Fish Community Structure of a Mangrove Creek, Tudor, Kenya

By

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DECLARATIONS

STUDENT'S DECLARATION

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

Signature………………………. Date………………….

Wainaina Mirriam Wambui

[NRM/PGFI/05/06]

SUPERVISORS' DECLARATION

This thesis has been submitted for examination with our approval as university supervisors:

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DEDICATION

I dedicate this work to my parents, brothers and sister. May God bless you all.

ABSTRACT

Tudor Creek is one of the largest mangrove tidal creeks in coastal Kenya that supports important artisanal fisheries. Despite the importance of estuarine habitats like creeks in the life cycle of fishes, there is little information on the ichthyofauna of mangrove tidal creeks in most of the Western Indian Ocean (WIO) region. This study therefore aimed at describing the fish assemblage structure within the Tudor Creek in coastal Kenya. The fish were sampled at four stations ranging from the mouth of the creek upto approximately 10 km inside the creek using a beach seine. Sampling was carried out for 10 months between October 2007 and July 2008 during the northeast (NEM) and southeast (SEM) monsoon season. In total, 92 species belonging to 45 families were sampled within the creek. There was seasonal within-creek variability in fish species abundance and diversity. Overall, the mean catch rates (individuals m^{-2}) was highest during the SEM season (0.336 ± 0.084) compared to NEM season (0.229 ± 0.044). The NEM season had significantly more species than the SEM season (82 and 54 species, respectively) (χ^2=317.760, $P<0.0001$). Fish community structure estimated by the ecological diversity indices showed variations between stations and seasons. The famil y Gobiidae contributed the highest to the total catch and species abundance in the creek (18.9%, 12 species, respectively). The transient (e.g. Carangidae, Fistularidae and Leiognathidae) and estuarine dependent fish (e.g. Lutjanidae, Gerreidae and Teraponidae) formed the main bio-ecological groups in the creek. The feeding groups in the creek were dominated by zoobenthivores (32.66%) while, herbivores had the lowest numerical abundance (<6%). The dominance of immature fishes in the samples indicated that Tudor Creek is an important nursery ground for many species. Fish assemblages in the creek formed a distinct seasonal structure that varied between stations suggesting the influence of habitat on fish distribution within the creek. The results of this study will contribute to scientific management of fisheries within the creek in the face of human pressure and climate change effects and will also add to the database on estuarine fishes from the WIO.

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CHAPTER 1

1.0 INTRODUCTION

Intertidal shallow aquatic environments such as mangroves, tidal creeks and tidal flats offer conditions which favor the presence of large assemblages of fish (Rozas & Zimmerman, 2000; Vidy, 2000). These habitats are important as nursery grounds, foraging areas and predation refugia for numerous fish and invertebrate communities (Adams, 1976; Heck and Thoman, 1984; Orth *et al*., 1984), and provide important benefits for commercial, subsistence and recreational fisheries (Bell & Pollard, 1989). Fish community structures of mangrove lined creeks are dominated by juveniles of marine species and contain few resident species or occasional visitors. Tidal creeks show a wide temporal variation in their species composition due to the environmental dynamics and migratory nature of most of the fish species (Rozas & Zimmerman, 2000). Even though these creeks perform important ecological functions, little is known about the dynamics of utilization of these habitats by fishes (Ong, 1982).

Tropical tidal creeks are often lined by stands of mangrove trees, frequently support extensive seagrass beds and macroalgal flats and form important link in the back reef complex (Layman *et al.,* 2004). Mangrove lined creeks are the dominant shallow intertidal habitats in subtropical and tropical estuarine systems and are an important habitat for post larval and juvenile fish (Robertson & Duke, 1987, Rooker & Dennis, 1991; Laegdsgaard & Johnson, 1995, 2001). It is widely believed that back-reef habitats such as mangrove creeks serve as "nursery areas" (Odum & Heald, 1972), traditionally defined as areas that have high juvenile densities because juveniles inhabiting these areas face lower predation pressure or higher growth rates than in other habitats (Odum & Heald, 1972). Mangrove wetlands provide estuarine residents, marine and freshwater transient species with essential food resources and shelter (Sheaves & Molony, 2000; Laegdsgaard and Johnson, 2001). Back-reef habitats, including tidal creeks, are also known to serve as important habitats for numerous commercially and ecologically important fisheries (Layman *et al.,* 2004).

Biological communities vary in time and space as a result of differences in habitat structure (Gorman & Karr, 1978), resource availability and biogeographical patterns (Jackson & Harvey, 1989; Tonn *et al*., 1990; Matthews & Robison, 1998) among other factors. Among the physico-chemical factors; water salinity, temperature, turbidity, depth, current strength and dissolved oxygen, have been identified as determinants of estuarine fish ecology (Whitefied 1988; Albaret, 1999). The influence of these factors on estuarine fish assemblages are variable between and within-latitudes (Albaret, 1999)

In Kenya, work on fish communities of tidal creeks is limited to studies done in Gazi Bay (De Troch *et al*., 1996; Kimani *et al*., 1996), Tudor Creek (Little *et al.,*1988) and in Mida Creek (Mwatha & Olembo, 1998). Tudor Creek is one of the largest creeks in Kenya and forms an important site for local artisanal fisheries (Wakwabi, 1988). Studies on fish communities of the creek are limited to that of Little *et al.,* (1988). However, the fish community structure of the creek is likely to have changed more than twenty years since the study by Little *et al.,* (1988) due to effects of fishing, pollution and climate change. This study therefore aimed at describing the fish community structure within Tudor

Creek and generate useful information for fisheries management, conservation and future monitoring.

1.1 Problem Statement

Estuarine ecosystems are facing an ever-increasing pressure and demand from human growth and development with large-scale destruction and modification of habitats (Engel & Summers*,* 1999; Perez-Ruzafa *et al.*, 2006). Human activities (e.g. pollution, overfishing and non-selective harvesting of mangroves) both in the catchment and in the adjacent marine environment increasingly threaten estuarine biodiversity. Additionally, climate change threatens the general biodiversity of marine and coastal habitats including tidal creeks (Robertson & Duke, 1987; Laegdsgaard & Johnson, 1995). In order to ascertain the importance of mangrove creeks in the overall ecology of Kenyan coastal estuaries, and in particular the conservation importance of these habitats to fishes, an understanding of their biodiversity and variability in community structure is needed.

Despite the importance of estuarine habitats like creeks in the life cycle of fishes, there is little information on the ichthyofauna of mangrove tidal creeks in the Western Indian Ocean (WIO) region (Little *et al.,* 1988, Kimani *et al* 1996; Barletta, 1999). Magrove lined creeks are important nursery grounds for commercially important species and are increasingly under anthropogenic influence, however, detailed studies of the fish communities associated with these habitats remain limited (Ong, 1982). In coastal Kenya, studies on fish communities of mangrove lined creeks are scarce and far in-between (e.g.

Little *et al*., 1988), however, these systems support important fisheries and provide useful connectivity to the seagrass-coral reef ecotones.

This study therefore aimed to examine the spatial and temporal variations in fish assemblages along Tudor Creek, one of the largest creeks in Kenya. The data generated was compared with historical data on the creek's fish community in order to determine changes in biodiversity within the creek. These data are necessary for developing management and conservation strategies for Tudor and other creeks on the Kenyan coast.

1.2 OBJECTIVES

1.2.1 General Objective

The general objective of this study was to describe the fish species assemblages and their distribution along Tudor Creek, one of the largest creeks in coastal Kenya.

1.2.2 Specific Objectives

The specific objectives of this study were:

- To determine the spatial and seasonal variation in fish species abundance within Tudor Creek.
- To determine the seasonal variability in fish assemblage structure (diversities, species composition, size and trophic composition) within Tudor Creek.
- To relate the observed fish assemblage structure with physico-chemical variables within the creek.

1.3 HYPOTHESES

This study was guided by the following statistical hypotheses:

H_0: There is no spatial and temporal variation in fish species richness and abundance within the creek.

H_0: There is no temporal and spatial variability in fish assemblage structure within the creek

H_0: There is no relationship between fish assemblage structure and physico-chemical variables along the creek.

CHAPTER 2

2.0 LITERATURE REVIEW

Tropical estuarine habitats differ in several respects from those of higher latitudes. While tropical marine ecosystems have been noted for minor seasonal changes or aseasonality (Sournia, 1969; Blackburn *et al*., 1970; Steven & Glombitze, 1972), temperate estuarine habitats usually show a more marked seasonality in some of the physico-chemical parameters mainly temperature and salinity (Rodriguez, 1975). Mangroves are the dominant vegetation and one of the most characteristic components of tropical and subtropical estuaries. The high ichthyo-diversity in creeks has been to a large extent due to heterogeneous and productive systems of mangroves (Harling, 1980; Valentine & Heck, 1999; Gell & Whittington, 2002) and sea grasses in these habitats. These habitats act as an important nursery areas for fishes (Chamberlain & Barnhart, 1993; Knieb, 1997). The fish assemblages of creek habitats have been found to share some similarities in species composition, however, the mangrove lined creeks have been demonstrated to contain greater species richness (Robertson & Duke, 1987; Thayer *et al.,* 1987; Laegdsgaard & Johnson, 1995). Therefore, one might assume that ecological habitats like seagrass beds that are close to mangrove creeks may support in greater fish abundance and diversity due to ecological connectivity.

Temperate estuaries are characterized by seasonal use by a few dominant transitory species (Rogers *et al.,* 1984). There are only a few fish species that are estuarine residents (Robertson & Duke, 1987). The majority of residents are small sized species such as gobies, siganids, ambassids, atherinids, stolephorids and some clupeids (Robertson & Duke, 1987). The proportions of resident species are relatively low: for example 11.6% are reported in St Lucia (Wallace & Van der Elst, 1975) and 20.6% in South Africa (Robertson & Duke, 1987). When coral reefs are adjacent to estuaries, they may be an important source of marine migrants (Spach *et al.,* 2004). Migration between marine and estuarine ecosystems has ecological (biodiversity interactions) and commercial (livelihood) significance (Nagelkerken *et al.,* 2000; Nagelkerken & van der Velde, 2002; Cocheret de la Morinière *et al.,* 2002).

As a result of the horizontal and vertical oscillations of temperature and salinity, estuarine biotopes are inhabited exclusively by highly tolerant eurythermal species. For some of these species, estuaries are essential habitats while for others they represent one phase in the species inshore-offshore migratory life pattern (Tzeng & Wang, 1992). In their pristine state, estuaries are notably poorer in number of species than surrounding marine and freshwater areas but richer in number of individuals per species (Allen, 1982). In terms of productivity, estuaries provide an optimal feeding and nursery habitat for a number of fish species of the upper infralittoral zone (Tzeng & Wang, 1992).

Numerous studies have concluded that fish (especially during ontogenetic changes) can move between different marine habitats that are located close to one another (Parrish, 1989; Rooker & Dennis, 1991; Robertson & Blaber, 1992; Nagelkerken *et al.,* 2000). Most of these studies concluded that estuarine habitats play an important role for coral reef fishes. A study in the Caribbean found that the species richness of juvenile coral fish was greater in habitats near mangrove than habitats that did not contain mangroves (Nagelkerken *et al.,* 2001). The authors attributed this to the coral fish utilizing such habitat as nursery grounds. Other studies on juvenile coral reef fish (Nagelkerken *et al.,*

2000) have indicated that individuals of some species shelter in the mangrove zones found in the back-reef habitats during the day and forage in the seagrass beds at night.

Fish fauna of coral reefs, mangrove creeks and seagrass beds overlap a great deal in composition, the greatest species diversity being associated with coral reefs (Johannes, 1978). Some of the most comprehensive studies that compare mangrove fish fauna with fish fauna in adjacent ecosystems include that of Blabber *et al.,* (1989) and Robertson & Duke (1987) in Australia. Coral-reef fish species have been poorly represented in seagrass habitats including estuarine habitats (Russell, 1983; Amesbury, 1988; Coles *et al.,* 1993), but higher proportions of reef-associated fish species have been collected from lagoonal and mangrove stations in Kenya (Little *et al.* 1988). Most studies of estuarine fish communities in the Western Indian Ocean (WIO), including those of Beckley (1984) in the Sandays estuary, Marias & Baird (1980) in the Swartkops estuary, Kok & Whitfield (1986) in the Swartvlei estuary, and Day (1974) in the Mormmbene estuary, are from temperate South Africa. Gell & Whittington (2002) report that ichthyodiversity in Quirimba (northern Mozambique) varies significantly among pure seagrass beds to coral reefs and mangroves lined creeks.

In Kenya, some work has been done in Gazi Bay (De Troch *et al*., 1996; Kimani *et al*., 1996) and Mida Creek (Mwatha & Olembo, 1998). De Troch *et al*., (1996) found three distinct fish communities; river fed creek, upstream and the bay proper, in Gazi Bay, Kenya. Additionally, differences in species distribution and densities between shallow lagoons and creeks have been reported in Kenya (Bock, 1972; 1975).

Apart from the high abundance of juvenile fish in mangroves and seagrass beds, studies have also suggested a high functional inter-dependence on these habitats. A comparison between bays of a single island with and without mangroves and/or seagrass beds showed that juveniles of 17 species were highly abundant in mangrove and seagrass dominated bays, but were largely absent in bays lacking these nursery habitats (Nagelkerken *et al.,* 2001). Furthermore, the juveniles of these reef-fish species almost exclusively occured in bays with mangroves and seagrass beds and are seldom found on the coral-reef, as found by monitoring studies on juvenile fish densities in reefs of the Caribbean islands Curaçao and Bonaire (Nagelkerken *et al.,* 2000.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study Area

This study was carried out within Tudor Creek, Mombasa, Kenya (Figure 1). The creek bounds Mombasa Island on the northwest and extends some 10 km inland. Three seasonal rivers; Kombeni, Tsatu, and Mtsapuni, flow into this creek (Wakwabi, 1988). The upper end of the creek is fringed by a well developed mangrove forest mainly of *Rhizophora mucronata* Lamk, and *Avicennia marina* (Forsk) Vierh. The creek is narrow and deeper at the entrance but broadens out and becomes shallower further inland. It has a surface area of about 20 km^2 at mean sea level of which, 80% constitutes the wider, shallower, upper end (Norconsult, 1975). The currents in Tudor Creek are generally strong inward tidal currents during the flooding tides which reverse during ebb tides (Norconsult, 1975). The offshore currents and the outward ebb currents near the entrance to the creek flow northwards during both the northeast monsoon (NEM) and the southeast monsoon (SEM) seasons.

The creek is hydrographically divisible into two (the creek mouth and upper more inlandward part waters) (Norconsult, 1975). While the water salinities, water temperature, and pH remain rather uniform at the entrance to the creek for most of the year, these factors vary with tide, time of day, and season in the upper creek waters (Wakwabi, 1988).

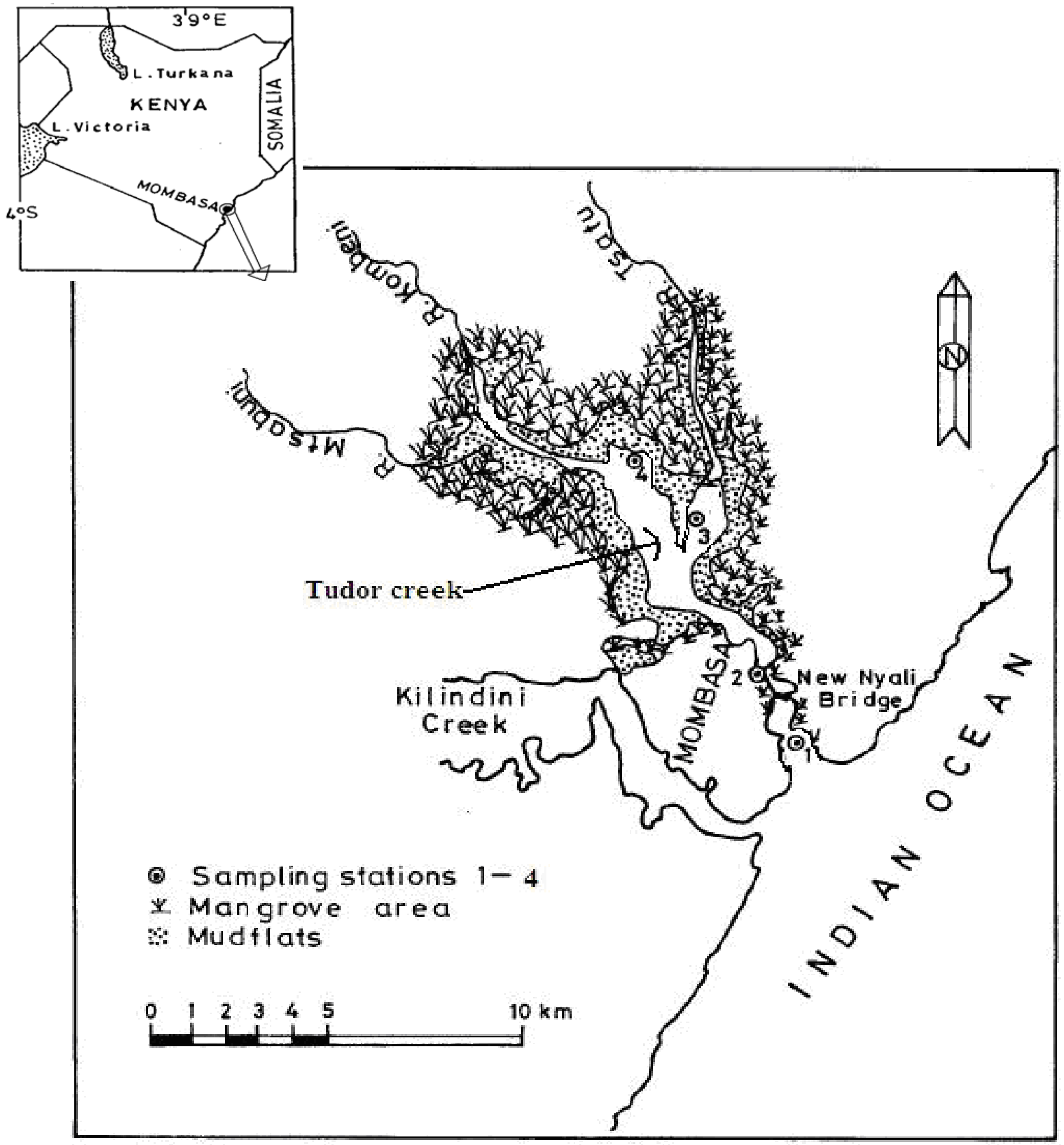


Figure 1:Map of study area showing Tudor Creek, Kenya, and the approximate location of sampling stations, 1-4.

The currents at the entrance channel of the creek behave like a stream reversing direction with flooding and ebbing tides, hence conditions here remain more or less marine. The currents are weaker towards the upper parts of the creek and the daily weather changes have a more appreciable effect on the water quality, producing a more fluctuating environment further up the creek (Wakwabi, 1988). The present study included the creek mouth, middle and upper part of the creek (Figure 1).

3.2 Sampling Design

Four stations (1-4) were selected to cover the upper, middle and lower parts of the creek (Figure 1). Station 1 was located near the mouth of the creek on a partially-exposed sandy beach with patches of seagrasses; Station 2, was a beach of muddy substrate backed by a fringe of mangroves; Station 3 was located at the mouth of a small channel leading into the creek, and had a muddy substratum and with a narrow fringe of mangroves; Station 4 was innermost on an exposed beach of sand-muddy substratum. The approximate interval between stations 1 and 2 was 4 km, station 2 and 3 were 2 km while, stations 3 and 4 were 3 km apart. The distances between stations were approximated from the product of speed of the boat and time of travel between stations.

Samples of fish were collected once every month from all the stations for 10 months (between October 2007 and July 2008) during spring tide dates (normally, shortly after the full and new moon). A small rubber motor boat (3 m long) was used to access the stations. Sampling for fish was done with a 25 m long by 2 m wide beach seine-net of ¾ inch mesh size. The net was laid perpendicular to the shore, then hauled against the current by four persons from the deeper part of the station towards the shore. Each single haul swept an area of about 327 m^2. Four replicate hauls were made at each station totaling to a swept area of approximately 1308 m^2 per station per month. For each replicate sample, all the fish caught were stored in labeled polythene bags and preserved in 5% formalin in the field. In the laboratory, fish were identified to species level, counted and measured for standard lengths to the nearest millimeter on a measuring board. Species identification followed identification guides of Smith & Heemstra (1986).

At each station, physico-chemical variables including; transparency, temperature, salinity and depth of water were determined before sampling for fish. Four random replicate measurements of the physico-chemical characteristics were taken at differents points within the site. Water transparency was measured using a Secchi disc. The Secchi disc, of approximately 8-inch diameter with alternating black and white quadrants was lowered into the water column until it was not visible from the surface. The depth in meters was noted. The disc was then hauled up and the point of reappearance was noted. The Secchi disc depth was taken as the mean of the two depths and this was then considered as a function of the water turbidity. Surface water temperature (ºC) was measured using a hand-held mercury in-glass thermometer (model, 4411). At each station, the thermometer head (mercury tip) was dipped into the water and the temperature reading recorded to the nearest 0.1 ºC. For salinity measurements, 10 ml of water from each station was collected into four labeled plastic bottles. Salinity of the samples was later determined in the laboratory using a calibrated refractometer. The face of the prism and the cover lens of the refractometer were carefully rinsed with deionized water, and dried with a cloth towel. Using an eye dropper, a drop or two of the stored water samples was placed onto the prism face. The prism cover was then closed and care was taken not to trap any air bubbles in the water on the prism face. The prism was then held towards light. The observer then looked though the refractometer and noted where the intersection was lying between the upper shaded portion and lower clear portions of the scale. This boundary represented the water salinity, to the nearest 0.01‰. Water depth at each station was taken by slightly dipping a portable eco-sounder (model SM-5) vertically into the water, the depth readings displayed on a screen were recorded to the nearest centimeter.

3.5 Data Analyses

To estimate fish density (individuals per m^2), fish numbers for every replicate sample in each station were divided by the area swept (327 m^2). Prior to statistical analysis, the density data was fourth root tranformed to increase the normality of distribution (Underwood, 1981). The choice of a parametric test was made after data were tested for homogeneity of variances using Levene's test (Shapiro & Wilks, 1966). Mean fish density and diversity indices were used to describe and compare the fish assemblage structure between stations and seasons. Analysis of variance (ANOVA) test in STASTICA 6.0 was used to test for differences in mean fish abundance between stations. Turkey HSD test was then used to partition any observed differences between stations (Underwood, 1981). The interaction between stations and season in affecting abundance of the main species was tested using two-way ANOVA.

Spatial patterns in fish assemblage structure were investigated using multivariate anaysis. A species mean abundance matrix was computed using Log (x+1) transformed density data and subjected to cluster analysis. The effect of rare species (occuring in <2% of samples) on the cluster analysis was eliminated by excluding them from the analysis (Clarke & Warwick, 1994). The species in the creek were clustered based on their aundance following group-average sorting based on Bray-Curtis similarity index (Clarke & Warwick, 1994) . The PRIMER 6 statistical package was used to perform the analysis. A multivariate simple Correspondence Analysis (CA) was used to further explore associations of species with respect to station and season using CANOCO 3.1 statistcal package. Species occuring in less than 2% of the samples were eliminated from the correspondence analysis in order to make it easy to identify the patterns of associations and for ease of interpreting the plots.

Diversity indices including; Shannon-Weiner's diversity index (*H'*), Margalef's species richness index (*D*) and Pielou's eveness index (*J'*) were used to assess assemblage structure within stations and in the sampled months (Livingstone, 1976; Bell *et al.*, 1984).

The Shannon-Wiener diversity index (*H'*) was calculated from the formula (Shannon & Weiner, 1963); $H' = n \log n - \sum (\phi \log \phi) / N$, Where *n* is the number of species in a sample, ф is the number of individuals in a species and *N* is the total number of individuals in a sample.

Margalef's species richness index, (D), was calculated from the formula (Margalef, 1968);

$D = S - \log_{10} N$, Where *S* is the number of species in the sample and *N* is the sample size.

Evenness component of *H'*, the Pielous's index (*J'*), was calculated from the formula (Pielou, 1966); $J' = H' / \text{Log}(S)$, Where *H'* is the number derived from the Shannon diversity index and *S* is the number of species in the sample.

A species-rank abundance curve was then plotted to visualize species richness and species evenness and further display relative species abundance, a component of biodiversity (Magurran, 2004). The curve overcomes the shortcomings of biodiversity indices that cannot display the relative role different variables played in their calculation.

Species were further categorized into bio-ecological groupings depending on their temporal utilization of the estuarine habitat during all or part of their life history stages (Smith & Heemstra, 1986). The bio-ecological groupings are:

1. Estuarine residents (ER): They are permanent residents spending their entire life (juvenile to adult) within the estuary and are highly adapted to estuary conditions by possessing specialized physiological adaptations.

2. Estuarine dependent (ED): They are also called opportunists or secondary residents. They spend only part of their life in the estuary, usually as juveniles, and generally have few physiological adaptations to estuary conditions.

3. Transients (T): Often stenothermal and stenohaline species enter the estuary only occasionally, usually when conditions in the estuary are very similar to those in

the open sea. Transients generally have no specialized adaptations to estuary conditions.

4. Rare (R): Species whose occurrence was very sporadic in the creek.

Apart from bio-ecological categories fish were also grouped on the basis of feeding habits (trophic categories).This was achieved by determining the diet of the species from literature (e.g. Fishbase, 2003; Smith & Heemstra, 1986). The species were then categorized as being; piscivore, herbivore, zooplanktivore, omnivore, zoobenthivore, and detritivore.

CHAPTER 4

4.0 RESULTS

4.1 Environmental Parameters

The physico-chemical parameters of Tudor Creek during the study period are presented in Table1. Mean monthly surface temperature varied between 28°C and 30°C recorded in April 2008 and December 2007, respectively. Turbidity ranged between 0.63 and 0.98 NTU recorded in October and December 2007, respectively. Salinity varied slightly between months and ranged between 33.27 and 34.04‰ in June and February 2008, respectively. The mean water depth at stations ranged between 0.95 and 1.01 m. ANOVA results showed no significant difference in the physico-chemical parameters between months (Table 1).

4.2 Seasonal Variation in Species Abundance

A total of 2124 fish belonging to 92 species and 45 families were sampled from the creek during the study (Table 2). A total of 57, 47, 45 and 50 species were sampled from stations 1, 2, 3 and 4, respectively. The species *Gerres oyena, Terapon jarbua, Lutjanus fluviflamma* and *Apogon cyanosoma* had the highest mean catch rate and were the most numerically abundant in the creek (Table 2). During the northeast monsoon (NEM) season, the species, *Siganus canaliculatus, L. fluviflamma, Aeoliscus punctulatus* and *Plotosus lineatus* were the most abundant while, *T. jarbua, G. oyena, A. cyanosoma* and *L. fluviflamma* were most abundant during the southeast monsoon (SEM) season (Table 2).

Table 1: Temporal variation in mean physico-chemical parameters within Tudor Creek during the study period. ± indicate Standard Error of the mean. F and P are test statistics of ANOVA

		Temperature(°C)	Turbidity (NTU)	Salinity (‰)	Depth(m)
Oct 2007		**29.33±0.41**	**0.63±0.10**	**33.42±0.26**	**0.98±0.09**
Nov		**29.39±0.24**	**0.94±0.17**	**33.92±0.19**	**0.95±0.08**
Dec		**30.19±0.32**	**0.98±0.17**	**33.83±0.17**	**1.00±0.09**
Jan2008		**29.50±0.42**	**0.94±0.17**	**34.03±0.26**	**0.95±0.10**
Feb		**29.61±0.38**	**0.73±0.17**	**34.04±0.23**	**0.97±0.07**
Mar		**29.26±0.34**	**0.77±0.22**	**34.01±0.22**	**1.01±0.10**
Apr		**28.46±0.24**	**0.70±0.17**	**33.29±0.41**	**1.03±0.08**
May		**29.13±0.32**	**0.81±0.19**	**33.28±0.43**	**1.10±0.09**
June		**29.13±0.23**	**0.81±0.19**	**33.27±0.37**	**1.00±0.08**
July		**29.10±0.24**	**0.89±0.21**	**33.33±0.38**	**0.99±0.08**
	F	**1.78**	**0.343**	**2.513**	**0.522**
ANOVA	**P**	**0.084**	**0.959**	**0.062**	**0.856**

Table 2: Mean fish density (no. m^{-2}) of beach seined fish species at Tudor Creek Kenya, during the northeast monsoon (NEM) and southeast monsoon season (SEM). SE denotes standard error of the mean. Dash (–) denotes absence of data. T, ED, ER &R denote Transient, Estuarine Dependent, Estuarine Resident & Rare species, respectively.

Family/Species	**Bio-ecological group**	**Total No.**	**% of Total**	**NEM no/m²**	**±SE**	**SEM no/m²**	**±SE**
GERREIDAE							
Gerres oyena	ED	204	9.60	1.024	0.301	4.377	2.672
TERAPONIDAE							
Terapon jarbua	ED	200	9.42	0.329	0.194	5.305	2.144
Pelates quadrinillineatus	T	12	0.56	0.406	0.293	0.232	0.180
LUTJANIDAE							
Lutjanus fluviflamma	ED	190	8.95	2.029	0.752	2.464	1.012
Lutjanus harak	ED	2	0.09	0.039	0.039	-	-
Lutjanus sanguienus	ED	3	0.14	0.019	0.019	-	-
APOGONIDAE							
Apogon cyanosoma	T	148	6.97	0.986	0.418	2.811	2.076
Apogon immaculatus	T	1	0.05	0.019	0.019	0.086	0.086
Apogon nigripes	T	10	0.47	0.039	0.027	0.231	0.230
Apogon novemfasciatus	T	1	0.05	0.019	0.019	-	-
Apogon spp	T	1	0.05	0.019	0.019	-	-
CARANGIDAE							
Caranx ignobilis	T	38	1.79	0.599	0.315	0.202	0.146
Caranx melanobrancus	T	10	0.47	0.193	0.174	-	-
Trachinotus bailoni	T	70	3.30	0.367	0.216	1.478	0.868
Trachinotus blochii	T	48	2.26	0.213	0.158	1.073	0.444
ATHERINIDAE							
Atherinomorus lacunosus	ED	36	1.69	0.387	0.347	0.464	0.320
PERCOPHIDAE							
Bembrops caudimacula	ED	1	0.05	0.019	0.019	-	-
Bembrops platyrhinchus	ED	3	0.14	-	-	0.029	0.029
BOTHIDAE							
Bonthus mancus	T	1	0.05	0.193	0.088	0.145	0.070
Paraplagusia bilineata	T	1	0.05	0.019	0.019	-	-

Table 2 Continued

Family/Species	Bio-ecological group	Total No.	% of Total	NEM no/m^2	±SE	SEM no/m^2	±SE
CANTHIGASTERIDAE							
Arothron immaculatus	T	12	0.56	0.155	0.077	0.116	0.116
Canthigaster benthii	T	1	0.05	0.039	0.039	0.029	0.029
CHANIDAE							
Chanos chanos	ED	1	0.05	0.019	0.019	-	-
TETRAODONTIDAE							
Cheladon laticeps	ED	4	0.19	0.058	0.042	0.029	0.029
FISTULARIIDAE							
Fistularia petimba	T	11	0.52	0.193	0.088	0.029	0.029
GOBIDAE							
Gobius albomaculatus	ER	2	0.09	0.039	0.039	-	-
Oxyurichthys opthalmonema	ER	114	5.37	1.333	0.385	1.305	0.391
Oxyurichthys papuensis	ER	70	3.30	0.831	0.218	0.783	0.583
Gobius keiensis	ER	43	2.02	0.831	0.579	-	-
Amblygobious albomaculatus	ER	13	0.61	0.077	0.046	0.261	0.179
Amblygobious spp	ER	1	0.05	0.019	0.019	-	-
Callogobious macullipinnis	ER	8	0.38	-	-	0.087	0.063
Acentrogobious audax	ER	6	0.28	0.116	0.080	-	-
Favonigobious melanobrancus	ER	96	4.52	0.541	0.251	1.971	0.799
Favonigobious recheii	ER	19	0.89	0.213	0.128	0.232	0.127
Yongeichthys nebulosus	ER	28	1.32	0.367	0.142	0.261	0.158
Goby spp	ER	2	0.09	0.039	0.039	-	-
LABRIDAE							
Halichoeres scapularis	T	1	0.05	0.019	0.019	-	-
Halichores iridis	T	1	0.05	0.019	0.019	-	-
Cheilio inermis	T	1	0.05	0.019	0.019	-	-
HEMIRAMPHIDAE							
Hemiramphus far	T	10	0.47	0.174	0.092	0.029	0.029
Stolephorus delicatulus	T	5	0.24	-	-	0.029	0.029
SYNGNATHIDAE							
Hippichthys spicifer	T	2	0.09	0.058	0.042	0.087	0.047
Sygnathoides bimaculatus	T	1	0.05	0.019	0.019	-	-

Table 2 Continued

Family/Species	Bio-ecological group	Total No.	% of Total	NEM no/m^2	±SE	SEM no/m^2	±SE
LEIOGNATHIDAE							
Leiognathus equula	T	35	1.65	0.232	0.118	0.667	0.393
Secutor insidiator	ED	4	0.19	0.058	0.058	0.029	0.029
SCARIDAE							
Leptoscarus vaigensis	T	11	0.52	0.155	0.082	0.058	0.040
Novaculochthys macroleptidotus	T	1	0.05	0.019	0.019	-	-
LETHRINADAE							
Lethrinus variegatus	ED	22	1.04	0.019	0.019	0.609	0.548
Lethrinus lentjan	ED	2	0.09	0.039	0.039	-	-
Lethrinus nebulosus	ED	2	0.09	0.019	0.019	0.029	0.029
Lethrinus spp	ED	7	0.33	0.135	0.052	-	-
Letrinus Sanguienus	ED	3	0.14	0.019	0.019	0.058	0.058
MONODACTLYLIDAE							
Monoactlylus argenteus	ED	42	1.98	0.657	0.389	0.232	0.112
Monodactylus plebeus	ED	2	0.09	0.039	0.039	-	-
Polydactylus plebeus	ED	1	0.05	-	-	0.058	0.058
Polydactylus virginicus	ED	7	0.33	-	-	0.029	0.029
CICHLIDAE							
Oreochromis mossambica	R	2	0.09	0.058	0.042	-	-
MONACANTHIDAE							
Paramonacanthus barnadi	T	27	1.27	0.271	0.150	0.377	0.190
MULLIDAE							
Parupeneus barbernus	ED	1	0.05	0.019	0.019	-	-
Upeneus sulphreus	ED	1	0.05	0.019	0.019	-	-
BLENNIDAE							
Petroscirtes breviceps	T	34	1.60	0.309	0.206	0.754	0.361
Loboteus surinamensis	T	6	0.28	0.135	0.086	0.029	0.029
EPHIPPIDAE							
Platax barnadi	ED	1	0.05	0.019	0.019	0.029	0.029
Platax orbicularis	ED	1	0.05	0.019	0.019	-	-
Platax pinnutus	ED	3	0.14	0.058	0.042	-	-
Platax teira	ED	2	0.09	0.039	0.027	0.087	0.087

Table 2 Continued

Family/Species	Bio-ecological group	Total No.	% of Total	NEM no/m^2	±SE	SEM no/m^2	±SE
HAEMULIDAE							
Plectorhincus gaterinus	T	4	0.19	0.077	0.046	-	-
Plectorhincus gibossus	T	2	0.09	-	-	0.029	0.029
Plectorhincus plagiodesmus	T	3	0.14	0.058	0.032	-	-
Pseudopeneus bariberinus	T	1	0.05	0.019	0.019	-	-
Gaterin gaterinus	T	2	0.09	0.039	0.027	-	-
PLOSTIDAE							
Plotosus lineatus	T	40	1.88	1.044	0.722	-	-
POMADASYIDAE							
pomedysis spp	R	1	0.05	0.019	0.019	-	-
CLUPEIDAE							
Sardinela gibosa	T	54	2.54	0.387	0.241	0.986	0.583
Anchovelia commersoni	T	4	0.19	0.077	0.036	-	-
SYNODONTIDAE							
Saurida undosquamis	T	37	1.74	0.135	0.059	0.870	0.429
NEMIPTERIDAE							
Scolopsis ghanam	T	2	0.09	0.039	0.039	-	-
SCORPAENIDAE							
Scorpaena mossambica	T	1	0.05	-	-	0.029	0.029
SIGANNIDAE							
Siganus canaliculatus	ED	117	5.51	2.261	1.102	-	-
SILAGINIDA*E*							
Silago sihami	ED	7	0.33	0.039	0.039	0.145	0.070
SOLEIDAE							
Solea blieeneri	R	6	0.28	-	-	0.116	0.090
SPHYRAENIDAE							
Sphyreana jello	ED	35	1.65	0.560	0.195	0.174	0.083
TYLOSURIDAE							
Tylosurus acus	T	2	0.09	-	-	0.261	0.174
CENTRISCIDAE							
Aeoliscus punctulatus	R	102	4.80	1.971	1.089	-	-
MUGULIDAE							
Valamugil seheli	ED	32	1.51	0.019	0.019	0.899	0.748
LOPHIIDCE							
Zenarchopterus despair	R	4	0.19	-	-	0.289	0.289
AMBISSIDAE							
Ambissis natalensis	ED	8	0.38	0.058	0.042	0.145	0.145
POMACENTRIDAE							
Abudefdeuf sexfaciatus	ED	6	0.28	-	-	0.087	0.087
ACROPOMADAE							
Acropoma japonica	R	1	0.05	0.019	0.019	-	-
SOLENOSTOMIDAE							
Solenostomus cyanopterus	R	1	0.05	0.019	0.019	-	-

Table 2 Continued

Family/Species	Bio-ecological group	Total No.	% of Total	NEM no/m^2	±SE	SEM no/m^2	±SE	
OSTRACIIDAE								
Lactoria cornutuS	R	3	0.14	0.039	0.027	0.029	0.029	
Platycephalus laticeps	ED	1	0.05	0.019	0.019	-	-	
								t test
TOTAL		2124	100	0.229	0.044	0.336	0.084	***t*= - 1.310 p= 0.193**

The mean density (no m^{-2}) of the beach seined fish at Tudor Creek, was highest during the SEM season (0.336 ± 0.084) compared to NEM season (0.229 ± 0.044) (Table 2). However, the seasonal difference in density was not significant (t= -1.310, P= 0.193, Table 2). The number of species between the two seasons was significantly different (χ^2=317.760, P<0.0001) with NEM significantly having more species than SEM season (82 and 54, respectively, Table 2). In the creek as a whole, the family Gobidae had the highest proportion of individuals to the total catch and highest number of species (18.9%, 12 species, respectively), followed by Lutjanidae (9.2%, 3 species), Carangidae (7.8%, 4 species) and Apogonidae (7.6%, 5 species) (Table 2). The family Teraponidae and Gerreidae, were represented by only one species but had relatively high percentage numerical contribution to the total catch (9.8% and 9.6%, respectively). Twenty-six families were represented by 1 species in the samples, 5 families were represented by 3 species while, 5 other families were represented by more than 5 species (Table 2).

The overall mean fish density (no. m^{-2}) was significantly different between stations (P<0.05) and was highest in stations 2 (0.39 ± 0.03) and lowest in station 3 (0.30 ± 0.01)

(Table 3). Tukey's HSD test partitioned the between station differences in the fish abundance to differentiate between stations 4 and 1 and that between stations 4 and 2 (Appendix 2). The highest and lowest mean Shannon-Weiner diversity index (*H'*) of 1.96 ± 0.12 and 1.69 ± 0.10 were recorded at stations 2 and 1, respectively (Table 3). Margalef's species richness index (*D*) followed the same trend as *H'*, with high and low *D* value in stations 2 and 1, respectively. The evenness index (*J'*) was highest in station 4 (0.89 ± 0.02) and lowest in station 1 (0.75 ± 0.04) (Table 3). *H'* and *D* did not differ significantly between the stations while *J'* differed significantly between the stations (Table 3).

The mean total catch for the common fish species within the creek was influenced by both the station and the season (2-way ANOVA, $P < 0.05$, Table 4). The abundance of *O. opthalmonema* and *Y. nebulosus* (estuarine residents species), was significantly affected by the station than season of sampling. While, the abundance of *O. papuensis,* an estuarine species, was significantly affected by both the station and season of sampling. The abundance of the non-commercial species, *S. undosquamis* and *T. jarbua* was conditional on the season of sampling. The abundance of commercially important species, *G. oyena, T. bailoni* and *L. equula* within the creek was influenced by the interaction of station and season (Table 4), indicating lack of independence of the factors in determining their distribution in the creek.

Table 2: Mean density, Shannon's diversity index (*H'*), Margalef's richness index (*D*) and Pielou's evenness index (*J'*). F and P are test statistics of ANOVA, ± indicate SEM

	Station1	**Station 2**	**Station 3**	**Station 4**	**F**	***P***
Fish Mean density (ind/m^2)	0.35± 0.01	0.39± 0.03	0.34± 0.01	0.30± 0.01	4.173	0.007
Shannon's diversity index *(H')*	1.69 ±0.10	1.96±0.12	1.79±0.12	1.92±0.13	0.67	0.58
Margalef's richness index *(D)*	2.48±0.27	2.95±0.28	2.53±0.23	2.70±.26	3.47	0.36
Pielou's eveness index (*J'*)	0.75±0.04	0.79±0.04	0.78±0.04	0.89±0.02	1.11	0.03

Table 3: Two-way ANOVA results on the influence of site, season, and interaction effects between site and season on the mean density (no. m^{-2}) of the common fish species within Tudor Creek. MS, df , F and P are test parameters

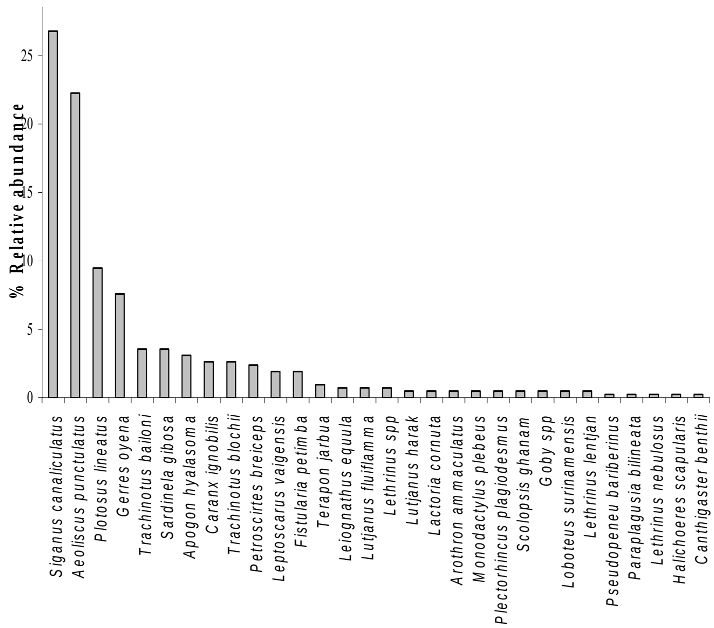
	Site			Season			Site × Season		
Species	MS	df	F	MS	df	F	MS	df	F
Gerres oyena	0.595	3	1.856	0.804	1	2.508	1.557	3	4.857*
Trachinotus bailoni	1.272	3	9.406*	0.304	1	2.251	1.531	3	11.323*
Oxyurichthys papuensis	1.542	3	8.172*	1.043	1	5.527*	0.139	3	0.737
Lutjanus fluviflamma	2.703	3	11.586*	0.001	1	0.004	0.396	3	1.698
Sphyreana jello	0.864	3	5.188*	0.279	1	1.675	0.309	3	1.856
Atherinomorus lacunosus	0.209	3	1.043	0.011	1	0.054	0.047	3	0.235
Oxyurichthys opthalmonema	1.816	3	6.047*	0.003	1	0.011	0.175	3	0.582
Caranx ignobilis	0.110	3	0.507	0.499	1	2.308	0.372	3	1.721
Leiognathus equula	0.487	3	2.671	0.013	1	0.069	0.618	3	3.388*
Sardinela gibosa	10.265	3	4.085*	3.446	1	1.371	2.377	3	0.946
Yongeichthys nebulosus	0.675	3	3.687*	0.095	1	0.519	0.044	3	0.239
Saurida undosquamis	0.421	3	2.155	1.150	1	5.890*	0.307	3	1.575
Petrocirtes previceps	0.113	3	0.465	0.838	1	3.444	0.008	3	0.035
Monodactlylus argenteus	0.278	3	1.183*	0.050	1	0.214	0.261	3	1.109
Terapon jarbua	0.071	3	0.154	3.023	1	6.618*	0.509	3	1.097
Favonigobious melanobranchus	0.793	3	2.459	1.4.08	1	4.368	0.304	3	0.943
Total	25.241	3	5.212*	48.278	1	9.969*	8.053	3	1.663

*Significant at $\alpha = 0.05$.

The relative seasonal abundance of the dominant species within stations is shown in Figure 2. During the northeast monsoon season, the rabbitfish, *S. canaliculatus,* had the highest relative abundance (26.8%) in station 1, *A. punctulatus* which occasionally occurred in large schools was also caught in large proportions (22.8%) in this station (Figure 2). The dory snapper, *L. fluviflamma,* had the highest relative abundance (28.6%) in station 2, while the other species in this station had relative abundances of less than 8%. In station 3, the estuarine resident species (*O. opthalmonema* and *G. keiensis*) dominated the catch (>16%) while *A. lacunosus* dominated the catches in station 4 during NEM season (Figure 2). Stations 1 and 2, were largely dominated by a few species (2 and 1 species, respectively) with the rest of the species in these stations showing low relative abundances (<5%). The species caught in stations 3 and 4, generally, had higher relative abundances compared to those in stations 1 and 2 (Figure 2). The razor fish, *A. punctulatus*, the marine catfish, *P. lineatus*, and the parrot fish, *L. vaigensis,* were restricted to station 1, while the estuarine resident gobiid species, *O. opthalmonema, O. papuensis, F. melanobranchus* and other gobies, were not found in stations 1, however, they were found in all the other stations. The mojarra, *G. oyena,* the dory snapper *L. fluviflamma* were not restricted to any stations and were common in all the stations during the NEM season.

During the southeast monsoon season, the carangid reef fishes (*T. bailoni* & *T. blochii*) and the schooling clupeid species *S. gibosa,* notably dominated the catch in station 1(Figure 3). The small pelagic fishes (*T. jarbua* and *A. cyanosoma*) and *L. fluviflamma* dominated the catches in station 2. Station 3 was dominated by *G. oyena* and *T. jarbua* while, *F. melanobranchus* dominated station 4 (Figure 3).

(1)



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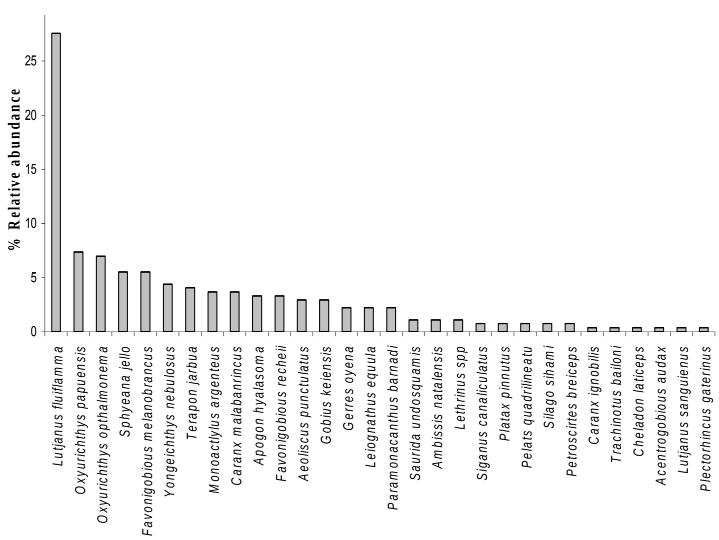
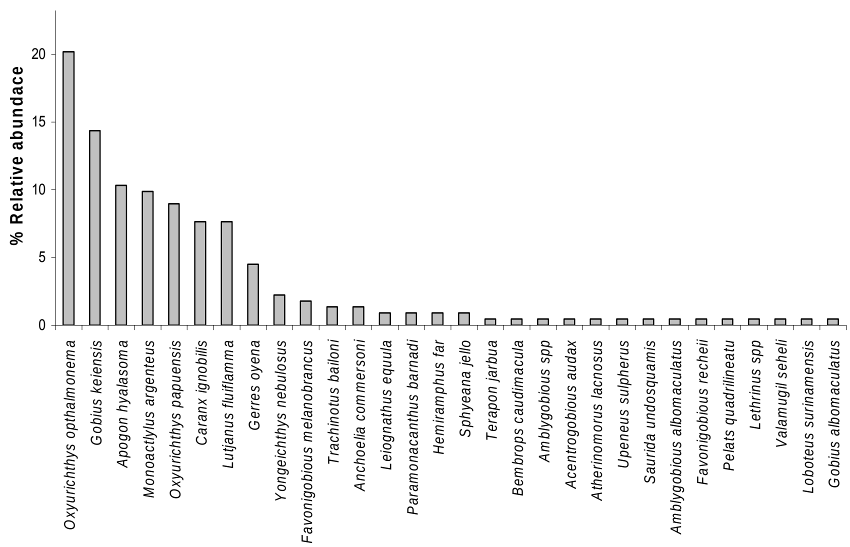


Species

Figure 2: Relative abundance (%) of the most abundant beach seine catches in Tudor Creek during the northeast monsoon season. 1-4 indicate stations within the creek.

Figure 2 Continued

(3)



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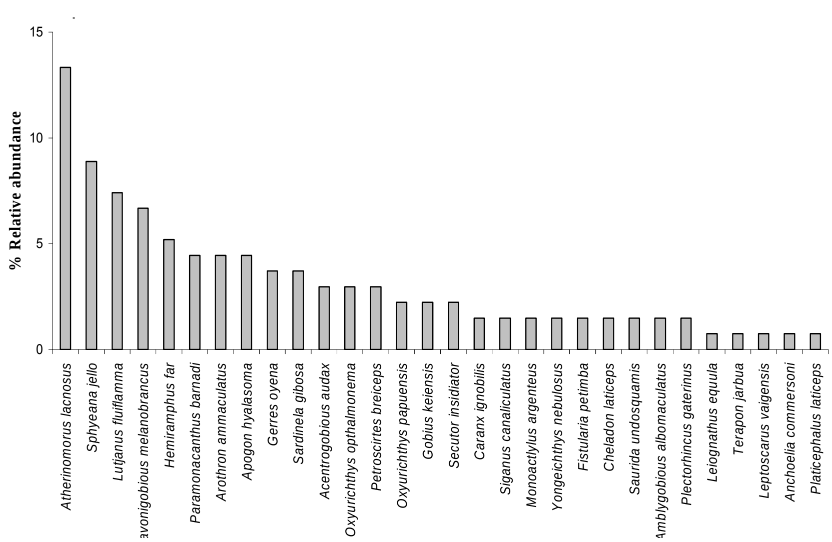
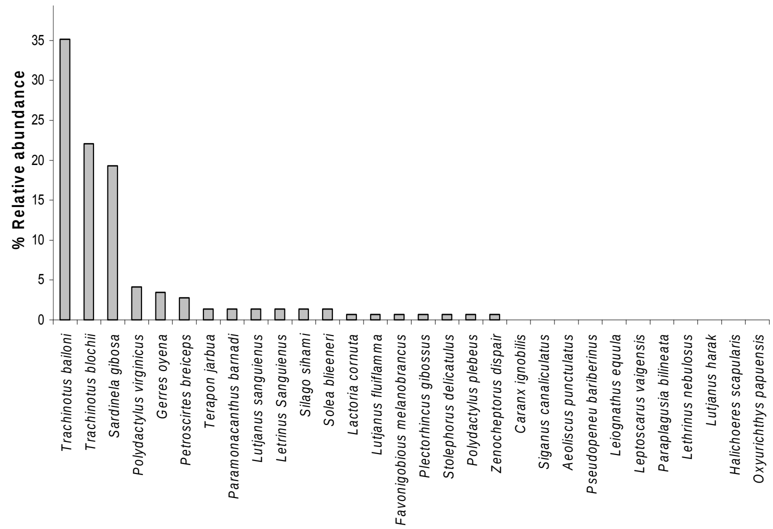


Species

(1)



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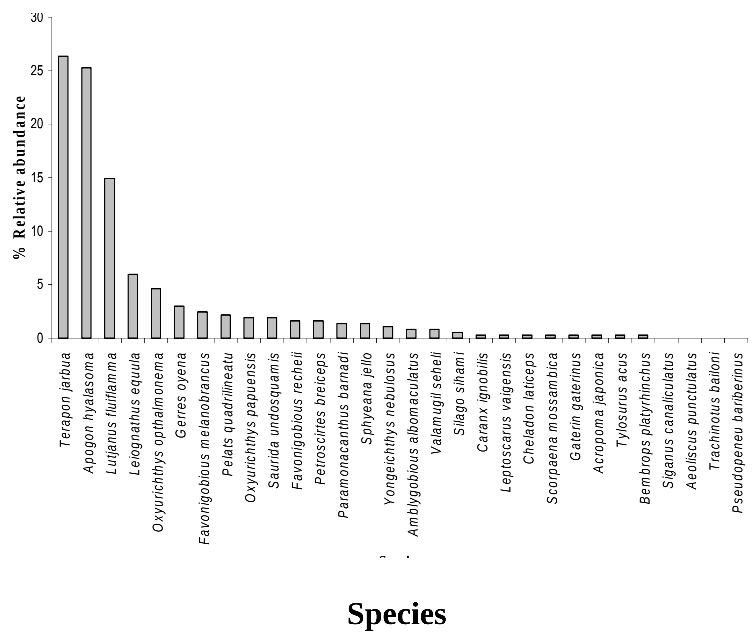
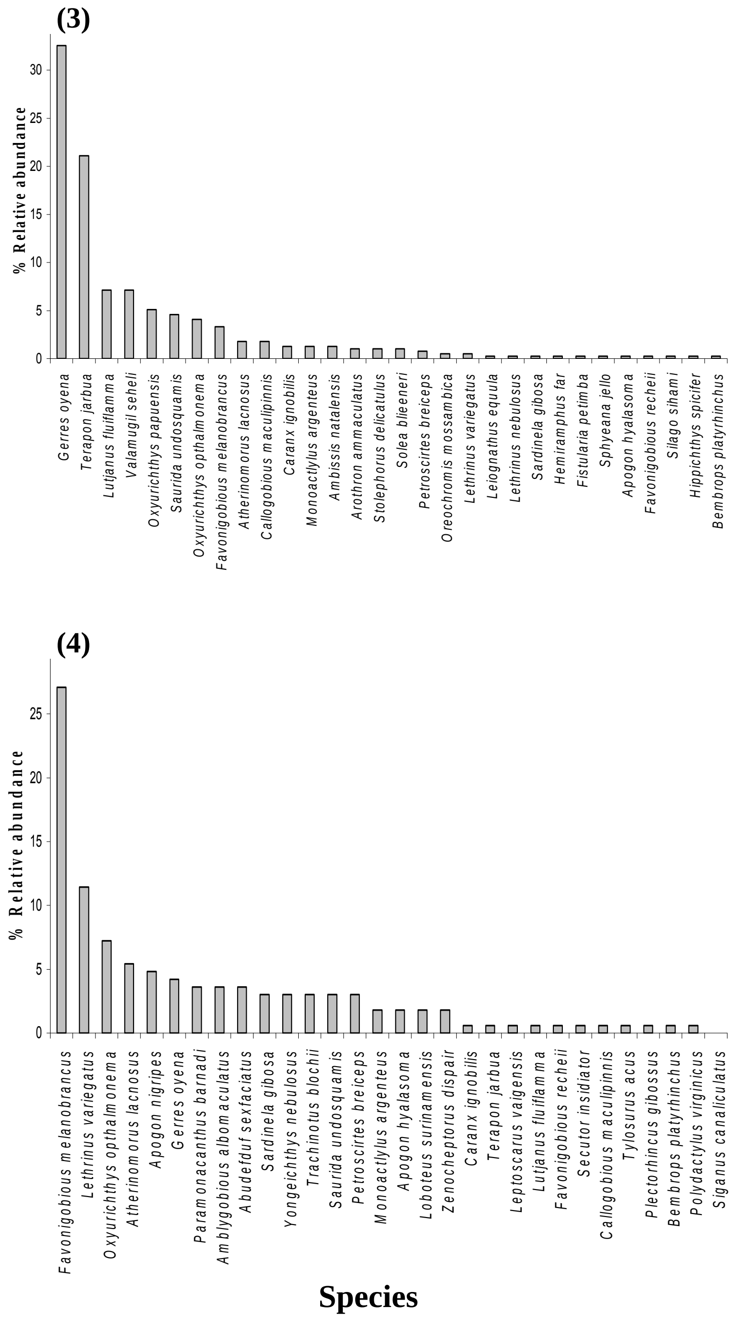


Figure 3: Relative abundance (%) of the most abundant beach seine catches in Tudor Creek during the southeast monsoon season. 1-4 indicate stations within the creek.

Figure 3 Continued



4.3 Species Diversity

The seasonal variation in the ecological indices is shown in Figure 4. Shannon- Weiner diversity index (*H’*), was highest during the NEM season in all stations except in station 3 where *H’* was higher during the SEM season. *H’* showed very small marginal seasonal difference in station 2 (Figure 4). Margalef’s species richness index (*D*), followed the same trend as *H’* at stations with NEM season recording higher values than SEM season. However, the species richness index showed a higher seasonal difference in stations compared to *H’* (Figure 4). The Pielou’s evenness index (*J’*), had a different trend from that of *H’* and *D*. *J’* values showed inconsistent seasonal variations between stations (Figure 4).

On a temporal scale, *D* ranged between 2.15 and 3.19 in March and July 2008, respectively (Figure 5). Generally, *D* showed an increase during the NEM but decreased during SEM season. *H’* ranged from 1.99 to 2.11 between the months of June and March, respectively (Figure 5). *J’*, however, remained nearly constant over time with the index ranging between 0.8 and 0.9 (Figure 5). Higher diversity indices were generally recorded in NEM compared to SEM months.

The species-rank abundance curves for the four study stations in the creek are presented in Figure 6. Stations 4 and 1 were the most diverse (34 and 32 species ranked, respectively,), while station 3 was the least diverse compared to the other stations (29 species ranked). From the slope of the curves, the species composition was more even in stations 4 and 2 (number of individuals was more equitably distributed among species sampled), while station 3 and 1 had the lowest evenness indicating unequal distribution of individuals per species as the higher ranked species had more individuals than the lower ranked ones.

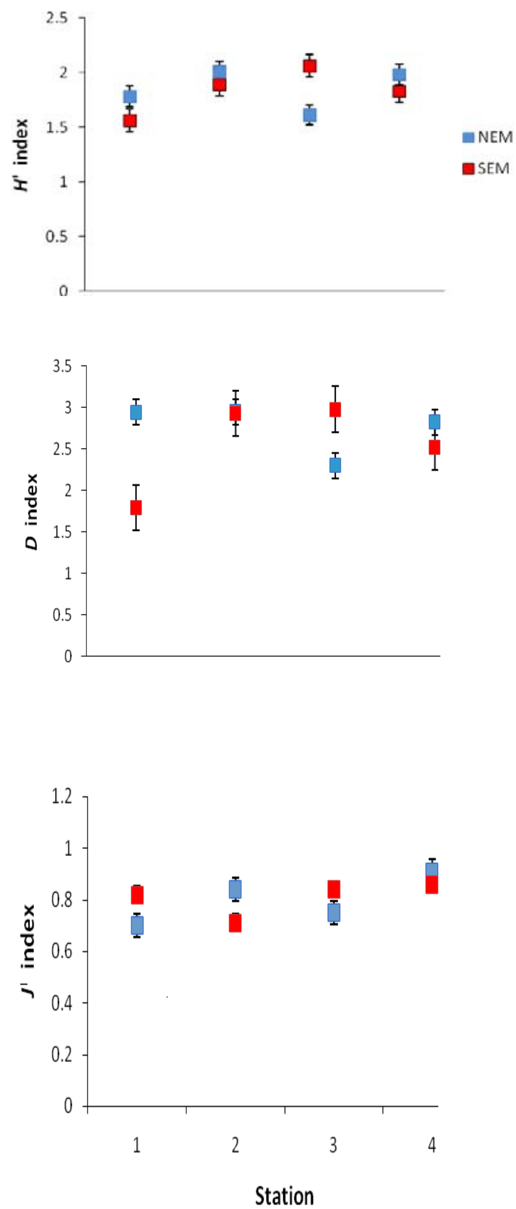


Figure 4: Seasonal variation of Shannon-Weiner diversty (*H’*), Margalef’s species richness (*D*), and Pielous’s eveness (*J’*) indices at the stations sampled within Tudor Creek. NEM-northeast monsoon, SEM-southeast monsoon season.

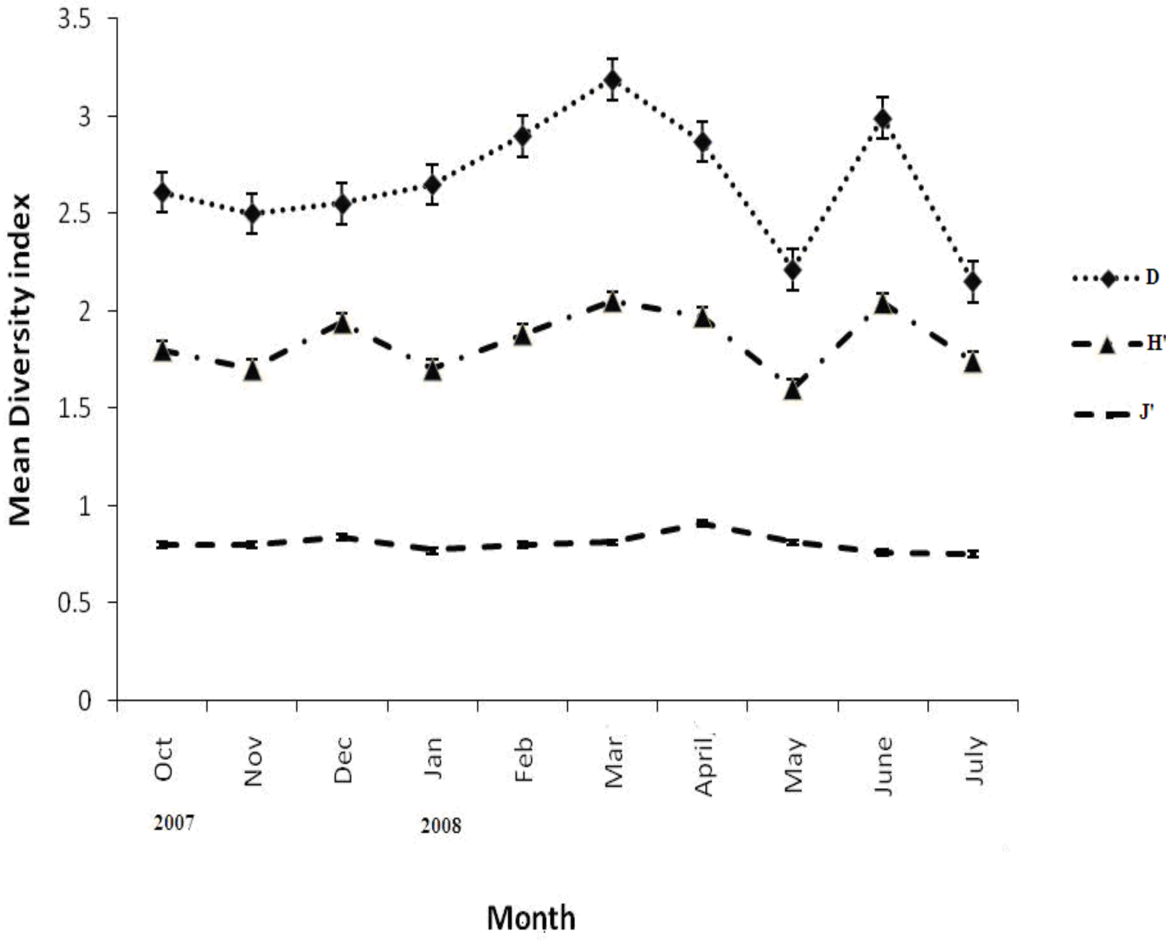


Figure 5: Temporal variation in mean Shannon Weiner diversty (*H'*), Margalef's species richness (*D*) and Pielous's eveness (*J'*), indices for fish assemblages within Tudor Creek. Error bar indicate standard error of the mean

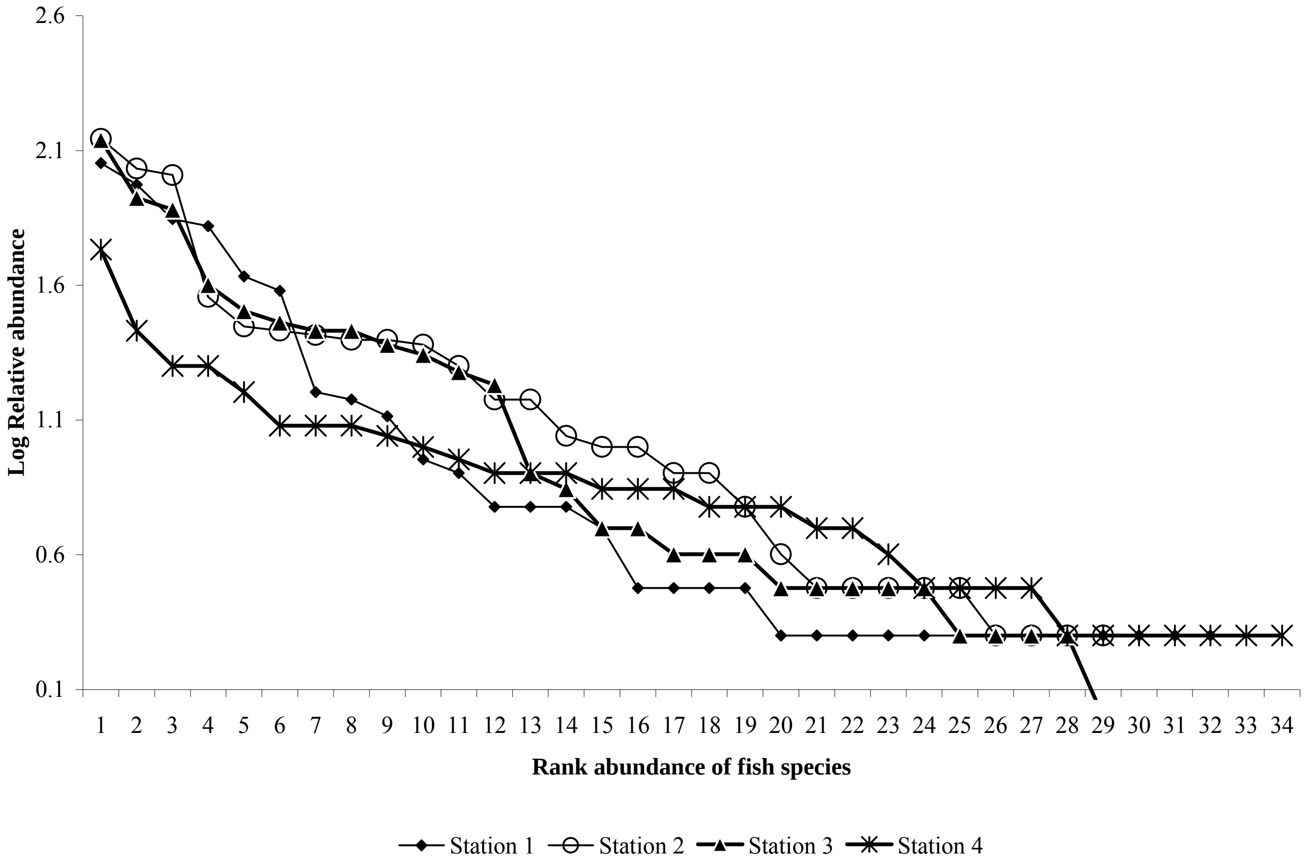


Figure 6: Species-rank abundance curves derived from total fish collections from the four stations sampled within Tudor Creek.

4.4 Patterns in Assemblage Structure and Species-Station Associations

The Bray-Curtis cluster analysis defined two main groups among the most abundant species in the creek (Figure 7). The grouping appear to represent the temporal and spatial use of the creek by the fishes. The first group (I) was represented by a mix of trasients species (*C. ignobilis, L. equula, G. oyena, A. cyanosoma, P. breviceps* and *T. jarbua*), estuary resident species (*O. opthalmonema, O. papuenis, Y. nebulosus* and *F. melanobranchus*) and a few estuarine dependant species (*L. fluviflamma* and *S. undosquamis*). Members of the first group were mostly from stations 2 and 3. Group two (II) was exclusivelly composed of transient species (*T. bailoni, T.s blochii, S. canaliculiatus* and *S. gibosa*) principally from station 1. Multidimensional Scaling (MDS) further clusterd the four stations into three main groups (2 and 3, 1, and 4) based on the distribution of the abundant species (Figure 8). The assemblage at station 1 was dissimilar from the other stations perhaps due to the predominance of the transient species (Figure 7). Station 2 and 3 showed closer similarity in species compostion consisting of group 1 in Figure 7. Station 4 was likely separeted from other stations due to the influence of river input as well as a sparse mangrove fringe.

The results of Correspondence Analysis (Figure 9) showed that only fish assemblage at station 1 formed a distinct seasonal structure from the other stations. During NEM season, station 1 was dominated by *S. canaliculatus, G. Oyena* and *C. ignobilis,* while, *S. gibosa* and *T. bailoni* dominated the station during SEM season (Figure 9). Fish assemblages were poorly separated between the seasons at station 4, however, NEM season appeared to be dominated by *P. breviceps, L. equula* and *A. lacunosus* in this station (Figure 9). The fish assemblage structure of this station was indistinct from that of stations 2 and 3 only during the SEM season. Fish assemblage structure at station 2 and 3 were indistinct between the two seasons and consisted of; *F. melanobrancus Y. nebulosus, T.jarbua, L.fluviflamma, S. jello, S.undosquamis,* O. *papuensis, O. opthalmonema, Apogon cyanosoma* (Figure 9).

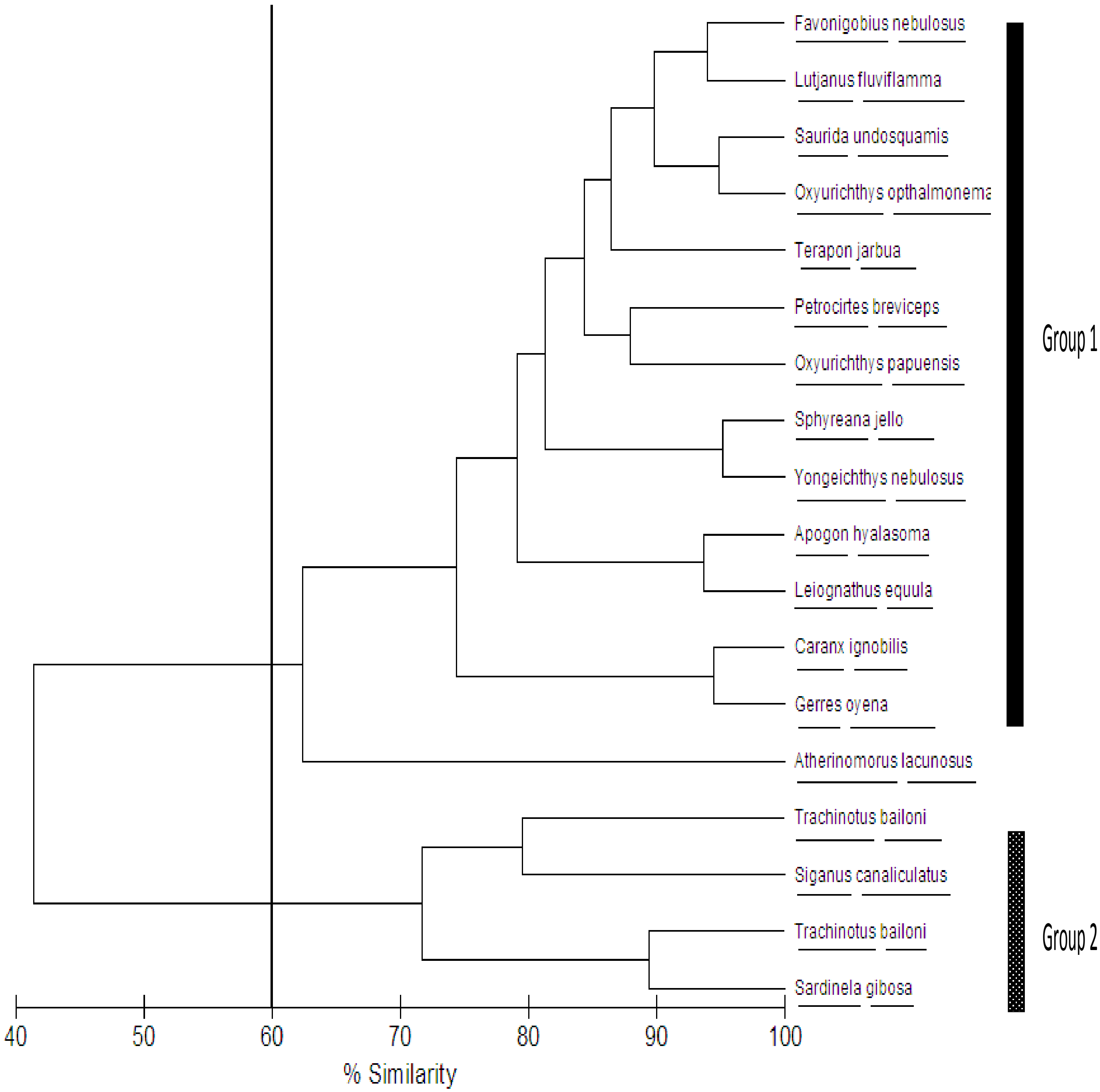


Figure 7: Correlation dendrogram for species in Tudor Creek based on Bray-Curtis similiraties of the most abundant species.

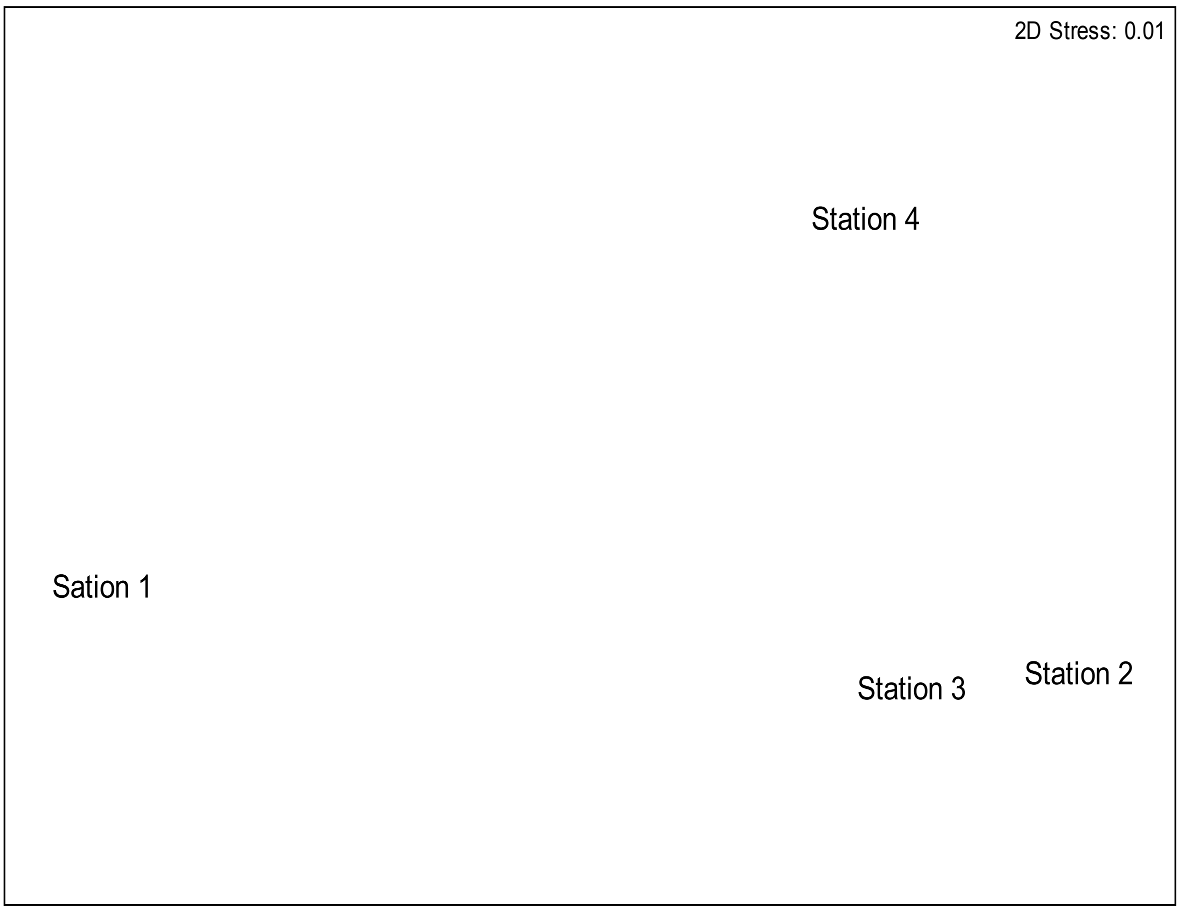


Figure 8: Multidimensional Scaling (MDS) ordination plot based on Bray-Curtis similarities of the most abundant species at stations within Tudor Creek.

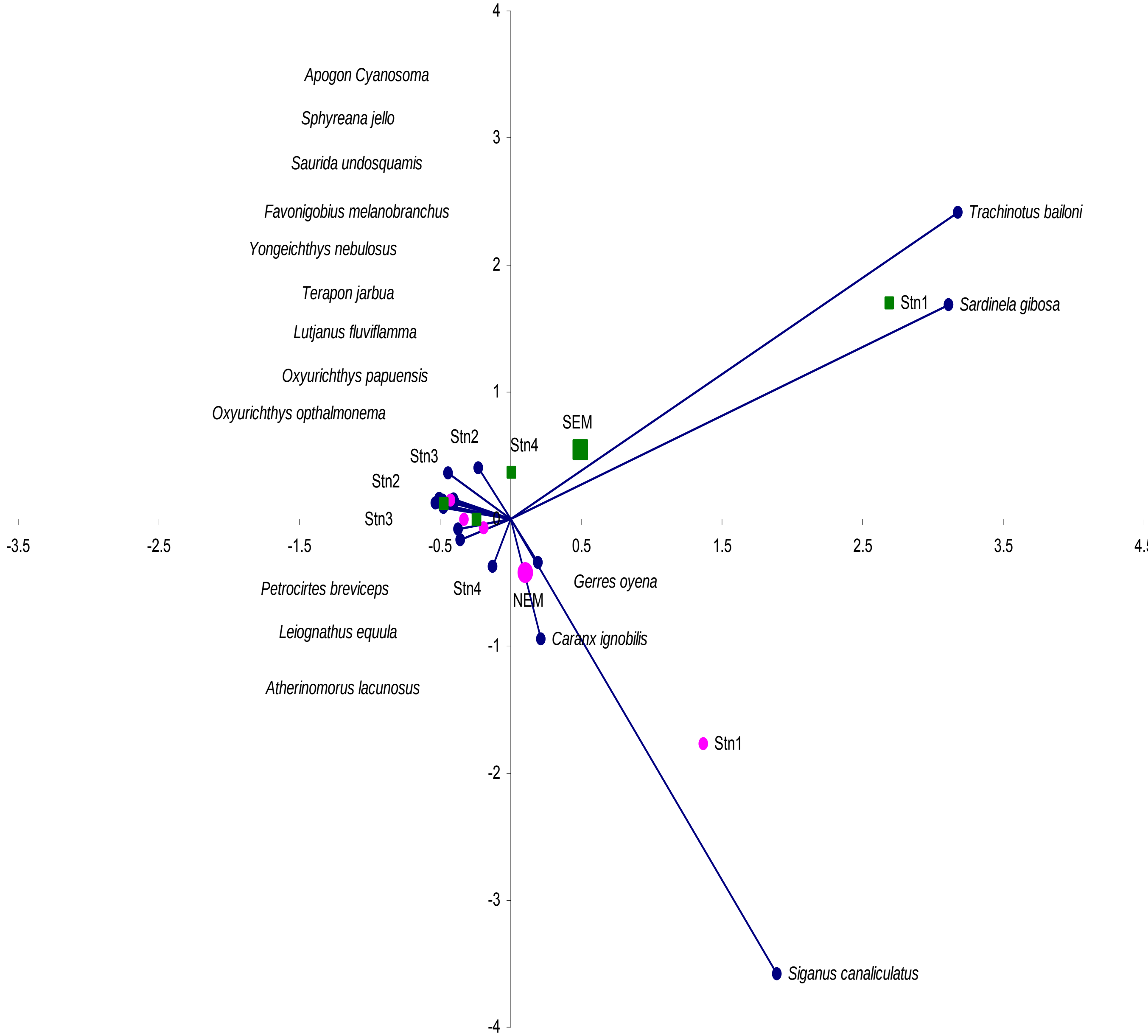


Figure 9: Multivariate Correspondence Analysis (CA) of the association of dominant fish species with the stations and seasons at Tudor Creek, Kenya, for species with catch rates >2%. Stations (●), Season (■)

4.5 Distribution of Trophic Groups

The most abundant trophic group in the creek consisted of zoobenthivores (e.g. Gobidae, Mullidae and Leiognathidae) (32.6%). The zoobenthivores dominated all the stations with highest relative abundance in the muddy station 4 (50.0%) and lowest in the sandy seagrass station 1 (36.7%) (Figure10). The herbivores (e.g. Siganidae and Scaridae) formed a small proportion (<6%) in all stations except in station 1 where they formed 22.08% of the trophic groups. The zoooplanktivores (e.g Clupeidae) occurred in low proportions (<3%) in stations 2, and 3 while, detritivores (e.g. Blennidae) were only found in station 4 where they formed the smallest percentage (1.88%) of the trophic groups (Figure 10).

4.7 Temporal use of the Creek by Fishes

Generally, during the sampling period transient fish (Leiognathidae, Fistularidae and Carangidae) and estuarine dependent fish (Lutjanidae, Gerreidae, Teraponidae and Atherinidae) formed the main bio-ecological groups constituting 44.42 and 31.43%, respectively, of the overall samples. The transient fish dominated the fish samples in the month of May 2008 (82.82%). The long-term proportion of the estuary resident species in the samples changed a little and remained about 19% (Figure 11). The rare groups (Centriscidae and Plostidae) formed a big proportion (41.67%) of the samples in November 2007, this was likely due to the occasional occurrence of large schools of the razor fishes, *A. punctulatus* and marine catfishes, *P. lineatus* in samples from station 1 (Figure 11). The proportion of estuarine dependent groups decreased during the SEM season.

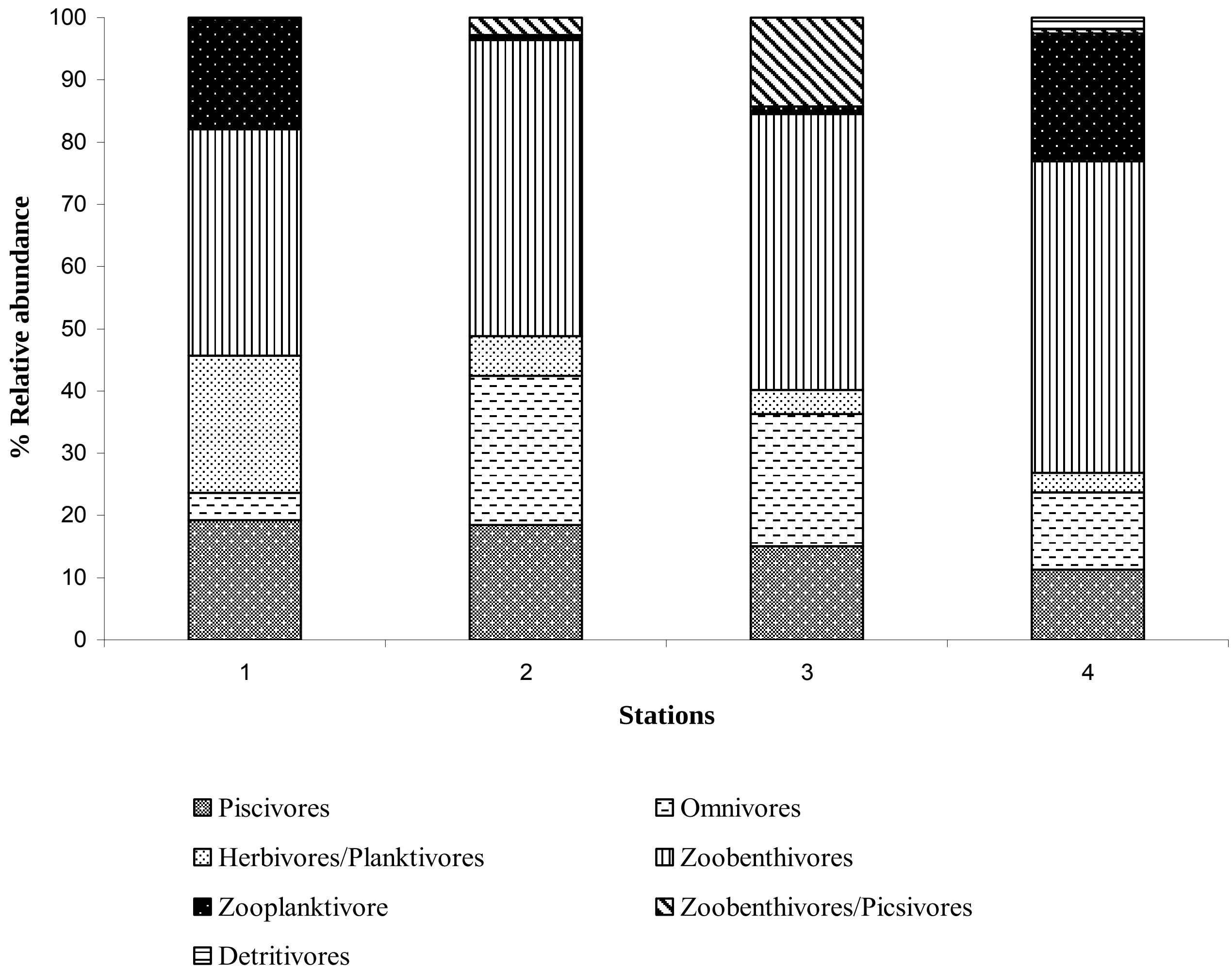


Figure 10: Relative abundance of various trophic groups of fishes in different stations within Tudor Creek.

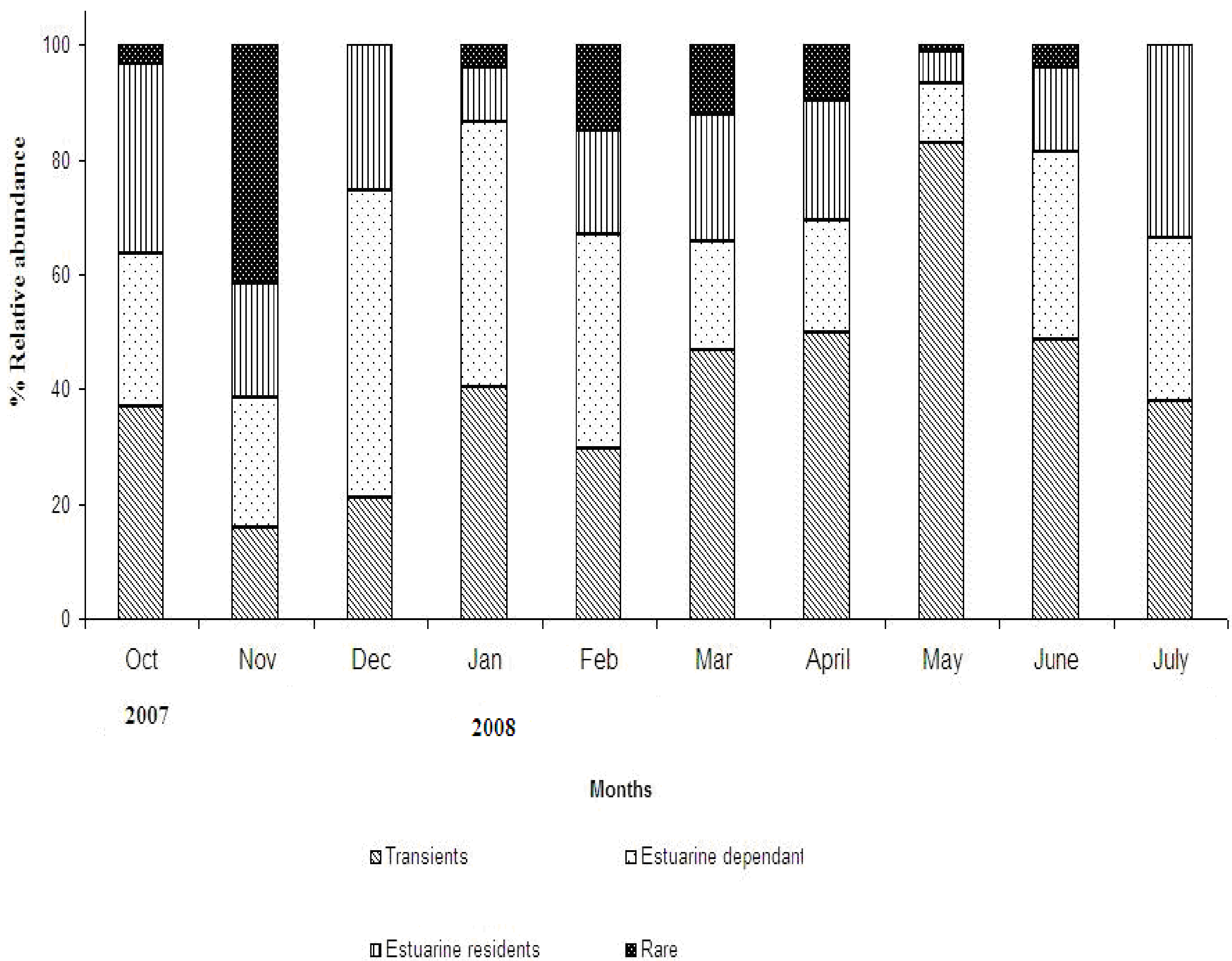


Figure 11: Monthly variation of relative abundance (%) of the bio-ecological groups of fishes within Tudor Creek, between October 2007 to July 2008.

4.6 Fish Size Distribution in the Creek

The size-frequency distribution of some of the common species in the creek is presented in Figure 12. The sizes of these species ranged from 0.1 to 17.9 cm while asymptotic sizes ($L\infty$) ranged from 18 to 140 cm (Figure 12). The size composition of the estuarine resident species; *O. papuensis, O. ophthalmonema* and *F. melanobranchus* consisted of a mix of immature and mature fish (Figure 12c, f & g). The estuarine dependent species, *S. jello*, size structure was skewed to the right (Figure 12e) with modal size being less than that of first maturity, while for *T. jarbua,* another estuarine dependent species, size structure was skewed to the left with modal size less than size at maturity (Figure 12b). The modal sizes of *L. fluviflamma,* an estuarine dependent species, was less than size at maturity indicating preponderance of immature fish while, *A. cyanosoma*, a transient species, had a mix of immature and mature individuals in the creek (Figure12d & j).

All the estuarine resident species were represented by a mix of juveniles and mature individuals, the rest of the common beach seined species were largely represented by immature individuals. The size structure of *S. canaliculatus, G. oyena, L. fulviflamma* and *S. jello* largely consisted of juveniles (Figure 12).

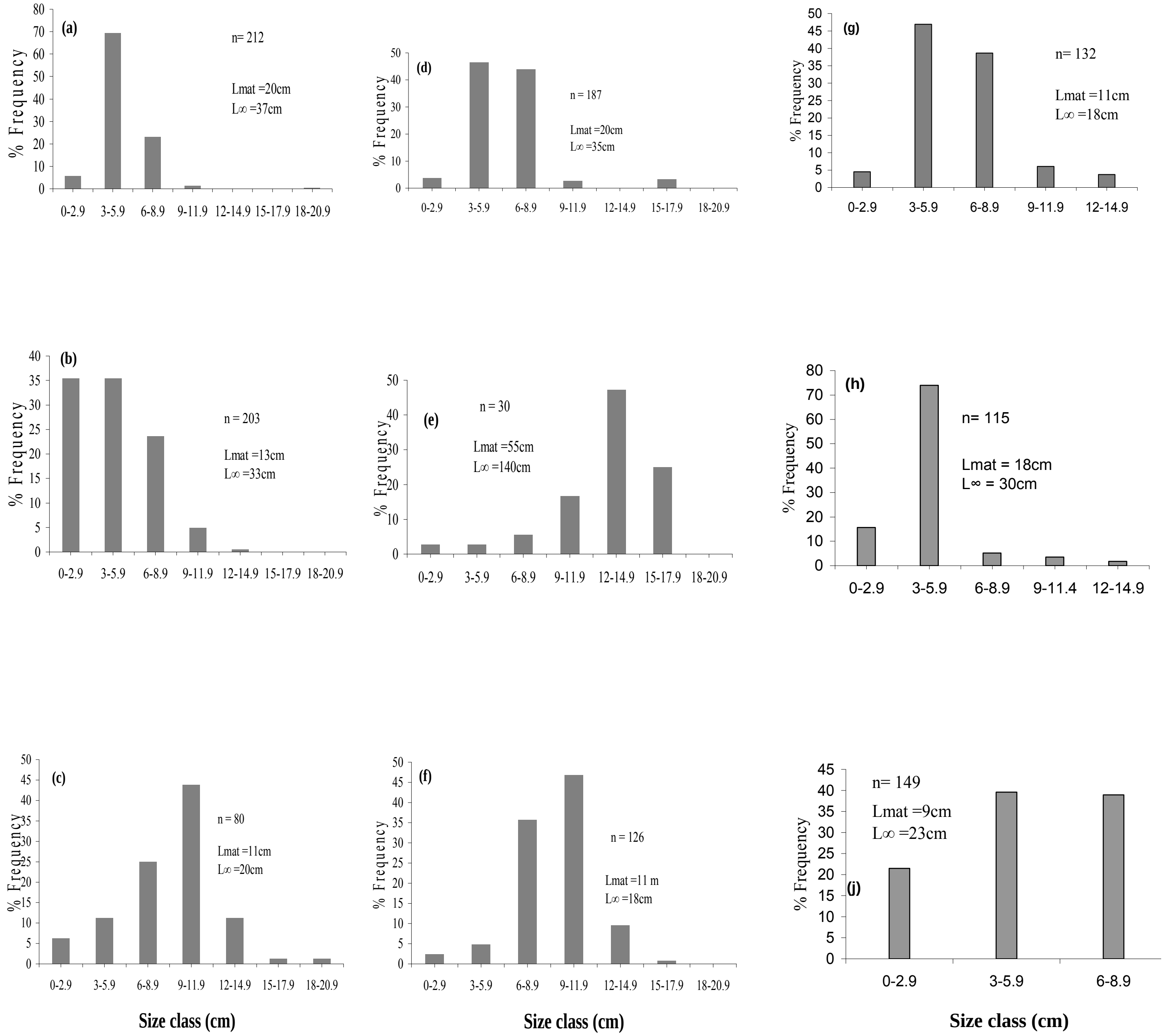


Figure 132: Length-frequencies distribution of the common fish species within Tudor Creek: *(a)Gerres oyena,* (b*)Therapon jarbua,* (c) *Oxyurchthys papuensis,* (d) *Lutjanus fluviflamma,* (e) *Sphyraena jello,* (f) *Oxyurchthys ophthlmonema* (g)*Favonigobious melanobranchus* (h) *Siganus canaliculatus* and (j) *Apogon cyanasoma*. n=Sample size, Lmat=Length at first maturity, L∞=maximum length.

CHAPTER 5

5.0 DISCUSSION

This study sampled 92 species of teleost fish in 45 families within Tudor Creek. The biodiversity found in this study seemed typical of tidal creeks and tropical estuarine systems. These marine ecosystems commonly contain a small number of species that contribute a large proportion of the population (Little *et al*., 1988; Kimani *et al*., 1996; Lin & Shao, 1999; Barletta, 1999; Vidy, 2000; Laffaille *et al.*, 2000; Lugendo *et al.,* 2007). In the present study, while there were generalist species (e.g. *G. oyena, L. fliviflamma A. cyanosoma* and *T. jarbua*) sampled at different stations, there were also a number of specialist species (e.g. *S. canaliculatus, S. jello, A. punctulatus* and *P. lineatus*) which exhibited habitat preference. This mix of bio-ecological groups seems to be a characteristic assemblage structure of bays, inshore and estuarine environments (Little *et al*., 1988; Laffaille *et al.*, 2000; Lungendo *et al*., 2007).

The fish assemblages of Tudor Creek differed considerably between stations. At the more oceanic station 1, the families; Siganidae, Carangidae and Clupeidae dominated while, Gerreidae, Teraponidae, Gobidae, and Lutjanidae dominated the more estuarine creek stations 2, 3 and 4. Overall, this distribution agrees with that found by Little *et al.,* (1988) in the same creek, however, this study found an inward shift in the distribution of Gerreidae than reported by Little *et al.,* (1988). The families Gerreidae, Clupeidae and Atherinidae have been found to dominate other creek systems in Kenya (Kimani *et al*., 1996) while the Gerreidae and Scaridae were reported to dominate estuarine systems in Tanzania (Lugendo *et al.,* 2007).

When compared with other estuarine habitats exhibiting similar environmental conditions, Tudor Creek had comparable species richness with Kilifi Creek in Kenya (Oyugi, 2005) but had lower species richness compared to Gazi (Kenya) and Chwaka (Zanzibar) Bays, respectively (Kimani *et al.,* 1996; Lugendo *et al.,* 2007). Compared to estuaries with marked changes in environmental parameters (mainly salinity) (Spach *et al.,* 2004 and Sanja *et al.,* 2005), Tudor Creek has a relatively high species diversity. The differences in species diversity and evenness between these studies are likely related to habitat differences between sites. The presence of a diversity of substrate types including mangrove fringed sections could explain the high species diversity within the creek. However, factors like differences in sampling technique, as well as sampling effort makes it difficult to objectively compare species diversity and abundance between different estuarine habitats.

Two main fish assemblages were identified during the analyses by the multivariate statistical techniques, the creek was occupied by permanent resident fishes and a group of transient fishes. The grouping seemed to correspond to habitat differences between stations. However, this study contradicts Little *et al.,* (1988) who reported similarity of assemblaege structure between stations in the creek. The dissimilarity in species composition of station 1 to the other stations is likely due to its lagoonal charasteristics, proximity to the coral reefs, and presence of patches of seagrass beds favouring reef associated fishes (e.g. *T. bailoni* and *T. blochii* and *S. canaliculatus*). The similarity in species composition of stations 2 an 3 likely reflect their estuarine characteristics providing no clear dominance of species.

This study found no effect of seasons on the assemblage structure at stations inside the creek (e.g. 2, 3 and 4) compared to station 1 at the creek mouth. This indicates the species assemblage composition inside the creek are more stable compared to the creek mouth. However, other studies have found site and season specific effects on species abundance within creeks (Nagelkerken *et. al.,* 2000). The abundance of commercial fishes (e.g. *G.oyena, T.bailoni* and *L. equula*) depicted significant interaction effects between stations and seasons an indication that the abundance of these species in Tudor Creek is conditional to both habitat type and seasonality. However, the abundance of the Gobidae family (*O.opthalmonema, Y. nebulosus* and *O .papuensis*) was more influenced by stations than seasons being more dominant on muddy substratum (Table 4). Similar distribution patterns for gobies within creeks have been reported in other similar studies (Blaber & Milton, 1990; Little *et al,.* 1988; Lugendo *et al.,* 2007).

In the present study, ecological diversity indices showed little temporal variability with higher values during the NEM season. Little *et al.,* (1988) reported similar observations with higher Shannon-Weiner species diversity during the NEM season in the same creek. Seasonal changes in species diversity within the creek are likely caused by movement of fishes between the creek and offshore areas (Day, 1974). The more calm conditions and higher productivity of the NEM season (MacClanahan, 1988; Obura, 2001) likely contributed to species movement into the creek during this season. In addition, the predominance of juvenile fishes in the creek suggests movement into the creek following spawning that is predominant during NEM season (MacClanahan, 1988).

The rank abundance curves imply the diversity of fishes within the creek was affected by the dominant groups (e.g Siganidae, Lutjanidae and Gerreidae) and that species evenness was variable within the creek. The variability in species evenness was likely related to differences in habitat quality within the creek (Gratwicke, 2005). The high species evenness and diversity in stations 2 and 4 was probably associated with the structural complexity caused by mangroves in these stations (Gratwicke, 2005). These findings of difference in diversity and evenness between the stations in Tudor Creek agree with results from other estuaries and lagoons (Allen, 1982; Robertson & Duke, 1987; Little *et al.,* 1988; Chong *et al,.* 1990). Furthermore, the diversity indices derived in this study were similar in scale to those obtained in other East African estuaries (Kimani *et al.,* 1996; Little *et al.,* 1988). These results suggest fish populations in East African creeks are structured by seasonal habitat changes with additional variability likely caused by anthropogenic effects.

In the present study, species in the family Gobidae (*O. opthalmonema, O. papuensis, G. keiensis*, *Y. nebulosus* and *F. melanobrancus*) were found to occur in all size-classes indicating that they are permanent residents of the creek. However, some species (e.g. *H. far, T. bailoni, L. equula, F. petimba, A. immaculatus* and *C. ignobilis*) used the estuary as a transient habitat (species that enter the estuary only occasionally, usually when conditions in the estuary are very similar to those in the open sea), while others (e.g. *G. oyena, L. fluviflamma, A.lacunous, S. canaliculatus, T. jarbua, S. jello, M. argenteus* and

L. vaigeinsis) appeared to use the creek only during part of their life-cycles (estuarine dependent). Most species use Tudor Creek as a nursery ground thereby confirming this widely believed function of estuaries (Heck & Thomas, 1984; Orth *et al.,* 1984; Spach *et al.,* 2004). The use of a small mesh-sized net and sampling at low water depths would partly explain the high catches of juveniles (Little *et al.,* 1988). However, seine nets have been used to sample estuarine fishes in many locations including; Chwaka Bay-Zanzibar (Lugendo *et al.,* 2007), Paranagua Bay-Brazil (Spach *et al.,* 2004), Botany Bay-Wales (Bell *et al.,* 1984) and Pantan estuary-Adriatic (Sanja *et al.,* 2005). The occurrence of mostly juvenile stages of species in the creek further underscores the important role these habitats play in facilitating between-habitat connectivity (Nagelkerken *et al.,* 2000; Cocheret *et al.,* 2004). Indeed other studies have demonstrated high species diversity in nearshore coastal habitats (e.g. reefs and seagrass beds) located adjacent to mangrove creeks (Biagi *et al*., 1998 Nagelkerken *et al.,* 2000). Therefore these habitats serve important conservation and economic roles.

This study recorded a 7-34% reduction in species richness in the creek from those found by Little *et al*., (1988). Although the diversity indices (*H'* and *J'*) are comparable to those found by Little *et al.,*(1988), the study found significant reduction in Margalef's species richness (*D*) compared to those reported more than 20 years ago for the creek indicating a decline in number of species per sample. The extent to which these changes in species composition is attributed to anthropogenic impacts and climate change effects is not well known and will require further investigations.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

In conclusion, the study found Tudor Creek estuary to have a high diversity of fishes of more than 90 species that is comparable to other tropical estuaries. The results showed that, high species evenness occurred on mangrove lined sections of the creek (stations 2 and 4). Seasonal change (NEM and SEM seasons) seemed to affect the species composition and abundance within the creek with higher species diversity during NEM season. Fish assemblage at the more oceanic station 1 seemed to form a distinct seasonal structure from the other inward estuarine stations, with different species dominating the stations during NEM and SEM seasons. At the innermost station 4, the fish assemblages were poorly separated between the seasons, however, NEM season appear to be dominated by three species, and the fish assemblage structure of this station was similar to that of stations 2 and 3 during the SEM season. These temporal variations in fish assemblages along the creek indicate the effect of seasonality in shaping the fish community structure of the creek.

Tudor Creek is an important habitat for the Gobiidae fishes that appear to spend their entire life cycle (juvenile to adult) in the creek. In addition, the creek provides a habitat function to the estuarine dependent (e.g. Lutjanidae, Gerreidae, Tetaponidae and Apogonidae) and the transient fish groups (e.g. Carangidae, Hemiramphidae, Chanidae and Leiognathidae). The presence of fish with sizes less than (that of) maturity, indicates that the creek is an important nursery ground for many fish species. Due to its species diversity, diverse trophic categories and its apparent nursery role for juvenile fishes, Tudor Creek serves important ecological functions. Management measures need to be taken to protect the creek from any possible negative human influence and mitigate possible climate change effects.

These findings will add to the database on the ichthyofauna of Kenyan coastal estuaries as well as in the WIO region. Tudor Creek is one of the largest sheltered Kenyan creeks, with important economic and conservation role. It is a vital source of livelihood for most fishermen within Mombasa island, the results of this study will contribute to management and conservation initiatives of its biodiversity.

6.2 RECOMMENDATIONS

From the results of this study the following recommendations are advanced:

1. Tudor Creek is an important nursery ground for many fish species and is utilized by different species during different stages in their life cycle, there is need for continuous monitoring program for conservation and fisheries management. This is particularly important because of the dependence on the creek by local fishermen for livelihood. The future of this source of livelihood depends on its good management based on scientific information such as that generated in this study
2. More detailed studies on the tropho-dynamics of the creek are required to understand the factors that influence the distribution and abundance of feeding guilds at different scales.
3. Other sampling methods targeting a wider size range of fishes on a wider temporal scale are required to be able to understand the utilization regimes and residency status of the different fish species and factors influencing the abundance of bio-ecological groups within the creek.
4. A further investigation on the anthropogenic impacts and climate change and the extent to which they affect species composition within the creek is needed.
5. There is need for a long term multi-disciplinary monitoring for ecosystem based approach to fisheries management, to help identifying the different factors which may contribute to changes in biodiversity and loss in habitat function.

6. There is a need to establish fish catch per unit effort (CPUE) trends as well as population parameters (growth parameters, mortality rates, exploitation rate, maximum sustainable yield and recruitment patterns). This information will be useful in formulating management and conservation policies as well as in the further development of the fishery in Tudor Creek.

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APPENDICES

Appendix 1: Anova results for comparison of mean fish density between stations.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	6033.887	3	2011.296	2.935	.035
Within Groups	106901.547	156	685.266		
Total	112935.433	159			

Appendix 2: Tukey HSD test following Anova results of mean fish density between stations**.**

(I) Station	(J) Station	Mean Difference (I-J) Lower Bound	Std. Error Upper Bound	Sig. Lower Bound	95% Confidence Interval Upper Bound	 Lower Bound
1	2	-3.1081663	5.3367919	.937	-17.136772	10.920440
	3	-.6956343	6.6165666	1.000	-18.163762	16.772493
	4	12.6616765(*)	4.2235337	.019	1.563084	23.760269
2	1	3.1081663	5.3367919	.937	-10.920440	17.136772
	3	2.4125320	7.1195783	.986	-16.315558	21.140622
	4	15.7698428(*)	4.9747040	.012	2.657047	28.882638
3	1	.6956343	6.6165666	1.000	-16.772493	18.163762
	2	-2.4125320	7.1195783	.986	-21.140622	16.315558
	4	13.3573108	6.3281343	.162	-3.408684	30.123305
4	1	-12.6616765(*)	4.2235337	.019	-23.760269	-1.563084
	2	-15.7698428(*)	4.9747040	.012	-28.882638	-2.657047
	3	-13.3573108	6.3281343	.162	-30.123305	3.408684

* The mean difference is significant at the .05 level.

Appendix 3: Tukey HSD test following Anova results of mean Pielou's evenness index (*J'*) between stations.

(I) Sites	(J) Sites	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound
1	2	-.0433429	.0459692	.782	-.167148	.080463
	3	-.0361385	.0459692	.860	-.159944	.087667
	4	-.1414459(*)	.0459692	.020	-.265251	-.017640
2	1	.0433429	.0459692	.782	-.080463	.167148
	3	.0072044	.0459692	.999	-.116601	.131010
	4	-.0981030	.0459692	.162	-.221909	.025703
3	1	.0361385	.0459692	.860	-.087667	.159944
	2	-.0072044	.0459692	.999	-.131010	.116601
	4	-.1053074	.0459692	.119	-.229113	.018498
4	1	.1414459(*)	.0459692	.020	.017640	.265251
	2	.0981030	.0459692	.162	-.025703	.221909
	3	.1053074	.0459692	.119	-.018498	.229113

* The mean difference is significant at the .05 level.