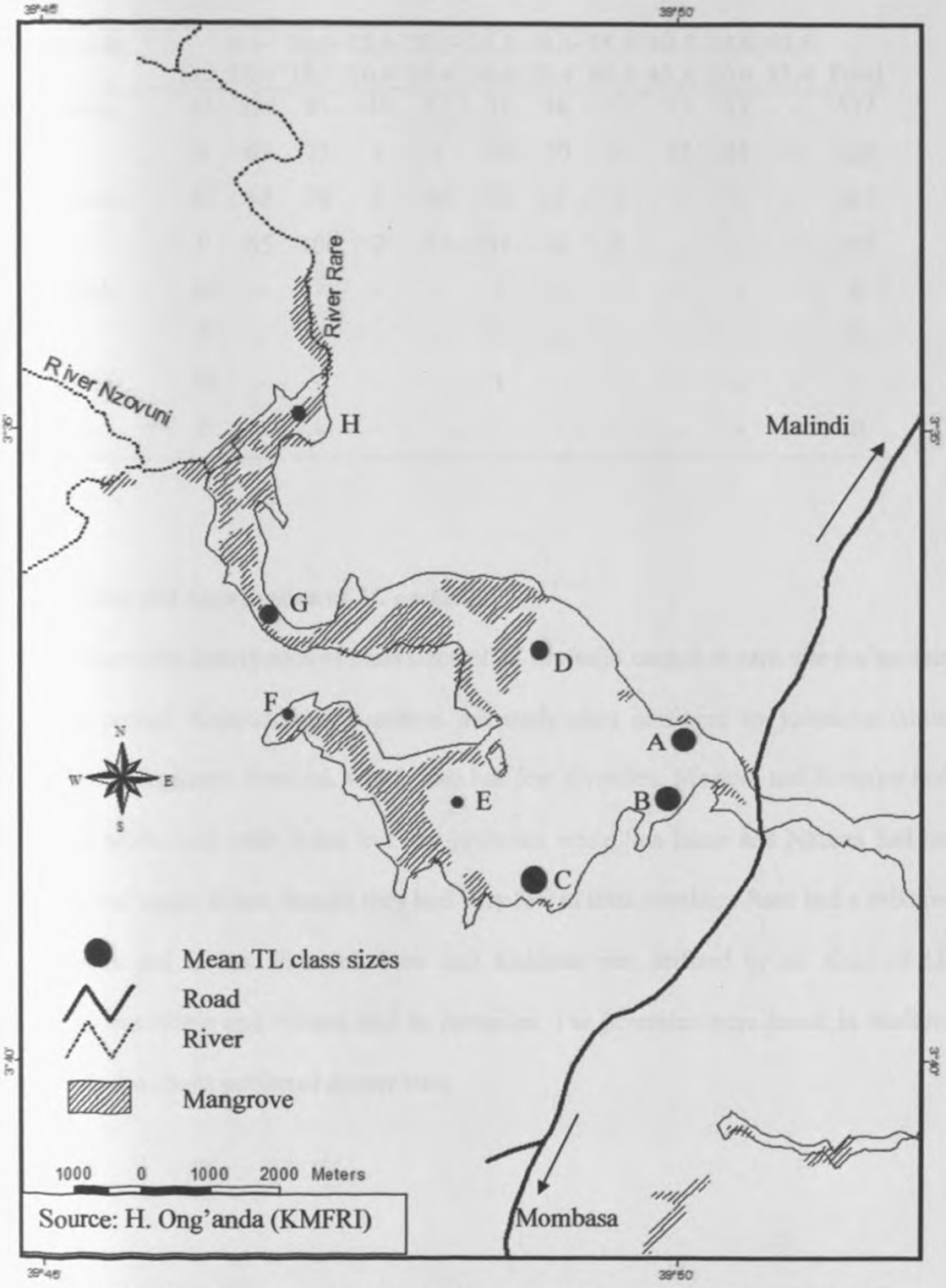


Figure 14: The distribution of Mugilidae by mean TL per study site (A- Sea Horse, B- Nkoma, C- Mazioni, D- Fumbini, E- Kidundu, F- Kombeni, G- Konjora and H- Rare).

Table 8: Class size distribution of Mugilidae by species and sex.

Species/ size (cm)	Sex	5.5-10.4	10.5-15.4	15.5-20.4	20.5-25.4	25.5-30.4	30.5-35.4	35.5-40.4	40.5-45.4	45.5-50.4	50.5-55.4	Total
M.cephalus	M	220	95	41	32	31	16	10	73	19	-	537
	F	65	23	4	1	18	30	13	42	31	1	228
V. buchanani	M	58	58	4	46	13	4	3	1	-	-	187
	F	65	100	7	12	11	6	2	-	-	-	203
M. capensis	M	-	-	-	-	9	-	-	-	-	-	9
	F	-	-	-	-	-	-	-	-	-	-	0
L. vaigiensis	M	-	-	-	-	1	-	-	-	-	-	1
	F	-	-	-	-	-	-	-	-	-	-	0

4.3.3.1 Class size distribution of *M. cephalus*

Table 9 shows the distribution of class sizes of *M. cephalus* caught at each site during this sampling period. Kidundu and Kombeni are study sites preferred by juveniles while larger fishes dominate Fumbini, which also has few juveniles. Mazioni and Konjora had more sub adults and adult fishes but few juveniles while Sea horse and Nkoma had no juveniles but larger fishes, though they had very few in total numbers. Rare had a mixture of juveniles and adults. Fumbini, Rare and Kidundu was utilized by all sizes of *M. cephalus,* Sea Horse and Nkoma had no juveniles. The juveniles were found in shallow sites while the adults preferred deeper sites.

Table 9: The class size distribution of *Mugil cephalus*.

Sites / Class size (cm)	5.5-10.4	10.5-15.4	15.5-20.4	20.5-25-4	25.5-30.4	30.5-35.4	35.5-40.4	40.5-45.4	45.5-50.4	50.4-55.4	Total
Fumbini	4	29	35	23	30	24	14	69	36	1	265
Kidundu	137	28	5	8	2	4	1	6	2	0	193
Kombeni	119	59	1	0	0	0	0	0	0	0	179
Konjora	2	0	2	0	9	8	0	6	2	0	29
Mazioni	1	0	0	1	2	3	2	16	5	0	30
Nkoma	0	0	0	0	0	0	3	6	1	0	10
Rare	22	2	2	0	3	3	1	6	3	0	42
Sea horse	0	0	0	1	3	4	2	5	2	0	17
Total	285	118	45	33	49	46	23	114	51	1	765

4.3.3.2 Class size distribution of *Valamugil buchanani*

Table 10 shows the size class distribution of *V. buchanani.* Kidundu and Rare are sites where many juveniles (5.5 – 15.4 cm) were found while Fumbini had a mixture of juveniles and few adults (up to 35.4 cm). Sea Horse and Nkoma did not record juvenile stages but the largest *V. buchanani* was caught at Nkoma. Mazioni had only six sub-adults, Konjora had only seven juveniles while Kombeni had only one juvenile throughout the study period. This species does not attain large sizes at Kilifi and the juveniles show preference for shallow sites.

Both *Myxus capensis* and *Liza vaigiensis* were all males, in the class size 25.5 – 30.4 cm and were caught at Rare and Fumbini respectively.

Table 10: The class size distribution of *Valamugil buchanani.*

Sites	5.5-10.4	10.5-15.4	15.5-20.4	20.5-25-4	25.5-30.4	30.5-35.4	35.5-40.4	40.5-45.4	45.5-50.4	50.4-55.4	Total
Fumbini	0	103	9	53	18	5	0	0	0	0	188
Kidundu	76	46	1	0	3	1	0	0	0	0	127
Kombeni	1	0	0	0	0	0	0	0	0	0	1
Konjora	5	2	0	0	0	0	0	0	0	0	7
Mazioni	0	0	0	0	2	2	2	0	0	0	6
Nkoma	0	0	0	5	0	2	3	1	0	0	11
Rare	40	7	2	0	0	0	0	0	0	0	49
Sea horse	0	0	0	0	1	0	0	0	0	0	1
Total	122	158	12	58	24	10	5	1	0	0	390

4.3.4 Influence of environmental variables on Mugilidae distribution

Spearman's Rank Order correlations (Multiple correlations) were used to establish which physico-chemical parameters influence Mugilidae distribution at each site. There was no significant correlation between Mugilidae and phosphates, nitrates, dissolved oxygen, temperature and depth at each site respectively. However, significant correlation with Mugilidae was recorded at Rare, where Secchi transparency ($P = 0.03$) and Sea Horse where Salinity ($P = 0.03$). When all sites were grouped (Table 11), Spearman Rank Order correlations showed significant correlations between Mugilidae with dissolved oxygen ($P = 0.03$); temperature ($P = 0.04$); salinity ($P = 0.01$); Depth ($P = 0.00$) and Secchi transparency ($P = 0.005$) indicating factors influencing their distribution. Nitrates ($P = 0.74$) and phosphates ($P = 0.38$) did not significantly influence Mugilidae distribution.

Table 11: Summary statistics for Spearman Rank Correlations between environmental variables and Mugilidae (Data combined from 2002 – 2004).

Variables	Spearman (R)	P
Mugilidae / Phosphates	0.085	0.401
Mugilidae / Nitrates	-0.033	0.742
Mugilidae / Dissolved oxygen	-0.222	*0.026
Mugilidae / Temperature	0.209	*0.037
Mugilidae / Salinity	0.252	*0.011
Mugilidae / Depth	-0.461	*0.000
Mugilidae / Secchi transparency (Turbidity)	-0.274	*0.006

Significant * P = 0.05

4.4 Discussion

The fish family with most species number is Gobiidae followed by Mugilidae but both are marine immigrants (Blaber, 1976, Kupschus & Tremain, 2001, Mbande et al., 2005, Ter Morshuizen et al., 1996, Thomson & Luther, 1984, Whitfield, 2005). In the coastal and estuarine waters of Australia *M. cephalus* and *Adrichetta forsteri* (Valenciennes) occur extensively while in the Gulf of Mexico, *Mugil curema* and *Mugil cephalus* are the dominant species (Chubb et al., 1981, Kupschus & Tremain, 2001). Lugendo (2007) reported only *Valamugil buchanani* at Chwaka bay, Zanzibar but at Gazi Bay, Kimani et al. (1996) reported four species *Liza vaigiensis, Valamugil saheli, Valamugil cunnesius* and *Mugil cephalus*. Amongst the four species caught in Kilifi creek during this study, it is only *M. cephalus* and *V. buchanani* present in the catch throughout the year. Despite the fact that the Mugilidae occurred in the catches throughout the year, their seasonal distribution pattern closely followed the observations of McClanahan (1988), that is , the catches being high during NE monsoons but low during SE monsoons. The observed high

percentage of occurrence at Kilifi concurs with Akin et al. (2005) who noted that Mugilidae are tolerant of fluctuating environmental conditions typical of creeks and estuaries around the world.

Mugil cephalus from North Queensland inshore waters had sizes ranging from 15.5 – 574.0 mm fork length (Grant & Spain, 1975). At Swan Avon estuary (Western Australia), total lengths of 22.0 – 400 mm *M. cephalus* and 30 – 350 mm *A. forsteri* were reported (Chubb et al., 1981). From Obidos lagoon (Portugal), *Liza ramada, Liza aurata* and *Chelon labrosus* with size ranges between 3 – 43 cm, 4 – 27 cm and 5 – 33 cm, respectively, were collected (Moura & Gordo, 2000). Kraiem et al. (2001)gave the size ranges (total length) of *Liza ramada* from the three North African wetlands as 12.0 – 45.0 cm (Edku), 10.0 – 44.0 cm (Ichkeul) and 12.0 – 39.0 cm (Merja Zerga). Giarrizzo et al, (2006) observed the total length size ranges of *Mugil curema* from Curuca estuary (North Brazil) as between 4.2 – 27.8 cm while Dulcic and Glamuzina (2006) reported *M. cephalus* sizes ranging from 25.0 – 63.0 cm from river Mirna, Northern Adriatic and 9.9 – 60.3 cm from Neretva estuary in the mid Adriatic. In this study, the class size data show that Kilifi creek is equally an important nursery area because most of the study sites had juvenile stages (5.5 - 20.4 cm) of Mugilidae as majority. Larger class sizes though with low percentages, utilized all the sites. This observation supports Cruz-Escalona et al. (2000) that juveniles use such areas as nursery for nourishment and for protection due to low incidence of predators. During this study, the highest percentage of Mugilidae obtained were juveniles at Kombeni and Kidundu. *M. cephalus* had higher numerical values at nearly all sites followed by *V. buchanani* but the males of *M. cephalus* had

higher numerical values than *V. buchanani*. The results support the observation that Mugilidae utilize estuaries, creek and open lagoons mainly in smaller sizes (Chubb et al., 1981, Griffiths, 2001, Whitfield, 2005).

The most difficult challenge is to separate and evaluate the influences of each suite of physical parameters influencing estuarine fishes because many are correlated with one another (Blaber, 2002). At Shellharbour lagoon (Australia), there is less dramatic changes in environmental variables a fact that explains stability of its fish fauna (Griffiths, 2001). At Chesapeake bay (U.S.A.) the fish community structure changed spatio-temporally as water temperature, salinity, and dissolved oxygen concentrations vary annually (Jung & Houde, 2003). Salinity influences the longitudinal distribution of fishes in estuaries (Whitfield, 1998), this study has indicated significant correlations between Mugilidae and salinity hence is one of the primary factors determining the longitudinal distribution of Mugilidae.

Turbidity influences fish communities in various ways such as acting as a cue for juveniles of marine fishes entering estuaries, protecting juveniles from visual predators (Blaber & Blaber, 1980) as well as reducing intra-specific predation (Blaber & Cyrus, 1983). In this study there was significant correlation between distribution of Mugilidae and turbidity, being highest at Kombeni (0.43±0.005 SE) and lowest at Sea Horse (2.92±0.029 SE) hence longitudinal gradient. In this study, it is suggested that turbidity influenced Mugilidae by protecting the juveniles from visual predators. No significant correlations between fish community and salinity, temperature and turbidity were

reported at Mngazana and Mngazi estuaries (Mbande et al., 2005), even though significant correlations between distributions of Mugilidae and dissolved oxygen, temperature and depth were also observed during this study.

During this study, four species of Mugilidae were identified as users of Kilifi creek. The most common species were *M. cephalus* and *V. buchanani*, which occurred in the catch throughout the sampling period. Mugilidae abundance was high during the Northeast monsoons than during the Southeast monsoons. Fumbini and Kidundu were the sites with the highest number of Mugilidae followed by Kombeni and Rare. All these sites were shallow with low secchi transparency. Juveniles (5.5 – 15.4 cm) comprised high percentage of Mugilidae at Kidundu and Kombeni, most of which were males but Fumbini had a mixture of class sizes. These sites also had mudflats, which are important feeding areas. The distribution of Mugilidae was significantly affected by temperature, dissolved oxygen, salinity, depth and transparency. Fumbini and Kidundu sites are important refuge, growth and feeding sites for Mugilidae *in situ* within the creek. These areas require the attention of Fisheries managers for protection to ensure conservation of Mugilidae and other fish feeding on benthos. The two species of Mugilidae with a possibility of mariculture within Kilifi creek were identified to be *M. cephalus* and *V. buchanani* because they were the main users of the area. It was therefore necessary to study their population parameters and reproduction in chapters five and six of this thesis respectively.

CHAPTER FIVE

5.0 Population parameters: Length-weight relationships, relative condition factor, age and growth of *Mugil cephalus* Linnaeus, 1758 and *Valamugil buchanani* (Bleeker, 1853) at Kilifi creek *in situ*.

5.1 Introduction

Jacot (1920) is among the pioneers who studied growth and development of mullets of the Atlantic coast of United States with an aim of artificial propagation having noted that their supply continually falls short of the demand. Growth is the measurable increase of an organic system in weight or length produced by its assimilation of materials obtained from its environment and is widely dependent on external factors (Von Bertalanffy, 1938). Diana (1995) drew two conclusions, that from an evolutionary or ecological point of view, interest is in the ultimate body size as well as ontogenic changes in size that influence feeding, mortality and reproduction; and from an aquaculture perspective, the capacity to grow may be of interest as well as how the environment through temperature and food availability which influence growth, hence growth is an indicator of success. Growth and age structure are essential features in the study of fish populations and many researchers have used annuli (Weatherly & Rogers, 1978), others have used length-weight relationships to estimate growth (Ilkyaz et al., 2006, Kraiem et al., 2001).

The grey mullets are more difficult to age than majority of marine fishes and most research has been done on *M. cephalus* L., which is of widespread distribution and is of considerable commercial importance (Kennedy & Fitzmaurice, 1969). They also reported that different workers in temperate regions have arrived at very different estimates for length at age attributed to differences in interpretation of scales, otoliths or other

structures used for age determination (Grant & Spain, 1975, Ibanez et al., 1999, Jacot, 1920, Kraiem et al., 2001, Moura & Gordo, 2000).

The determination of length-weight relationship in fish is important both for practical and biological points of view (Bagenal & Tesch, 1978). They also observed that in fisheries, lengths are much quickly and accurately determined under field conditions than weight. An equation for length-weight relationship enables the conversion of lengths into weights later in the laboratory. It also enables one to obtain the expected weight for length of individual fish, which is used in the calculation of the relative condition factor. Morato et al., (2001) reported that length and weight data are useful and standard results of fish sampling programs and are essential for a wide number of studies including estimating growth rates, age structure and aspects of fish population dynamics. These relationships are often used to calculate the standing stock biomass, condition indices, in the analysis of ontogenetic changes and several aspects of fish population dynamics. Treasurer (1976) noted that length which has less annual fluctuation is a more reliable indicator of growth than weight.

Condition indices have been used for assessment of fish population health (Hartman & Margraf, 2006). Chan and Chua (1980) reported that in *Liza subviridis* the relative condition factors varied between the juvenile males and females. Nzioka (1981) observed higher condition factor for females than males which he attributed to the fact that the ovaries constituted 4 % of the total body weight of ripe females compared to 0.7 % of the total body weight of ripe testes.

Various researchers have estimated age and growth in fish (Hemphill, 1995, Hickling, 1970, Weatherly & Rogers, 1978). Moura and Gordo (2000) identified five species of mullets at Obidos lagoon, estimated their age from otoliths and from length frequency analysis and reported no significant differences between the growth curves obtained using the two methods. Between the ages of 0 – 5 years, a high increase in length was observed in *M. curema* during the first year exceeding that of *M. cephalus* but after three years increase in length is greater in *M. cephalus* and low in *M. curema* (Ibanez et al., 1999).

Thomson (1966) reported that in sub-tropical and temperate waters, growth of mullet ceases in winter but reaches its maximum at mid-summer but in tropical waters no regular formation of annuli occurs on scales and otoliths. Age and growth has been estimated from length-weight relationships by various researchers to establish the age of the largest possible length (asymptotic length) in fish after being incorporated in the Von Bertalaffy equation (Wootton, 1998). The asymptotic length for *Liza aurata* in Homa lagoon was estimated as $L_{\square}$ = 43.2 cm (Ilkyaz et al., 2006). Ibanez et al., (1999) reported differences in asymptotic growth parameters in *M. cephalus* (females $L_{\square}$ = 622.9 mm and males $L_{\square}$ = 603.9 mm) and *M. curema* (females $L_{\square}$ = 454.6 mm and males $L_{\square}$ = 411.8 mm) from the gulf of Mexico. They also estimated longevity ($A_{0.95}$) of *M. cephalus* as 28.32 years and *M. curema* as 18.68 years.

This study examines growth in terms of length-weight relationship, Condition factors and age determination of Mugilidae *in situ* within Kilifi creek as an important fishery component of the creek for it's fisheries management purposes.

5.2 Methodology

All Mugilidae obtained at each study site (section 2.2) were treated as described in section 2.4.2.

5.2.1 Data analysis

a). The length-weight relationship for each species was determined using the formula of Bagenal and Tesch (1978) $\mathbf{W = aL^b}$. Where W = the total body wet weight (g); L = the total length (cm); a = a constant on the y-axis and b = an exponent describing the slope of the regression, it usually lies between 2 and 4. This equation gives a parabolic line, but the relationship is best described by a straight line, which was fitted by plotting logarithmic transformation of observed lengths against the observed weights. Fish with the same length-weight relationships will cluster about the straight line but there is some scatter due to individual variations.

A test of isometry was done to test whether the regression coefficients "*b*" of the monthly length-weight relationships calculated for both *M. cephalus* and *V. buchanani* was significantly different from the expected isometric 3. This test is based on calculating the static (t^) using the formula by Pauly 1984 in (Kulmiye, 1997) as shown below:

$\mathbf{t^{\wedge} = [(sd_x/sd_y)(\ b\text{-}3\ /\sqrt{(1\text{-}r^2)}]\sqrt{(n\text{-}2)}}$ where:

sd_x = standard deviation of log10 of monthly lengths; sd_y = standard deviation of Log10 of the monthly weights; n = number of fish examined and r^2 = coefficient of determination from the regression analysis.

The statistic (t^) is significantly different from 3 if its value is greater than the tabulated value of t (in the t-table) at n-2 degrees of freedom.

b). Relative condition factor was calculated using the formula of Bagenal and Tesch (1978) $\mathbf{Kn = 100w / l^b}$. Where w = observed total weight; l = observed total length of a fish; b = an exponent calculated from the length- weight equation. Relative condition factor was related to sex and season.

c). The Von Bertalanffy Growth Formula (VBGF) was used to estimate length at infinity and relative age from length measurements (Bagenal & Tesch, 1978, King, 1995, Von Bertalanffy, 1938) expressed as $L_t = L_\infty (1 - \exp[-K(t - t_o)])$. Where L_t = length at age t, L_∞ = asymptotic length (when catabolism equals anabolism); K = the rate of change of length increment; t_o= the hypothetical time at which the fish length would have been zero.

The constant a and exponent b calculated in part (a) above was used to estimate length at infinity (L_∞) based on the Electronic Length Frequency Analysis (ELEFAN I) computer programme incorporated in Food and Agricultural Organization-International Center for

Living Aquatic Resources Management (FAO-ICLARM) Stock Assessment Tool (FISAT) (Gayanilo et al., 1996).

The von Bertalanffy growth curves were then drawn for *M. cephalus* and *V. buchanani* on Excel spread sheet and the age of fish was determined by plotting the calculated L_t against t.

5.3 Results

5.3.1 Length-weight relationship

5.3.1.1 Length-weight relationship in *Mugil cephalus*

A total of 765 *M. cephalus* obtained during the sampling period from all the eight sites was used in this analysis. Figure 15 shows length–weight relationship in males where 537 specimens with the length and weight ranges between 5.7 cm weighing 3 g and 48 cm weighing 1169.3 g were used. The calculated mean length and weight were 19.3 cm and 214.4 g, respectively, while the regression line fitted for length on weight was $\mathbf{Log_{10}\ W = 1.7457 + 2.8658\ Log_{10}\ L}$. The test of isometry for the monthly length-weight relationship in males is given in Table 12. All correlations were highly significant ($P<0.05$) with coefficient of determination of 90% in all months. The overall exponent ($b=2.8658$) was significantly different from 3 ($t^{\wedge} = 21.2138$; $P < 0.05$). The monthly exponents were not significantly greater than 3 in only six months but significantly greater than 3 in nearly all months. The exponential value of 2.8658 shows that length increases with increase in weight (negative allometric growth) and the regression coefficient was found to be highly significant ($t = -22.524$; d.f. = 536; $P < 0.05$).

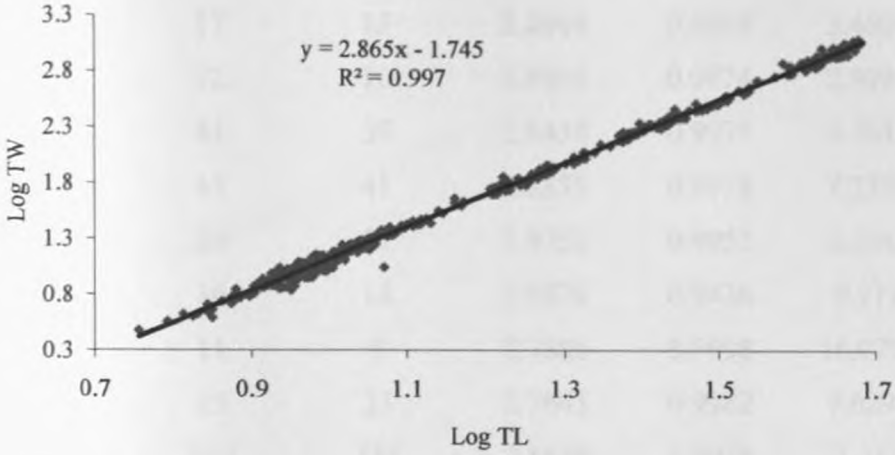


Figure 15: Length-weight relationships in male *M. cephalus* (Pooled totals obtained during the study period used).

Table 12: Test of isometry for the monthly length-weight regression for male *M. cephalus* (*Significant at 5 % level).

Month	Total number	d.f	b	r^2	t^	$t_{0.05}$, n-2
Oct 02	53	51	2.9806	0.9984	1.1611	2.008
Nov	20	18	2.8869	0.9984	4.1519*	2.101
Dec	29	27	2.8706	0.9967	4.0706*	2.052
Jan 03	46	44	2.8326	0.9964	6.5216*	2.015
Feb	17	15	2.9499	0.9975	1.3139	2.131
Mar	28	26	2.8916	0.9982	4.5014*	2.056
Apr	30	28	2.873	0.9958	3.6018*	2.048
May	1	0				
Jun	6	4	2.7239	0.9989	6.1101*	2.776
Jul	3	1	2.7303	0.9975	1.9731	12.706
Aug	8	6	2.8763	0.996	1.6623	2.447
Sep	4	2	2.5467	0.9978	5.3609*	4.303
Oct	23	21	2.8354	0.9992	9.4017*	2.08
Nov	30	28	2.7974	0.9812	2.7686*	2.048

Dec	24	22	2.9254	0.9978	2.6045*	2.069
Jan 04	21	19	2.8457	0.9989	7.1221*	2.093
Feb	17	15	2.8964	0.9984	3.4604*	2.131
Mar	12	10	2.8654	0.9974	2.9094*	2.228
Apr	41	39	2.8438	0.9975	6.7633*	2.024
May	43	41	2.8355	0.9974	7.2759*	2.02
Jun	29	27	2.8752	0.9955	3.3546*	2.052
Jul	16	14	2.9576	0.9426	0.2174	2.145
Aug	11	9	2.7886	0.9998	16.0797*	2.262
Sep	25	23	2.7643	0.9982	9.6296*	2.069
Overall	537	535	2.8658	0.9974	21.2138*	1.96

In females (Figure 16), the length-weight ranges were between 6.1 cm weighing 3.8 g and 50.7 cm weighing 1385 g with mean length and weight of 27.7 cm and 432.6 g, respectively, from a total of 228 observations. The regression line fitted for length on weight was $\mathbf{Log_{10}\ W = 1.7973 + 2.8955\ Log_{10}\ L}$. The test of isometry for the monthly length-weight relationship in males is given in Table 13. All correlations were highly significant ($P<0.05$) with coefficient of determination of 90% in most months except April (2003 and June 2004). The overall exponent ($b=2.8955$) was significantly different from 3 ($t^{\wedge} = 13.5536$; $P < 0.05$). The monthly exponents were significantly greater than 3 in only six months but not significantly greater than 3 in the remaining months. The exponential value of 2.8955 indicates that length increases with increase in weight (negative allometric growth) and the regression coefficient value was found to be highly significant ($t = -20.990$; d.f. = 227; $P < 0.05$).

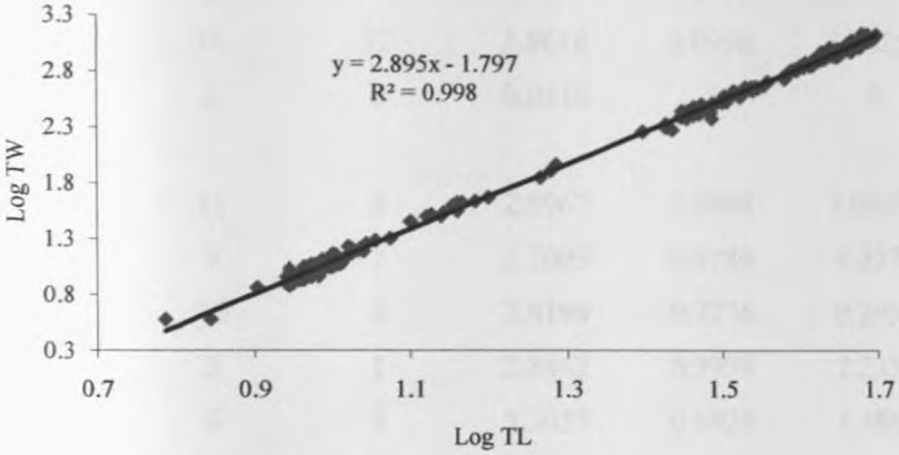


Figure 16: Length-weight relationships in female *M. cephalus* (Pooled totals obtained during the study period used).

Table 13: Test of isometry for the monthly length-weight regression for female *M. cephalus* (*Significant at 5 % level).

Month	Total number	d.f	b	r^2	t^	$t_{0.05}$, n-2
Oct 02	42	40	2.9489	0.9991	3.6514*	2.021
Nov	3	1	3.024	0.9962	0.1287	12.706
Dec	17	15	2.843	0.9995	9.5622*	3.131
Jan 03	9	7	2.9297	0.9988	1.8316	2.365
Feb	9	7	2.8767	0.9983	2.7480	2.365
Mar	21	19	2.7583	0.9947	5.2325*	2.093
Apr	3	1	0.2498	0.8503	2.3898	12.706
May	1					
Jun	5	3	2.8721	0.9933	0.9391	3.182
Jul	3	1	3.0613	0.9999	2.0024	12.706
Aug	4	2	2.831	0.999	2.6758	4.303
Sep	2	0	0.1559	1		
Oct	3	1	3.2299	0.9526	0.3191	12.706
Nov	26	24	3.0068	0.9837	0.0861	2.064
Dec	17	15	2.9081	0.9989	3.6883*	3.131

Jan 04	8	6	2.904	0.9985	2.0891	2.447
Feb	14	12	2.8618	0.9996	8.3625*	2.179
Mar	2	0	0.0416	1	0	
Apr						
May	11	9	2.8967	0.9988	3.0865*	2.262
Jun	9	7	2.2005	0.6789	1.3977	2.365
Jul	10	8	2.8198	0.7276	0.2954	2.306
Aug	3	1	2.8442	0.9994	2.2357	12.706
Sep	6	4	3.2057	0.9926	1.4863	2.776
Overall	228	226	2.8955	0.9984	13.5536*	1.96

5.3.1.2 Length-weight relationship in *Valamugil buchanani*

A total of 390 *V. buchanani* obtained during the sampling period from all the eight sites were used in this analysis. Figure 17 shows the length–weight relationship in males. In 187 male *V. buchanani* with length–weight ranges between 7.1 cm weighing 5.1 g and 41 cm weighing 697.3 g, respectively, the calculated mean length was 16.5 cm and mean weight was 86.4 g. The regression line fitted for length on weight was $\mathbf{Log_{10}\ W = 1.7648 + 2.8924\ Log_{10}\ L}$. The test of isometry for the monthly length-weight relationship in males is given in Table 14. All correlations were highly significant ($P<0.05$) with coefficient of determination of between 70 to 90% in most months though there were no samples obtained in some months or were too few to be considered. The overall exponent ($b=2.8911$) was significantly different from 3 ($t^{\wedge} = 8.6449$; $P < 0.05$). The monthly exponents were significantly greater than 3 in only three months but not significantly greater than 3 in nine months. The exponential value of 2.8911 show that length increases

with increase in weight (negative allometric growth) and the regression coefficient was found to be highly significant (t = -17.013; d.f. = 186; P < 0.05).

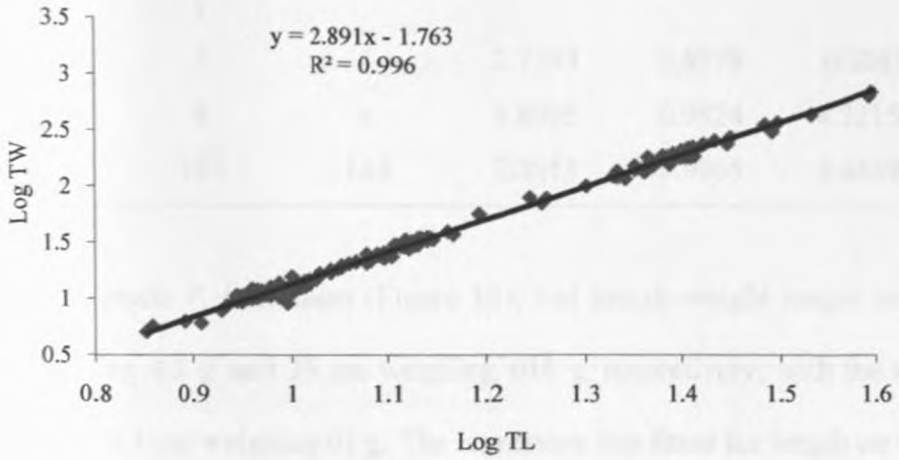


Figure 17: Length-weight relationship in male *V. buchanani* (Pooled totals obtained during the study period used).

Table 14: Test of isometry for the monthly length-weight regression for male *V. buchanani* (*Significant at 5 % level).

Month	Total number	d.f	b	r^2	t^	$t_{0.05}$, n-2
Jan 03	2	0	1.0759	1		
Mar	35	33	2.8116	0.9895	3.3155*	2.035
Apr	12	10	2.9947	0.8975	0.0166	2.228
May	2	0	1.2866	1		
Jun	35	33	2.4669	0.7123	1.9534	2.035
Sep	11	9	2.7071	0.8852	0.9014	2.262
Oct	6	4	2.9991	0.9987	0.0166	2.776
Nov	3	1	2.8333	0.9823	0.4383	12.706
Dec	25	23	2.9004	0.9973	3.1652*	2.069
Jan 04	2	0	0.9808	1		
Feb	8	6	3.078	0.9867	0.5347	2.447
Mar	23	21	2.8542	0.9956	3.5213*	2.08

Apr	3	1	2.9091	0.9446	0.1290	12.706
May	6	4	2.867	0.9949	1.2958	2.776
Jun	2	0	1.1134	1		
Jul	1					
Aug	3	1	2.7393	0.8279	0.2087	12.706
Sep	8	6	3.8995	0.9824	4.2215*	2.446
Overall	187	185	2.8911	0.9965	8.6449*	1.96

The 203 female *V. buchanani* (Figure 18), had length–weight ranges were between 7.2 cm weighing 4.5 g and 39 cm weighing 616 g, respectively, with the calculated mean length of 14.1 cm weighing 61 g. The regression line fitted for length on weight was **$\text{Log}_{10} W = 1.7787 + 2.9034 \text{ Log}_{10} L$.** The test of isometry for the monthly length-weight relationship in females is given in Table 15. All correlations were highly significant ($P<0.05$) with coefficient of determination of between 80 to 90% in most months though there were no samples obtained in some months or were too few to be considered. The overall exponent ($b=2.9034$) was significantly different from 3 ($t^{\wedge} = 6.1757$; $P < 0.05$). The monthly exponents were significantly greater than 3 in five months but not significantly greater than 3 in eight months. The exponential value of 2.9034 indicates that length increases with increase in weight (isometric growth) and the regression coefficient was found to be highly significant ($t = -15.990$; d.f. = 202; $P < 0.05$).

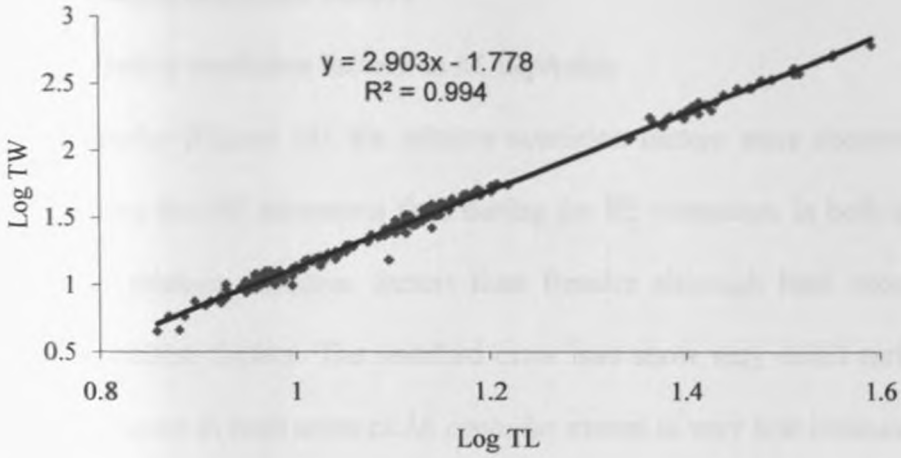


Figure 18: Length-weight relationship female *V. buchanani* (Pooled totals obtained during the study period used).

Table 15: Test of isometry for the monthly length-weight regression for female *V. buchanani* (*Significant at 5 % level).

Month	Total number	d.f	b	r^2	t^	$t_{0.05}$, n-2
Jan 03	2	0	1.003	1		
Mar	52	50	2.8791	0.9869	2.5595*	2.009
Apr	7	5	3.0992	0.9841	0.5631	2.571
Jun	8	6	2.8207	0.8847	0.4313	2.447
Aug	2	0	0.7951	1		
Sep	18	16	2.8781	0.949	0.7308	2.120
Oct	6	4	3.2766	0.9953	2.4569*	2.776
Nov	3	1	0.4624	0.9951	78.1990*	12.706
Dec	35	33	2.8992	0.9737	1.2187	2.035
Feb	22	20	2.8821	0.9113	0.5864	2.086
Mar	18	16	2.7617	0.995	4.8690*	2.120
May	20	18	2.9429	0.997	1.5006	2.101
Jun	2	0	0.9448	1		
Aug	5	3	2.8574	0.9912	0.9174	3.182
Sep	3	1	1.3089	0.9753	8.1188	12.706
Overall	203	201	2.9034	0.9942	6.1757*	1.96

5.3.2 Relative condition factors

5.3.2.1 Relative condition factors in *M. cephalus*

In *M. cephalus* (Figure 19), the relative condition factors were observed to be slightly higher during the NE monsoons than during the SE monsoons in both sexes. The males had higher relative condition factors than females although both sexes exhibit higher relative condition factors. The standard error bars show very small variation in relative condition factors in both sexes of *M. cephalus* except in very few instances.

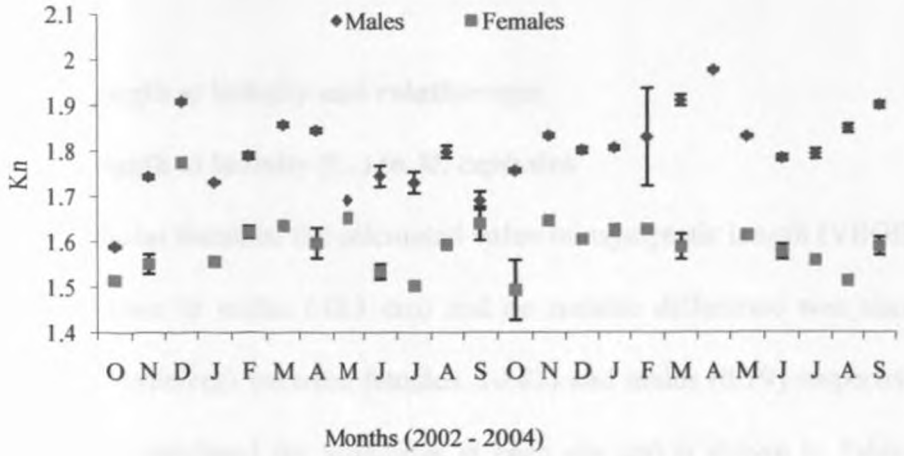


Figure 19: Relative condition factors (Kn) of *M. cephalus* (Bars represent SE).

5.3.2.2 Relative condition factors in *V. buchanani*

In *V. buchanani* (Figure 20), the relative condition factors could not be related to seasons and there was small difference between males and females. In both species, low variations in the monthly relative condition factors between the sexes as well as during the different seasons were observed, although the lowest values were high (above 1.5).

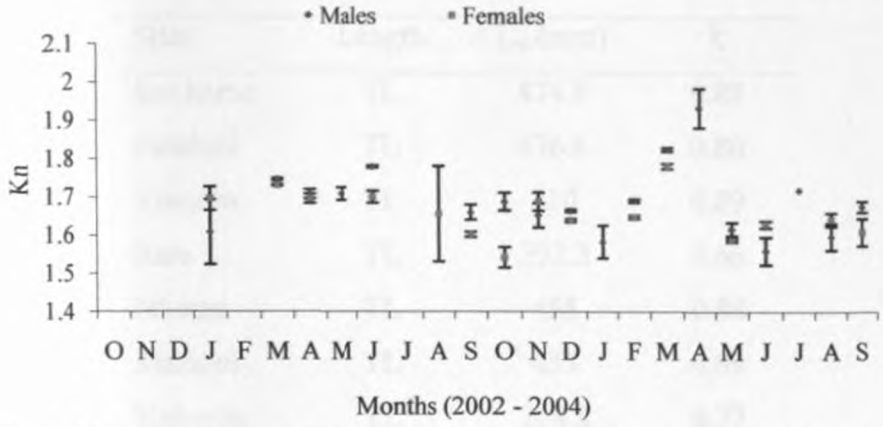


Figure 20: Relative condition factors (Kn) of *V. buchanani* (Bars represent SE).

5.3.3 Length at infinity and relative ages

5.3.3.1 Length at infinity (L_∞) in *M. cephalus*

In *M. cephalus* females, the calculated value of asymptotic length (VBGE) L_∞ (51.48 cm) is higher than in males (48.3 cm) and no notable difference was also observed in K (growth coefficient) between females (0.83) and males (0.79) respectively. Asymptotic length was calculated for Mugilidae at each site and is shown in Table 16. The largest possible fishes were found at Sea Horse, Nkoma, Fumbini and Mazioni while the smallest fishes were found at Kombeni and Kidundu.

Table 16: Length at infinity of Mugilidae at Kilifi study sites (TL – total length).

Sites	Length	L_∞ (mm)	k
Sea horse	TL	474.8	0.88
Fumbini	TL	476.6	0.80
Konjora	TL	310	0.89
Rare	TL	292.2	0.66
Nkoma	TL	458	0.88
Mazioni	TL	455	0.89
Kidundu	TL	214.8	0.77
Kombeni	TL	168	0.82

No physico-chemical parameter was limiting (Ref. Table 2) and these contributed to high growth rates observed in both *M. cephalus* and *V. buchanani* at Kilifi. The highest mean numbers of Mugilidae per site was 19 at Fumbini, 13 at Kidundu and eight at Kombeni respectively. Sea Horse, Mazioni, Konjora and Nkoma had the least mean numbers indicating low numbers of Mugilidae while Rare had a mean number of four.

5.3.3.2 Relative age in *M. cephalus*

Figure 21 shows the theoretical growth curves for *M. cephalus* determined graphically from the von Bertalanffy's equation for ages 0 – 10 years. There is a clear distinction between *M. cephalus* males and females. During the first two years of life (Table 17), *M. cephalus* grew rapidly in length with average increases of 14.2 and 13.6 cm during the first year and 7.7 and 6.0 cm during the second year in males and females respectively. From the third to the tenth year, growth decreased to 0.11 and 0.39 cm in males and females respectively. The males grow faster than females throughout the ten years.

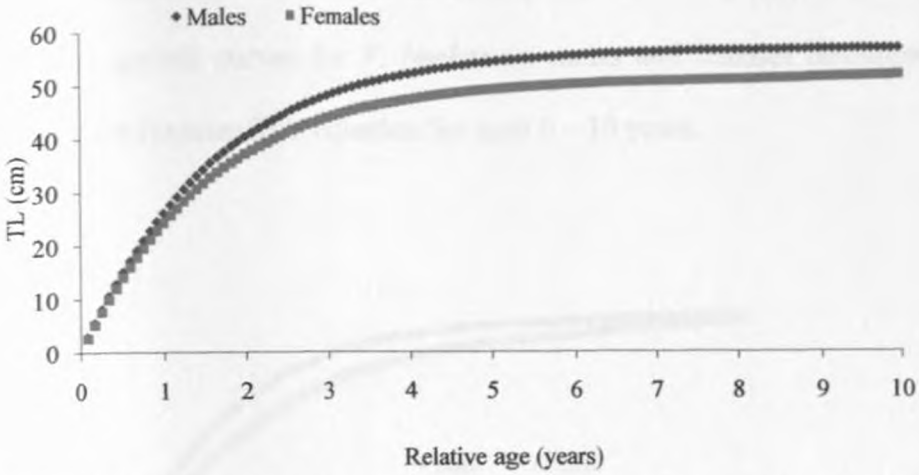


Figure 21: Von Bertalanffy growth curve of *M. cephalus* at relative age.

Table 17: Growth differences in relative TL with increase in relative age in *M. cephalus*.

	Relative length (cm)	
Year	Males	Females
1	26.20	24.35
2	40.40	37.92
3	48.10	43.94
4	52.27	47.51
5	54.53	49.39
6	55.75	50.58
7	56.42	50.90
8	56.77	51.28
9	56.97	51.66
10	57.08	52.05

5.3.3.3 Length at infinity (L_∞) in *V. buchanani*

In *V. buchanani* males, the calculated value of asymptotic length (VBGE) L_∞ (42.88 cm) is higher than in females (41.75 cm) and a notable difference was also observed in K

(growth coefficient) between males (0.77) and females (0.61). Figure 22 shows the theoretical growth curves for *V. buchanani* males and females determined graphically from the von Bertalanffy's equation for ages 0 – 10 years.

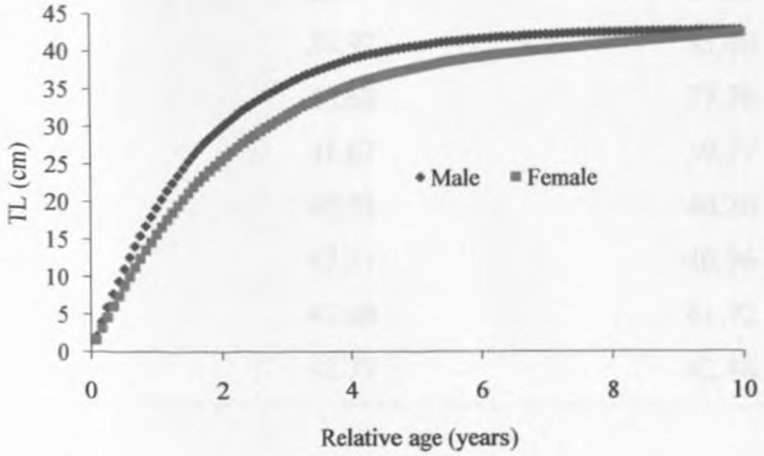


Figure 22: Von Bertalanffy growth curve of *V. buchanani* at relative age.

5.3.3.4 Relative age in *V. buchanani*

The specific growth differences in length at relative age are shown in Table 18. Males of were observed to grow faster than females but later after ten year their growth rates were the same. The rate of growth was rapid during the first two years with average increases in length of 10.6 and 9.79 cm in the first year and 5.86 and 6.12 cm during the second year in males and females respectively. From the third to tenth year, growth decreased to 0.09 and 0.76 cm in males and females respectively. The younger fish grow faster than older fish and females seem to grow faster than males in later ages as shown by Figure 22.

Table 18: Growth differences in relative TL with increase in relative age in *V. buchanani.*

	Relative length (cm)	
Year	Males	Females
1	19.21	15.67
2	29.81	25.46
3	35.67	31.58
4	38.92	35.40
5	40.68	37.78
6	41.67	39.27
7	42.21	40.20
8	42.51	40.96
9	42.68	41.72
10	42.77	42.48

5.4 Discussion

The values of parameter *b* i.e., the rate of growth, which is also the slope of the growth curve, are usually between 2 and 4. When the value of *b* is equal to 3 fish are said to show isometric growth while values less than or greater than 3 show allometric growth (Bagenal & Tesch, 1978, Verdiell-Cubedo et al., 2006). In this study, males and females of *M. cephalus* exhibited negative allometric growth ($b < 3$) as was reported by Ibanez et al., (1999). In *V. buchanani,* males exhibited negative allometric growth while females had isometric growth ($b = 3$). Positive allometric growth for *M. cephalus* was reported from Adriatic estuarine system, Dulcic and Glamuzina (2006) and also from Western Mediterranean Sea (Verdiell-Cubedo et al, 2006). Giarrizzo et al., (2006) observed negative allometry in *Mugil curema, Mugil gaimardianus* and *Mugil incilis* from Curuca

estuary in northern Brazil. Ilkyaz et. al., (2006) also observed negative allometric growth in the males and females of *Liza aurata* in Homa lagoon. Therefore, length-weight relationship in fishes observed among localities can be affected by several factors including habitat, season, food availability, health, number of specimen and differences in the observed length ranges (Bagenal and Tesch, 1978; Wootton, 1998) hence the variation seen at Kilifi in the present study.

For the relation of growth between sexes, some authors have shown that there are no differences between sexes for *M. cephalus* (Cech & Wohlschlag, 1975, Grant & Spain, 1975), but other workers have shown that there are significant differences in growth between the sexes (Ibanez et al., 1999). Differences in growth between sexes were also observed in both *M. cephalus* and *V. buchanani* during this study. Sometimes the females grow slightly faster (Cech & Wohlschlag, 1975, Hickling, 1970), live longer than the males or at least are predominant among older fish (Hickling, 1970), an observation made on *M. cephalus*. In general, the values of the relationship between length and weight obtained in this study are similar to those expressed by authors reporting on other Mugilidae species (Giarrizzo et al., 2006, Ilkyaz et al., 2006).

Seasonal fluctuation in the relative condition is small in both sexes of *M. cephalus* and *V. buchanani*. This can be attributed to feeding at the same rate throughout the year as observed by Siddiqui, (1977). Males of both *M. cephalus* and *V. buchanani* have higher relative condition factor than females, this contrasts observation in *Siganus sutor* (Valenciennes, 1835) and *Scolopsis bimaculatus* (Ruppell, 1828) in the same region

where females had higher relative condition than males (De Souza, 1988, Nzioka, 1981). Some investigators ascribe fluctuations in condition factor to gonad weight (Kulmiye, 1997, Le Cren, 1951, Mwatha, 1997, Ntiba, 1986, Ntiba & Jaccarini, 1990, Nzioka, 1981), others attribute it to feeding rate of fish (Siddiqui, 1977). In *Sillago sihama* (Forsskal, 1775), relative condition is related to both gonad weight and feeding (Reddy & Neelakantan, 1993) but in Mugilidae at Kilifi creek, the high relative condition may be attributed only to the feeding intensity and gonad weight.

Because of the constancy of the environment and non seasonal breeding habits of fishes in tropical areas, annuli marks are being laid down at any time of the year and in any number, therefore, many studies have been carried out to find a method of age determination (Weatherly & Rogers, 1978). Researchers in different areas have employed different methods of aging mullets (Cardona, 1999a, Ilkyaz et al., 2006, Jacot, 1920). In this study the estimated asymptotic lengths in mullets were determined from the length-weight relationships. These were 48.3 cm and 51.48 cm in male and female *M. cephalus,* respectively, and the growth coefficient values (k = 0.79 in males and 0.83 in females) show that males approach asymptotic length earlier than females. In *V. buchanani*, the estimated asymptotic length for males and females were 42.88 cm and 41.75 cm, respectively. The growth coefficient values (k = 0.77 in males and 0.61 in females) show that males also reach asymptotic length ealier than females. Ibanez et al., (1999) reported higher values in *M. cephalus* (females $L_{\square}$ = 622.9 mm and males $L_{\square}$ = 603.9 mm) and in *M. curema* (females $L_{\square}$ = 454.6 mm and males $L_{\square}$ = 411.8 mm). Grant and Spain, (1975) calculated $L_{\square}$ = 604.6 mm in *M. cephalus* (unsexed) and $L_{\square}$ is higher in all those sites

outside the tropics than is observed in this study. However, the asymptotic length of *M. cephalus* is decreasing because earlier workers calculated bigger values from large fishes, which are not available currently in the catch (Table 19). The asymptotic length for Mugilidae at each site (Table 16) confirms that fry for stocking in aquaculture farms can be obtained from Kombeni and Kidundu (Personal observation).

Table 19 compares growth parameters of *M. cephalus* for Kilifi and other localities. The asymptotic length at the coastal lagoons varied among locations but marine zones of Black sea and Australia have the largest asymptotic lengths than marine zones of the Gulf of Mexico. The asymptotic lengths at Kilifi are lower than those of other coastal lagoon areas both within and outside the Gulf of Mexico but the K values for Kilifi are much higher than in those areas.

Table 19: Growth parameters of *M. cephalus* from the Gulf of Mexico and other localities. (TL – Total length, M – males, F – females, Sp. – species. Source: Ibanez et al., 1999).

Authority	Locality	Determination Method	Length	Sex	L_∞ (mm)	K
This study	Kilifi, Kenya	Length-weight relationship	TL	M	483.0	0.79
			TL	F	514.8	0.83
Gulf of Mexico Coastal lagoons						
Ibanez et al., 1999	Tamiahua, Mexico	Otoliths	TL	F	622.9	0.11
		Otoliths	TL	M	603.9	0.11
Marquez, 1974	Tamiahua, Mexico	Scales	TL	Sp.	510.0	0.34
Diaz and Hernandez, 1980	Tamaulipas, Mexico	Scales	TL	Sp.	588.0	0.19
Marine zones						
Cech and Wohlschlag, 1975	Texas, USA	Scales	TL	F	407.0	0.32
		Scales	TL	Sp	450.0	0.24
Broadhead, 1958	N &NW Florida, USA	Scales and Tag	TL	F	374.0	0.82
			TL	M	379.0	0.66
Other localities Marine zones						
Ilin, 1949	Black sea	Scales	TL	Sp.	1089.0	0.05
Kesteven, 1942	Australia	Scales	TL	Sp	1729.0	0.06
Thomson, 1951	West Australia	Scales	TL	Sp.	609.0	0.30
Thomson, 1963	Australia	Scales	TL	Sp.	727.0	0.23
Coastal lagoons						
Romero and Castro, 1983	Chiapas, Mexico	Scales	TL	Sp.	458.5	0.21
Ezzat, 1964	France	Otoliths	TL	Sp.	417.7	0.47
Serbetis, 1939	Rome, Italy	Scales	TL	Sp.	563.0	0.56
Morovic, 1954	Venice, Italy	Scales	TL	Sp.	611.0	0.21
Allesio, 1976	Orbetello, Italy	Scales	TL	Sp.	615.0	0.40
Morovic, 1957	Vransko, Yugoslavia	Scales	TL	Sp.	590.0	0.23
Heldt, 1948	Tunisia	Scales	TL	Sp.	620.4	0.65
Farrugio, 1975	Tunisia	Scales	TL	Sp.	693.0	0.19

Differences in growth rates were noted in both *M. cephalus* and *V. buchanani* during this study as the fish age. Gerking, (1966) in (Cech & Wohlschlag, 1975) indicated that explanations for age-specific growth differentials depend on physiological-ecological variables as effective length of growing season, food availability, feeding rates, food utilization rates, efficiency of food utilization and comprehensive metabolic requirements. Besides these, less than optimal conditions of temperature, dissolved oxygen levels, salinity, photoperiod and general water quality place metabolic stress on fishes reducing their scope for activity (Fry, 1971). During this study, food for Mugilidae was abundant in the creek because the water temperatures and dissolved oxygen concentrations were high throughout the year hence the high growth rates observed.

Finally, it is important to take into account that differences between growth rates are important even in very close areas. These differences could be explained by the different methods applied for age determination (Oren, 1981); by world-wide distribution of the species and its different survival strategies and on the other hand, the differences between growth rates can also occur because of commercial exploitation, when fishing is very intense, the commercial size of fish decreases and the variation of the K coefficient increase (Ibanez, et al., 1999).

During this study, negative allometric growth was observed in male and female *M. cephalus,* male *V. Buchanani* while female *V. Buchanani* showed isometric growth. Relative condition factors were high throughout the sampling period with low seasonal fluctuation in both sexes of the same species. In *M. cephalus* and *V. buchanani,* males

reach asymptotic lengths earlier than females. Difference in growth rates was observed in both species with males growing faster than females. In *M. cephalus*, females persist in the population than males but in *V. buchanani*, it is the males persisting in the population.

CHAPTER SIX

6.0 Reproductive biology of *Mugil cephalus* L. and *Valamugil buchanani* (Bleeker) at Kilifi creek.

6.1 Introduction

The family Mugilidae plays an important role in commercial fisheries and aquaculture worldwide. Consequently a body of information exists especially on various aspects of its reproductive biology including those of Oren (1981), Abou-Seedo and Dadzie (2004), Ibanez and Gallardo-Cabello (2004), Chan and Chua (1980), Ibanez and Benitez, (2004) and Chang et al., (2000).

Studies in Mugilidae reproduction include attempts made in various countries to induce spawning in mullets (Liao, 1975, Sebastian & Nair, 1975); histological studies on gonads (Pien & Liao, 1975); egg and larval development (Kuo et al., 1974, Sylivester et al., 1975); recruitment and hatching, (Chang et al., 2000), and parasites and diseases (Paperna, 1975).

The ratio between total numbers of males to females of fish in a population is referred to as sex ratio. Nzioka (1985) found that in *Scolopsis bimaculatus*, the overall sex ratio of males to females was 1: 1.7, however he observed that the sex ratio did not deviate significantly from 1: 1 during the breeding season. De Souza (1988) reported 1:0.93 males to females in *Siganus sutor,* Mwatha (1997) reported the overall sex ratio 1: 1.4 in *Leptoscarus vaigiensis* with no change during the breeding season while Kulmiye (1997)

observed no significant deviation from 1: 1 in *Lethrinus harak*. Ilkayaz et al, (2006) reported 1:1.87 in favour of females in *Liza aurata*.

The size at first maturity of a fish is generally described as the minimum length at which 50% of the fish in a population are sexually mature (King, 1995, Kulmiye, 1997, Mwatha, 1997, Nzioka, 1985, Wootton, 1998). Knowledge of the size at first maturity is important in the determination of the minimum legal size that may be needed to secure potential reproductive stocks (Wootton, 1998). Shine (1990) observed that in animal species, males and females attain different adult body sizes. He suggested that pre-maturational growth, age at maturity or both are the primary determinants of sexual dimorphism in the adult body size and that post-maturational differences in growth or survival rates between the sexes probably influence the direction of the adult sexual size dimorphism. Cardona (1999a) reported that in grey mullets, growth of males and females cannot be studied separately until adulthood because there is no sexual dimorphism. Hickling (1970) recorded the length at sexual maturity in the English grey mullet *Crenimugil labrosus* (Risso) as 35 cm in males and 38 cm in females while Kennedy and Fritzmaurice (1969) recorded 38.8 cm for males and 45 cm for females of the same species.

The reproductive organs in fishes are internal and longitudinally placed within the body cavity from where they communicate with the outside via the genital openings. They originate as paired structures and remain so in most species. The size and colour of the reproductive organs vary according to the stage of sexual maturity and most testis are creamy white and smooth while most ovaries are yellow to orange when ripe (Aloo,

1988). The general morphology of the gonads has been a subject of investigation by a number of workers. The maturity stages of a fish designated, usually by Roman numericals, describe the phase of development of the most advanced germ cells in the fish gonad. From morphology of the fish and their gonads, stages of maturation have been ascribed to individual fishes in a population (Bagenal & Braum, 1978). Maturity stages have been designated with Roman numericals I – VI depending on species and after spawning, the ovary may return to either stage II or III depending on species or the type of spawning. Maturity stages of ovary is taken to mean the degree of ripeness of the ovaries and testes of a fish (Holden & Raitt, 1974). It is assumed that development of both ovaries and testes are synchronous and can be classified either macroscopically or microscopically. The percentages of macroscopic stages are then plotted in a histogram and used to determine the time when majority of the population is in the final spawning stage (King, 1995).

A Gonadosomatic index (GSI) is used to follow the reproductive cycle of a species over the year at monthly intervals and it assumes that a gonad increases in size with increasing development and it also compares mass of gonad with the total mass of the animal (King, 1995). In most fishes, the males and females have the highest GSI values just before and at the onset of spawning. GSI provides a simple index, which describes changes in the relative size of gonads over time. Mugilidae are batch or multiple spawners, and have a relatively low GSI, but they have a high rate of egg production if they produce many batches in a season (Wooton, 1998).

Fecundity of fish is defined as the number of ripening eggs in the female prior to the next spawning period (Bagenal & Braum, 1978). Bagenal (1978) also reported that fecundity in fishes is proportional to the size of the adult female, to the size of ovary and to the egg size. Different methods ranging from gravimetric through volumetric to actual physical counts of all the eggs have been used to determine fecundity in different species. Bagenal (1978) also noted that fertility, which is the number of eggs shed, is different from fecundity.

From fisheries data (Annual Reports, 2000 – 2008) mullets are always present among the pelagic fish landed by artisanal fishermen in Kenya, an indication of harvests along the coast. Sivalingam, (1981) reported that many species of mullets spawn at different times of the year and there is scanty information on the local biology of these fishes apart from their occurrence.

This study aims at establishing sex ratio, size at first maturity and maturity stages of gonads, gonadosomatic index and fecundity of both *M. cephalus* and *V. buchanani* at Kilifi creek.

6.2 Methodology

6.2.1 Sex ratio

Variations in the ratio of male to female *M. cephalus* and *V. buchanani* at Kilifi creek were determined by sexing all the fish in the monthly catches. The significance of the results was tested monthly using the chi-square formula (Bailey, 1981):

$$\chi^2 = (f-F)^2 / F$$

Where **f** = Observed and **F** = Expected.

A variance test of homogeneity of the binomial distribution was performed on the monthly samples to verify significant difference in sex variation using the formula (Snedecor & Cochran, 1989):

$$\chi^2 = \frac{\sum p_i a_i - \bar{p} A}{\bar{p}\bar{q}}$$

Where $p_i = a_i / n_i$; a_i = Males or females, n_i = monthly totals, A = totals of (a_i), $\bar{p}$ = totals of males (A)/ overall total (N), $\bar{q}$ = Totals of females (A) / overall total (N).

6.2.2 Minimum size at sexual maturity

To determine the size at which 50% of fish in the population become sexually mature, the percentage occurrence of males and females collected in different stages of maturity were calculated for *M. cephalus* and *V. buchanani*. In this study, fish in stage II was considered mature because it is in this stage that gonadal activity is initiated and at the same time, the stage has fish that have spawned before and are restarting the spawning cycle once again. The percentage occurrence of different maturity stages (II - V) in various class sizes of both species were graphically fitted by plotting a cummulative percentage curve of numbers of fish at each class size against midpoints of the class sizes.

6.2.3 Maturity stages of gonads

The ventral side of both *M. cephalus* and *V. buchanani* were slit open, gonads removed, weighed and recorded. The ovaries had different shades of yellow depending on maturity stage testes, tapering from the anterior to the posterior (Plate 16) while The testes were

flattened and whitish in colour, also tapering from the anterior to the posterior (Plate 17). In order to assess maturity stages of *M. cephalus* and *V. buchanani*, both macroscopic and microscopic (histology) examination were carried out. Histological studies were used to determine the structure of gonads, to determine any changes undergone by gonads and to confirm that the gonads had been assigned appropriate macroscopic maturity stages.

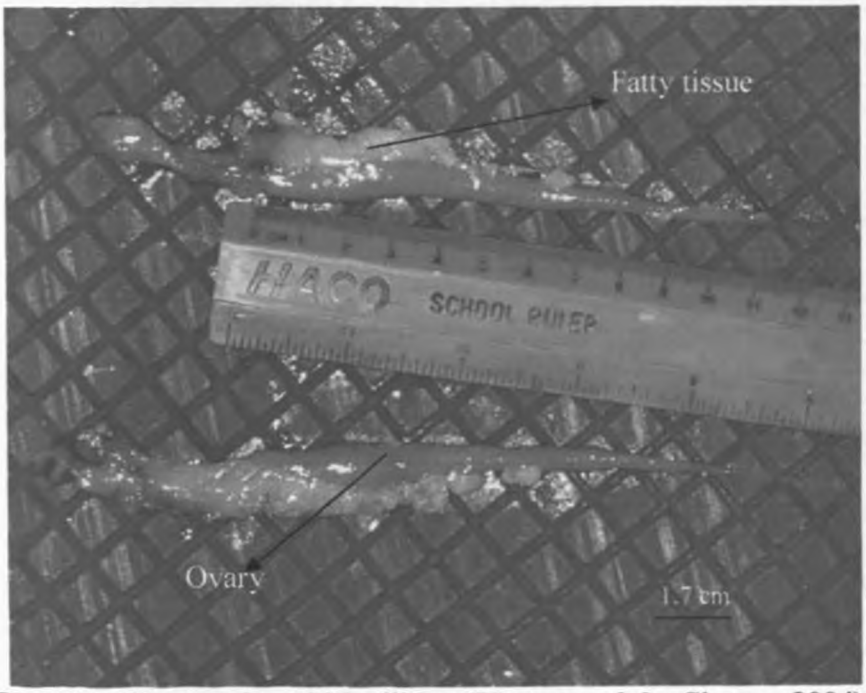


Plate 16: The ovaries of Mugilidae (Photograph by Sigana, 2004).

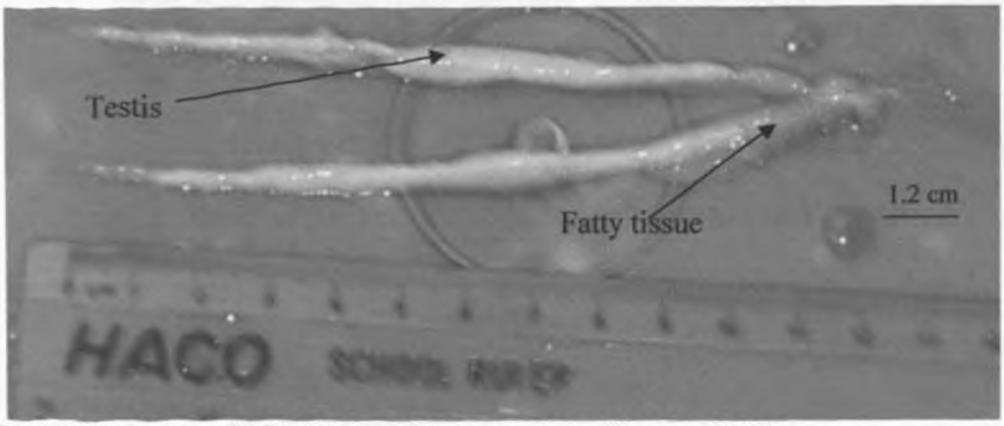


Plate 17: Testes of Mugilidae (Photograph by Sigana, 2004).

6.2.3.1 Macroscopic appearance of Mugilidae gonads

This method was used with an aim of examining a large number of fish frequently to get a representative picture of the stage of maturity of the population and the changes with time. Macroscopic gonad maturity stages were based on gonad colour and width in millimetres. Very mature females had yellow ovaries while male testis were white and could not be easily classified with the naked eye.

6.2.3.2 Microscopic appearance of Mugilidae gonads

Both testes and one half of ovary were preserved in Bouin's fixative for 48 hours then stored in 70 % Ethyl alcohol and transported to University of Nairobi laboratory for histological studies. In the laboratory, the mid-region of the gonadal lobe (5mm) was exercised, made rigid by dehydration and impregnated in molten wax. The impregnated tissue was then set into a block of wax to enable its mounting on a microtome for section cutting. Sections, of 10 µm thick were done on a rotary microtome and the sections were the stained (Ref. Humason (1972)).

Excess Xylene was removed from the slide around the sections and a drop of DPX mountant was placed over the sections and a cover slip applied over the sections. Observations were made under the Leitz Laborlux 12 compound microscope at ×100 magnification. Photographs were taken using an Olympus camera DP 12 mounted on Olympus BX 51 microscope at ×100 magnification.

6.2.4 Gonadosomatic Index (GSI)

After the determination of sex and maturity stages of *M. cephalus* and *V. buchanani,* gonads were weighed to the nearest milligram. Gonadosomatic Index (GSI), which represents the percentage of gonad wet weight relative to the total body wet weight, was calculated using the formula (King, 1995):

$$GSI = (\text{Gonad weight}/\text{Total body weight}) \times 100$$

The mean monthly GSI values were calculated and related to seasons. The relationship between gonad and total weight is best described by a straight line which can be fitted by plotting logarithmic transformations observed total weight against gonad weight and related by regression analysis.

6.2.5 Fecundity of Mugilidae

After the determination of maturity stages of both males and females of *M. cephalus* and *V. buchanani,* the male gonads were discarded while one half of the female ovaries were preserved in Gilson's fluid (Bagenal, 1978). These ovaries were small in size, the preservative penetrated easily to preserve the eggs and also broke down the ovarian tissue. The process was aided by repeated, though spasmodic, shaking of the bottles in which the ovaries were preserved. Tap water added to the specimen bottles whose capacity was 30 ml then emptied into 100 ml beaker. Any suspended ovarian tissue was removed and any adhering eggs physically separated. There was no decanting of the supernatant because the fluid was clear. Volumetric sub-sampling method was used to count the oocytes whereby both oocytes and water were stirred so that the eggs were well distributed throughout the water, then three 10 µl sub-samples taken quickly with a

micro-pipette (Gilson S57418C (P100)), poured on three different parts of a Sedgewick rafter cell. Each sub-sample was counted under the compound microscope at a magnification of 25X. Fecundity was estimated from the mean of the total count, multiplied by volume of sample bottle then doubled to represent the two ovaries. The relationship between fecundity and total length was determined using the formula (Bagenal & Braum, 1978):

$$F = ax^b$$

Where F = fecundity, x = standard length, a = a constant and b = exponent. This relationship was transformed into a straight line by a logarithmic transformation. Regression analysis was used to estimate the linear relationship between total fecundity and total length and also between total fecundity and gonad weight.

6.3.1 Sex ratios

6.3.1.1 Sex ratios of *M. cephalus*

Table 20 shows the sex of 765 specimens of *M. cephalus* collected during the study period, grouped by months. The overall sex ratio was 1: 0.42 males to females, which shows significant deviation from the expected 1:1 ($\chi^2 = 124.65$; d.f. = 1; $P < 0.05$). It was observed that the females never dominated the catch at any specific time. The variance test of homogeneity of the binomial distribution of the sex ratio showed a highly significant difference in the monthly samples during the sampling period of 24 months ($\chi^2 = 75.173$; d.f. = 23; $P < 0.05$).

Table 20: Sex ratio of *M. cephalus* observed during the study period. (Pooled sex ratio differed significantly from 1:1; $\chi^2 = 124.65$; $P < 0.05$)

Month	Males	Females	Total	M: F ratio
October	53	42	95	1.0: 0.79
November	20	3	23	1.0: 0.15
December	29	17	46	1.0: 0.59
January – 2003	46	9	55	1.0: 0.20
February	17	9	26	1.0: 0.53
March	28	21	49	1.0: 0.75
April	30	3	33	1.0: 0.10
May	1	1	2	1.0: 1.00
June	6	5	11	1.0: 0.83
July	3	3	6	1.0: 1.00
August	8	4	12	1.0: 0.50
September	4	2	6	1.0: 0.50
October	23	3	26	1.0: 0.13
November	30	26	56	1.0: 0.87
December	24	17	41	1.0: 0.71
January – 2004	21	8	29	1.0: 0.38
February	17	14	31	1.0: 0.82
March	12	2	14	1.0: 0.17
April	41	0	41	41.0: 0.0
May	43	11	54	1.0: 0.26
June	29	9	38	1.0: 0.31
July	16	10	26	1.0: 0.63
August	11	3	14	1.0: 0.27
September	25	6	31	1.0: 0.24
Total	537	228	765	1.0: 0.42

The sex ratio in relation to size is summarized in Table 21 and the length frequencies in Figure 23. The size of males ranged from 5.7 – 48.0 cm and showed more of a bimodal distribution with the highest peak in the 5.5 – 10.4 cm class size and a smaller one in the 40.5 – 50.4 cm class size. The female sizes ranged from 6.1 – 50.7 cm and also showed a bimodal distribution with the highest peak at 5.5 - 10.4 cm and another smaller one at 40.5 – 50.4 cm class sizes. Comparison of the overall mean sizes of males and females in different size classes showed no significant difference between the sexes ($t = 1.913$; d.f. = 9; $P > 0.05$). The variance test for homogeneity of the binomial distribution in relation to class size frequency distribution showed a very significant evidence of heterogeneity ($\chi^2 = 99.54$; d.f. = 9; $P < 0.05$). Over 50 % of both males and females were below 20.4 cm size class, however, the mid range 28.2 lies within the class size 25.5 – 30.4 cm.

Table 21: Sex ratio of *M. cephalus* in relation to class sizes.

Class size	Males	Females	Total	M: F ratio	% of Total
5.5 – 10.4	220	65	285	1.0: 0.30	37.3
10.5 – 15.4	95	23	118	1.0: 0.24	15.4
15.5 – 20.4	41	4	45	1.0: 0.10	5.9
20.5 – 25.4	32	1	33	1.0: 0.03	4.3
25.5 – 30.4	31	18	49	1.0: 0.58	6.4
30.5 – 35.4	16	30	46	1.0: 1.88	6.0
35.5 – 40.4	10	13	23	1.0: 1.30	2.6
40.5 – 45.4	73	42	115	1.0: 0.58	15.0
45.5 – 50.4	19	31	50	1.0: 1.63	6.5
50.5 – 55.4	0	1	1	0.0: 1.0	0.1
Total	537	228	765	1.0: 0.42	100

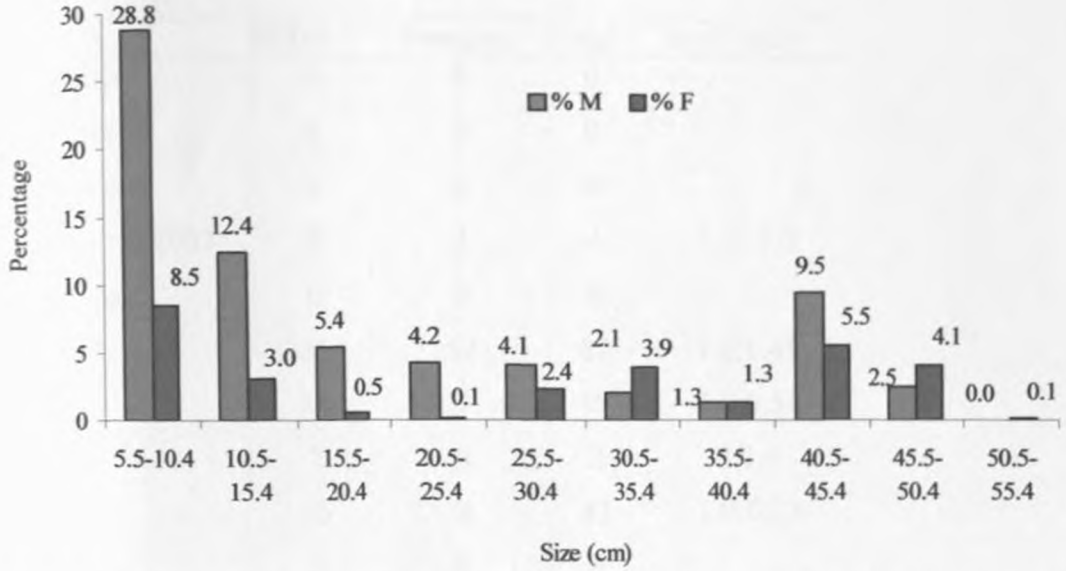


Figure 23: The length-frequency distribution of *M. cephalus* (Values show actual percentages).

6.3.1.2 Sex ratios of *V. buchanani*

Table 22 shows the sex of 390 specimens of *V. buchanani* collected then grouped by months. March, August, September, February, May and August have high female ratios beyond the 1:1. The variance test of homogeneity of the binomial distribution of the sex ratio showed significant difference in the monthly samples over the study period of 24 months ($\chi^2 = 50.49$; d.f. = 23; $P < 0.05$). The overall sex ratio did not differ significantly from the expected 1:1 ($\chi^2 = 0.328$; d.f. = 1; $P > 0.05$).

Table 22: Sex ratio of V. *buchanani* observed during the study period. (Pooled sex ratio was not significantly different from 1:1; $\chi^2 = 0.328$; $P > 0.05$).

Month	Males	Females	Total	M: F ratio
October	0	0	0	
November	0	0	0	
December	0	0	0	
January – 2003	2	2	4	1.0: 1.0
February	0	0	0	
March	35	62	87	1.0:1.49
April	12	7	19	1.0:0.58
May	2	0	2	2.0:0
June	35	8	43	1.0:0.23
July	0	0	0	
August	0	2	2	0.0:2.0
September	11	18	29	1.0:1.64
October	6	6	12	1.0:1.0
November	3	3	6	1.0:1.0
December	26	35	61	1.0:1.35
January – 2004	2	0	2	2.0:0
February	8	22	30	1.0:2.75
March	23	18	41	1.0:0.78
April	2	0	2	2.0:0
May	6	20	26	1.0:3.33
June	2	2	4	1.0:1.0
July	1	0	1	1.0:0
August	3	5	8	1.0:1.67
September	8	3	11	1.0:0.38
Total	187	203	390	1.0:1.09

The sex ratio in relation to size is summarized in Table 23 and length frequencies shown in Figure 24. The size of males ranged from 7.1 – 41.0 cm and showed a bimodal

distribution with the highest peak in the 0 – 15.4 cm and smaller one in the 20.5 – 25.4 cm class sizes. The female sizes ranged from 7.2 – 39.0 cm and also showed a bimodal distribution with the highest peak at 10.5 -15.4 cm and smaller one at 20.4 – 25.4 cm. The females dominated the catch in the smaller size classes (0 – 20.4 cm) contributing 75 % of the total catch while males dominated the catch in larger size classes (20.4 – 50.4 cm). Significant difference in class size sex ratio is greatest at 20.4 cm. The mid–range class size was 24.1cm lying within class size 20.4 – 24.4 cm. Comparison between the overall mean sizes of males and females in different class sizes showed no significant difference between the sexes ($t = -0.275$; d.f. = 7; $P > 0.05$). The variance test for homogeneity of the binomial distribution in relation to class size frequency distribution showed a very significant evidence of heterogeneity ($\chi^2 = 27.53$; d.f. = 4; $P < 0.05$).

Table 23: Sex ratio of *V. buchanani* in relation to class sizes.

Class Size	Males	Females	Total	M: F	% of Total
5.5 - 10.4	58	65	123	1.0:1.12	31.5
10.5 - 15.4	58	100	158	1.0:1.72	40.5
15.4 - 20.4	4	7	11	1.0:1.75	2.8
20.4 - 25.4	46	12	58	1.0:0.26	14.9
25.5 - 30.4	13	11	24	1.0:0.85	6.2
30.5 - 35.4	4	6	10	1.0:1.5	2.6
35.5 - 40.4	3	2	5	1.0:0.67	1.3
40.5 - 45.4	1	0	1	1.0:0.0	0.3
Total	187	203	390	1.0:1.08	100

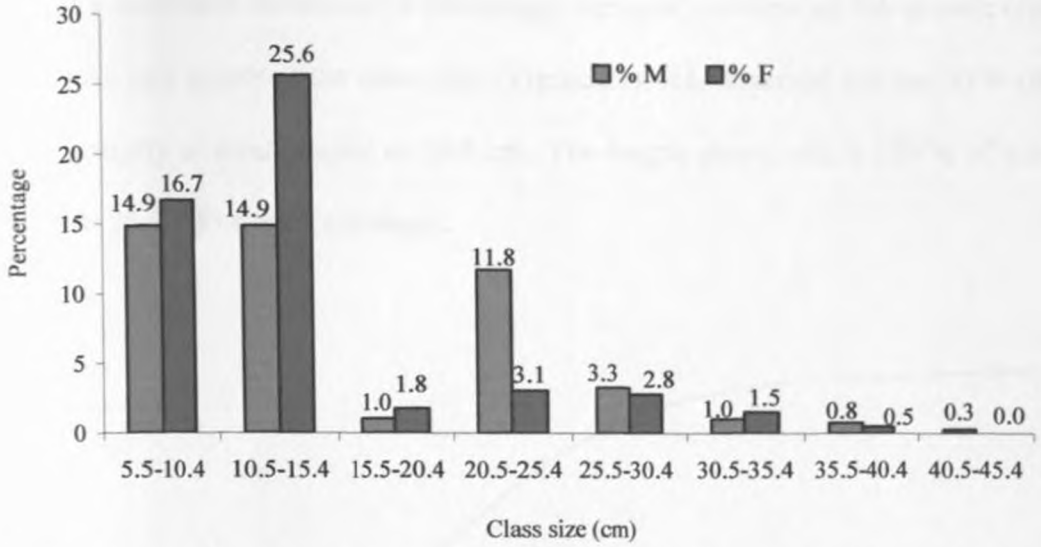


Figure 24: The length frequency distribution of *Valamugil buchanani* (Values show actual percentages).

6.3.2 Minimum size at sexual maturity

6.3.2.1 Minimum size at sexual maturity in *M. cephalus*

The percentages of occurrence of male *M. cephalus* in different stages of maturity are presented in Table 24. The cummulative frequency data (II – V) is graphically fitted by

Table 24: Percentage occurrence of male *M. cephalus* in different maturity stages and in various class sizes.

	Maturity stages					
Class size (TL cm)	I (<1mm)	II (1-2mm)	III (3-4 mm)	IV (5-6 mm)	V (>7 mm)	II – V Cummulative %
5.5-10.4	100	0	0	0	0	0
10.5-15.4	100	0	0	0	0	0
15.5-20.4	95	5	0	0	0	5
20.5-25-4	21	70	5	5	0	85
25.5-30.4	0	95	0	0	5	100
30.5-35.4	0	92	8	0	0	100
35.5-40.4	0	100	0	0	0	100
40.5-45.4	0	42.5	37	15	5.5	100
45.5-50.4	0	11	42	26	21	100

plotting a smoothed cummulative percentage curve of numbers of fish at each class size against the mid points of the class sizes (Figure 25). It is observed that the 50 % of males reach maturity at total lengths at 20.8 cm. The length above which 100 % of males are mature is 25.5 - 30.4 cm total length.

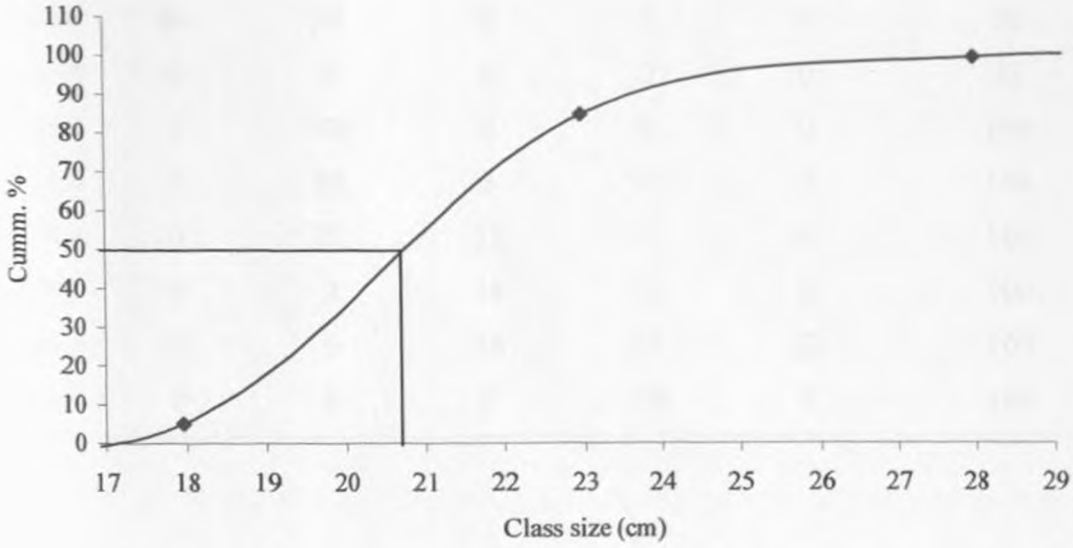


Figure 25: Changes in the percentage of male *M. cephalus* with size showing 50 % maturity.

Table 25 shows the percentage occurrence of female *M. cephalus* in different maturity stages. The cummulative frequency data (II – V) is graphically fitted by plotting a smoothed cummulative percentage curve of numbers of fish at each class size against the mid points of the class sizes (Figure 26). It is observed that the 50 % of females reach maturity at total lengths at 25.2 cm. The length above which 100 % of females are mature is 25.5 - 30.4 cm total length.

Table 25: Percentage occurrence of female *M. cephalus* in different maturity stages and in various class sizes.

	Maturity stages					
Class size (TL cm)	I (<1mm)	II (1-2mm)	III (3-4 mm)	IV (5-6 mm)	V (>7 mm)	II – V Cummulative %
5.5-10.4	98	2	0	0	0	2
10.5-15.4	100	0	0	0	0	2
15.5-20.4	80	20	0	0	0	20
20.5-25-4	0	0	0	0	0	22
25.5-30.4	0	100	0	0	0	100
30.5-35.4	0	97	3	0	0	100
35.5-40.4	0	21	71	7	0	100
40.5-45.4	0	2	34	63	0	100
45.5-50.4	0	6	16	45	32	100
50.5-55.4	0	0	0	100	0	100

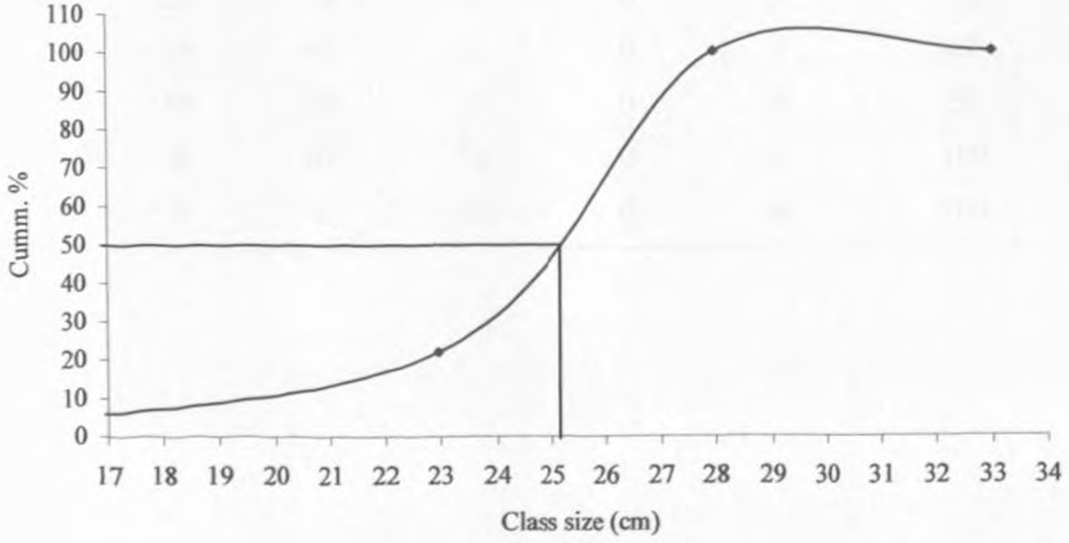


Figure 26: Changes in the percentage of female *M. cephalus* with size showing 50 % maturity.

6.3.2.2 Minimum size at sexual maturity in *V. buchanani*

The percentages of occurrence of male *V. buchanani* in different stages of maturity are presented in Table 26. The cummulative frequency data (II – V) is graphically fitted by plotting a smoothed cummulative percentage curve of numbers of fish at each class size against the mid points of the class sizes (Figure 27). It is observed that the 50 % of males reach maturity at total lengths at 20.7 cm. The length above which 100 % of males are mature is 35.5 - 40.4 cm total length.

Table 26: Percentage occurrence of male *V.buchanani* in different maturity stages and in various class sizes.

	Maturity stages					
Class size (TL cm)	I (<1mm)	II (1-2mm)	III (3-4 mm)	IV (5-6 mm)	V (>7 mm)	II – V Cummulative %
5.5-10.4	100	0	0	0	0	0
10.5-15.4	100	0	0	0	0	0
15.5-20.4	100	0	0	0	0	0
20.5-25-4	22	76	2	0	0	78
25.5-30.4	38	62	0	0	0	62
30.5-35.4	50	50	0	0	0	50
35.5-40.4	0	67	33	0	0	100
40.5-45.4	0	0	100	0	0	100

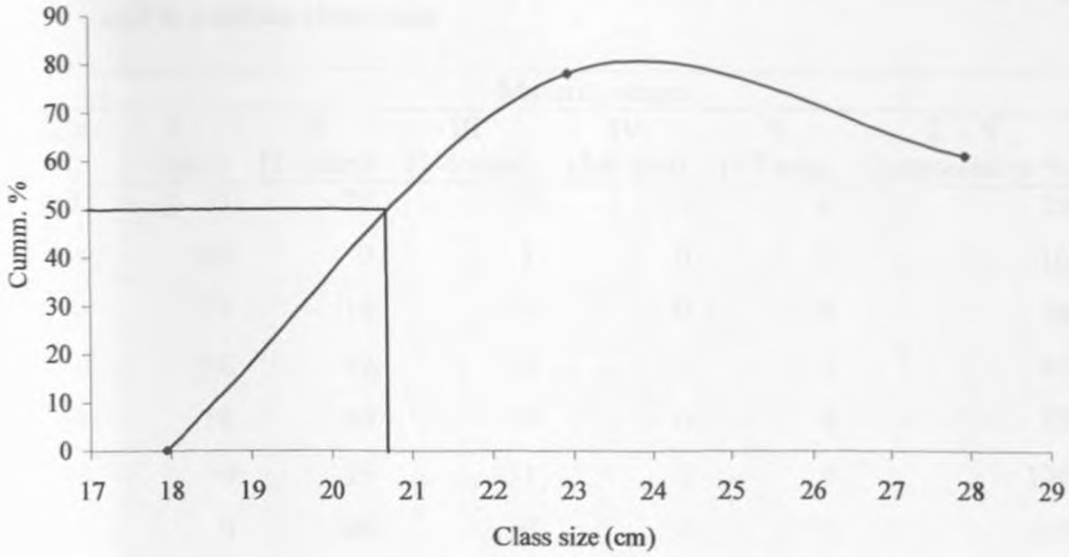


Figure 27: Changes in the percentage of male *V. buchanani* with size showing 50 % maturity.

The percentages of occurrence of female *V. buchanani* in different stages of maturity are presented in Table 27. The cummulative frequency data (II – V) is graphically fitted by plotting a smoothed cummulative percentage curve of numbers of fish at each class size against the mid points of the class sizes (Figure 28). It is observed that the 50 % of females reach maturity at total lengths at 24.4 cm. The length above which 100 % of females are mature is 30.5 - 35.4 cm total length.

Table 27: Percentage occurrence of female *V. buchanani* in different maturity stages and in various class sizes.

	Maturity stages					
Class size (TL cm)	I (<1mm)	II (1-2mm)	III (3-4 mm)	IV (5-6 mm)	V (>7 mm)	II – V Cummulative %
5.5-10.4	75	25	0	0	0	25
10.5-15.4	90	9	1	0	0	10
15.5-20.4	71	14	14	0	0	29
20.5-25-4	58	42	0	0	0	42
25.5-30.4	18	64	9	0	9	82
30.5-35.4	0	29	71	0	0	100
35.5-40.4	0	100	0	0	0	100

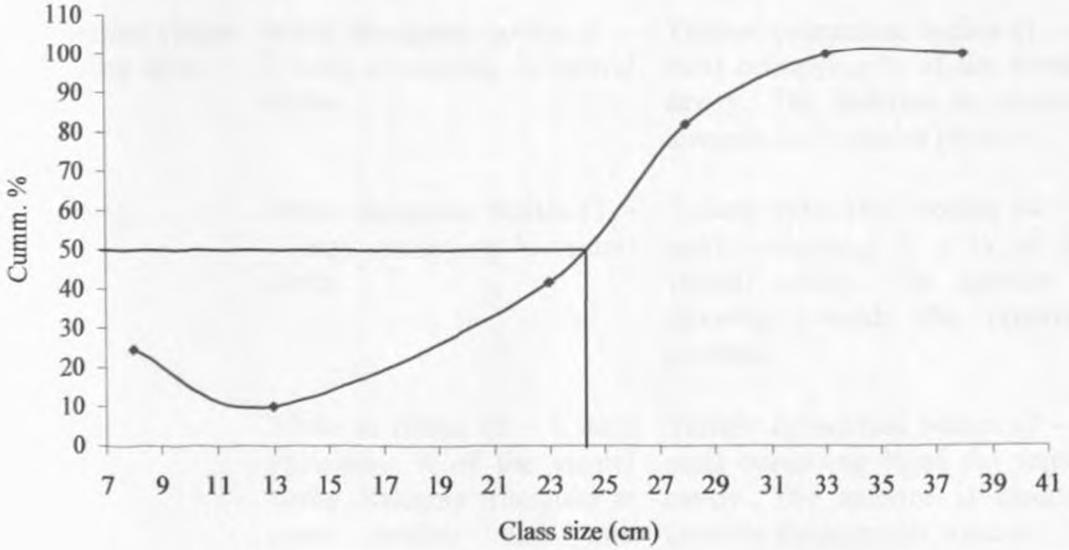


Figure 28: Changes in the percentage of female *V. buchanani* with size showing 50 % maturity.

6.3.3 Maturity stages of gonads

Mugilidae are heterochronal or partial spawners and a key devised for *Rastrelliger* species and grey mullet *Liza surbviridis* (Chan & Chua, 1980, Holden & Raitt, 1974) shown on Table 28 was used. Descriptions of macroscopic appearance of gonadal maturity stages in both *M. cephalus* and *V. buchanani* were similar and classification was based on gonad colour and width in millimetres.

Table 28: Macroscopic appearance of the maturity stages of *M. cephalus* and *V. buchanani* gonads.

Maturity stage	Testis	Ovary
I. Immature virgin	Two small threadlike colourless bodies (<1 mm occupying ⅔ ventral cavity), lying close under the vertebral column.	Two small threadlike elongated colourless bodies (<1mm occupying ⅓ - ½ ventral body cavity) lying close under the vertebral column.
II. Developing virgin or recovering spent	White elongated bodies (1 – 2 mm), occupying ⅔ ventral cavity.	Yellow cylindrical bodies (1 – 3 mm) occupying ½ of the ventral cavity. The anterior is tapering towards the posterior portion.
III. Maturing	White elongated bodies (3 – 4 mm), occupying ⅔ ventral cavity.	Yellow cylindrical bodies (4 – 6 mm) occupying ½ - ⅔ of the ventral cavity. The anterior is tapering towards the posterior portion.
IV. Mature	White in colour (5 – 6 mm) occupying ⅔ of the ventral cavity. Roughly triangular in cross section and milt appears on pressure of the abdomen.	Yellow cylindrical bodies (7 – 8 mm) occupying ⅔ of the ventral cavity. The anterior is tapering towards the posterior portion.
V. Gravid	Fully mature and white in colour (>7 mm), covering ⅔ of the ventral cavity. The testis is almost circular and milt is freely extruded by pressure.	Swollen bright yellow cylindrical ovaries (>9 mm) occupying ¾ of the ventral body cavity. The eggs are laden with yolk.

6.3.3.1 Macroscopic appearance of gonad maturity stages in *M. cephalus*

Males with maturity stages above stage one were present throughout the sampling period indicating that *M. cephalus* reproduce all year round (Figure 29). Majority in the samples were juvenile stage I and II. Males with total lengths of up to 25.4 cm were still in maturity stage I, however, in the same class size some male *M. cephalus* were in stage V of development as shown by Figure 30 indicating differences in maturing rates. Males in larger class sizes above 40.5 cm were common in later stages of development showing that they developed through stages faster.

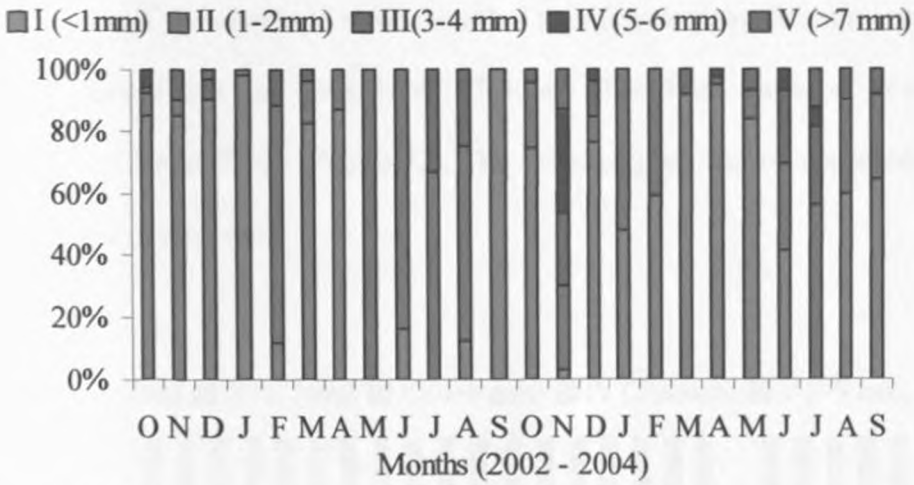


Figure 29: Percentage frequency distribution of maturity stages of male *M. cephalus* obtained throughout the sampling period.

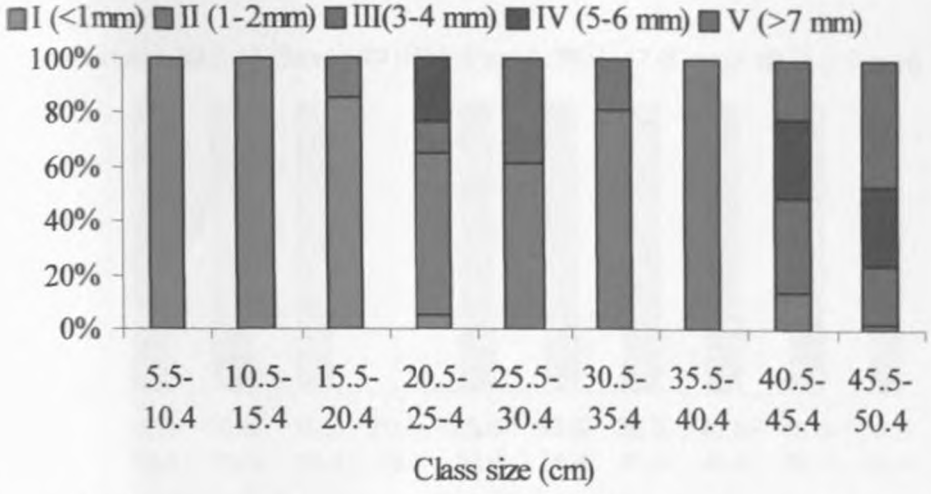


Figure 30: Percentage frequency distribution of maturity stages of *M. cephalus* males by class sizes.

Figure 31 also shows that stages I and II were present all the year round in females and later stages of development were recorded in a few months. Maturity stage III females were observed in class sizes 30.4 –35.4 cm while later stages of development were observed in larger fishes (Figure 32). The breeding peak season appeared to occur in the second half of the year.

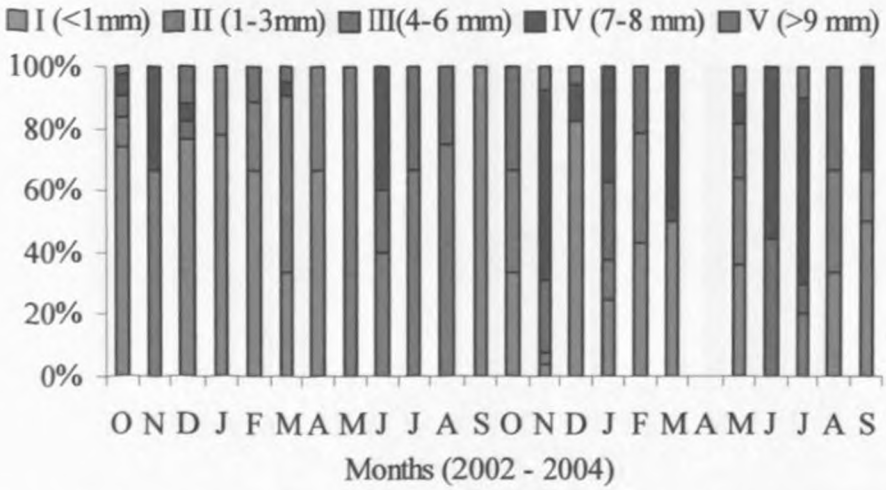


Figure 31: Percentage frequency distribution of maturity stages of female *M. cephalus* obtained during the sampling period.

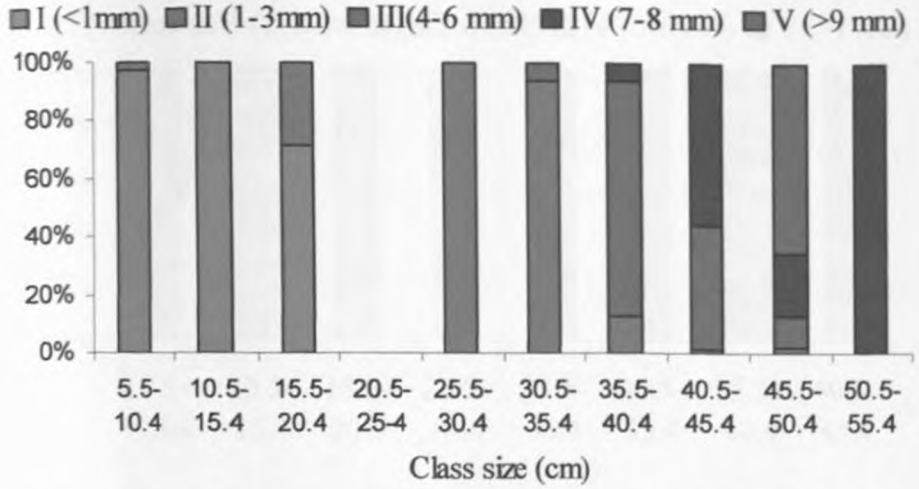


Figure 32: Percentage frequency distribution of maturity stages of female *M. cephalus* by class sizes.

6.3.3.2 Macroscopic appearance of gonad maturity stages in *V. buchanani*

All male gonads obtained could be grouped up to stage III indicating that this species is a continuous breeder in Kilifi creek (Figure 33). The largest immature male fish was in the range of 30.5– 35.4 cm and the largest male was in the range of 40.5 – 45.4 cm as shown by Figure 34. This indicates that this species mature in larger class sizes.

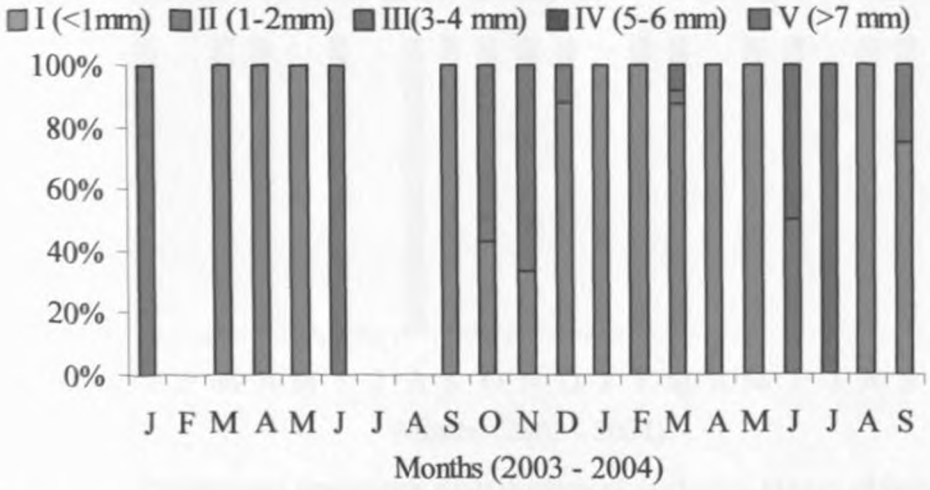


Figure 33: Percentage frequency distribution of maturity stages of male *V. buchanani* obtained throughout the sampling period.

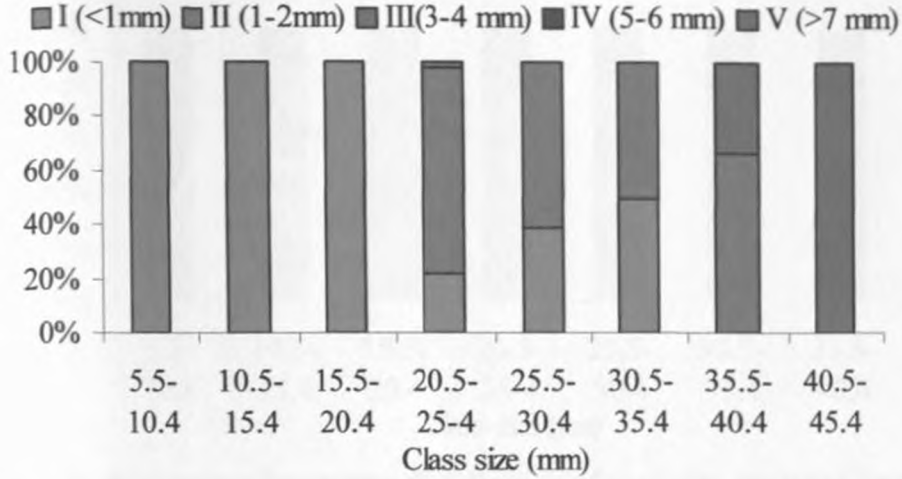


Figure 34: Percentage frequency distribution of maturity stages of male *V. buchanani* by class sizes.

Figure 35 shows that females are also continuous breeders with all maturity stages five observable stages recorded. Immature females were recorded up to class size 25.5 – 30.4 cm but the largest female caught was in the range of 35.5 – 40.4 cm (Figure 36). Like males, they also mature in larger class sizes and possibly move offshore to spawn, hence the absence of later developmental stages.

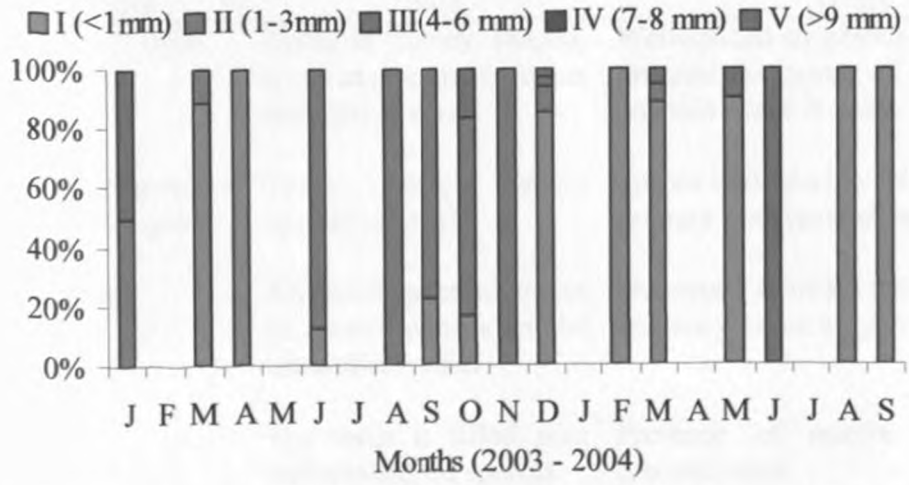


Figure 35: Percentage frequency distribution of maturity stages of female *V. buchanani* obtained throughout the sampling period.

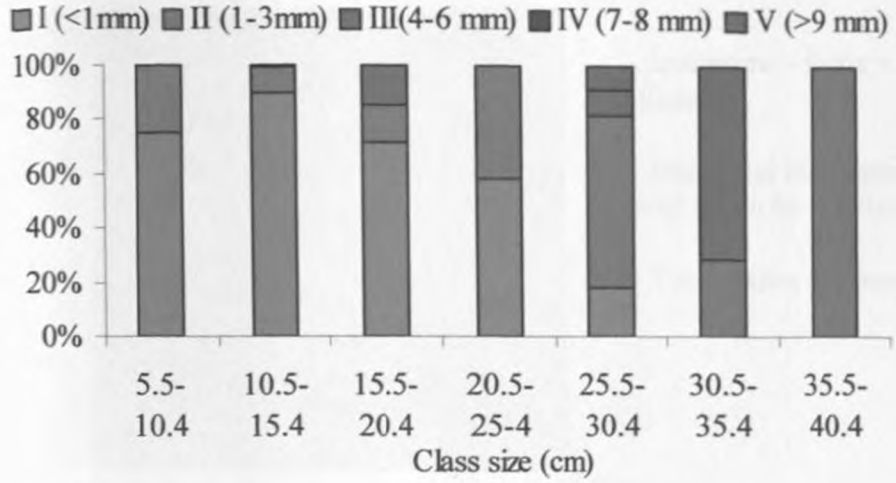


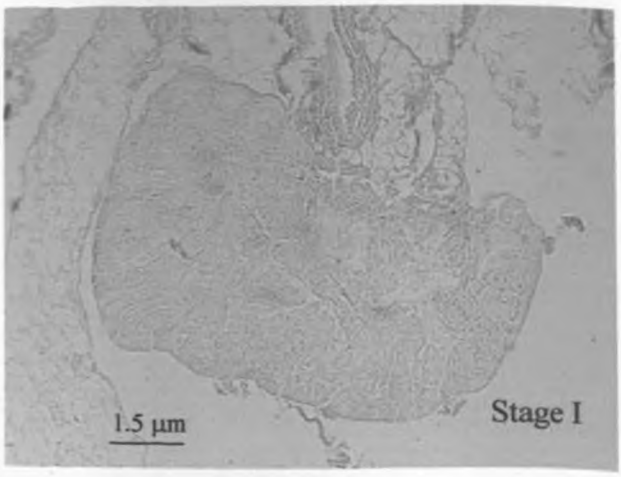
Figure 36: Percentage frequency distribution of maturity stages of female *V. buchanani* by class sizes.

6.3.3.3 Microscopic appearance of gonad maturity stages in Mugilidae

Microscopic descriptions of gonadal maturity stages in both *M. cephalus* and *V. buchanani* were similar and the six stage descriptions (Table 29) but with slight modification (Chan & Chua, 1980, El-Halfawy et al., 2007) were used. Plates 18 and 19 are the descriptions of male testis development.

Table 29: Microscopic appearances of the maturity stages of *M. cephalus* and *V. buchanani* gonads.

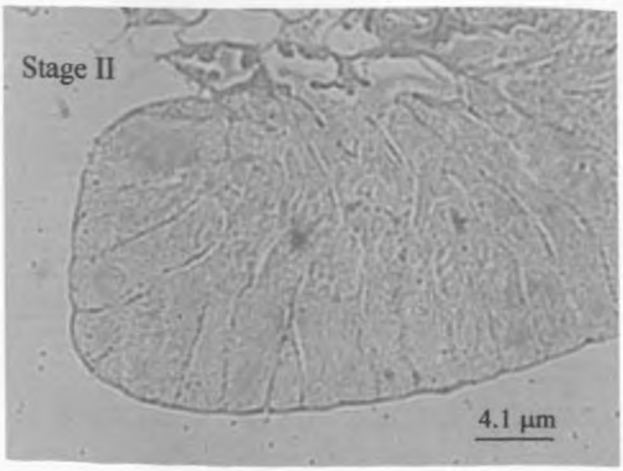
Maturity stages	Testis	Ovary
I. Immature/Virgin	Testis is kidney shaped, small in size and contains spermatogonia.	Well-spaced ovigerous folds oriented towards the centre of the ovary and oogonia occur in nests.
II. Developing virgin or recovering spent	Testis begins active spermatogenesis.	Spaces between the folds are smaller, primary oocytes at all stages present
III. Maturing	All developmental stages of spermatogonia in the testis observable.	Ovigerous folds fill the ovarian cavity and oocytes are larger in size.
V. Gravid	The testis is filled with well-developed sperms.	Presence of mature yolky stages predominates.
VI. Spent	Residual spermatozoa present	Irregular convoluted folds containing large atretic follicles present.



- Immature – testis < 1 mm in diameter,

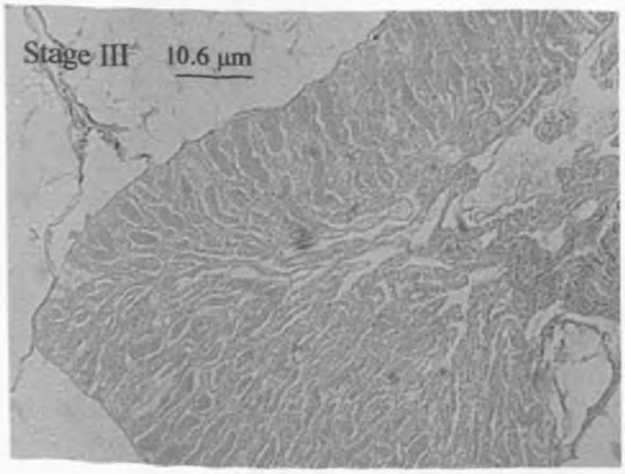
- Eosin and Haematoxylin not well taken by the tissue.

- The lobules are very tinny.



- Developing spermatogonia, primary and secondary spermatocytes.

- Lobules are distinct.

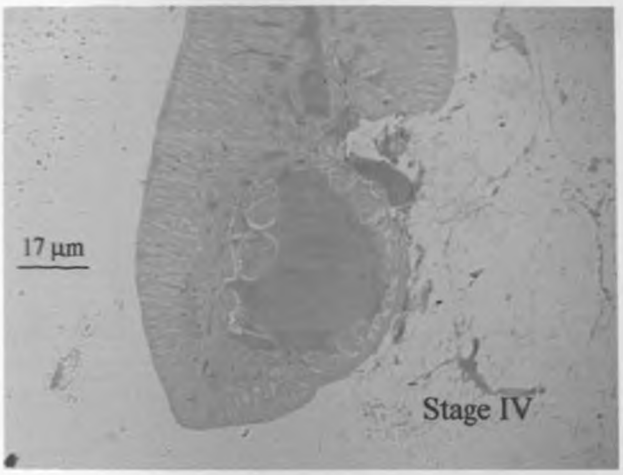


- Active testis showing development throughout the testis tissue.

- Pockets of spermatids visible in the lobules.

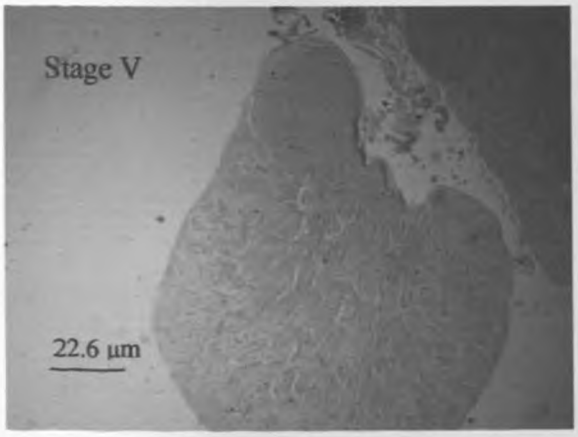
-Lobules increase in size.

Plate 18: Microscopic appearance of Mugilidae testis at stages I, II and III (Magnification ×100).



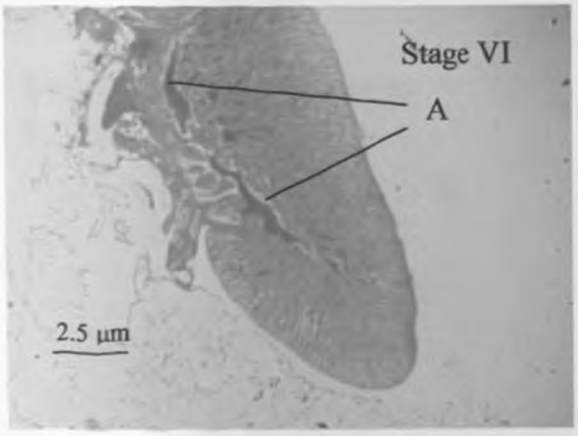
- Spermatids collect in sac-like structures.

- Some primary and secondary spermatocytes observed in large lobules.



- Entire testis filled with well-developed spermatids with majority in sac-like structure.

- Lobules are very large.

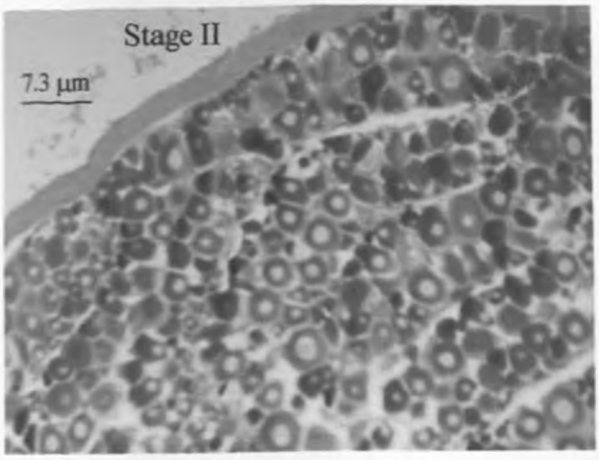


- Spent testis-showing remnants of spermatids within previous sac-like structures (A).

- Lobules are smaller and developing primary and secondary spermatocytes are visible

Plate 19: Microscopic appearance of Mugilidae testis at stages IV, V and VI (Magnification ×100).

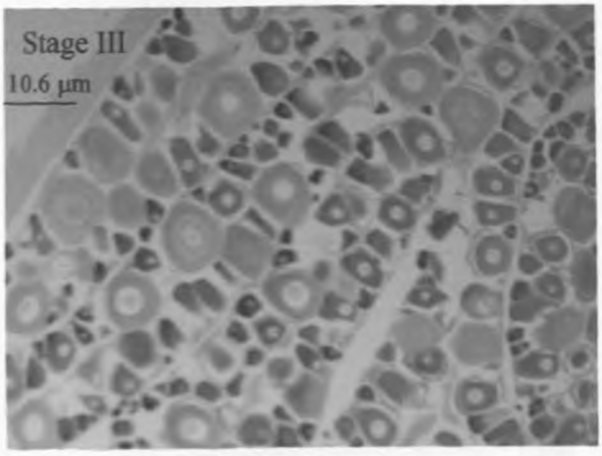
Plates 20 and 21 show microscopic appearance of female ovary development.



- Developing ovary with smaller spaces between folds.

- Oocytes increase in size.

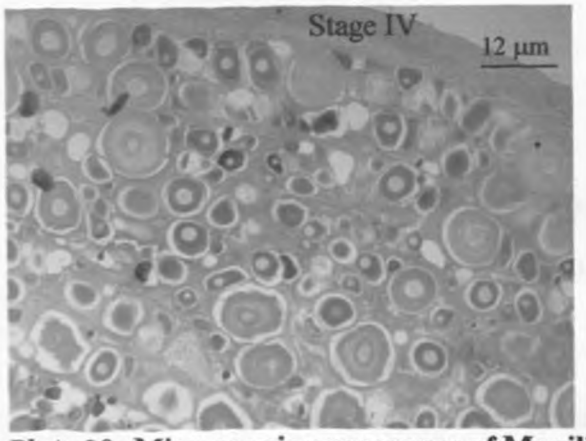
- The cytoplasm is large with visible granules.



- Ovary showing absence of spaces between folds.

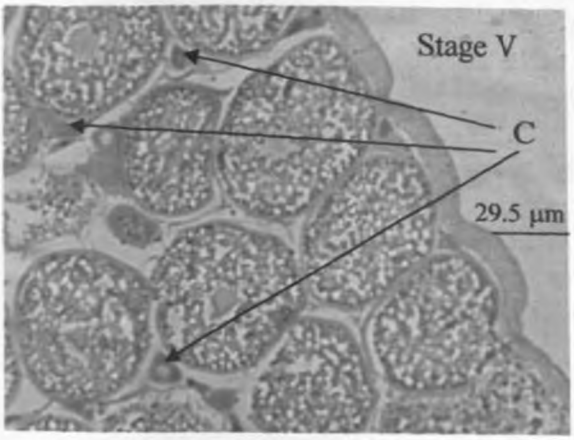
- ¾ of oocytes are large in size.

- Some primary and secondary oocytes clearly visible.



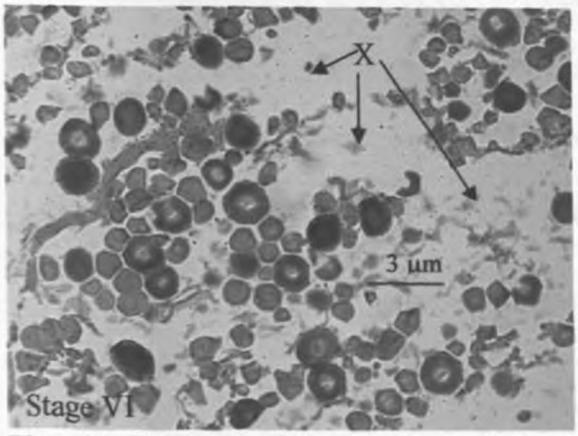
- Oocytes are large, evenly distributed and with distinct stages of development.

Plate 20: Microscopic appearance of Mugilidae ovaries at stages II, II and IV (Magnification ×100).



- Entire tissue filled with well-developed granulated large oocytes.

- Few primary oocytes visible (C).



– Spent ovary showing many oogonia and visibly large empty spaces (X).

Plate 21: Microscopic appearance of Mugilidae ovaries at stages V and VI (Magnification ×100).

6.3.4 Gonadosomatic index

6.3.4.1 Gonadosomatic index of *M. cephalus*

A total of 112 males and 129 female *M. cephalus* were used in analysing gonadosomatic index changes throughout the study period. This was because many of the specimens were juvenile males and females with very small gonads, which could not be weighed by the available type field balance. Figure 37 shows variation in mean monthly GSI

throughout the study period. During the first year of sampling, GSI was high (up to 0.7) in the NEM and low (up to 0.1) in SEM in both sexes but in the second year, it was higher in females than in males and very low (less than 0.05) in males between December, January, February and August. The pattern displayed proves that in Kilifi, *M. cephalus* reproduce throughout the year. The SE bars show great variation in months with very few specimens but in most months this variation was minimal. A regression analysis was carried out to establish the relationship between gonad wet-weights and total body wet-weights in both males and females (Figures 38 and 39). The regression coefficient of 0.2917 in males was low showing that the gonad is small in comparison with total body weight but was high in females (0.7431) because the gonads increase in size as they mature. The gradient of the slope in males is gentle indicating small difference between gonad weight and body weight but it is steep in females because at larger sizes, their ovaries contribute greatly to their body weight.

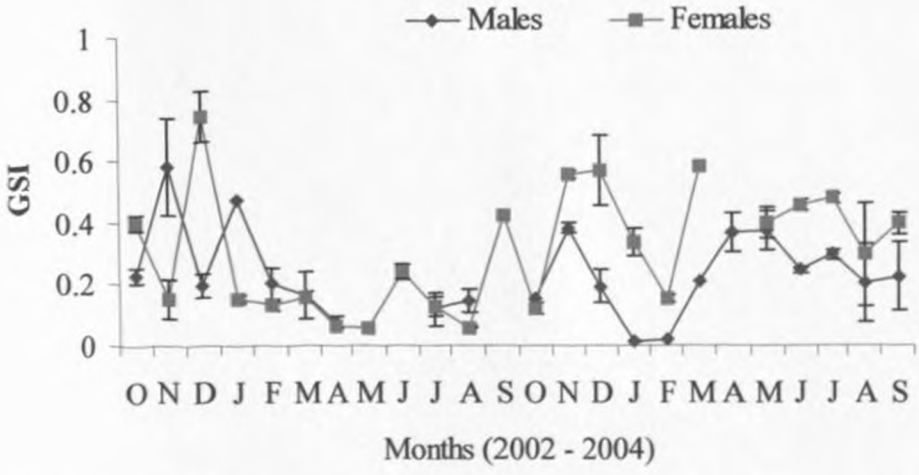


Figure 37: Mean monthly Gonadosomatic index variation in *M. cephalus*.

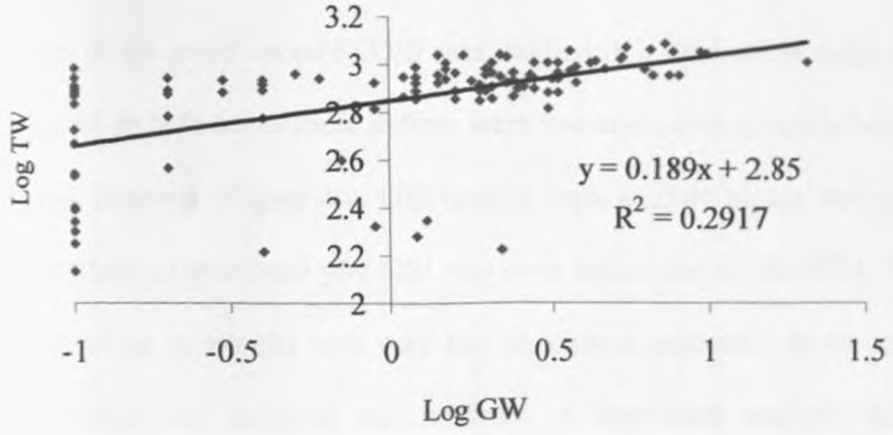


Figure 38: Relationship between Log gonad-wet weights to Log total body-wet weights in male *M. cephalus*.

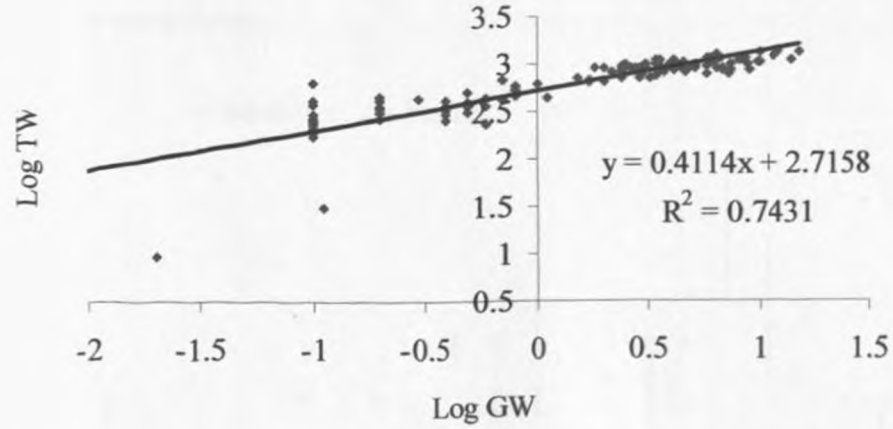


Figure 39: Relationship between Log gonad-wet weights to Log total body-wet weights in female *M. cephalus*.

6.3.4.2 Gonadosomatic index of *V. buchanani*

Changes in the mean monthly GSI was studied in a total of 54 male and 70 female *V. buchanani*. In both sexes these indices were low and no relationship between seasons and GSI was observed (Figure 40). GSI indices were slightly higher during the NEM in the first year but in the second year GSI was even higher during the SEM. The SE bars show great variation in months with very few specimens especially in the second year but in most months this variation was minimal. A regression analysis was carried out to establish the relationship between gonad weight and total body weight. The regression coefficient of 0.3702 in males (Figure 41) was low showing that the gonad is small in comparison with total body weight but in females (Figure 42) the relationship between gonad weight and total body weight gave a high value of 0.768 indicating that gonads are larger in heavier fishes.

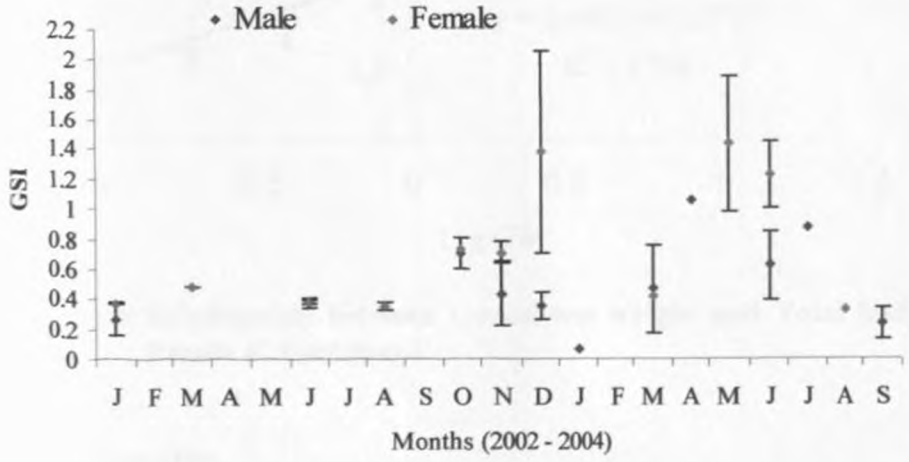


Figure 40: Mean monthly Gonadosomatic index variation in *V. buchanani*.

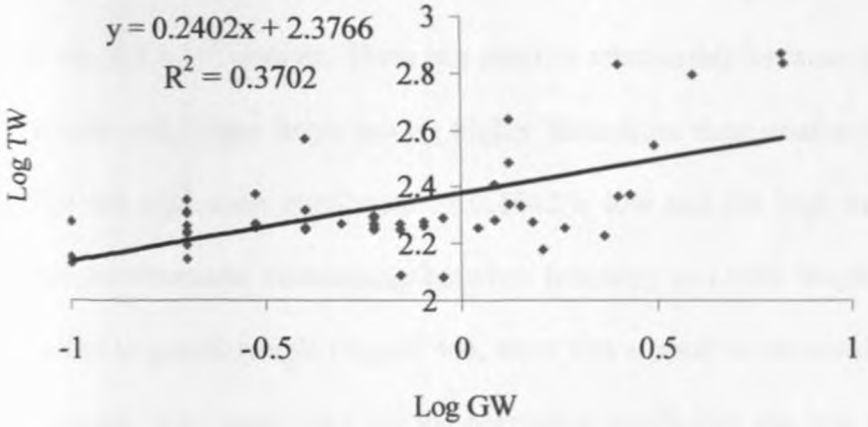


Figure 41: Relationship between gonad-wet weight and total body-wet weight in male *V. buchanani.*

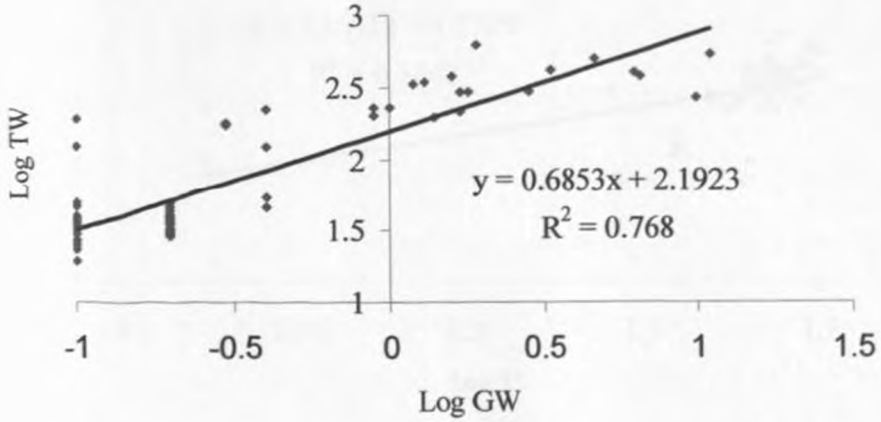


Figure 42: Relationship between Gonad-wet weight and Total body-wet weight in female *V. buchanani.*

6.3.5 Fecundity

6.3.5.1 Fecundity of *M. cephalus*

In *M. cephalus* the lowest fecundity was 11.4×10^4 oocytes in a female measuring 35 cm and weighing 441.8 g, although the smallest female sampled (10.1 cm TL) had 1.2×10^6 oocytes. The highest fecundity of 13.3×10^6 oocytes was recorded in a 45.5 cm TL fish

weighing 1085.4 g. The mean fecundity from 75 females ranging between 10.1 and 50.7 cm TL was 5.2×10^6 oocytes. There is a positive relationship between fecundity and total body length with larger fishes having higher fecundities than smaller fishes (Figure 43). However the regression coefficient of 0.1642 is low and the high exponent of 4.7709 indicates an allometric relationship between fecundity and total length. When fecundity was related to gonad weight (Figure 44), there was a positive relationship indicating that larger gonads carry many eggs but the regression coefficient was low (0.355). Again the high exponent of 6.4515 shows an allometric relationship between the two parameters.

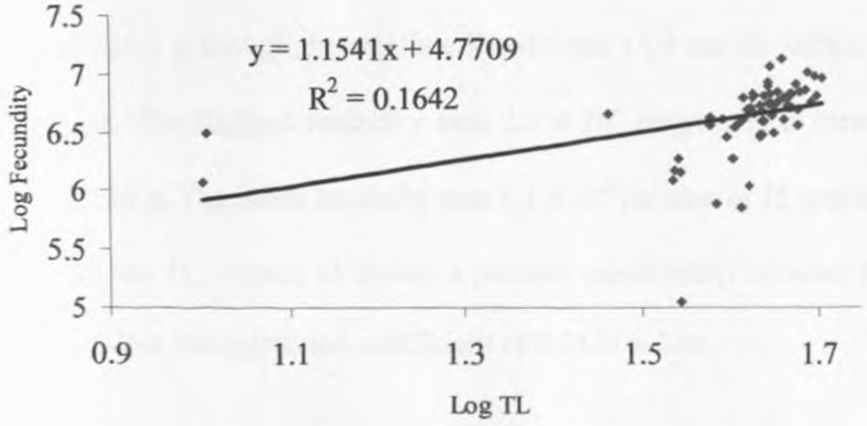


Figure 43: Relationship between fecundity and total body length in female *M. cephalus*.

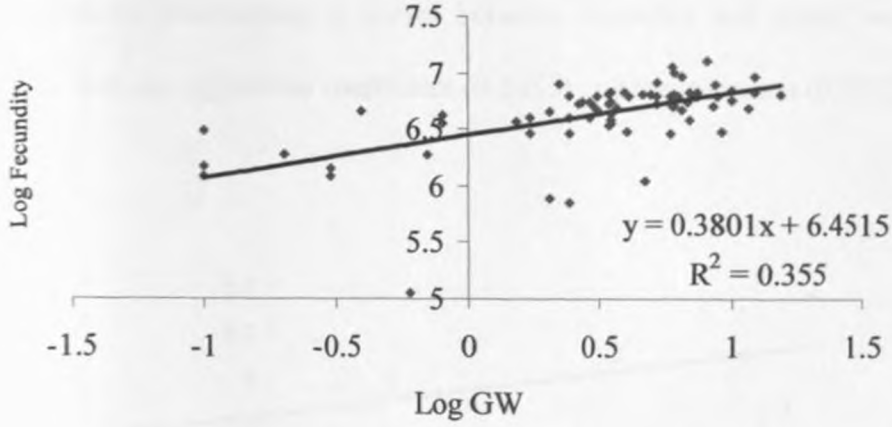


Figure 44: Relationship between fecundity and gonad weight in female *M. cephalus*.

6.3.5.2 Fecundity of *V. buchanani*

The lowest fecundity was 15×10^4 oocytes in a female measuring 22.1 cm TL and weighing 124.5 g though the smallest female was 15.9 cm TL with a fecundity of 92×10^4 oocytes. The highest fecundity was 2.5×10^6 oocytes in a female 39 cm TL and weighing 616 g. The mean fecundity was 1.1×10^6 oocytes in 15 specimens ranging from 15.9 to 39 cm TL. Figure 45 shows a positive relationship between fecundity and total body length but the regression coefficient of 0.2439 is low.

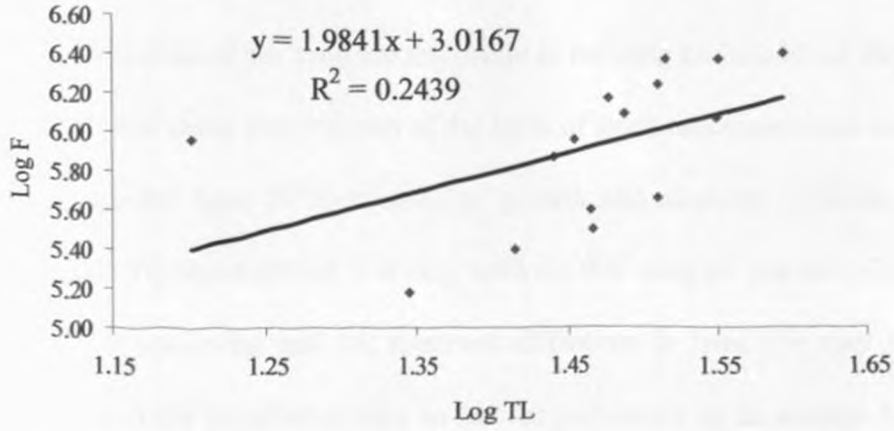


Figure 45: Relationship between total body length and fecundity in female *V. buchanani*.

An allometric relationship is shown between fecundity and gonad weight (Figure 46 below). Both the regression coefficient (0.1155) and the exponent (0.2952) are low.

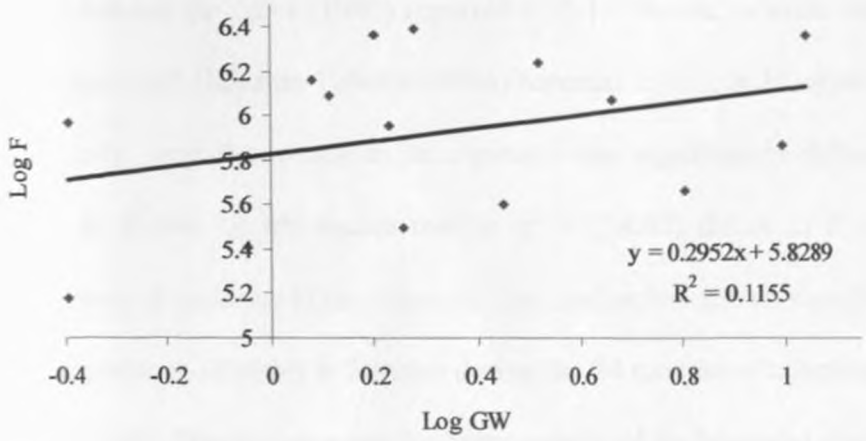


Figure 46: Relationship between fecundity and gonad weight in female *V. buchanani.*

6.4 Discussion

6.4.1 Sex ratio of Mugilidae

The determination of sex ratio are important in building knowledge of the general biology of an exploited stock forming part of the basis of stock assessment and males and females of some species have different rates of growth and mortality (Holden & Raitt, 1974). Bagenal (1957) reported that it is very unlikely that unequal number of the two sexes are produced at spawning and the apparent difference in later life may be due either to differences in the population such as habitat preference or in samples brought about by different behaviour to the fishing methods. Sex composition of any school of mullet is

unpredictable (Thomson, 1966). More females than males have been reported in *Liza ramada* (El-Halfawy et al., 2007), *Upeneus moluccensis* (Kaya et al., 1999), *Rhinomugil corsula* (Mortuza & Rahman, 2006), *Liza klunzingeri* (Abou-Seedo & Dadzie, 2004), *Liza subviridis* (Al-Daham & Wahab, 1990) and in *Agonostomus monticola* (Aiken, 1998). Silva and De Silva (1980) reported 0.95:1.0 female to male ratio in *M. cephalus* while Ibanez and Gallardo-Cabello (2004) reported 1:1.11 in *M. cephalus* from Mexico. In this study, overall sex ratio in *M. cephalus* was significantly different from 1:1 ratio (1:0.42) as shown by chi-square results (χ^2 = 124.65; d.f. = 1; $P < 0.05$). A test of homogeneity of variance of the binomial distribution has shown significant heterogeneity in the proportions of males to females during the 24 months of sampling (χ^2 = 75.173; d.f. = 23; $P < 0.05$). The variance test for homogeneity of the binomial distribution in relation to class size frequency distribution also showed a very significant evidence of heterogeneity (χ^2 = 99.54; d.f. = 9; $P < 0.05$). In *V. buchanani* overall sex ratios did not differ from 1:1 (χ^2 = 0.328; d.f. = 1; $P > 0.05$) however, binomial distribution of the sex ratio showed significant difference in the monthly samples (χ^2 = 50.49; d.f. = 23; $P < 0.05$). The variance test for homogeneity of the binomial distribution in relation to class size frequency showed significant heterogeneity (χ^2 = 27.53; d.f. = 4; $P < 0.05$). In *M. cephalus* and *V. buchanani*, the comparison between means sizes of males and females in different class sizes showed no significant differences between the sexes (t = 1.913, d.f. = 9, $P > 0.05$; t = -0.275, d.f. = 7, $P > 0.05$) respectively. Mortuza and Rahman (2006) never mentioned factors responsible for fluctuation of male and female ratio in population. In both species, bimodal class size distribution was observed which concurs with observations of Thurman II (1985) that bimodal populations are observed in

populations which reproduce continuously but with peaks during certain times. Fatima and Khan (1993) gave several suggestions for dominance of one sex in the catches such as: segregation of sexes through various periods of the year; size differences; gear selectivity related to sex morphology and physiological activity and differences either by natural or by artificial mortality. The observations in this study could have resulted from either schooling behaviour in feeding of juveniles or from selective fishing method during sampling as also observed by Abou-Seedo and Dadzie (2004). The results also agree with Kevesten (1942) in Thomson (1963) who observed that in any school sampled either sex could predominate, though there was no evidence of total segregation.

6.4.2 Minimum size at sexual maturity in Mugilidae

Wootton (1998) observed that the capacity of the population to support a fishery depends on its ability to meet the losses in the fishery by compensatory changes in survivorship, growth and fecundity which includes decreases in the age at maturity, increases in the size at maturity with correlated increase in fecundity. Size at sexual maturity is important in assessing the optimum age of first capture of a species; time and place of spawning are used to plan fishing tactics and the term is used to describe a fish which is spawning for the first time (Holden & Raitt, 1974). Size at sexual maturity in Mugilidae vary in different regions, Al- Daham and Wahab (1990) reported 137 and 142 mm TL for males and females respectively in *Liza subviridis* from an estuary in southern Iraq, Silva and De Silva (1980) observed 34.0 and 31.5 cm TL for males and females respectively in *Mugil cephalus* from Sri Lanka, Samad and Abbas (1999) gave the range at 145 – 149 mm and 138 – 141 mm TL in males and female *L. subviridis*, 139 – 142 mm and 131 – 136 mm

TL in males and female *L. carinata* and 145 – 147 mm and 141 –145 mm TL in males and female *Valamugil cunnesius* along Karachi coast. El-Halfawy et al., (2007) reported 18.6 cm and 19.8 cm TL in *L. ramada* in Lake Timsah, Suez canal. During this study, the minimum size at sexual maturity in *M. cephalus* was estimated to be 20.8 cm TL in males and 25.2 cm TL in females. In both sexes 100% sexual maturity was attained at class size 25.5 to 30.4 cm TL. In *V. buchanani* minimum size at sexual maturity was estimated at 20.7 cm TL in males and 24.4 cm TL in females. In males 100 % sexual maturity was attained at class size 35.5 to 40.4 cm TL and 30.5 to 35.4 cm TL in females. From the above observations, males mature before females as confirmed by Chua & Chan, 1980 and summarized by El-Halfawy et al., (2007). In all reported regions outside the tropics, Mugilidae mature at larger sizes but in the tropics, they mature at smaller sizes as noted by Thomson, (1963) in (Chan & Chua, 1980). In the widely studied *M. cephalus* the reported size ranges are from 23 to 40 cm in males and 24 to 41.5 cm in the female (Chan & Chua, 1980). Abou-Seedo and Dadzie (2004) suggested that maturation of males at small sizes compared to females was to ensure that fish have more accommodative capacity for increased egg production. The findings of this study concur with observations of other workers as reported by Chan and Chua, (1980).

6.4.3 Maturity stages of ovary in Mugilidae

6.4.3.1 Macroscopic development in gonads of Mugilidae

Several researchers have identified and classified Mugilidae gonads from different species and areas e.g., five stages in both testes and ovaries of *Rhinomugil corsula, L. ramada, L. aurata* and *Chelon labrosus* (Fatima & Khan, 1993, Moura & Gordo, 2000);

six maturity stages in testes and seven in ovaries of *Liza subviridis* (Chua and Chan, 1980); seven stages in gonads of *Liza Klunzingeri* and *M. cephalus* respectively, (Abou-Seedo & Dadzie, 2004, Ibanez & Gallardo-Cabello, 2004) and eight stages in gonads of *Liza aurata* (Hotos et al., 2000). During this study, five macroscopic and six microscopic stages were classified according to existing earlier descriptions in both *M. cephalus* and *V. buchanani.* The high percentages of stages I and II throughout the two years of study, proved that most Mugilidae in this area are juveniles, indicating continuous breeding. Stage I was obtained in the male and female *M. cephalus* in class sizes 25.4 cm and 20.4 cm, respectively. The spawning peak period appears to be between October to December and again June to July when ovaries at maturity stage IV are in the population after which they move out to spawning grounds offshore (El-Halfawy et al., 2007). Chan and Chua (1980) reported that macroscopic characterization is non arbitrary but provides a useful and convenient method of determining the maturity stage of fish and is the reason the method was used during this study.

6.4.3.2 Microscopic development in gonads of Mugilidae

Most researchers have used histological methods to identify maturity stages in Mugilidae which are isochronal spawners (Chan & Chua, 1980, El-Halfawy et al., 2007, McDonough et al., 2003). Robb (1982) observed that oocyte development is a continuous process until after spawning when the first batch of eggs are released after which there is no initiation of new development but only maturation of those oocytes already containing yolk granules. During this study, all microscopic stages identified were present but the sample size was few or absent in some months, hence could not be related to seasons or

different class sizes. In *Liza klunzingeri*, Abou-Seedo and Dadzie (2004) reported synchronous oocyte development with a single spawning which they related to unstable nature of the habitat but the Mugilidae in tropical waters are multiple spawners because of ontogeny of the species.

6.4.4 Gonadosomatic indices of Mugilidae (GSI)

Mugilidae migrate to sea to spawn but no evidence exists that spawning occurs in a specific location based on known characteristics of currents, depth and temperature (Hickling, 1970, Hotos et al., 2000, Oren, 1975), GSI has been used to establish spawning period in Mugilidae. Hotos et al., (2000) established the reproductive period of *Liza aurata* in Klisova lagoon to be from August through to November when GSI is high while Hickling (1970) stated that *Chelon labrosus* had full gonads between January to April at the Isles of Scilly. Grant and Spain (1975) reported high GSI in *M. cephalus* between May and August in North Queensland inshore waters. Variation in GSI was clearly observed in males and females of *M. cephalus* at Kilifi, which possibly spawns between November to February and a smaller peak between June and July but during the second year, GSI was above 0.2 throughout indicating continuous spawning. *V. buchanani* had low GSI values in the first year and extremely higher values in the second year during NEM and similarly a small peak during June and July also indicating continuous spawning at Kilifi. It can be concluded that as gonadal maturity had a similar cycle and they become much heavier contributing significantly to body wet-weight. These findings concur with those of Abou-Seedo and Dadzie (2004) that Mugilidae

environment is much stable in the tropics hence allowing continuous spawning hence supply of fry for aquaculture farmers from the Kilifi creek.

6.4.5 Fecundity in Mugilidae

Fecundity has been used in stock assessment studies, in egg and larval survival studies, estimates of the size of a and for stock discrimination stock (Holden & Raitt, 1974). Fecundity in Mugilidae from Kilifi correlated highly with total length and gonad weight as observed in *M. cephalus* from South Carolina estuaries (McDonough et al., 2003). The total counts used during this study gave very high oocyte counts ranging from 11.4×10^4 to 13.3×10^6 oocytes in *M. cephalus* and from 92×10^4 to 2.5×10^6 oocytes in *V. buchanani*. Some researchers chose oocytes of particular size for counting, therefore reported much lower fecundity (McDonough et al., 2003). Bagenal (1978) reported that fish at higher latitudes produce fewer and larger eggs compared to tropical species which produce numerous and small oocytes. Baumar and Julian (2000) reported estimates between 19×10^4 to 110×10^4 oocytes in *M. curema* while Hotos et al., (2000) reported absolute fecundity between 8×10^4 and 1.41×10^6 in *L. aurata* in the Klisova lagoon. Grant and Spain (1975) reported fecundity ranges between 1.572×10^6 and 4.74×10^6 in Australia, which is still lower than observed during this study. Hickling (1970) observed that fecundity varied greatly in Mugilidae species in the world but is higher in the tropics as confirmed in the present study. A positive correlation was also observed between fecundity and both total length and gonad weight as reported by Alvarez-Lajonchere (1982). From fecundity studies, the two species can easily be discriminated and M.

cephalus with high fecundities can be cultured and supply fry for stocking in mariculture ventures in Kenya.

From this study, sex ratios in *M. cephalus* were significantly different from 1:1 ratio but were 1:1 in *V. buchanani* and could have resulted from schooling behaviour in juveniles or fishing methods during sampling. The Minimum size at sexual maturity in *M. cephalus* was estimated to be at 20.8 cm TL in males and 25.5 cm TL in females while in *V. buchanani* 20.7 cm TL in males and 24.4 cm TL in females. Five maturity stages were classified macroscopically and six stages classified microscopically but were similar in both *M. cephalus* and *V. buchanani.* The spawning peak period appears to be between October and December (NEM) and again between June and July (SEM) when ovaries at maturity stage IV are in the population after which they move out to spawning grounds offshore. Mugilidae in tropical waters are multiple spawners because of stability of their habitat. Variation in GSI observed in males and females of *M. cephalus* and *V. buchanani* indicating continuous spawning concurred with maturity stages classification. Fecundity varied greatly in Mugilidae species in the world but is higher in the tropics.

CHAPTER SEVEN

7.0 General discussion, conclusions and recommendations

7.1 General discussion and conclusions

Estuaries are highly productive with respect to fishery resources and that fisheries productivity and yields are related to high primary production that is supported by high nutrient inputs. Aquaculture production of estuarine dependent species has added significant supplements to wild fishery harvests. Mullet are estuarine dependent and their catches have been fluctuating in Kenya as shown in Table 1. In Thailand, fishery in estuarine areas includes both capture and culture fisheries but in Kenya they are exclusively for capture fisheries. There are many estuaries in Kenya and Kilifi creek is among the best where culture can be tried. The crustacean resources were mainly prawns and crabs. Mugilidae are among the 38 fin fish families identified at Kilifi. The Mugilidae species obtained at Kilifi were *Mugil cephalus*, *Valamugil buchanani*, *Liza vaigiensis* and *Myxus capensis*. The species with the highest numbers in the catch during the study period was *M. cephalus* followed by *V. buchanani*. The species distribution of *M. cephalus* and *V. buchanani* showed no specific pattern related to seasons and this indicated their availability throughout the year. The mean variations in the physico-chemical parameter analysis show that the creek is pristine (Chapter 2). This creek supports a diversity of fishery organisms as shown by the diversity indices used.

From the class size distribution (Figure 13), the major users of this creek are mainly juveniles (5.5 – 15.4 cm TL). The Mugilidae had highly significant regression coefficient indicating that as length increases, weight also increases and this confirms growth within the area. In *M. cephalus* females, the value of asymptotic length L_∞ (51.48 cm) is higher

than in males (48.3 cm). In *V. buchanani* males, the calculated value of asymptotic length L_∞ (42.88 cm) is higher than in females (41.75 cm). This also confirms the largest possible sizes that can be obtained in the area. In both species, low variations in the monthly relative condition factors between the sexes as well as during the different seasons were observed, although the lowest relative condition factor values were high indicating their 'well being' within the creek. Fumbini site was used by all class sizes and can be confirmed to be an area for the establishment of aquaculture ponds to culture Mugilidae in future. Studies in class size distribution confirm the availability of fry for stocking in aquaculture ponds.

In *M. cephalus*, the overall sex ratio was 1: 0.42 males to females, a significant deviation from the expected 1:1 while in *V. buchanani,* it did not differ significantly from the expected 1:1. The minimum size at sexual maturity was observed at 20.8 cm in males and 25.2 cm TL in females in *M. cephalus* and was 20.7 cm in males and 24.4 cm TL in females in *V. buchanani*. All male and female gonads obtained could be macroscopically grouped above stage I indicating that *M. cephalus* and *V. buchanani* are continuous breeders in Kilifi. Fecundity was also very high especially in *M. cephalus*. In both species, mean monthly GSI was high again showing that the creek is ideal for the culture of Mugilidae.

In conclusion, this study has confirmed that the different habitats within the creek contribute to variation in composition and distribution of fishery organisms and the assemblage of fishery organisms at Kilifi is not similar to those estuaries within the Indo-Pacific region. The most common Mugilidae species were *M. cephalus* and *V. buchanani*,

which occurred in the catch and their abundance was high during the North East Monsoons than during the South East Monsoons. Sex ratios in *M. cephalus* was significantly different from 1:1 ratio but were 1:1 in *V. buchanani* and could have resulted from schooling behaviour in juveniles or fishing methods during sampling. Variation in GSI was observed in males and females of both *M. cephalus* and *V. buchanani* indicating continuous spawning. Fecundity varied greatly in Mugilidae species in the world but is higher in Kilifi, which lies in the tropics. Mugilidae in tropical waters are multiple spawners because of stability of their habitat. The spawning peak period of Mugilidae in Kilifi appears to be between October and December and again between June and July when ovaries at maturity stage IV are in the population after which they move out to spawning grounds offshore. Sites such as Fumbini and Kidundu require conservation by fisheries managers because of their utilization by most fishery organisms and as important sites for Mugilidae survival within the creek.

7.2 Recommendations

In Kenya, aquaculture accounts for a very small fraction of the national fish production having contributed not more than 1.0 per cent of the national fish production at any one given year in the past. Aquaculture, apart from supplying the much-needed protein, has proved to be a source of self-employment, income generation and therefore contributing towards the government overall goal of poverty reduction. There is need therefore to give this sector more prominence in the national plans and resource allocation (Annual Report, 2005). Both fresh water and mariculture are practised but most aquaculture production is mainly fresh water. Fresh water culture has developed facilities that include training and demonstration centres, research centres, fish seed production centres and extension and

information material. Mariculture is practised at the coast on a very small scale and culture organisms include Prawns, oysters and seaweeds. There are no developed facilities for fin fish culture. Baobab fish farm (an intensive fish farm) was the only major fish culture enterprise in the coastal province but it concentrated on fresh water fish and has since collapsed. There has not been any attempt to culture marine fish and it is with this background that this study was initiated.

Kilifi creek is pristine and is easily accessible by road being only 50 km from Mombasa city. Before establishing an aquaculture venture within the creek, further research work is required to study the ecological relationships because the creek has a high fin fish diversity. Further research is also required to establish the food of Mugilidae as a culture organism and how to enhance its continuous availability with the creek. Suggestion should also be made to future developers against polluting the creek by biologists to maintain the ecological balance.

8.0 References

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9.0 ANNEX

Annex 1: Kilifi fin fish identification

	Order		Family		Species
1	Perciformes	1	Acanthuridae	1	*Acanthurus xanthopterus*
	Perciformes		Acanthuridae	2	*Naso brevirostris*
	Perciformes	2	Ambassidae	3	*Ambassis natalensis*
2	Siluriformes	3	Ariidae	4	*Ariodes dussumieri*
3	Pleuronectiformes	4	Bothidae	5	*Pseudorhombus arsius*
	Perciformes	5	Carangidae	6	*Caranx papuensis*
	Perciformes		Carangidae	7	*Ulua mentalis*
	Perciformes		Carangidae	8	*Scomberoides tol*
	Perciformes		Carangidae	9	*Decapterus kurroides*
	Perciformes		Carangidae	10	*Alectis indicus*
	Perciformes		Carangidae	11	*Carangoides oblongus*
	Perciformes		Carangidae	12	*Gnathanodon speciosus*
	Perciformes		Carangidae	13	*Trachinotus blochii*
	Perciformes	6	Chaetodontidae	14	*Heniochus acuminatus*
	Perciformes		Chaetodontidae	15	*Chaetodon auriga*
4	Gonorhynchiformes	7	Chanidae	16	*Chanos chanos*
5	Clupeiformes	8	Chirocentridae	17	*Chirocentrus nudus*
	Clupeiformes	9	Clupeidae	18	*Pellona ditchella*
	Clupeiformes		Clupeidae	19	*Sardinella gibbosa*
6	Sqatiniformes	10	Dasyatidae	20	*Himantura gerrardi*
	Perciformes	11	Drepanidae	21	*Drepane longimanus*
7	Elopiformes	12	Elopidae	22	*Elops machnata*
	Clupeiformes	13	Engraulidae	23	*Thryssa vitrirostris*
	Clupeiformes		Engraulidae	24	*Stolephorus punctifer*
	Perciformes	14	Ephippidae	25	*Tripterodon orbis*
	Perciformes		Ephippidae	26	*Platax orbicularis*
	Perciformes	15	Gerreidae	27	*Gerres filamentosus*

	Perciformes		Gerreidae	28 *Gerres oyena*
				Oxyurichthys
	Perciformes	16	Gobiidae	29 *ophthalmonema*
	Perciformes	17	Haemulidae	30 *Plectorhynchus gaterinus*
	Perciformes		Haemulidae	31 *Pomadasys kaakan*
	Perciformes		Haemulidae	32 *Plectorhinchus playfairi*
	Perciformes		Haemulidae	33 *Pomadasys multimaculatum*
	Perciformes	18	Holocentridae	34 *Ostichthys kaianus*
	Perciformes	19	Leiognathidae	35 *Leiognathus equula*
	Perciformes		Leiognathidae	36 *Leiognathus leuciscus*
	Perciformes		Leiognathidae	37 *Secutor insidiator*
	Perciformes		Leiognathidae	38 *Gazza minuta*
	Perciformes		Leiognathidae	39 *Leiognathus elongatus*
	Perciformes	20	Lethrinidae	40 Lethrinidae
	Perciformes	21	Lobotidae	41 *Lobotes surinamensis*
	Perciformes	22	Lutjanidae	42 Lutjanidae
	Perciformes	23	Monodactylidae	43 *Monodactylus argentia*
	Perciformes	24	Mugilidae	44 *Mugil cephalus*
	Perciformes		Mugilidae	45 *Valamugil buchanani*
	Perciformes		Mugilidae	46 *Liza vaigiensis*
	Perciformes		Mugilidae	47 *Myxus capensis*
	Perciformes	25	Mullidae	48 *Upeneus vittatus*
8	Anguilliformes	26	Muraenidae	49 *Thyrsoidea macrura*
	Perciformes	27	Polynemidae	50 *Polydactylus sextarius*
	Perciformes	28	Scaridae	51 Scaridae
	Perciformes	29	Sciaenidae	52 *Johnius amblycephalus*
	Perciformes	30	Scombridae	53 *Rastreliger kanagurta*
	Perciformes	31	Serranidae	54 *Epinephelus*
	Perciformes	32	Siganidae	55 *Siganus sutor*
	Perciformes	33	Sillaginidae	56 *Sillago sihama*

	Perciformes	34	Sparidae	57 *Sarpa salpa*
	Perciformes		Sparidae	58 *Acanthopagrus berda*
	Perciformes	35	Sphyraenidae	59 *Sphyraena baraccuda*
9	Aulopiformes	36	Synodontidae	60 *Saurida gracilis*
	Perciformes	37	Teraponidae	61 *Terapon jarbua*
	Perciformes		Teraponidae	62 *Terapon theraps*
	Perciformes	38	Trichiuridae	63 *Trichiurus lepturus*

10.0 List of acronyms

	Acronym	Meaning
1.	BOD	Biological Oxygen Demand
2	Cumm.	Cummulative
3.	FAO	Food and Agricultural Organization
4.	GPS	Geographical Positioning System
5.	GSI	Gonadosomatic index
6.	ppm	Parts per million
7.	TL	Total length
8.	UV	Ultra violet
9.	VBGE	Von Batalanffy Growth Equation