ASSEMBLAGE STRUCTURE OF DECAPOD CRUSTACEANS IN THE MALINDI-UNGWANA BAY, KENYA.

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DECLARATION

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DEDICATION

This Thesis is dedicated to my late father, Johnson Ndoro Chimwenga, my mother Janet Manyaza Kambu, beloved wife Constance Kafedha; Sons; Martin Kenga and Henry Katana, daughters; Marion Mkambe and Michelle Manyaza.

ABSTRACT

Decapod crustaceans support both the artisanal and semi-industrial fisheries in Kenya and the Western Indian Ocean (WIO) region. Despite their commercial value, data on their assemblage structure is lacking in most of the WIO region but the data are important for stock management. This study aimed at bridging the data gaps by providing information on the seasonal variation in assemblage structure of decapod crustaceans in Malindi-Ungwana Bay, Kenya. Samples were collected during the northeast monsoon (NEM) and southeast mosoon (SEM) seasons in a two-week experimental bottom trawling survey under the South West Indian Ocean Fisheries Project (SWIOFP). Samples were collected during NEM and SEM seasons between 22nd January to 4th February 2011 and 22nd May to 4th June 2011, respectively. A total of 43 transects covering an estimated area of 546.4 nm^2 were trawled in four depth zones (0-10 m, 10-20 m, 20-40 m and 40-100 m) in both seasons. Twenty species of decapod crustaceans belonging to 7 families were sampled in both seasons. The species were distributed in the families; Penaeidae, Portunidae, Calappidae, Majidae, Matutidae, Palinuridae and Scyllaridae. The penaeid shrimps had a higher relative numerical abundance both in the NEM and SEM seasons of 89.3 and 85.3 %, respectively. Of the penaeid shrimps, *Fenneropenaeus indicus*, had the highest relative abundance of 57.6% during NEM and 41.5% during SEM season. Sex ratios of the penaeid shrimps were skewed towards females in the depth zones 2 (10-20 m) and 3 (20-40 m). Analysis of Similarity (ANOSIM) test indicated significant difference in total crustacean abundance (individuals/km^2) between the depth zones, (R=0.375; P=0.001; considering all seasons) but no significant difference between the seasons (R= -0.031; P=0.602; considering all depths). The mean species richness in the bay was higher during SEM than NEM season for all depth zones. ANOVA indicated significant effect of depth (F=3.4773; df=2, 29; P=0.044) but not season (F=0.5155; df=1, 29; P=0.479) on species diversity. The crustacean assemblage structure in the bay was more influenced by depth profiles than seasonality. The shrimps, *F. indicus*, *Penaeus monodon* and the crab, *Portunus sanguinolentus* were mostly associated with depth zone 1(0-10 m), while the shrimps *Metapenaeus monoceros*, *Penaeus japonius* and the crab *Ashtoret lunaris* were closely associated with depth zone 2 (10-20 m). There was no clear species association with depth zone 3 and 4. Canonical Correspondence Analysis (CCA) indicated the influence of temperature, salinity, Secchi depth and dissolved oxygen in the bathymetric distribution of the crustaceans in the bay. It is recommended that seasonal distribution of the crustaceans be taken into consideration when developing crustacean fishery management plans for the bay. Additionally, surveys in the bay should examine annual changes on assemblage structure in addition to biomass changes for species.

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LIST OF ACRONYMS

ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
DoF	Director of Fisheries
FAO	Food and Agriculture Organization
ITCZ	Inter Tropical Convergence zone
KCDP	Kenya Coastal Development Project
KMFRI	Kenya Marine and Fisheries Research Institute
NEM	North-east Monsoon
SEM	South-east Monsoon
SWIOFP	South West Indian Ocean Fisheries Project
SWIO	South West Indian Ocean
WIO	Western Indian Ocean

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CHAPTER ONE

INTRODUCTION

1.1Background Information

Marine decapod crustaceans account for nearly 5.7 % of all fin and shell fish landings by weight world-wide (FAO, 2008) and the landings have been on the upward trend in the last decade (FAO, 2008, 2012). The rise in decapod crustacean catches is partly due to dwindling fish stocks worldwide (Pauly *et al*., 1998; Jackson *et al*., 2001; Worm *et al*., 2006; FAO, 2010). Crustacean stocks are, however, increasingly being threatened with overfishing (FAO, 2012) mostly because of this shift in target species globally. Decapod crustaceans support large artisanal and industrial fisheries in the South West Indian Ocean (SWIO) region (van der Elst *et al*., 2009). In Kenya, shallow water prawns, crabs and lobsters are caught by both artisanal and commercial fishers while, deep-water crustaceans are fished by semi-industrialized and industrialized trawlers operating exclusively in Malindi-Ungwana Bay (Mwatha, 2005; Fulanda et al., 2011; Fennessy, 2012; Munga et al., 2012). Kenya landed from both artisanal and semi-industrial fisheries a total of 994 tonnes of crustaceans in 2003 comprising 2.7 % of the SWIO landings (van der Elst et al., 2009; DoF, 2006). The extent to which fishing pressure affects the assemblage structure of the crustaceans in the bay is not known but may be significant (Fulanda et al., 2011).

The fresh water discharge into Malindi-Ungwana Bay is thought to contribute to the high crustacean biomass in the bay relative to other sites in coastal Kenya (KMFRI, 2003; Fulanda et al., 2011). Marine benthic communities like crustaceans may be influenced in their distribution patterns and assemblage structure by several abiotic and biotic factors as well as fishing mortality. Studies indicate that important abiotic factors influencing abundance include: depth profile (Munoz, et al., 2008; Fanneli et al., 2007), salinity gradient (Gillett, 2008), substratum structure (Lavrado et al., 2000) and rainfall patterns (Teikwa and Mgaya, 2003) amongst others. Environmental productivity (Follesa et al., 2009) as well as biological interactions (Jackson, et al., 2001) are important biotic factors that may affect local assemblage structure of crustaceans. A limited number of studies on decapod crustaceans exist in the WIO region relative to the temperate latitudes; examples include Groeneveld and Melville-Smith (1995), Groeneveld (2000) and Maynou and Cartes (2000). In Kenya, the composition and distribution of crustaceans in Malindi-Ungwana Bay is thought to be influenced by seasonality and depth amongst other factors (Mwatha, 2005), however, there have been no data to validate this notion. Decapod crustaceans are a dominant or sub-dominant faunal component in tropical assemblages such as in coastal Eastern Africa. They form an important link between lower and higher trophic levels (Cartes and Carrass, 2004). Studies on their assemblage structure may offer useful information on trophodynamics and ecosystem function at a local scale (Papiol et al., 2012).

This study therefore aimed at bridging the data gaps by providing information on the spatial and temporal variation in assemblage structure of decapod crustaceans in the bay to assist management of the fishery and to assist with understanding stock performance over time.

1.2 Statement of the problem

Information on the decapod crustacean fishery resources of Kenyan waters is inadequate for purposes of management and conservation of stocks (Groeneveld et al., 2009). Experimental trawling for crustaceans has been done at Malindi and Ungwana Bays by the Food and Agriculture Organization (FAO/UNDP, 1979, 1982) and by the Kenya Marine and Fisheries Research Institute (KMFRI) in 2003 but these have concentrated on penaeid prawns. Available data from FAO fishery surveys on crustaceans in Kenya are almost three decades old and the recent surveys (2005, 2009) conducted by KMFRI were mainly prawn-based and did not cover the other crustaceans or examine factors affecting abundance. Therefore there is a gap on knowledge in marine benthic community structure.

1.3 Justification

Malindi-Ungwana Bay supports Kenya's only commercial penaeid shrimp fishery supporting about 2000 fishers and is therefore an important source of livelihood to coastal communities (Ochiewo, 2006). Malindi-Ungwana Bay fishing grounds are considered to be some of the most productive and extensive shrimping areas on the East African coast (Mutagyera, 1984). The composition, distribution, abundance and diversity of decapod crustaceans in the bay in relation to abiotic and biotic factors remain largely unknown. However, the information would be useful for conservation and management of the stocks.

Knowledge on assemblage structure and population dynamics of benthic communities inhabiting continental shelf and slopes (e.g decapod crustaceans) are important for management and conservation of stocks especially where communities have significant commercial value as in the WIO region. Unfortunately, population ecology of decapod crustaceans in Kenya and the rest of the WIO region has received little attention (van der Elst et al., 2009). Most studies have concentrated on the taxonomy, stock assessment and functional biology of single species (Wakwabi and Jaccarini, 1993, 1996; Teikwa and Mgaya, 2003; Mwatha, 2005; Fondo *et al*, 2010). More recent studies have concentrated on the fishery impacts on commercial penaeid prawns (Munga et al., 2012; Fulunda et al., 2011). The present study contributes to the knowledge gap in marine benthic community structure in the WIO region by describing the assemblage structure of decapod crustaceans and its relationship with abiotic factors and seasonality within Malindi-Ungwana Bay, Kenya.

1.4 Objectives of the study

The broad objective of the study was to provide information on the assemblage structure of decapod crustaceans in Malindi-Ungwana Bay necessary for sustainable exploitation of the stocks. The specific objectives were:-

1. To determine the seasonal variation in composition, relative abundance and diversity of the decapod crustacean species in Malindi-Ungwana Bay.
2. To relate species abundance and composition of decapod crustaceans to bathymetric profile of Malindi-Ungwana Bay.
3. To determine seasonal variation and depth distribution of maturity stages of the dominant penaeid crustacean species within the bay.
4. To relate the environmental variables of the bay to abundance of the dominant crustacean species in the bay.

CHAPTER TWO

LITERATURE REVIEW

2.1 Malindi-Ungwana Bay Physical Environment

Malindi-Ungwana Bay complex which covers an area of about 35,300 km^2 is the only area along the Kenyan coastline with suitable trawling grounds and high biomass of shallow water prawns (Mutagyeria, 1984; Mwatha, 2005). The bay is influenced by a number of current systems including the South Equatorial Current, the East Africa Coastal Current and the seasonal Somali Current that flow off coastal East Africa (McClanahan, 1988; van der Elst et al., 2009). The marine environment around the bay is defined by a series of seasonal upwelling cycles driven by the movement of the Inter-Tropical Convergence Zone (ITCZ) (McClanahan, 1988). There are two seasons that influence the oceanographic condition of the bay all year round; these are northeast monsoon (November-March) and southeast monsoon (April-October) seasons (McClanahan, 1988). The greatest amount of rainfall occurs during the southeast monsoon (April-October) when winds pass over the Indian Ocean. During the northeast monsoon, the air mass passes over the drier Somali land mass and therefore coastal areas receive only a small rainfall peak (McClanahan, 1988). Southeast monsoons are characterized by high cloud cover, rain, wind energy and decreased temperature, salinity and light. This is in contrast to northeast monsoon season (November to March) when variables are reversed. These climatic phenomena ultimately affect physical, chemical and biological oceanographic processes along the

Kenyan coast (McClanahan, 1988). For example, there are higher surface water chlorophyll concentrations during the SEM season (Kaunda-Arara, et al., 2009).

Malindi-Ungwana Bay is drained by two large rivers; River Sabaki in Malindi and Tana River to the north. The Tana River is the longest in Kenya being approximately 850 km in length with a catchment area of 95,000 km^2 (Tychsen, 2006). An average of 4,000 million m^3 of freshwater is carried by the river into the ocean and Ungwana Bay with peak flows occurring between April and June and a shorter high flow period during November and December (Tychsen, 2006). Some 3 million tonnes of sediment are also discharged annually into the bay by this river (Tychsen, 2006). The river produces a complex of tidal creeks, flood plains, coastal lakes and mangrove swamps known as the Tana Delta extending about 30 km upstream (Tychsen, 2006). The Tana River, contributes more than 50% of the total river discharges into the Kenyan sector of the Indian Ocean (Kitheka *et al*., 2005). The maximum river discharges into the bay recorded during the southeast and northeast monsoons were 750 and 350 m3 s^{-1}, respectively (Kitheka *et al.*, 2005). The peak river discharges occur in May and November and the total daily sediment load of the river varies from 2796 tons day^{-1} during the dry season to 24,322 tons day^{-1} during the rainy season (Kitheka *et al*., 2005). The net export of sediments to Ungwana Bay results in a large plume of highly turbid water that is driven by currents generated by the monsoon winds. During the northeast monsoon season, the plume moves southward and during the southeast monsoon, the plume moves northward (Kitheka *et al*., 2005).

The Sabaki River is the second longest in Kenya with a length of 650 km and a catchment area of 70,000 km^{2}. (Tychsen, 2006). The river discharges 2,000 million m^3 of freshwater and 2 million tonnes of sediment annually into Malindi-Ungwana Bay through the Sabaki estuary north of Malindi (Tychsen, 2006). The Sabaki River basin experiences wide variations in river discharge related partly to the two monsoon seasons (KMFRI, 2003). During the southern monsoon, high flows are observed in the period between March and June. The peak river discharge of $382m^3s^{-1}$ occurs in May (KMFRI 2003). During the northern monsoon, high discharges usually occur in the period between November and January with peak river discharge in November. The river discharge varies from 7 to $382m^3s^{-1}$ (KMFRI, 2003).

2.2 Crustacean Fishery

Decapod crustaceans support large artisanal and industrial fisheries in the Western Indian Ocean (WIO) region (SWIOP/CNRO, 1990; SWIOP/MNRT; van der Elst *et al*, 2009) According to van der Elst *et al* (2009), the WIO fisheries yielded 350,000 tonnes of crustaceans in 2003, dominated by shrimps and crabs. The South WIO countries which include Madagascar, Mozambique, Mauritius, Kenya, Comoros, Tanzania, France (Mayotte and Reunion), Seychelles and South Africa, landed 35,000 tonnes of crustaceans in 2003 or 10% of the total WIO landings. The bulk of the crustacean catches in the SWIO come from Mozambique and Madagascar shallow-water penaeid shrimp fisheries (van der Elst et al., 2009). Shallow-water shrimps, crabs and lobsters are caught by both artisanal and commercial fishers in the WIO countries. The deep-water crustaceans are caught by semi- industrialized and industrialized trawl vessel for shrimps, langoustines and traps for lobsters

(Mutagyrera, 1984; Groeneveld and Melville-Smith, 1995; Fennessy and Groeneveld, 1997; Groeneveld (2000, 2012 a, b), Groeneveld *et al* (2009), Fennessy (2012)). Kenya landed from both artisanal and semi-industrial fishery, a total of 994 tonnes of decapod crustaceans in 2003 accounting for 2.7 % of the SWIO landings (van der Elst et al., 2009; DoF, 2006). The Kenyan landings consisted of 67, 18, and 15 % prawns, lobsters and crabs, respectively mainly from penaeidae, portunidae and palinuridae families (DoF, 2006). In 2011, Kenya landed a total of 574 tonnes of decapod crustaceans from the artisanal fishery alone. This consisted of 48, 36 and 16% prawns, crabs and lobsters, respectively. All crustacean industrial landings in Kenya originate from Malindi-Ungwana Bay, but a ban on industrial trawling was, imposed from 2006 to 2010 (DoF, 2011) so as to address the conflict between the artisanal and the semi industrial prawn trawl conflict.

Decapod crustaceans in Kenya have been recognized as a resource of considerable financial value both for the artisanal fisherman and the potential exporter. The lobsters, p prawns and crabs are caught in shallow water areas by artisanal fishermen and semi-industrial trawling in Malindi-Ungwana Bay (Mutagyera, 1984). The penaeid shrimps caught in the bay are: *Fenneropenaeus indicus, Penaeus monodon, P. semisulcatus, P. japonicus* and *Metapenaeus monoceros* (Mutagyera, 1984; Mwatha, 2005; Fulanda et al., 2011). The shallow water spiny lobster species landed from the bay include; *Panulirus ornatus, P. longipes, P. versicolor, P. homarus, P. dasypus,* and *P. penicillatus*, while the portunid crab species *Scylla serrata, Portunus pelagicus* and *P. sanguinolentus* are also from the bay (Mutagyera, 1984) .

Historical trawl surveys undertaken by the research vessel R/V Professor Mesyatsev from 1975-1977 in Malindi-Ungwana Bay and on the North Kenya Bank (Figure. 1) showed that the spiny lobster (*Puerulus carinatus)* was the dominant crustacean species in the 200-250 m strata off Ungwana Bay, where catches of 20-60 kg/h were frequently made in June, July and December, with catches exceeding 100kg/h on some occasions (Birkett, 1979). Catch rates for other lobsters caught in the bay included *Linuparis somniosus* (3-4kg/h), *Thenus orientalis* (20-50kg/h), *Ibacus novemdentatus* (10kg/h) and *Metanephrops andamanicus* (3-4 kg/h) at a depth range of between 240-500 m. The large portunids (swimming crabs e.g *Charybdis spp*) were sometimes caught in commercial amounts but they were generally small in size (Birkett, 1979).

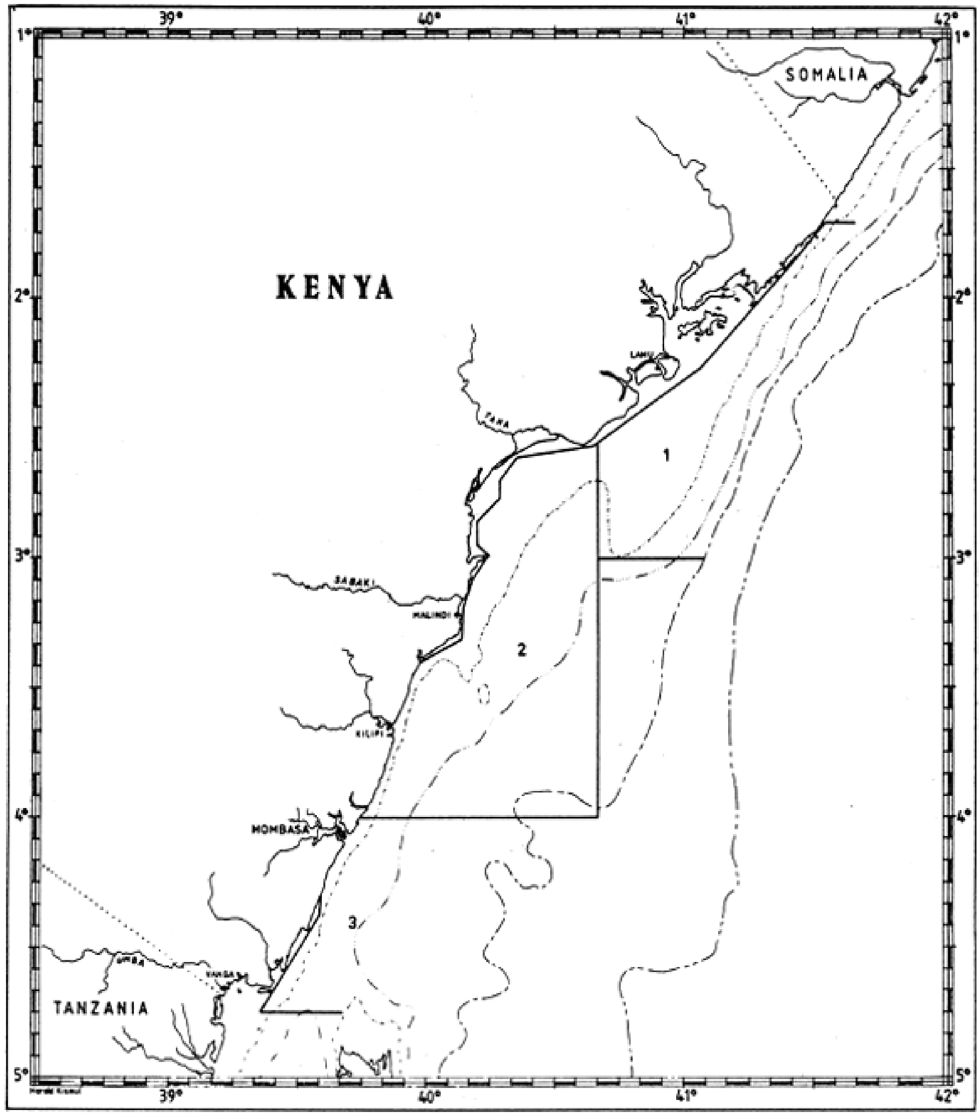

Figure 1. The areas covered by R/V Professor Mesyatsev surveys: (1) North Kenya Bank area (2) Malindi - Ungwana Bay area, (3) The Southern area. (Source: Iversen, 1984)

Historical offshore trawl surveys also exist for R/V Ujuzi from 1979 to 1981 (FAO/UNDP, 1982), where deep-water prawns were identified as mainly consisting of *Heterocarpus woodmasoni* commonly known as the Indian nylon prawn. The surveys found deep water prawns were abundant off Ungwana Bay with highest densities off Malindi Bay (FAO /UNDP, 1982). Other potentially valuable deep water crustaceans caught during these experimental trawling surveys included deep sea lobsters *Puerulus angulatus, Metanephrops andamanicus* and the slipper lobster, *Thenus orientalis.* According to Mutagyera (1984), R/V Ujuzi catch rates ranged from 0.1 to 200 kg/hr. The catches were higher during the southeast monsoon than in the northeast monsoon and in one of the trips, a mean abundance of 720 kg/nm^2 for prawns and 244 kg/nm^2 for lobsters was estimated.

Iversen (1984) reported that the catch rates of shrimps and prawns by R/V Dr. Fridtjof Nansen in depths between 200-300 m were very poor; usually less than 1–2 kg/hr. Recent studies in Malindi-Ungwana Bay report variable but reduced catch rates of the decapod crustaceans (Mwatha, 2005; Kimani et al., 2009).

Trawl survey Studies on shallow water crustaceans conducted in Malindi-Ungwana Bay by Mwatha (2005) showed that the Indian white prawn, *Fenneropenaeus indicus*, comprised 46% of the valuable crustaceans. The other penaeids *Metapenaeus monocerous*, *Penaeus monodon*, *P. semisulcatus* and *P. japonicus* contributed 21, 20, 12 and 1 %, respectively, of the catches with spatial and temporal variability in the catch composition being evident. Another study reported *F. indicus* to account for 55-70% of the shrimp species in the bay while *M. monoceros*, *P. semisulcatus, P.*

monodon and *P. japonicus* accounted for 5-15 % of the shrimp abundance (Fulanda et al., 2011). Spiny lobsters caught in the shallow water fishing grounds of the bay include; *P. ornatus, P. longipes, P. versicolor, P. homarus, P. dasypus* and *P. penicillatus* (Mutagyera, 1984; Fulanda et al., 2011).

Kimani *et al*, (2009) Kenya Coastal Development Project (KCDP) trawl survey, reported mean prawn biomass (Kg/nm^2 ± SE) estimates at Ungwana and Malindi bays as 1057.2±522.7 and 415.3 ±121, respectively. The catch composition of prawns by weight during the survey comprised mainly of *F. indicus (*45.09 %), *P. monodon* (8.13 %;), *P. monoceros* (26.33 %), *P. semisulcatus* (10.26 %) and *P. japonicus* (2.31 %).

All the surveys undertaken in Malindi-Ungwana Bay (2005-2011) indicated that *F. indicus*, was the most abundant prawn species in shallow waters of the bay. The 2005 survey (Mwatha, 2005) recorded *P. monodon* as being the second most abundant, however, the KCDP 2009 and the 2011 reference surveys recorded *M. monoceros* as the second most abundant species. The results therefore indicate temporal changes in species abundances within the bay.

2.3 Assemblage Structure and Influencing Factors

The local composition of decapod crustaceans is influenced by several factors. In coastal Tanzania, the penaeid prawns (*F. indicus*, *P. monodon, M. monoceros and P. japonicus*) have been found to occur in high biomass during the rainy rather than dry seasons (Teikwa *et al*., 2003). Rainfall is thought to initiate the migration of prawns offshore by lowering salinities or simply by mechanical flushing of water run-off and by disturbing bottom sediments (Teikwa and Mgaya., 2003). The onset of the wet season triggers an offshore migration of the juveniles, which are then recruited to the fishery areas (Teikwa and Mgaya, 2003). The penaeid prawns, which are a very important component of the estuarine and marine systems in the tropics, can be found from very shallow fringes of tropical estuaries down to about 1000 m depth on the continental slope (Garcia, 1988). The degree to which each stage of the life cycle of crustaceans is linked to the marine or estuarine environment is greatly variable. Some species spend their entire life cycle in the estuaries (e.g. *Metapenaeus mastersii*), others in the strictly marine environment down to 1000 m (e.g *Plesiopenaeus edwardsianus*), but many species use both environments at variable times (Garcia, 1988). Therefore local assemblage structure will show temporal variability.

The abundance of crustacean species has been correlated with physical factors such as temperature, oxygen and depth profile (Bianchi, 1992). These variables covary and it is difficult to interpret their effects separately. However, studies have increasingly shown the effect of depth on assemblage structure of crustaceans (Abello *et al*., 1988; Ungaro *et al*, 1999; Fanneli *et al*., 2007; Munoz et al., 2008). These studies have also shown that the species are linked closely to sediment type and to the amount of suspended organic matter. Sediment characteristics have been found to strongly influence occurrence and distribution of many benthic decapod crustaceans, especially those with burrowing habits (Abello *et al*., 1988; Zettler, 2001; Fanneli *et al*., 2007). The influence of depth is likely because depth integrates many physical characteristics (e.g. temperature, oxygen, salinity, light, etc). Ye *et al*., (1999) found that depth was the most influential factor compared to temperature and salinity in structuring the distribution of penaeid prawns in Kuwait waters. Wienner and Read (1982) found that decapod crustacean assemblages showed definite changes in abundance and composition with seasons and depth in South Atlantic Bight waters. Limits on distribution of crustaceans and their densities have also been attributed to food resources and temperature variability (Fanneli et al., 2007). Lavrado *et al* (2000) and Papiol *et al* (2012) in a study of bentho-pelagic assemblages in the middle slope of the Balearic basin in northwest Mediterranean found that temperature, salinity, turbidity and river discharge were the main environmental variables explaining megafaunal assemblages. All these variables directly or indirectly affect availability of trophic resources at bathyal depths. Temperature and salinity are intrinsically related to depth, and are likely the variables which influence organisms with depth (Papiol *et al*., 2012). Diversity of organisms often decreases with depth and this may be related to effects of temperature and productivity (Papiol *et al*., 2012).

Trophic relationships have often been used to explain community organization at different spatial and temporal scales (Follesa *et al*., 2009). The lowest values of species richness (S) of megafauna are often found on the lower continental slopes, which could be explained by a decrease in food supply enhancing competitive exclusion of the species (Follesa *et al*., 2009). Trophic position is also important in defining time-related changes in marine ecosystems and the trophic level of species may change depending on environmental variability (Cartes and Carrass, 2004). The extent to which trophic relationships affect crustacean abundance in Malindi-Ungwana Bay is not known but may be significant. High river runoff to deltas and bays may enhance phytoplankton production and accumulation of fresh organic matter over the continental shelf necessary to support faunal assemblages (de Juan and Cartes, 2011). The accumulation of organic matter in a deltaic system like Ungwana Bay can be directly exploited by suspension and deposit feeders thereby enhancing the trophic relationships. The effects of the river plume over the continental shelf as in Ungwana Bay (Kitheka *et al*, 2005) may be to enhance productivity of the megafauna (de Juan and Cartes, 2011).

Evidence from retrospective records strongly suggests that major structural and functional changes due to overfishing occurred worldwide in coastal marine ecosystems over many centuries (Jackson, et al., 2001). Severe overfishing drives species to ecological extinction because overfished populations no longer interact significantly with other species in the community (Jackson, *et al*., 2001). Overfishing results into changes in assemblage structure of ecological communities, because unfished species of similar trophic level assume the ecological roles of overfished species until they too are overfished or die of epidemic diseases related to overcrowding (Jackson, *et al*., 2001). Pauly *et al* (1998) reported that fishing down the marine food webs to lower trophic levels leads at first to increasing catches then to a transitional associated with stagnating or declining catches which indicate that the exploitation pattern is not sustainable. However, the extent to which fishing has influenced assemblage structure of crustaceans in Malindi-Ungwana Bay is not clear but is likely significant. Further, the interaction of fishing and ecological factors may have significant effects on the assemblage structure of decapod crustaceans in the long term and will need investigation. This study provides data that can form a benchmark for retrospective analysis of changes in assemblage structure of crustaceans in the bay.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Study Area

The study was carried out within Malindi-Ungwana Bay on the northern coast of Kenya (Figure 2). Malindi-Ungwana Bay lies between latitudes 3º 30'S and 2º 30'S and longitudes 40º 000'E and 41º 000' E. The bay is within Malindi and Tana River districts in the coast province of Kenya and includes areas from Malindi Bay northwards to the Tana River delta at Kipini (Figure 2) covering an estimated 200 km of coastline (Mueni, 2006). The bay is the only known trawlable shallow area of the coastal waters of Kenya (Brusher, 1974; Mutagyera, 1984; Mwatha, 2005). This area has a continental shelf ranging from 15 to 60 km in width (Mwatha, 2005). The continental shelf is wider at Kipini (Figure 2) where it attains a width of between 20-30 km with waters of less than 20 m depth. The shelf is narrower (5-10 km) at Malindi with depths averaging 40 m (Iversen, 1984). Malindi-Ungwana Bay complex covers an estimated area of about 35,300 km^2 (Iversen, 1984; Mwatha, 2005).

Highest salinities occur during NEM when air temperatures and solar insolation are high and rainfall and discharge low (Mclanahan, 1988). Local runoff is greatest during the SEM. The total effect is such that the SE monsoon has the greatest influx of freshwater and terrestrial nutrients into the bay. Nutrient concentrations in rivers are quite high due to poor inland soil conservation practices (Mclanahan, 1988). This seasonality affects chemical and biological processes along the coast. For example, there are higher surface water chlorophyll concentrations during the SEM season (Kaunda-Arara, et al., 2009).

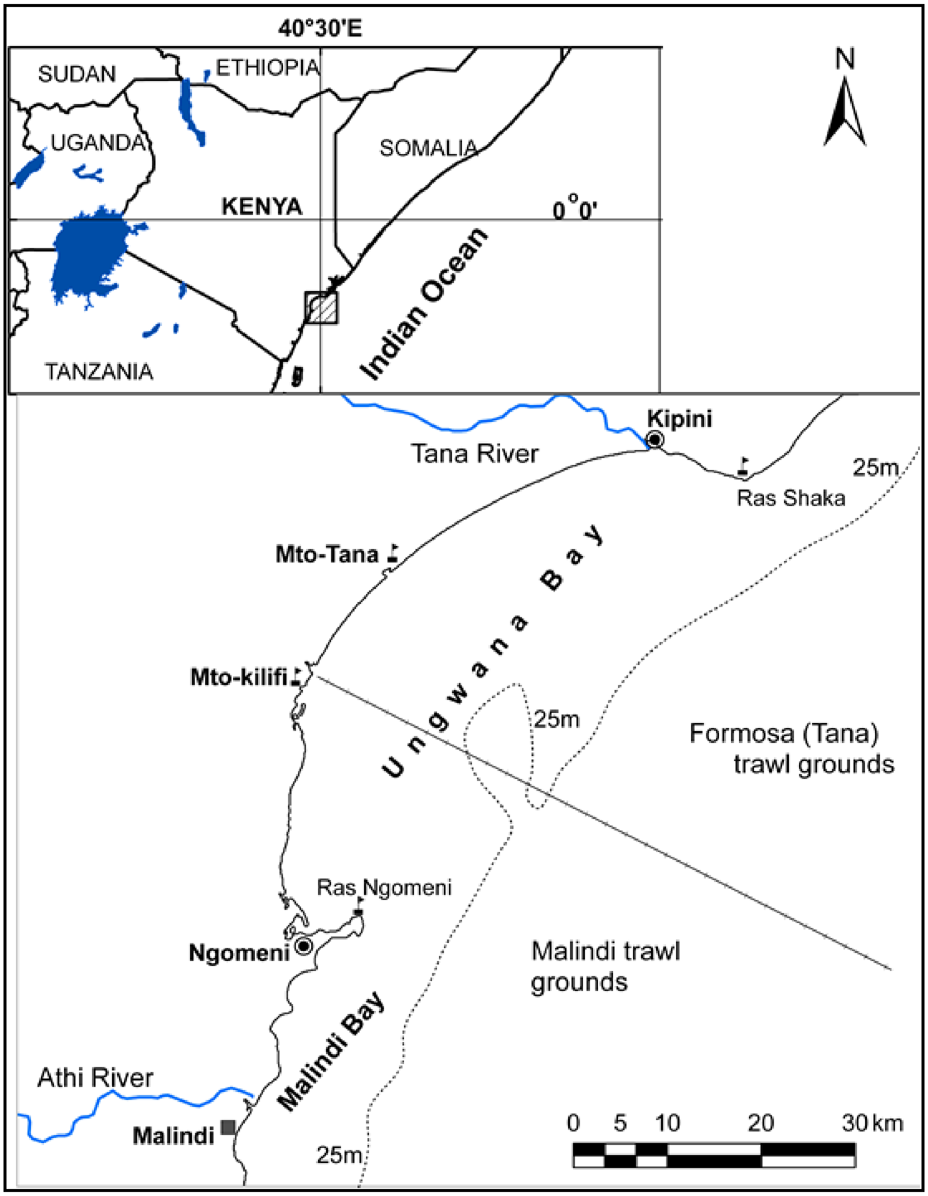

Figure 2. Map of the Malindi – Ungwana Bay. Note the rivers Sabaki (Athi River) and Tana discharging into the bay and the demarcation of the Formosa and Malindi fishing grounds of the commercial bottom trawlers (Source: Munga et al., 2012).

3.2 Sampling Design

The data was collected from two inshore trawl surveys in the bay using the MV Vega (Plate 1).

Plate 1. MV VEGA, the trawler used for crustacean surveys within Malindi-Ungwana Bay. (Source: Author, 2011)

The vessel is a medium-sized Kenyan prawn trawler that was wet leased under the auspices of the South West Indian Ocean Fisheries Project (SWIOFP). The first survey was conducted between 22nd January and 4th February 2011 covering the northeast monsoon season while the second survey was conducted between 22nd May and 4th June 2011 during the southeast monsoon season. The surveys therefore covered the monsoon seasonality on the Kenyan coast.

The MV Vega is 24.96 m in length, 7.20 m wide with a draft of 2.5m with 146 Gross Registered Tons (GRT) and a Net tonnage of 98 tons. The vessel has an engine capacity of 496 HP draft and is registered in Kenya. The trawler was fitted with two outrigger trawl nets made of nylon material. The total length of each net was 44.3 m consisting of the wings, the net body and the cod end. The wings were 19.1 m long with a 45 mm mesh size; the net body was 19.1 m long with a 70.4 mm mesh size while the cod end was 6.1 m long and of 45 mm mesh size. Both nets had a head rope of 22.5 m long, a 25.4 m long foot rope and a restraining chain of 28 m between the two trawl doors. Two wooden doors with metal frame were fitted at the head of each net to keep the mouth of the net open. The nets were lowered by hydraulic winch at the same time and the start time was recorded as the nets reached the sea floor while the end time was recorded when the vessel started to pull in the nets.

A total of 45 trawl transects (Figure 3) were conducted within the bay during a 13 day survey period in each season. The surveys were stratified by depth into four depth zones of 0-10 m (zone 1); 10-20 m (zone 2); 20-40 m (zone 3) and 40-100 m (zone 4).The trawling depth zones were not uniform because the depth away from the shore drastically increases to off the Bay.

The percentage area of each depth zone at a site was used to determine the appropriate proportion of sampling time available for each depth zone during the 13 sea days, assuming a total of four trawls per day. The area estimated for the four depth zones were; 137.3, 234.1, 136.3, and 38.7 nm^2 for Zone 1, 2, 3, 4, respectively. The number of trawls were allocated proportionally to the zone area: zone 1 was allocated 8 trawls, while zones 2, 3 and 4 were allocated 17, 13 and 5 trawls, respectively, making a total of 43 trawls within the 13 days of each seasonal survey. The trawl transects per depth band (Figure 3) were run parallel to the shoreline to remain within the depth zone as much as possible, while avoiding very shallow areas as well as coral and rocky areas. The geographical coordinates of the start and end position of each trawl transect were determined using a GPS. The coordinates of a subsequent transect, about 3 nautical miles from the starting position was set to guide the direction of each trawl. Trawling was done during the day from 0600 hrs to 1800 hrs and each trawl lasted for one hour and at a speed of 2.5-3.0 knots. The same transects were trawled during the northeast and southeast monsoon surveys following the same protocol.

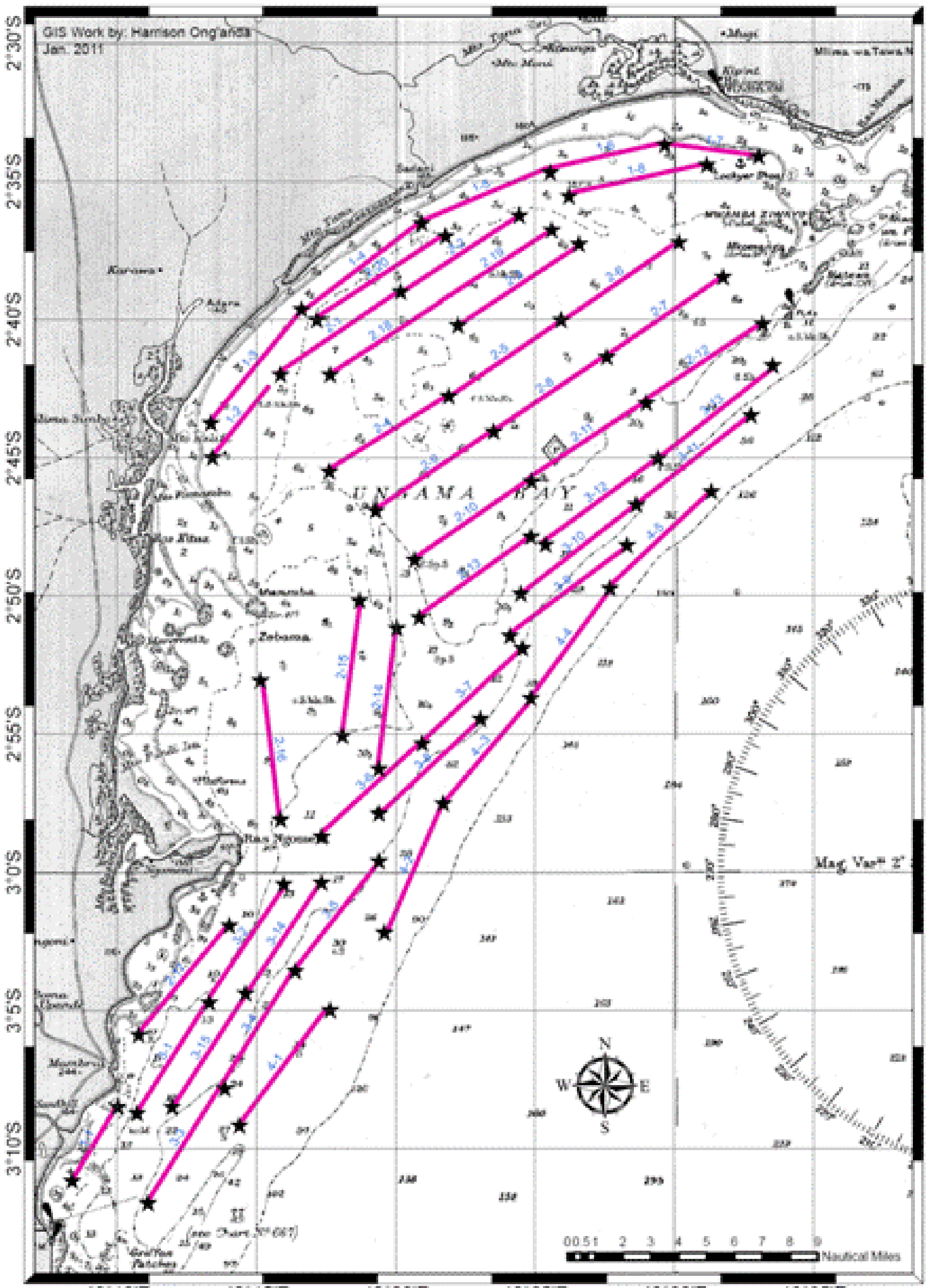

Figure 3. The transects trawled during the crustacean surveys indicated as straight lines. The stars indicate the start and end points of each transect. Number of transects trawled totalled 43 in both northeast and southeast monsoon seasons (Source: Ong'anda, 2011)

3.3. Environmental Data

Data on environmental variables were taken at the starting point of each trawl. Sea surface temperature and dissolved oxygen were determined from water samples collected using a bucket and a mercury thermometer and an oxygen probe, respectively. A water sample was collected on the bottom of the sea using a Niskin bottle and measured for dissolved oxygen, temperature and salinity by using an oxygen probe, thermometer and a hand held refractometer, respectively. Water transparency was measured using a Secchi disc. The depths (in meters) at each transect position were measured by the use of an echo sounder on the bridge of the boat.

3.4 Biological Data

At the end of each trawl, the net was hauled onto the deck and the decapod crustaceans sampled. When the catch was small and manageable (e.g sample could be worked within an hour), the whole haul was treated as a single sample which it was sorted into various decapod crustacean groups (e.g prawns, crabs and lobsters). The crustaceans were all identified to species following identification keys from FAO (1984) and Richmond (2010). Individuals in identified crustacean group were counted and weights of individual specimens taken on an electronic weighing scale to the nearest 0.1g; carapace lengths and widths of the species were measured to the nearest 1 mm using a vernier calliper. The measurement across the tips between the widest spines was considered the carapace width of the crabs (Sukumaran, 1996).

For catches that were too large to be handled requiring over one hour to manage, unwanted debris and plants were first removed; all big specimens were then removed, identified and weighed individually to the nearest gramme. This weight was later added to the other subsampled portions of the catch to determine weight of the total haul. The remaining catch was assumed to be uniformly mixed after thorough mixing and all species equally represented throughout the catch. The catch was then sub-divided into portions (sub-samples) of equal size and one portion was randomly selected as the sub-sample to be analysed. The total weights **(a kg)** of the other portions were taken on a balance to the nearest 0.1g and recorded.

The total weights of the species in the haul were estimated by multiplying the species weight in the sub-sample **(b kg)** by a raising factor that was obtained from the following formula:

Raising factor = (a+b)/b

Individual carapace size (cm), weight (in kg) and sex were recorded for the species in the sub-sample.

Maturity stages for the penaeid were determined by use of the five-stage macroscopic gonad maturity stages described by King (1995) by looking at the size of the gonads (for either male or female) from the dorsal part of the shrimp, as follows:-

Stage I: undeveloped—found only in young shrimp, ovaries small and translucent,

Stage II: developing—ovaries larger, opaque, and yellowish, with scattered melanophores over the surface,

Stage III: nearly ripe—ovaries larger and yellow to greenish,

Stage IV: ripe—ovaries green, filling virtually the whole space among other organs;

Stage V: spent—spawned ovaries flabby and mud coloured,

The results of maturity analysis are presented for the most dominant penaeid shrimps in the bay.

3.5 Data Analyses

The total weight of the species in each haul was estimated by multiplying the weight of species in the sub-sample by the raising factor. Biomass estimates of penaeid prawns, brachyurans (crabs) and palinurids (lobsters) were calculated using the swept area method (Sparre and Venema, 1998). Each distance trawled per transect was estimated in units of nautical miles (nm) by the following formula:

$$D = 60 * \mathrm{Sqrt}\left((Lat1-Lat2)^2 + (Lon1-Lon2)^2 * \cos^2(0.5*(Lat1+Lat2))\right)\ldots\ldots\ldots\ldots\ldots(1).$$

Where:

Lat1	=	Latitude at start of haul (degrees)
Lat2	=	Latitude at end of haul (degrees)
Lon1	=	Longitude at start of haul (degrees)
Lon2	=	Longitude at end of haul (degrees)

The estimated distance trawled was then multiplied by the length of the head rope (22.5 m) of the net to get the trawled area (nm^2). A correction factor X2 = 0.5 was used to correct for the net configuration (Pauly, 1980).

Therefore, swept area (A) = D * 22.5 * 0.5…………………………………… (2)

The catch in weight (kg) per unit area of a species was then calculated using the following formula:

$$\frac{Cw}{A} \qquad \text{units: kg/nm}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where:

A = Area swept (nm^2)

CW = Catch in kg

The estimated total biomass, B (kg) in a stratum was calculated from the following formula:

$$B = \frac{\Delta \times A}{X1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where:

Δ = Density of species in stratum being trawled (equation 3), A= Area of stratum being trawled (nm^2)

X1=Sampling proportion of crustaceans present in the area swept (X1 = 1 assuming all crustaceans are fully accessible to the trawl). The density values were then transformed to kg/km^2 ($1km^2 = 0.291nm^2$).

Multivariate analysis was used to describe assemblage structure within the bay. Hierarchical agglomerative clustering in which samples are successively fused into larger groups (Clarke and Warwick, 2001) was used to describe similarity of transects.

ANOSIM (Analysis of similarity) test was used to test for significant differences in crustacean density between the depth zones and seasons. The resulting R-values are a measure of variation between samples, ranging from -1 to 1. Values tending to zero indicate that there is little difference in species composition between depths/seasons while values tending to +1 demonstrate that the compositions are different (Clarke and Warwick, 2001). Correspondence Analysis (CA) was used to analyse the structure of the distribution of species relative to depth zones and seasons while Canonical Correspondence Analysis (CCA) was used to analyse the influence of physical factors (depth, temperature, dissolved oxygen and salinity) on species distribution during the NEM and SEM seasons. The statistical analyses were performed using the program PRIMER version 6 (Clarke and Warwick, 2001).

One-Way ANOVA (on log(X+1) transformed data) was used to test for differences in overall crustacean biomass (all species combined) between the depth zones in both the northeast and southeast monsoon seasons. Two-Way ANOVA was used to test for the effect of season and depth on overall crustacean biomass, species richness and diversity.

Taxonomic richness (S) and Shannon-Wiener diversity indices (H’) were used to describe the assemblage structure. Richness (S) wa**s** taken as the total number of species of crustaceans in a stratum. Mean richness was calculated according to depth zone and season. The Shannon-Wiener diversity index (H’) measures the diversity of taxa in categorical data (Pillans *et al.,* 2007). The Shannon-Wiener diversity index was calculated using the following formula (Pillans *et al*., 2007):

$$H' = -\sum_i p_i \log(p_i)$$

Where;

pi is the proportion of the total count arising from the *i*th species in the stratum or season.

CHAPTER FOUR

RESULTS

4.1 Species Composition and Abundance

A total of 20 species of decapod crustaceans belonging to 7 families were sampled in the NEM and SEM seasons combined. During the NEM season, 11 species were caught, dominated particularly by penaeid shrimp (5 species); the Portunidae and Calappidae were each represented by two species, while the Matutidae and Scyllidae each had one species (Table 1). During SEM season, 19 species were caught dominated by Portunidae (9 species) however caught in low mean abundances as compared to the penaeid shrimp (5 species). The Calappidae, Matutidae, Majidae, Scyllidae and Palinuridae each had one species (Table 1)

Among the penaeid species, *Fenneropenaeus indicus* had the highest mean abundance (no/km^2 ± SE) of 8318 ± 4132 followed by *Metapeneus monoceros, Penaeus semisulcatus* and *Penaeus monodon* with mean abundances of 1489 ± 689, 1069 ± 415 and 1008 ± 439, respectively (Table 1). The other crustaceans were recorded in low mean abundances of less than 400 individuals per square kilometre (Table 1).

Table 1. Mean abundance (individuals/Km^2± SE) and % numerical composition of decapod crustaceans caught in trawls during the northeast (NEM) and southeast monsoon (SEM) seasons in Malindi-Ungwana Bay. - indicates absence of catch. Value without Standard error indicate the species appeared in one transect only

Species	n %	NEM	n%	SEM
Penaeidae				
Fenneropenaeus indicus	57.6	8318 ± 4132	41.5	12151 ± 3329
Penaeus japonicus	0.9	149 ± 35	0.6	418 ± 135
Metapenaeus monoceros	12.5	1489 ± 688.8	27.0	6790 ± 1580
Penaeus monodon	8.9	1008 ± 439.3	5.9	1233 ± 294
Penaeus semisulcatus	9.8	1069 ± 414.6	10.3	3777 ± 1784
Portunidae				
Portunus sanguinolentus	9.3	347± 156.1	9.7	331 ±106
Thalamita crenata	0.1	19	0.05	20
Charybdis feriatus	-	-	0.6	38 ±7
Charybdis helleri	-	-	0.8	144 ± 124
Charybdis natator	-	-	0.2	81
Charybdis smithii	-	-	0.5	172
Podophthalmus vigil	-	-	0.05	21
Portunus pelegicus	-	-	0.05	21
Scylla serrata	-	-	0.3	33 ± 13
Calappidae				
Calappa calappa	0.3	40	-	-
Calappa pelii	0.1	21	0.4	168
Matutidae				
Ashtoret lunaris	0.7	97	1.0	91 ± 17
Majidae				
Majid sp.	-	-	0.2	31 ± 11
Scyllidae				
Thenus orientalis	0.4	20 ± 0.4	0.7	58 ± 24
Palinuridae				
Panulirus ornatus	0.3	-	0.1	21± 0.3

During the SEM season, 19 species were sampled. In addition to 11of the 12 species sampled in the NEM season (Table 1), 8 more species were sampled during the SEM season (Table 1). A total of 767 and 1808 individuals were sampled during the NEM and SEM seasons, respectively. The penaeid prawns had a higher numerical abundance both in NEM and SEM, 89.7 and 85.3 %, respectively. The Portunidae represented 9.4 % and 12.25 % of the catch numerically in the NEM and SEM season, respectively. Very low lobster (Palinuridae) abundances were recorded both during the NEM and SEM seasons (Table 1).

Among the penaeid shrimps, *F. indicus* had recorded the highest numerical percentage abundance in both the NEM (57.6 %) and SEM (41.5 %) seasons with the other penaeids occurring in variable proportions (Table 1).

4.2 Bathymetric Distribution and Abundance of Species

Among the penaeid shrimps, *F.indicus* and *P. japonicus* were restricted to depth zones 1 and 2 during both the NEM and SEM seasons. *M. monoceros* occurred in depth zones 1 to 3 during both seasons with higher catches in depth zones 1 and 2 during the SEM season. *Penaeus monodon* and *P. semisulcatus* occurred in depth zones 1 to 3 during the SEM season with *P. semisulcatus* having higher catches in zone 1and zone 2 than during NEM. None of the penaeids were sampled in depth zone 4 (Table 2). For the portunid crabs, only *P. sanguinolentus* occurred in considerable densities in both seasons and mainly in shallower depths (Table 2). More portunid species were sampled during the SEM (n=12) compared to the NEM season (n=4). For the palinurids (lobsters), *T. orientalis* was sampled in depth zones 1, 2 and 3 in both seasons while the other species, *P. ornatus* was sampled in depth zones 1 and 2 during the SEM season.

Results of Two-Way crossed ANOSIM test indicated a significant difference in crustacean composition between the depth zones, (R=0.375; P=0.001; considering both seasons) but no significant difference in composition between the seasons (R= -0.031; P=0.602; considering all depths) (Table 3).

Table 2. Seasonal distribution and abundance (individuals/Km^2±SE)) of decapod crustaceans within depth zones during (a) NEM and (b) SEM season at Malindi-Ungwana Bay. (-) indicates absence of catch. Value without Standard error means the species appeared in one transect only.

	Depth Strata			
Species	**Zone 1 (0-10 m)**	**Zone 2 (10-20 m)**	**Zone 3 (20-40 m)**	**Zone 4 40-100 m)**
(a) NEM season				
Fenneropenaeus indicus	11265 ± 5383	458 ±386	-	-
Penaeus japonicus	248	116 ± 16	-	-
Metapenaeus monoceros	1918 ± 953	735	367 ±320	-
Penaeus monodon	1239 ±539	199 ± 74	-	-
Penaeus semisulcatus	-	564 ±544	1405 ± 577	-
Portunus sanguinolentus	576± 201	117 ± 12	-	-
Thalamita crenata	19	-	-	-
Charybdis feriatus	-	-	-	-
Charybdis helleri	-	-	-	-
Charybdis natator	-	-	-	-
Charybdis smithii	-	-	-	-
Podophthalmus vigil	-	-	-	-
Portunus pelagicus	-	-	-	-
Scylla serrata	-	-	-	-
Calappa calappa	40	-	-	-
Calappa pelii	-	21	-	-
Ashtoret lunaris	97	-	-	-
Majidae sp.	-	-	-	-
Thenus orientalis	20	21	20	-
Panulirus ornatus	-	-	-	-
(b) SEM season				
Fenneropenaeus indicus	15437± 4217	8208± 5210	-	-
Penaeus japonicus	520 ± 294	350± 161	-	-
Metapenaeus monoceros	7003± 2046	7024±3141	4342	-
Penaeus monodon	1127 ± 428.2	1799 ± 250	632	-
Penaeus semisulcatus	1799 ± 250	6680 ± 3144	461± 234.0	-
Portunus sanguinolentus	486 ±168	176 ±59	21	-
Thalamita crenata	20	-	-	-
Charybdis feriatus	41±1.0	41±12	21	-
Charybdis helleri	-	20	-	268
Charybdis natator	-	81	-	-
Charybdis smithii	-	-	-	172
Podophthalmus vigil	-	-	21	-
Portunus pelagicus	-	21	-	-
Scylla serrata	20	39±19	-	-
Calappa calappa	-	-	-	-

Table 2 continued.

	Depth Strata			
Species	**Depth zone 1 (0-10 m)**	**Depth zone 2 (10-20m)**	**Depth zone 3 (20-40 m)**	**depth zone 4 (40-100 m)**
Calappa pelii	-	-	167	-
Ashtoret lunaris	90 ± 24	98	-	-
Majidae sp.	20	42	-	-
Thenus orientalis	20 ± 0.2	54±34	145	-
Panulirus ornatus	20	21	-	-

Table 3. Two-Way crossed ANOSIM test for the difference in crustacean composition between depth zones (considering all seasons) and between seasons (considering all depth zones). P-value ≤ 5% are significant and highlighted.

Groups	R Statistic	% Significance level	Number of permutation
Depth zones	0.375	**0.1**	999
Seasons	-0.031	60.2	999

A pairwise ANOSIM comparison test indicated low significant difference in crustacean between depth zones 1 and 2 (R=0.181; P=0.035) and highly significant difference in abundance between depth zone 1 and 3 (R=0.808; P=0.001). There was no significant comparative difference between the other depth zones (Table 4).

The mean overall crustacean density (kg/km^2 ± SE) in the different depth zones during the NEM and SEM seasons are shown in Figure 4 Box plot. A higher mean density of decapod crustaceans was recorded from depth zone 1(64.2 ± 18.7) during the NEM season while Zones 2 and 3 recorded similar catch rates of 15.7±5.5 and 17.9 ± 9.5, respectively, during this season (Figure 4 a). No crustaceans were caught in depth zone 4 (Figure 3 a). One-way ANOVA indicated no significant difference (F=3.0155; df=2, 47; P=0.059) in crustacean biomass between the three zones. During the SEM season depth zones 1 and 2 produced similar catch rates of 67.14 ± 18.6 and 56.65 ± 18.1, respectively, while zones 3 and 4 produced lower catch rates of 14.25 ± 5.8 and 1.31 ±1.1, respectively (Figure 4 b). One-way ANOVA indicated no significant difference (F=1.47188; df=2, 83; P=0.22) in crustacean biomass between the three zones.

Table 4. Pair-wise ANOSIM comparison test for the difference in crustacean composition between depth zones based on abundance (Individuals/km^2). P- value ≤ 5% are significant and highlighted in bold italic.

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number Observed
1, 2	0.181	***3.5***	5662800	999	30
1, 3	0.808	***0.1***	54450	999	0
1, 4	0.952	12.5	8	8	1
2, 3	0.093	20.3	25025	999	193
2, 4	0.593	10	10	10	1
3, 4	0.5	40	5	5	2

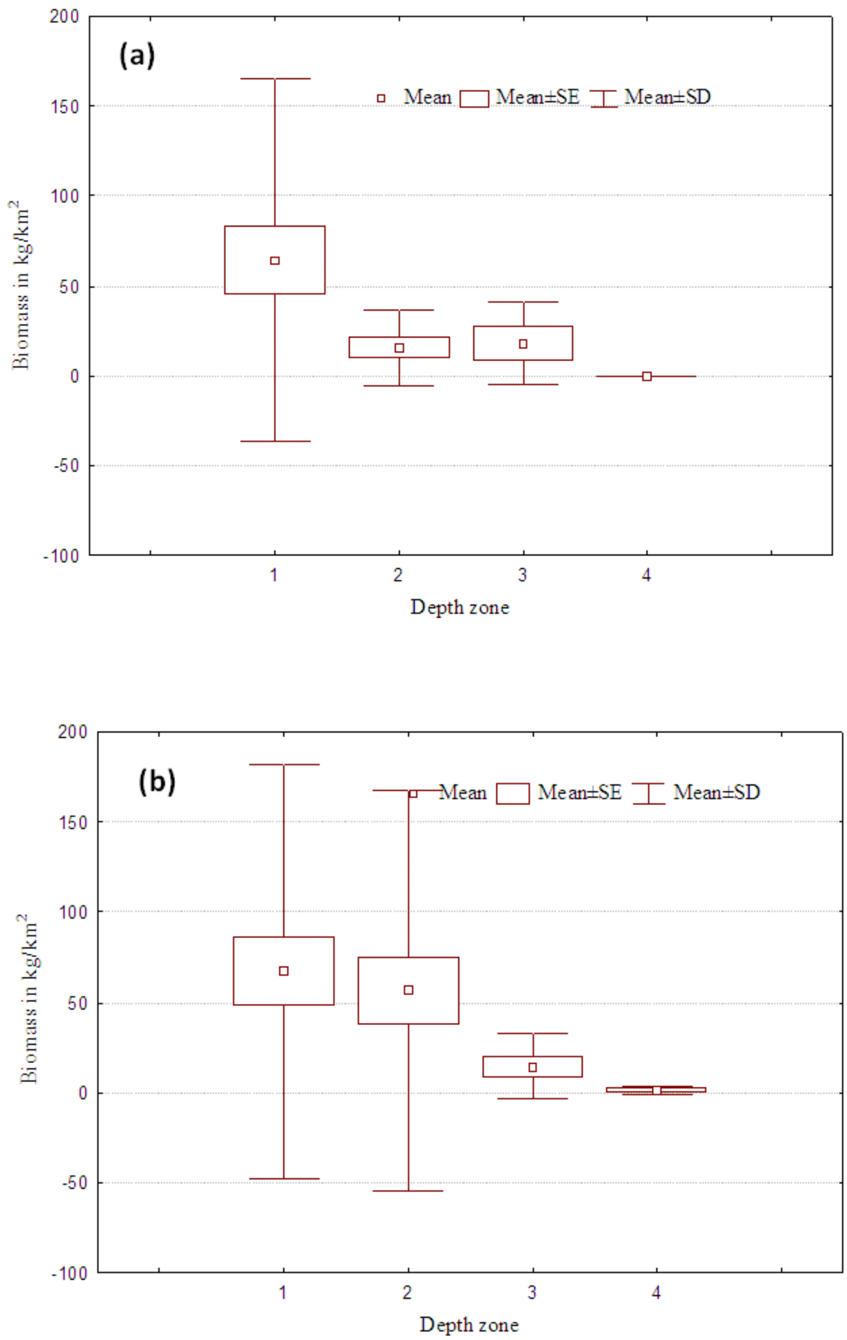

Figure 4. Box plots of total decapod crustacean catches (kg/km^2) by depth zones during (a) NEM and (b) SEM season in Malindi-Ungwana Bay. Zone 1 (0-10 m), Zone 2 (10-20 m), Zone 3 (20-40 m), Zone 4 (40-100 m).

Two- way ANOVA showed a significant effect of depth on crustacean biomass (F=3.89; df.=2, 130; P=0.022) but no effect of season (F=0.014; df.=1, 130; P=0.95) (Table 5) and the interaction of seasons and depths did not affect crustacean biomass significantly (F=0.57; df=2,130; P=0.54) indicating independent effects of factors (Table 5).

The mean prawn (Penaeidae) catches (kg/km^2) ± SE) between the different depth zones during the NEM and SEM seasons are shown in Figure 5. A higher biomass of prawn was obtained from depth zone 1 (78.7 ± 22.6) during the NEM season. Depth zones 2 and 3 recorded a near equal catch rates of 20.4±7.0 and 20.9 ± 11, respectively. One-way ANOVA test indicated no significant difference in prawn biomass (F=2.14; df=2, 36; P=0.13) between the three zones during NEM season. No prawns were caught in depth zone 4 (Figure 5 a). During the SEM season, depth zones 1 and 2 had nearly equally catch rates of prawns of 112.4± 30.3 and 103 ± 31.01 respectively, higher than recorded during NEM. One–Way ANOVA test indicated no significant difference in prawn biomass, (F=0.93; df=2, 43; P=0.40) during the SEM season. No prawns were caught in depth zone 4 during the SEM season (Figure 5 b).

Table 5. Two–Way ANOVA test on the effect of depth and season on total crustacean biomass in Malindi-Ungwana Bay. Data are log (X+1) transformed to downweight high abundance species.

	SS	DF	MS	F	P
Season	0.0027	1	0.0027	0.0033	0.954
Depth Zone	4.1099	2	2.0549	3.8885	***0.022****
Season*Depth zone	1.0021	2	0.5011	0.6157	0.542
Error	105.790	130	0.8138		

* **Significant at α= 0.05**

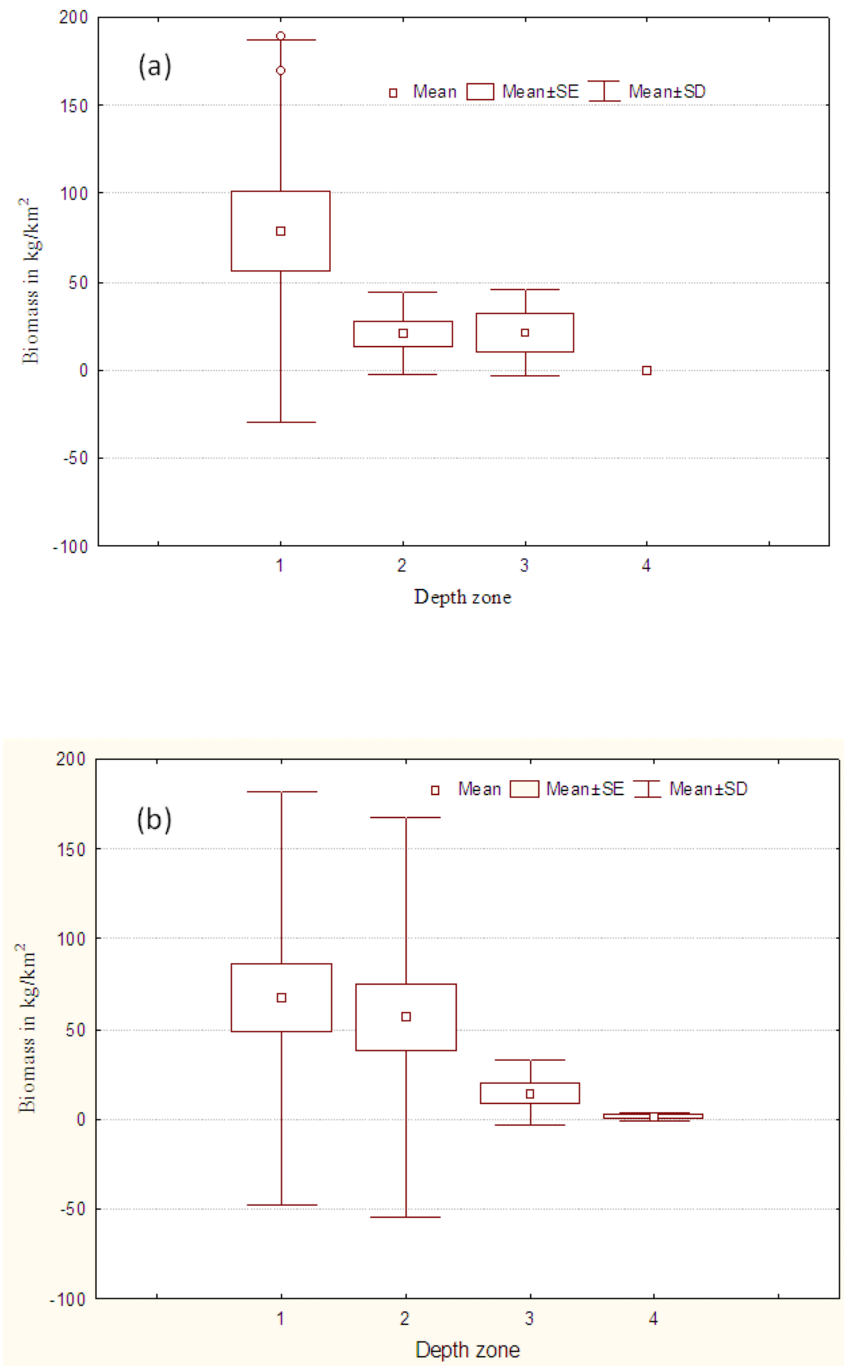

Figure 5. Box plots of penaeid shrimp (kg/km^2) by depth zones during (a) NEM And (b) SEM season in Malindi-Ungwana Bay. Zone 1 (0-10 m), Zone 2 (10-20m), Zone 3 (20-40 m) Zone 4 (40-100 m).

4.3 Species Richness

The species richness in the bay appeared to be higher during SEM than NEM season, for all depth zones but the finding was not significant (Figure 6). The results of Two-Way ANOVA indicated no significant effect of either depth ($F = 2.77$; $df = 2, 29$; $P = 0.08$) or season ($F = 1.43$; $df = 1, 29$; $P = 0.24$) on species richness as was the case for the interaction effect of season and depth ($F = 0.40$; $df = 2, 29$; $P = 0.67$) (Table 6).

4.4 Diversity

The mean Shannon-Wiener diversity of the crustaceans was also higher during the SEM season for depth zones 1 and 3 with little seasonal difference between zone 1 and 2 (Figure 6b). Depth zone 2 had the highest diversity among the zones especially during the NEM season.

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The results of Two-Way ANOVA indicated a significant effect of depth ($F=3.4773$; $df=2, 29$; $P=0.044$) but not season ($F=0.516$; $df=1, 29$; $P=0.479$) on diversity. There was no significant interaction effect of depth and season on diversity ($F=0.459$; $df=1, 29$; $P=0.636$) (Table 6).

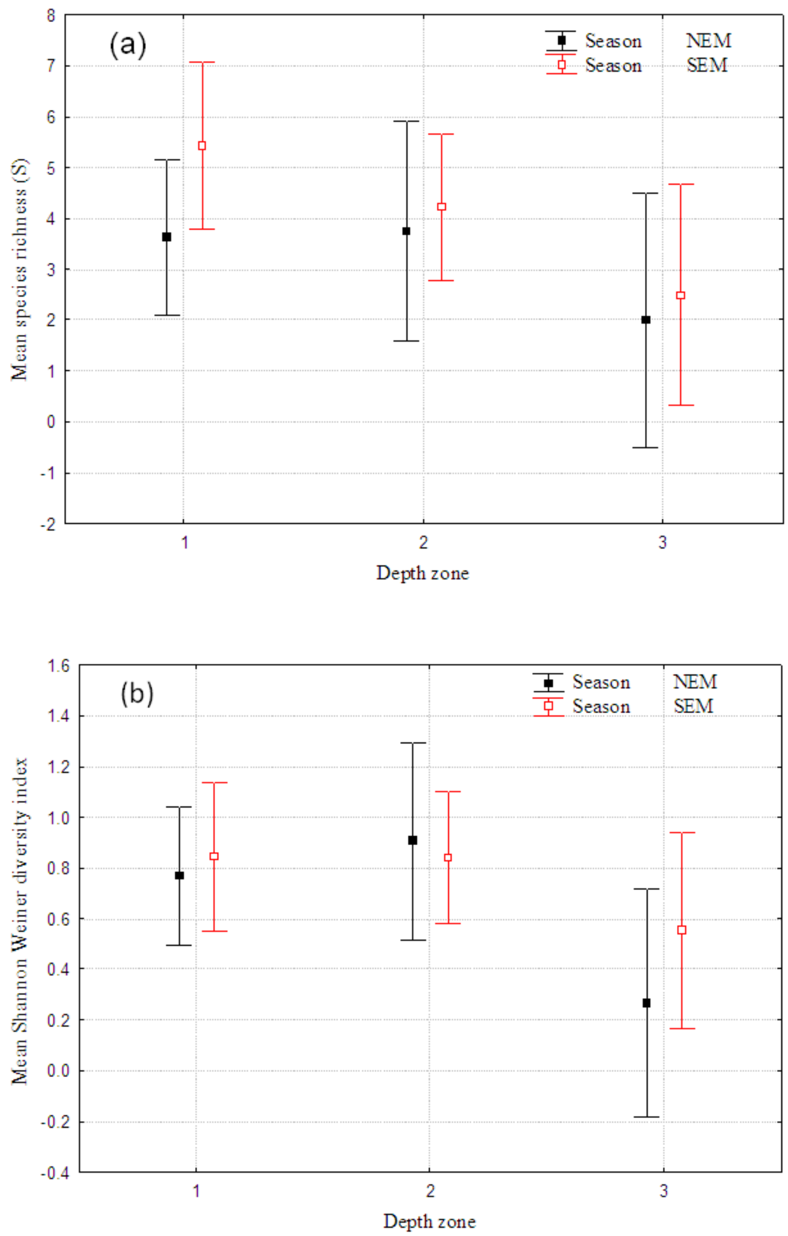

Figure 6. The variation of (a) mean species richness and (b) mean species Diversity of decapod crustaceans with depth in Malindi-Ungwana Bay. Error bars indicate SE. Zone 1(0-10 m), Zone 2 (10-20 m), Zone 3 (20-40 m).

Table 6. Results of Two-Way ANOVA test for effect of depth and season on species richness and diversity within Malindi-Ungwana Bay

	SS	DF	MS	F	p
a) Richness					
Depth	24.5870	2	12.294	2.766	0.080
Season	6.3557	1	6.356	1.430	0.241
Depth*Season	3.5542	2	1.777	0.400	0.674
Error	128.8948	29	4.445		
b) Diversity					
Depth	1.00279	2	0.501	3.477	***0.044****
Season	0.07433	1	0.074	0.516	0.479
Depth*Season	0.13236	2	0.066	0.459	0.636
Error	4.18149	29	0.144		

*__Significant at α= 0.05__

4.4 Population Structure

4.4.1Size distribution of the Penaeid crustaceans

Fenneropenaeus indicus, the size distribution was near normal in all the depth zones during the SEM season (Figure 7b). During the NEM season, the species had larger size classes in depth zone 3 (modal size = 37 mm) and 2 (modal size = 32 mm), while a near normal size distribution occurred in zone 1 (Figure7a). For the speckled shrimp, *M. monoceros*, the size distribution was near normal in depth zone 3 during the NEM season (Figure 8a) and zone 1 during the SEM season (Figure 8b). This species had larger size classes in depth zone 1 (modal size = 37 mm) and zone 2 (modal size = 32 mm) in the NEM season (Figure 8a). The SEM season had smaller size classes of *M. monoceros* in depth zone 2 (modal size =22 mm) and zone 3 (modal size=27 mm) (Figure 8b). The size distribution of the giant tiger prawn, *P. mondon*, was not normal in all the depth zones for both seasons (Figure 9). During the NEM season, larger size classes were recorded in depth zone 1 and 2 with 42 mm as the modal size (Figure 9a). The SEM season had larger size classes in depth zone 1 (modal size =42 mm) and smaller sizes in depth zone 2 with 32 mm as the modal size (Figure 9b).

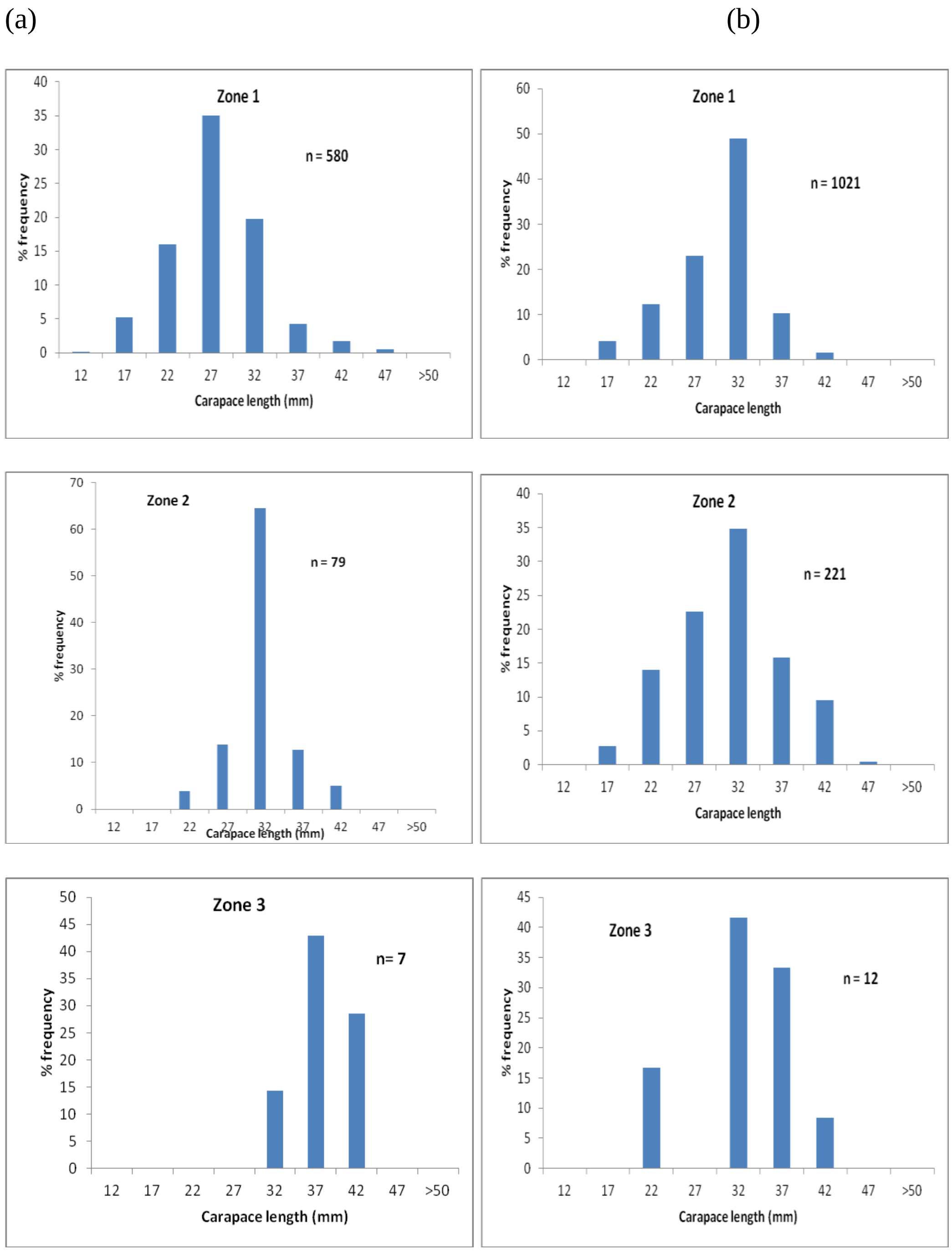

Figure 7. Size- frequency distribution of *Fenneropenaeus indicus* within depth zones 1(0-10m) , 2 (10-20m) and 3 (20-40m) during (a) NEM and (b) SEM seasons within Malindi-Ungwana Bay

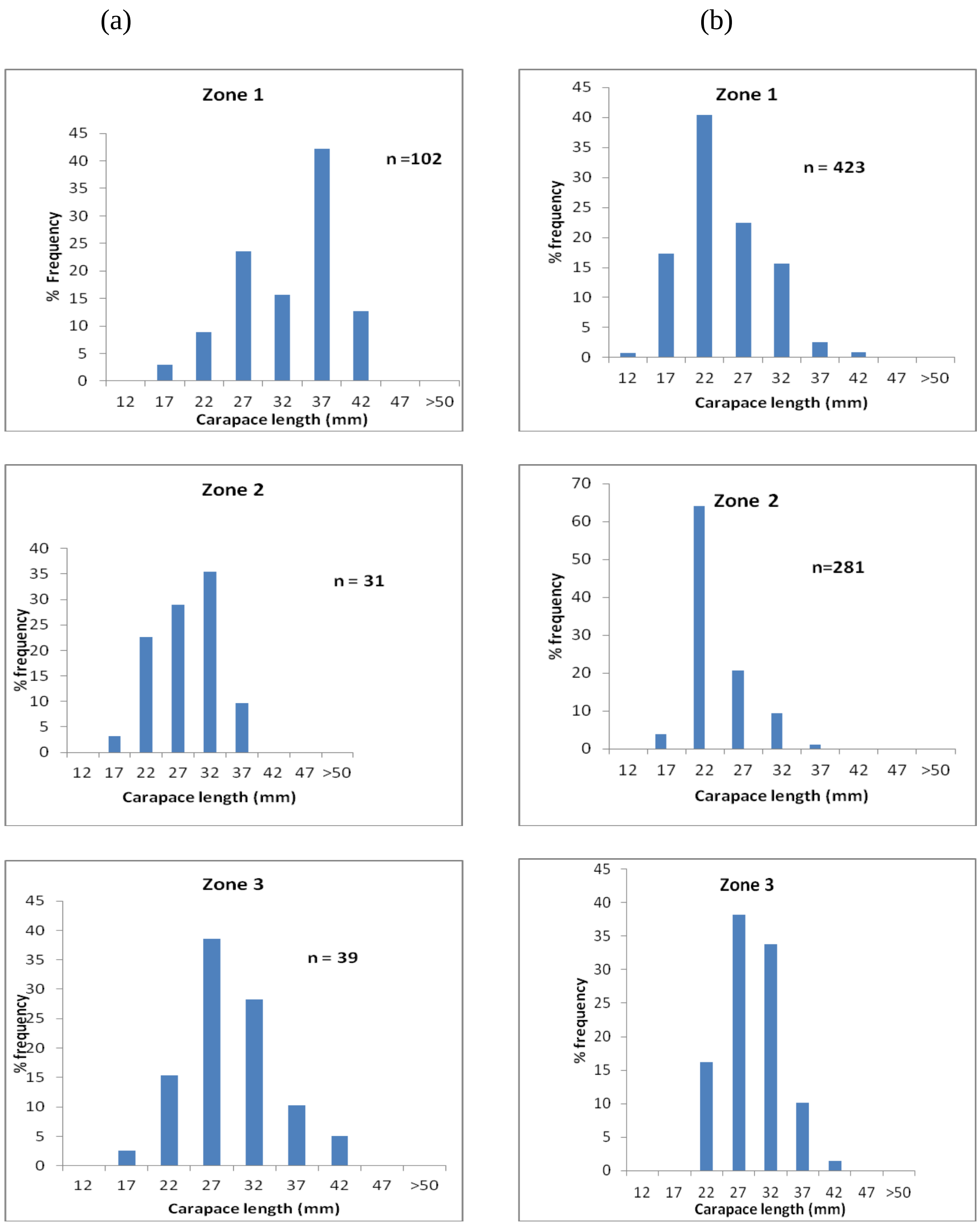

Figure 8. Size-frequency distribution of *Metapenaeus monoceros* within depth zones 1(0-10m) , 2 (10-20m) and 3 (20-40m) during (a) NEM and (b) SEM seasons within Malindi-Ungwana Bay.

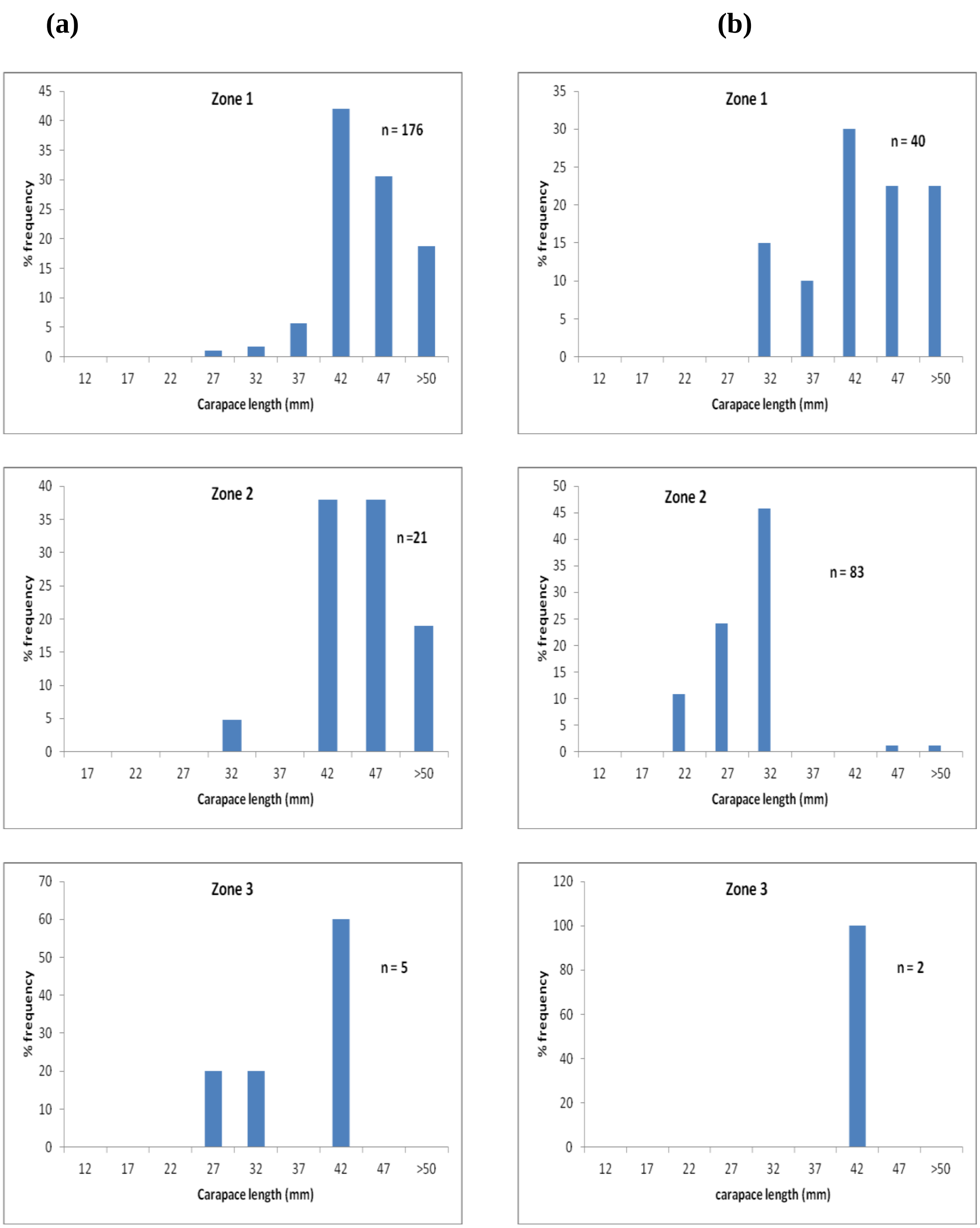

Figure 9. Size- frequency distribution of *Penaeus monodon* within depth zones 1(0-10m) , 2 (10-20m) and 3 (20-40m) during (a) NEM and (b)SEM seasons within Malindi-Ungwana Bay.

4.4.2 Sex Ratios

During the NEM season, *M. monoceros* had significantly different sex ratios in favour of females in all depth zones. *Fenneropenaeus indicus* had significantly different sex ratios in depth zone 1 and 2 that was skewed towards the males (1:0.2) and females (1:2) , respectively. *Penaeus monodon* had a significantly different sex ratio in depth zone 1 skewed in favour of the males (1:0.4) (Table 7). During the SEM season, *M. monoceros* had sex ratios in favour of females in depth zone 1and 2 (Table 7). *Penaeus indicus* had a significantly different sex ratio in depth zone 1 only, in favour of males. *Penaeus monodon* showed significantly different sex ratio in depth zone 1 and 2, in favour of males in zone 1 and females in zone 2 (Table 7). *Penaeus semisulcatus* had sex ratios that were not significantly different in each zone and were near unity. For *M. monoceros,* the overall sex ratio was in favour of females in both seasons (1:2.5 and 1: 2.8) while for *F. indicus*, sex ratios were skewed in favour of males both in NEM and SEM seasons. The overall sex ratio for *P. monodon* was significantly skewed towards males and females in NEM and SEM season, respectively. The overall sex ratios for *P. japonicus* and *P. semisulcatus* were not significantly different in both seasons (Table 7).

Table 7. Sex ratio (M:F) of prawn species in the depth strata within Malindi-Ungwana Bay during (a) NEM and (b) SEM season. * Significant at α= 0.05, n = sample size, Zone 1 (0-10 m), Zone 2 (10-20 m), Zone 3 (20-40 m).

Species	Sex Ratio M:F									
	Zone 1	**n**	**Zone 2**	**n**	**Zone 3**	**n**	**Overall Ratio**	**n**	**χ^2 overall**	**P**
(A)NEM										
M. monoceros	1 : 2.4*	102	1 : 4.2*	31	1: 2.0*	39	1 : 2.5*	172	31.84	1E^{-05}
F. indicus	1 : 0.2*	580	1 : 2.0*	79	_	6	1 : 0.3*	665	164.75	1E^{-05}
P. japonicus	1 : 0.8	9	1 : 2.5	14	_	0	1 : 1.5	23	1.087	0.297
P. monodon	1 : 0.4*	176	1 : 0.9	39	1 : 2.5	7	1 : 0.5*	122	26.02	1E^{-05}
P. semisulcatus	_	0	1 : 1.1	19	1 : 0.7	77	1 : 0.7	96	2.27	0.132
(B)SEM										
M. monoceros	1 : 2.6*	423	1 : 3.7*	281	1 : 1.1	68	1 : 2.8*	772	160.50	1E^{-05}
F. indicus	1 : 0.8*	1022	1 : 1.2	220	_	12	1 : 0.7*	1254	35.17	1E^{-05}
P. japonicus	_	9	_	9	_	0	1 : 0.8	18	0.22	0.637
P. monodon	1 : 0.3*	40	1 : 4.2*	83	_	0	1 : 1.7*	123	8.71	0.003
P. semisulcatus	1 : 0.9	28	1 : 1	207	1 : 0.8	52	1 : 0.9	287	0.34	0.562

4.4.3 Bathymetric Distribution of Maturity Stages

During the NEM season, all species had higher percentages of immature and developing individuals (Stage I and II) in all depth zones as compared to the maturing and mature individuals (stage; III, IV and V) (Figure 10). For *F. indicus*, higher catches of immature and developing individuals were made in zone 1 than in zone 2. *Metapenaeus monoceros* had a nearly similar distribution with more immature and developing individuals in depth zone 1 than in depth zone 2. (Figure10). *Penaeus monodon* were in roughly similar proportions of developing and mature stages in depth zone 1 and 2. *Penaeus. Semisulcatus* was mainly recorded from zones 1 and 3 with mature individuals only found in the latter zone.

During the SEM season, *F. indicus* had higher percentage of immature and developing (stages I and II) individuals in depth zone 1 and 2, while zone 3 had only a few individuals that were mostly in stages III and IV (Figure 11). *Metapenaeus monoceros* had higher abundance of immature and developing individuals in all depth zones. For *P. monodon*, depth zone 2 had higher numbers of specimens that were in near ripe and ripe (stages III and V) conditions than depth zone 1 and 3. The species, *P. semisulcatus* showed the distribution of all the maturity stages in the three depth zones. However, spent specimens were most abundant in depth zone 3, while zone 1 and 2 contained more of the immature individuals (Figure 11)

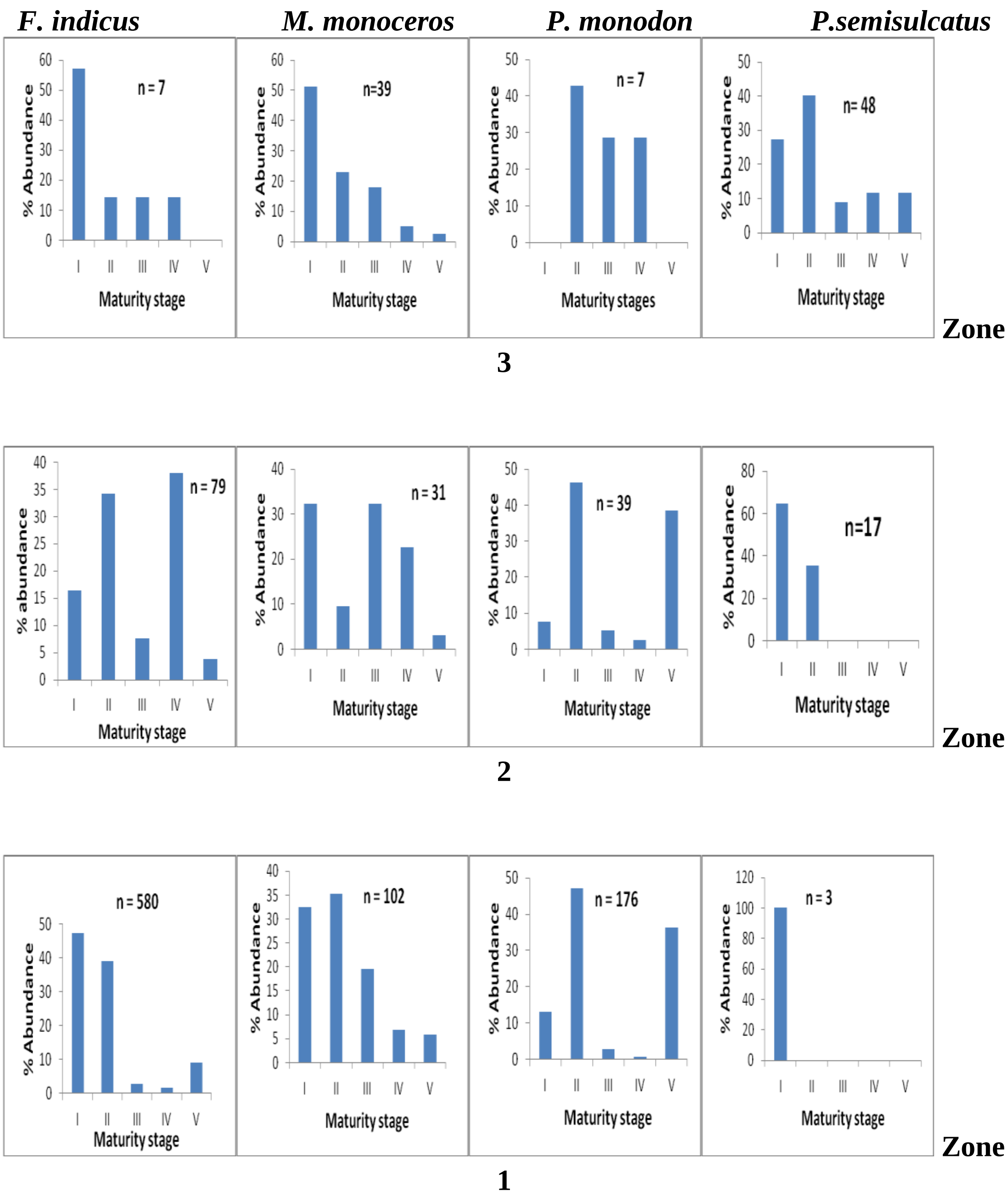

Figure 10. Bathymetric distribution of the common penaeid shrimps in different maturity stages in Malindi-Ungwana Bay during the northeast monsoon season. Zone 1 (0-10 m), zone 2 (10-20 m) and zone 3 (20-40 m)

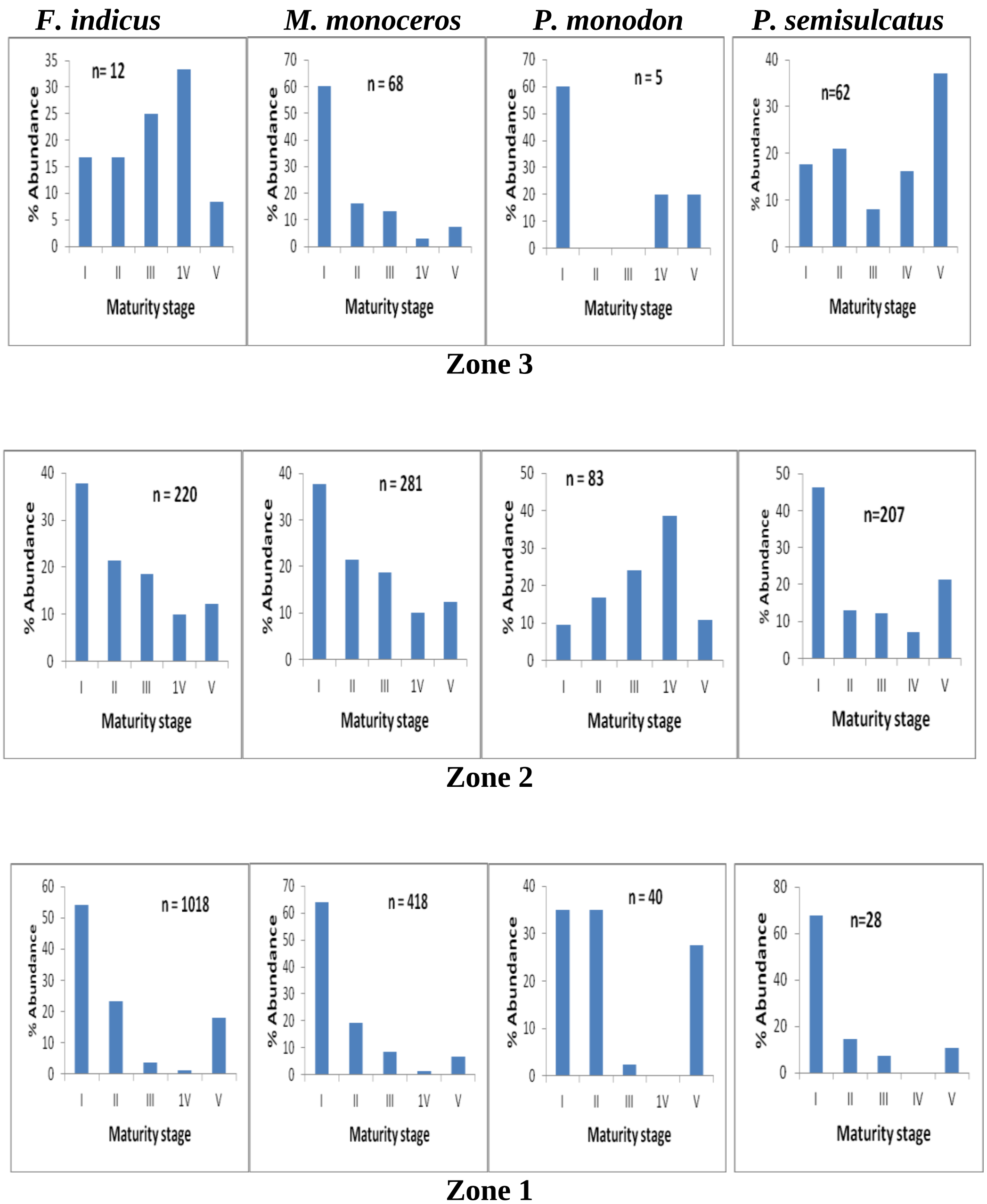

Figure 11. Bathymetric distribution of the common penaeid shrimps in different maturity stages in Malindi-Ungwana Bay during the southeast monsoon season. Zone 1 (0-10 m), zone 2 (10-20 m) and zone 3 (20-40 m)

4.5.1 Classification of Trawls and Species

The dendrogram of similarity among trawls (transects) based on overall species abundance shows that the trawls displayed different seasonal distribution of species (Figure 12). Four main groups can be defined representing the decapod crustacean assemblages within Malindi-Ungwana Bay. The first branch similarity tree discriminates mostly between depth zone 2 assemblages of the SEM season from the mixed season depth zone 2 and 3 assemblage (branch 2). However, the separation of these two assemblages is less clear (Figure 12). The group 3 of the dendrogram divides into 2 sub-groups 3a and 3b. The 3a sub assemblage appears to belong to depth zone 2 and 3 in the SEM season while the 3b group belongs to depth zone 1 mixed seasonal assemblage. The trawls can further be sub-divided into an assemblage structure (branch 4) that divides into sub-groups 4a and 4b. The 4a sub-assemblage appears to belong to depth zone 1 in the NEM season while the 4b sub-assemblage consists of depth zone 1 mixed seasonal assemblage.

The dendrogram of similarity among species based on abundances shows different species distribution and associations (Figure13). Two main groups (1 and 2) can be defined representing the decapod crustacean assemblages within Malindi-Ungwana Bay. The first branch similarity tree discriminates between mostly depth zone 1 assemblages (1) from depth zone 2 assemblages (2). Depth zone 1 assemblage can be further divided into sub-assemblage **1a** which consists of crabs and lobsters; sub-assemblage **1b** which is a mixture of crabs and prawns and a sub-assemblage of only prawns **(1c)** (Figure13). The species, *F. indicus, M. monoceros, P. moodon, P.*

sanguinolentus, P. japonicas, P. semisulcatus, C. feriatus, T. orientalis and *A. lunaries* were grouped at a high level of similarity of about 65% (Figure 13). This assemblage represents the dominant species in depth zone 1 (Table 1) from both seasons. The second assemblage had a 45% similarity and consisted of; *P. ornatus, P. pelagicus, C. natator, C.calappa* and *S. serrata*. The species; *C. smithii, C. helleri, C. pelii, P. vigil* and *T. crenata* did not belong to any distinct assemblage in the bay. The assemblages divide into sub-assemblages (1a, b, c; 2a and b) (Figure 10). The second assemblage divides into sub-groups **2a** and **2b** (Figure 13). The **2a** sub-assemblage seems to consist of a mixture of Portunidae, Majidae and Calappidae crabs while, the **2b** sub-assemblage consists of portunid crabs only (Figure13).

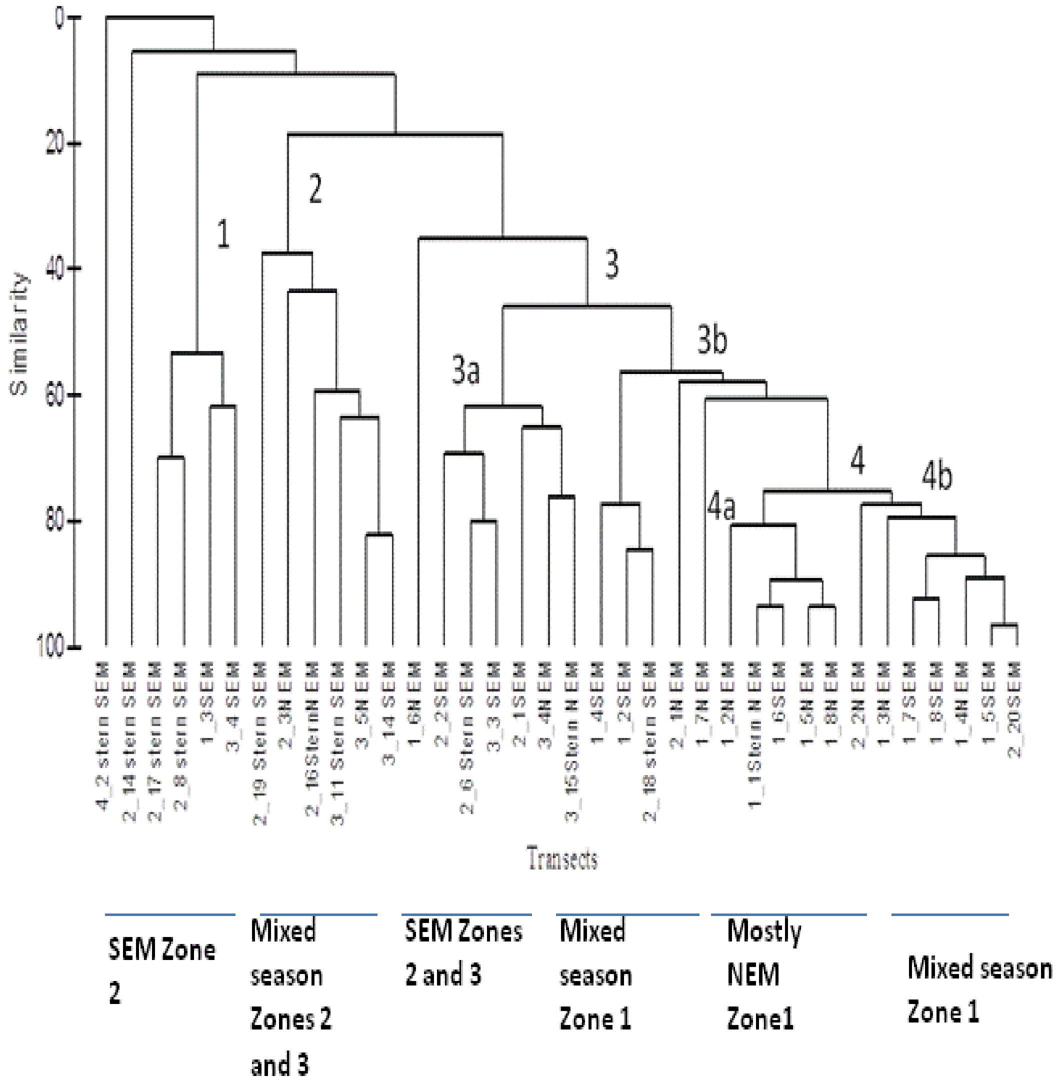

Figure 12. Dendrogram for hierachical clustering (using group average linking) of northeast monsoon and southeast monsoon trawls (transects) based on log (X+1) transformed species abundances. The first and second figures on the x-axis represent the depth zone and transect number, respectively. (Source: Author, 2013)

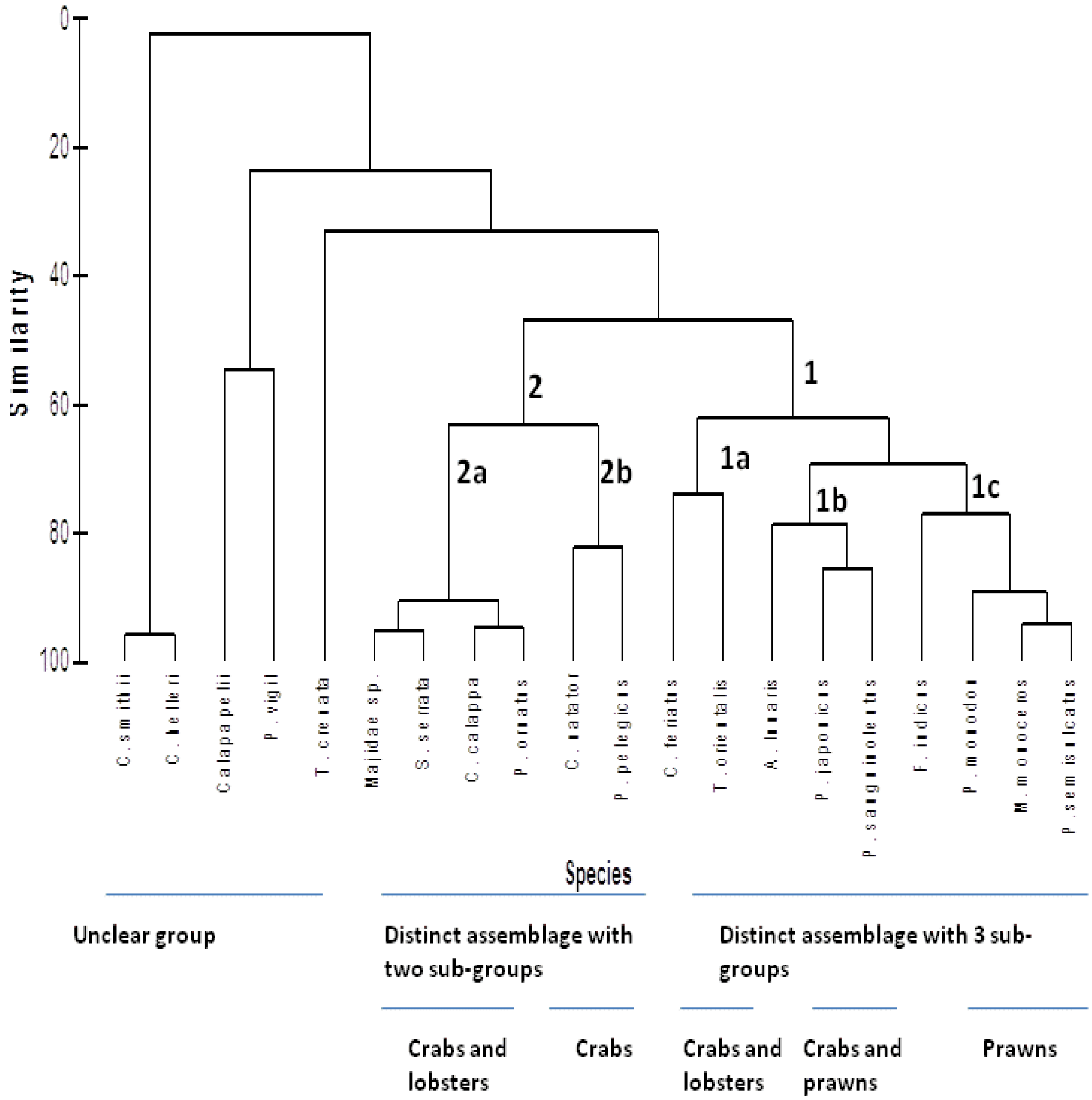

Figure 13. Dendrogram for hierarchical clustering (using group average linking) of decapods crustacean species based on species mean abundances. The species names are as shown in Table 1. (Source: Author, 2013)

4.5.2 Simple Correspondence Analysis

The structure of the distribution of species relative to depth zones and seasons was described by the use of Correspondence Analysis of the 9 dominant species (Figure 14). This analysis shows that the assemblage structure is clearly separated more by the depth zones than by seasons. The species; *F. indicus*, *P. monodon* and *P. sanguinolentus* are mostly associated with depth zone 1 (0-10 m) with no seasonal preference for this distribution. The species; *M.* m*onoceros*, *P. japonicus* and *A .lunaris* are closely associated with depth zone 2 (10-20 m) in both the NEM and SEM seasons indicating lack of seasonal influence in their distribution. However, *P. semisulcatus* seems to have a closer association with depth zone 2 during the NEM than the SEM season. The scyllid, *T. orientalis,* and the portunid, *C. feriatus,* were associated with depth zone 3 in the SEM than in the NEM season (Figure 14). Depth zone 4 did not have a distinct seasonal association with any species.

4.6 Environmental Parameters

During the NEM season, temperature (^{0}C**)** was highest in depth zone 1 (28.0 ± 0.2) and lowest in depth zone 2 (27.3 ± 0.06). There was little variation in salinity (36.1-36.8 ‰**)** between the depth zones (P > 0.05). Depth zone 1 had the lowest Secchi depth (1.4 ± 0.20 m) while depth zone 4 had the highest readings (13.8 ± 0.86 m). There was no significant difference in Secchi depths between the zones (Table 8). The dissolved oxygen concentration (mg/l ± SE) ranged from 5.79 ± 0.19 in zone 1 to 6.9 ± 0.55 in zone 4. There was no significant difference in dissolved oxygen concentration between the depth zones (P > 0.05). During the SEM season, temperature was lowest in depth zone 1 (27.1± 0.19 ^{0}C) and highest in depth zone 2

(29.1 ± 0.09 ^{0}C), however, there was no significant difference in temperature between the zones (Table 8). Depth zone 3 and 1 had the highest (35.3 ± 0.33 ‰) and the lowest (34.8± 0.54 ‰) salinity values, respectively. The variability in salinity between the depth zones was not significant ($P > 0.05$).

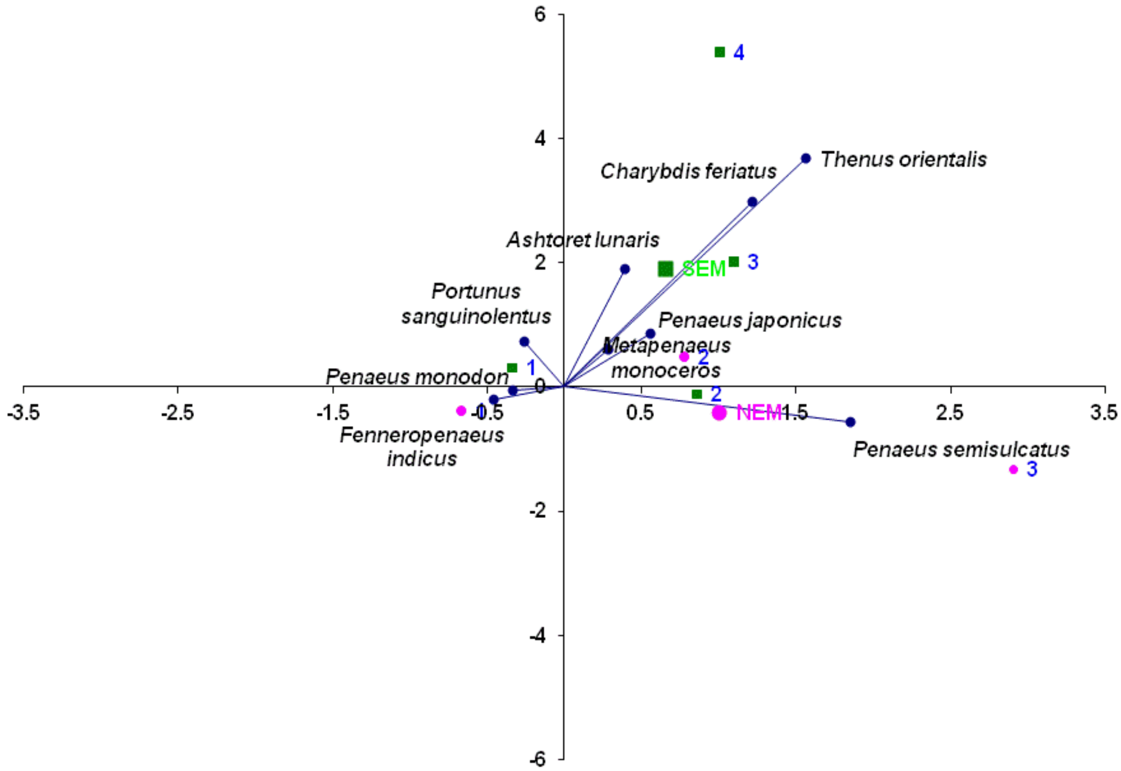

Figure 14. Correspondence Analysis (CA) of the association of species with depth zones and seasons (SEM (■), NEM (●)) for the 9 most dominant species in Malindi-Ungwana Bay. Analysis is based on log transformed species abundances. Zone 1(0-10 m), Zone 2 (10-20 m), Zone 3 (20-40 m), Zone 4 (40-100 m). NEM= northeast monsoon SEM= southeast monsoon season. (Source: Author, 2013)

Table 8. Bathymetric variation of environmental parameters (mean ± SE) **within the Malindi- Ungwana Bay during (a) NEM and (b) SEM season. (-) not determined. Zone 1 (0-10 m), Zone 2 (10-20 m), Zone 3 (20-40 m), Zone 4 (40-100 m)**

Depth zone (m)		**Temperature (^{0}C)**	**Salinity (‰)**	**Secchi depth (m)**	**Dissolved oxygen (mg/l)**
(a) NEM					
Zone 1		28.00 ± 0.02	36.20 ± 0.18	1.4 ± 0.20	5.79 ± 0.19
Zone 2		27.3 ± 0.06	36.4 ± 0.19	7.8 ± 0.69	6.02 ± 0.31
Zone 3		27.7 ± 0.08	36.1 ± 0.08	12.3 ± 1.29	5.87 ± 0.53
Zone 4		27.4 ± 0.08	36.8 ± 0.48	13.8 ± 0.86	6.9 ± 0.55
ANOVA	F	1.204	2.005	17.277	0.577
	P	0.319	0.133	1.515	0.633
(b) SEM					
Zone 1		27.1± 0.19	34.8± 0.54	2.0 ± 0.15	-
Zone 2		29.1 ± 0.09	34.9 ± 0.16	8.35 ± 0.03	-
Zone 3		28.9 ±0.13	35.3 ±0.33	17.4 ± 2.06	-
Zone 4		29 ± 0	35 ± 0	23.5 ± 0.35	-
ANOVA	F	20.839	0.453	33.889	
	P	5.558	0.857	1.303	

4.7 Canonical Correspondence Analysis (CCA)

The relationship between species distribution with respect to environmental variables in the three depth zones during the NEM and SEM seasons are shown in figures 15 and 16 as analysed by Canonical Correspondence Analysis (CCA). During the NEM season, the species; *P. japonicus*, *P. monodon*, *M. monoceros*, *P. sanguinolentus*, *T. orientalis* were more associated with depth zone 2 and were influenced mostly by salinity, dissolved oxygen and Secchi depth in their distribution. The crab C. *pelli*, was associated with depth zone 2 but apparently was not influenced by the selected environmental variables in its distribution (Figure 15).

During the SEM season, the species, *T. crenata*, *P. sanguinolentus*, *F. indicus*, *P. japonicas* were distributed in zone 1 and were not influenced by any of the measured parameters (Figure16). However, the *C. feriatus* and *M. monoceros* were more influenced by salinity in their distribution in depth zones 2 and 3. The mud crab, *S. serrata*, and the shrimp *P. semisulcatus*, were mostly influenced by temperature in their distribution in depth zone 2. However, *C. helleri* and *C. natator* were not influenced by any of the measured factors in their distribution in depth zone 2. Similarly, *T. orientalis*, *P. vigil* and *C. pelli* were distributed in zone 3 and not influenced by the measured factors (Figure 16)

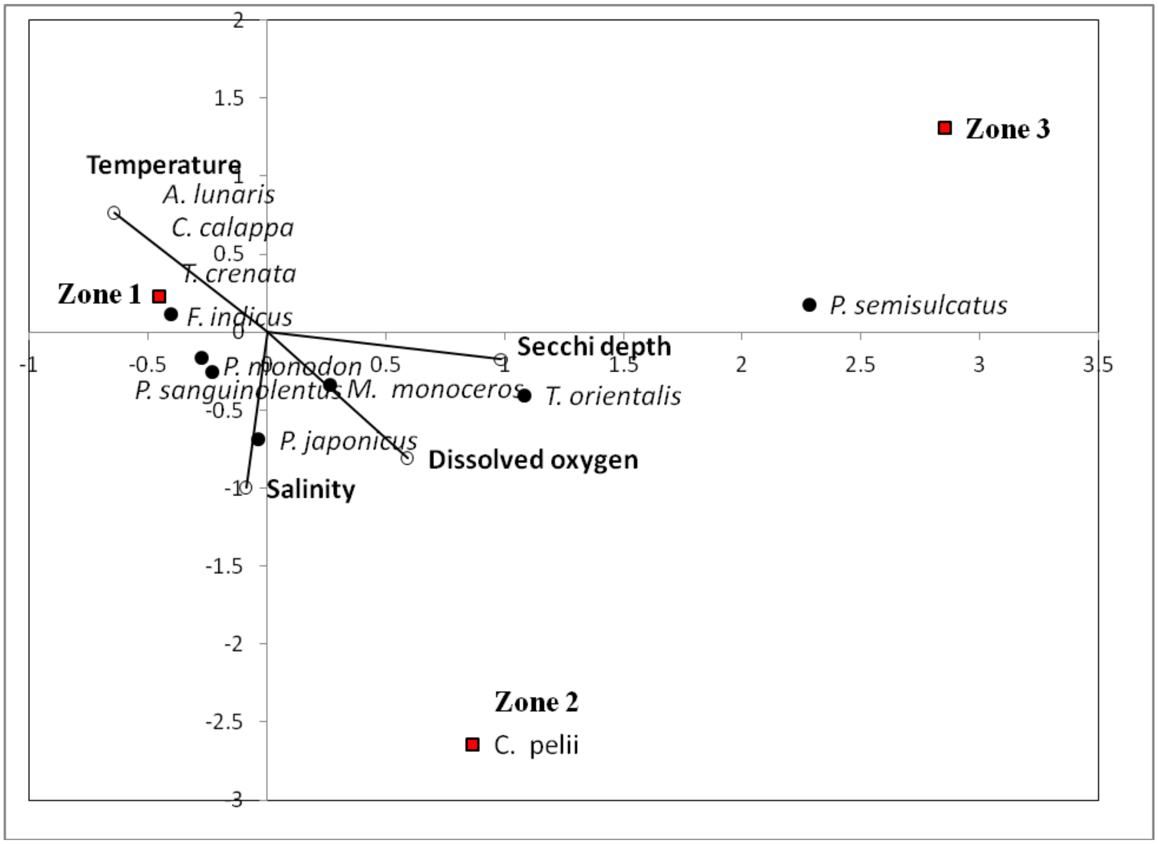

Figure 15. Canonical Correspondence Analysis (CCA) showing the association of decapod crustaceans species distribution with physical factors (salinity, secchi depth and temperature,) in the three depth zones (zone 1(0-10 m), zone 2 (10-20 m), zone 3 (20-40 m)) in Malindi-Ungwana Bay during the NEM season. Species names are as shown on table 1.

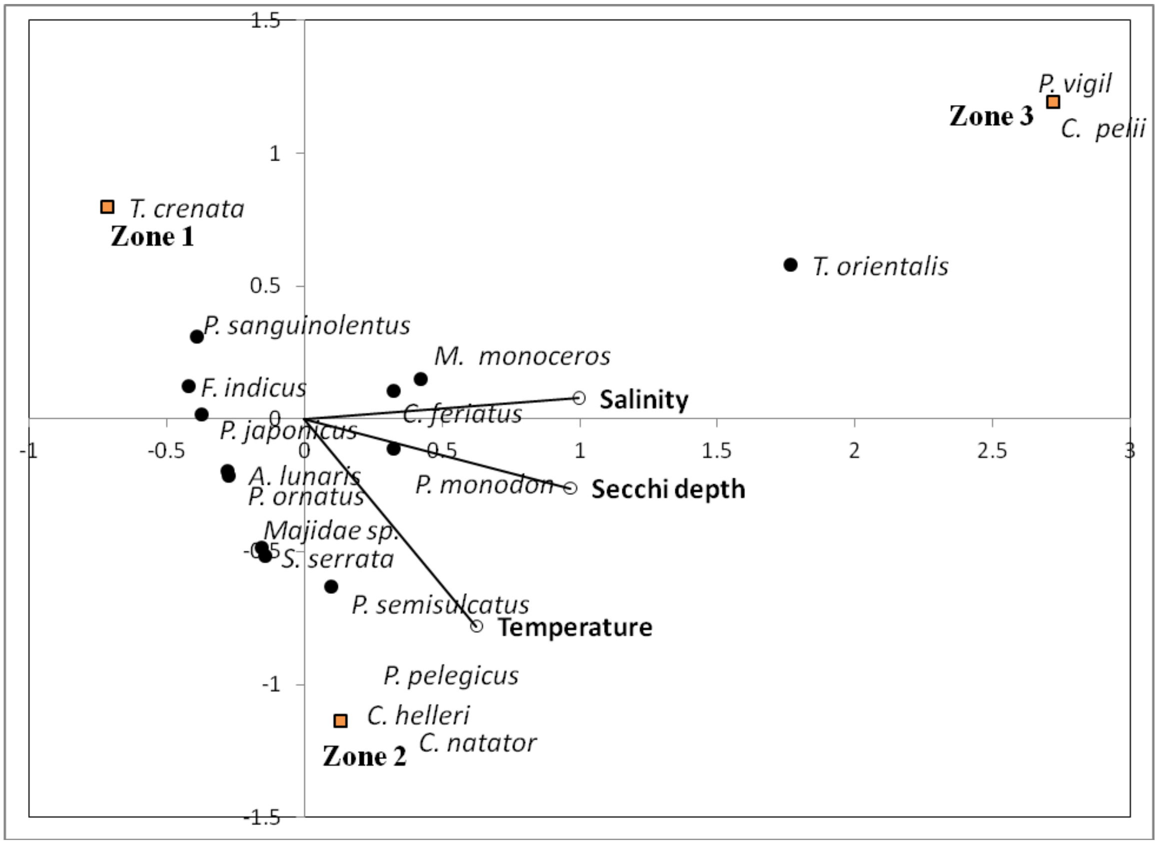

Figure 16. Canonical Correspondence Analysis (CCA) showing the association of decapod crustaceans species distribution with physical factors (salinity, secchi depth and temperature,) in Malindi-Ungwana Bay in the three depth zones (zone 1(0-10 m), zone 2 (10-20 m), zone 3 (20-40 m)) during the SEM season. Species names are as shown on table 1.

CHAPTER FIVE

DISCUSSION

Out of the seven families of decapod crustaceans recorded in this study, the penaeidae were the most abundant group both in the NEM and SEM seasons. Higher abundances were recorded in SEM than in the NEM season. This could be attributed to more recruitment of prawns during the SEM season or higher vulnerability to gear during this season. Other studies in this bay have recorded similar seasonal distribution with higher biomass of prawn recorded during the SEM months of April and May (Mwatha, 2005). Significant differences in relative abundance of penaeid shrimps have been found between the dry and wet seasons elsewhere suggesting that rainfall strongly influences prawn catches (Teikwa and Mgaya, 2003; de Freitas, 2011). This study also recorded higher abundances of the crustaceans during the rainy SEM season. Rainfall is thought to initiate the migration of prawns offshore from estuaries either by lowering salinities or simply by mechanical flushing of water run-off and by disturbing bottom sediments (Teikwa and Mgaya, 2003; de freitas 2011). Juvenile prawns are less tolerant of fresh water as they grow (Staples and Vance, 1986) thus, when the salinity of the water in the nursery areas decreases, the juveniles tend to move to the more saline open ocean. The onset of the wet season will therefore trigger an offshore migration of the juveniles, which are then recruited in the offshore fishery areas.

The results indicate that the penaied shrimps are mostly restricted to the depth zones 1 and 2 (0-10 and 10-20 m) during both seasons. However, *P. semisulcatus*, *M. monoceros* and *P. monodon* had a wider bathymetric distribution that was more distinct during the SEM season. This could be attributed to a higher tolerance of the environmental factors by these species than the other penaieds. Similar wide spatial scale distribution has been reported for *P. semisulcatus* in Kuwait (Ye *et al*., 1999), for *M. monoceros* in the Iskenderum Bay (Can *et al*., 2004), and in the Gulf of Antalya, Turkey (Yilmaz *et al*., 2009). The wider depth distribution for *M. monoceros* has been attributed to variations of temperature with depth **(**Ye, *et al*., 1999). In Mozambique, de Freitas (2011) reports that adults of *P. monodon* and *P. semisulcatus* have been found in offshore waters on the continental shelf between 3 and 50 metres, although they were more abundant between 3 and 20 metres. This study similarly found the species to be restricted to depth ranges of upto to 20 metres. For the portunid crabs, only *P. sanguinolentus* had a wider depth distribution in both the NEM and SEM seasons probably suggesting a broader tolerance to the environmental factors than the other brachyurans. The other portunids such as; *C. pelii*, *T. crenata*, *C. calappa* and *A. lunaris* were caught in very low numbers in the depth zones.

The mean density of the crustaceans showed seasonal variation with depth with more crustaceans being found in the shallower depth (zone 1) during the NEM season compared to deepest depths (zone 2 and 3). During the SEM season, depth zone 2 had a mean abundance more than three times higher than during the NEM season. There is an increase in river discharge into the bay during the wet SEM season which brings organic matter to the bay and increased primary productivity (de Juan and Cartes, 2011). The increased productivity during the SEM season could account for the observed higher crustacean abundance in this season. Some results suggest seasonal migration of the crustaceans between shallow inshore and deep offshore waters (Teikwa and Mgaya, 2003; Mwatha, 2005) thereby accounting for differences in seasonal productivity. Mwatha (2005) also reported spatial and temporal variability in the catch composition in Malindi-Ungwana Bay. The present study found that the biomass of prawns was distributed further offshore during the months of April and May during SEM. Significant difference in relative abundance of crustaceans between dry and wet season were also observed by Teikwa and Mgaya (2003) in Bagamoyo, Tanzania.

During the NEM season, *F. indicus*, *M. monoceros* and *P. monodon* had a size distribution that was generally skewed to the right (more smaller individuals) in depth zones 1, 2 and 3. This indicated a dominance of smaller individuals of these species in these zones. It may be likely that these zones are used as a nursery ground by the species (Garcia, 1988; de Freitas, 2011). During the SEM season, there was noticeable increase in the number of individuals of all species in all the depth zones. The increase in the number of individuals in all three shallowest depth zones could suggest dispersal of juveniles and sub-adults from the inshore nursery grounds to offshore waters during SEM season. During the NEM season, *P. indicus*, *M. monoceros*, *P. monodon* and *P. semisulcatus* had large proportion of immature (stages I and II) individuals in depth zones 1, 2 and 3. Immature individuals were more commonly found in the shallower depth zones 1 and 2. This distribution of immature individuals in these depth zones conforms to the widespread notion that the shallower zones are nursery grounds for these species (Garcia, 1988; Macia, 2004; de Freitas, 2011). However, during the SEM season more ripe and spent individuals (stages III, IV and V) were sampled in depth zones 2 and 3. This pattern suggests dispersal of juvenile and sub-adult individuals from the nursery grounds to the offshore waters during the SEM season where they grow into adult stages.

Changes in salinity and temperature likely contributed to high diversities observed during the SEM season, with peak diversity in depth zone 2 (10-20m). Increased runoff will result into temperature and salinity stratification in the bay (Papiol et al., 2012) which may contribute to higher larval survival (due to thermal warming of waters) and hence high species diversity in the bay during the SEM season. Other studies have found diversity to be affected by temperature, salinity and prey availability within estuarities and bays (Vance et al., 1985; Papiol et al., 2012).

The sex ratios for almost all the penaeid species in the bay deviated significantly from the expected 1:1 ratio. Sex ratio for *M. monoceros* was significantly skewed in favour of the females in all depth zones for both NEM and SEM seasons while, sex ratio for *F. indicus* was in favour of the males in depth zone 1 for both seasons while in depth zone 2, the ratio was skewed in favour of the females for both NEM and SEM seasons. Dominance of one sex is uncommon in penaeid shrimps (Teikwa and Mgaya, 2003) and the deviations could perhaps be attributed to size-specific selectivity by gears.

Another possible explanation in skewed sex ratios could perhaps be due to size-depth variations in distribution of species as maximum attainable size of most penaeid females is greater than that of males (Teikwa and Mgaya, 2003). However, a spatial variation in sex ratios with underlying ecological causes is likely to affect recruitment rates of species.

The trawled transects during the survey in Malindi-Ungwana Bay were defined in four main groups based on catch rates. The first branch similarity tree discriminated mostly between depth zone 2 transects of SEM from the mixed season depth zone 2 and 3 trawls, however, the separation of these two groups was less clear. The third group had two sub-groups which divided the trawls into depth zone 2 and 3 in the SEM season and depth zone 1 mixed seasonal groups. The trawls were further sub-divided into a fourth group that had two sub-groups, the first belonging to depth zone 1 in the NEM season and a second group that belonged to depth zone 1 mixed seasonal groups. The results indicate seasonal and bathymetric influence on the catch rates of the trawls.

The dendrogram of similarity among species based on abundance defined two main decapod crustacean assemblages within Malindi-Ungwana Bay. The first assemblage discriminated between mostly depth zone 1 assemblages from depth zone 2 assemblages. Depth zone 1 mostly consisted of *F. indicus*, *M. monoceros*, *P. modon, P. sanguinolentus, P. japonicas, P. semisulcatus, C. feriatus, T. orientalis* and *A. lunaries* while, zone 2 assemblage consisted of, *P. ornatus*, *P. pelagicus*, *C. natator, C. calappa* and *S. serrata*. Most penaeid shrimps were clustered in depth zone 1 probably because of the higher primary productivity and favourable environmental conditions such as dissolved oxygen, temperature and salinity in this zone. Fanelli *et al*. (2007) found that the distribution of species depends on a number of environmental variables, such as temperature and food availability, which can affect both the maximum density attained and the extreme limits of their distribution. Wienner and Read (1982) observed that decapod crustacean assemblages show definite changes in abundance and composition with seasons and depth. Munoz *et al*. (2008) did not detect seasonality in decapod assemblages in the West Mediterranean Sea and this was attributed to the interaction between assemblages. The depth zone 2 assemblage found in this study consisted of a mixture of Portunidae, Majidae and Calappidae crabs. The presence of most of the species in depth zone 1 and 2 could be due to high primary productivity and other favourable environmental factors such as salinity, dissolved oxygen and substrate type. However, the study did not quantify productivity at depths and bottom structure.

Correspondence Analysis showed that the assemblage structure of crustaceans in Malindi-Ungwana Bay is clearly separated more by the depth zones than by seasons. The species, *F. indicus, P. monodon* and *P. sanguinolentus* were mostly associated with depth zone 1 (0-10 m) with no apparent seasonal preference. The species, *M.* m*onoceros P. japonicus* and *A. lunaris* were closely associated with depth zone 2 (10-20 m) in both the NEM and SEM seasons. *Thenus orientalis* and *C. feriatus* were, however, more associated with depth zone 3 in the SEM season only. Although the study showed depth to be the main structuring factor in the spatial distribution of species in the bay, environmental variables directly related to depth such as temperature and dissolved oxygen could play an important role in this distribution. During the NEM season, *F. indicus, A. lunaris, T. crenata* and *C. calappa* in depth zone 1 were highly influenced by temperature in their distribution. The environmental variables that influenced depth zone 2 distribution was mostly dissolved oxygen as shown by the Canonical Correspondence Analysis output. During the SEM season, the measured environmental variables which included salinity, temperature and Secchi depth were influential in depth zone 2 and 3 distribution of species. Species in depth zone 2 were, however, more under the influence of temperature (*P. semisulcatus*) and Secchi depth (*P. monodon*) in their distribution while those in zone 3 were influenced more by salinity (*M. monoceros, C. feriatus* and *T. orientalis*) in their distribution. Although the environmental variables affecting assemblage structure in the bay are nested in the depth profiles, the influence appear to vary with seasons in each depth zone.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Twenty species belonging to seven families of decapod crustaceans were recorded in the study. The penaeid shrimps were the most abundant group in the three depth zones and seasons. Higher abundances for most crustacean groups were recorded in the SEM than in the NEM season. This variation is attributed to seasonal changes in oceanographic conditions and crustacean behaviour. Decapod crustacean composition, abundance and distribution in Malindi-Ungwana Bay are mostly influenced by depth than by seasonality and most of the biomass is found in depth zone 1 (0-10 m) and zone 2 (10-20 m). Depth zone 4 (40-100 m) which is more offshore recorded very low biomass and species occurrence. For the penaeid shrimps, *F. indicus* is the most abundant species followed by *M. monoceros* in both NEM and SEM seasons. Portunid crabs and palinurids (lobsters) occurred in very low numbers in the samples. It can be concluded that the bay is richer in penaeid shrimps than any other group of decapod crustaceans.

Generally smaller individuals of the crustaceans were found in depth zones 1 (0-10 m) and 2 (10-20 m) than in zone 3 (20-40 m) and zone 4 (40-100 m) suggesting a nursery ground in shallow areas. During the SEM season, there was substantial increase in the number of individuals in all depth zones for all species indicating more uniform bathymetric dispersal in this season. A high proportion of individuals of larger sizes were also recorded by all species in all depth zones. The appearance of smaller individuals and higher number of immature and maturing individuals in depth zone 1 than in zones 2 and 3, the zone closer to the River Sabaki and Tana estuaries, is an indication that the zone is a nursery and breeding ground for crustaceans. The differences in size composition between the depth zones and between seasons suggest dispersal of the decapods across the bay from the backwaters of the estuaries. It can be concluded that there is dispersal of the crustaceans from the shallow inshore to the deeper offshore waters areas during SEM season providing a recruitment trawl fisheries.

The mean species richness in the bay was higher during SEM than NEM season for all depth zones. The mean diversity of the crustaceans was also higher during the SEM season. Depth had significant effect on the diversity of the crustaceans than did seasons, however, there was no significant interaction effect of depth and season on diversity.

The assemblage structure was clearly separated more by the depth zones than by seasons with the species, *F. indicus, P. monodon* and *P. sanguinolentus* mostly associated with depth zone 1 (0-10 m) with no seasonal bathymetric preference while, species *p. japonicus* and *A. lunaris* were closely associated with depth zone 2 (10-20 m) in both the NEM and SEM seasons. There was no distinct separation for *Metapenaeus monoceros* between deprh zone 1 and 2. During the NEM season species in depth zone 1 were highly influenced by temperature while dissolved oxygen influenced species in depth zone 2. During the SEM season, species in depth zone 2 were influenced mostly by temperature while those in zone 3 were influenced more by salinity.

6.2 Recommendations

Following the results of this study, the following broad recommendations are made:

1. It is recommended that spatial and temporal variation in assemblage structure of crustaceans should be considered when developing a fisheries management plan for this bay.
2. The study has indicated that the bay is a likely nursery ground for the decapod crustaceans, if juveniles mostly in the shallow depths, are harvested at young age, then recruitment overfishing could occur and result to collapse of the fishery. It is therefore recommended that trawling activities when allowed be restricted to depths greater than 10 metres, because most of the juveniles are found in depths lower than 10 metres. The trawl fishery is currently regulated by distance from the shore. Trawling is not allowed in areas below 3nm from the shore. The cod-end mesh sizes should also be adjusted to allow for escape of juvenile crustaceans during trawling. A mesh size of
3. From the study, the sex ratios were generally skewed towards the females in the depth zones. Harvesting of spawning females could reduce the fishery recruitment potential due to reduction in spawning stock biomass. It is recommended that effective measures (e.g monitoring of sex ratio of catches) should be taken to maintain sufficient spawner abundance to prevent recruitment overfishing. This will include determination of spawning areas and closure of the spawning areas to fishing during spawning season.
4. There is need for more long term studies to determine temporal and spatial stability in the assemblage structure of crustaceans as determined by this study.

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