THE BIOLOGY AND FISHERY OF COMMON OCTOPUS (*OCTOPUS VULGARIS*, CUVIER 1797) IN THE KENYAN SOUTH COAST

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Declaration

I, Gideon M. Kivengea, hereby declare that I have written this thesis, that it is the record of work I carried out and that it has not been submitted in any previous application for an academic degree.

Signature ____________________ 18·11·2014

Mr. Gideon M. Kivengea — Date

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

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Dedication

This work is dedicated to my parents, the late Mr. Wilson Kivengea Nzivo and Mrs. Mary Kivengea

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Acronyms

ANCOVA	-	Analysis of covariance
BMU	-	Beach Management Units
BW	-	Body weight
CA	-	Competent Authority
CEC AF	-	Fishery Committee for the Eastern-Central Atlantic
CPUE	-	Catch Per Unit Effort
DML	-	Dorsal Mantle Length
EEZ	-	Exclusive Economic Zone
EU	-	European Union
FAO	-	Food and Agriculture Organization of the United Nations
GMP	-	Good Manufacturing or Management Practices
GSI	-	Gonadosomatic index
HACCP	-	Hazard Analysis at Critical Control Points
IFP	-	Industrial Fish Processor
IOTC	-	Indian Ocean Tuna Commission
IUCN	-	International Union for Conservation of Nature
IUU	-	Illegal, Unreported and Unregulated fishing
KEBS	-	Kenya Bureau of Statistics
MCS	-	Monitoring, Control and Surveillance
MPAs	-	Marine Protected Areas
NEM	-	Northeast monsoon
OW	-	Ovary weight

SEM - Southeast monsoon

SWIO - South West Indian Ocean

TL - Total length

TW - Testis weight

VML - Ventral mantle length

WIO - West Indian Ocean

Abstract

Although common octopus catches are increasing globally, lack of information on the species biology and fishery has been a major concern in its management particularly in Kenya. The present study aimed at investigating the fishery, reproductive and feeding biology of common octopus from Shimoni and Vanga which are some of the major fish landing sites in the Kenyan South coast. Sampling was done monthly from November 2010 through November 2012 using traditional fishing spear ‘mkuki’ or ‘shomo’. For each specimen, body weight (BW), total length (TL), dorsal mantle length (DML), ventral mantle length (VML) and gonad weights were recorded. Maturity stages and Gonadosomatic Index (GSI) were determined using standard methods. Stomach content analysis was determined using both the frequency of occurrence method and the dominant (numerical) method. For the processing and markets of common octopus, information was collected from logbook records, and landings from fishermen and fish industries.

A total of 1,599 specimens were collected, 746 males and 853 females. The size distribution range of the females varied between 5.40 cm and 24.50 cm DML and from 0.07 kg to 5.50 kg BW, while the DML of males ranged from 5.80 to 18.50 cm and the BW from 0.08 kg to 3.95 kg. The monthly mean DML values ranged between 9.52 ± 1.81cm and 13.53 ± 2.51cm at Shimoni and 9.14 ± 1.56 cm to 13.00 ± 2.36 cm at Vanga. The monthly mean DML and BW values showed a decreasing trend over the two-year period, an indication that octopus population was under high exploitation pressure. The sex ratio was 1:1.1 (males: females) for both Shimoni and Vanga during the study period. However, there was no seasonal or annual significant difference ($p > 0.05$) in sex ratio. When the sex ratio was analyzed by size intervals, the only significant difference ($p < 0.05$) was observed in sizes over 18 cm DML in favour of the females. The results of histological analysis of gonads indicated that common octopus may be breeding all year round with spawning peak from June to

August. Maturity and gonadosomatic indices showed similar annual changes, especially in the case of females. The female length at first maturity was 10.8 cm (DML $_{50\%}$), while for the male was 10.5 cm (DML $_{50\%}$), respectively. There was no significant difference, statistically between female and male length at first maturity. The common octopus preferred crustaceans (mainly crabs) to other food items and its diet preference was not influenced by seasons. The processing of octopus was done using both traditional techniques and modern facilities that are fully compliant with the food safety standards for export markets. The value-added octopus final products ranged from traditional dried octopus to chilled and frozen packed octopus. The species was marketed fresh, frozen and dried, mostly for human consumption. A small local market was found to exist for common octopus of which most of it was sold in local seafood tourist restaurants. International markets existed in various countries including Italy, Spain, France and Portugal. The scientific information gathered during this study on the fishery, reproductive and feeding biology of common octopus will go a long way in informing policy directions and the management of octopus in Kenya.

Key words: common octopus, fishery, reproductive, feeding, Shimoni, Vanga.

CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 Background

Octopuses are marine molluscs in the Phylum - Mollusca, Class - Cephalopoda, Order - Octopoda, Suborder – Incirrina and Family – Octopodidae. The name cephalopods literally means head foot and have their appendages attached to the head, they include octopuses, squids, and nautiluses (Caddy, 2004). There are two groups of octopoda, the cirrate and the incirrate. The cirrate have cirri (which are large motor organelles of hypotrich cilliates form from fused cilia) and are by far less common than the incirrate which contain the more traditional forms of octopus (Scheel, 2002).

The common octopus is found worldwide in the shallow waters of tropical, subtropical, and temperate areas. Common octopus has been long considered of cosmopolitan occurrence in temperate and tropical seas (Roper et al. 1984), but a possible occurrence of cryptic species among common octopus has also been reported (Mangold, 1998; Guerra et al. 1999). Mangold (1998) stated that the species are abundant in the Eastern Atlantic Ocean, the Mediterranean Sea and off the coast of Japan.

The common octopus is a benthic cephalopod distributed on muddy, rocky and sandy bottoms from the coastline to the edge of the continental shelf (Mangold, 1983; Belcari & Sartor, 1999). In the West Indian Ocean (WIO) region, it is fished from intertidal reef flats and subtidal reefs during low water tides. In the Mediterranean, this species is the most commercially important among all cephalopods (Mangold, 1983). It is fished mostly by trawlers as a bycatch but other gears are also involved, i.e. beach seines, trammel nets, fyke nets, pots and traps (Belcari & Sartor, 1999).

Octopuses, known as “pweza” in Kiswahili, have been collected for centuries in the West Indian Ocean and are a favoured food item. The common octopus is the main target species in the Kenyan South coast and usually comprises 99 % of the catch (Dept. of Fisheries, 2009). Octopus are collected either by walking over the lower reaches of the intertidal reef flat or by snorkelling along the reef edge where they live in small holes (dens) and crevices, often hidden by small stones, rubble and pieces of shell. Once spotted, a slender stick or metal spear is inserted into the den and jerked up and down, thus causing the octopus to grasp the stick item which is then withdrawn (Marshall et al. 2001).

The common octopus grows extremely fast, increasing in weight by as much as 200 g in only 10 days, and thus potentially supporting a highly productive fishery (Mangold, 1983). This is only possible if it is well managed, which requires an understanding of the species biology. When females are ready to spawn, which happens only once in their lifetime, they barricade their den (Mangold, 1983). Following spawning, they attach the eggs to the den roof, clean and aerate them for about 30 days, and then die (Mangold, 1983). The ‘brooding’ is essential for successful hatching, and so a reduction of fishing pressure during this season is highly recommended (Mangold, 1983). Furthermore, as females normally brood at their largest size, fishing of large individuals could reduce recruitment and eventually stock size (Perry et al. 1999). In heavily fished areas both size and weight of octopus is often low, and reproductive output may already be affected (Norman, 2000).

Although common octopus recorded a significant commercial value of 394 metric tonnes valued at Ksh 49,402,000.00 in 2012 and is an important target species for the fisheries in the Kenyan South coast, little research has been done on its biology, physiology and population dynamics (Dept of Fisheries, 2012a).

1.2 Problem Statement

The common octopus contributes the bulk of all cephalopods landed in the Kenyan coast. It is one of the most desirable octopus species for food and commercial purposes by majority fishermen. The decline in many teleost fish stocks due to overexploitation has led to increased use of octopus as an alternative source of protein. However, the extent that octopus stocks can withstand this escalating pressure is largely unknown, due to lack of relevant scientific information on the species. There is no study on the biology and fishery of octopus that has ever been done in the Kenyan coast hence basic knowledge on octopus population distribution, abundance, size classes and condition factor as well as reproductive biology is deficient, yet such knowledge is necessary to guide proper management of the fishery. Knowledge of reproductive biology of octopus is essential for predicting population stability and fluctuations which can be used to design octopus management measures such as closed fishing areas and seasons. This study therefore aims at contributing to the above effort by providing critical fishery and biological information needed to guide the sustainable utilization of the resource.

1.3 Overall objective of the study

The general objective of this study is to provide an understanding of the biology and fishery of common octopus in the Kenyan South coast.

1.3.1 Specific objectives of the study

The specific objectives of the study were:

i. To describe the growth and temporal distribution of common octopus,

ii. To describe the reproductive biology of common octopus,

iii. To describe the food and feeding habits of common octopus,

iv. To describe the relative abundance (CPUE), value addition and marketing processes of common octopus,

1.4 Significance of the study

This study was aimed at providing critical scientific information that is required for future monitoring and guidance on the management of common octopus fishery in the Kenyan coast. Understanding the species reproductive biology will help the State Department of Fisheries to design strategies in establishing nursery or breeding grounds to protect the young and the brood stocks and to design appropriate management measures like closed fishing areas and seasons aimed at sustainable utilization of the fisheries resources. Scientific knowledge on common octopus food and feeding habits will help in informing policy directions and the management of the fishery. Information on relative abundance, value addition and marketing processes of common octopus will also be necessary to guide proper management of the fishery. The information generated will also provide basis for future research work.

1.5 Scope and limitations of the study

The study basically focused on the biology (growth and temporal distribution, reproductive biology, food and feeding habits) and some aspects of the fishery (relative abundance (CPUE), value addition and marketing processes) of common octopus in the Kenyan South coast. The study was carried out over a period of two years between November 2010 and November 2012 focusing on two study sites namely; Shimoni and Vanga. Specimen collection was done on monthly basis. The main limitation of this study was that collection of specimen was predominantly concentrated in the intertidal zones as venturing into the deep waters (subtidal zones) required big fishing vessels and better fishing gears.

1.6 Literature Review

1.6.1 Marine fisheries landing trends - a global perspective

Overexploitation of traditional fisheries, overcapitalisation of fleets, increases in product demand and growing world populations have all put increasing pressure on marine ecosystems (Caddy, 1999). It is estimated that approximately 70 % of the world's fisheries are either overexploited, depleted or recovering (Rosenberg et al. 1993). This state of depletion is particularly evident in the developed and industrialised nations of the northern hemisphere, but is also found to a lesser extent in developing countries (Rosenberg et al. 1993). Overexploitation levels of fisheries in the United States of America and the European Union alone have reached 45 % and 59 %, respectively (Rosenberg et al. 1993). Some of the better-known fishery collapses have been the Peruvian anchovy and the Canadian cod stocks (Buckworth, 1998). Both fisheries collapsed after overfishing caused by fleet overcapitalisation in the case of Peru, technological advances in the cod fishery, and the failure of management to acknowledge risks within the management measures employed (Muck, 1989; Walters & Maguire, 1996).

Caddy (1999) suggested that the depleted state of marine resources worldwide is not only attributable to the 'tragedy of the commons' in open-access fisheries, but to the shortcomings of general management paradigms. For example, limited licence schemes and target reference points have not prevented the overexploitation and collapse of fisheries. The failure of fisheries management to take technological advances into account has caused an increase in effort and a decrease in fish stocks even where limited licence schemes were in place (Caddy, 1999). Moreover, the uncertainty or risk in management measures such as target reference points has largely been ignored in the past (Cochrane, 2002). The lack of failsafe mechanisms (reliable mechanisms such as reducing fishing effort progressively through pre-negotiated decision rules when larger numbers of independently determined limit reference points are exceeded) to reduce this risk has had disastrous consequences, with collapses of even those fisheries managed by 'safe' Maximum Sustainable Yield (MSY) target points (Caddy, 1999). MSY is now considered as a limit reference point rather than a target point, with MSY only used as a target in the rebuilding of stocks.

As the global human population currently estimated at 7.4 billion continues to grow and fish production declines (Watson & Pauly, 2001), demand for, and prices of, marine products are likely to increase. However, new fisheries are still being developed, and fisheries landings of underdeveloped and underutilised resources have increased considerably in the last twenty years compared to traditional finfish fisheries (Perry et al. 1999). Many of these underdeveloped resources are marine invertebrates, the landings of which have increased by approximately 46 % between the mid- 1980s and mid-1990s, compared to only 19 % and 3 % growth for pelagic and demersal finfishes, respectively (FAO, 1997). Countries such as Canada and Australia are particularly focussed on the development of new invertebrate fisheries. Currently, 35 invertebrate species are exploited in Canada, and these contributed to a 130 % increase in invertebrate landings in British Columbia over the mid-1980s-1990s period (Perry et al. 1999). Comparatively, Canadian ground fish landings only increased by 58 %, while pelagic landings of species such as herring decreased by 20 %. In Australia, 78 % of new fisheries are based on invertebrates, comprising 14 previously unexploited species (Halmarick, 1999).

FAO (2005), has indicated that the larger portions of the global marine catches are pelagic species; with small pelagics (herrings, sardines, anchovies, etc.) representing around 26 % (22.5 million tonnes) of the total catch in 2002, down from 29 % in the 1950s and 27 % in 1970s. The larger pelagics (tunas, bonitos, billfishes and miscellaneous pelagics) accounted for

21 % (17.7 million tonnes) of the total catches in 2002, an increase in their share from 13 % in the 1950s. Demersal fishes (flounders, halibuts, soles, cods, hakes, haddocks and miscellaneous demersals) contributed 15 % of the total catches in 2002 (with 12.3 million tonnes), compared with almost 26 % of the world catches in the 1950s and 1970s. Miscellaneous coastal fishes remained stable at 6 % and then 7 % (with 6.1 million tonnes) in 2002, while crustaceans (crabs, lobsters, shrimps, prawns, krill, etc.) increased from 4 % in the 1950s and 1970s to 7 % (5.8 million tonnes) in 2002. Molluscs (abalones, conchs, oysters, mussels, scallops, clams, squids, octopus, etc.) increased slightly from 6 % in the 1950s and 1970s to 8 % (6.8 million tonnes) in 2002. There was a slight increase in the proportion of unidentified fish in 2002 with 13 % of the total catches (10.7 million tonnes), up from 11 % in the 1950s and 1980s.

1.6.2 Global landing trends of octopus

Octopuses have been exploited in coastal regions around the world for more than 2, 000 years and the global octopus production has increased substantially over the last 50 years as shown in figure 1.1. Common octopus is the most exploited species and often supports artisanal subsistence fisheries, commercial fisheries as well as recreational fisheries (Roper et al. 1984). The fishing effort has also increased substantially as a result of increased market demand and the high prices that are paid for common octopus (Boyle & Rodhouse, 2005).

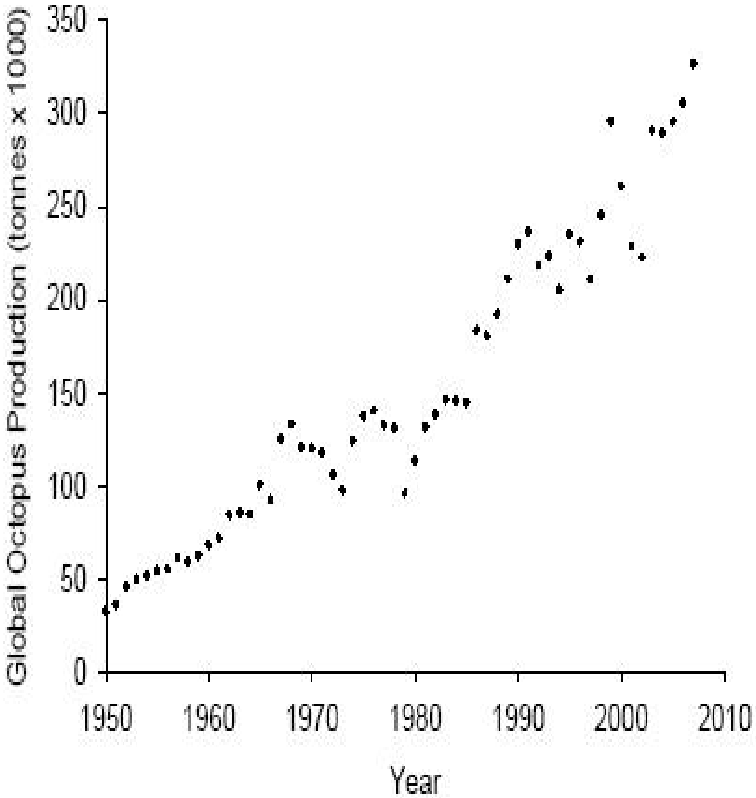

Figure 1.1: Global octopus production as from 1950 to 2009 (Source: FAO, 2009).

1.6.3 National marine fisheries landing trends

The Kenyan marine catches attributed to octopus showed a gradual increase from values of 49 metric tonnes in 1992 to values of 290 metric tonnes in the year 2008 (Figure 1.2). The high peaks in octopus landings, which were recorded in 1995 and 1997, occurred at the same time period when finfish landings were at their lowest. This may be an indication that, due to poor catches in finfishes, fishermen turned to capture of invertebrate species. The Kenya's State Department of Fisheries estimates that there are about 10,000 fishers directly engaged in fishing along the Kenyan coast (Dept of Fisheries, 2011). The national estimate is derived from the number of licenses issued for fishers and boats registered at the different landing sites. However, there are a number of problems with these methods. First, compliance is low, particularly for the registration of fishers. Secondly, an average of two or three artisanal fishers share a fishing vessel, however, some vessels carry over 12-15 fishers e.g. dug-out canoes which are un-powered or over 20 fishers if using powered fishing boats.

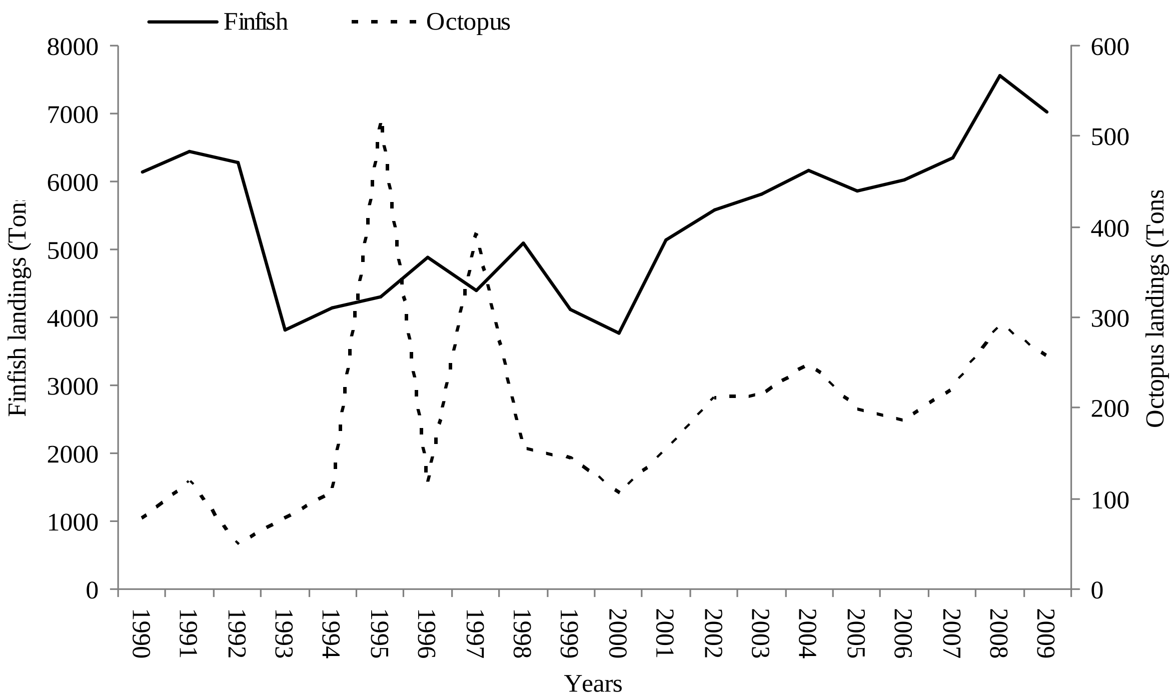

Figure 1.2: Landing trends of octopus and finfish in Kenyan coastline as from 1990 to 2009 (Source: Dept of Fisheries, 2011).

Other fishers neither have nor use vessels, particularly speargun fishers who swim and those who glean on the reefs and in shallow water. In addition, some people fish as a part time activity and are likely to be excluded in such counts. Kenya's artisanal fishery includes a wide range of gear types, the selection of which involves many historical and preference factors for individual fishermen (Glaesel, 1997), and these change with environment, social and economic pressures over time (Ochiewo, 2004). Furthermore, fishing activity changes according to tidal and seasonal cycles as water depth, daylight and the monsoon seasons affect accessibility of different fishing grounds for different vessels and gears (Obura et al. 2001). Artisanal fishing is the main economic activity of the majority of the people living along the Kenyan coastline stretching all the way from Kiunga in the north to Vanga in the south (Tarbit, 1986). It provides employment, food and income, directly, as well as indirectly. Commercial fishing along the coast also contributes to foreign exchange earnings (Bakari, 1997).

The fisheries sector in Kenya plays an important role in the economic and social development of the country (Dept of Fisheries, 2012b). Most coastal fisherfolk are artisanal and subsistence fishers with most fishing being carried out inshore close to the reefs. Rarely is fishing undertaken beyond the territorial waters (a belt of coastal waters extending at most 12 nautical miles from the baseline of a coastal state) as artisanal fishing is mostly done from small non motorised crafts which cannot venture into the deep waters – the contiguous zone and the exclusive economic zone (Dept of Fisheries, 2011). The artisanal fisheries in Kenya supplies 95 % of the country's total marine catch, generating an estimated US$ 3.2 million per year and accounting for between 2 % and 6 % of total fish production in the country (Dept of Fisheries, 2009). Hence, while the entire fisheries sector only contributes 0.5 % to national GDP, it is nevertheless a vital component to economic activity in the coastal regions. Population growth along with high levels of poverty in the coastal regions, has contributed to increases in the number of small-scale fishers, with a 34 % increase documented between 2004 and 2008. This has, in turn, placed great strain on fish stocks along the coast, resulting in the over-exploitation of fisheries resources. This has, subsequently, resulted in an overall decline in small-scale landings, evident in the 50 % decrease in demersal coral reef fish yields through the 1990's (Dept of Fisheries, 2011). Rabbit fish and scavengers (which make up nearly 40 % of the small-scale fishers' landings) also declined by 40 % in the 1990's, while the catch of tuna has been declining since 2004 (Dept of Fisheries, 2011).

1.6.4 Description and behaviour of common octopus

The common octopus is a marine mollusc in the family Octopodidae. The cephalopods, whose name literally means head foot, have their appendages attached to the head and include octopuses, squids, and nautiluses (Caddy, 2004). It has eight long tentacles protruding from a globe-shaped head (or mantle). Two rows of suckers line each of the tentacles and can sense and taste. While it was commonly believed that the octopus appendages were all arms, recent studies by marine experts have shown that two of the limbs act more as legs, allowing the octopus to walk across the sea floor and push off when swimming (Scheel, 2002). The octopus also has the ability to regenerate a tentacle (autotomy) if it loses one. Similar to a squid, the common octopus is classified as a mollusc, which is a soft-bodied invertebrate without a shell. The octopus has no skeletal structure but does possess a skull, which protects its brain. It also has a sharp beak and a toothed tongue called a radula.

When confronted with a potential threat, the octopus employs several defence tactics. Common octopus has both primary and secondary defence mechanisms against their predators. The primary defence mechanism includes the use of ‘crypsis,’ also known mainly as camouflage or colour changing to match their environment. The secondary defences are only used when the primary response fails, and the octopus is detected by its predator. These responses include flight and inking, deimatic (frighten) behaviour, defensive postures, and deflective markings (Hanlon & Messenger, 1996). The octopus ability to camouflage is astounding and it is theorized that this ability developed as an adaptation for protection from predation due to the evolutionary loss of an external shell (Ferguson & Messenger, 1991). The common octopus achieves colour change in part by chromatophores, iridophores, and leucophores; all structures of the skin in increasing depth (Froesch & Messenger, 1978). Chromatophores are generally known as elastic pigment sacs with muscle fibres attached letting them expand and contract while iridophores contain sacks of reflective plates that reflect light through thin film interference (Ferguson & Messenger, 1991). The leucophores are important because they allow for the reflection of white light and consequently allow the skin to reflect wavelengths of light which are prevalent in their habitat and produce disruptive patterns (Froesch & Messenger, 1978). The other aspect to cephalopod camouflage is the brain, which contains nerves coated in chromatophore fibers, controlling coloration patterning

(Froesch, 1973). .

Deimatic (frighten) behaviour includes threatening or bluffing actions in order to cause the predator to hesitate (Hanlon & Messenger, 1996). Sometimes this behaviour will scare away the predator or give the octopus enough time to flee in a jet of ink. Specific deimatic coloration patterns and body postures of common octopus are a paling of the skin, darkening of suckers and area around eyes, tentacles and web spread widely, and a jetting of water (Froesch, 1973). They are also known to threaten the predator by throwing out their tentacles towards the attacker (Ferguson & Messenger, 1991).

Another defence tactic is flight. After releasing a cloud of purple-black ink, the octopus propels itself by funnelling water from its gills at the top of its mantle through its siphon, located at the bottom of the mantle. It can reach speeds as high as 40 km/h (25 mph), but cannot maintain this speed for long (Scheel, 2002; Norman, 2000). Octopuses are solitary animals that make their homes in rocks and coral or dig burrows. They scatter rocks and shells (or midden) around their dens to hide them. They leave the dens only to eat or reproduce (Norman, 2000).

1.6.5 Growth and Temporal distribution of common octopus

The common octopus is, undoubtedly, one of the most studied cephalopod species in the world. It has been the object of a number of studies, related mainly to its growth and temporal distribution (Mangold, 1983). Despite this fact, its scientific studies are still limited to few areas such as the Mediterranean Sea, Tunisa and South Africa (Belcari & Sartor, 1999). While worldwide the greatest octopus fishery takes place in the Saharan Bank (off the Northwest coast of Africa), other large fisheries exist along the European Atlantic coast and the Mediterranean Sea, as well as in the waters off Japan and Venezuela (Guerra, 1997). In the Mediterranean Sea, common octopus is the most landed cephalopod species (Tsangridis et al.

2002). The same phenomenon is also witnessed in the Spanish Mediterranean, where common octopus landings averaged around 4,000 tonnes per year between 2000 and 2010. Most of the catches were due to the fishing activities of coastal trawlers, as well as artisanal fishing fleets (Fern-Ndez & Esteban, 2003).

The temporal distribution and population dynamics of common octopuses is very diverse (Guerra, 1981). The abundance and population size structure of common octopus in the Mediterranean and in Northwest Africa is highly variable (Mangold, 1983), with migrations between inshore and deeper offshore areas related to spawning behaviour and temperature variations (Mangold & Boletzky, 1973; Guerra, 1981). Similar migration patterns were found on the East coast of South Africa (Smale & Buchan, 1981) and in South Carolina (Whitaker et al. 1991). Smith (1999) noted a shallower depth distribution for juveniles than for larger animals on the West coast of South Africa. This was also found for the common octopus in Bermuda (Mather & O'Dor 1991), indicating the importance of spatial dynamics within populations. The global geographical distribution of common octopus is as shown in figure 1.3 below;

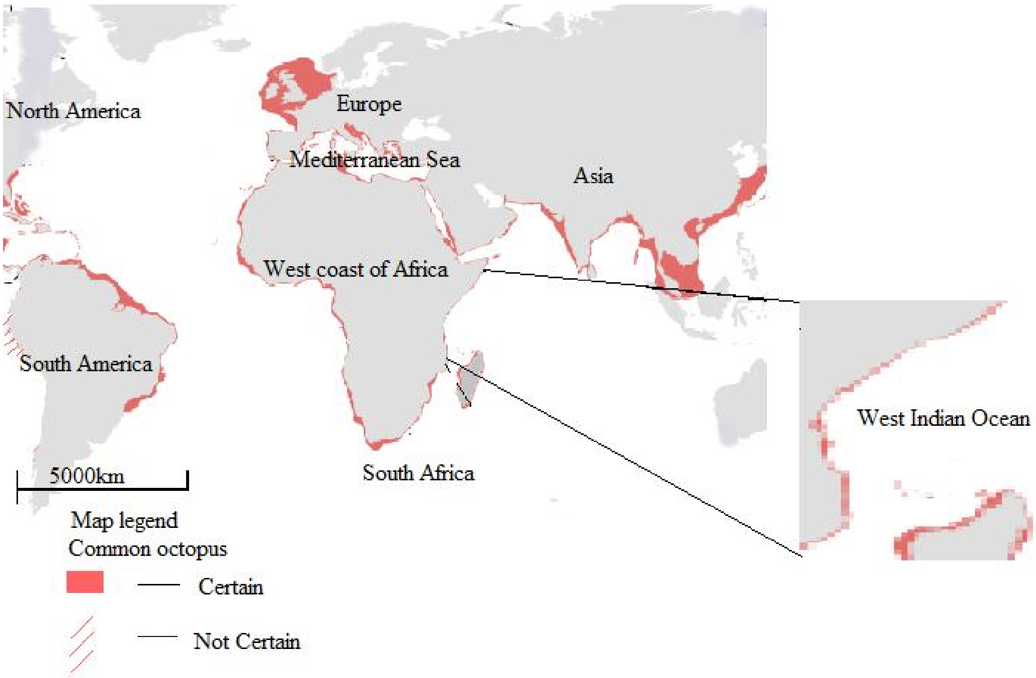

Figure 1.3: The global geographical distribution of common octopus (Source: FAO 2009, Fishery Statistics)

Growth of common octopus was studied by Guerra and Manriquez (1980) in the Occidental Mediterranean, and Hatanaka (1979); and by Domain et al. (2000) and Dia (1988) in the Atlantic. In Tunisia, growth of common octopus was studied by Ezzeddine-Najai (1992) and Zghidi-Barraj (2002) in the Gabes Gulf. Studies of age determination of common octopus have been done using both direct and indirect methods. The direct methods include examination of statoliths (Gonçalves, 1993). Octopus beaks have also been used in other aging studies (Hernandez-Lopez & Casto-Hernandez, 2001; Raya & Hernandez-Gonzalez, 1998), but they have so far proved inadequate for aging purposes as validation with aquaculture for common octopus was actually not possible. For these reasons, indirect methods are in most cases applied (Gonçalves, 1993). The indirect methods are based on the analysis of size frequencies, such as Battacharya's method (Battacharya, 1967). It consists of following the chronological evolution of length or weight size distribution in the specimens that represent the studied population. Age determination of common octopus is difficult because of its short longevity, fast growth, and size variation (Hatanaka, 1979).

1.6.6 Reproductive biology of common octopus

Zguidi (2002) reported that female common octopus in the Gulf of Gabès, Tunisia, normally attains sexual maturity at an average weight of between 1,200 to 1,450 g. He, further, found out that females have spawning seasons from February to September with peaks between March and July. The males are mature all the year round. The breeding is preceded by an inshore migration in autumn with males preceding the females (Zguidi, 2002). In early spring, a large number of adult females isolate themselves in shelters for spawning (Caverivière, 1990).

Regardless of life-history strategy, almost all octopus species are terminal spawners. According to Rocha et al. (1999), common octopus have a merobenthic life-history strategy where the number of eggs from a single egg batch are in the 100,000s and the small hatchlings go through a planktonic 'paralarval' stage prior to settling on the benthos. The species which have a holobenthic life-history strategy, for example, *Octopus maya*, *Octopus tetricus* and *Eledone moschata*, have the number of eggs from a single egg batch in 100s, the hatchlings are much larger and they take up an immediate benthic life style similar to adults (Hanlon & Messenger, 1996). According to Guerra (1979), common octopus is normally solitary and territorial during spawning seasons. It digs into soft substrata to rest quietly during the daytime. Juveniles and females bury themselves in sandy and muddy sediment to shelter against predator attack (Boletzky, 1996).

Because of their solitary lifestyle, mating in common octopus does not include long term pairing, monogamy, or intricate courtship (Hanlon & Messenger, 1996). It is not confirmed exactly how the mating process occurs, but two methods are known. The males either mount the females and deposit their spermatophores or deposit the sperm sacs from a distance alongside the females. Either way, the whole occurrence takes on average an hour, with a sperm sac being deposited every fifteen minutes (Hanlon & Messenger, 1996). Common octopuses are oviparous and have separate sexes with no sex reversal or hermaphrodites, and females spend extended amounts of time caring for their eggs. According to Anderson et al. (2003), female common octopus die soon after their eggs hatch as they are very weak to eat due to massive decrease in their digestive gland weight while males become senescent after mating (the biological significance of this reproductive strategy is that, the species is naturally resilient to fishing pressure due to its short lifespan). After a successful mating and when the conditions are right for fertilization, the female lays her eggs (Hanlon & Messenger, 1996). The female octopus releases 100,000-500,000 eggs. Her eggs are attached to a substrate inside the den either in a group or individually, so that she may protect and take care of them. This stage of sexual maturity drastically changes the female's physiological processes and activities. Her body stops growing and she stops leaving the den to look for food, discontinuing eating for the rest of her life. All of her time is spent cleaning and aerating the eggs. Meanwhile, the hatchlings are carried by the currents, and they feed on plankton for 45-60 days. Only a few of the hatchlings survive to adulthood (Scheel, 2002). After mating, the male octopus often is seen engaged in undirected activities, even during the day, in the wild and in captivity. In captivity, this behaviour may continue for some time while in the wild, it probably results in the octopus quickly becoming an easy prey (Katsanevakis & Verriopoulos, 2005). Octopus lifespan vary among species but can be between six months to five years. The entire lifecycle of common octopus only lasts between twelve and fifteen months (Katsanevakis & Verriopoulos, 2005).

Working in the Gulf of Alicante, Northwestern Mediterranean, Gonz lez et al. (2011) found out that gonadosomatic index analyzed in female common octopus increased with sexual maturation. The maximum values of the index occur when reproductive activity is at its highest. In males, the testis and the Needham sac (spermatophore sac) increase in weight before the beginning of the spawning season for the females (Mangold, 1983). Hanlon and Messenger (1996) reported that male common octopus produces and maintains sperms in spermatophores. It then deposits the spermatophore sacs into the females using the hectocotylus (is one of the arms of male cephalopods that is specialized to store and transfer spermatophores to the female). The hectocotylus has a hollow groove for the sac to fit into, which it then uses to deposit the sperm into the female's oviduct. Males usually reach sexual maturity ahead of the females, although they are still able to coordinate reproduction at the same time (Silva et al. 2002). This is possible because the female stores the sperms in their oviducal gland until they are sexually mature and ready to fertilize them (Hanlon & Messenger, 1996). The female can keep the sperms inside their oviducal gland for up to two thirds of their life time. This also allows the females to collect sperm sacs from various partners and use whichever sacs for fertilization of her eggs. Since courtship is severely reduced or absent, male and female common octopus do not show any form of specific coloration patterning or particular postures. At the most, males may show off their large suckers to confirm gender (Hanlon & Messenger, 1996).

The common octopus undergoes seasonal spawning migrations (Case, 1999; Tsangridis et al. 2002) moving to coastal waters during particular months of the year (Quetglas et al. 1998) and congregating in shallow waters to spawn. Fishermen take advantage of spawning aggregations. This is reflected in the seasonal peaks of catches (Hernandez-Garcia et al. 1998). According to a study on Alaska common octopus by Conners and Jorgensen (2006), the populations inhabit deep waters during mating season from July to October and move to shallow waters between October and July to spawn. They, further, established that common octopus migrate inshore between October and November then return to deeper waters from February to March, travel inshore again in late April and migrate back to deeper waters in August and September. Migration patterns can be predicted and used by fishermen to target octopus and other species and also by researchers to collect specimens. Because females stay in one location while brooding and rarely leave their eggs, they can be easily targeted by fishermen. The common octopus, which broods in shallow waters, is especially easy to target (Case, 1999). When not in the spawning season, octopuses are generally solitary, shy and shelter-seeking animals (Mangold, 1983).

1.6.7 Food and feeding habits of common octopus

The common octopuses are carnivorous predators and prefer to feed on a variety of live prey species (Fiorito & Gherardi, 1999). They are known to feed, particularly, on crabs, bivalves, and gastropods (Fiorito & Gherardi, 1999). Common octopuses have also been found to feed on polychaetes, other crustaceans, cephalopods, and various species of bony fishes (Hanlon & Messenger, 1996). Although octopus cannot see colours, they are able to identify their prey by movement, shape, features, and scent (Fiorito & Gherardi, 1999). One method they use during hunting is known as 'groping' in which they use their tentacles to feel along rocks, sediment, and in holes for potential food (Fiorito & Gherardi, 1999). In another method, they use their web for covering prey when pouncing on top of them while a third tactic involves the siphon in which they blast sediment with water to reveal buried prey (Hanlon & Messenger, 1996). A number of other hunting modes are ambushing, stalking, and luring (Hanlon & Messenger, 1996). There are various studies which report on the amount of time dedicated to feeding by octopus. In Bermuda, specifically, Mather and O'Dor (1991) found out that common octopus spent a relatively short amount of time feeding, on average twelve percentage of their day.

The common octopus usually spends its first 5 - 12 weeks of life actively preying on plankton. The passage to the next benthic phase is a gradual process (Boletzky, 1974, 1977), and even when it descends to the sea bottom, it continues to feed mainly halfway down without exhibiting a radical change in its feeding habits. When its descent becomes final, however, common octopus exhibits behaviour perfectly comparable to that of the adult stage; it lies on the bottom of the sea and uses its tentacles to catch its prey, feeding mostly at night (Itamy et al. 1963).

Their radula (tonguelike organ in certain molluscs) is extremely efficient tools for aiding eating of these organisms, especially for penetrating a thick mollusc shell or arthropod cuticle. The octopus will grasp the organism and drill a tiny hole with their radula and using their salivary papilla insert a paralyzing toxin which relaxes the organism allowing their shell or exoskeleton to be penetrated (Fiorito & Gherardi, 1999). Bivalve molluscs are torn apart using the octopus tentacles and suckers, but can also be drilled if this fails. However, pulling open bivalves has a much higher energy cost than drilling alone. Once they have fed, the mollusc shells are scattered around their den area in piles known as 'middens' (Fiorito & Cherardi, 1999).

Despite their ferocity as invertebrate predators of the oceans, common octopuses are preyed upon by numerous dominant carnivores. Pinnipeds (marine mammals) in oceans around the world feed on cephalopods (Klages, 1996). Seals are a threat to the octopus because they are fast swimmers and easily tire octopuses who cannot keep up fast swimming speeds for an extended period of time (Klages, 1996). Large predatory fish such as the barracuda and eels are very dangerous to common octopus and eels are thought to use developed smell senses to locate them (Hanlon & Messenger, 1996). .

Cephalopods play an important role in marine food webs. They are both predators of smaller fishes and invertebrates, and the prey of larger fishes and mammals (Klages, 1996; Clarke, 1996). Caddy (1983) suggested that an inverse relationship exists between predatory fishes and octopus populations. Given that short-lived species, such as cephalopods, are widely believed to benefit from anthropogenic changes to faunal abundance, the relationship between cephalopods and their predators can be influenced by commercial exploitation of the predator (Clarke, 1983). Several authors have suggested that octopus fisheries started in the Saharan Bank region as a consequence of overexploitation of Seabream populations (Garcia, 1968; Caddy, 1983; Caddy & Rodhouse, 1998).

1.6.8 The fishery, processing and marketing of common octopus

Cephalopods are a highly nutritious food for human consumption. Because of lack of bones, the average edible part of the cephalopods is between 80 % and 85 % of the total body, which is higher than that of crustaceans (40–45 %), teleosts (40–75 %) and cartilaginous fish (25 %) (Kreuzer, 1984). During the second half of the 20th Century, cephalopods were considered as less conventional resources, and, consequently, the catching of these species was recommended as a way of diversifying the fishing effort. Cephalopod landings have increased (FAO, 2001; Aguado-Gimenez & Garcia-Garcia, 2005; Miliou et al. 2005) and their fisheries are among the few resources still with some potential for exploitation (Hatanaka, 1979; Bravo de Laguna & Balguerias, 1993; Hernández-García, 1995; Guerra, 1997).

Although octopus contributes about 12 % to world cephalopod catches, they are highly desirable and commands high prices, competing directly with finfish and supporting a growing demand worldwide (Cortez et al. 1999). While the global market continues to grow, many octopus fisheries in Northern Africa may have already reached their peak. In contrast, the octopus fisheries of the Western Indian Ocean are continuing to show growth and it is noted that some countries are yet to exploit their fisheries commercially (Cortez et al. 1999). The common octopus form a large part of the world octopus market and industry, with 20,000 to 100,000 tonnes caught on average per year (Caddy, 1999). However, the species catch exceeded 100,000 tonnes in the year 2001 (Hernandez-Lopez & Castro-Hernandez, 2001).

The common octopus accounts for about fifty percent of total world octopus catch (Hernandez-Lopez & Castro-Hernandez, 2001). Octopus is a favourite dish in restaurants around the world, particularly in countries whose diets comprise largely of sea food. In Japan and Greece, especially, it is eaten raw, fried, smoked, and in a variety of other preparations (Nagai & Nobutaka, 2002). Because of demand, the common octopus is a target species for many fisheries (Caddy, 1999). In North Western Africa alone, it is the number one target species for fisheries (Hernandez-Lopez & Castro-Hernandez, 2001). There are many repercussions of the large scale fishing of common octopus for human consumption, many of which the full effects are unknown, such as changes in the population dynamics and species distribution (Katsanevakis & Verriopoulos, 2005).

1.6.9 Fisheries legal and regulatory framework in Kenya

The Government policy for the fisheries sub-sector has been to maximize production by proper utilization of resources. The policy encourages fish filleting for export, rationalization of tariff structures on inputs of fish processing machinery and support of programmes that provide boats and gear (engines and nets) to fishermen. The State Department of Fisheries is the National institution mandated to manage the fisheries sector and operates under the Ministry of Agriculture, Livestock and Fisheries (Gov of Kenya, 2013).

Basic fisheries legislation is set out in six parts and 26 sections of the Fisheries Act 1989 (Act No. 5 of 1989; revised 1991). The Act applies to marine, inland fisheries, aquaculture and broadly empowers the Director of Fisheries, with the approval of the Cabinet Secretary, to issue regulations to promote the development of fisheries and aquaculture and to ensure the proper management of specific fisheries, including the possibility of declaring closed seasons and/or areas, access limitations, and restrictions on fishing methods, gear, and the characteristics of fish that may be caught.

CHAPTER 2: STUDY AREA, GENERAL MATERIALS AND METHODS

2.1 Description of the Kenyan coastline

The Kenyan coastline is approximately 640 km long stretching from 1° 42' S bordering Somalia in the North, to 4° 40' S bordering Tanzania in the South. It consists of 12 nautical miles ("nautical mile" means the international nautical mile) of territorial waters and an Exclusive Economic Zone (EEZ) ["exclusive economic zone" means the exclusive economic zone of Kenya established and delimited by section 5 of the Maritime Zones Act, 1989] of 200 nautical miles (Maritime Zones Act, 1989 (Cap. 371), with a total area of 142, 400 km² (FAO, 2009). The coastal area is characterized by a variety of tropical marine and wetland ecosystems including coral reefs, sea grass beds and mangroves. Fringing reefs as well as coral reefs are well developed in the Kenyan coast (McClanahan & Mangi, 2001). However, to the North, where there are large areas of loose sediment and significant freshwater influences, levels of development are lower. Patterns of biodiversity appear to follow the patterns of reef development, with generally higher diversity in the South coast. Active coral growth is not continuous along the fringing reefs, but is interspersed with extensive sea grass and algal beds (Spalding et al. 2001).

According to 1990 national population census, the Kenyan coast region had a population of 2,325,307 persons of which some are artisanal and commercial fishermen (Gov. of Kenya, 2009). Fishing using hand lines, traps, spear guns, and gill and seine nets is common, with artisanal fishing concentrated near shore in territorial waters. Commercial fishing is operated from sail powered dhows. Other fisheries, including netting for aquarium fish and sport fishing in offshore waters, are increasing (Spalding et al. 2001). Stocks in several coastal localities are considered to be overexploited and marine parks and reserves have been established. Fishing is prohibited in the parks and only traditional methods of hand lines and traps are permitted in the marine reserves. According to Spalding et al. (2001), protection of these areas has had clear impacts, with increases in fish abundance and diversity as well as live coral regeneration.

2.2 Description of the study sites

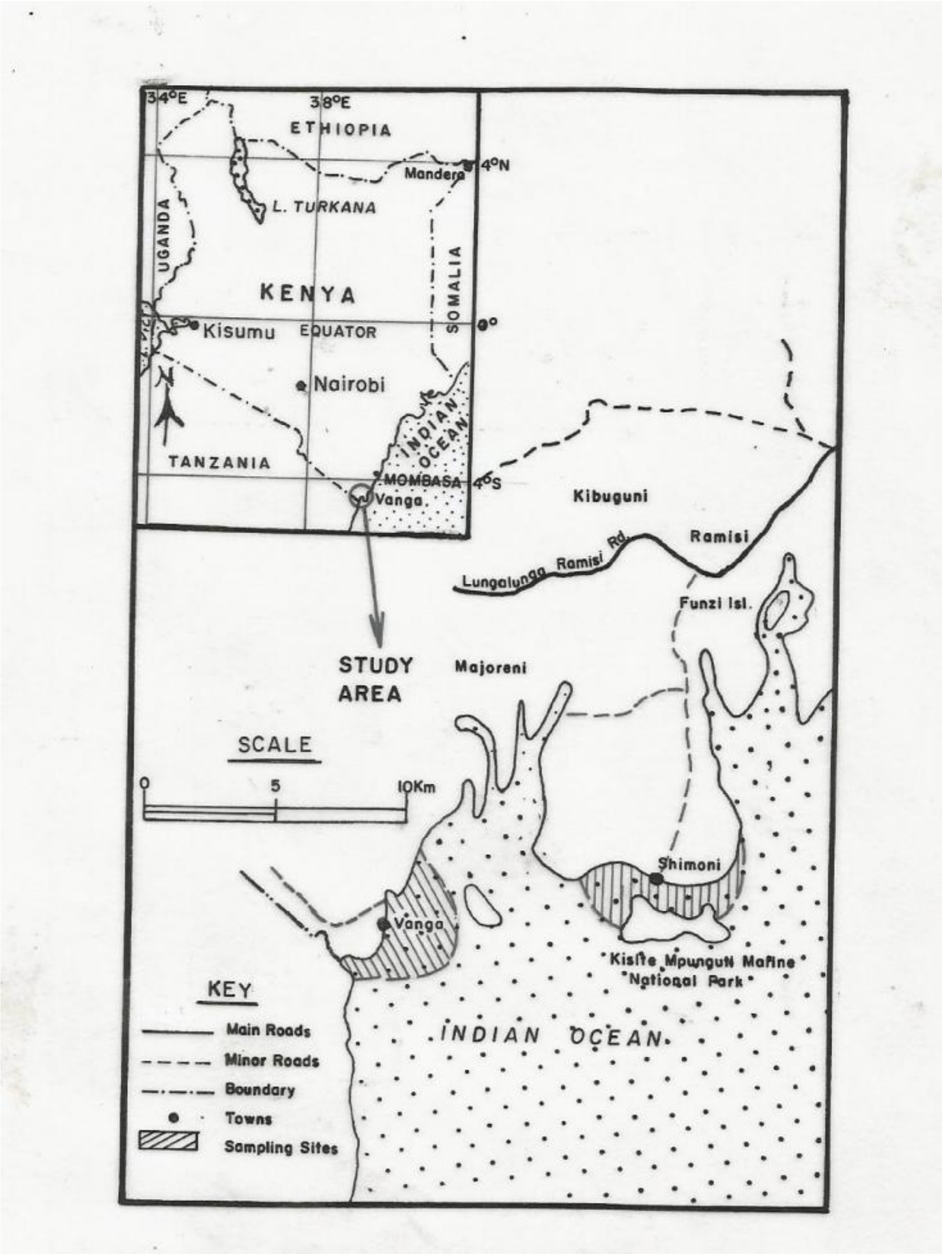

Figure 2.1: A map of Kenya showing the location of the study areas; Shimoni and Vanga in south coast Kenya. (Source: Google Map, 2013)

Sampling for common octopus was carried out at Shimoni and Vanga along the Kenyan South coast as shown in figure 2.1. The two study sites were 28 kilometres apart. According to the marine waters fisheries frame survey 2012 report, (Dept of Fisheries, 2012a) Shimoni and Vanga are the main fish landing sites along the Kenyan South coast. Shimoni is located at latitude: 4° 38' 23" S; longitude: 39° 23' 24" E. It is 70 kilometres from Mombasa town towards the Tanzanian border. Vanga town is located at latitude: 4° 39' 01" S; longitude: 39° 14' 11" E. It is 108 kilometres from Mombasa town towards the Southern Kenya–Tanzania boarder. The climatic conditions of the Kenyan South coast during the study period can best be described in terms of its rainy weather and seasons. The long rain season was from April to June. During this period, rainfall was heavy, particularly in the afternoon or early evening. The short rainy season was from October to December. Temperature-wise, there was no really any huge difference from one month to the next (27^{o}C - 31^{o}C). January to March tended to see the highest temperatures, with the coolest weather between July and August. However, it was generally warm all year round during the daytime. Generally, the climate was tropical humid. The coastal communities were involved in several socio-economic activities. The activities included artisanal fishing, fish processing and water transportation services. Cephalopod fishery was very active in the Kenya South coast. The common octopus was commercially very important and accounted for a large percentage of octopus fisheries. Women and children, walked along reef flats with a spear at low tide searching for octopus while men dived in deeper areas of reef flats or used to hunt for octopus at high tide using a mask, snorkel and a spear. Women also played a major role in octopus trade. Hence, octopus in the Kenyan coast had significant commercial value and was a favoured food item.

2.3 Characteristics of the common octopus

The current study covered two main aspects of the Kenyan common octopus populations. The first component was dealing with the biology (growth and temporal distribution, reproductive biology, food and feeding habits) and the second one was dealing with the fishery (relative abundance, value addition and marketing processes) of common octopus at Shimoni and Vanga. The common octopus occurs worldwide in tropical, sub-tropical, and temperate waters including the Kenyan South coast. It is found in habitats that range from shallow tidal pools to ocean depths of about 200 m. Common octopus is highly variable in colour and pattern, but often a mottled combination of red, brown, and pale coloration. Maximum size is about 1 m in length from the top of its body (mantle) to the tips of its arms. An adult can weigh about 3-6 kg. Common octopus, like other octopods, has eight arms attached to its body. Each arm has two rows of suckers and there may be as many as 250 suckers on each one. Body of the octopus is bulb-shaped and contains all of the octopus' organs and its mouth. The mouth is located on the underside, where the arms converge. In the centre of the mouth is a beak that is made of keratin, the same substance that is in the human fingernail and the rhinoceros horn. The beak is used to bite food items into pieces prior to swallowing. The body parts of common octopus are as shown in figure 2.2 below;

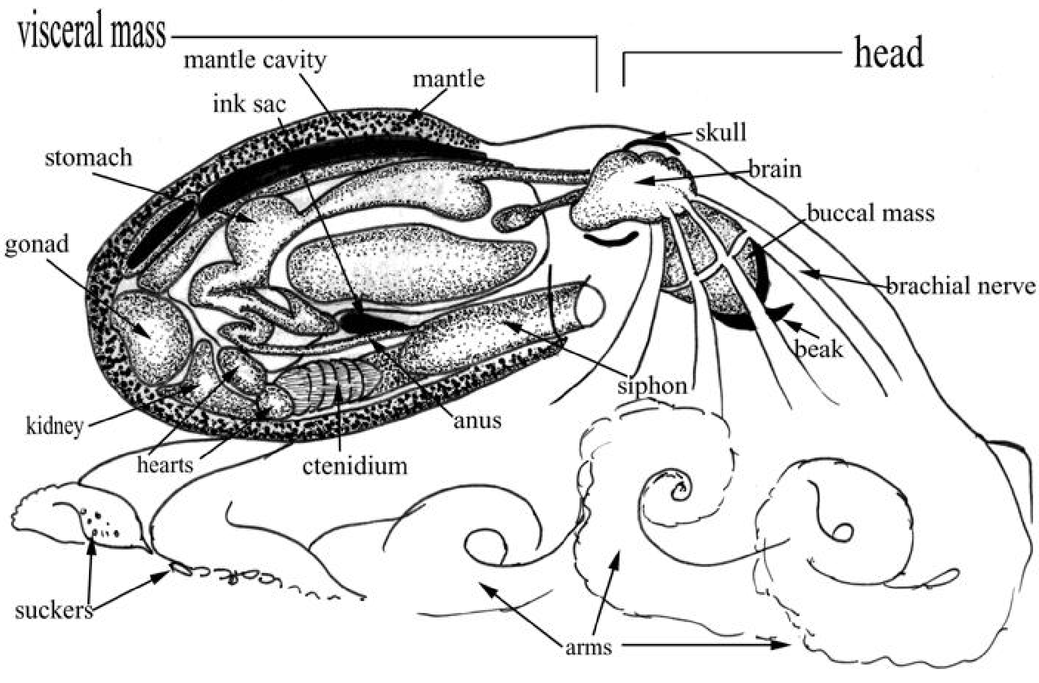

Figure 2.2: The body parts of common octopus (Adopted from Brusca & Brusca, 2003)

The common octopus is medium to large sized animal, chunky in appearance (Plate 2.1). The mantle (head section) of the octopus can reach about 25 cm long, and tentacles about 1 m long. Some may reach 3 m in total length. The tentacles are stout, of about equal length and thickness but dorsal pair of tentacles are slightly shorter. A shortened right tentacle III of males is hectocotylized by modification of the tip into a very small, spoon-shaped ligula. The ligula index (length of ligula expressed as percentage of length of hectocotylized arm) is less than 2.5 and has 7 to 11 gill lamellae on outer side of the gill, including terminal lamella. This tentacle is used during reproduction.

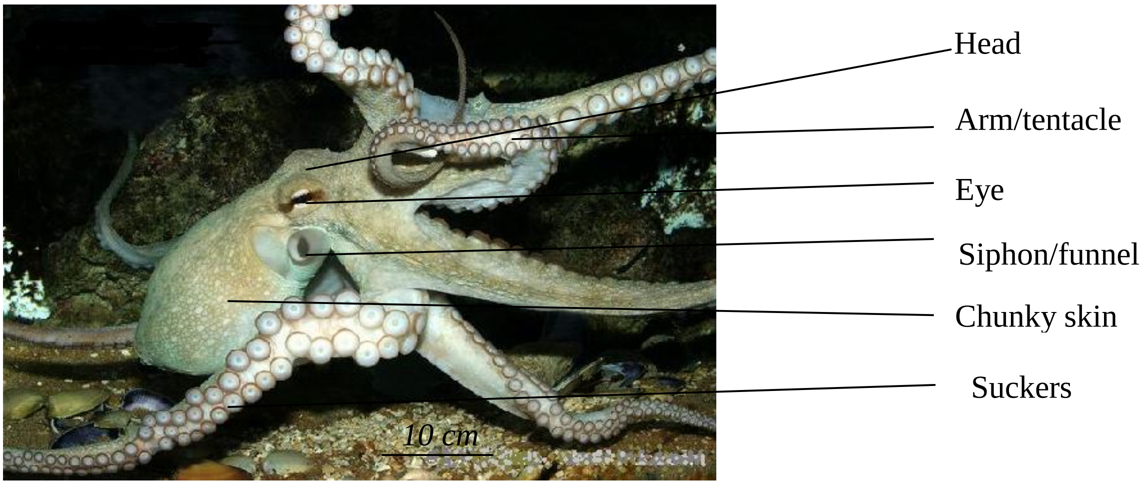

Plate 2.1: A labelled diagram of common octopus (Adopted from Brusca & Brusca, 2003)

In the life cycle of common octopuses, the eggs hatch and the juveniles live in the planktonic stage for 1.5-2 months. The juveniles that don't get eaten as part of the planktonic food web live up to 1.5 years.

2.4 Study design

Wild common octopuses were collected on monthly basis from November 2010 through November 2012 from the two study sites (Shimoni and Vanga). The specimen collection at each site was randomly selected each month in an effort to increase the statistical robustness of the research design. A total of 1,599 specimens were collected, 746 males and 853 females.

Common octopuses were collected predominantly during low spring tides. During such times, the water was exceptionally clear, common octopuses could be spotted from a pirogue (dugout canoe) as they moved slowly over areas of reef flat or their dens could be spotted in the reef flat. Holes (dens) of a suitable size were often marked by middens near the entrance (small piles of stones and discarded bivalve shells). The holes were prodded with a spear to see if there was an octopus present. If there was an octopus present, it generally wrapped its tentacles around the spear or tried to push the spear out. The octopus was then usually dug out of the hole by slowly twisting the spear until the tentacles became entangled or until the body of the octopus was pierced. The spear was then removed from the hole with the octopus attached. If the octopus had dug deep into the hole and could not be dug out, fishermen used another spear to break up the coral around the hole to release the octopus.

2.5 Common octopus fishing method

The main gear used in hunting of common octopus was a fishing spear/hooked stick shown in plate 2.2. The gear whose size ranges between 1 to 1.5 m in length was used to pry out the octopus from its hole. Once freed from the hole, the octopus was then killed by use of the spear or a wooden club.

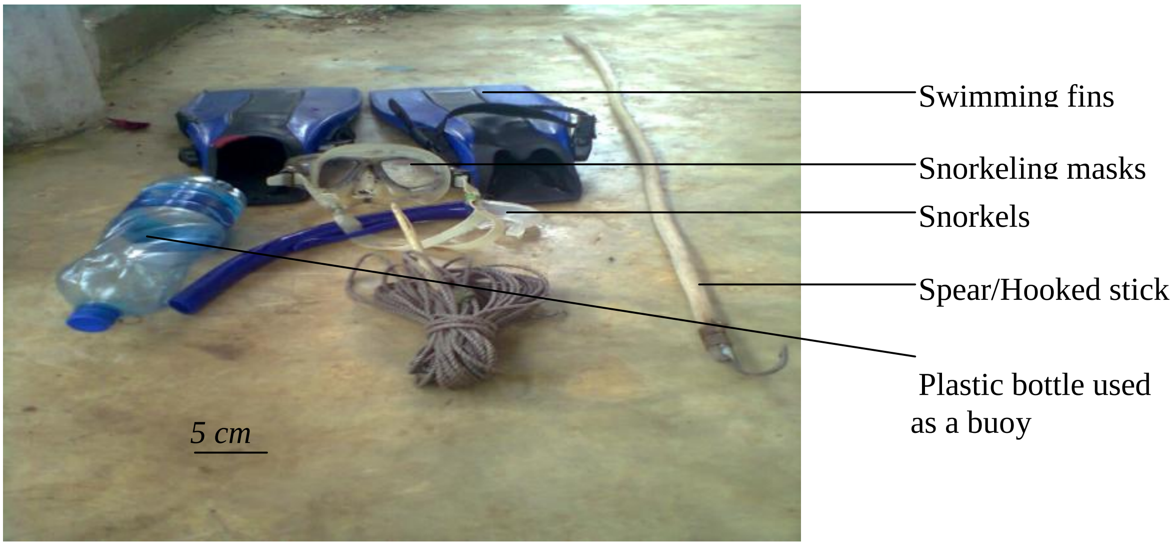

Plate 2.2. Common octopus fishing equipment.

2.6 Treatment of specimens

For all specimens captured, for each individual, the following measurements and information was recorded;

1. The sex, which was determined by observations of the presence of the spermatophoric groove and hectocotylus on the third right arm for males and absence of these features for females as shown in plate 2.3.

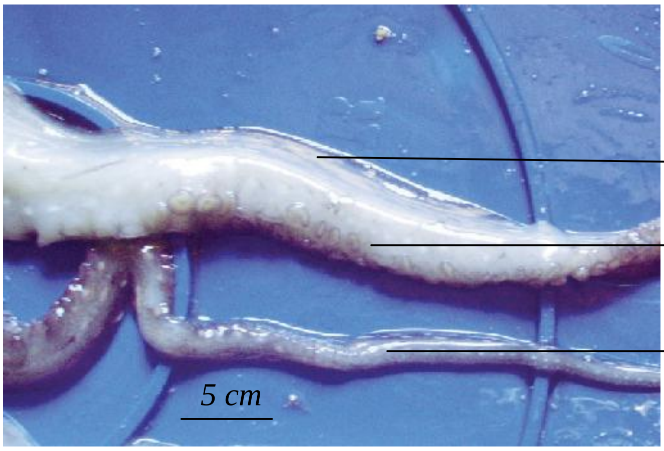

Plate 2.3 The difference between the 'third right arm' of a male octopus (top) and female octopus (bottom) (Adopted from WIOMSA, 2008)

2. The total body wet weight (BW, kg) was measured using a top loading electronic balance.
3. The total length (TL, cm) was measured using a measuring board/tape.
4. The total external gonad wet weight was measured using an analytical balance.
5. The dorsal mantle length (DML, cm) was measured using a measuring board/tape.
6. The ventral mantle length (VML, cm) was measured using a measuring board/tape.

The TL, DML and VML dimensions are shown in figure 2.3.

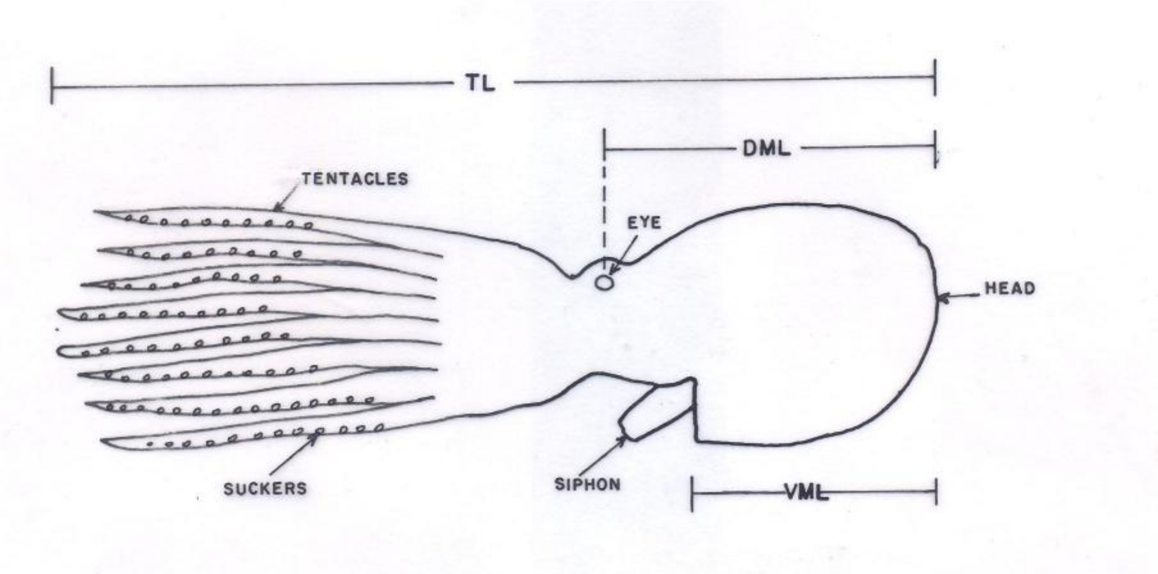

Figure 2.3: Size measurements of common octopus; total body length (TL), dorsal mantle length (DML) and the ventral mantle length (VML) (Adopted from Sakaguchi et al. 1999)

2.7 Preservation of specimens

In the laboratory, the stomach contents were put in labelled plastic bags and preserved in a deep freezer for later microscopic analysis. Ovaries were preserved in Gilson's fluid (Bagenal & Erich, 1978) made up of 100 ml 60 % methyl alcohol, 880 ml distilled water, 15 ml 80 % glacial acetic acid and 20 g mercuric chloride. For histological analysis, ovaries and testes were preserved in Bouin's Solution made up of saturated picric acid – 300 ml, Formaldehyde – 100 ml and Glacial acetic acid – 20 g. This fluid preserved and hardened the gonads ready for further analysis.

CHAPTER 3: GROWTH AND TEMPORAL DISTRIBUTION OF COMMON OCTOPUS

3.1 Introduction

Data on the size class frequency distribution and length-weight relationships of common octopus have commonly been analyzed to yield important biological information (Mangold, 1983). This information is very useful for proper exploitation and management of the common octopus population (Hatanaka, 1979). The data has also a number of important applications in octopus stock assessment as seasonal variations in octopus growth can be tracked this way (Mangold, 1983; Hatanaka, 1979). At the same time, the relationship of length-weight estimates, the condition factor (K), and the common octopus biomass through the length frequency can give scientific knowledge of relative growth of the species (Mangold, 1983). The condition factor is used in order to compare the "condition", "fatness" or wellbeing of octopus. It is based on the hypothesis that heavier octopus of a particular DML are in a better physiological condition (Ricker, 1973). The condition factor is also a useful index for monitoring of octopus feeding intensity, age, and growth rates.

A number of challenges have been experienced in determining octopus growth in natural conditions (Guerra, 1979; Hatanaka, 1979). Growth rate is easily calculated for octopus maintained in the laboratory conditions, but comparison with growth under natural conditions is questionable (Mangold, 1983). In natural field conditions, growth and age can be correlated when there is clear evidence that a single year class from a stable population is under consideration, but where the spawning season is extended as in the common octopus (Mangold, 1983), identifying year classes is difficult (Guerra, 1979).

Despite the usefulness of temporal distribution and population dynamics data, scientific information of common octopus and its importance in the fishery of Kenya is very scarce. This study will seal this information gap which is crucial in the management of the common octopus fishery in the country.

3.2 Materials and Methods

3.2.1 Assessment of class size distribution of common octopus

The individual dorsal mantle lengths were used to determine the class sizes. Population structure by class sizes of common octopus was presented using frequency histograms (length frequency plotted against the actual dorsal mantle lengths to obtain frequency). Separate histograms were made for the individual body weight (BW) measurements in each study site.

3.2.2 Assessment of relative weight growth of common octopus

The application of the dorsal mantle length (DML)-weight relationship was carried out on 1,599 specimens (746 males and 853 females) collected from the Kenyan South-coast. DML values, used as a reference length in the samples, ranged from 5.0 to 24.0 cm. The length weight equations were established for both sexes, separately and cumulated, using the following equation;

W = a x [DML.sup.b]

Where 'W' is the full weight, 'a' is a constant (intercept of the regression), DML is the dorsal mantle length, and 'b' is the allometry {the growth of body parts at different rates, resulting in a change of body proportions} coefficient (regression coefficient). After logarithmic transformation, the relationship becomes as follows;

LogW = log a + b x log(DML)

To determine the nature of allometry, the value of the parameter b was compared with the theoretical value 3 using the t-test at ($P < 0.005$). Parameters ‘a’ and ‘b’ for the linear correlation were compared using Mayrat's test (Mayrat, 1967).

3.2.3 Assessment of relative condition factor of common octopus

This was used to compare the “condition” or “well being” of octopus, and was based on the hypothesis that the heavier the octopus of a given length the better the condition.

Relative Condition Factor (K) was calculated as described by Ricker (1973);

$$K = \frac{100w}{l^b}$$

Where:

w = total wet weight of common octopus

l = DML length of common octopus

b = the value obtained from the length-weight ratio.

3.3 Results

3.3.1 Dorsal mantle length (DML) class size frequency distribution

A total of 1,599 individuals (792 from Shimoni and 807 from Vanga) were analysed.

The DML class size frequency distribution for females at Shimoni ranged from 5 to 24 cm while for the males ranged from 5 to 17 cm as shown in figure 3.1. The smallest individual was 5.40 cm and maximum length was 24.50 cm. Class sizes 11 and 12 recorded the highest number of female octopus. The percentage frequency for class sizes 5-7 and 17-24 was 9.2 % while that of class sizes 8-16 was 90.8 %. The highest number of males was recorded in class size 10. No males were recorded above class sizes 17. The percentage frequency for class sizes

5-7 and 17-24 was 5 % while that of class sizes 8-16 was 95 %. The population structure was positively skewed.

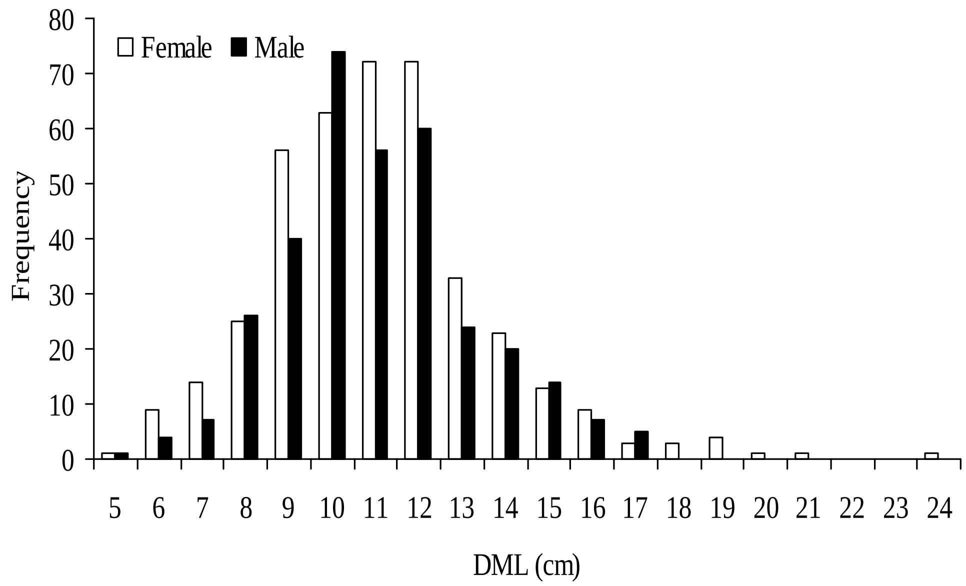

Figure 3.1: DML class size frequency distribution of common octopus **by sex at Shimoni**

The class size range of females at Vanga ranged from 5 to 20 cm for females and 6 to 18 cm for males as shown in figure 3.2. Class size 10 recorded the highest number of female octopus. The percentage frequency for class sizes 5-7 and 17-24 was 10.2 % while that of class sizes 8-16 was 89.8 %. The highest number of males was recorded in class size 10. No males were recorded above class sizes 18. The percentage frequency for class sizes 5-7 and 17-24 was 6.4 % while that of class sizes 8-16 was 93.6 %. The population structure was positively skewed.

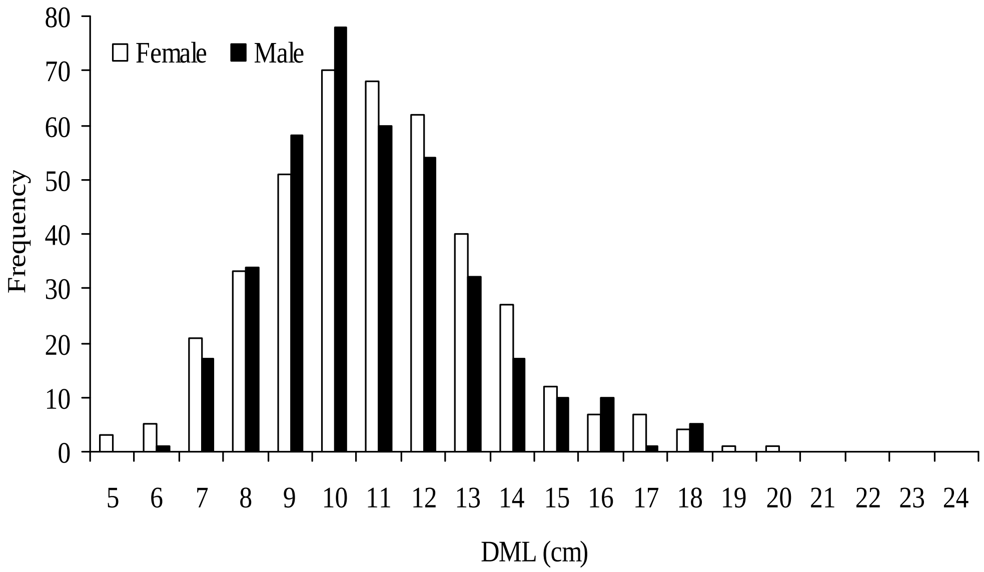

Figure 3.2: DML class size frequency distribution of common octopus **by sex at Vanga.**

The distribution curves for all class size frequencies (females and males) at Shimoni and Vanga showed a normal distribution. Small individuals 5 - 7 cm and large individuals 15 - 24 cm were very few at both the two sampling sites. The class size range at Shimoni was wider 5 – 24 cm than at Vanga 5 – 20 cm. The predominant class size for males at Shimoni was 10 cm while for the females was 11 and 12 cm. At Vanga, the predominant class size for males was 10 while for the females was 10 and 11 cm.

3.3.2 Monthly mean DML distribution

The monthly mean DML size distribution at Shimoni showed a decreasing trend over the two year sampling period as shown in figure 3.3. The lowest monthly mean DML sizes were noted in the months of August and September. The overall mean DML size for females was 11.5 ± 4.6 cm and for males was 11.3 ± 1.2 cm, which showed no significant difference ($p>0.05$) [$t = 0.5$, $df = 46$, $p = 0.6$].

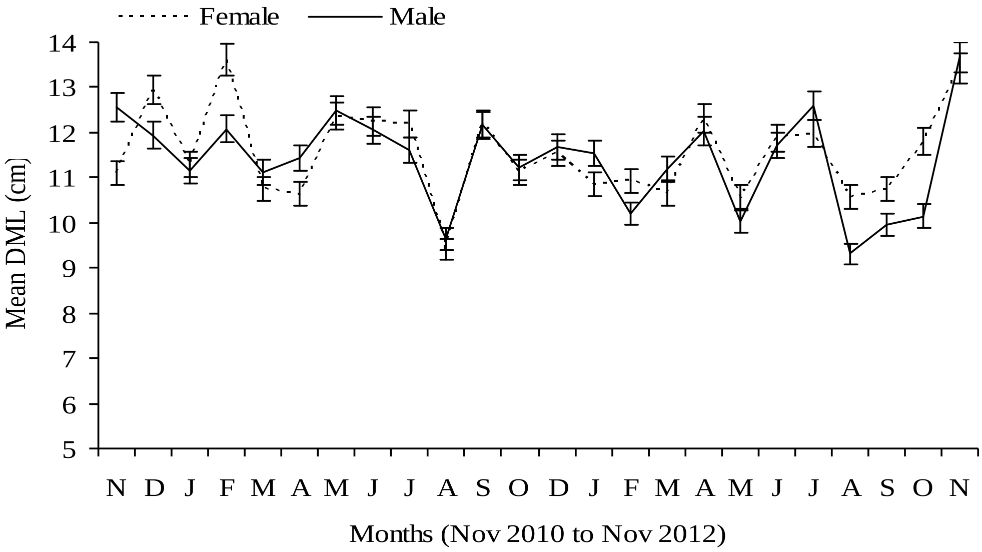

Figure 3.3: Monthly mean DML distribution of common octopus **at Shimoni.**

The monthly mean DML size distribution at Vanga showed a decreasing trend as shown in figure 3.4. The lowest monthly mean DML size was recorded in the month of August. The overall mean DML size for the females was 11.3 ± 2.5 cm and for males was 11.2 ± 2.3 cm, which was not significantly different ($p>0.05$) $t = 0.5$, $df = 46$, $p = 0.6$.

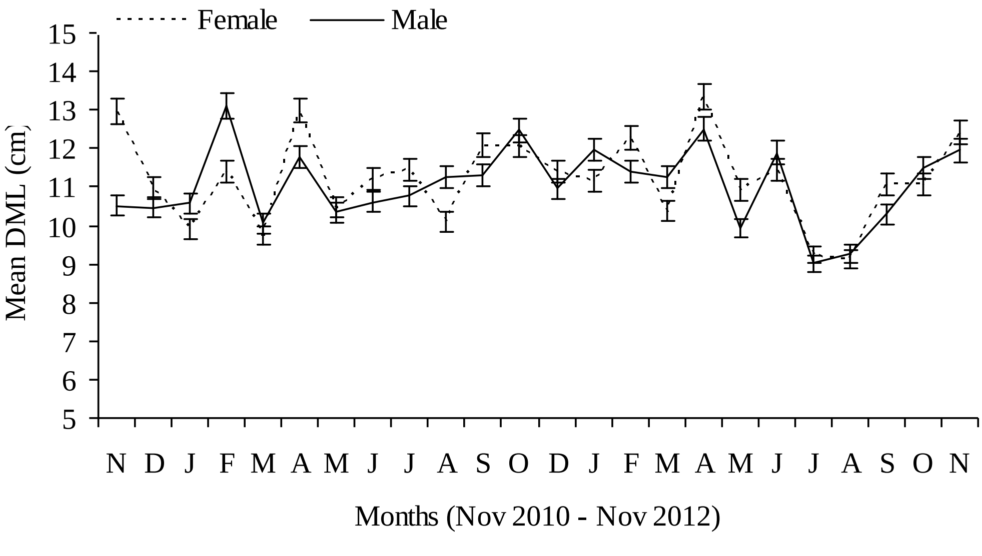

Figure 3.4: Monthly mean DML distribution of common octopus **at Vanga.**

Considering all individuals analysed in both Shimoni and Vanga, the mean DML size for the females was 11.38 ± 2.53 cm and 11.23 ± 2.21 cm for the males, which was not significantly different ($p>0.05$) ($t = 1.253$, $df = 1558$, $p = 0.21$). The mean DML sizes for females at Shimoni (11.5 ± 4.6 cm) was not significantly different from those specimens obtained at Vanga (11.31 ± 2.5 cm), $p > 0.05$) $t = 1.1$, df 46, $p = 0.3$. Likewise, the mean DML sizes of males at Shimoni (11.3 ± 1.2 cm) was not significantly different from those analysed at Vanga (11.2 ± 2.3 cm) ($p>0.05$) $t = 1.2$, df 46, $p = 0.3$.

3.3.3 The BW class size frequency distribution of common octopus

The BW class size frequency distribution of female common octopus at Shimoni ranged from 0.5 to 5.5 kg while that of the males ranged from 0.5 to 4 kg as shown in figure 3.5. The females recorded higher weights in class sizes 0.5, 1, 2 and 2.5 kg. No individuals were recorded in class sizes 4.5 and 5 kg. The largest female recorded in the current study was from Shimoni and was in class size 5.5 kg.

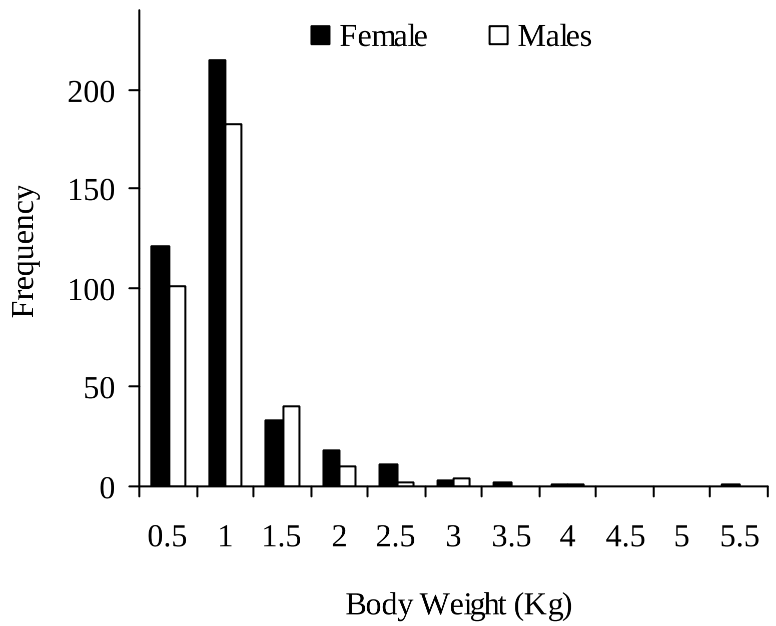

Figure 3.5: BW class size frequency distribution of common octopus by sex at Shimoni

The BW class size frequency distribution of female common octopus at Vanga ranged from 0.5 to 3.5 kg for both male and females as shown in figure 3.6. Females dominated in class sizes 1.5 and 2.0 kg while class size 3 recorded equal number of males and females. In class size 3.5 kg, males dominated.

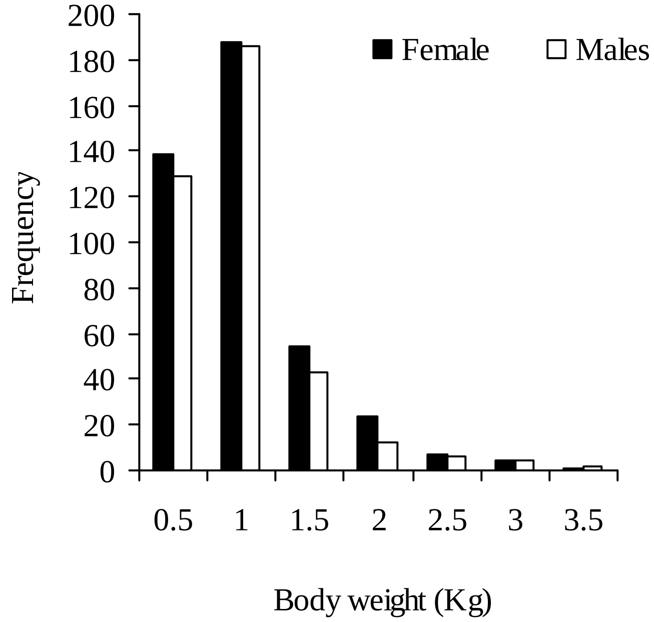

Figure 3.6: BW class size frequency distribution of common octopus by sex at Vanga.

The BW class sizes for all individuals analysed from Shimoni and Vanga ranged from 0.5 to 5.5 kg for females and 0.5 to 4 kg for males.

The BW class size frequency distribution curves for both females and males showed that individuals in BW class sizes 0.5 – 1 kg were predominant in both Shimoni and Vanga. However, the overall BW class size range at Shimoni proved to be wider (0.5 – 5.5 kg) than at Vanga (0.5 – 3.5 kg).

3.3.4 Monthly mean BW distribution of common octopus

The monthly mean BW size distribution for common octopus at Shimoni is shown in figure 3.7. The monthly mean BW size distribution showed a decreasing trend over the two year sampling period. The lowest monthly mean BW was recorded in the month of August. The overall mean BW for females was 0.81 ± 0.3 kg while for the males was 0.75 ± 0.2 kg which was not significantly different ($p > 0.05$) $t = 0.7$, df 46, $p = 0.5$.

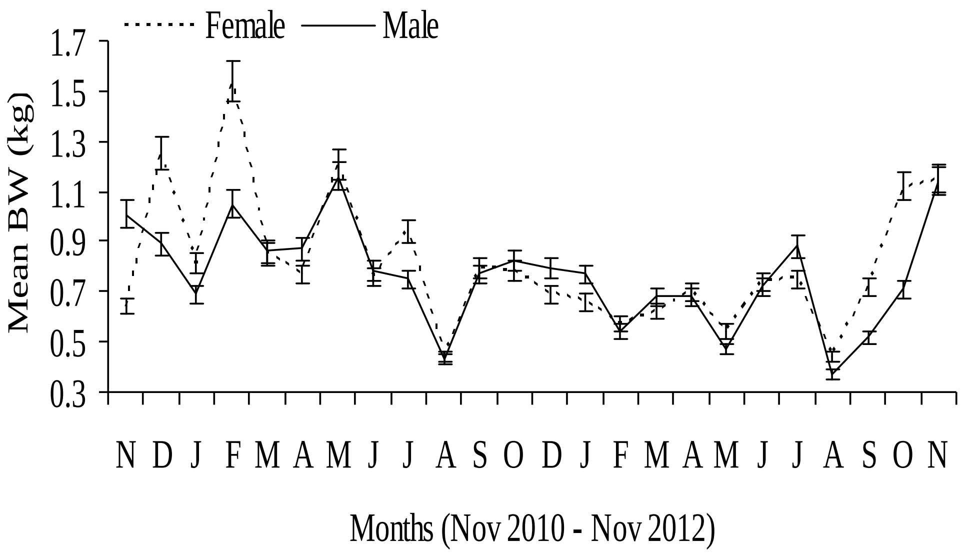

Figure 3.7: Monthly mean BW distribution of common octopus at Shimoni.

The monthly mean BW size distribution at Vanga is as shown in figure 3.8 and showed a decreasing trend over the two year sampling period. The lowest monthly mean BW was recorded in the month of July and a peak in April. The overall mean BW for females was 0.76 ± 0.2 kg while for the males was 0.74 ± 0.2 kg which was not significantly different ($p > 0.05$) $t = 0.4$, df 46, $p = 0.7$.

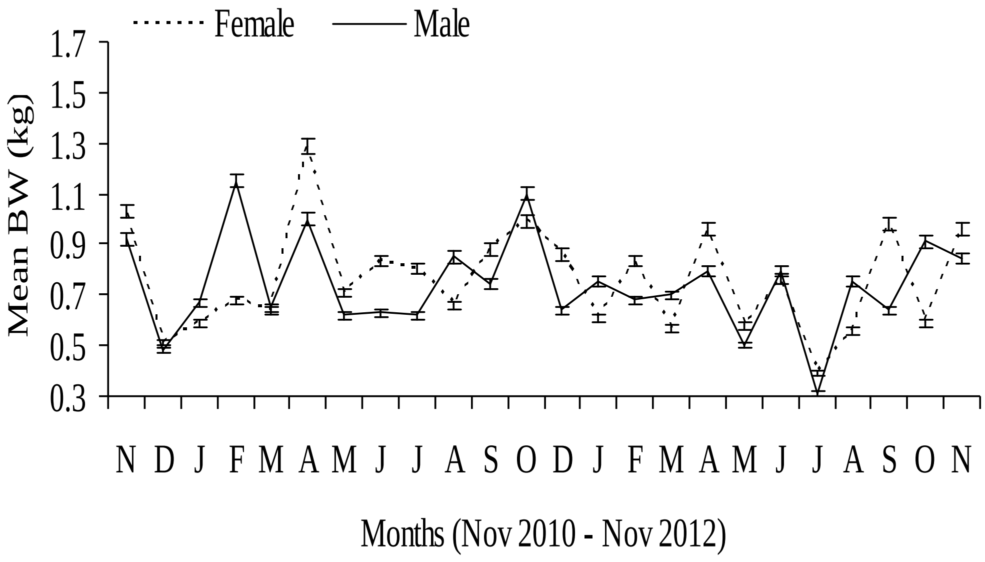

Figure 3.8: Monthly mean BW distribution of common octopus at Vanga.

The overall mean BW for females from both Shimoni and Vanga was 0.77 ± 0.5 kg while for the males was 0.74 ± 0.5 kg, which was not significantly different ($p>0.05$) ($t= 1.3$, df 1558, $p = 0.2$).

The overall mean BW for females at Shimoni was 0.81 ± 0.27 kg while at Vanga was 0.76 ± 0.21 kg which showed no significant difference ($p>0.05$), $t = 0.73$, df 46, $p = 0.47$.

The mean BW for males at Shimoni was 0.76 ± 0.2 kg while at Vanga was 0.74 ± 0.2 kg, showing no significant difference ($p>0.05$) $t= 0.45$, df 46, $p = 0.7$.

3.3.5 Length-weight relationship of common octopus at Shimoni

The length-weight relationships for the female and male common octopus are shown in figure 3.9 and 3.10 respectively. The results show that the 'b' value for the male was 2.6 and for the female was 2.5.

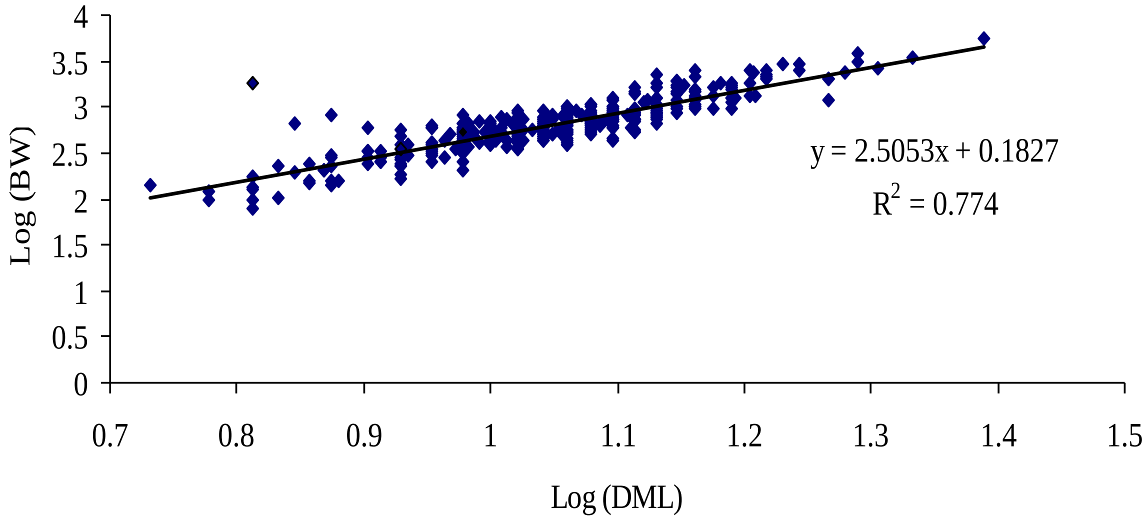

Figure 3.9: The length-weight relationship for female common octopus at Shimoni.

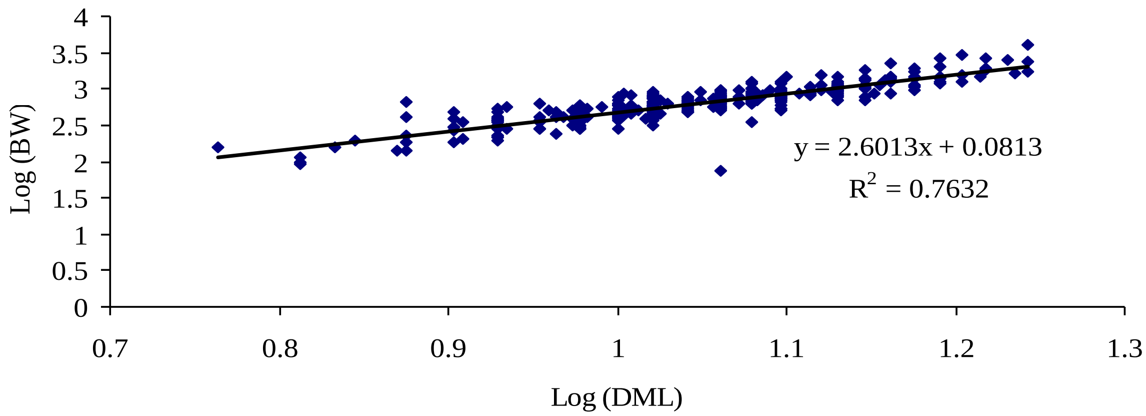

Figure 3.10: The length-weight relationship for male common octopus from Shimoni.

The growth coefficient (b) values obtained for both females and males at Shimoni ranged between 2.5 and 2.6 and differed significantly ($p<0.005$) from 3, which indicates that the common octopus had negative allometric growth. The results of the ANCOVA indicated homogeneous slopes in the length-weight relationship by sex ($p>0.05$), meaning that there was no significant difference in the slopes or the rates at which females and males grew in weight.

3.3.6 Length-weight relationship of common octopus at Vanga

The length-weight relationships for the female and male common octopus are shown in figure 3.11 and 3.12 respectively. The results show that the 'b' value for the male was 2.7 and for the female was 2.4.

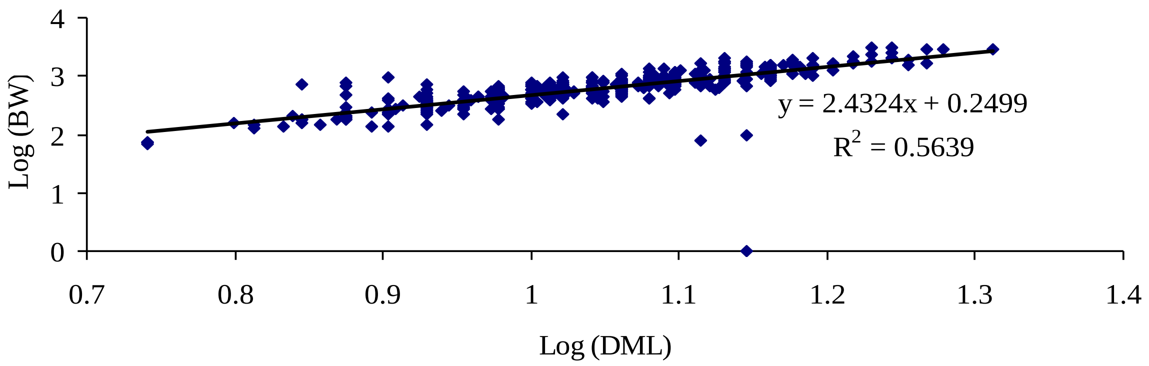

Figure 3.11: The length-weight relationship for female common octopus at Vanga.

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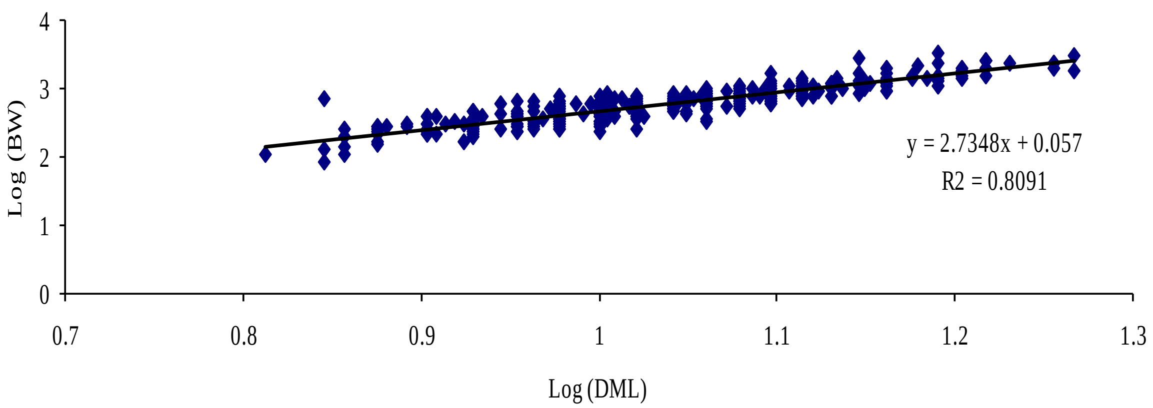

Figure 3.12: The length-weight relationship for male common octopus at Vanga.

The growth coefficient (b) values obtained for both females and males at Vanga ranged between 2.4 and 2.7 and differed significantly ($p<0.005$) from 3, which indicates that the common octopus had negative allometric growth. The results of the ANCOVA indicated homogeneous slopes in the length-weight relationship by sex ($p>0.05$), meaning that there was no significant difference in the slopes or the rates at which females and males grew in weight.

3.3.7 Condition factor (K) of common octopus at Shimoni and Vanga

The current results showed that females from Shimoni recorded a higher monthly mean condition factor (K) than males as shown in figure 3.13. The condition factor (K) was lower for males than for females. The monthly mean condition factor for both sexes was relatively high during the NE monsoons and low during the SE monsoons. The lowest K values were recorded in the month of June and August.

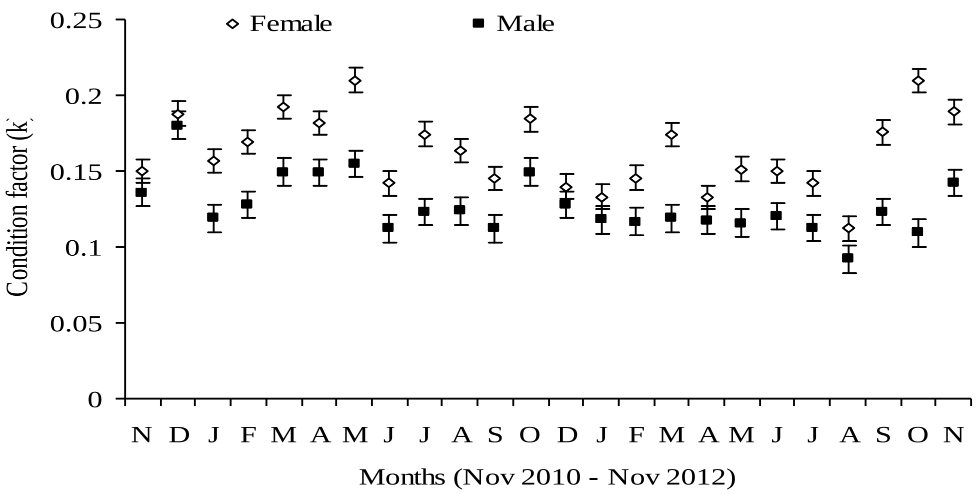

Figure 3.13: Monthly mean condition factor of common octopus at Shimoni

Females from Vanga recorded a higher monthly mean condition factor (K) values than males as shown in figure 3.14. The condition factor (K) was lower for males than for females. The monthly mean condition factor for both sexes was relatively high during the NE monsoons and low during the SE monsoons. The lowest K values were recorded during the month of July for both sexes.

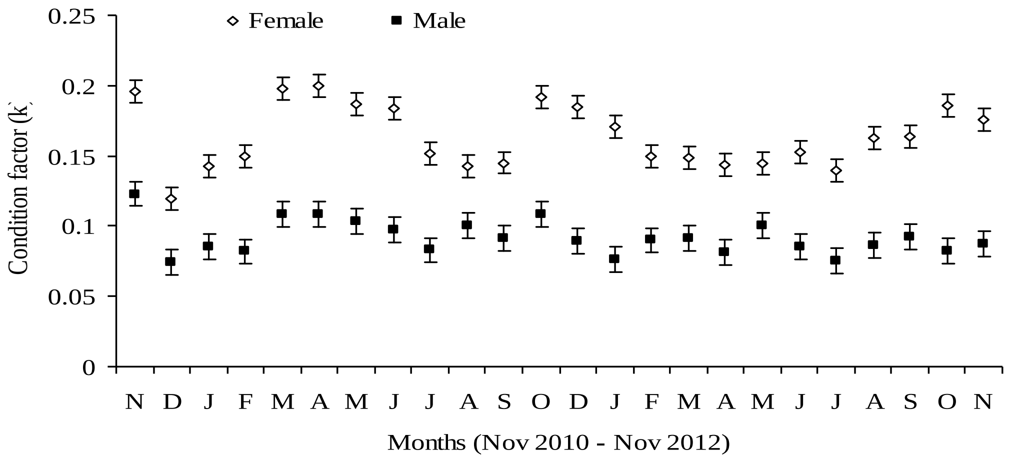

Figure 3.14: Monthly mean condition factor of common octopus at Vanga

3.3.8 Monthly demographic structure of common octopus

The monthly demographic structure of common octopus is as shown in demographic graphs in Appendix iii, iv, v and vi. Two or more distinct cohorts were recorded in almost all the months analysed.

3.4 Discussion

The DML class sizes recorded in the current study for common octopus from both Shimoni and Vanga (5 to 25 cm) was within the range cited by Tsangridis et al. (2002) who reported that in the fisheries of Kavala and Limenas in the Mediterranean Sea, the range of DML class sizes for common octopus varied from 5 to 27 cm DML while the mean class size was 11 cm DML. Mangold (1983), while still working at the same site reported a DML class size frequency distribution ranging from 3 to 20 cm. The largest individual recorded in the current study (24.5

cm) was smaller than what was recorded by Sánchez and Obarti (1993), who also in the Mediterranean Sea, found out that the class size frequency distribution of common octopus showed a wide range, the maximum length recorded was 27 cm DML, the longest length in the Mediterranean. The smallest individual recorded in the current study (5 cm) was much bigger than the smallest individual recorded by Dia (1988) of 1 cm DML on the coast of the Atlantic. The low proportions of large individuals noted in the current study was comparable to what was noted by Mangold (1983) in the Mediterranean Sea, who attributed this to a number of factors among them the disappearance of the largest octopuses from trawling grounds to spawning areas. The gradual decrease in the monthly mean DML witnessed in the current study was similar to what was observed in the Saharan Bank region (Garcia, 1968; Caddy, 1983; Caddy & Rodhouse, 1998). This was attributed to overexploitation of the resource. This, therefore, could be an indication that the octopus fishery in the Kenyan South coast was under high fishing pressure.

The common octopus studied composed individuals less than 1 kg in body weight. The BW class size range recorded in the current study of 0.5 to 5.5 kg was far much wider than what was cited by Pham and Isidro (2010) in Azores, Portugal, who showed that the BW class size composition of the common octopus catches showed a large dispersion of 989 g to 1.1 kg, but was predominantly composed of small individuals of less than 150 g. This indicates that Kenyan common octopuses were larger than individuals reported from Portugal and Mediterranean Sea which can be attributed to a number of factors. First, the capture of high numbers of predominantly small individuals reported from Portugal and Mediterranean Sea may be attributed to trawl fishing which has high probability of capturing juveniles as opposed to spear fishing which is very selective and chances of capturing juveniles is very minimal. Secondly, the larger individuals reported in the current study may have been as a result of favourable environmental conditions in the region. It may also be as a result of low fishing pressure in Kenyan South-coast compared to Portugal and Mediterranean Sea. The monthly mean BW distribution showed a gradual decrease over the two-year study period in both Shimoni and Vanga - an indication that this resource was under high fishing pressure.

The current results of demographic structure of both female and male octopus showed two or more cohorts per month. This is more or less the same as what was cited by Mangold-Wirz (1963) at the Catalan sea who reported the presence of two or more distinct cohorts in a population which he attributed to the presence of new recruits and adults in the population, respectively. He attributed the same phenomenon to rapid population turnover, short life span, and reproduction period of common octopus and also attributed the presence of single cohorts composed of individuals of more than 10 cm DML to scarcity of catches or postponement of reproductive periods. The presence of two or more distinct cohorts of males and females, reported in the current study, may be an indication that recruitment was continuous through out the year in the population. The current study also noted an increasing trend of young individuals (new recruits) during the month of July, which may be deemed to correspond to the common octopus major recruitment period. Similar studies done in the East coast of Tunisia, by Mangold (1983) established that major recruitment periods of common octopus were between the months of November and May.

The results of the current study which showed no significant differences in the length-weight relationships of common octopus by sex compare well with the results of Guerra and Manríquez (1980) and Gonçalves (1993) who did not record any significant differences in common octopus length-weight relationships by sex. Similar studies by Silva et al. (2002) and Hernández-García et al. (2002) also indicated that it was not frequent to find differences in the length-weight relationships by sex in common octopus. The length-weight relationships reported for octopus in the North Western Mediterranean by Quetglas et al. (1998) showed higher values of the allometric exponent than those reported earlier by Sánchez and Obarti (1993). According to Morey et al. (2003), length-weight relationship parameters are dependent on the range of data used. When the individuals used in the calculation are larger, the allometric exponent tends to be smaller. The results of the current study indicated a negative allometric growth, which compares well with what was established by Zghidi-Barraj (2002) at the Gabes Gulf, the East coast of Tunisia who showed that the DML-weight relationships of common octopus indicated a negative allometric growth.

The weight growth of common octopus in the current study, which showed that individuals measuring 14 cm DML weighed between 850 g and 1.55 kg, is comparable to what was recorded by Zghidi-Barraj (2002) at Tunisia and Mauritania. He showed that at size 14 cm DML, an octopus from the Eastern coast of Tunisia weighed 872.98 g whereas the one from Mauritania weighed 1,460 g. According to research works conducted on growth of common octopus by Zghidi-Barraj (2002) at the Southern Tunisian coast, Guerra (1978) at the Occidental Mediterranean Sea, and Hatanaka (1979) and Dia (1988) at the coasts of the Atlantic, a number of conclusions were drawn about the growth of common octopus in those different areas. Eastern coast of Tunisia had a weight growth comparable with those of the Gabes Gulf (DML, 14 cm). Common octopus from the Southern coast of Tunisia was 200 g larger. The weight growth of common octopus from Tunisia's Southern coast was comparable with that of the Occidental Mediterranean Sea, although they were clearly inferior to those of the Northeastern coast of the Atlantic.

The lowest condition factor (K) values in the current study recorded during the months of June, July and August may be an indication of the peak months for spawning of common octopus. Mangold (1983) at East coast of Tunisia noted that the condition factor (K) was influenced by age of octopus, sex, season, stage of maturation, fullness of gut, type of food consumed, amount of fat reserve and degree of muscular development. With females, the (K) value decreased rapidly when they shed their eggs. Mangold (1983) further confirmed that lowest (K) values during the more developed stages might mean resource transfer to gonads during the reproductive period.

3.5 Summary and conclusions

The present study investigated the growth and temporal distribution of common octopus from Shimoni and Vanga at the Kenyan South-coast. Sampling was conducted monthly over a period of two years during November 2010 through November 2012. Individual wet body weight (BW, kg), total length (TL, cm), dorsal mantle length (DML, cm) and ventral mantle length (VML, cm) were recorded for each specimen. A total of 1,599 specimens were sampled comprising 746 males and 853 females.

The dorsal mantle length (DML) class size frequency distribution results showed that females recorded higher abundance than males in most class sizes. The body weight (BW) percentage frequencies established that in most class sizes, females were more abundant than males. The monthly mean DML distribution showed a decreasing trend over the two year study period. The same phenomenon was also witnessed in the monthly mean BW distribution which showed a gradual decreasing trend, an indication that common octopus was under high fishing pressure. According to Norman (2000), in heavily fished areas both size and weight of octopus is often low, and reproductive output may already be affected. The condition factor (K) analysis indicated that the peak breading season of common octopus in the Kenyan South-coast was on the months of June to August. Based on the results gathered in this study, a closed season is recommended during the peak spawning months of common octopus.

CHAPTER 4: REPRODUCTIVE BIOLOGY OF THE COMMON OCTOPUS IN KENYAN SOUTH COAST

4.1 Introduction

Common octopus has great social and economic impact in the small-scale fishery context of the West Indian Ocean (McClanahan & Mangi, 2001). Although it is an important resource supporting a fishery of almost 394 metric tonnes a year, (Dept of Fisheries, 2012b), no reproductive biology study has been carried out on the species in the Kenyan coastal waters. This is despite the fact that common octopus has been studied intensively in other areas of the world (Mangold, 1983; Gonçalves, 1993).

Studies have shown that, spawning of common octopus occurs all year round with two main peaks in spring and autumn, although it varies depending on the study site (Guerra, 1975; Hatanaka, 1979; Sánchez & Obarti, 1993; Gonçalves, 1993; Quetglas et al. 1998; Hernández-García et al. 2002; Silva et al. 2002; Caverivière et al. 2002; Oosthuizen & Smale, 2003). The fecundity expressed as the number of ova in the ovary is important in understanding the reproductive potential of octopus. The large number of eggs emphasizes the importance of fertility in the common octopus compared to other octopus species. Biological characters such as extended spawning season, method of reproduction, spawning migration and high fertility ensure a high yearly recruitment to the stock. According to Mangold (1983), during spawning migrations, common octopus moves inshore and as such, a large number of maturing males and females are subject, before breeding and spawning, to precocious capture by fishermen which cut off their way inshore.

Scientific information on the common octopus reproductive biology is very important as it gives an insight of the fishery which is very important in its management. For example, fecundity studies are important in understanding the reproductive potential of the species. Biological information such as spawning seasons, methods of reproduction and spawning migrations inform on recruitment potential of the stock. The common octopus has great social and economic impact in the small-scale fishery context in the Kenyan coast and it is an important resource supporting a fishery of almost 394 metric tonnes a year (McClanahan & Mangi, 2001). Nevertheless, no reproductive biology study has ever been carried out on the species in the Kenyan coastal waters (Dept of Fisheries, 2012a). The scientific information gathered during the current study on the reproductive biology of the species will go a long way in informing policy directions and the management of the fishery in Kenya. This part of study was therefore aimed at studying the reproductive activities of common octopus in the Kenyan South coast. The overall goal being to determine the spawning seasons, estimate the size at first maturity and fecundity of this species.

4.2 Materials and Methods

4.2.1 Assessment of sex ratio of common octopus

Sex was determined by observations of the presence of the spermatophoric groove and hectocotylus on the third right arm for males and absence of these features for females. The actual number of common octopus whose sexes were successfully determined were considered for sex ratio and the sex ratio expressed as the ratio of number of males to females was analyzed on monthly, annually and seasonally basis.

Significant deviations from the 1:1 proportion were tested by the chi-square (χ^2) test.

$$\chi^2 = \Sigma \frac{(f - F)^2}{F}$$

Where;

f = observed number of individuals in a population.

F = expected number of individuals in a population.

The sex ratio in relation to size (DML) frequency distribution for common octopus was also determined for both males and females. In sex ratio, a variance test of homogeneity of the binomial distribution was performed on the monthly samples to verify whether there was significant difference in sex variation.

4.2.2 Assessment of size at first maturity in common octopus

Maturation and reproduction were assessed using a maturity scale and several indices. A four (I: immature, II: maturing, III: mature and IV: post-spawning) maturity scale for both males and females was used (Inejih, 2000). Common octopus belonging to maturity stage II onwards were considered as mature octopus and were used for the purpose of calculating the size at first maturity. Data for 24 months was pooled together. The length at which 50 % of common octopuses were mature was considered as length at first maturity.

The size at first maturity ($DML_{50\%}$) was estimated by fitting the length-frequency distribution of the proportion (P_i) of mature females to a logistic model, $P_i = 1/1+\exp[-(a + bDML_i)]$, where $DML_{50\%} = -a/b$, by means of nonlinear methods deriving the regression line by the least squares method using the Gauss-Newton algorithm (Quinn & Keough, 2002).

Where;

P_i = represents the relative frequencies of fully mature individuals in length class DML_i

'a' and 'b' = are the regression constants, and

$DML_{50\%}$ = is the dorsal mantle length at 50 % sexual maturity.

The body weight (BW) at first maturity was also estimated following the same procedure.

4.2.3 Assessment of maturity stages of gonads of common octopus

In the laboratory, gonad portions from the middle region of the ovary were cut and preserved in Bouin's solution for histological study. The portions fixed in Bouin's solution were dehydrated in graded alcohols (30 %, 50 %, 70 %, 80 %, 90 %, 95 %, 100 %), cleared in xylene, embedded in paraplast wax, sectioned at 5 µm and stained in iron haemotoxylin and eosin (Carson, 1992). Then they were examined under a dissecting microscope (magnification 40×) for identification of the maturity stages.

4.2.4 Assessment of the Gonadosomatic Index (GSI) of common octopus

The reproductive cycle was defined by combination of the monthly frequency of males and females in each maturity stage and the variations in the monthly average of the indices. Those indices were the gonadosomatic index (GSI) (Kume & Joseph 1969).

$$GSI_m = \left(\frac{\text{Testis weight}}{\text{Testis weight} - \text{Body weight}}\right) \times 100$$

$$GSI_f = \left(\frac{\text{Ovary weight}}{\text{Ovary weight} - \text{Body weight}}\right) \times 100$$

Where;

m = males

f = females

4.2.5 Assessment of relative fecundity of common octopus

Female specimens with mature ovaries were collected from November 2010 to November 2012. Approximately 10 specimens were analysed each month. Average fecundity was estimated and egg diameter measured along a horizontal axis using a calibrated eye-piece graticule under a standard dissecting microscope at a magnification of 40×. The specimens for fecundity estimates were stored in Gilson's fluid for 3 months. The plastic bottles containing these specimens were vigorously shaken from time to time to aid in the release of oocytes from the ovarian walls. Before counting the eggs, the contents of each bottle were poured into a petri dish and those oocytes not liberated from the ovarian tissue removed by teasing. The oocytes were repeatedly washed in tap water. The clean and separated oocytes were transferred to another 1 litre beaker containing tap water. A plastic ruler was used to stir vigorously the egg suspension to ensure an even distribution of oocytes in the suspension column. After 10 strokes of the ruler a subsample was taken by a Labsystem finelet pipette. One aliquot usually gave sufficient numbers of large and small oocytes to yield satisfactory counts and diameter distributions. The oocytes were pipetted into a zooplankton chamber, and their diameter measured.

The fecundity (F) for each octopus was calculated following the formula given by Simpson (1951) as follows:

$$F = \frac{V}{V_i} n \times \frac{W}{W_i}$$

Where;

n = number of oocytes in the subsample;

V = volume of the egg suspension;

V_i = volume of subsample;

W = weight of whole ovary;

W_i = weight of portions of ovary fixed

4.3 Results

4.3.1 Sex ratio of common octopus

The common octopus sex ratio (M: F) at Shimoni was 1:1.2 as shown in table 4.1. The sex ratio showed predominance of males in the month of June and October. The results showed significant differences in sex ratio (χ^2 = 5.024, df = 1, p = 0.025).

Table 4.1: Monthly common octopus sex ratio variations at Shimoni 2010-2012

Month	*Males*	*Females*	*n*	*Sex ratio (M:F)*
November	8	25	33	1:3.1
December	15	13	28	1:0.9
January	14	19	33	1:1.4
February	17	20	37	1:1.2
March	12	22	34	1:1.8
April	22	14	36	1:0.6
May	14	22	36	1:1.6
June	18	19	37	1:1.1
July	20	18	38	1:0.9
August	18	19	37	1:1.1
September	19	18	37	1:0.9
October	14	23	37	1:1.6
December	12	17	29	1:1.4
January	16	22	38	1:1.4
February	13	20	33	1:1.5
March	22	18	40	1:0.8
April	13	24	37	1:1.8
May	14	23	37	1:1.6
June	24	13	37	1:0.5
July	16	17	33	1:1.1
August	15	18	33	1:1.2
September	8	12	20	1:1.5
October	10	5	15	1:0.5
November	7	10	17	1:1.4
Total	**361**	**431**	**792**	**1:1.2**

The sex ratio (M:F) recorded at Vanga was 1:1 as shown in table 4.2. The sex ratio showed predominance of males in the month of August. Significant deviations by the 1:1 proportion were tested by the χ^2 test (χ^2 = 1.7, df = 1, p = 0.25) and showed no significant difference.

Table 4.2: Monthly common octopus sex ratio variations at Vanga 2010 -2012

Month	*Males*	*Females*	*Total*	**Sex ratio (M:F)**
November	3	7	10	1:2.3
December	9	25	34	1:2.7
January	20	17	37	1:0.8
February	16	20	36	1:1.2
March	23	14	37	1:0.6
April	21	16	37	1:0.8
May	17	20	37	1:1.2
June	20	17	37	1:0.9
July	13	25	38	1:1.9
August	21	16	37	1:0.8
September	15	22	37	1:1.5
October	17	20	37	1:1.2
December	19	18	37	1:0.9
January	19	18	37	1:0.9
February	12	20	32	1:1.6
March	19	21	40	1:1.1
April	15	22	37	1:1.5
May	19	18	37	1:0.9
June	20	17	37	1:0.8
July	17	23	40	1:1.3
August	19	16	35	1:0.8
September	10	9	19	1:0.9
October	6	7	13	1:1.2
November	15	14	29	1:0.9
	385	422	807	1:1

The results at both Shimoni and Vanga show no significant differences ($p > 0.05$) in annual sex ratios. However seasonally, during the Northeast monsoon (NEM), the sex ratio ($p < 0.05$) significantly favoured females. No significant difference was noted during the South east monsoon (SEM).

4.3.2 Size at sexual maturity of common octopus

The analysis of length at first maturity for female common octopus at Shimoni is as shown in figure 4.1. The female size at maturity ($DML_{50\%}$) was 10.82 cm.

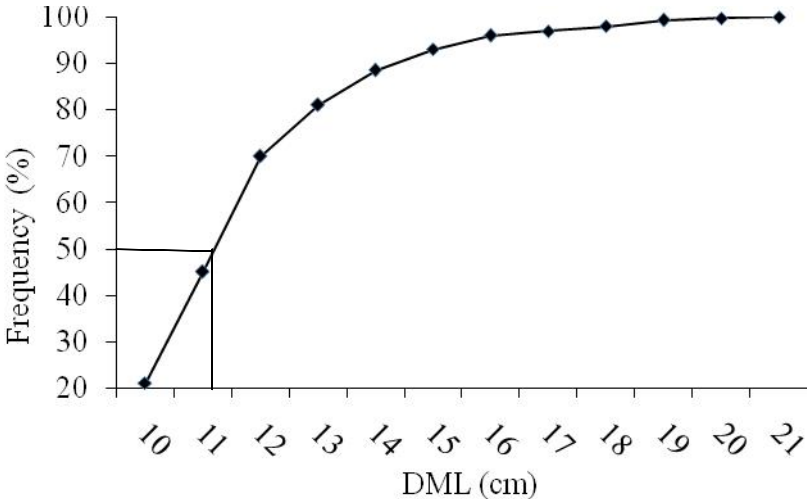

Figure 4.1: The cumulative frequency curve of lengths for maturity stages II, III and IV in females from Shimoni.

The analysis of length at first maturity for female common octopus at Vanga is as shown in figure 4.2. The female size at maturity ($DML_{50\%}$) was 10.81 cm.

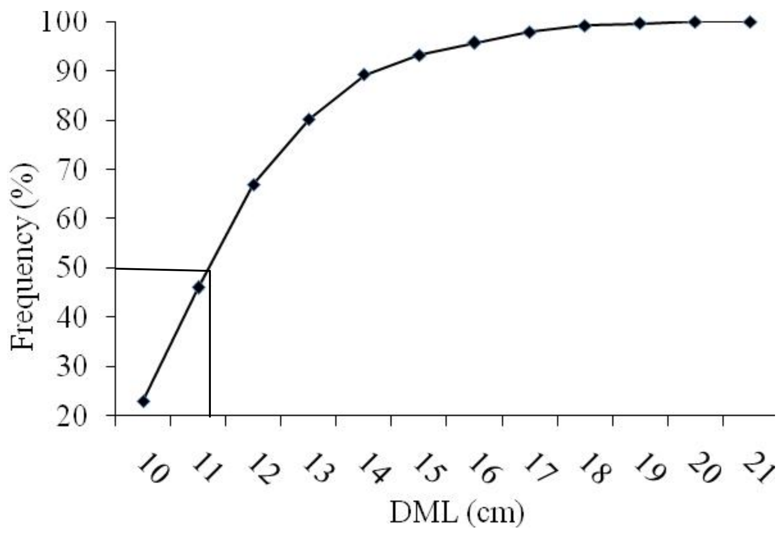

Figure 4.2: The cumulative frequency curve of lengths for maturity stages II, III and IV in females from Vanga.

The analysis of length at first maturity for male common octopus at Shimoni is as shown in figure 4.3. The male size at maturity ($DML_{50\%}$) was 10.53 cm.

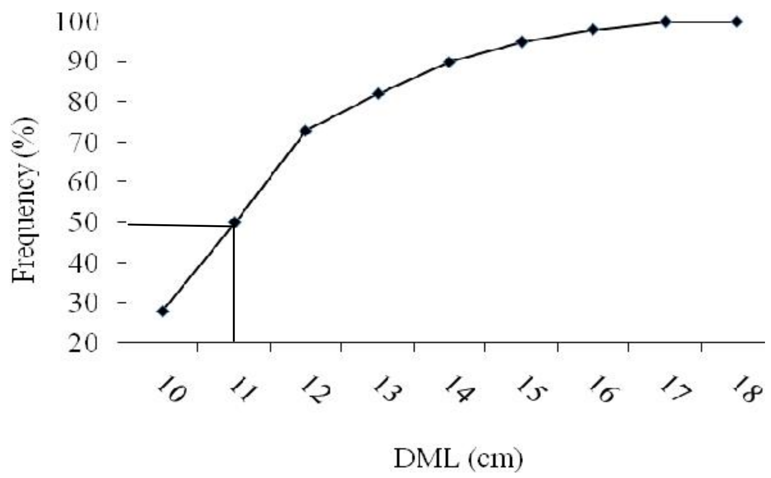

Figure 4.3: The cumulative frequency curve of lengths for maturity stages II, III and IV in males from Shimoni.

The analysis of length at first maturity for male common octopus at Vanga is as shown in figure 4.4. The male size at maturity ($DML_{50\%}$) was 10.50 cm.

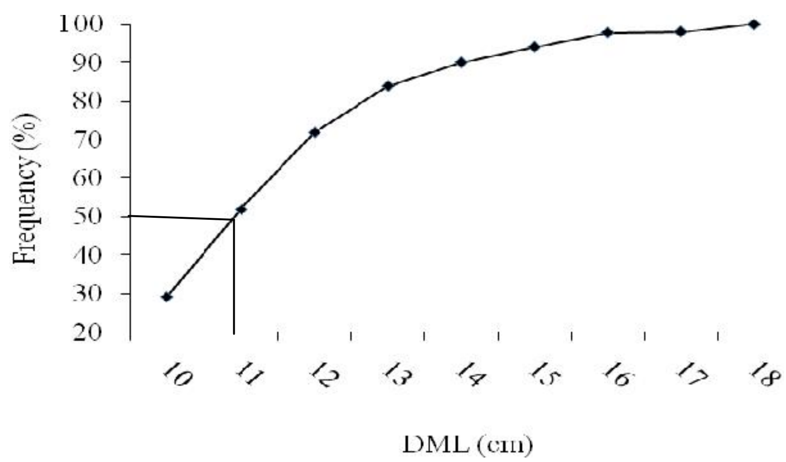

Figure 4.4: The cumulative frequency curve of lengths for maturity stages II, III and IV in males from Vanga.

4.3.3 Maturity stages for female common octopus gonads

Maturity stages for female common octopus were adopted from Inejih (2000), Gonçalves (1993), Ntiba and Jaccarini (1990) as shown in tables 4.3.

Table 4.3: The four female's reproductive stages of common octopus

Stage	Description
Stage I: Immature	Small ovary generally weighing <3 g with no follicles present and a thick outer wall; small white oviducal glands located mid-way down very narrow proximal and distal oviducts.
Stage II: Maturing	Ovary slightly larger and with a thinner wall than stage I with follicles and/or very small eggs present; oviducts longer and white oviducal glands larger and positioned further up the proximal oviduct.
Stage III: Mature	Ovary very large (>20 g) packed tightly with elongated striated eggs without stalks, the oviducal glands are large and dark in colour and positioned high up the proximal oviduct.
Stage IV: Post-spawning	Majority of eggs have stalks, are fully formed and less compressed than in stage III; eggs present in the oviducts and dark oviducal glands located further down the proximal oviduct; post-spawning - shrunken ovary with only follicles and a few fully formed eggs still present; oviducts slightly reduced in size unless containing eggs; the oviducal glands smaller but still dark in colour.

The visual appearance of different maturity stages of female common octopus gonads are as shown in plates 4.1 to 4.4, respectively.

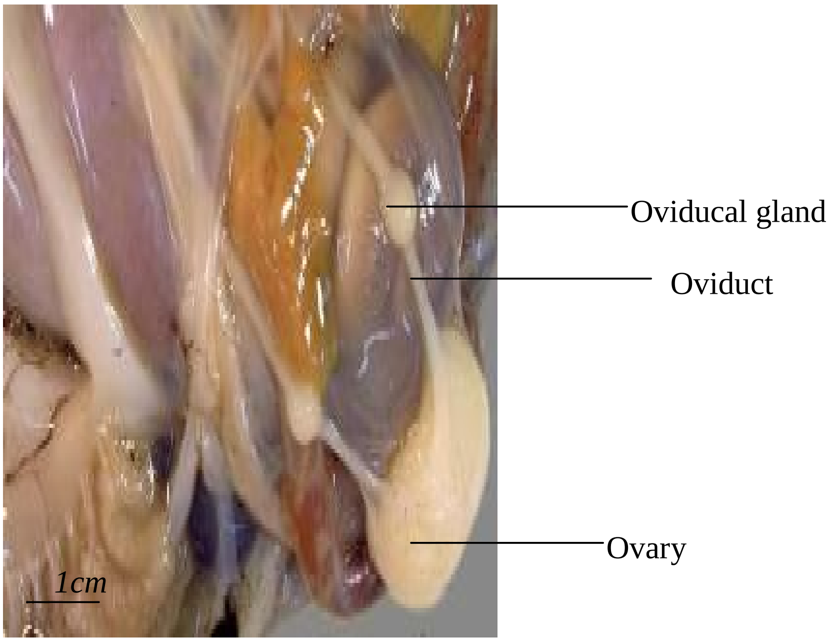

Plate 4.1: Stages I of female common octopus.

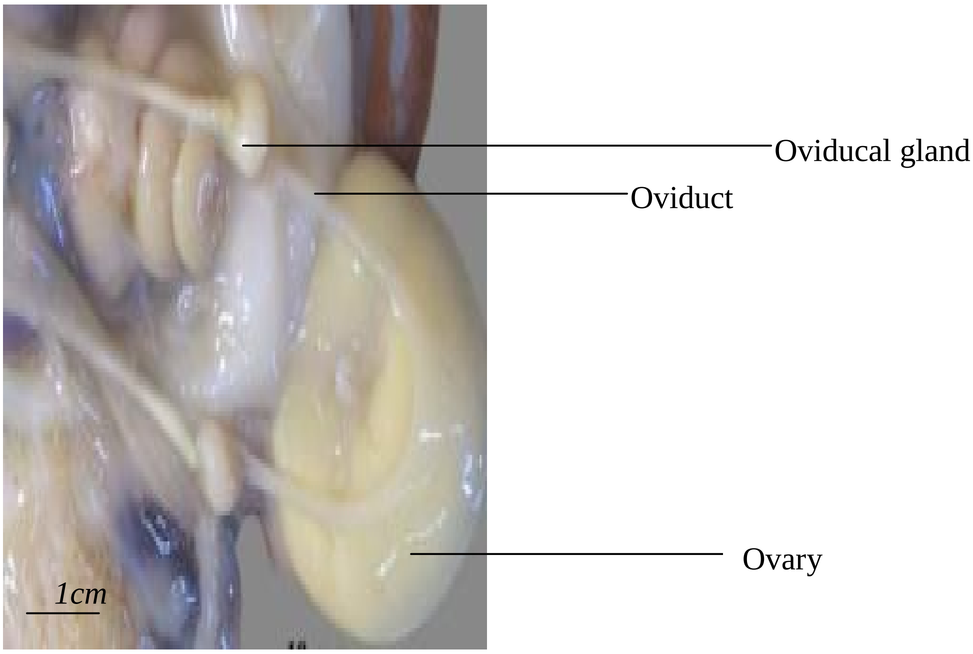

Plate 4.2: Stages II of female common octopus.

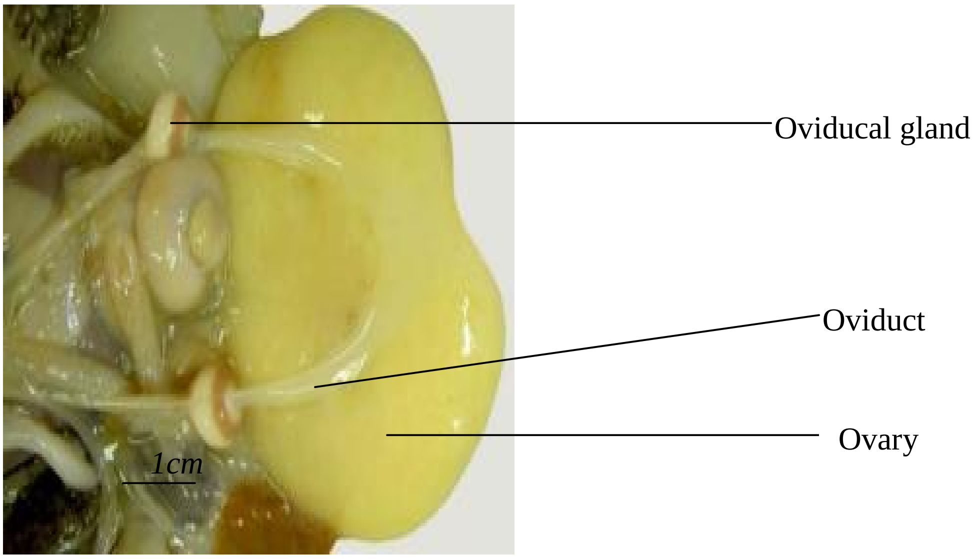

Plate 4.3: Stages III of female common octopus.

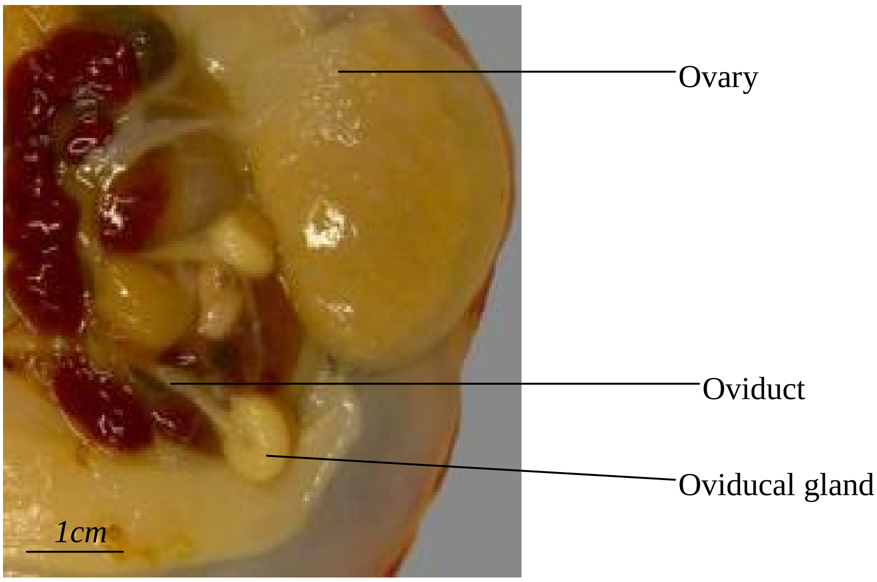

Plate 4.4: Stages IV of female common octopus.

The female common octopus maturity stages as examined under dissecting microscope are as shown in plates 4.5 to 4.8, respectively.

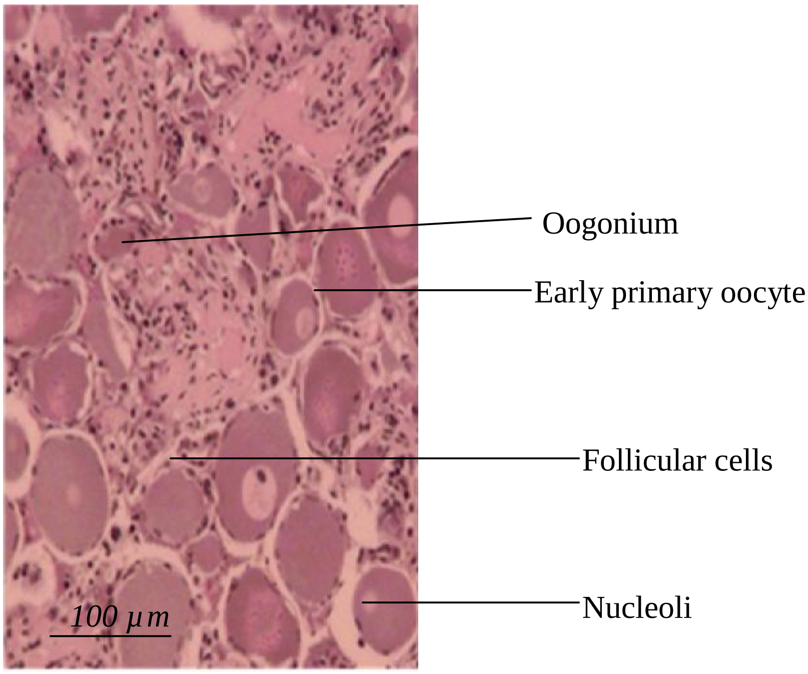

Plate 4.5: Microscopic stages I of female common octopus.

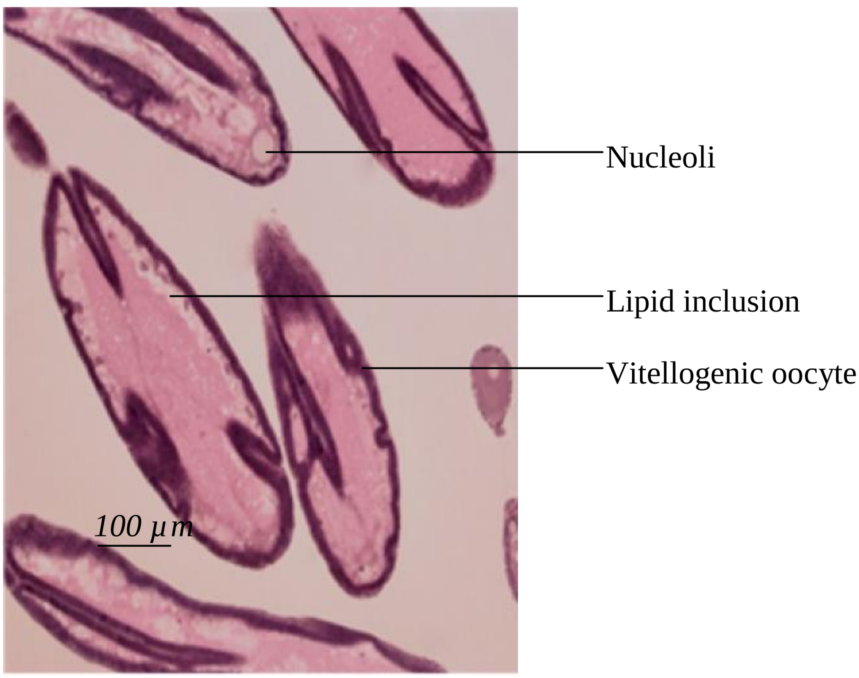

Plate 4.6: Microscopic stages II of female common octopus.

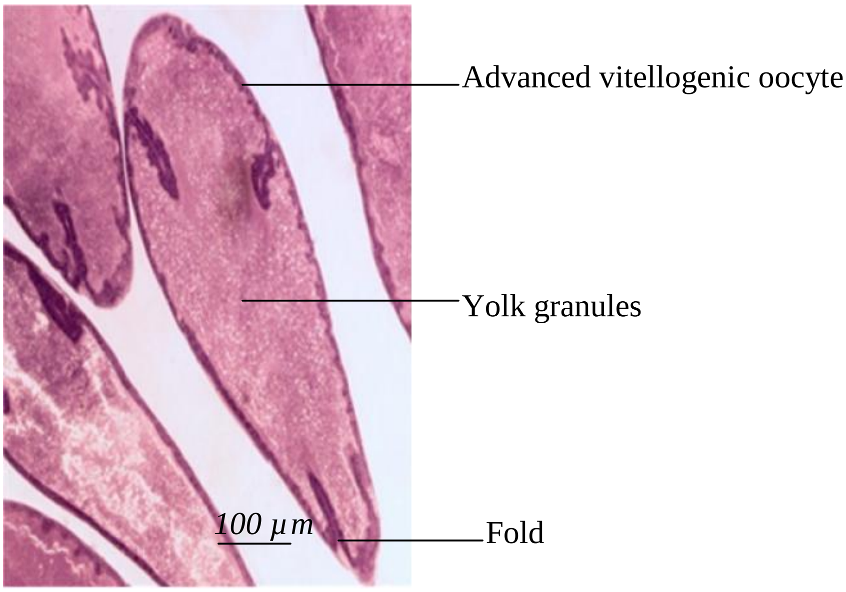

Plate 4.7: Microscopic stages III of female common octopus.

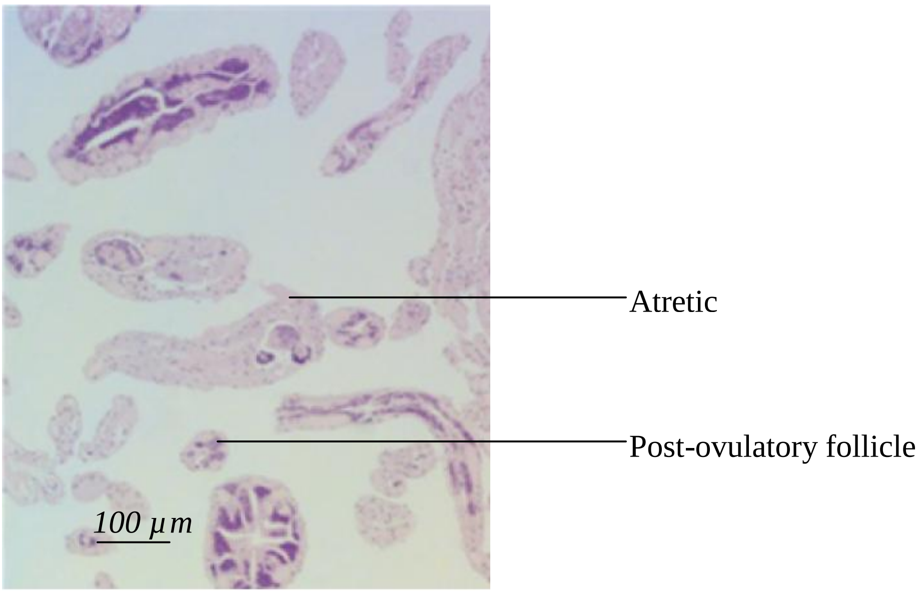

Plate 4.8: Microscopic stages IV of female common octopus.

The monthly evolution of the maturity stages of females by percentage throughout the entire sampling period at Shimoni are as shown in figure 4.5. Mature females in stage III were found in all months except in August 2011, June 2012 and August 2012 while stage IV females (post spawned) were found in February 2011, May 2011, December 2011 and November 2012.

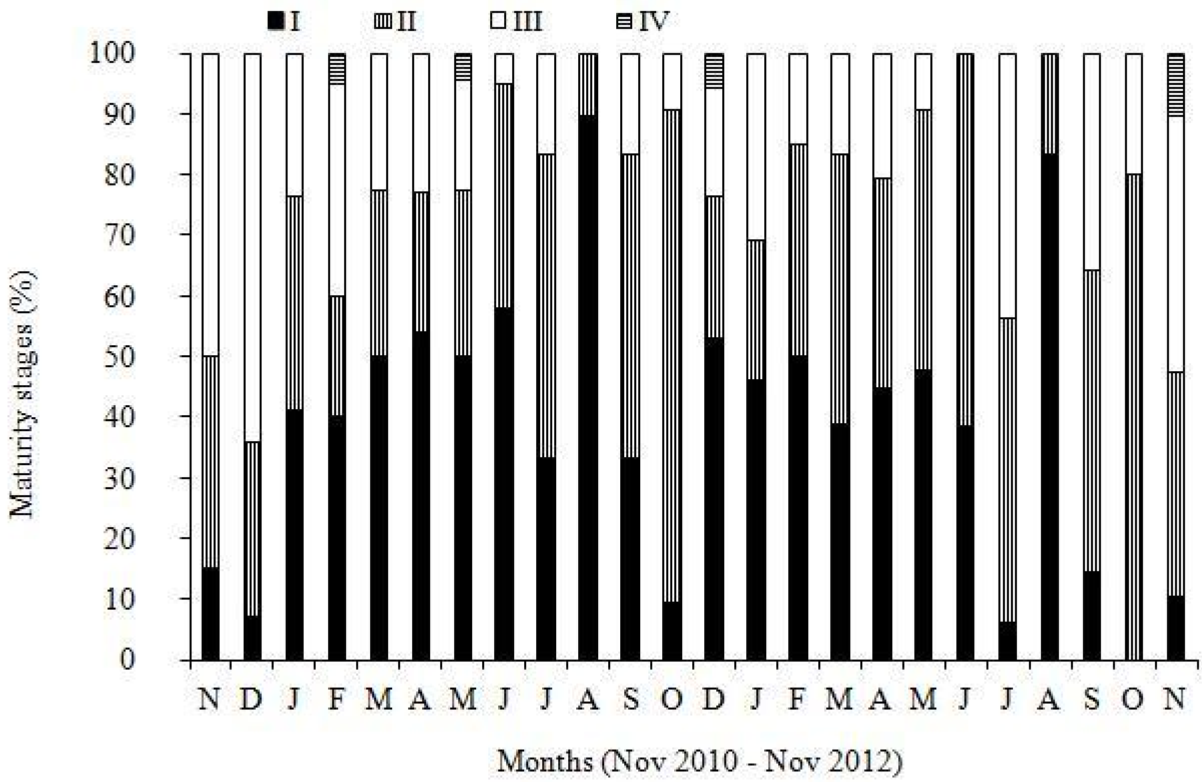

Figure 4.5: Monthly percentages of female common octopus in different maturity stages. I - Immature, II – Maturing, III - Spawning and IV- Post-spawning from Shimoni.

The monthly evolution of the maturity stages of females by percentage at Vanga are as shown in figure 4.6. Mature common octopus females were recorded in all the sampling months except in January, July and August 2012.

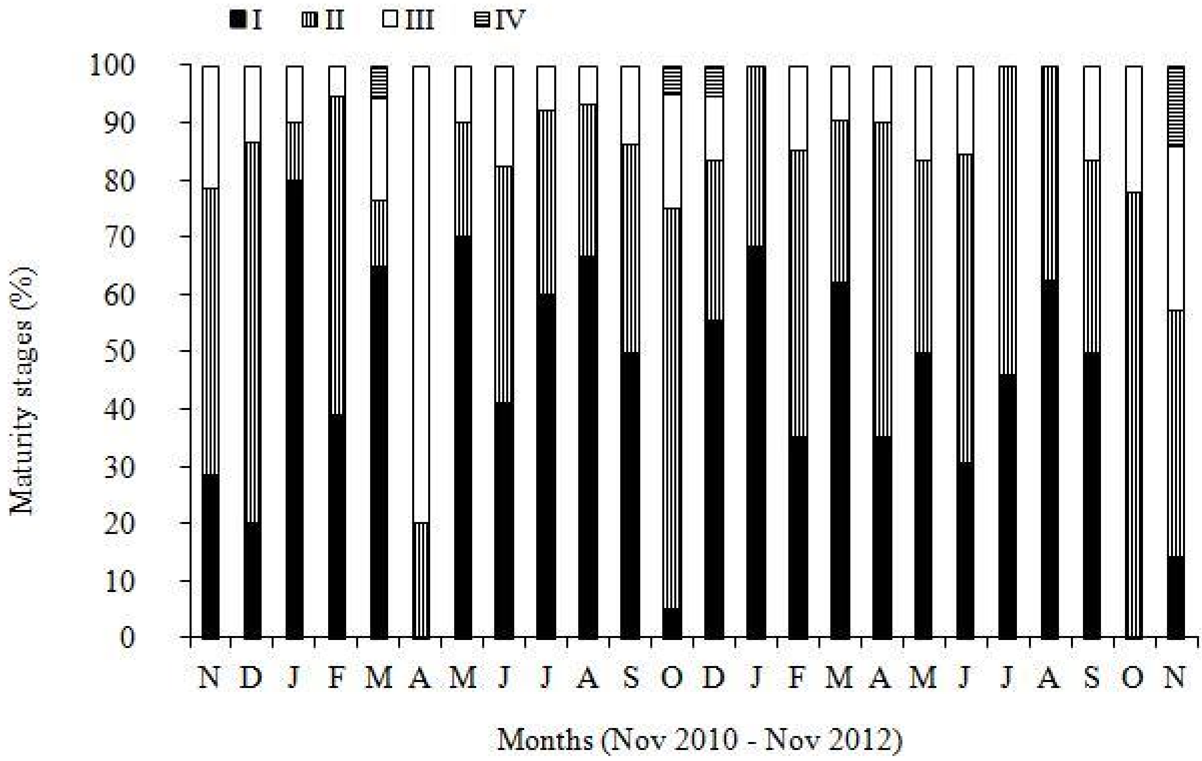

Figure 4.6: Monthly percentages of female common octopus in different maturity stages. I - Immature, II – Maturing, III - Spawning and IV- Post-spawning from Vanga.

4.3.4 Maturity stages for male common octopus gonads

The maturity stages for male common octopus were adopted from Inejih (2000), Gonçalves (1993), Ntiba & Jaccarini (1990) is as shown in table 4.4.

Table 4.4: The four male reproductive stages of common octopus

Stage	Description
Stage I: Immature	The accessory gland systems and testis were indistinct.
Stage II: Maturing	The testis was larger than the accessory gland and visible through the wall of the genital bag.
Stage III: Mature	The testis and accessory gland were of similar size and spermatophores present in the Needham's Sac and/or penis.
Stage IV: Post-spawning	The testis was small and striated and spermatophores present in the penis and/or Needham's Sac.

The visual appearance of maturity stages of male gonads are as shown in plates 4.9 to 4.12, respectively.

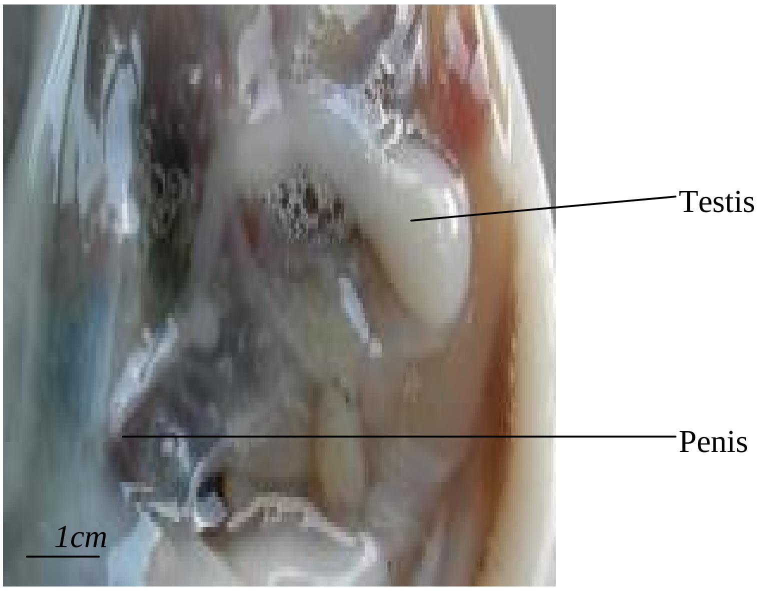

Plate 4.9: Stages I of male common octopus.

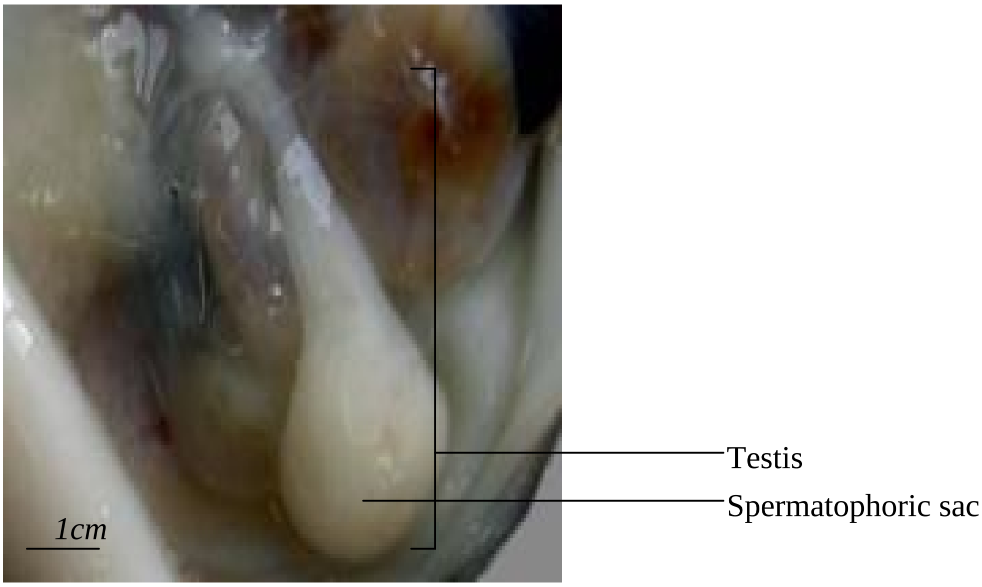

Plate 4.10: Stages II of male common octopus.

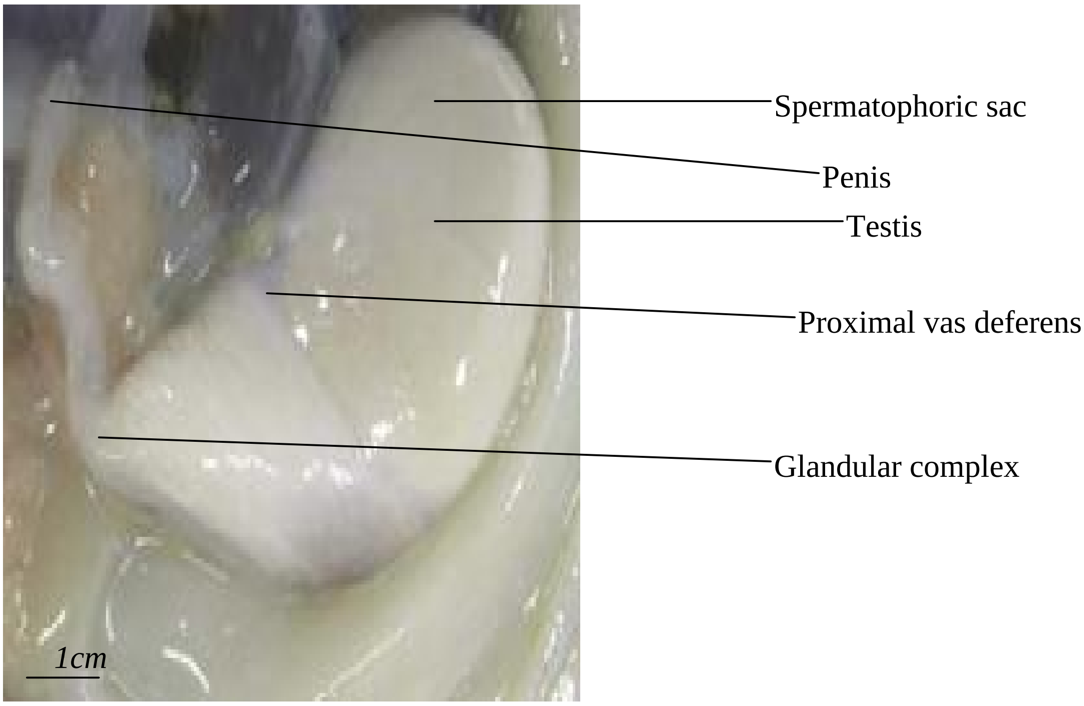

Plate 4.11: Stages III of male common octopus.

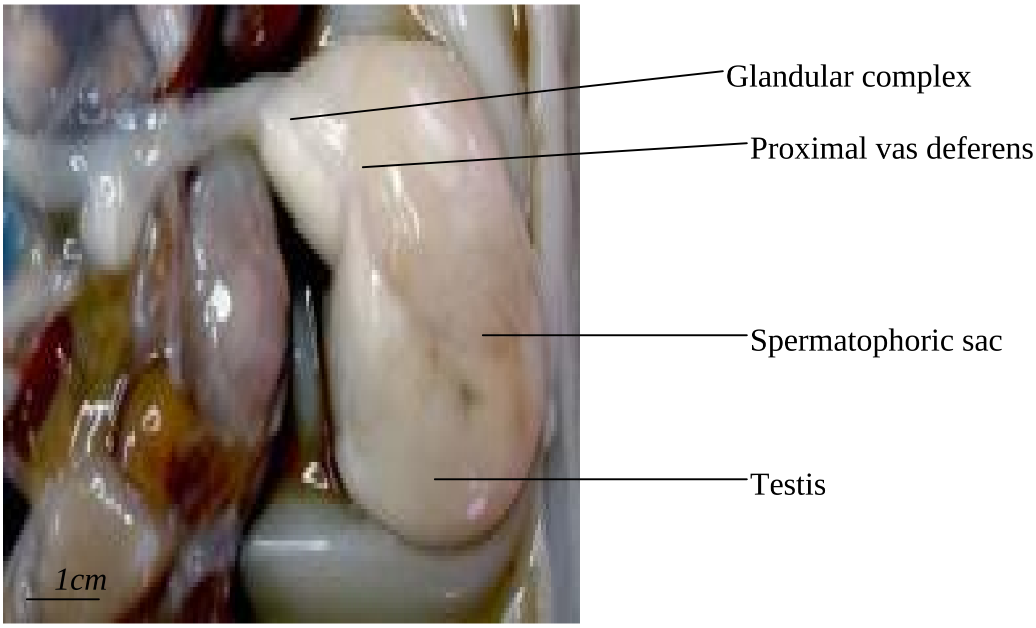

Plate 4.12: Stages IV of male common octopus.

The male common octopus maturity stages as examined under dissecting microscope are as shown in plates 4.13 to 4.16, respectively.

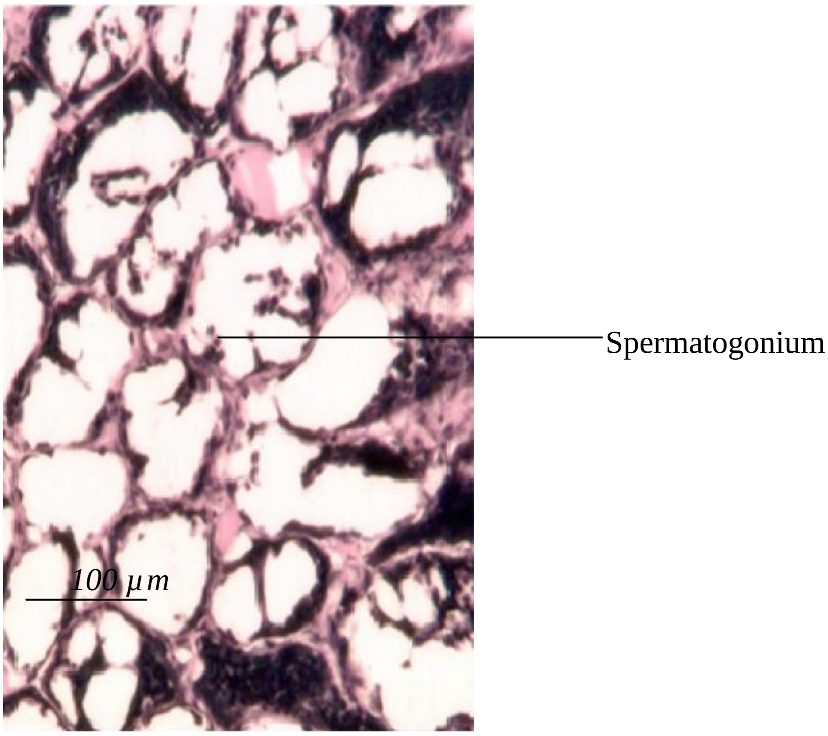

Plate 4.13: Microscopic stages I of male common octopus.

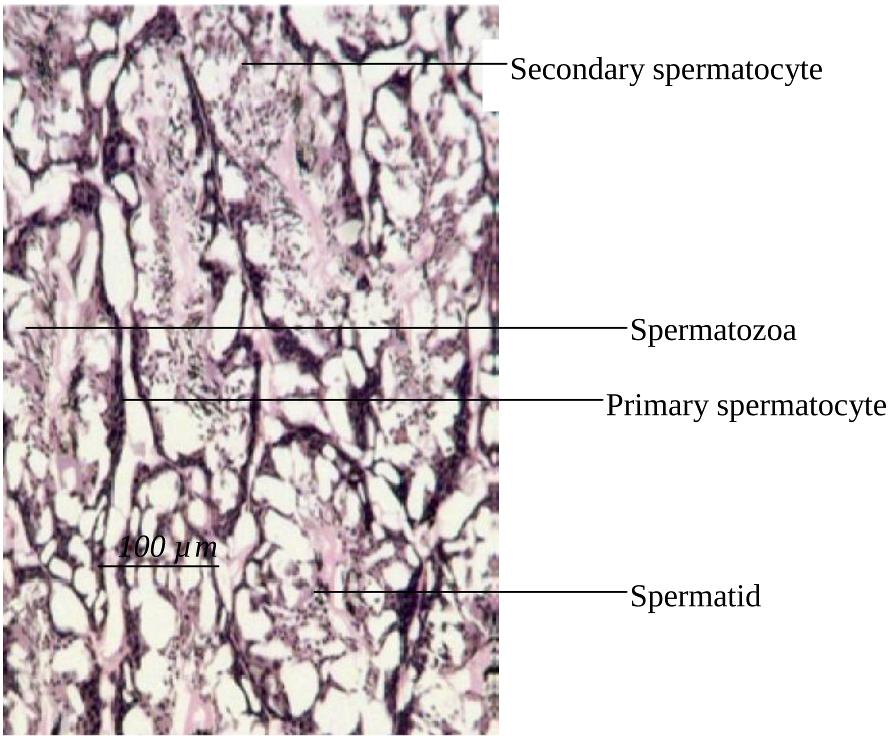

Plate 4.14: Microscopic stages II of male common octopus.

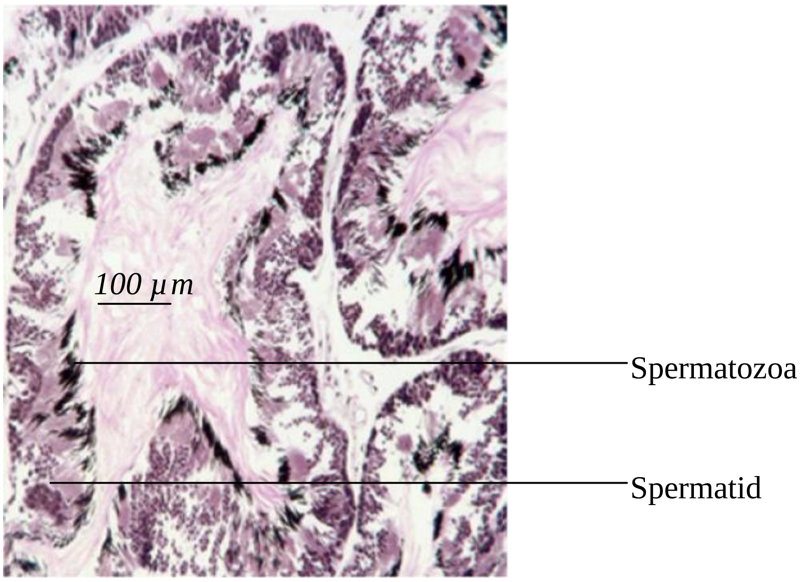

Plate 4.15: Microscopic stages III of male common octopus.

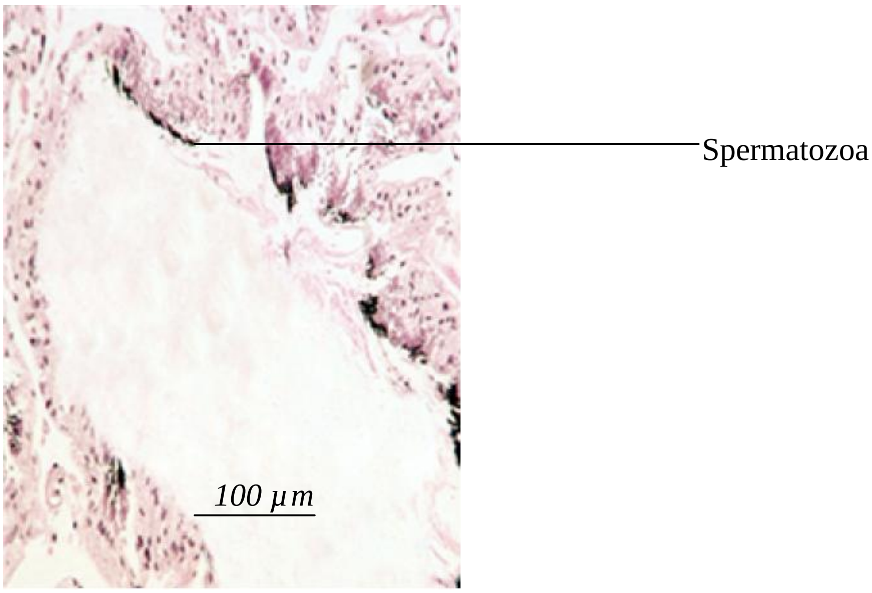

Plate 4.16: Microscopic stages IV of male common octopus.

The monthly evolution of the maturity stages of males by percentage at Shimoni are as shown in figure 4.7. Mature male common octopuses were recorded throughout the entire sampling period. All the males analysed in November 2012, mainly composed of individuals in Stages III and IV.

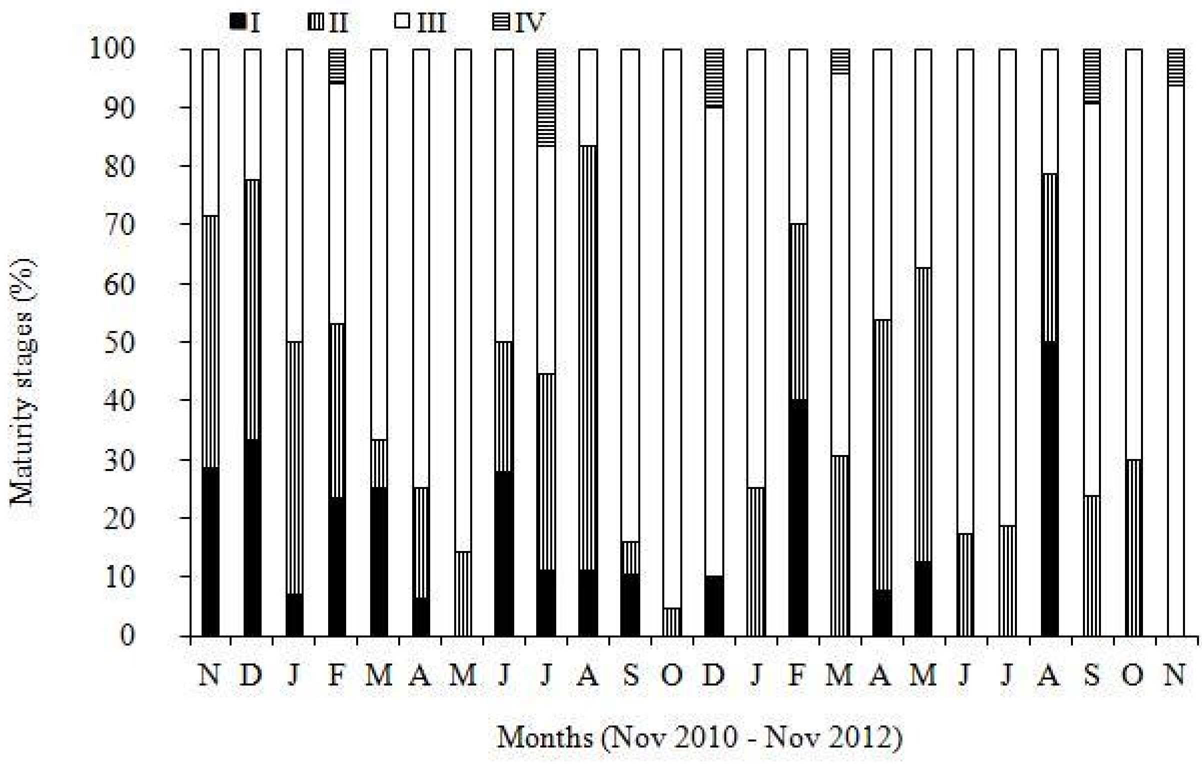

Figure 4.7: Monthly percentages of male common octopus in different maturity stages. I - Immature, II – Maturing, III - Spawning and IV- Post-spawning from Shimoni.

The monthly evolution of the maturity stages of males by percentage at Vanga are as shown in figure 4.8. Mature male common octopuses were also recorded throughout the entire sampling period. All the males analysed in October 2011 composed of individuals in Stages III and IV.

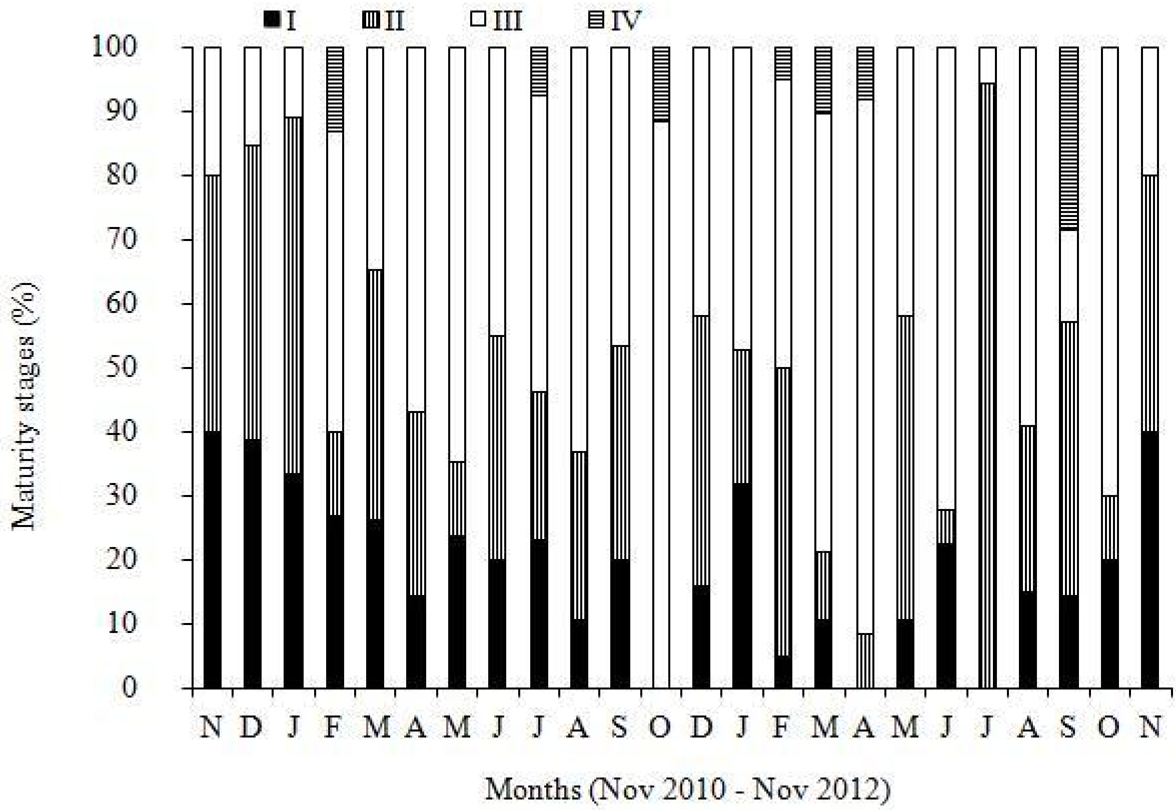

Figure 4.8: Monthly percentages of male common octopus in different maturity stages. I - Immature, II – Maturing, III - Spawning and IV- Post-spawning from Vanga.

4.3.5 Gonadosomatic Index (GSI) of common octopus

The monthly evolution of the gonadosomatic index (GSI) for females and males at Shimoni are as shown figure 4.9. Low GSI values were witnessed during the month of August 2011 for both sexes. High GSI values were recorded during the month of December 2011. Both females and males recorded high GSI values during the Northeast monsoon (November to February) as compared to the Southeast monsoon (May to August) seasons.

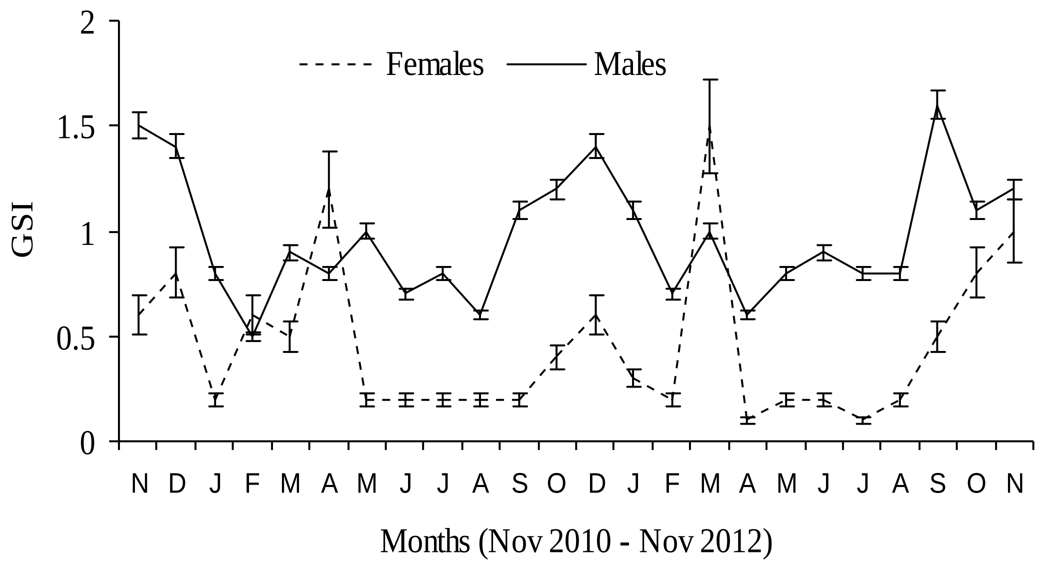

Figure 4.9: Monthly changes of the gonadosomatic index (GSI±SE) in male and female common octopus at Shimoni

The monthly evolution of the gonadosomatic index (GSI) for females and males at Vanga are as shown in figure 4.10. Low GSI values were recorded during the months of August and September. High GSI values were witnessed during the months of April, October, and November. Both females and males recorded high GSI values during the Northeast monsoon (November to February) as compared to Southeast monsoon (May to August) seasons.

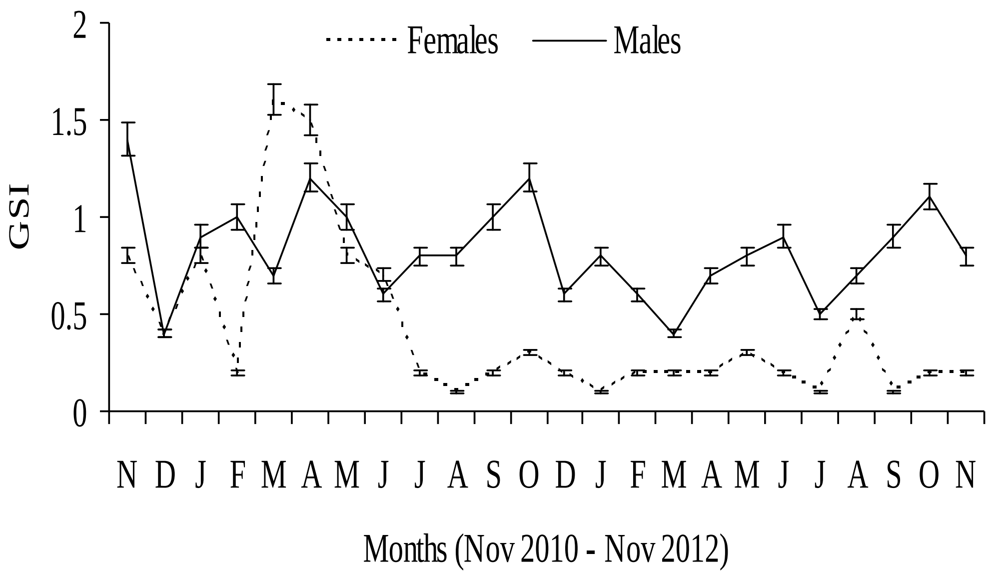

Figure 4.10: Monthly changes of the gonadosomatic index (GSI±SE) in male and female common octopus at Vanga.

4.3.6 Fecundity of common octopus

The mean monthly fecundity estimates are as shown in figure 4.11. The lowest number of oocytes counted in a single female octopus was 5,200 while the highest number of oocytes counted was 389,000. The mean fecundity was 154,057 ± 29.1. Fecundity was highest in the months of January, September and April and lowest in the months of March and August. Very low fecundity was recorded in the month of May. The seasonal (NEM and SEM) mean fecundity variations was significantly different ($p<0.05$) ($t = 0.5185$, df 22 and $p = 0.031$). The mean diameter of the long axis of the eggs of common octopus was estimated at 1.4 ± 0.2 mm.

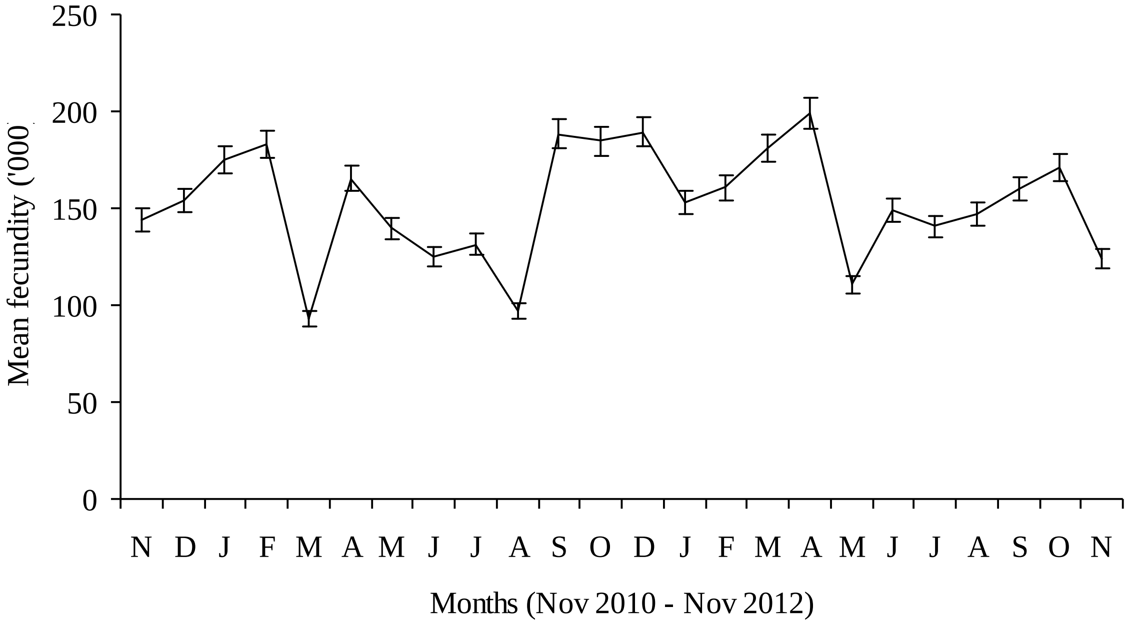

Figure 4.11: Monthly mean fecundity estimates (±SE) of common octopus.

4.4 Discussion

The sex ratio (1:1) recorded in the current study agrees well with studies done by Otero et al. (2007) who reported a sex ratio of 1:1 for common octopus at the Balearic Islands and along the Galician coastline in the North-western Mediterranean. The phenomenon witnessed in the current study where females dominated in the larger class sizes was also witnessed in studies undertaken in several parts of the Atlantic Ocean by Silva et al. (2002) on common octopus who showed that when sex ratio was expressed in class size intervals, females dominated at larger class sizes. This was attributed to a number of factors among them differences in growth rates of the two sexes (Silva et al. 2002; Mangold, 1983). The dominance in the sex ratio by males witnessed in the months of April and June in the current study may be compared to the results found in the Mediterranean Sea (Mangold-Wirz, 1963), and of Morocco-Mauritania (Hatanaka, 1979; Dia, 1988), where sex ratios significantly favourable to males were found. This was further witnessed by García (1968) who found a slight dominance of males in the

Saharan octopus populations, while Guerra (1979) did not find differences in the number of males and females in the same area.

Such variations in the sex ratio have been cited to be difficult to explain and some authors attribute this to a combination of different factors such as; migration behaviour, associated with sexual maturation and to spawning processes (Mangold-Wirz, 1963) in the Mediterranean; feeding behaviour related to reproduction; post-spawning mortality; differences in the growth rates of either sex (Mangold, 1983), among others. Many of the possible causes of these differences in the sex ratios found in other areas could be attributed to the sampling strategy (Caverivière et al. 2002). In South Africa, Oosthuizen (2003) established that females were found to dominate the intertidal areas while no differences were found subtidally. Most of the females found in the subtidal zone were mature, a behaviour attributed to mating purposes as earlier cited by Mangold (1983).

The sizes at first maturity reported in the current study of 10.8 cm DML for females and 10.5 cm DML for males are relatively less than what was reported by Sánchez & Obarti (1993) in their study in the Gulf of Cádiz in the Mediterranean coast who reported size at first maturity of 11-13 cm DML for which both males and females attain their maturity. Similar studies by Guerra (1975) in the Mediterranean showed that males reached sexual maturity much earlier than females. Dia (1988) in the Gabes Gulf found out that males became sexually mature when smaller in size than females. Other studies have also indicated that males reach sexual maturity earlier than females in any studied area (Gonçalves, 1993; Silva et al. 2002; Oosthuizen & Smale, 2003). The precociousness of the male sexual maturity is recorded in Western Mediterranean (Mangold, 1963) and Atlantic populations (Dia, 1988). However, male maturity in the Gabes Gulf occurred at smaller size than in the Atlantic populations (11.8 cm in spring spawning and 12.2 cm in fall spawning) and at greater size than Western Mediterranean ones

(8-9 cm). Females of the Gabes Gulf attained sexual maturity at greater size than Western Mediterranean (Mangold, 1963) and Atlantic populations (Dia, 1988) which reached maturity, respectively, at 130 mm, 118 and 135 mm in mantle length.

The results of maturity stages in the current study showed that mature females and males appeared throughout the entire sampling period. This may be an indication that common octopus in the Kenyan coast spawn through-out the year. This concurs with studies done by Silva et al. (2002); Oosthuizen and Smale (2003) at the Gulf of Cádiz and South Africa who indicated that common octopus reproductive period extended throughout the year. In a similar study conducted by Mangold-Wirz (1963) in the Mediterranean, the reproductive period of common octopus also seemed to extend through-out the year, from January to October, with one or more spawning peaks.

Based on the results recorded in the current study, the Northeast and Southeast monsoon seasons seemed to have no influence on the spawning patterns of common octopus in Kenyan south coast. Similar studies by Hatanaka (1979), Hernández-García et al. (2002) and Silva et al. (2002) in the Gulf of Cádiz and South Africa found out that a number of factors such as climatic conditions affected spawning patterns of common octopus. Spawning peak was recorded during spring and extended to the onset of winter. Silva et al. (2002) however, pointed out that seasons had very little influence on the spawning patterns of common octopus.

The low GSI values witnessed during the months of August and September in the current study may have been an indication of the end of the spawning period of common octopus. This is comparable to earlier studies by Mangold (1983) who showed that the Gonadosomatic Index (GSI) is an index of gonadal maturity, a higher index shows that the gonads are developing, and lower value indicates the end of the spawning period. Guerra (1975) reported that in female common octopuses, GSI increase with sexual maturation. Maximum values of the GSI occur when reproductive activity is at its highest. In males, the testis and the Needham sac (acting as a reservoir for spermatophores before mating), increase in weight before the beginning of the spawning season for females.

In the current study, the fecundity estimates of common octopus ranged from 5,200 to 389,000 eggs, a range that is within what was estimated by Oosthuizen and Smale (2003) in South Africa, and in the Gulf of Cádiz by Silva et al. (2002) who reported common octopus fecundity estimates of between 12,000 and 500,000 eggs. The high fecundity estimates recorded in the month of April in the current study may be attributed to high number of mature individuals ready for the peak spawning season. The mean egg diameter of 1.4 ± 0.2 mm estimated at the current study was a bit less than what was estimated by Isshiki et al. (2012) from Tokyo Bay, Japan, who found out that the mean diameter of the long axis of common octopus eggs was 2.3 ± 0.3 mm. Other similar studies by Hatanaka (1979) estimated a mean length of oocytes at 3.224 ± 0.805 mm, ranging from 1.69 to 4.9 mm. The smaller mean egg size recorded during the current study may be attributed to the relatively smaller mean body sizes of the octopus recorded during the current study.

4.5 Summary and conclusions

Although common octopus catches are increasing globally, lack of information on the species reproductive biology has been a major concern in its management particularly in Kenya. The present study aimed at investigating the reproductive biology of common octopus from Shimoni and Vanga in the Kenyan South-coast. Sampling was done monthly from November 2010 through November 2012 using traditional fishing spear. For each specimen body weight (BW, kg), total length (TL, cm), dorsal mantle length (DML, cm), ventral mantle length (VML, cm) and gonad weights were recorded. Maturity stages and Gonadosomatic Index

(GSI) were determined using standard methods. A total of 1,599 specimens were collected, 746 males and 853 females.

Sex ratio results showed predominance of males during the months of July and August which may be an indication that females had disappeared from fishing grounds for breeding purposes. The monthly evolution of maturity stages results showed that mature females in stage III were recorded in all months except in the months of June to August which may indicate that majority of mature females were in their nests spawning. A high number of spent females were recorded in the months of November and December which was a sign of post-spawning season. The gonadosomatic index results showed low values were witnessed during the months of August and September which may have been an indication of the end of the spawning period. Following all these findings, this study concludes that common octopus in the Kenyan south-coast spawn all the year round with peak season experienced during the months of June to August. The monthly evolution of maturity stages results recommend a closed season during the peak spawning season.

CHAPTER 5: FOOD AND FEEDING HABITS OF THE COMMON OCTOPUS

5.1 Introduction

The study of the food and feeding habits of common octopus is a subject of continuous research because it constitutes the basis for the development of a successful fisheries management programme on common octopus capture (Fiorito & Gherardi, 1999). According to Muthiga and McClanahan (1987), octopus fishery is one of the most important locally and commercially exploited marine resources for human consumption in the Kenyan coast.

Studies on natural feeding of common octopus permit identification of the trophic relationships present in aquatic ecosystems, identifying feeding composition, structure and stability of food webs (Mather & O'Dor, 1991). Studies of species resources requirements have been used in attempts to understand factors controlling the distribution and abundance of organisms (Hanlon & Messenger, 1996). Data on different food items consumed by common octopus may eventually result in identification of stable food preference and in creation of trophic models as a tool to understand complex marine ecosystems (Boletzky, 1974, 1977). Various studies have been done on the diets of common octopus from various parts of the world. According to Fiorito and Gherardi (1999), common octopus is known to feed particularly on crabs, bivalves, and gastropods. They have also been found to feed on polychaete worms, other crustaceans, cephalopods, and various species of small bony fishes (Hanlon & Messenger, 1996).

There is no scientific information available on the food and feeding habits of common octopus which contributes the bulk of all cephalopods landed in Kenya (Dept of Fisheries, 2012a). So, this part of the study is aimed at providing information about stomach contents and feeding habits of common octopus in the Kenyan South coast.

5.2 Materials and Methods

5.2.1 Collection and treatment of specimen

Specimens were dissected and their whole stomachs put in deep freezers soon after capture and transported to biological science laboratory for further analysis. Stomachs which were not analysed immediately were fixed in 5 % formalin and preserved in 70 % ethyl alcohol.

The stomachs with food contents were then dissected and the contents emptied into a petri-dish. Prey remains were examined under a binocular microscope and identified to the lowest possible taxon. Fish remains included bones (usually vertebrae), otoliths, scales, eye-lenses, skin and flesh. Crustaceans were rarely intact and remains usually consisted of fragments of exoskeleton, eyes or pinkish flesh. Cephalopod remains included beaks, tentacles, suckers, flesh and skin. Gastropods and bivalves were recognised from flesh and shell remains. Polychaetes were recognised from jaws and chaetae. All the hard parts were identified by use of published descriptions (Clarke, 1986).

5.2.2 Methods of stomach content analysis

i. **Assessment of fullness of common octopus stomachs (Points method)**

The degree of apparent fullness of stomachs was determined and points were assigned as 0 for empty stomachs, $\frac{1}{2}$ for half stomachs and 1 for full stomachs, then index of bulkiness was calculated as described by Clarke (1986).

ii. **Assessment of frequency of occurrence (FO) of food items**

The proportion of stomachs containing each prey type was calculated and expressed as a percentage of the total number of stomachs as described by Hyslop, (1980).

$$\text{Diet}_i^{FO} = \frac{N_{\text{octopus},i}}{N_{\text{octopus}}} \times 100$$

Where;

Diet_i^{FO}	=	percentage (%) of prey '*i*' in the diet, estimated using frequency of occurrence method.
$N_{\text{octopus},i}$	=	number of octopus that have prey of type '*i*' in the stomach.
N_{octopus}	=	number of all octopus examined.

iii. Assessment of stomachs dominated by a certain prey (Dominance method)

The proportion of stomachs dominated by mass by a certain prey was calculated and expressed as a percentage of the total number of stomachs (Hyslop, 1980).

$$\text{Diet}_i^{DM} = \frac{N_{\text{octopus},iw}}{N_{\text{octopus}}} \times 100$$

Where;

Diet_i^{DM}	=	percentage (%) of prey '*i*' in the diet, estimated using dominance method.
$N_{\text{octopus},iw}$	=	number of octopus in which prey type '*i*' dominates (i.e., has the largest mass) the stomach content, based on the masses of digested prey.
N_{octopus}	=	number of all octopus examined.

iv. Assessment of numeric percentage of each prey type (Numeric method)

In this method, the diet was expressed as the numeric percentage of each prey type relative to the total number of prey. The prey percentages were first calculated for each octopus separately and then averaged over all individuals (Hyslop 1980).

5.3 Results

5.3.1 The stomach fullness indices of common octopus

The monthly feeding intensity percentages at Shimoni are as shown in figure 5.1. A total of 779 stomachs were analysed for fullness indices and the results showed that full stomachs recoded 56.10 %, half full 37.99 %, and empty 5.91 %. High numbers of empty stomachs were recorded during the months of September, October and December. There was no significant difference in annual stomach fullness (Full stomachs $t = 1.58$, df 22, $p = 0.13$, Half full stomachs $t = -1.23$, df 22, $p = 0.23$, Empty stomachs $t = 0.77$, df 22, $p = 0.45$). Further, no significant difference was detected in seasonal variations of stomach fullness (Full stomachs $t = -0.74$, df 22, $p = 0.47$, Half full stomachs $t = -1.8$, df 22, $p = 0.08$, Empty stomachs $t = 1.03$, df 22, $p = 0.31$).

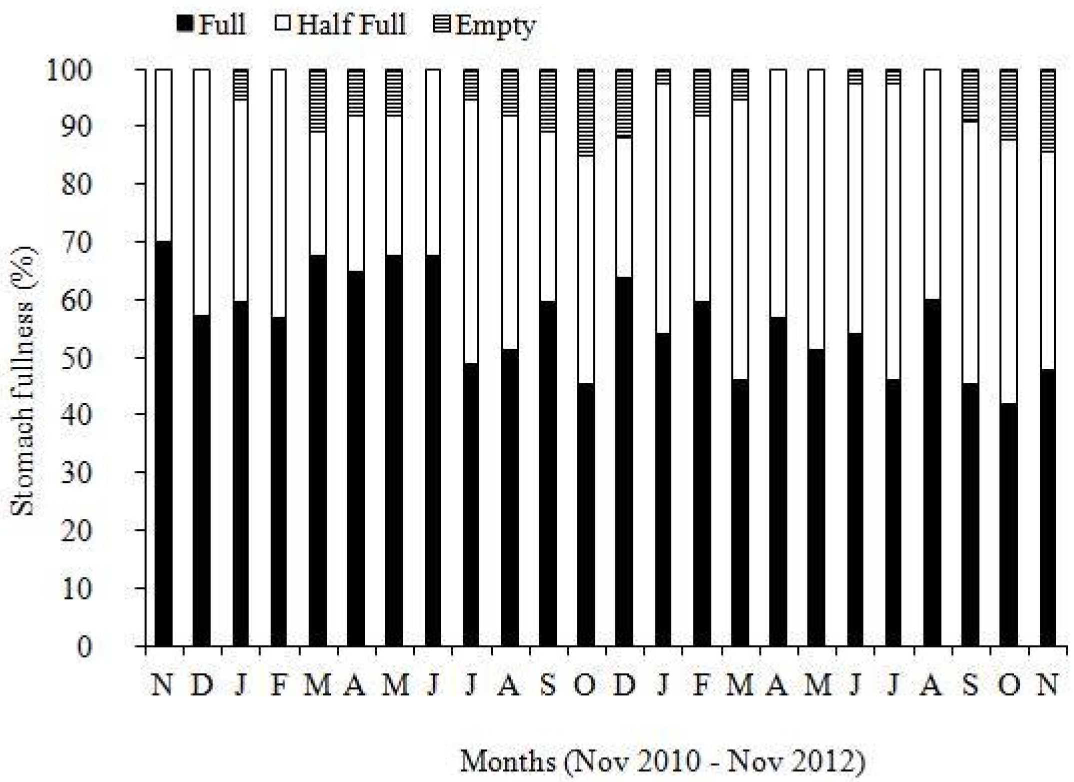

Figure 5.1: Monthly stomach fullness in percentages of common octopus at Shimoni.

The monthly feeding intensity percentages at Vanga are as shown in figure 5.2. A total of 763 stomachs were analysed for fullness indices and the results showed that full stomachs recoded 52.95 %, half full 42.20 % and empty 4.85 %. High numbers of empty stomachs were recorded during the months of October, November and December. There was no significant difference in annual stomach fullness (Full stomachs t = -0.43, df 22, p = 0.67, Half full stomachs t = 0.00, df 22, p = 1.0, Empty stomachs t = -0.42, df 22, p = 0.68). Further, no significant difference was detected in seasonal variations of stomach fullness (Full stomachs t = -1.15, df 22, p = 0.14, Half full stomachs t = -0.52, df 22, p = 0.61, Empty stomachs t = 1.95, df 22, p = 0.06).

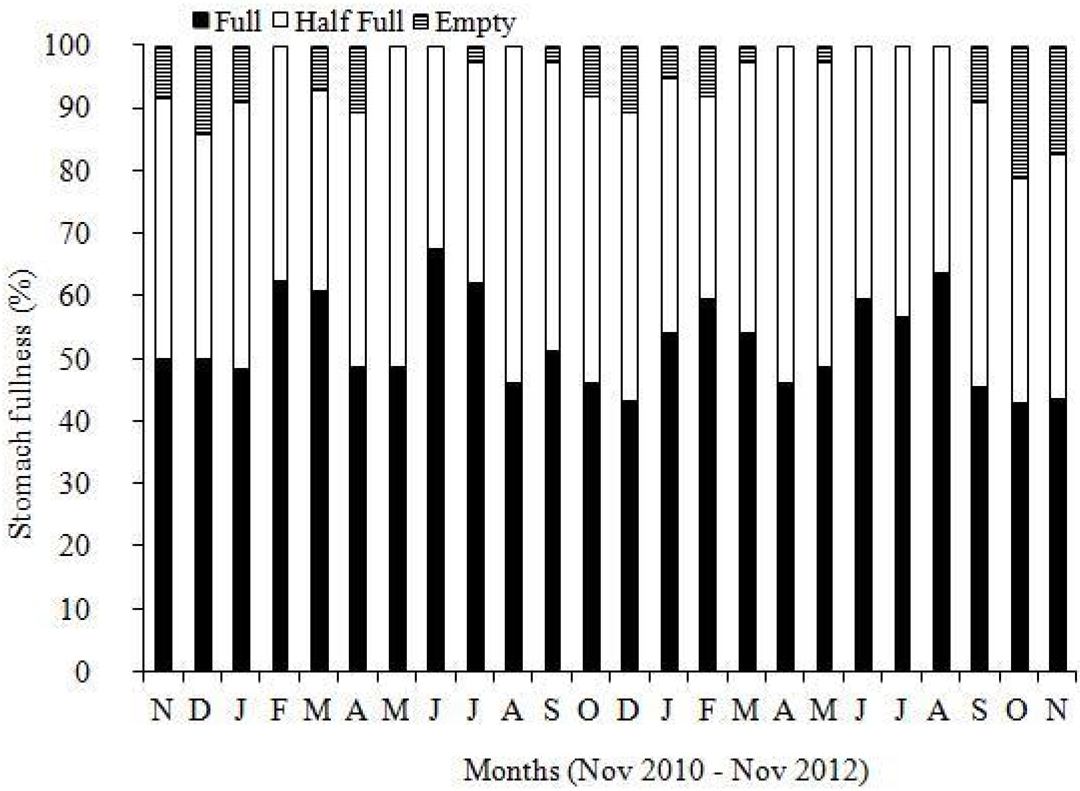

Figure 5.2: Monthly stomach fullness in percentages of common octopus at Vanga.

5.3.2 Common octopus stomach fullness analysis by length class

The analysis of male stomach fullness by length class at Shimoni is as shown in figure 5.3. The number of empty stomachs was relatively higher in large length classes compared to the small length classes for the males. The highest numbers of individuals with full stomachs were recorded in length class 12.

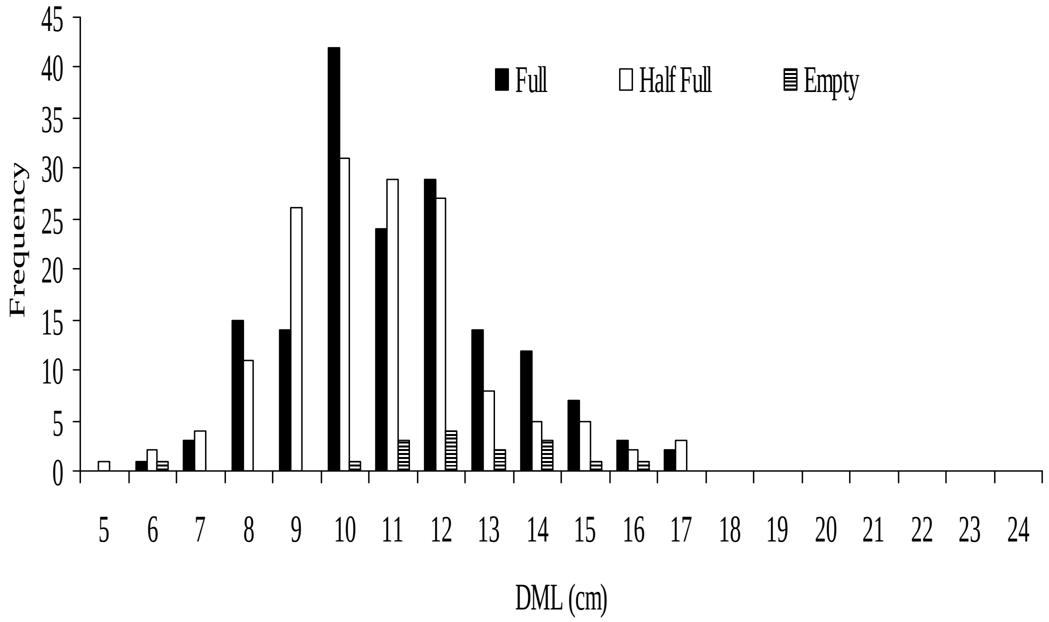

Figure 5.3: Stomach fullness analysis by length class for males from Shimoni.

The analysis of female stomach fullness by length class at Shimoni is as shown in figure 5.4. The number of empty stomachs was relatively higher in length classes 11, 12 and 13 cm.

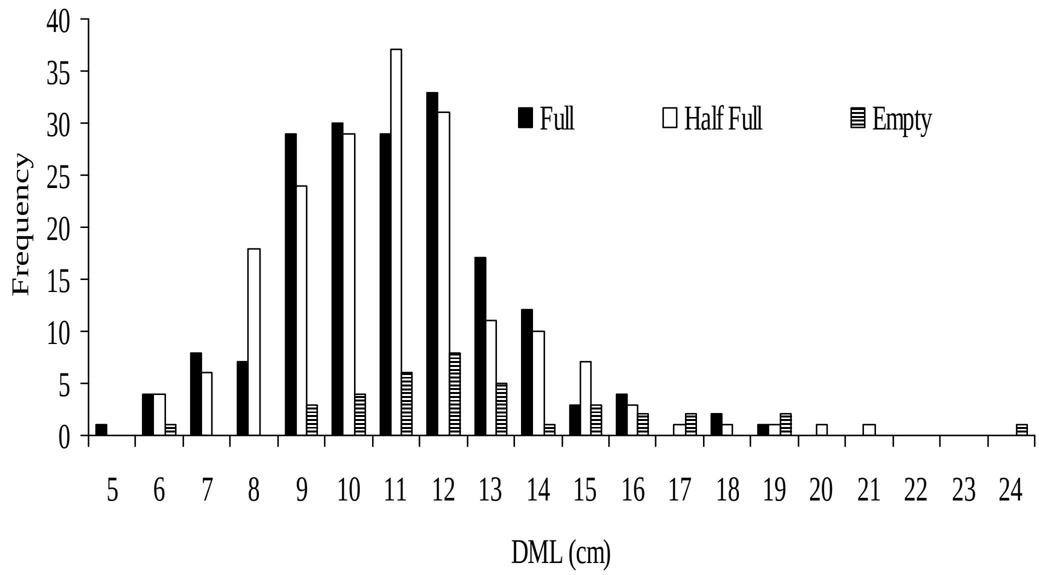

Figure 5.4: Stomach fullness analysis by length class for females from Shimoni

The analysis of male stomach fullness by length class at Vanga is as shown in figure 5.5. The number of empty stomachs increased with increasing length class interval. The highest numbers of empty stomachs were recorded in length class 12 cm whereas the highest numbers of half full and full stomachs were recorded in size class 10 cm.

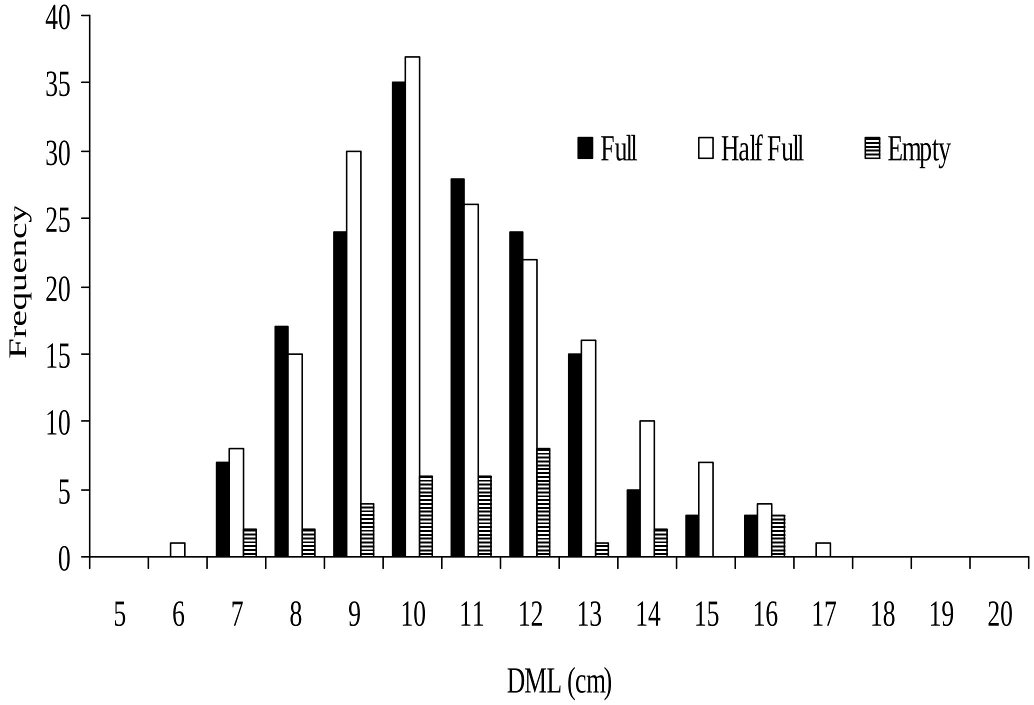

Figure 5.5: Stomach fullness analysis by length class for males from Vanga

The analysis of female stomach fullness by length class at Vanga is as shown in figure 5.6. The number of empty stomachs increased with increasing length class interval with the highest being recorded in length class 10 cm. The length class 10, 11 and 12 cm recorded the highest numbers of individuals with half full stomachs whereas length class 10 cm recorded the highest individuals with full stomachs.

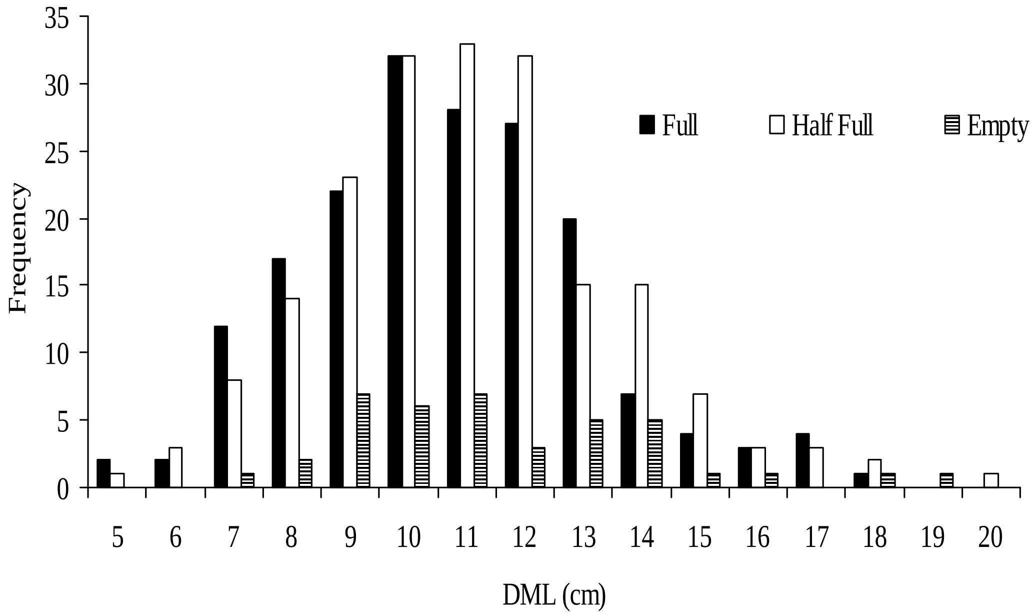

Figure 5.6: Stomach fullness analysis by length class for females from Vanga

5.3.3 Common octopus frequency of occurrence (FO) analysis

The monthly stomach contents analysis of common octopus at Shimoni is as shown in figure 5.7. The most important prey items were identified to the phylum level of classification. A perusal of indices indicated that crustaceans formed 57 %, molluscs 20 %, echinoderms 3.7 %, teleosts 1.1 % and the remaining 18.2 % were unidentified food items. The lowest percentages of crustaceans consumed were recorded in the months of August and December. No annual significant differences in monthly stomach content percentages were noted (Crustaceans t = 0.74, df 24, p = 0.94, molluscs t = 0.07, df 24, p = 0.95, Echinoderms t = -0.01, df 24, p = 0.99, Teleosts t = 0.01, df 24, p = 0.99 and Unidentified food items t = 0.01, df 24, p = 0.99). No seasonal significant differences in monthly stomach content percentages were noted (Crustaceans t = - 0.12, df 24, p = 0.91, molluscs t = -0.23, df 24, p = 0.82, Echinoderms t = -0.01, df 24, p = 0.99, Teleosts t = 0.01, df 24, p = 0.99 and Unidentified food items t = -0.00, df 24, p = 1.00).

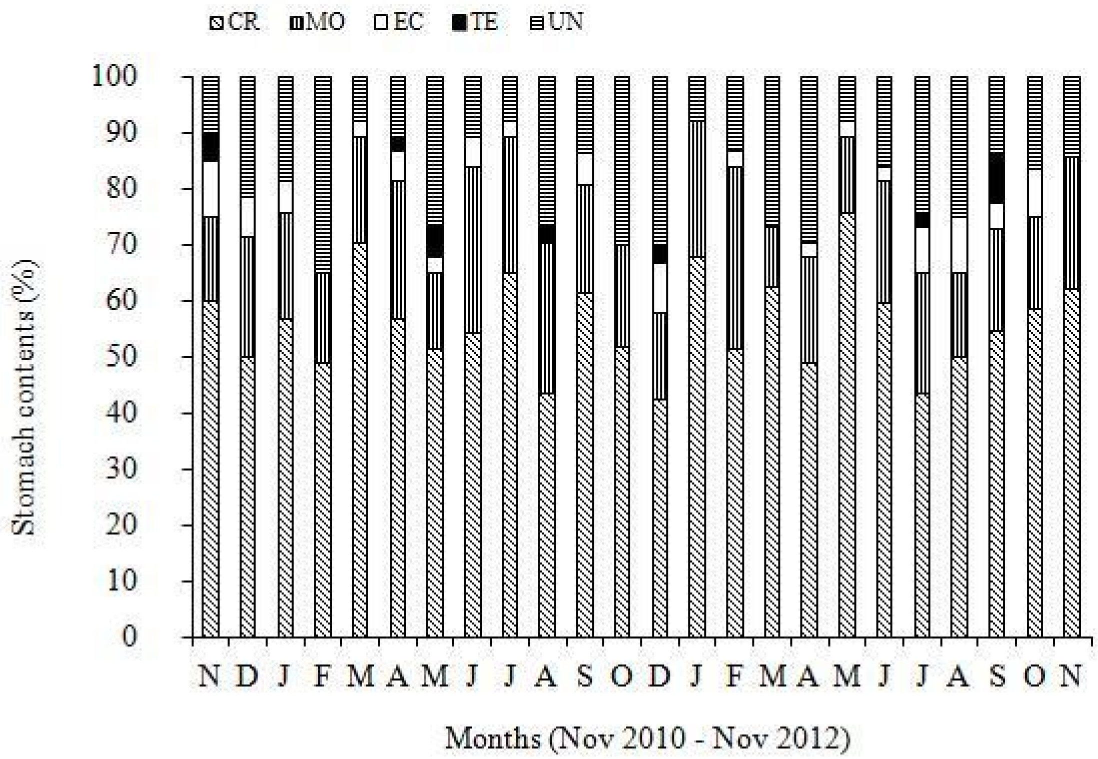

Figure 5.7: Monthly stomach content percentages of common octopus at Shimoni, CR – Crustaceans (crabs/shrimps), MO – Molluscs (octopus), EC – Echinoderms (Sea urchins/Starfishes), TE – Teleosts (fin fishes) and UN – Unidentified food items.

The monthly stomach contents analysis for common octopus at Vanga is as shown in figure 5.8. The frequency of occurrence indices indicated that crustaceans recorded 53.4 %, Molluscs 15.2 %, Echinoderms 4.9 %, Teleosts 2.2 % and unidentified food items 24.3 %. The lowest percentage of crustacean consumption recorded was in the month November. No annual significant difference in monthly stomach content percentages was noted ($p>0.05$). Crustaceans $t = -0.05$, df 24, $p = 0.96$, molluscs $t = -0.02$, df 24, $p = 0.98$, Echinoderms $t = 0.06$, df 24, $p = 0.96$, Teleosts $t = -0.01$, df 24, $p = 0.99$ and Unidentified food items $t = 0.07$, df 24, $p = 0.94$. No seasonal significant difference in monthly stomach content percentages was noted ($p>0.05$). Crustaceans $t = - 0.28$, df 24, $p = 0.78$, molluscs $t = -0.02$, df 24, $p = 0.98$, Echinoderms t = -0.09, df 24, p = 0.993, Teleosts t = 0.05, df 24, p = 0.96 and Unidentified food items t = -0.15, df 24, p = 0.88.

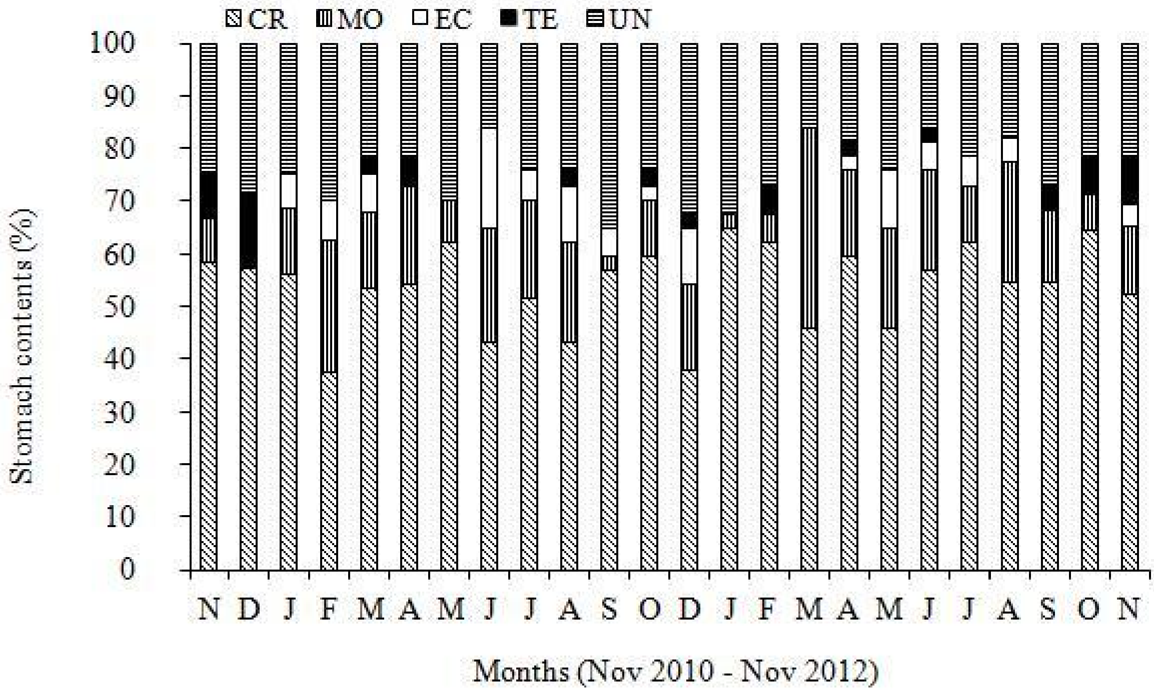

Figure 5.8: Monthly stomach content percentages of common octopus at Vanga, CR – Crustaceans (crabs/shrimps), MO – Molluscs (octopus), EC – Echinoderms (Sea urchins/Starfishes), TE – Teleosts (fin fishes) and UN – Unidentified food items.

5.3.4 Stomach contents analysis by length class

The stomach content analysis by length size of common octopus at Shimoni is as shown in figure 5.9 .The results showed that there were high levels of unidentified food items in small length classes compared to larger length classes. The common octopus of bigger dorsal mantle length class sizes was found to have ingested crustaceans (crabs) in large quantities than those in smaller length classes.

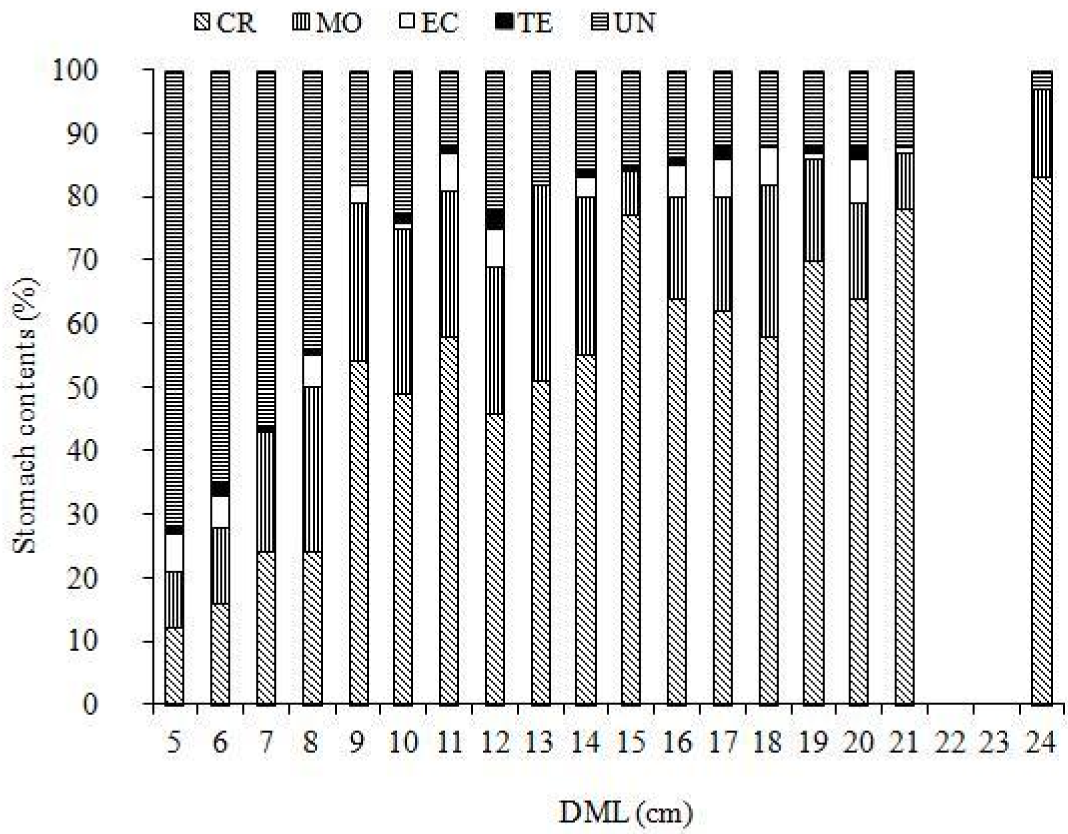

Figure 5.9: Percentage stomach content (diet) by length class of common octopus at Shimoni, CR – Crustaceans (crabs/shrimps), MO – Molluscs (octopus), EC – Echinoderms (Sea urchins/Starfishes), TE – Teleosts (fin fishes) and UN – Unidentified food items.

The stomach content analysis by length size of common octopus at Vanga is as shown in figure 5.10. The results show that common octopus of bigger dorsal mantle length class sizes was found to have ingested crustaceans (crabs) in large quantities than those in smaller length classes.

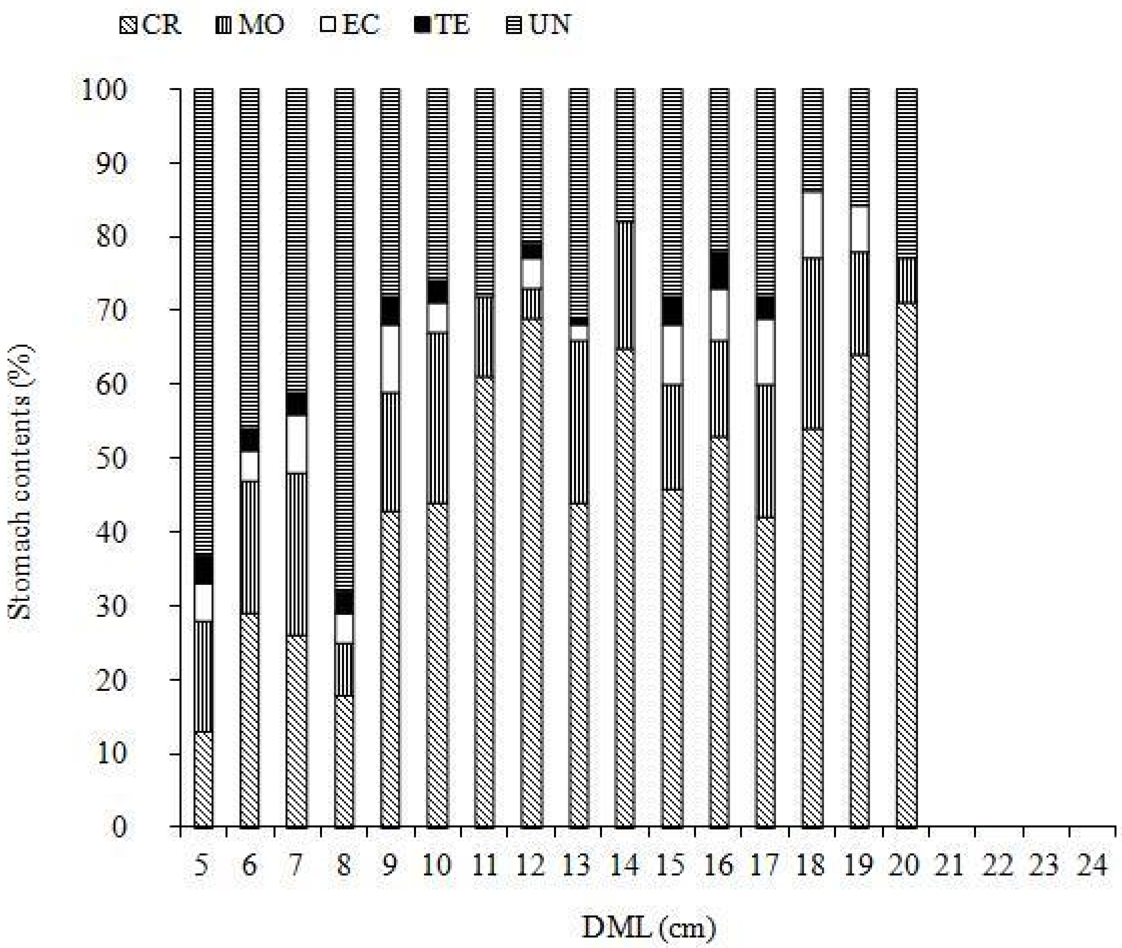

Figure 5.10: Percentage stomach content (diet) by length class of common octopus at Vanga, CR – Crustaceans (crabs/shrimps), MO – Molluscs (octopus), EC – Echinoderms (Sea urchins/Starfishes), TE – Teleosts (fin fishes) and UN – Unidentified food items.

5.4 Discussion

The study of the feeding habits is useful and essential for understanding the functional role of common octopus within their ecosystem (Dewan & Saha, 1979). In the present study, the high percentage of empty stomachs recorded during the months of September, October and November may have been due to a number of factors, such as breeding behaviour, time of capture, availability of food, size of octopus and whether they feed during the day or night time. Nigmatullin and Ostapenko (1976) reported that common octopus feed primarily during the night. Given that during the current study, octopus fishing was done during the day, this might have contributed highly in the number of half and empty stomachs recorded in the current study. This is because chances of getting a nocturnal feeder with full stomach in the morning hours are relatively higher as compared to the evenings when the food in the stomach is expected to have been digested. This may explain the reason behind the high number of individuals with half full stomachs since most of octopus fishing was done around mid day when half of the food eaten was probably already digested.

The current study indicated that the number of empty stomachs increased with increasing length class interval. This may be attributed to the breeding behaviour of common octopus. According to Mangold (1963), the stomach emptiness and fullness indices are very important in assessing common octopus feeding intensity. After laying eggs, the females stop feeding. They spend around three months without eating any food but busy caring for their eggs and males hardly resume their normal feeding behaviour after the mating season (Mangold, 1963). This may mean that most of the empty stomachs recorded in the larger length classes may have been as a result of high number of post-spawning individuals.

The results of the current study showed that crustaceans (crabs) seemed to be the most preferred food item for common octopus, molluscs were second preferred food item and, lastly, echinoderms and teleosts. This agrees well with studies done by Mangold (1983) who established that, stomach contents of common octopus were found to consist predominantly of crustaceans (80 %) and other food items consisting of 20 % (12 % fish and 8 % other cephalopod species). Mangold (1983) further proved that when a choice was offered in the laboratory between live crustaceans (mostly crabs), bivalves, gastropods and fish, the common octopus in Catalonia always preferred crabs, and ignored the other species. Similarly, in North-Western Africa the proportions were 61.5 % crustaceans, 29.5 % fish, and the rest being molluscs (Nigmatullin & Ostapenko, 1976). However, different results were obtained by Ambrose and Nelson (1983) in French Mediterranean waters. These authors analysed the remains that were found near the areas inhabited by common octopus and reached the conclusion that molluscs made up 80 % of their diet and the remaining 20 % were crustaceans. Cortez et al. (1995), however, noted that data on the feeding habits of octopus may be biased by the sampling methods used, and the proportion of food items found in the stomach might be underestimated, while in studies based on debris found near middens they may be overestimated. Castro and Guerra (1990) proved that benthic cephalopods tend to prey mainly on crustaceans. However, according to Boyle (1990), the prey spectrum in the diet of most marine organisms is related to the most readily available prey. Studies on the East coast of South Africa by Smale and Buchan (1981) showed that common octopus had a greater preference for bivalves mainly *Perna perna*, which formed up to 88 % of their diet. Therefore, the high percentage of crustaceans in the stomachs of common octopus in the current study may be attributed to their preference for these kinds of prey or their availability in the octopuses' environment. The little variation in seasonal and annual stomach diet composition may be an indication that neither seasons nor annual variations had any effect on common octopus diet.

The results of the current study indicate that the nature of food ingested by common octopus was somehow size dependent. The stomachs content analysis by length size indicated that common octopus with bigger dorsal mantle length class sizes were found to have ingested large quantities of crustaceans. This concurs well with earlier studies which have shown that the nature of food ingested by common octopus is size dependent to some extent. Stomach content analysis of common octopus of bigger dorsal mantle length size groups more often were found to have ingested mostly crabs in large quantities than those in smaller length groups. Cortez et al. (1995) noted the occurrence of benthic organisms like crabs and sea urchins in bigger size common octopus which was an indication that larger octopus feed very close to or near the bottom of the seabed, a phenomenon which was also witnessed by Nigmatullin and Ostapenko (1976). The reason behind bigger individuals ingesting large amounts of crabs in the current study was attributed to their bigger stronger beaks which are capable of crushing big crabs. The big sized octopus are also capable of swallowing small crabs as opposed to the small octopus which, according to earlier literature cited by Cortez et al. (1995) are only capable of drilling a hole in the prey and siphoning of the internal contents. This may also explain why the level of unidentified food items was relatively high in individuals with small length class.

5.5 Summary and conclusions

The present study investigated aspects of food and feeding habits of common octopus sampled from Shimoni and Vanga in the Kenyan South-coast. Sampling was done monthly from November 2010 through November 2012 using traditional fishing spear. Stomach content analysis was done using the Points method, Frequency of occurrence method, Dominance method and Numeric method. The results of the current study have shown that common octopus preferred crustaceans (crabs) to other diets and its diet preference was not influenced by seasonal variations. The stomach content analysis by size groups established that common octopus of larger size groups were found to have ingested crustaceans (mostly crabs) in large quantities, an indication that the nature of food ingested by the species was somehow size dependant. The high percentage of empty stomachs recorded during the months of September, October and December might have been as a result of starving behaviour of common octopus during breeding season. The high number of empty stomachs recorded in larger individuals might have been as a result of starving post-spawned individuals. The scientific information gathered during this study on food and feeding habits of common octopus will go a long way in informing policy directions and the management of the fishery.

CHAPTER 6: THE FISHERY, PROCESSING AND MARKETING OF COMMON OCTOPUS

6.1 Introduction

The number of studies on the fishery of common octopus populations has increased over the last twenty years and the role of the cephalopod in the marine fisheries and their increasing value as a globally exploited resource (Boyle & Boletzky, 1996; Guerra, 1997). Despite these recent advances there is still much to be investigated in order to improve the quality and quantity of the information concerning common octopus, from management to value-addition and marketing of octopus products (Pierce & Guerra, 1994; Caddy, 1997).

The range of value-added cephalopod products, is very broad and includes chilled, frozen, dried and canned products, and, recently, as components of ready made meals (Caddy, 1997). The largest share of sales is of chilled and frozen products. Common octopus is eaten in many parts of the world and is typically marketed fresh, frozen and dried salted. The interest for its use is traditionally influenced by geographical and cultural reasons (Seixas et al. 2005). This species has a high demand and commands high prices through its distributional range and supports artisanal as well as industrial fisheries (Napoleaõ et al. 2005b).

In the recent past, there has been a great progress in marketing, quality assurance and freshness assessment of fish products, but there have been only few studies on cephalopod quality, most of them being directed at squid (Aguado-Gimenez & Garcia-Garcia, 2005; Miliou et al. 2005). Octopus fishery exist because they provide social and economic benefits to society whose benefits is to achieve economic growth within coastal areas, focusing on small and medium enterprise development, thereby, creating employment opportunities, developing human resources and enhancing transformation in the fishing sector. This part of study was therefore aimed at describing the fishery, processing and marketing of common octopus in the Kenyan South coast.

6.2 Materials and Methods

6.2.1 Assessment of the Catch Per Unit Effort (CPUE) of common octopus

In order to estimate relative abundance and identify overall landing trends of common octopus, the CPUE was calculated using standardised techniques described by Muthiga and McClanahan (1987). The CPUE was expressed as kg/fisher/day. All the CPUE data was tested for normality using a Kolmogorov-Smirnov-Lilliefors (KSL) test. Since the data was not normally distributed even after several transformations, non-parametric Wilcoxon and Kruskal-Wallis tests were used.

6.2.2 Assessment of common octopus landings

Artisanal fisheries information on the average catch and the number of days an individual spent fishing in each month was examined based on logbook records of octopus landings from the fishermen as shown in table 6.1.

Table 6.1 Common octopus logbook data sheet

Logbook of octopus landings

Name of vessel……………………………………………..	Date……………………….
Vessel registration number	…………………………………………………………………
Agent's Name	…………………………………………………………………
No. of fishermen per boat	…………………………………………………………………
Target species	…………………………………………………………………
Landings (kg)	…………………………………………………………………
Gear used	…………………………………………………………………
Fishing time	Day………………. Month………….. Hours…………….

Date and place of landings	…………………………………………………………………
No. of fishing operations	…………………………………………………………………

6.2.3 Assessment of industrial and traditional value addition processes by use of a Questionnaire

A questionnaire was used to collect information on industrial and traditional value addition processes as well as collecting information on local and international marketing processes of common octopus as shown in the table 6.2 below.

Table 6.2 Questionnaire on industrial and traditional octopus processes

Questionnaire on octopus processes

Name of interviewee ……………………………………………………………………….

Zone/Industry ……………………………………………………………………….

What fishing activity are you engaged in:

Traditional processing………………………………………………………………………

Industrial processing ……………………………………………………………………….

Octopus trader………………………………………………………………………………..

Which of the following artisanal octopus processing do you undertake?

Octopus smoking ………………………………………………………………………

Sun drying ………………………………………………………………………

Octopus pounding ……………………………………………………………………….

Outline key advantages and disadvantages of the process………………………………….

Industrial octopus processing plant:

Name the products produced Fresh… Frozen…… Canned….. Ready meal…

Capacity of the plant (kg) ………………………………………………………….

Processing method …………………………………………………………

Advantages and Disadvantage of the method	…………………………………………..
Source of octopus (vessels) Off-shore ……….	Shore-based…….. Near-shore……..
Local and international marketing processes of octopus	
Where do you sale your products	……………………………………………………….
Price per kg	………………………………………………………..
Quantity (kg)	………………………………………………………..
Challenges experienced	………………………………………………………..

6.3 Results

6.3.1 Monthly common octopus landings

The monthly common octopus catches recorded in the Kenyan South coast between November 2010 and November 2012 are as shown in figure 6.2. The results show that there was a gradual decrease in total catches landed, over the period. However, a notable increase in catches was recorded during the Northeast monsoon season with maximum peaks recorded in the month of February whereas low catches were recorded during the Southeast monsoon seasons with the lowest catches recorded in the month of April.

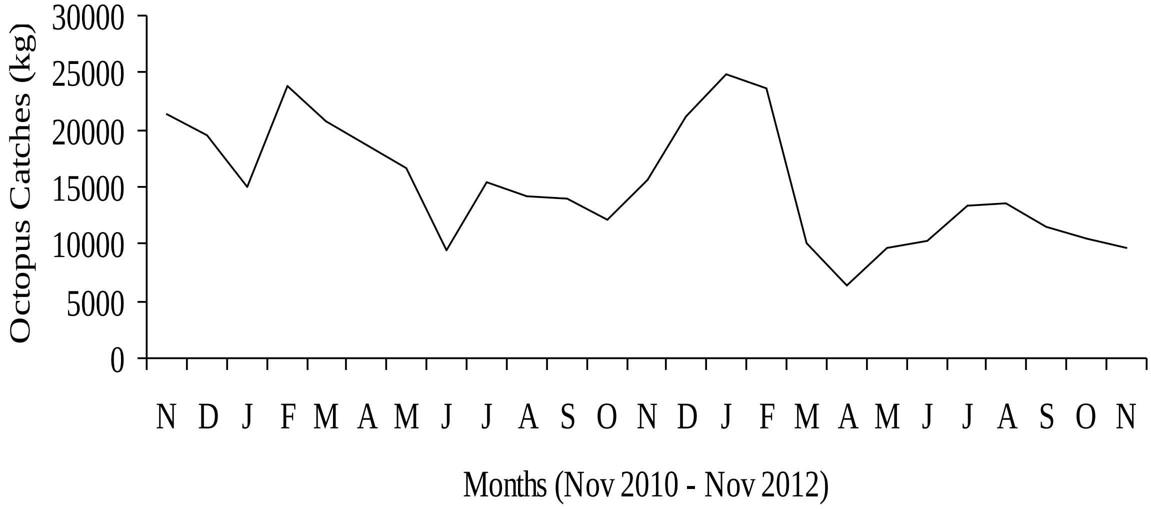

Figure 6.1: Monthly common octopus catches (kg) during the period Nov 2010 – Nov 2012.

The relationship between monthly catches and monthly CPUE is as shown in figure 6.3. A mean CPUE of 6.09 ± 1.4 kg/fisher/day was recorded during the Northeast monsoon season and a mean CPUE of 3.9 ± 0.9 kg/fisher/day during the Southeast monsoon season. There was a gradual increase in monthly CPUE as from August 2012 despite decrease in catches. The CPUE did not show any seasonal significant difference ($t = 4.5$, $df = 22$, $p > 0.05$) as well as annual significant difference ($t = 1.39$, $df = 22$, $p > 0.05$).

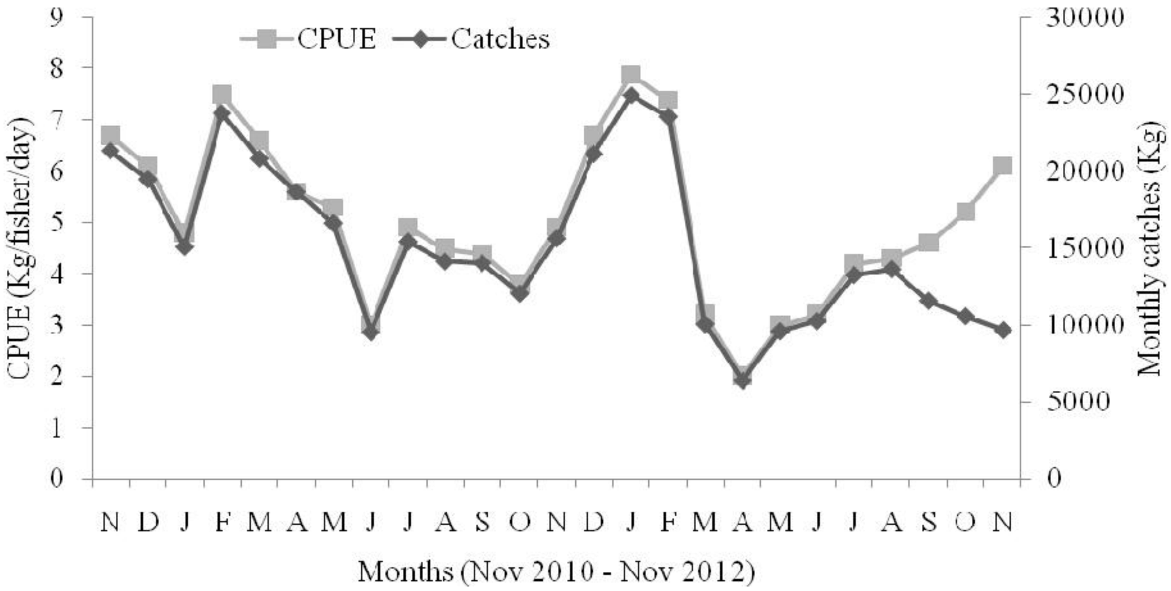

Figure 6.2: The relationship between monthly catches and CPUE.

6.3.2 Traditional processing of common octopus

The final product of traditional processing was pounded fresh octopus and sun dried octopus tentacles or gutted dried octopus.

i. Pounding the flesh of common octopus

The common octopus has no bones; most of its meat is in its eight tentacles, which are so elegant an evolutionary design that they have become a model for robotics engineers, who call them “hyper redundant manipulators.” Without a skeleton to support the muscles and anchor them with tough tendons, the octopus arm muscles support each other, and the anchoring connective tissues are spread throughout the muscles. They are much tougher than the connective tissues of bony fish.

Traditional octopus processing often involved pounding the flesh on hard surface to tenderize its fibres. Then after that, the octopus was cleaned by removing internal organs, the eyeballs and beak. The skin was massaged with salt for 20 minutes. Then the octopus meat was ready for cooking.

ii. Sun drying of common octopus

Sun dried gutted whole octopus is shown in plate 6.1. The equipment used for drying was usually simple, inexpensive and locally available. The raw salted and fermented octopus was spread directly on the bare ground, grass, old mats, nets, stones or raised drying racks. The process of drying octopus in the sun was greatly influenced by the size of octopus, whether gutted whole or tentacles only, and prevailing weather conditions. During hot dry periods, fermented octopus was dried within two to three days, especially if they were small species or cut pieces. Larger species took four to five days under these conditions. In the wet season, drying was very slow and extended beyond seven days in some instances. A lot of spoilage was experienced by processors during this period due to the humid conditions and rain falling onto the octopus. During the period of drying, the processors spread, carefully arranged or hanged the octopus on the drying equipments (racks, stones, ground, lines or beams). The octopuses were turned once or twice during the day for even exposure of the entire surface to sunlight. In the evenings, the semi-dry product was collected in a basket or heaped together on the drying platform and covered with polythene sheets or any suitable water impermeable material.

Plate 6.1: Sun dried gutted common octopus.

6.3.3 Industrial processing of common octopus

The results of the current study established that industrial processing of common octopus was carried out in four main industries along the Kenyan coast as detailed in table 6.3.

Table 6.3: Common octopus processing industries and their end products

Industry	Raw material	Processed product	Product form
Trans Africa Fisheries Ltd	Whole octopus	Tenderized and non tenderized frozen octopus	Gutted
Sea Harvest Ltd	Whole octopus	Tenderized and non tenderized frozen octopus	Gutted
AMCO Ltd	Whole octopus	Tenderized and non tenderized frozen octopus	Gutted
Crustacean processors Ltd	Whole octopus	Tenderized and non tenderized frozen octopus	Gutted

The industrial processing started by receiving the raw products, rolling, second washing, grading and setting, blast freezing, glazing and second weighing, packaging, cold storage and dispatching of the final product. Food safety measures were done by undertaking microbiological and heavy metals analysis.

i. Receiving of common octopus at the processing factory

The industrial processing started by receiving of octopus at the processing factory. The fresh octopuses were brought to the factory from the landing sites aboard company trucks. The trucks carried the octopuses in insulated cooler boxes bearing flaked ice. At all times the ratio of the ice to octopus in the cooler boxes was maintained at not less than 1:1. The octopuses were tied together in bundles using clean single - manila ropes. On arrival at the factory, the truck proceeded to the vehicle-washing bay where it was washed in order to get rid of any micro-organisms and soil on it. After cleaning, the truck proceeded to the entrance to the receiving area from where the cooler boxes containing the octopuses were offloaded. The cooler boxes were conveyed into the receiving area from where they were opened, the octopuses were then removed and placed into perforated plastic crates. The remnants of the ice were then disposed of.

The sorting of the octopuses with desirable characteristics from the ones with undesirable characteristics such as missing tentacles or damaged skin was done and any octopus with undesirable characteristics was rejected at this stage. The rejects were put in a bin specific for this purpose ready for disposal. This was followed by first weighing. This process also took place on a stainless steel table in the receiving area. The octopuses were weighed on a calibrated weighing scale and their weights recorded. The weighed octopuses were then put in perforated plastic trays ready for washing. The first washing was done on a stainless steel table in the receiving area. The octopus were individually washed under chilled running water to remove any soils on them. Care was taken to ensure that all the tentacles, in particular, were thoroughly scrubbed and rinsed. After washing the octopuses were put in clean perforated plastic trays and conveyed into the processing area. Gutting was the next process and was conducted on a stainless steel table in the processing area by trained personnel. The belly of the octopuses were slit manually using a sharp stainless steel knife. The gut was then turned inside out in order to release their contents in one piece. The operation was conducted under chilled running water which was used to simultaneously clean the octopuses in order to ensure that they were not tainted with foreign matter or the ink.

ii. Rolling of octopus in sodium chloride solution

This process was only performed during the processing of tenderized octopus. A 2.5 % sodium chloride solution was prepared by dissolving 2.5 kg of salt in 100 litres of chilled water in a stainless steel tank. The salt solution enabled the octopus to curl effectively and also substantially reduce the microbiological load in the octopus. The solution was then poured into the tumbler together with flake ice, 125 kg (or less) of the octopuses was added and the lid tightly closed. The machine was then switched on and left to roll for 30 minutes. After one cycle, the tumbler was emptied and cleaned in readiness for the next cycle of curling.

iii. Second washing, grading and setting of octopus to give them flower shape

The curled octopuses were individually washed under chilled, running, potable water to remove all traces of foams and then placed in clean plastic trays. The octopuses were then graded according to their individual sizes. The curled octopuses were then set onto blast freezing trays to give them the shape of a flower. This improved the appearance of the octopuses and gave them a higher appeal. The trays were then taken into the blast freezer.

iv. Blast freezing, glazing and second weighing of octopus

The freezing trays holding the octopuses were then placed inside the preset blast freezer and arranged in the freezing shelves in a manner that freezing was spread uniformly. The blast freezer had a dial temperature gauge for efficient monitoring of temperature changes and it could freeze a product up to a core temperature of -25 ºC within 8 hours. By the time the product was removed from the blast freezer its core temperature was -18 °C or below. This process took place in a stainless steel glazing tank in the processing area. The octopuses were then immersed in chilled potable water for a period of 1 minute and then removed. By this time the octopuses had formed a thin uniform coat of ice around them. The glazing water was changed after every 200 kilograms of glazed product. The octopuses were weighed on a calibrated weighing scale and their weights recorded. The weighed octopuses were then put in perforated plastic trays ready for packing into polythene bags.

v. Packaging, cold storage and dispatch of finished products of octopus

The octopuses were packed into 15 kg polythene bags according to their grades. The polythene bags bearing the product were then packed into 15 kg waxed master cartons. The cartons had labels containing the necessary information pertaining to the batch number, date of production, species (common name) and the permanent reference number. The octopuses packed in strapped labelled waxed master cartons were then passed on into the cold store. The temperature of the cold store was set at -20 ºC and the temperature variations were monitored both manually at an hourly frequency and by the use of a thermograph. The final frozen products were dispatched in a clean, tested and pre-chilled reefer container after completing all the necessary formalities pertaining to documentation. When offloading products, the container was placed with the door facing the down-wind side to prevent heat gain. The loaders were in clean gear and absolute care was taken to protect the packages from contamination, time and temperature abuse.

vi. Product sampling for microbiological and heavy metals contamination

A random product sample for microbiological and heavy metals analysis was taken from the consignment of products by officers from the State Department of Fisheries quarterly and submitted to an accredited laboratory for microbiological and heavy metals analysis to confirm the efficiency of the Quality Management System. The parameters analysed included: total plate count at 37 °C, total coli form counts, *Escherichia coli*, *Staphylococcus aureus*, *Salmonella species*, *Vibrio parahaemolyticus*, lead, cadmium and mercury.

vii. External verification and certification of compliance of octopus products

For external verification, the State Department of Fisheries was the Competent Authority (CA) for the purposes of verifying and certifying compliance of octopus products. The CA was responsible for the external verification of octopus industry's Hazard Analysis at Critical Control Points (HACCP) System. Local inspectors inspected the establishment once a month. National inspectors also inspected the establishment at lest once in a year. Reports of both the local as well as the national inspections are filed and acted upon. The common octopus industrial processing flow diagram is shown in figure 6.1.

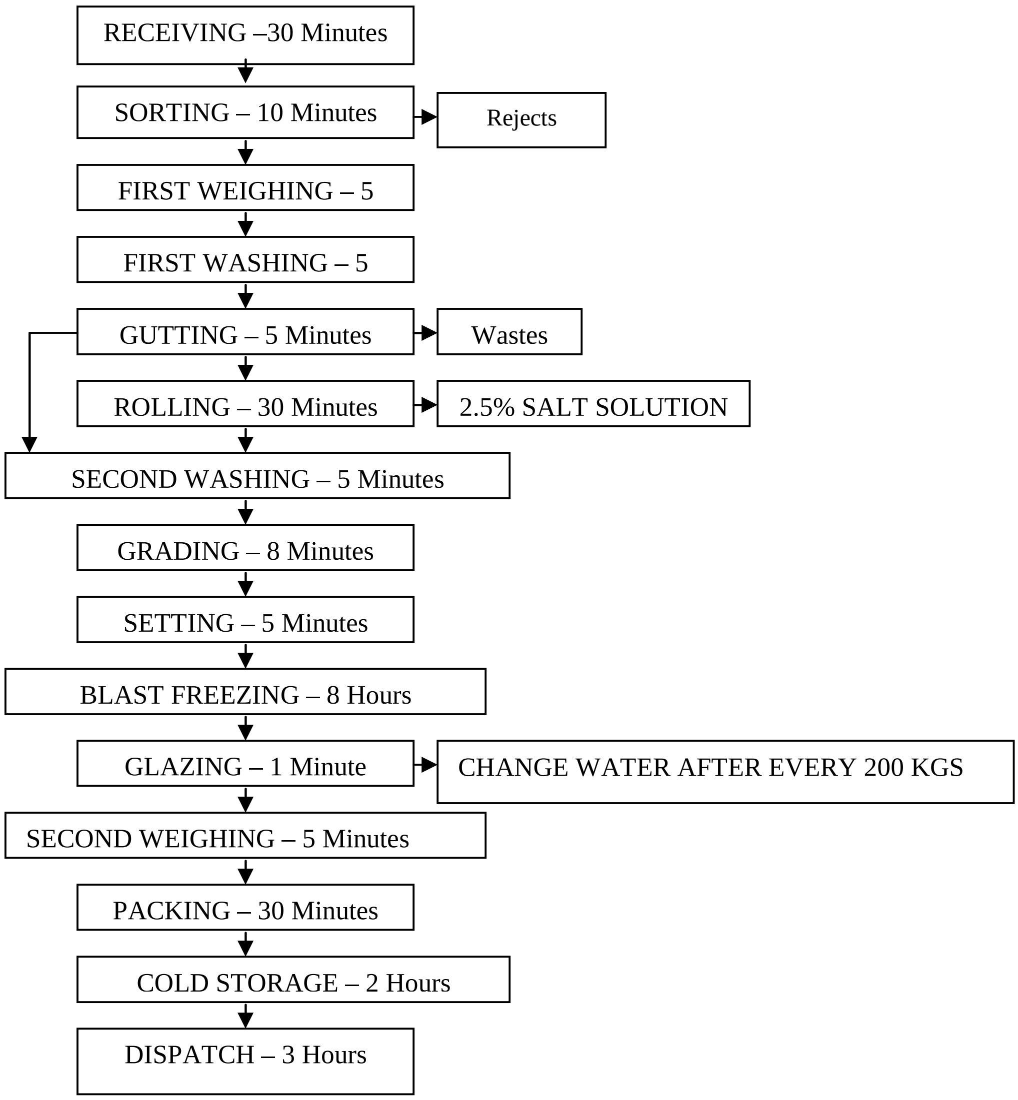

Figure 6.3. Flow diagram of an octopus-processing line.

6.3.4 Marketing of common octopus

i. Local markets for common octopus

The retailing of common octopus was done in urban open-air markets displayed as shown in plate 6.2. In most cases, octopus was sold directly on the beach to local traders and industrial octopus processor agents. The agents bought octopus that met the processors' criteria (e.g., size, freshness). Lower quality grade octopuses were sold to a number of successive intermediaries along the supply chain: collecting traders, regional traders, wholesalers, and retailers. The prices were highly dependent on the level of supply and demand. The selling price of common octopus by artisanal fishermen fluctuated from Ksh 80.00 per kg to Ksh 160.00 per kg (selling price for the artisanal fishermen to middlemen) depending on the prevailing market circumstances. The selling prices for the middlemen also fluctuated from Ksh 160.00 per kg to Ksh 280.00 per kg (selling price for the middlemen to the industry owners).

Plate 6.2: Display of marine products among them common octopus at an open air market in Likoni open air market – Mombasa.

ii. International markets for common octopus

The prices, size ranges and product forms of common octopus sold in the European Union markets (Italy, Spain, France and Portugal) are presented in table 6.4. Gutted common octopus was generally graded into different sizes and sold frozen. Different grades (sizes) fetched different prices. The processing industries exported the frozen octopus to the international markets. Markets for common octopus existed in various countries although the EU region was the main market for Kenyan octopus products.

Table 6.4: Examples of the grades, sizes and prices in United States Dollars (USD) and Kenyan Shillings (Ksh) of common octopus sold in European Markets from Kenya (exchange rate for 1 USD is Ksh 89.00).

Grade	Weight per piece (g)	Price (USD/kg)	Price (Ksh/kg)
T9	<300	4.5 USD	382.50
T8	300 – 500	5.0 USD	425.00
T7	501 – 800	5.5 USD	467.50
T6	801 – 1200	6.0 USD	510.00
T5	1201 – 1500	6.5 USD	552.50
T4	1501 – 2000	7.0 USD	595.00
T3	2001 – 3000	7.5 USD	637.50
T2	3001 – 4000	8 USD	680.00
T1	>4000	8.5 USD	722.50

6.4 Discussion

6.4.1 Common octopus catches

The current study showed a gradual decreasing trend of octopus catches as well as CPUE during the two-year sampling period. The decreasing trend of both catches and CPUE was an indication that the octopus fishery may have been under a high fishing pressure. Similar studies by Sauer et al. (2011) in Rodrigues, Western Indian Ocean, showed that the total catch of octopus dropped substantially between 1994 and 2008. During that period, however, there was an increase in CPUE, which was as a result of an increase in the time spent fishing by individuals on a daily basis, as both the total catch and number of fisher-days decreased. In the current study however, there was a gradual decrease in octopus catches an indication that the octopus fishery was under high fishing pressure. The clear spike in both catches and CPUE, noted during the Northeast monsoon seasons in the current study, may have been due to favourable fishing conditions witnessed during the season. Sampling was also undertaken during the two main monsoon seasons. The Northeast monsoon, from November to February is characterized by gentler winds from the northeast and sunny, dry conditions associated with easy fishing. The Southeast monsoon from May to August is dominated by strong winds off the ocean from the southeast, with rough seawater conditions and frequent rain, claimed to cause difficulties in fishing.

6.4.2 Traditional processing of common octopus

The current study established that sun-drying is the main, yet an important step in the traditional method of octopus processing in Kenya. Octopus was sun dried to reduce water content and therefore slow down or stop growth of micro-organisms responsible for fermentation or spoilage. Drying was in most cases combined with salting to reduce the moisture content to sufficient levels that could ensure a longer shelf-life. The period taken for sun-drying depended on the size of the octopus being sun dried. Big octopus took two to three days while small ones took a day or so depending on the day's weather conditions. The shelf-life for a well dried octopus was six months to one year. The sun drying process in Kenya is comparable to what Ioannis and Theodoros (2007) described in Greece. They showed that sun drying of octopus in Greece was not only done for preservative purposes but also for the great taste associated with sun dried octopus. Octopus was hanged up in the air and in the sun to dry out for at least a day before cooking it. According to Napoleaõ et al. (2005a), the sun drying method of octopus has been in use for centuries following the discovery that it was better to dry octopus before grilling it. Having such a strong sun during summer in Greece, it was the easiest and cheapest method. Fishermen would leave octopus out to dry the whole day and then cook it in the evening (Ioannis & Theodoros, 2007).

However, during the current study, it was observed that some activities, which were undertaken during the traditional sun drying and salting, could amount to health risks to consumers, processors and the environment. These activities related to octopus gutting, washing, salting/fermentation, drying and waste disposal as well as the use of poor quality salt and curing containers. For example, during gutting process, it was observed that in some cases, octopus was placed on dirty containers. This practice could cause microbial contamination of the octopus. During the washing process, it was also noted that clean piped water was often not available in most cases. Therefore, water from the sea was used to wash the octopus. The sea water is often polluted by domestic waste, making it a possible source of chemical and microbial poisoning. It was also proven that during the drying process, lack of use of salt could result in uncontrolled fermentation. Under such conditions, the octopus muscles may become ideal for growth of pathogenic organisms and the product may decay within a short period. Such products could pose a health hazard to consumers. It was also noted that reuse of salt may also lead to contamination of fresh batches of octopus with micro-organisms. During sun drying process, it was also observed that octopus was often dried on the ground except in very few occasions where raised drying racks were used. The sun drying octopuses on the ground were prone to attack by pets, rodents and house flies. Another environmental hazard that was noted with sun drying octopus was the strong offensive smell associated with fermented octopus. This was pronounced during drying as processing sites were often located near octopus landing sites.

The traditional octopus tenderizing process witnessed in the current study involved pounding the octopus flesh on hard surface (either on a rock or hard surface) to tenderize its fibres. Dipping the octopus in boiling water was also another alternative tenderizing method used in the Kenyan South coast. The octopus was boiled in a large pot of water for 30 seconds. No boiling was done any longer than that as it could destroy the flavour. The other method commonly used was placing the octopus meat in a deep freezer. According to the local people, the cold caused some of the fibrous tissue to break down and make for a more tender result. The octopus was not supposed to be left in the freezer for too long, as the desirable gelatinous tissue was bound to start to break down as well. Ideally, it was supposed to be left in the freezer for at least eight hours but less than a full day. It was also established that tenderizing and cooking processes for octopus, were almost synonymous. Octopus was allowed to cook in an oven for a few hours. The slow cooking time was meant to tenderize the meat as it got cooked; its natural juices were released to enhance the flavour. The octopus tenderizing processing witnessed in Kenya was similar to what is happening in many parts of the world as Seixas et al. (2005) found out that in Greece, Spain, Italy and Japan, salting was essential in helping to induce tenderness of octopus. They also found out that brief dips in boiling water also helped tenderize octopus, or long slow cooling, or the addition of a wine cork to the cooking liquid.

6.4.3 Industrial processing of common octopus

The current study established that Kenyan octopus processing industries were compliant to internationally accepted industrial procedures. The octopus internationally accepted industrial processing procedure as described by Ioannis and Theodoros (2007) requires that at the factory, frozen whole common octopus undergoes receiving, sorting, first weighing, first washing, gutting, rolling, second washing, grading, setting, blast freezing, glazing and second weighing before packing the final product. According to Aguado-Gimenez and Garcia-Garcia (2005), octopus industrial processing must put in place appropriate food safety systems which ensures supply of safe and high quality octopus products.

The food safety system operates under Hazard Analysis at Critical Control Points (HACCP) principles and Sanitation Standard Operating Principles (SSOP) (Seixas et al. 2005). HACCP is widely accepted as a voluntary control programme in the food industry, and is now a prescribed part of meat and poultry slaughter in the US, and is required during processing of seafood and juices as well (Aguado-Gimenez & Garcia-Garcia, 2005). There can hardly be HACCP without Good Manufacturing or Management Practices (GMP) (Aguado-Gimenez & Garcia-Garcia, 2005).

In most octopus processing industries, the food safety system has incorporated ISO 22000:2005 Food Safety Management Systems, to ensure that all their products meet and exceed their consumer food safety and quality expectations at all times (Seixas et al. 2005). Quality Management System must be reviewed periodically to correspond to the dynamism brought about by the need to improve in the quality of products in compliance with International Standards (Aguado-Gimenez & Garcia-Garcia, 2005). The current study established that Hazard Analysis and Critical Control Points (HACCP) was a systematic preventive approach which was practiced in all octopus processing industries in Kenya to ensure food safety and allergenic, chemical and biological hazards in production processes that could cause the finished product to be unsafe, and was used to design measures to reduce these risks to a safe level. The HACCP system was also used at all stages of octopus production and preparation processes including packaging and distribution. This method, which in effect seeks to plan out unsafe practices based on science, differed from the traditional "produce and sort" quality control methods that do nothing to prevent hazards from occurring and must identify them at the end of the process. The main disadvantage of the HACCP system was that it focused only on the health safety issues of a product and not in the quality of the product.

According to Kreuzer (1984), new institutions have also emerged to implement the additional regulations required for exporting octopus. The octopus industry is now governed directly by at least six sets of standards operated through several national agencies and the European Union (EU), the latter having the most significant regulations on the fisheries sector (Aguado-Gimenez & Garcia-Garcia, 2005). The regulations are based on HACCP principle, and define the practices governing octopus production, handling, packaging, and transporting of fishery products destined for EU. It also imposes strict standards regarding construction of buildings, equipment, purification tanks, storage tanks intended for holding octopus prior to export, on-premises laboratories, strict record keeping, and accurate labelling are other requirements (Kreuzer, 1984). The current study has established that some local institutions in Kenya, such as the Kenya Bureau of Standards (KEBS), also implement additional regulations in governing octopus production, handling and packaging. KEBS coordinates all activities concerning the development and implementation of both local and international standards relevant to Kenya. Food standards applied in Kenya can be categorized as either mandatory or voluntary. Mandatory standards are set by the State Department of Fisheries in the form of regulations, which include technical requirements such as testing, certification and labelling. Voluntary standards, on the other hand, are set through formal coordinated approaches of key stakeholders in the supply chain (business associations, NGO initiatives or are developed and monitored by individual companies). These include some of the standards observed by associations such as Kenya Fish Processors and Exporters Association (AFIPEK). The voluntary standards are not legally mandatory but some (ISO 9000 standards for quality management) have become de-facto mandatory standards. They are required when producers want to compete in international markets.

The current study established that sales of domestic octopus products in modern retail outlets such as supermarkets were limited. A small percentage (<10 %) of octopus products were sold in open air markets/fish markets and the rest in sea food restaurants and hotels. This is contrary to a study done by Howgate et al. (1992) in South Africa, who found out that common octopus, was generally consumed locally. A very small local market existed for the common octopus in Kenya.

The current study established that there was readily available market for common octopus internationally. The major export market for common octopus in Kenya is the EU region and then the emerging markets of Asia (Dept of Fisheries, 2012a). According to Kenya Tropical Sea Life, an ornamental fish exporter, there is untapped market for ornamental marine organisms to United States of America and China. This is in agreement with other studies by Oosthuizen (2003), in South Africa, who found out that the European Union markets were the most dominant export markets for common octopus.

6.5 Summary and conclusions

This part of study was aimed at describing the fishery, processing and marketing of common octopus in the Kenyan South coast where the species has a high demand, commands high prices and supports artisanal as well as industrial fisheries. Relative abundance indices (CPUE) were estimated using standardised techniques described by Muthiga and McClanahan *(*1987). Artisanal fisheries information on the average catch and the number of days an individual spent fishing in each month was examined based on logbook records of octopus landings from the fishermen. A questionnaire was used to collect information on industrial and traditional value addition processes as well as to get information on both local and international marketing processes of common octopus. The CPUE results showed that common octopus landings were highly influenced by seasonal variation (NEM and SEM) in the Kenyan South coastal waters. The high landings recorded during the NEM were attributed to favourable fishing conditions witnessed during the season. The study also established that the traditional value addition processes recorded in the Kenyan South coast involved pounding of the flesh of octopus on hard surface to tenderize its fibres and sun drying of gutted whole octopus or the tentacles. The industrial processing of octopus involved the use of appropriate food safety systems which ensured supply of safe octopus products - tenderized and non tenderized frozen octopus. The main disadvantage of the food safety systems was that, it was only focused on the health safety issues of the product and not in the quality of the product. The current study established that there was readily available market for common octopus internationally but very small locally. The major export market for common octopus in Kenya was the EU region and then the emerging markets of Asia. To minimise the level of contamination during processing of common octopus by local communities, this study recommends that i) drying of octopus should be done on raised racks ii) when drying octopus on ground, octopus should always be spread on a clean mat iii) no overlapping of octopus during drying and iv) nets and screens should be used to protect octopus from pets, rodents and house flies during sun drying. To promote local market, this study recommends an “Eat more octopus campaigns” to sensitize locals on importance of octopus products.

CHAPTER 7: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 General Discussion

The main aim of this study was to determine the fishery, reproductive biology, food and feeding habits of common octopus in the Kenyan South coast. This was the first time such a study has been conducted in the Kenyan coast and the study specifically focused on; determining the growth and temporal distribution of common octopus, determining the reproductive biology of common octopus, determining food and feeding habits of common octopus and establishing of value addition and marketing processes of common octopus.

The current study was able to establish that octopus fishing industry in Kenya plays a vital role in the national economy as it is a substantial export resource and a foreign exchange earner. The amount of octopus exploited has been steadily increasing. Over a twenty-two year period from 1990 to 2012, the yearly octopus catch increased from a total of 79 metric tonnes valued at Ksh 1,047,000.00 to 394 metric tonnes valued at Ksh 49,402,000.00 (Dept of Fisheries, 2012b). The study also established that fishing of octopus at the Kenyan South coast was predominantly done by artisanal fishermen and it was concentrated only in the intertidal zones.

The most commonly used octopus fishing gear is the spear/harpoon. However other gears such as pointed sticks are also used to a lesser extent. Octopus fishing is either done on foot or by use of small non-powered or powered boats. The study established that only about 10 % of the fishing boats are powered, a factor that leads to most of fishing effort being concentrated only in the intertidal zones and rarely was fishing undertaken beyond territorial waters – 20 km (Dept of Fisheries, 2012a). Hence, the subtidal resource of this species in the Kenyan coast is virtually unexploited. The study also established that the main laws governing octopus fishing activities in Kenya are contained in the Fisheries Act Cap 378 (Revised 2005). Under the Act, the State Department of Fisheries is the Government authority charged with the responsibility of regulating commercial and artisanal fishing in Kenya's waters. It is mandated to oversee the development, management, exploitation, utilization, and conservation of the Kenyan fisheries resources.

The current study also addressed numerous knowledge gaps in the growth and temporal distribution of common octopus. The most important of those findings was demonstrated by the dorsal mantle length (DML) class size frequency distribution which showed that females in both Shimoni and Vanga were growing longer in size than males. This was further supported by the measurements of the longest individuals in Shimoni and Vanga which were 24 and 20 cm for females and 17 and 18 cm for males, respectively. The monthly mean DML distribution showed a decreasing trend over the two-year sampling period thus verifying the fact that octopus fishery was under high pressure. The monthly BW class size frequency distribution results showed that in most class sizes, females were more abundant than males and the gradual decreasing trend in the monthly mean BW distribution was evident that the resource was experiencing high fishing pressure.

The condition factor (K) analysis was done to determine the spawning season of common octopus. Although the condition factor results alone can not give a definite answer to the spawning periods of common octopus, it was found to be a very important indicator of the peak spawning months of the species. This was based on the low (K) values recorded during the months of June, July and August, which were attributed to females shedding their eggs. By combining the results of the condition factor (K) analysis with that of monthly demographic structure, which showed two or more distinct cohorts per month, the breeding process of common octopus seemed to be taking place through-out the year with a peak in the months of June to August.

The importance of sex ratio information was best demonstrated in the investigation between male and female predominance. The predominance of males during the months of July and August in the common octopus population may have been an indication that females had disappeared from fishing grounds for breeding purposes. Mangold-Wirz (1963) pointed out that nesting females never went out of their nests and were therefore inaccessible to fishing. This, combined with the information gathered from the monthly evolution of maturity stages of common octopus which showed that mature females in stage III were recorded in all months except in the months of June to August, could suggest that majority of mature females were in their nests spawning. A notable increase in spent females was also recorded in the months of November and December, a sign of post spawning season. Further investigations in the Gonadosomatic Index showed that, low GSI values were witnessed during the months of August and September which may have been an indication of the end of the spawning period. The combination of all these results may also give an indication that common octopus in the Kenyan South coast spawn all the year round with peak season experienced during the months of June to August.

The present study demonstrated that the high numbers of empty stomachs recorded in the months of September, October and December may have been as a result of the breeding behaviour of common octopus. This is based on the investigations that higher numbers of empty stomachs were recorded in the larger length classes – composed of mature individuals - an indication of post-spawned individuals.

The stomach content analysis indicated that seasonal variations had no influence on common octopus diet and feeding behaviour. Further investigation in the stomach content analysis by length class established that common octopus with bigger dorsal mantle lengths class sizes were found to have ingested crustaceans (crabs) in large quantities, an indication that the nature of food ingested by the species was apparently size dependent.

The catch per unit effort (CPUE) data was analysed to determine patterns of fishing pressure of common octopus in the Kenyan coast. The gradual decreasing trend of both octopus catches and CPUE from November 2010 to November 2012 indicated that the fishery was under high fishing pressure. The high catches and CPUE values recorded during the Northeast monsoon season was attributed to the favourable fishing conditions experienced during that period while the unfavourable fishing conditions experienced during the Southeast monsoon season was attributed to the low CPUE recorded during the period. Hence, it was clear that seasonal variations highly influenced octopus catches within the Kenyan South coast.

The information gathered from octopus catches and CPUE analysis was evident that octopus fishing activities in the Kenyan South coast are highly driven by external markets. This was witnessed in the last three months of sampling – September, October and November 2012 when the prices of octopus products in the European markets were very low. As a result, all common octopus processing industries stopped processing and exporting octopus. The situation was worsened by the fact that all the local octopus processing industries do not undertake any canning of processing octopus, meaning that their export products can not be stored for long. These eventually affected artisanal octopus fishing activities along the entire Kenyan South coast as many fishermen, who were engaged in octopus fishing, stopped fishing and turned into other activities as there were very little local markets for octopus.

This study has provided comprehensive scientific information on the growth and temporal distribution of common octopus by examining the length-weight relationships, growth and condition factor. In reproductive biology, information has been documented on sex ratio, size at sexual maturity, maturity stages of gonads, Gonadosomatic index (GSI) and fecundity estimates. Stomach fullness indices and stomach contents analysis was done to establish diet and feeding habits of common octopus. An insight on the fishery of common octopus was done by analysing the catches, catch per unit effort, processing and marketing of octopus products. All these combined gave a clear picture of the fishery, reproductive biology, food and feeding habits of common octopus on the Kenyan South coast.

7.2 Conclusion

The dorsal mantle length (DML) class size frequency distribution results showed that females were more abundant than males in most class sizes. The (BW) class size frequency distribution results showed that in most class sizes, females were more abundant than males. The monthly mean DML distribution showed a decreasing trend over the two year sampling period. The same phenomenon was also witnessed in the monthly mean BW distribution which showed a gradual decreasing trend, an indication that common octopus was under high fishing pressure. According to Norman (2000), in heavily fished areas both size and weight of octopus is often low, and reproductive output may already be affected. The condition factor (K) analysis indicated that the peak breading season of common octopus in the Kenyan South-coast was on the months of June to August.

Sex ratio results showed predominance of males during the months of July and August which might have been an indication that females had disappeared from fishing grounds for breeding purposes. The monthly evolution of maturity stages results showed that mature females in stage III were recorded in all months except in the months of June to August which might have been an indication that majority of mature females were in their nests spawning. A high number of spent females were recorded in the months of November and December which might have been as a result of post-spawning season. The gonadosomatic index results showed low values during the months of August and September might have been an indication of the end of the spawning period. Following all these findings, this study concludes that common octopus in the Kenyan South-coast spawn all the year round with peak season experienced during the months of June to August.

The results of the current study have shown that common octopus preferred crustaceans (mostly crabs) to other diets and its diet preference was not influenced by seasonal variations. The stomach content analysis by size groups established that common octopus of larger size groups were found to have ingested crustaceans (crabs) in large quantities, an indication that the nature of food ingested by the species was somehow size dependant. The high numbers of empty stomachs recorded during the months of September, October and December was linked to the starving behaviour of common octopus during breeding season. The high number of empty stomachs recorded in individuals of large size groups was also attributed to starving post-spawned individuals.

The CPUE results showed that common octopus catches were influenced by seasonal variation (NEM and SEM) in the Kenyan South coast. The high landings recorded during the NEM were attributed to favourable fishing conditions witnessed during the season. This study also established that the traditional value addition processes recorded in the Kenyan South coast were mainly pounding and sun drying. The process was easy and cheap although it was unhygienic. The octopus industrial processing plant operated two main lines; the tenderized frozen octopus line and the non tenderized frozen octopus line. The process adhered to international health safety standards although there was very little focuses on the quality of the product. The current study established that there was readily available market for common octopus internationally but very small locally.

7.3 Recommendations

7.3.1 Future studies

i. The current study was confined to the Kenyan South coast and as such, future studies on biology and fishery of common octopus can be done in the entire Kenyan coast.
ii. The current study focused on temporal distribution of common octopus, further studies can be done on the species spatial distribution in the Kenyan coast.
iii. In terms of food and feeding habits of common octopus, the current study did not cover the planktonic stage (young stage). Therefore, there is need for future studies on food and feeding habits of the panktonic stage of common octopus at the Kenyan coast.

7.3.2 Management and policy actions

Based on the monthly evolution of maturity stages results, this study recommends a closed season during the peak spawning season of common octopus. The size at first maturity results makes this study recommend a ban on collection of immature octopus (less than 10.8 cm DML). To minimise the level of contamination during processing of common octopus by local communities, this study recommends that relevant authorities (State Department of Fisheries and the Public Health) should ensure that the community observes very high hygiene during the processes. To promote local market, this study recommends an "Eat more octopus campaigns" to sensitize locals on importance of octopus products. This study also recommends that the relevant Government institutions should use the scientific information gathered during this study in informing policy directions and the management of octopus in Kenya.

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Appendix I: Data collection sheet

Data collection Sheet

Landing Site_____________________________Date__________________________________

No.	Date	Area fished	Sex	Body Weight (g)	Total length (cm)	Dorsal Mantle length (cm)	Ventral Mantle length (cm)	Ovary/testis weight (g)

Appendix II: Tide table

High-Low Predictions for Mombasa *(by SLPR2 Software)*

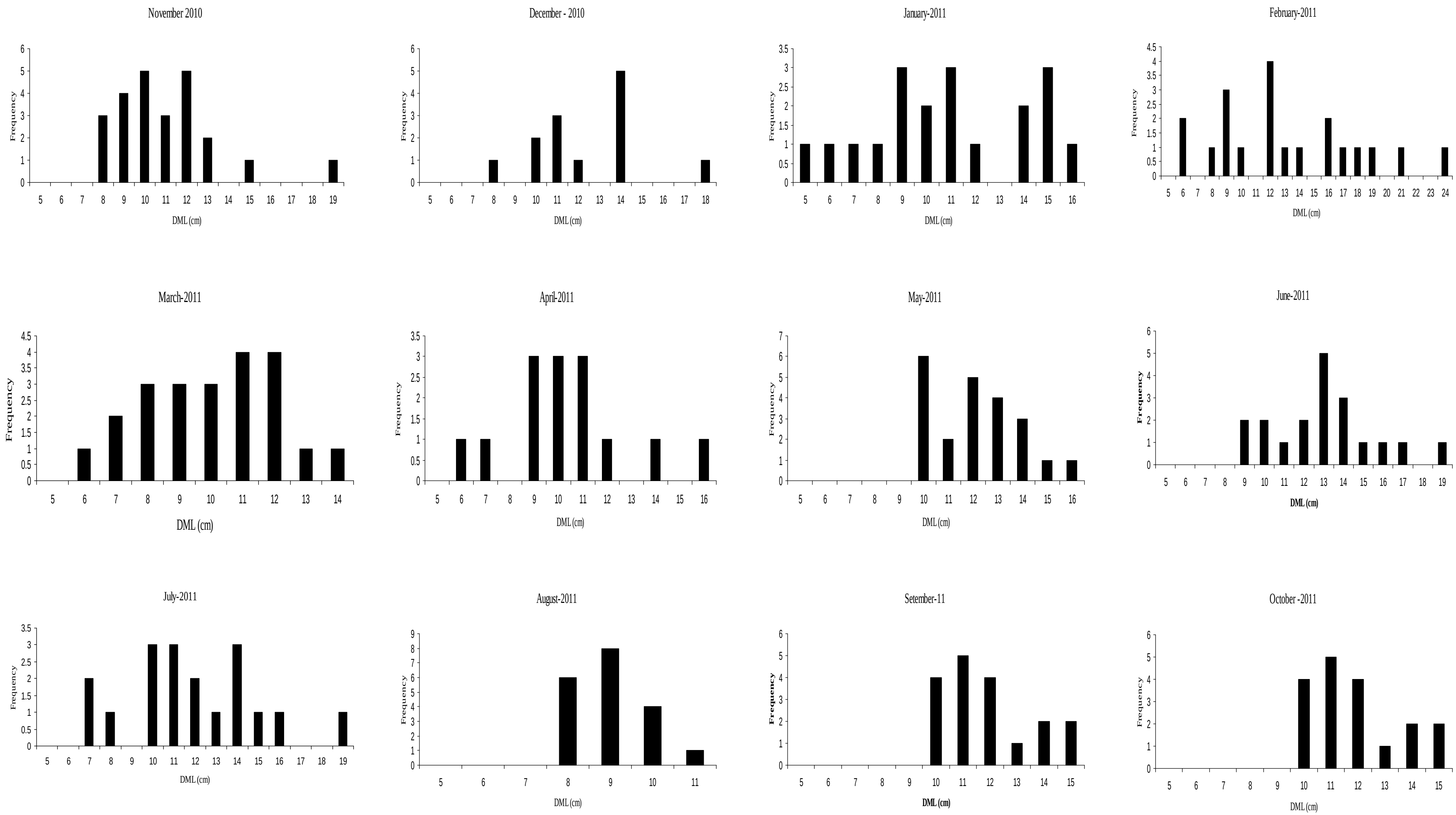
DECEMBER 2010

HL	DATE		TIME	HGT	TIME	HGT	TIME	HGT	TIME	HGT
1	1	12	0609	1.10	1216	2.53	1815	0.97	0054	3.09
1	2	12	0723	0.86	1330	2.61	1919	0.87	0153	3.31
1	3	12	0821	0.62	1430	2.74	2014	0.74	0244	3.49
1	4	12	0910	0.41	1520	2.87	2103	0.62		--
0	5	12	0329	3.61	0953	0.27	1604	2.97	2147	0.53
0	6	12	0412	3.66	1033	0.21	1645	3.02	2229	0.50
0	7	12	0452	3.64	1111	0.22	1723	3.04	2308	0.52
0	8	12	0529	3.56	1148	0.30	1759	3.01	2346	0.61
0	9	12	0604	3.41	1223	0.41	1835	2.96	0023	0.74
0	10	12	0638	3.23	1258	0.55	1912	2.88	0102	0.91
0	11	12	0713	3.02	1333	0.72	1951	2.79	0144	1.10
0	12	12	0750	2.79	1411	0.89	2035	2.70	0235	1.27
0	13	12	0833	2.57	1454	1.07	2130	2.62		--
1	14	12	0339	1.41	0931	2.35	1549	1.21	2238	2.59
1	15	12	0503	1.45	1053	2.21	1659	1.30	2356	2.65
1	16	12	0632	1.35	1225	2.20	1815	1.29	0103	2.79
1	17	12	0740	1.15	1338	2.29	1919	1.20	0155	2.97
1	18	12	0829	0.92	1432	2.44	2011	1.06	0240	3.16
1	19	12	0910	0.70	1515	2.60	2055	0.91		--
0	20	12	0320	3.35	0948	0.51	1554	2.77	2136	0.75
0	21	12	0359	3.50	1024	0.36	1632	2.91	2215	0.63
0	22	12	0437	3.62	1100	0.26	1709	3.03	2253	0.54
0	23	12	0516	3.67	1136	0.22	1746	3.12	2333	0.51
0	24	12	0554	3.65	1213	0.23	1826	3.17	0015	0.54
0	25	12	0634	3.54	1251	0.30	1907	3.18	0059	0.64
0	26	12	0715	3.34	1331	0.42	1952	3.15	0149	0.79
0	27	12	0800	3.08	1413	0.59	2041	3.08	0246	0.96
0	28	12	0852	2.77	1502	0.78	2140	2.99		--
1	29	12	0357	1.12	0958	2.48	1602	0.98	2253	2.92
1	30	12	0527	1.17	1128	2.29	1720	1.12	0017	2.93
1	31	12	0702	1.06	1307	2.29	1847	1.12	0133	3.05

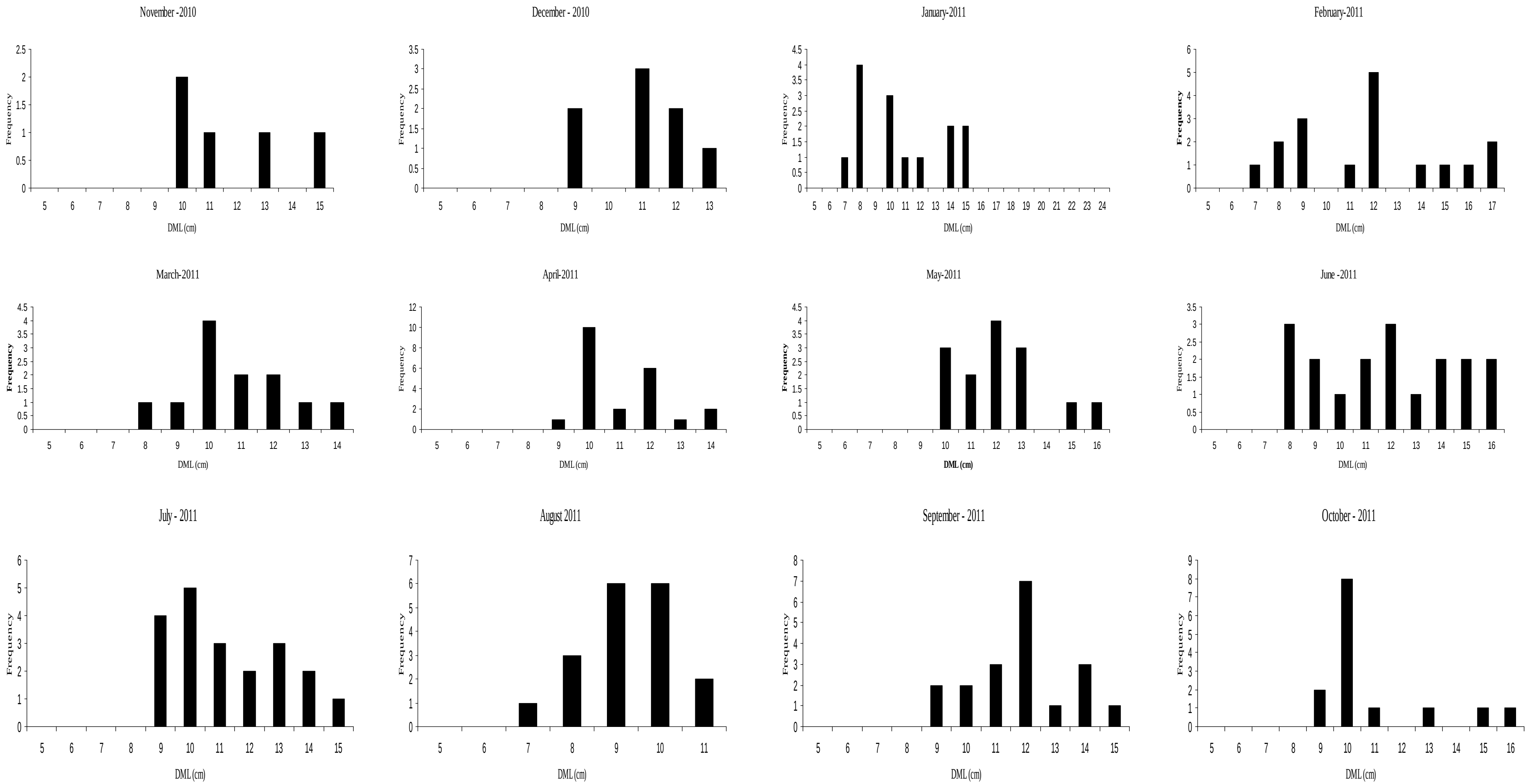
0 – Spring tide
1 – Neap Tide

Height in metres

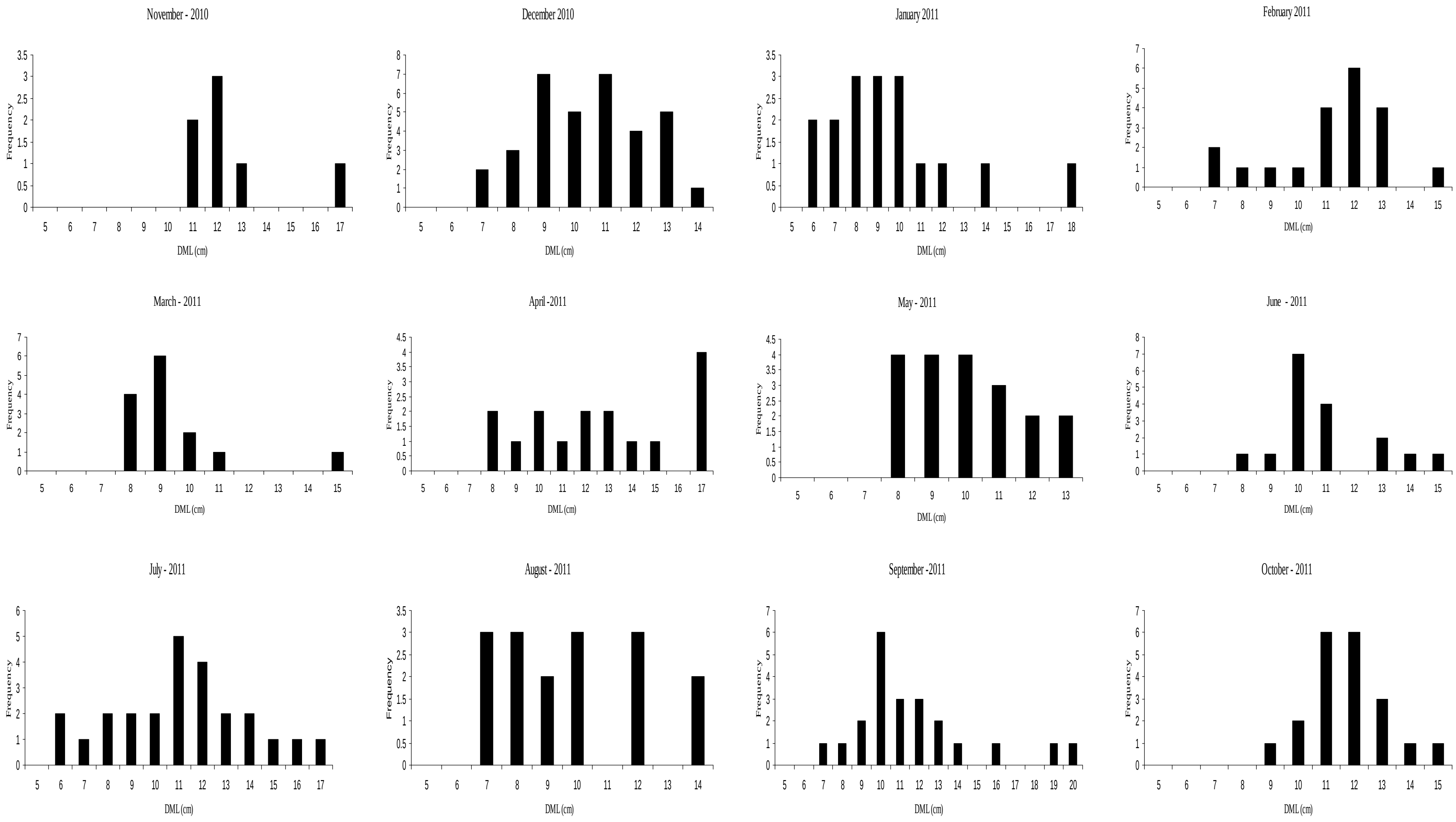
Appendix III: **Demographic structure of female *Octopus vulgaris* from Shimoni.**



Appendix IV: Demographic structure of male *Octopus vulgaris* from Shimoni.



Appendix V: **Demographic structure of female *Octopus vulgaris* from Vanga .**



Appendix VI: Demographic structure of male *Octopus vulgaris* - Vanga.