GENETIC DIVERSITY AND POPULATION ABUNDANCE OF THE WILD PENAEID SHRIMPS OF MALINDI–UNGWANA BAY IN KENYA: IMPLICATIONS FOR AQUACULTURE AND CONSERVATION

RASHID MOHAMED KAKA, BSc. Fisheries (Moi); MSc. Aquaculture (Ghent)

A THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN ANIMAL GENETICS AND BREEDING

DEPARTMENT OF ANIMAL PRODUCTION
FACULTY OF VETERINARY MEDICINE
UNIVERSITY OF NAIROBI

2020

DECLARATION

This thesis is my original work and has not been presented for an award of a degree in any other University.

Rashid Mohamed Kaka, MSc. Aquaculture (Ghent); BSc. Fisheries (Moi)

Signature: ………………………………………………………..   Date: 7th August, 2020

This thesis has been submitted with our approval as University Supervisors:

Signature: ………………………………………………………..   Date: 8/08/2020

Prof. Joseph Owino Jung'a, PhD

Department of Animal Production, University of Nairobi

Signature: ………………………………………………………..   Date: 9/8/20

Prof. Mohamed Badamana, PhD

Department of Animal Production, University of Nairobi

Signature: ………………………………………………………..   Date: 7/8/2020

Dr. Harrison Charo Karisa, PhD

WorldFish Egypt and Nigeria, Cairo, Egypt

DEDICATION

To my dearest and loving wife, Madina Juma and our children Daa Halima, Yasmin, Ishi and Rahma for their care, love and support.

To my mother, Daa Halima Shillingi Akida for her indebted support, love and continued prayers.

Lastly, to my late father, Mohamed Abdalla Kaka for his inspirational advises and encouragements in undertaking this glorious path of honour.

ACKNOWLEDGEMENTS

First and foremost, I am forever grateful to the Almighty Allah for guiding and giving me strength to come this far in my education.

I sincerely feel grateful to my supervisors Prof. Joseph Owino Junga, Prof. Mohamed Badamana and Dr. Harrison Charo Karisa for the much tireless support, guidance, patience and encouragement throughout my research period.

I would like to thank Dr. Renison Kahindi Ruwa of the Kenya Marine and Fisheries Research Institute (KMFRI) for allowing me to collect my samples during the shallow water trawling surveys for shrimps. I would also like to acknowledge Prof. Shaukat Abdulrazak for his unequivocal advice and guidance in pursuing my research.

I express my sincere gratitude that this research was carried out with assistance from the National Council for Science and Technology (NACOSTI) of Kenya, Grant No. NCST/5/003/2nd CALL PhD/38. Similarly, I am also grateful to the Southwest Indian Ocean Fisheries Project (SWIOFP) for supporting the shallow water trawling surveys for shrimps under component 2 on Crustaceans.

Last but not least, I feel indebted to Collins Ndoro and Dixon Odongo, for their great helps during the collection of data and samples. Special thanks to Hamisi Mlalanaro for his unconditional assistance in the laboratory.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

PAGE

LIST OF ABBREVIATIONS AND ACRONYMS

ACD	Agglomerative Cluster Dendrogram
ANOVA	Analysis of Variance
BL	Body Length
BW	Body Weight
CL	Carapace Length
DFA	Discriminant Function Analysis
FAO	Food and Agriculture Organization of the United Nations
K	Fulton's condition factor
KMFRI	Kenya Marine and Fisheries research Institute
MSY	Maximum Sustainable Yield
NEM	Northeast monsoon season
L_{50}	Length at first maturity
PCA	Principle Component Analysis
PFMP	Prawn Fishery Management Plan 2010
SEM	Southeast monsoon season
SSB/R	Spawning Stock Biomass per Recruitment
SWIOFP	Southwest Indian Ocean Fisheries Project
TL	Total Length
UNDP	United Nations Development Programme

ABSTRACT

Penaeid shrimps have recently become one of the most valuable fishery resources in Malindi–Ungwana Bay in the north coast of Kenya that resulted to the adoption of a Prawn Fisheries Management Plan 2010. The genetic diversity and population abundance of penaeid shrimps were studied based on morphometric length–weight relationships during monsoon seasons in 2011 from Malindi–Ungwana Bay with southeast monsoon (SEM) being cooler than northeast monsoon (NEM). A total of 1364 penaeid shrimps were randomly collected from the four main artisanal fishing areas in the estuaries and two other areas within the shallow waters trawling grounds. In the estuaries, sampling was done using a 25.4 mm stretched mesh size seine net, while in the shallow waters' trawling grounds, a 70 mm mesh size towing net was used onboard the trawler. *Fenneropenaeus indicus* was the most abundant species with a relative proportion of 30.8%, followed by *Metapenaeus monoceros* (24.9%), *Penaeus semisulcatus* (15.2%), *Marsupenaeus japonicus* (10.3%), *Penaeus monodon* (9.7%) and *Penaeus canaliculatus* (0.9%). The results of this study showed higher shrimp abundance during SEM compared to NEM season despite its proportional decrease with increasing water depths. The overall combined sex ratio deviated from the expected ratio of 1:1 ($p < 0.05$) with females dominating the total catch (1 male: 1.50 female), while the length–weight relationship of most penaeid species exhibited positive allometric growth significantly different from 3.0 ($p < 0.05$) with strong relationship between lengths and weights of these species. The carapace length of six penaeid shrimps at first maturity (L_{50}) suggested that their spawning starts at different sizes with *P. monodon* achieving L_{50} at the largest size and *M. monoceros* at the smallest size. The results of this study further showed several penaeid shrimps displayed intraspecific morphological variability where shape differentiation increased with size. Following good condition factors and high abundance of *M. monoceros* and *F. indicus* with matured gonads in both seasons, this study confirmed the two species as resilient and suitable for shrimp mariculture breeding programmes in Kenya. Generally, high variability among individual shrimps within each population indicated the presence of high genetic diversity which has given rise to genetically panmictic populations in Malindi–Ungwana Bay. However, the population of *P. canaliculatus* in the Malindi–Ungwana Bay is considered as unique evolutionary taxa for conservation. This study further recommends conservation measures to prevent growth overfishing in the estuarine area.

Key words: abundance; condition factor; genetic diversity; morphometric variation; penaeid shrimp; phenotypic plasticity; population; seasonal; sex ratio; variability

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1 Background Information

Penaeid shrimps in Kenya are mainly exploited in Malindi–Ungwana Bay, which is located between north of Malindi in Kilifi County and Ras Shaka, north of Kipini in Tana River County covering the Ungwana Bay. The Malindi–Ungwana Bay is characterized by two major rivers in Kenya which discharge into the bay, with River Sabaki in the south of the Bay about 45 nautical miles from River Tana further in the north (Iversen, 1984; Kitheka, 2002). The productivity of the bay is influenced by the nutrients discharge from the two major rivers, as well as patterns of monsoon winds, tides and the offshore Somali and East African Coastal currents (C. N. Munga, Kimani, Ruwa, & Vanreusel, 2016). The Malindi–Ungwana Bay has, however, a shallow continental shelf, extending between 15 and 60 km offshore, with the inshore water mean depth of 12 m at 1.5 nm during spring tide that increases very rapidly to 100 m after 7 nm towards offshore waters (Kitheka, 2002). The Bay supports a significant part of the artisanal fishery, as well as the only commercial trawl fishery within Kenyan territorial waters (Bage, 2013; Dzoga *et al.*, 2018).

The Malindi–Ungwana Bay is highly productive and has become the main fishing ground for Kenya's commercial shrimps fishery such as: Indian white prawns (*Fenneropenaeus indicus*), Giant tiger prawns (*Penaeus monodon*), Green tiger prawns (*Penaeus semisulcatus*), Speckled shrimp (*Metapenaeus monoceros*) and Kuruma shrimp (*Marsupenaeus japonicus*) (Mutagyera, 1984; Munga *et al.*, 2012; van der Elst and

Everett, 2015). The penaeid shrimp fisheries make great contributions to the domestic market as well as export commodities to Great Britain, Italy, the Netherlands, Germany, Belgium, Portugal, Spain, Cyprus, Malta, France and Poland (FAO, 2016). The annual total shrimp catches which occurred between 1990 and 2017 fluctuated from 150 to 1,320 metric tons with two peaks of over 1,300 metric tons in 1998 and 2001 (E. Kimani, Omukoto, Mueni, Mirera, & Fondo, 2018). The lowest catch of less than 150 metric tons occurred in 2009 from the artisanal shrimp fishery alone as the shrimp trawling was closed in September 2006 by the Government of Kenya following the resource use conflicts between the artisanal and trawler groups. Despite the fact that shrimp trawling resumed in 2011 under the Prawn Fishery Management Plan 2010, shrimp catches continued fluctuating below the peak of 1,300 metric tons. The artisanal fishery, however, was not well covered under this management plan for shrimp fishery as opposed to the semi–industrial trawl fishery whose existent information was used to design the plan (Omukoto *et al.*, 2015). The shrimp fishery of Malindi–Ungwana Bay, however, showed signs of growth overfishing which is critical to the understanding of genetic diversity of penaeid shrimp populations in the Bay.

Genetic diversity is used to provide crucial information in the assessment and management of wild stocks within the common fishing grounds. It forms the basis for species' survival, development and evolution (Feng, Liu, Chiang, & Gong, 2017). It is also used to evaluate the ability to respond to environmental changes by populations (Cao & Li, 2016). Thus, the morphological studies on penaeid shrimp in Malindi–Ungwana Bay can potentially contribute to better management and conservation strategies for a population and lead to a better understanding of the taxonomy as well as stock identification. In Kenya, however, information about the use of morphometric characters or morphological traits to study genetic diversity of penaeid species is very scant on Malindi–Ungwana Bay. In regards to their ecological significance as well as economic importance in the shrimp industry, penaeid shrimps have become the focus of considerable genetic research for the effective management of shrimp fishery in the Malindi–Ungwana Bay (Thomas K. Mkare, Von Der Heyden, Groeneveld, & Matthee, 2014).

1.2 Problem statement

The main penaeid shrimp stocks in the Southwest Indian Ocean have shown clear signs of overexploitation, prompting the fisheries authorities in the concerned countries to introduce more stringent management measures (FAO, 2018). For nearly four decades, semi–industrial shrimps trawling operated under the repealed Fisheries Act in the shallow waters of Malindi–Ungwana Bay with fluctuating number of trawlers between four and twenty concentrating around the shallow estuaries of Tana and Sabaki Rivers (Fulanda *et al.*, 2011; Kimani *et al.*, 2012). Abila (2010) reported increased fishing efforts in the mid 1990s with all those involved in the shrimp fishery exerting pressure on the penaeid shrimp stocks. However, the repealed legislation was not backed by any scientific information.

Hoof and Steins (2017) reported stocks of penaeid shrimps in Malindi–Ungwana Bay showed signs of overfishing due to high fishing mortality rate above the one that generates maximum sustainable yield (MSY). The declines of shrimp abundance and sizes in the shallow trawling waters made trawling operations progressively moved towards the estuaries creating potential conflicts between the artisanal and trawler groups in the partitioning of the fishing grounds (Bernerd Fulanda *et al.*, 2011). The shrimp trawlers persistently failed to comply with the repealed Fisheries legislation by fishing within the five nautical miles band earmarked for artisanal fishery which led to entanglement of fishing gear belonging to artisanal fishers (Fulanda *et al.*, 2011; Kimani *et al.*, 2012). Many of the shrimp trawlers opted out of bay due to unnecessary increase in resource user conflicts coupled with increased overhead costs resulted from settling compensation for the artisanal fishers.

The unresolved conflicts escalated and threatened to become violent, prompting the Government of Kenya to declare a moratorium ban in September 2006 to restore sanity in the sector. Later, the ban was lifted in May 2011 to pave way to a more responsive shrimp fishery regulation, the Prawn Fishery Management Plan 2010 (Kimani *et al.*, 2012; Bage, 2013).

1.3 General Objectives

The overall objective of this study was to evaluate the genetic diversity of the wild penaeid shrimps and provide relevant information on the suitability of shrimp mariculture based on the morphometric studies in Malindi–Ungwana Bay.

1.3.1 Specific objectives

1. To determine the seasonal population abundance of wild penaeid shrimps in Malindi–Ungwana Bay.
2. To evaluate the relative growths and condition factors of different penaeid shrimps in Malindi–Ungwana Bay for sustainable mariculture programs.
3. To evaluate the genetic diversity based on the morphometric variations within and between different penaeid shrimps in Malindi–Ungwana Bay.

1.4 Hypotheses

1. Every penaeid shrimp has unequal population abundance in Malindi–Ungwana Bay.
2. The relative growths and condition factors of different penaeid shrimps in Malindi–Ungwana Bay are not equally suitable for sustainable mariculture programs.
3. Low genetic diversity in penaeid shrimp population of Malindi–Ungwana Bay has not led to its population decline that threatens its evolutionary potential.

1.5 Justification

The shrimp fishery trawling in Malindi–Ungwana Bay was initiated after a series of successful feasibility surveys by the Kenya Government, United Nations Development Programme (UNDP) and Food and Agriculture Organization (FAO) in early 1960s (Iversen, 1984). The shrimp trawlers landed an average of 400 metric tons of shrimps per year in the 1970s, 1980s and 1990s (C. N. Munga *et al.*, 2016). Hoof and Steins (2017) reported that shrimp fishery in Malindi–Ungwana Bay was operating beyond the maximum sustainable yield (MSY) with very high average fishing mortality (F) rate of 1.99. The Spawning Stock Biomass per Recruitment (SSB/ R) was also estimated at 0.06 lower than 0.2 required for MSY while the exploitation rate (F/ Z) of between 0.59 and 0.76 for penaeid shrimp was found to be above 0.5 (F/Z > 0.5), an indication for over exploited shrimp fishery (Hoof & Steins, 2017). In a bid to mitigating shrimp fishery from collapse as well as minimizing damage to the estuarine and mangrove ecosystems, this study seeks to address threats of growth overfishing in Malindi–Ungwana Bay by looking at the genetic diversity of the penaeid shrimps using morphometric studies; and further suggest possible breeding programs for shrimp mariculture in the Bay.

Morphometric study is cost effective as compared to molecular genetics and frequently employed as a technique for describing or identifying the difference between populations. Morphometry has been successfully applied to compare geographically isolated populations, describe spatial distribution and elucidate intraspecific variation (Hanif *et al.*, 2019). Studies that aim to provide insights to genetic diversity of penaeid shrimps based on morphometric studies with a view of looking at alternative shrimp production to ease pressure in the capture fishery are therefore justified. Thus, the adoption and implementation of proposed recommendations of this study would help in sustainable use and conservation of penaeid shrimp fishery in Kenya.

CHAPTER TWO

2. LITERATURE REVIEW

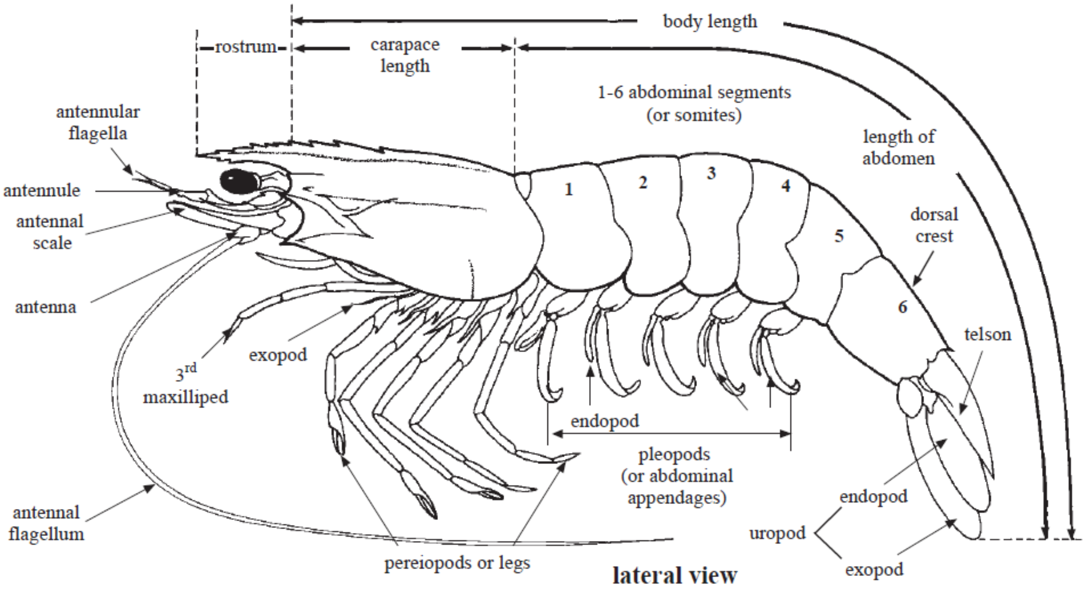
2.1 General biology of Penaeid shrimp

2.1.1 Systematic position

Penaeid shrimps belong to phylum Arthropoda characterized by jointed appendages and an exoskeleton or cuticle which periodically molts. Penaeid shrimps are considered as more highly evolved crustaceans of the class Malacostraca (Jose, 2013). They are referred to as a group of primitive shrimps belonging to the Superfamily Penaeoidae of the order Decapoda (Radhakrishnan *et al.*, 2012). They are called primitive because female broadcasts fertilized eggs into the water column (Gillett, 2008). Rafinesque (1815) provided taxonomical keys for the identification of penaeid shrimps as follow:

Classification

Phylum: **Arthropoda**
  Subphylum: **Crustacea**
    Superclass: **Multicrustacea**
      Class: **Malacostraca**
        Subclass: **Eumalacostraca**
          Superorder: **Eucarida**
            Order: **Decapoda**
              Suborder: **Dendrobranchiata**
                Superfamily: **Penaeoidea**
                  Family: **Penaeidae**



(Chan, 1998)

Figure 2.1: Diagram showing the structural parts of Penaeid shrimp.

Generally, Penaeid shrimps grow from small to large sized body from 2.5 to 35 cm (Jose, 2013). They have 5 pairs of legs which are well developed, with the first 3 pairs of legs forming a pincer. Their abdomen has lateral plates on the posterior part of pleura covering the anterior part of succeeding pleura. Penaeid shrimps are bisexual and easily distinguishable by the presence of a corpulatory organ such as petasma on first pair of pleopods of males, while the females have the posterior thoracic sternites modified into a sperm receptacle process such as thelycum which holds the spermatophores after mating (Rao, Radhakrishnan, & Jose, 2013).

2.1.2 Habitat and distribution of Penaeid shrimp

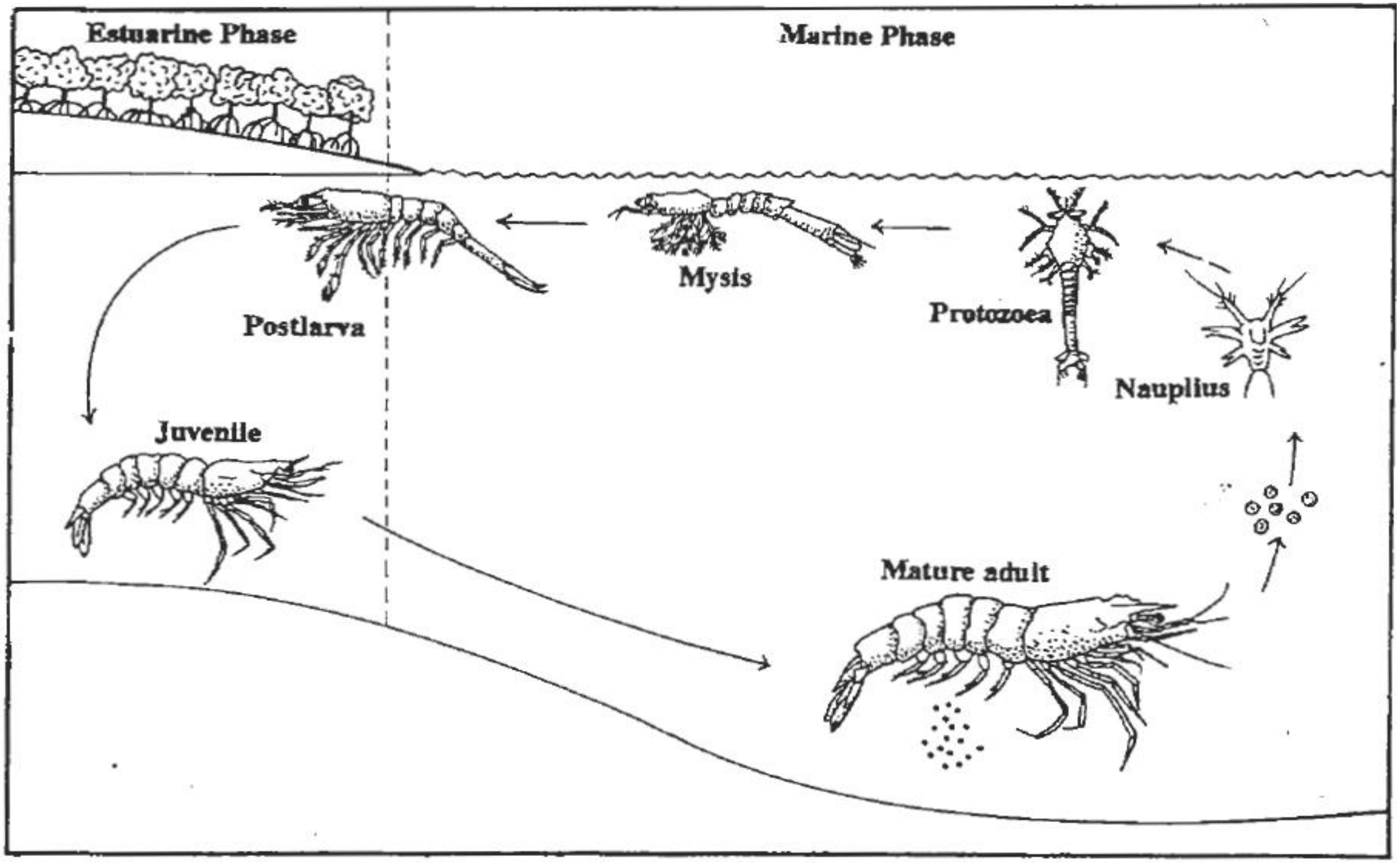
Penaeid shrimps are an ecologically diverse group of species that are found within the inshore and shallow habitats of the estuarine and marine environments throughout the tropics, particularly in areas where conditions are favourable for mangroves, lagoons, wide shallow shelf areas, etc. They are found within very shallow fringes of tropical estuaries or the continental shelves at depth of less than 100 m while others are found at depths of nearly 1000 m (Garcia, 1988). Many penaeid shrimps are benthic, living on a large variety of bottoms such as rock, mud, peat, sand and fragments of shells or mixtures of these materials (Jose, 2013). Shrimp abundance is greatly affected by population age structure, depth, catchability and season (Bishop and Khan, 1991). In the estuarine waters, Dall *et al.* (1990) showed juveniles and sub adults of penaeid shrimps dominate size classes. This has resulted to the development of shrimp fishery comprising of artisanal fishery that involves fishing of shrimps within the estuaries, and semi–industrial prawn fishery that involves deep sea shrimp trawling (Teikwa and Mgaya, 2003; Gillett, 2008). However, semi–industrial fishery in Kenya which contributes significantly to the total marine fishery landings is restricted to shallow coastal waters of depths up to 20 m deep, around where rivers Sabaki and Tana discharge into the Indian ocean (Iversen, 1984; Kitheka, 2002; Mwatha, 2002; Fulanda, 2003; 2011).

Penaeid shrimps constitute very important fishery resources in developing countries by representing a very valuable commodity for export (FAO, 2018). The Malindi–Ungwana Bay is one of the most important fishing grounds for penaeid shrimps along the Kenyan Coast (E. Kimani *et al.*, 2018). Though there are more than 3,000 penaeid shrimp species worldwide, only 40 species are in fact commercially exploited (Whetstone, Treece, Browdy, & Stokes, 2002). At least 22 penaeid shrimp species have been reported in East Africa, where presently eight species are of commercial interest occur in Malindi–Ungwana Bay (Omukoto *et al.*, 2015). All the commercial value shrimps contributing to the fishery in Malindi–Ungwana Bay belong to the Superfamily Penaeoidea, which is divided into families Solenoceridae, Benthescymidae, Aristeidae, Sicyoniidae and Penaeidae. The penaeid shrimps found in the Malindi–Ungwana Bay are *Fenneropenaeus indicus***,** *Metapenaeus monoceros***,** *Penaeus semisulcatus*, *Marsupenaeus japonicus*, *Metapenaeus stebbingi*, *Melicertus latisulcatus, Penaeus merguiensis*, *Penaeus monodon* and *Penaeus canaliculatus* (Omukoto *et al.*, 2015; Kimani *et al.*, 2018; Kaka *et al.*, 2019)**.**

2.1.3 Types of life cycles

For all known members of the family Penaeidae, the sequence of development is similar: planktonic larvae, with several naupliar, protozoea, mysis and postlarval stages, followed by juvenile and adult stages (Figure 2.2)(Dall *et al.*, 1990). The degree to which each stage of the life cycle is linked to the marine or estuarine environment is greatly variable (Garcia, 1988). The greatest differences are, however, in the preferred habitats of postlarvae, juveniles and adults: whether they are predominantly estuarine, inshore or offshore, and whether demersal or pelagic (Dall *et al.*, 1990).

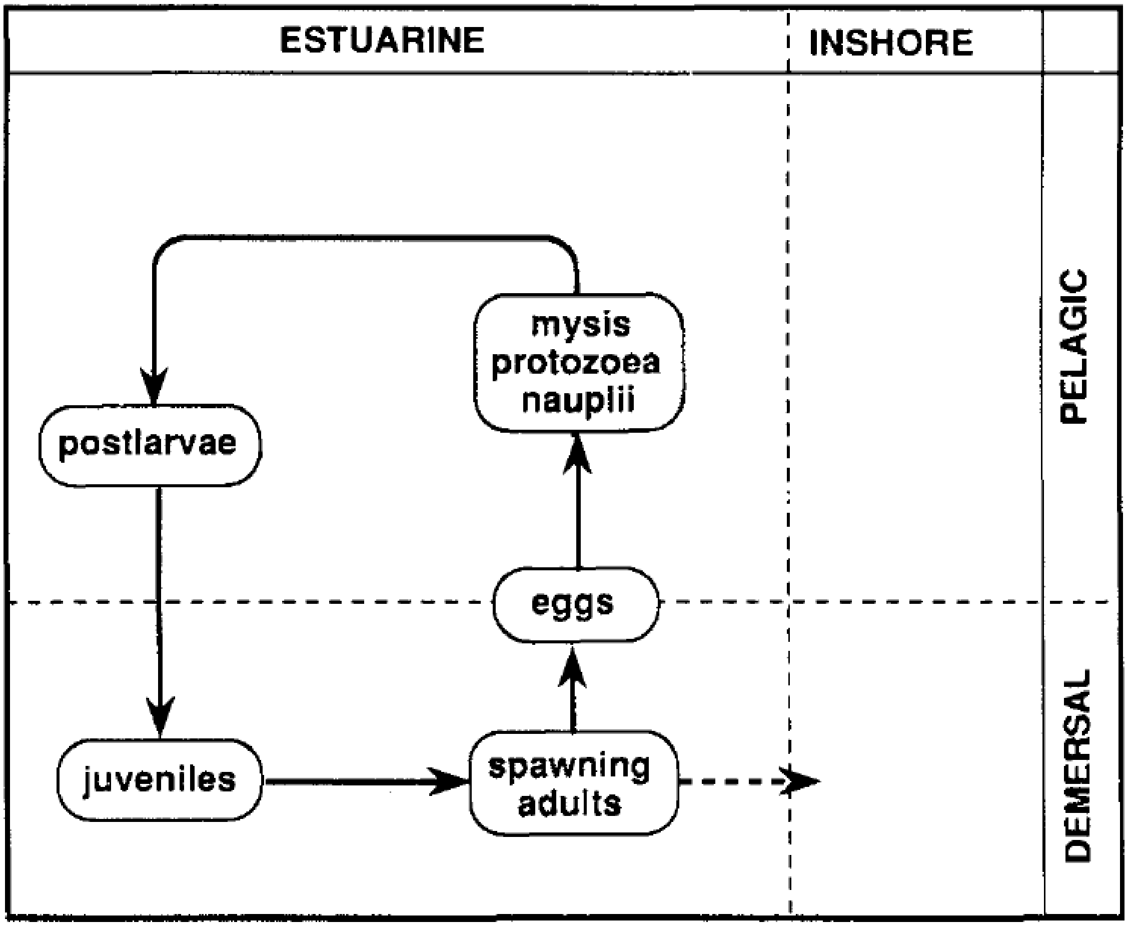
Generally, in Type I of life cycles represent exclusively estuarine where postlarval shrimps migrate upstream to feed and grow before retreating to a slightly more saline waters in estuarine than upstream to join the adult populations (Dall *et al.*, 1990). Most of the penaeid shrimps belong to Type II of life cycles where postlarval shrimps inhabit the estuaries until they grow to juveniles or sub adults and start emigrating offshore to complete their life cycle (P. Rönnbäck, Macia, Almqvist, Schultz, & Troell, 2002). Dall *et al.* (1990) described Type III of life cycles as highly restricted preferably to those inhabiting high salinities sheltered inshore waters, whereas Type IV of life cycles have their entire life in the offshore waters. Like Type II, all Type III species appear to spawn on the continental shelf, but mostly below 100 m depth (Dall *et al.*, 1990).



(Dall *et al.*, 1990)

Figure 2.2: General life cycle of a typical penaeid shrimp.

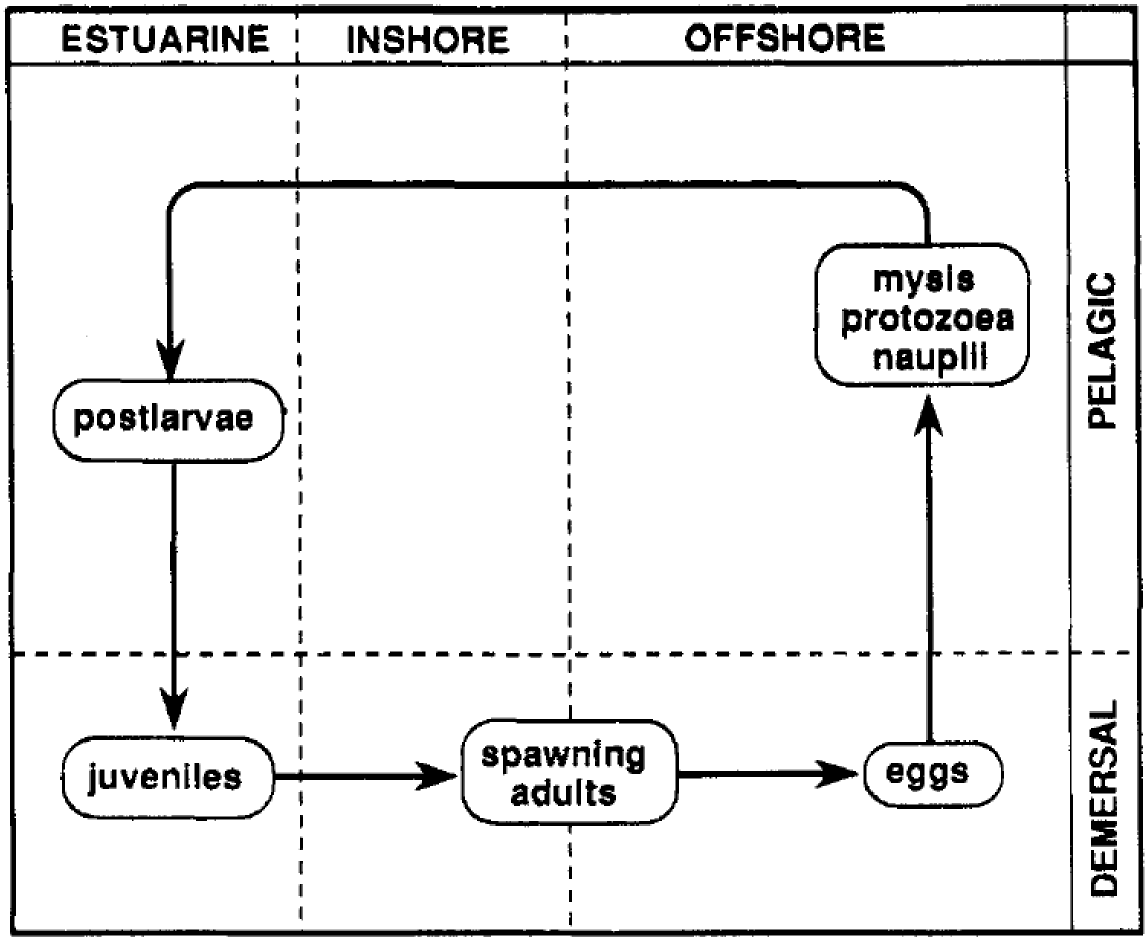
In the Type I life cycle appears to be restricted to the smaller species of Metapenaeus. All stages are estuarine and the eggs may not be completely demersal (Figure 2.2.1). In such estuarine species, the postlarval shrimps tend to migrate upstream into water of lower salinity and as they grow, the juveniles move progressively towards higher salinities in the lower estuary (Dall *et al.*, 1990). More often in Type I life cycle, spawning in penaeid shrimp takes place in the sheltered inshore waters where depth varies with the species.



(Dall *et al.*, 1990)

Figure 2.2.1: Type I life cycle of penaeid shrimp.

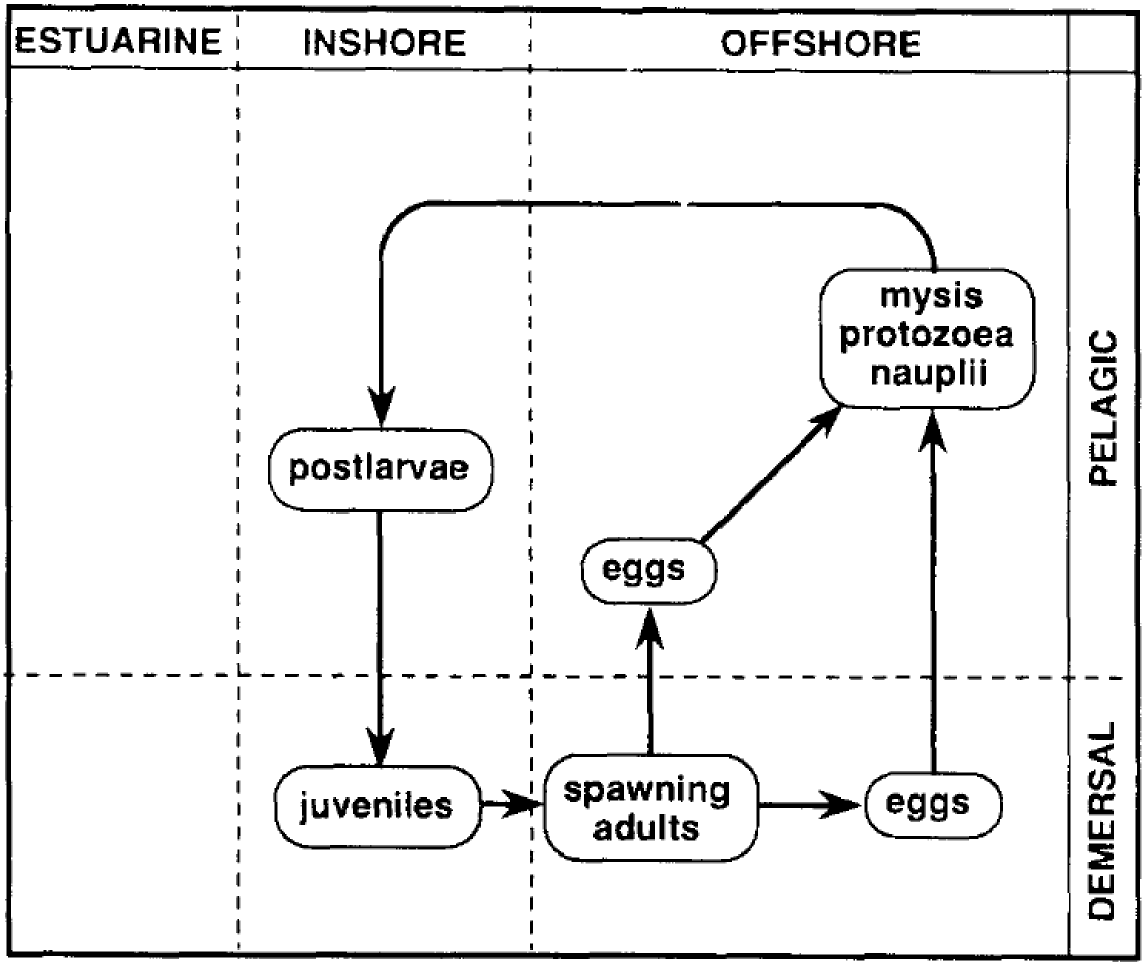
In the Type II life cycle, the postlarval shrimps migrate to estuarine waters which they use as nurseries during their critical early life stages (Figure 2.2.2). When they become sub-adults with a completely developed petasma and thelycum, the matured juveniles emigrate from the estuaries, some species spawn relatively close to the inshore waters, while others move into deeper waters of the continental shelf to spawn. The Type II life cycle is characteristic of most Penaeus and Metapenaeus species (Dall *et al.*, 1990).



(Dall *et al.*, 1990)

Figure 2.2.2: Type II life cycle of penaeid shrimp.

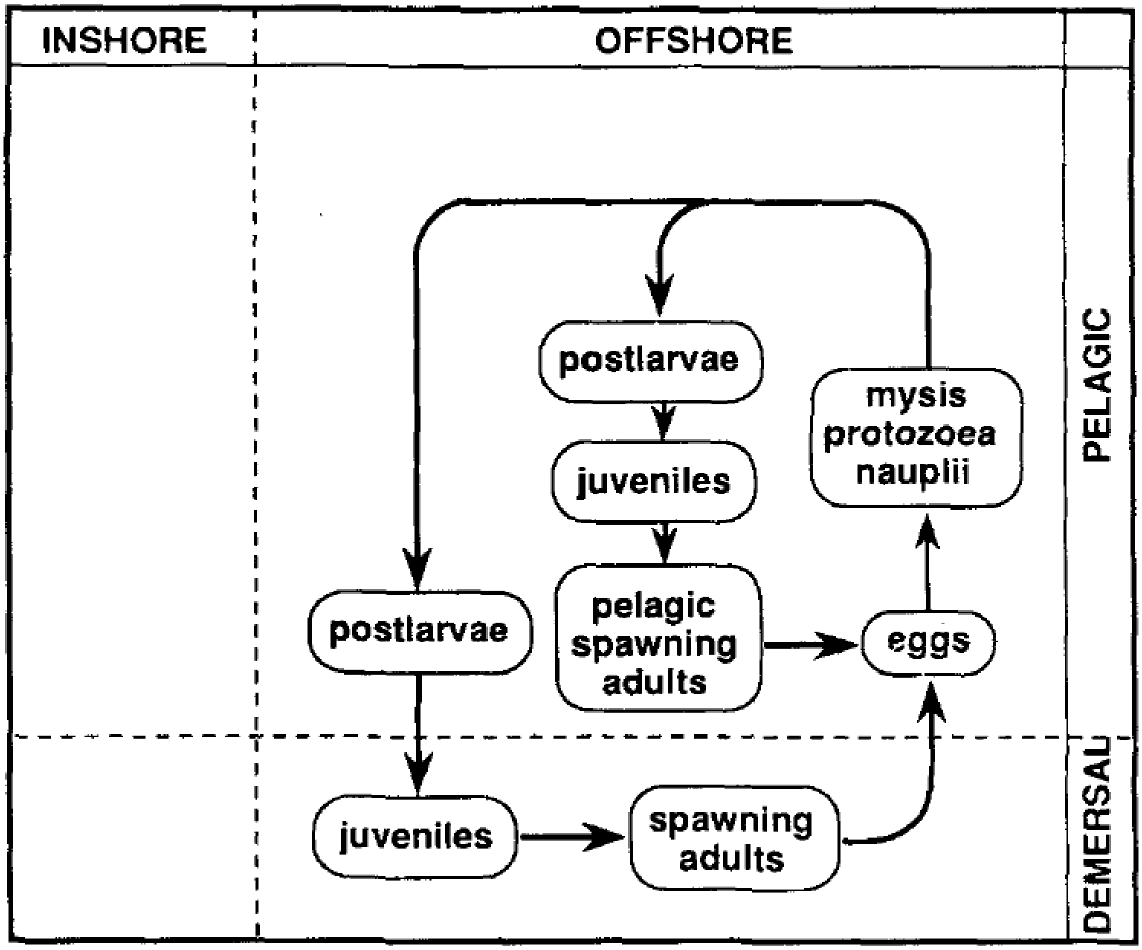
In the Type III life cycle, the postlarval shrimps migrate to shallow inshore waters which are relatively high in salinity and more often sheltered with seagrass or algal beds (Figure 2.2.3). Seagrasses are the preferred nursery grounds for most of the Type III species while a few may inhabit sandy muds, sands or coralline rubble. The offshore migrations are similar to those of Type II with some species in this group have pelagic eggs. This life cycle is a characteristic of some species of Metapenaeus and Penaeus.



(Dall *et al.*, 1990)

Figure 2.2.3: Type III life cycle of penaeid shrimp.

In the Type IV life cycle, penaeid shrimp have life cycles that are entirely offshore. They are fully pelagic species. Probably, they do not have a benthic phase as indicated by a separate cycle in Figure 2.2.4. However, others are deep water species with benthic juveniles and adults. The eggs of these two sub-groups are probably pelagic.



(Dall *et al.*, 1990)

Figure 2.2.4: Type IV life cycle of penaeid shrimp.

2.1.4 Migrations

In order to complete their life cycles, penaeid shrimps often occupy different habitats during their life-history stages. There are four types of migrations that occur:

(a) Larval and postlarval migration from the spawning ground to the nursery ground. Most of the adult penaeid shrimps spawn offshore, while the juveniles utilize estuarine or inshore habitats as in the case of Type II and III life history cycles, respectively. Dall *et al.* (1990) suggested that active vertical migration during the pelagic larval phase coupled with water currents at night of a new moon could be the most likely mechanism that brings postlarvae to their nursery areas.

(b) A juvenile migration out of the nursery area. The nursery grounds for postlarval and juvenile stages of most of the penaeid shrimps studied are within the inshore areas, such as estuaries or shallow coastal waters. At the end of the period in the nursery grounds, the juvenile shrimps migrate offshore, usually to deeper water, a migration that may involve a considerable long shore movement. Migration from one habitat to another requires the shrimps to respond either to some internal physiological cue associated with size or to some change in their environment or both (Dall *et al.*, 1990).

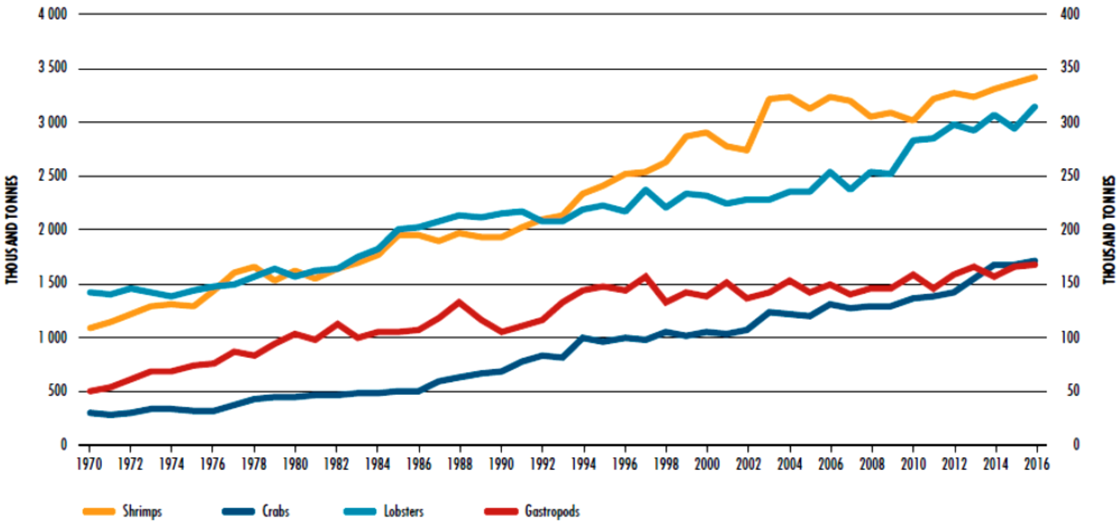
(c) An adult migration to deeper water offshore. After leaving their nursery grounds as sub-adults, most of the penaeid shrimps move towards the offshore into deeper waters assisted by water currents.

(d) A spawning migration in some species. As the penaeid shrimps grow and mature, many species move even further into offshore deeper waters.

Generally, shrimp distribution is caused by one or more interactions of biotic and abiotic factors that may result to some variability within apparently similar nursery areas (Jose, 2013). Although some studies have relatively well described spatiotemporal variations of shrimp juveniles distribution in different shallow water habitats, factors such as salinity, turbidity, depth, substrate types that affect shrimps distribution and abundance in Malindi–Ungwana Bay are fairly known as varied results have emerged within same species (Kimani *et al.*, 2012; Munga *et al.*, 2013; Omukoto *et al.*, 2015; Taylor, 2016; Jamizan and Chong, 2017).

2.2 The shallow water shrimp fishery

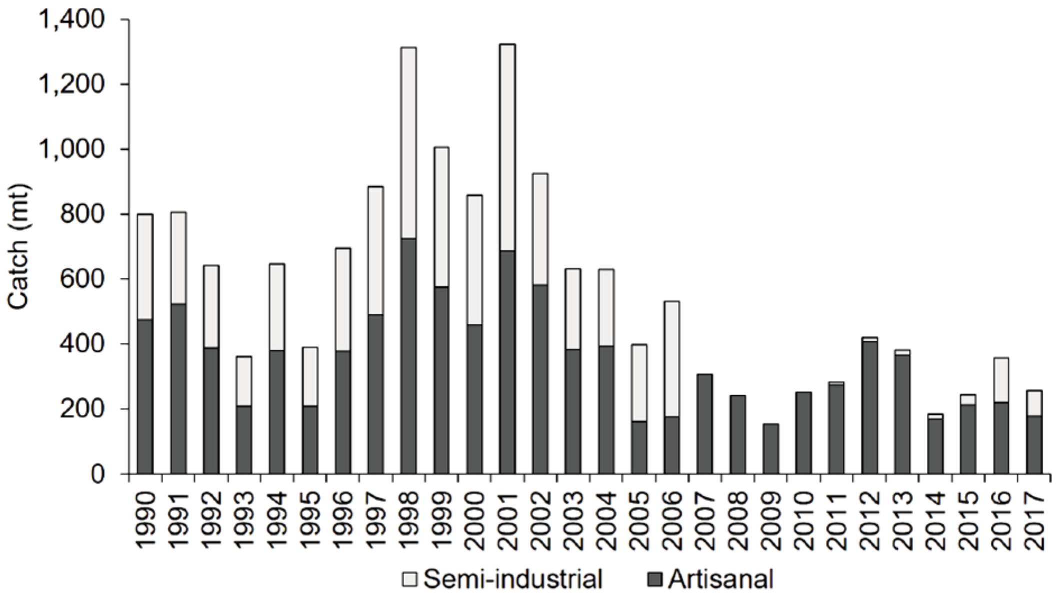
The penaeid shrimps are often exploited by small scale fisheries in the estuaries as well as trawl semi–industrial fisheries in the shallow and offshore waters (Omukoto *et al.*, 2015; Kimani *et al.*, 2018). For nearly four decades, semi–industrial shrimps trawling has been operating in the shallow waters of Malindi–Ungwana Bay concentrating around the shallow estuaries of Tana and Sabaki (Fulanda *et al.*, 2011; Kimani *et al.*, 2012). About 900 small–scale fishers are engaged in the shrimp fishery using various gear types to harvest penaeid shrimps including over 300 prawn seine nets and 175 cast-nets (E. Kimani *et al.*, 2018). Global capture fisheries production for penaeid shrimps showed a steady increase (Figure 2.3), while the annual landings in Malindi–Ungwana Bay declined markedly between 2001 and 2005 (Figure 2.4) (FAO, 2018; Kimani *et al.*, 2018).



NOTE: Values for shrimps and crabs on the left axis, values for lobsters and gastropods on the right axis.

(FAO, 2018)

Figure 2.3: Global catch trends of valuable species groups.



(E. Kimani *et al.*, 2018)

Figure 2.4: Annual landings for penaeid shrimps in Malindi–Ungwana Bay.

The declining of shrimp abundance and sizes made fishing operations by the trawlers to move progressively towards the estuaries and at the same time shifted to night hours, creating potential conflicts between trawlers and artisanal fishers in the partitioning of the fishing grounds (Bernerd Fulanda *et al.*, 2011). The artisanal fishermen also complained over declining catches, perceived environmental degradation, destruction of their gear by trawlers and excessive trawl by–catches whose low market prices competed unfairly with artisanal catches (E. Kimani *et al.*, 2018). Majority of the shrimp trawlers opted out of Malindi–Ungwana Bay due to unnecessary increase in resource user conflicts coupled with increased overhead costs resulted from settling compensation for the artisanal fishers (C. N. Munga *et al.*, 2016). The unresolved conflicts escalated and threatened to become violent, prompting the Government to declare a moratorium ban in September 2006 to restore sanity in the sector (Munga *et al.*, 2016; Kimani *et al.*, 2018). In 2011, the Prawn Fishery Management Plan of 2010 was gazetted to regulate the penaeid shrimp fishery in Kenya (Government-of-Kenya, 2011). However, the artisanal fishery is not well covered under this management plan for penaeid shrimp fishery as opposed to the semi–industrial trawl fishery whose existent information was used to design the plan (Omukoto *et al.*, 2015).

2.3 Development of Penaeid shrimp aquaculture in Kenya

Modern shrimp farming began in the late 1960s and early 1970s when French researchers in Tahiti developed techniques for intensive breeding and rearing of various penaeid shrimp species, including *P. japonicus, P. monodon and later P. vannamei* and *P. stylostris* (Gillett, 2008). By 1990, shrimp aquaculture was credited with 25 percent of world shrimp harvests and about half of all shrimp exports (Briggs, Funge-smith, &

Phillips, 2005). The world shrimp farming is a fast-growing industry and has undergone an exponential expansion over the last few decades (Mmochi, 2015). Recently, the global aquaculture production for crustaceans in 2016 was 7.9 million tonnes, with the first sale value estimated at USD 57.1 billion (FAO, 2018). FAO (2018) further reported that marine shrimps dominated the production of crustaceans typically farmed in coastal aquaculture which have become the most important source of foreign exchange earnings for a number of developing countries.

In 1989, the defunct State Department of Fisheries made its first attempt on coastal aquaculture of penaeid shrimps in Kenya on a 60 hectare farm at Ngomeni prawn farm in Malindi with funding from Food and Agriculture Organization of the United Nations (FAO) (Rönnbäck *et al.*, 2002). Despite adopting an extensive production system for shrimp culture in traditional brackish water tidal ponds and produced 227 metric tons by end of 1990, the substantial quantities of shrimps produced was a clear demonstration of the economic viability of shrimp farming in the coastal zone (Mmochi, 2015). The farm provided technical assistance for the development of two satellite farms along Mtwapa creek in Kilifi, Wampare’s shrimp farm and Kwetu Training Centre shrimp farm, before it collapsed in 2001 (Mirera, 2011).

For any successful coastal aquaculture venture, information on the cost–benefit analysis involved in the extensive versus semi–intensive systems of the shrimp production in traditional brackish water tidal ponds needs to be addressed adequately (Kaka *et al.*, 2019). For this reason, there is need to have appropriate information about things such as production by different culture systems, input costs and availability, marketing demand, supply and prices making economic decisions on aquaculture investments. Despite focus on maintaining critical standards in the environmental and biological aspects of running the shrimp production, knowledge of good management on the relevant inputs and of their relationships in the entire production process is equally critical (Gammanpila, 2015).

2.4 Genetic diversity based on morphological traits

Morphometric studies are essential to understand the taxonomy as well as stock identification or identify the difference between population (Rebello *et al.*, 2016). Analysis of phenotypic variation in morphometric characters remains the most commonly used method to delineate stocks despite the advent of techniques which directly examines biochemical or molecular genetic variation (Oa, Oik, & Amadioha, 2018). Morphometry has also been successfully applied to compare geographically isolated populations, describe spatial distribution and elucidate intraspecific variation (Hanif *et al.*, 2019). Identifying intraspecific units or stocks of a species with unique morphological characteristics has now become more powerful and enables a better management of these subunits of species and ensures better management and conservation of the fishery resources (Dwivedi & Dubey, 2013). In the past, scientists assumed variation of morphometric characters was entirely genetic, but recent studies have proved its relation with environmental factors including physico–chemical parameters of water, habitat and substrate types (Siddik *et al.*, 2016). Siddik *et al.* (2016) further suggested that although genetic and physiological differences between stocks revealed by molecular markers is more trustworthy, morphometric variations are still considered an important tool in stock characterization and identification. Studies of morphometric on penaeid shrimps have been conducted on *P. monodon, P. indicus, P. japonicus, P. semisulcatus, M. momoceros* among others (Li *et al.,* 2016; Sharawy *et al.*, 2016; Komi and Francis, 2017). In Malindi–Ungwana Bay, information about the use of morphometric characters or morphological traits to study genetic diversity of penaeid shrimp is very scanty.

The management of the genetic diversity is used to provide crucial information for fishery planning and management of wild stocks within the common fishing grounds. For sustainable harvest and conservation of biodiversity, it is important to study the relationships between ecological and evolutionary processes in maintaining and creating biological diversity of wild populations (Kristjansson, Leblanc, Skúlason, Snorrason, & Noakes, 2018). Genetic diversity forms the basis for species' survival, development and evolution, while it is used to evaluate the ability to respond to environmental changes by populations (Cao and Li, 2016; Feng *et al.*, 2017). The analyses of genetic diversity and population structure provide baseline information for maintaining productive fisheries, sustainable harvesting (Cao & Li, 2016). The extent of genetic diversity in natural population results from an interplay between forces generating local genetic differentiation and forces generating genetic homogeneity (Awodiran & Ogunjobi, 2016). Hence, the level of population genetic variation among penaeid shrimps in Malindi–Ungwana Bay can be influenced by such processes as founder events, genetic drift, mutation, recombination, migration (gene flow) and selection.

Morphological characteristics of penaeid shrimps are known to be phenotypically plastic and seasonally influenced by the physical environment factors during spawning and early juvenile stages of their life (Munasinghe & Senevirathna, 2015). Morphometric studies allow for hypotheses testing by describing and quantifying shape differences between biological groups using multivariate methods for shape variation between groups

(Adams, Rohlf, & Slice, 2004). On the other hand, the use of multivariate techniques such as principal components and discriminant functional analyses to quantify morphometric variables are receiving increased attention in stock identification (Mojekwu and Anumudu, 2015; Hanif *et al.*, 2019). Thus, morphometric differences can provide the basis for comparing stock structure between stocks at different locations, which is used to understand population dynamics and short-term and environmentally induced variations; they may possibly provide an appropriate method for different management strategies of penaeid shrimp populations to obtain optimum yields (Sen *et al.*, 2011). Indeed, establishing relationships between shrimp morphology and habitat characteristics is crucial for conservation efforts. This is so, because a shrimp’s survival might be critically compromised during habitat modifications or when specimens are translocated for repopulation purposes (Morais, Rufino, Reis, Dias, & Sousa, 2013).

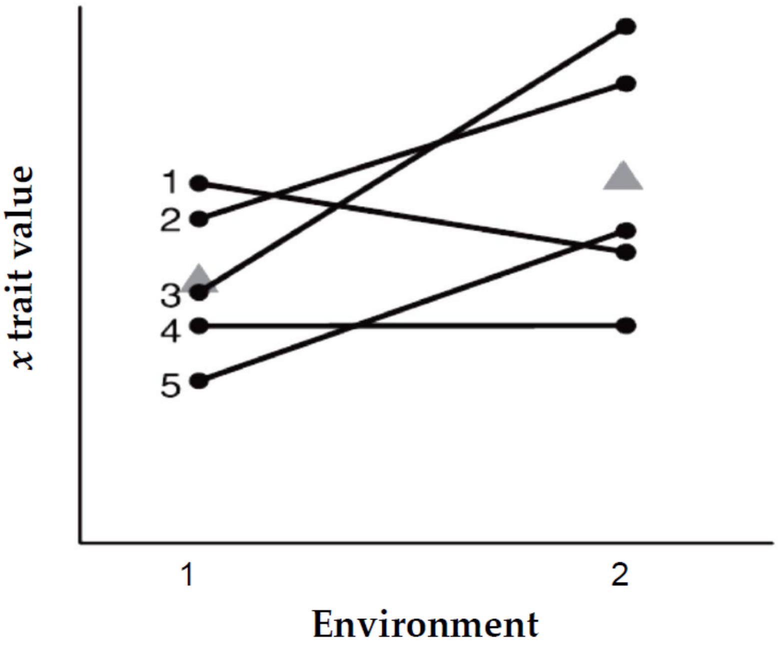
2.4.1 Phenotypic plasticity and local adaptation

Phenotypic plasticity is the ability of a genotype to produce more than one phenotype in order to match the environment and is depicted by plots of some fitness parameters against an environmental factor; a so–called reaction norm (Lind *et al.*, 2015; Blamires *et al.*, 2018). Morphological variability reflects both environmental and genetic influences (Carvalho, Keunecke, & Lavrado, 2019). For a case of penaeid shrimps in the wild, individuals face the challenge of maximizing fitness under heterogeneous conditions. Habitat heterogeneity or increased numbers of microhabitats within a specific environment are believed to favour increased phenotypic plasticity or has been suggested to promote the evolution of phenotypic plasticity (Kristjansson *et al.*, 2018). Thus, phenotypic plasticity is common in penaeid shrimps because of their wide geographical distribution (Carvalho *et al.*, 2019). The ability of individuals to respond to environmental heterogeneity largely depends upon changes in gene expression, framed by physiological, behavioral, and anatomic constraints (Taugbøl, Arntsen, Østbye, & Vøllestad, 2014). Such interactions between genes and environment are most often realized through development, thus providing phenotypic variation upon which natural selection can act (Beck *et al.*, 2019). The extraordinary diversity and adaptive fit of organisms evolving under natural selection depends fundamentally on the generation of heritable phenotypic variation (Uller, Moczek, Watson, Brakefiel, & Laland, 2018). Phenotypes are the result of causal interactions at multiple levels of biological organization, including genes, cells, tissues, and organisms and their environments. In essence, such selection refines a trait through evolutionary adjustments in both the form and regulation of trait expression (Levis & Pfennig, 2016). The outcome of this process is an adaptive phenotype that, relative to its initial state, has been modified both in its morphological and physiological attributes as well as in its environmental sensitivity (Levis and Pfennig, 2016; 2019). Of course, other evolutionary forces such as genetic drift, mutation and so on could also alter the degree of plasticity.

Phenotypic plasticity can be visualized by the use of reaction norms (Whitman & Agrawal, 2009). The resulting reaction norm describes expression of a single genotype across a range of environments. These patterns might vary from allele to allele within populations or from gene to gene between species (Davis & Townsend, 2009). If underlying genetic variation exists in either the tendency or manner in which individuals respond to this environmental change, then selection can act on these ‘reaction norms’ and improve the phenotype’s functionality by altering the phenotype’s form (Levis &

Pfennig, 2019). Selection on the novel phenotype in the new environment would then simultaneously alter the reaction norm and improve the performance of the population, resulting in the genetic assimilation of the trait in the new environment (Auld, Agrawal, & Relyea, 2010).

Figure 2.5 shows hypothetical reaction norms, for a specific trait (*x* length) for five genotypes in a population. Each genotype expresses a different mean value for *x* length in Environment 1 because of Genetic variance (proportion of phenotypic variation attributable to genes). However, when subjected to a new environment, most genotypes alter their *x* length. In this case, when comparing the grand means (the triangles) in each environment, we see that *x* length generally increases in Environment 2 because of the Environmental variance (proportion of variation caused by the environment). However, each genotype exhibits a different reaction norm.



(Whitman & Agrawal, 2009)

Figure 2.5: Hypothetical reaction norms for five genotypes in one population

For instance, Genotype 4 shows no plasticity for this particular trait: mean *x* length remains the same in both environments. In contrast, Genotype 3 shows extreme phenotypic plasticity for mean *x* length, growing very long *x* length in Environment 2. Alternatively, for Genotype 1, mean *x* length decreases in Environment 2. The fact that each Genotype shows a different response (non–parallel reaction norms) represents a combination of genotype and environment interaction, indicating genetic variation in plasticity itself, upon which natural selection can act to alter the shape and variance of the species' reaction norm (Whitman & Agrawal, 2009). Phenotypic plasticity can occur because specific genes are only expressed in certain environments or because specific genes or alleles are environmentally sensitive and their expressions differ in different environments (Kristjansson *et al.*, 2018).

2.4.2 Genetic variation

Genetic variation is an important element with regards to the ability of the species to adapt and evolve (Ibrahim, Nor, & Abukashawa, 2015). Genetic variation is also one of the essential components for selection programs that aim to enhance ecologically or economically important traits (Sekar *et al.*, 2014). There are reasons to believe that the direction of plasticity and the main axis of genetic variation can be aligned (Noble, Radersma, & Uller, 2019). Similarly, Levis and Pfennig (2018) suggested that individuals within the same population often harbour genetic variation in the degree to which they respond to environmental cues. Thus, morphometric expression are determined by gene expression in particular environmental conditions (Kristjansson *et al.*, 2018; Carvalho *et al.*, 2019). If underlying genetic variation exists in either the tendency or manner in which individuals respond to environmental change (as is nearly always the case), then selection can act on the reaction norms and improve the phenotype’s functionality by altering the phenotype’s form (Levis & Pfennig, 2019). And if these initially environmentally induced phenotypes increase fitness, then genetic accommodation can lead to allele frequency change, influencing the expression of those phenotypes (Jones & Robinson, 2018).

Penaeidae shrimps differ in variety of morphological characteristics that are the expression of genetic differences among them (Rajakumaran, Vaseeharan, Jayakumar, & Chidambara, 2014). Given the wide variability in life-history types and the range of habitats occupied by different life-history stages, it is not surprising that penaeid shrimps exhibit rather complex seasonal life-history patterns (Carvalho *et al.*, 2019). All different types of life cycles of the family Penaeidae cover ranges of heterogeneous environment which require different morphological traits that match with local environments associated with high fitness throughout the ranges (Jørgensen, Pertoldi, Hansen, Ruzzante, & Loeschcke, 2008). For each type of adaptation, specific genetic variation is needed (Lundqvist, Andersson, & Lonn, 2008). Hence, life-history dynamics of the penaeid shrimps vary markedly both within species and between species, probably as a result of the different life history stages encountering differing environmental conditions (Carvalho *et al.*, 2019).

CHAPTER THREE

3. SEASONAL POPULATION ABUNDANCE AMONG PENAEID SHRIMPS IN MALINDI–UNGWANA BAY: IMPLICATIONS TO SHRIMP FISHERY MANAGEMENT IN KENYA

3.1 Abstract

The species abundance among populations of penaeid shrimps in Malindi–Ungwana Bay were investigated immediately after moratorium ban on shrimp trawling was lifted in 2011. Penaeid shrimps in Malindi–Ungwana Bay are considered to be main source for export revenue and hence, their stocks need effective management strategies. In this study, it was hypothesized that every penaeid shrimp has unequal population abundance in Malindi–Ungwana Bay. The effects of environment on species abundance and distribution patterns were investigated during the two monsoon seasons, Northeast monsoon and Southeast monsoon seasons. A total of 1364 specimens were randomly collected from the six sample stations in the estuaries and shallow waters fishing grounds of the Malindi–Ungwana Bay. The most abundant species at 30.8% was *Fenneropenaeus indicus* followed by *Metapenaeus monoceros* (24.9%), *Penaeus semisulcatus* (15.2%), *Marsupenaeus japonicus* (10.3%), *Penaeus monodon* (9.7%) and the least was *Penaeus canaliculatus* (0.9%). The study showed high number of juveniles recruited in the Malindi–Ungwana Bay suggesting that this Bay is the nursery area for *M. monoceros, F. indicus, P. semisulcatus* and *P. monodon*. This study confirmed higher shrimp abundance during Southeast monsoon than in Northeast monsoon seasons despite its significant proportional decrease with increasing water depths. Hence, this study recommends a review of the Prawn Fisheries Management Plan of 2010 to thwart growth overfishing in the estuarine area.

3.2 Introduction

Malindi–Ungwana Bay has been considered as the main source for commercial shrimp production in Kenya despite recent declines on the wild stocks, largely due to fishing activities (Kaka *et al.*, 2019). Fishing effort in the Bay has increased steadily since 2011 with a significant proportion of the fishing activities (38%) taking place within the designated no-trawl area through encroachment (Thoya *et al.*, 2019). Malindi–Ungwana Bay is one of the penaeid shrimp rich regions in the Western Indian Ocean (WIO) and at least eight penaeid shrimps have so far been documented (Omukoto *et al.*, 2015). Kimani *et al.* (2018) reported five penaeid shrimps are commonly captured in the artisanal and commercial catches along the Kenya coast which include: the Indian white prawn (*Fenneropenaeus indicus*); Giant tiger prawn (*Penaeus monodon*); Speckled shrimp (*Metapenaeus monoceros*); Green tiger prawn (*Penaeus semisulcatus*); and Kuruma prawn (*Marsupenaeus japonicus*). Despite some attempts at stock estimation have been made by Le Manach *et al.* (2015) to reconstruct tentatively marine fishery in Kenya, inadequacy of information on penaeid shrimp distribution has impeded efforts to improve measures on the effectiveness of shrimp fishery management in Kenya.

The understanding of biotic and abiotic factors that influence the distribution of shrimps still remains critical to the understanding of relationship between the migratory shrimp and their estuarine habitat. Some studies have investigated how the distribution of penaeid shrimps is modulated by variation in ecological parameters, particularly the type of sediment, salinity, depth and temperature (Demetriades and Forbes, 1993; Anger, 2001; Castilho *et al.*, 2008). Salinity and temperature are two of the most important water quality parameters that influence growth and survival of aquatic organisms (M. Kumlu, Eroldogan, & Aktas, 2000). The response to these abiotic factors is known to be species specific and that salinity and temperature may interact to influence growth and survival in shrimps (Metin Kumlu, Kumlu, & Turkmen, 2010). Dall *et al.* (1990) showed how penaeid shrimps which were closely related could be differentiated by their habitat preferences which are influenced by salinity, temperature, turbidity, substrate type and depth. Demetriades and Forbes (1993) reported that such variances in the environmental variables have led to seasonal changes in the distribution of shrimps.

This study hypothesized that every penaeid shrimp has unequal population abundance in Malindi–Ungwana Bay. The environmental factors effecting shrimp abundance and distribution patterns were investigated during the two monsoon seasons, Northeast monsoon (NEM) and Southeast monsoon (SEM) seasons. The present study intended to determine the seasonal population abundance of wild penaeid shrimps in Malindi–Ungwana Bay. The information generated in this study is aimed at improving the effectiveness of the shrimp fishery management in Kenya.

3.3 Materials and Methods

3.3.1 Study area

Malindi–Ungwana Bay comprises of the larger northward Ungwana Bay and the smaller southward Malindi Bay (Figure 3.1). The bay is characterized by relatively shallow water ranging between 12 and 18 metres deep within the areas of 1.5 to 6.0 nautical miles from shore and up to 100 metres deep beyond 7 nautical miles (E. Kimani, Manyala, Munga, & Ndoro, 2011). There were six sample stations, four of which were located within the estuaries (S1, S2, S3 and S4), while the other two sample stations (S5 and S6) were within the shallow waters (Figure 3.1; Table 3.1) (Kaka *et al.*, 2019). The choice of establishing sample stations was mainly considered on the basis of areas frequently used by artisanal fishers or trawlers as well as the estuarine areas around the river mouths of River Tana and River Sabaki. The discharge of two rivers, Tana and Sabaki into the bay contributes to its higher biological productivity, which varies between the northeast (NEM) and southeast (SEM) monsoon seasons that prevail on the Kenyan coast (Thoya *et al.*, 2019). The shallow water survey was stratified by depth and distance from shore, and the entire bay was divided into four depth zones using regular polygons. The total area of each zone was estimated in ArcGIS area calculator such as; less than 10 m depth (137.3 nm^2) represented Zone 1, 10 – 20 m (234.1 nm^2) for Zone 2, 20 – 40 m (136.3 nm^2) for Zone 3, and lastly, 40 – 100 m (38.7 nm^2) represented Zone 4 (E. N. Kimani *et al.*, 2012). For estuarine sample stations S1, S2 S3 and S4 were located within the Zone 1. The shallow waters sample stations, S5 was located off the mouth of River Sabaki in Zone 3, while S6 was located off the mouth of River Tana in Zone 1.

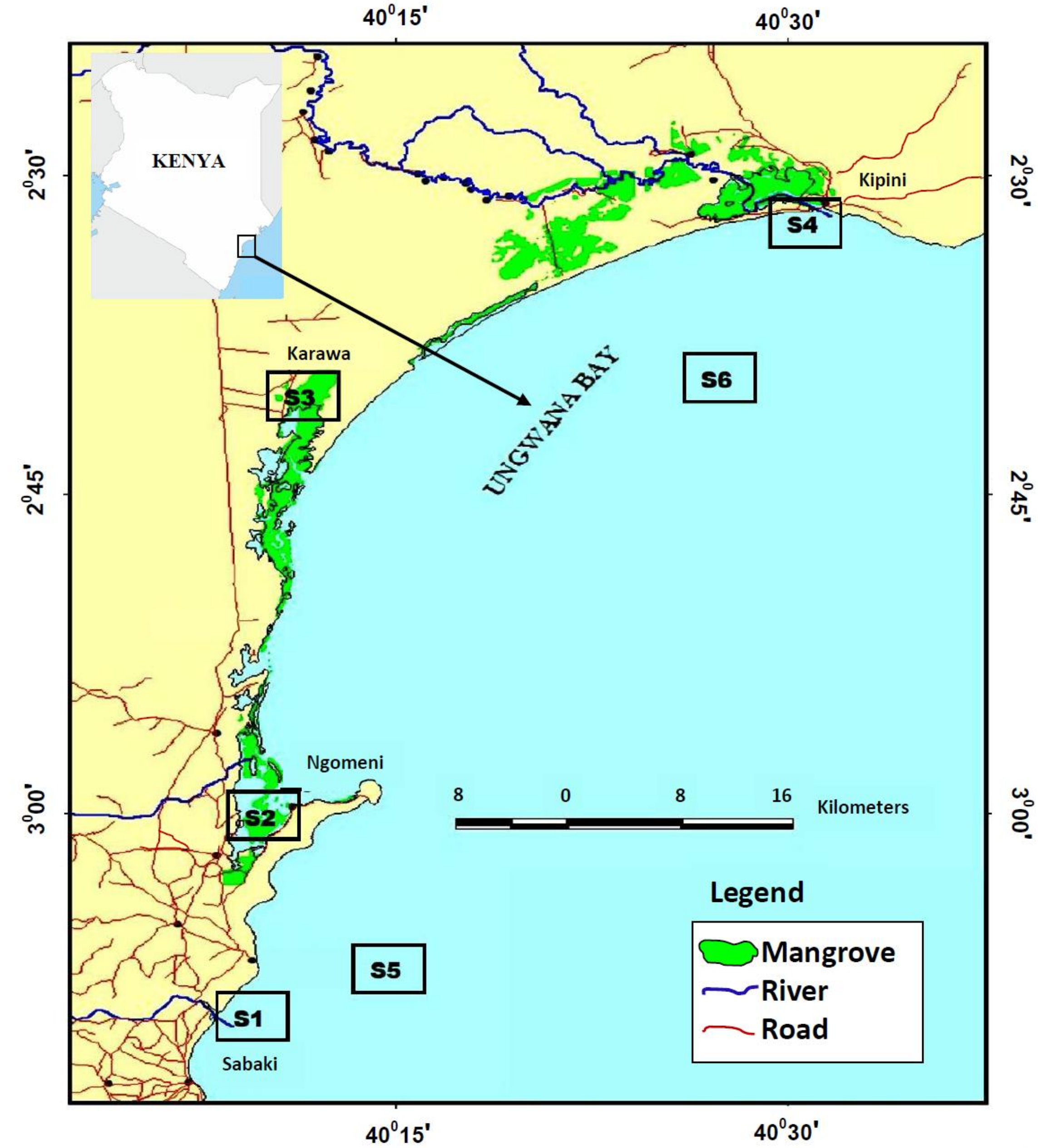


Figure 3.1: Map showing the location of sample stations (S1, S2, S3, S4, S5 and S6) in Malindi–Ungwana Bay.

Table 3.1: Description of the sample stations in Malindi–Ungwana Bay.

Sample station	Name of the sample Station	Coordinates	Habitat type
S1	Around the mouth of River Sabaki	S 03º 09' 28" E 040º 08' 02"	Soft Muddy
S2	Ngomeni	S 02º 59' 27" - S 03º 00' 04" E 040º 09' 54" - E 040º 10' 31"	Creek/ Sea grass/ Silt
S3	Kurawa	S 02º 43' 17" E 040º 10' 44"	Creek/ Sand/ Silt
S4	Mvundeni Kengeleni beach	S 02º 32' 02" - S 02º 32' 03" E 040º 30' 17" - E 040º 31' 07"	Soft Muddy/ Fine Silt
S5	Off the mouth of River Sabaki	S 03º 01' 36" – S 03º 11' 29" E 40º 10' 57" – E 40º 16' 38"	Soft Muddy/ Silt
S6	Off the mouth of River Tana	S 02º 33' 31" – S 02º 35' 31" E 40º 29' 12" – E 40º 31' 41"	Sand/Silt/Fine Silt/Sea grass

3.3.2 Data Collection

A total of 1364 specimens were randomly collected from the six sample stations in the estuaries and shallow waters fishing grounds. Sample collections were carried out in two separate surveys of ten and thirteen days during Southeast monsoon (SEM) and Northeast monsoon (NEM) seasons respectively. The NEM season is characterized by lower precipitation rates, higher salinities and reduced river discharge, while the SEM season has reversed sea conditions (Kitheka, Obiero, & Nthenge, 2005). In the estuaries stations, 8 hauls were made daily by two people using a seine net of 1 inch mesh size measuring 20 m long by 1.25 m high (Kaka *et al.*, 2019). In the shallow waters, surveys of one hour intervals were conducted at a speed of 2.5 knots using a 496 horsepower Fishing Vessel (FV VEGA) fitted with a 70 mm mesh size towing net of 44.3 m long and 45 mm mesh size cod end. The sample collections were carried out as described in Chapter Three. The samples were sorted out by species, identified morphologically according to Chan (1998) and weighted per species.

The morphometric measurements for body length (BL), carapace length (CL) and total length (TL) were taken to the nearest 0.1 mm using a vernier calliper. Where individual measured < 21 mm CL, it was regarded as juvenile (Brito & Pena, 2007). The water sample was collected for salinity and temperature measurements using a niskin bottle where water temperature and salinity were recorded for each station before the start of every sampling (Kaka *et al.*, 2019). Additionally, water depths from S5 and S6 were determined by use of echo sounder device onboard the Fishing Vessel VEGA while those from the estuaries were determined using handheld portable ultrasonic echo sounder water depth meter.

3.3.3 Data analyses

The one–way Analysis of Variance (ANOVA) followed by Tukey HSD multiple comparison tests was used to test for significant differences in the environmental factors (temperature, distance from the shore, water depth and salinity) between sampling stations. The multiple linear regressions were also used to evaluate environmental factors' influence on the abundance of species. The species abundance (%) was determined as the number of a particular species, indicating a percentage of the total catch of that species, while the relative abundance (%) of juveniles per species in every catch was comparatively determined in every sample station for each season (Fynn & Mensah, 2012).

Sex ratio of the penaeid shrimps was determined by calculating proportions of males and females. The differences in sex ratio between male and female individuals of the penaeid shrimps were analysed and tested for significance of any deviation by using non-parametric Chi–square (χ^2) goodness of fit test (Pearson, 1934). All statistical analyses were calculated using the program Minitab 17 (Mathews, 2005).

3.4 Results

3.4.1 Species composition and population abundance

In this study, the following penaeid shrimps were found in Malindi–Ungwana Bay: *Fenneropenaeus indicus* was the most abundant species at 30.8% followed by *Metapenaeus monoceros* (24.9%), *Penaeus semisulcatus* (15.2%), *Marsupenaeus japonicus* (10.3%), *Penaeus monodon* (9.7%) and the least was *Penaeus canaliculatus* (0.9%). During the NEM season, *F. indicus* was the most abundant species followed closely by *M. japonicus*, while *M. monoceros* and *P. monodon* were third and forth abundant species respectively (Table 3.2). Although *P. semisulcatus* was the second least abundant species, it dominated the catches from S5. *F. indicus* dominated the catches from S4 and S6, while *P. monodon* dominated in S2 and S3. There were no shrimps found at S1 during the NEM season. In estuarine sample stations, *F. indicus* was the only species with high number of juveniles at S2 and S3, while juveniles of *M. monoceros* dominated the catches from S5 and S6 in the shallow waters.

During the SEM season, *F. indicus* was the most abundant species at 29.6%, closely followed by *M. monoceros* (28.6%) and third distant by *P. semisulcatus* at 19% (Table 3.3). During this season, *F. indicus* dominated the catches from S3 and S6, while *monoceros* dominated at S2 and S6. The catches from S5 were equally dominated by *M. monoceros*, *P. semisulcatus* and *F. indicus*, while S1 comprised of juveniles of *Metapenaeus* and *Penaeus* species. In the estuarine waters, juveniles of *M. monoceros* dominated catches from S3 and S4, while juveniles of *F. indicus* and *P. monodon* dominated catches from S3. *M. monoceros* showed considerable number of juveniles (34.5%) were present at S5 during NEM and virtually absent during SEM season. Generally, *F. indicus* and *P. canaliculatus* remained the most and least abundant species appearing in the catches in both seasons respectively.

Table 3.2: Species abundance (%) of penaeid shrimps in Malindi–Ungwana Bay during Northeast Monsoon season.

Species	**Station**						**Species Abundance**
	S1	***S2***	***S3***	***S4***	***S5***	***S6***	
Penaeus sp.	–	–	–	–	–	–	***0.0%***
Metapenaeus sp.	–	–	–	–	***2.1*** *[50]*	***1.1*** *[0]*	***0.9%***
M. monoceros	–	–	–	–	***30.9*** *[34.5]*	***25.3*** *[10.4]*	***17.1%***
P. canaliculatus	–	–	–	–	***7.4*** *[0]*	–	***1.6%***
F. indicus	–	**38.6** *[59.3]*	**36.7** *[18.2]*	**75.0** *[0]*	**16.0** *[0]*	**31.8** *[3.5]*	***33.3%***
M. japonicus	–	**60.0** *[0]*	**56.7** *[0]*	–	–	**17.6** *[0]*	***24.7%***
P. semisulcatus	–	**1.4** *[0]*	–	–	**31.9** *[0]*	–	***7.1%***
P. monodon	–	–	**6.6** *[0]*	**25.0** *[0]*	**11.7** *[0]*	**24.2** *[0]*	**15.3%**
Sample size (n)	**0**	**70**	**60**	**32**	**94**	**182**	

Relative abundance *[%]* of juvenile shrimp per species in each station

Table 3.3: Species abundance (%) of penaeid shrimps in Malindi–Ungwana Bay during Southeast Monsoon season.

Species	**Station**						**Species Abundance**
	S1	***S2***	***S3***	***S4***	***S5***	***S6***	
Penaeus sp.	**2.0** *[100]*	**20.0** *[66.7]*	–	**62.0** *[100]*	–	–	***4.8%***
Metapenaeus sp.	**98.0** *[100]*	**5.0** *[33.3]*	–	**24.0** *[100]*	–	–	***6.9%***
M. monoceros	–	**41.7** *[4]*	**10.0** *[66.7)*	**4.0** *[100]*	**34.5** *[0]*	**32.4** *[9.9]*	**28.6%**
P. canaliculatus	–	–	–	–	–	**0.9** *[0]*	**0.5%**
F. indicus	–	–	**70.0** *[64.3]*	–	**31.0** *[0]*	**33.3** *[1.1]*	**29.6%**
M. japonicus	–	–	–	–	–	**5.9** *[0]*	**3.6%**
P. semisulcatus	–	**33.3** *[35]*	**1.7** *[0]*	–	**34.5** *[0]*	**18.8** *[0]*	**19.0%**
P. monodon	–	–	**18.3** *[27.3]*	**10.0** *[0]*	–	**8.7** *[0]*	**7.0%**
Sample size (n)	**50**	**60**	**60**	**50**	**142**	**564**	

Relative abundance *[%]* of juvenile shrimp per species in each station

3.4.2 Shrimp sizes

The results for size frequency data, for male and female, collected during the two seasons are comparatively plotted in Figures 3.2 – 3.7. In this study, some distinct differences were observed in the size distribution patterns of penaeid shrimps in Malindi–Ungwana Bay. For females, the smallest individuals with a total length of 80 mm TL were observed in *P. monodon* during SEM season while the largest sizes (> 280 mm TL) were observed in the same species during the same season. The smallest male individual (70 mm TL) was observed in *M. monoceros* during the NEM season while large sizes (> 210 mm) were observed in *P. monodon* in both seasons. However, *P. canaliculatus* had only a mean TL for male shrimp of 150.3±24.8 mm during NEM season, while a mean TL for female shrimp of 155±7.4 mm during SEM season (Figure 3.3). For *P. monodon,* high mean TL for male and female shrimp were 190.8±13.4 mm and 197.8±38.8 mm respectively during NEM season (Figure 3.2).

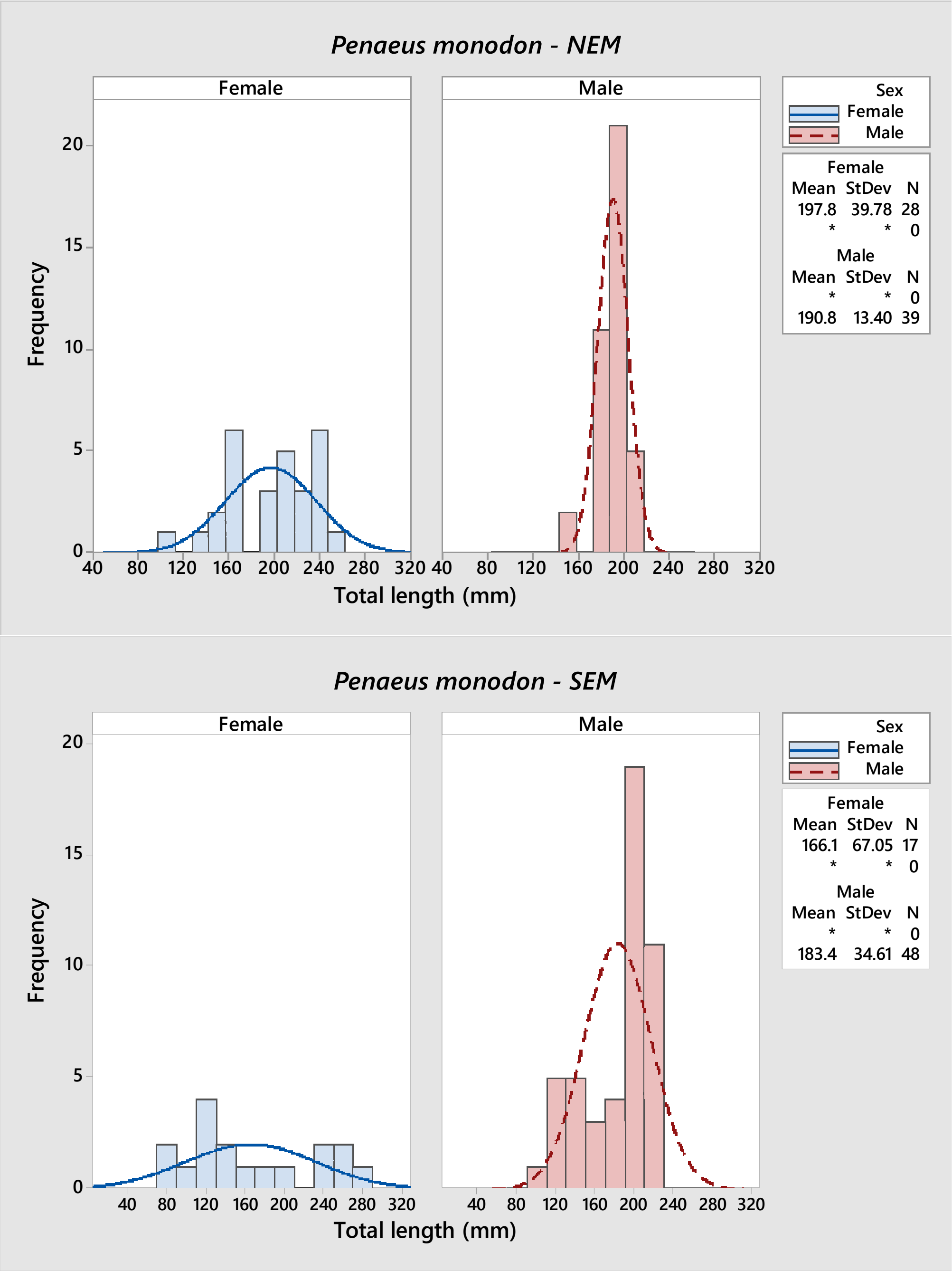


Figure 3.2: Length frequency distribution and normal curve of *Penaeus monodon*.

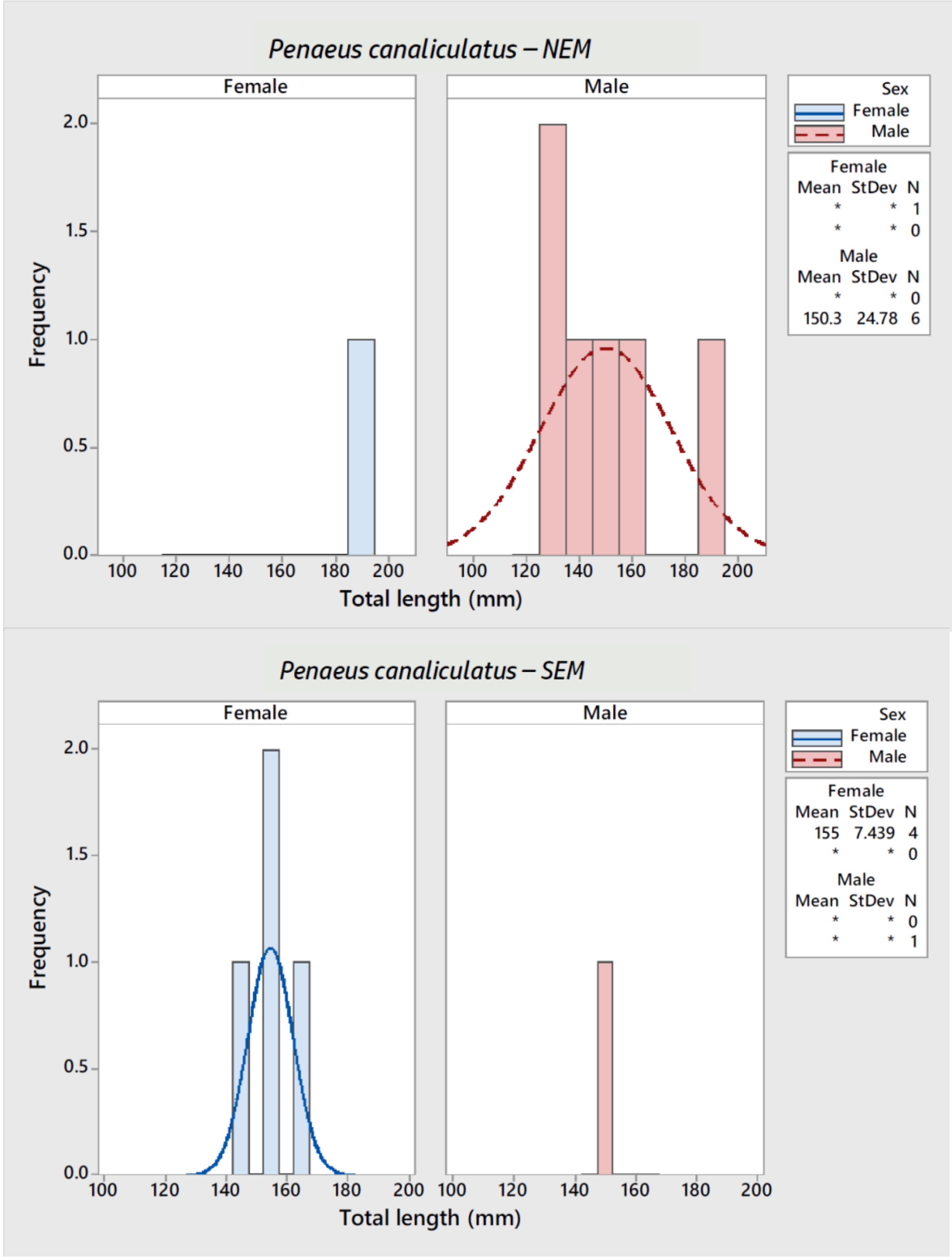


Figure 3.3: Length frequency distribution and normal curve of *Penaeus canaliculatus*.

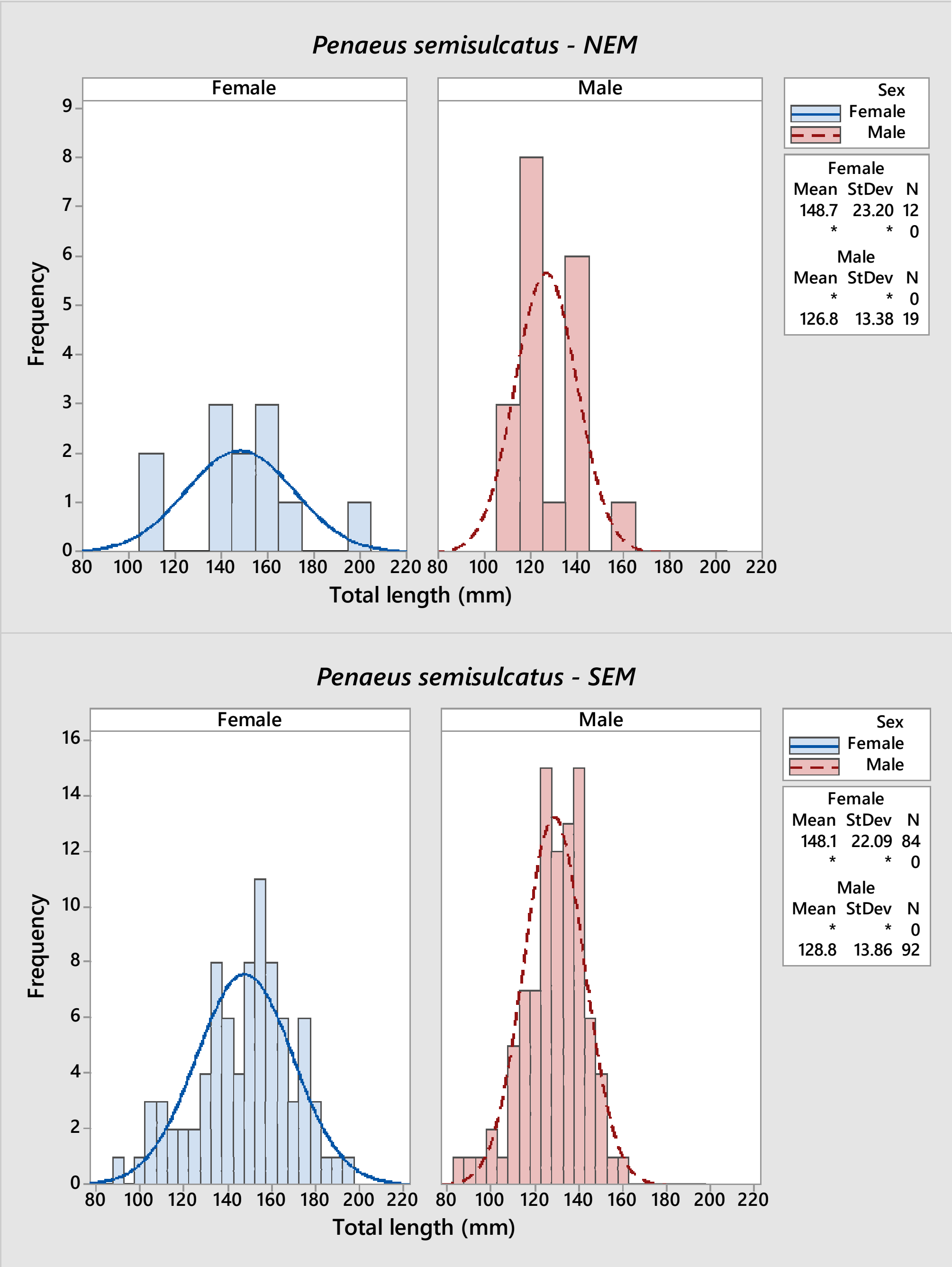


Figure 3.4: Length frequency distribution and normal curve of *Penaeus semisulcatus*.

The highest mean TL for *P. semisulcatus* was 128.8±13.9 mm for male during SEM season, while 148.7±23.2 mm for female during NEM season (Figure 3.4). In contrast, for *M. japonicus*, the highest mean TL was 132.4±17.6 mm for male during NEM season, while 145.6±17.0 mm for female during SEM season (Figure 3.5).

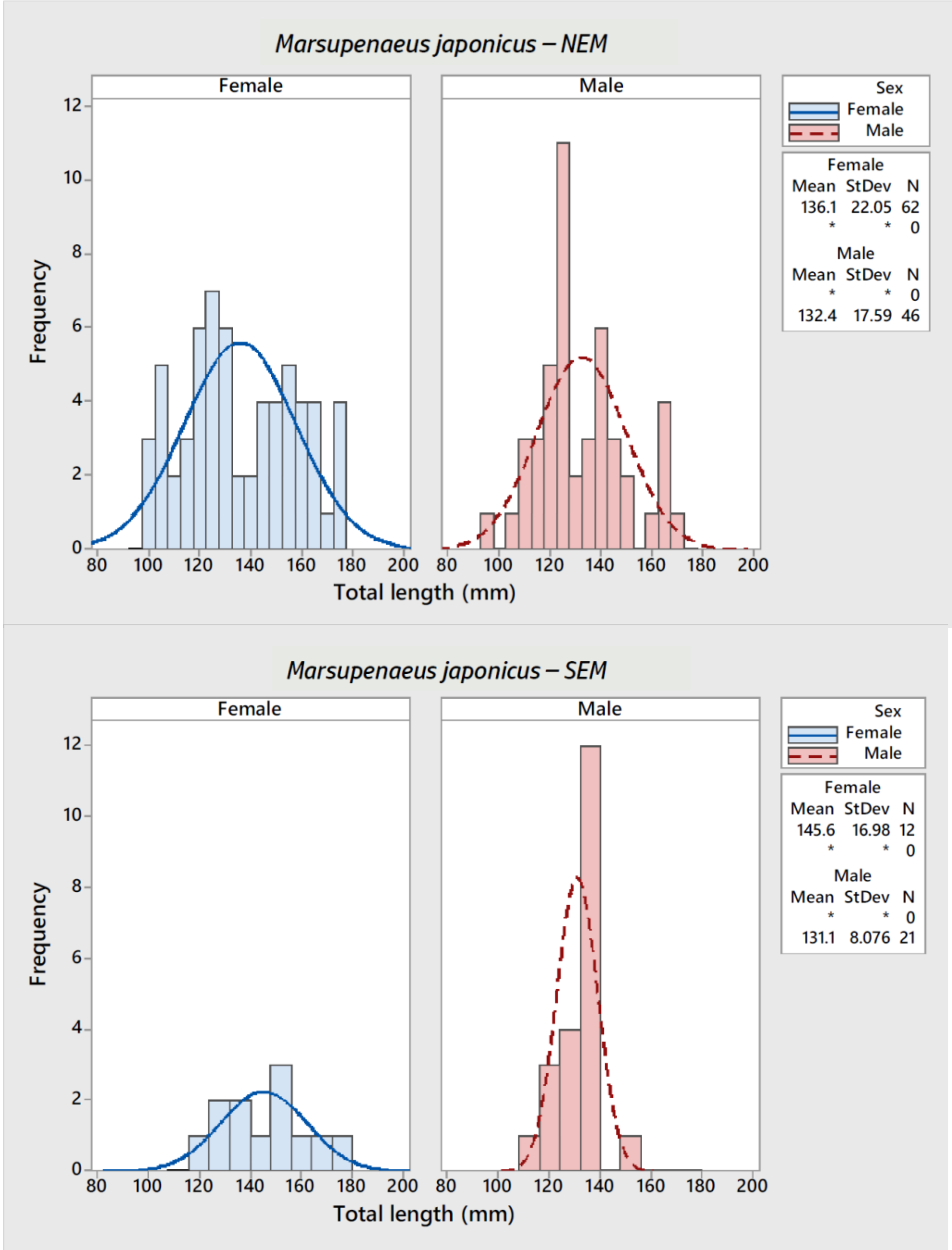


Figure 3.5: Length frequency distribution and normal curve of *Marsupenaeus japonicus*.

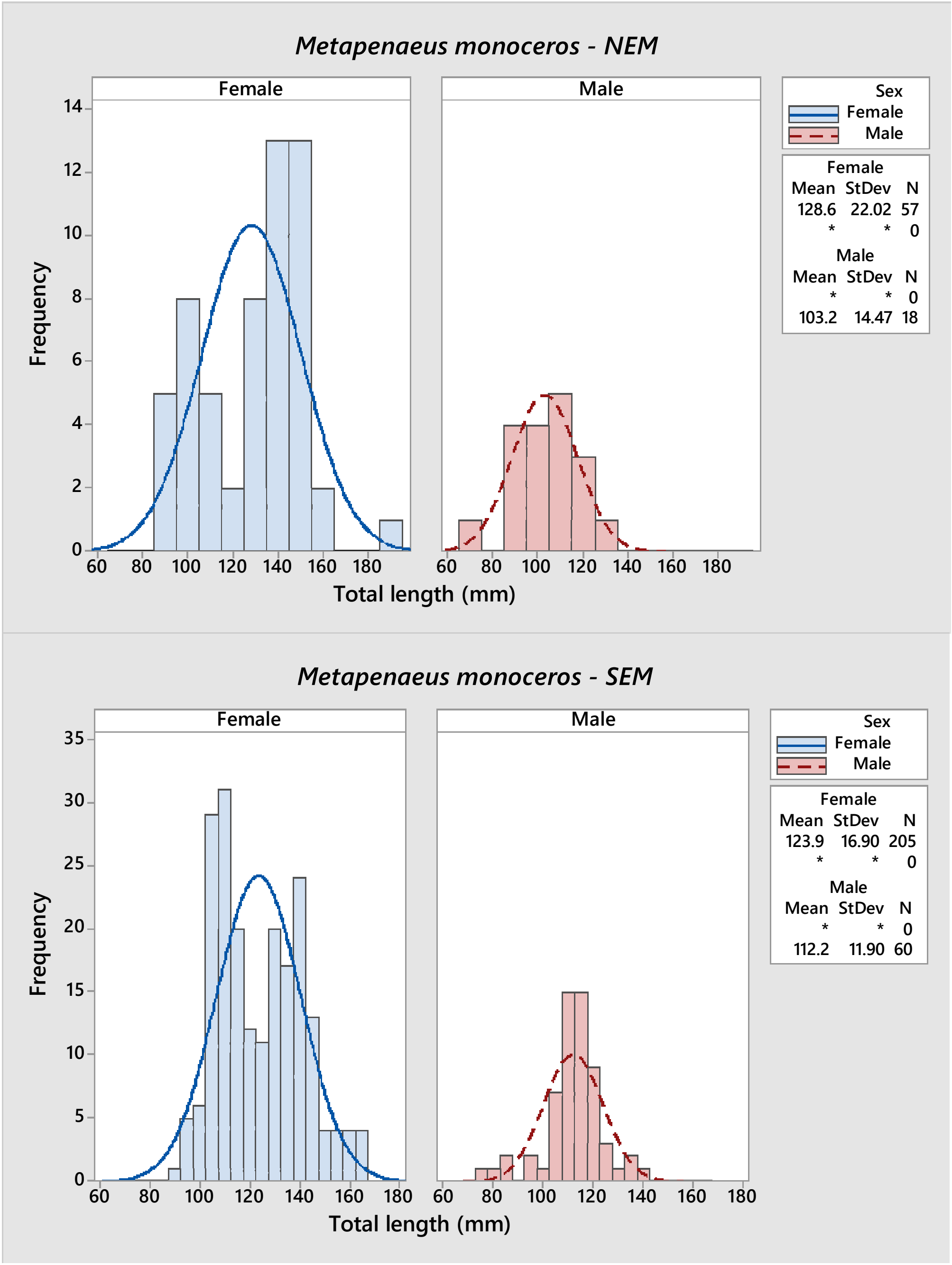


Figure 3.6: Length frequency distribution and normal curve of *Metapenaeus monoceros*.

The highest mean TL for *M. monoceros* was 112.2±11.9 mm for male during SEM season, while 128.6±22.0 mm for female during NEM season (Figure 3.6). For *F.*

indicus, high mean TL for male and female shrimp were 147.1±16.0 mm and 158.3±21.4 mm respectively during SEM season (Figure 3.7).

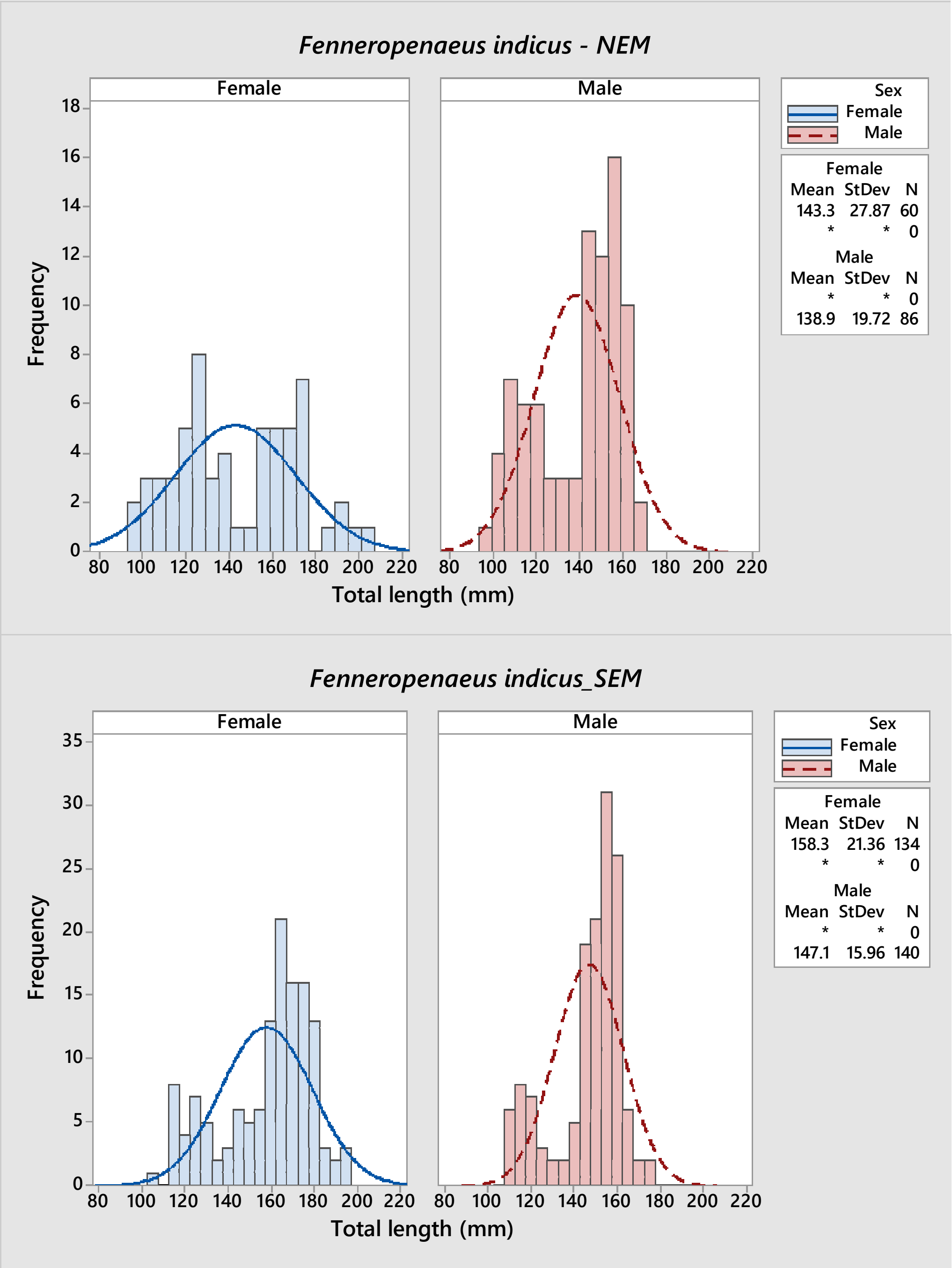


Figure 3.7: Length frequency distribution and normal curve of *Fenneropenaeus indicus*.

3.4.3 Environmental parameters and species associations

The results of multiple linear regression between the shrimp abundance and environmental variables in Malindi–Ungwana Bay are summarized in Table 3.4. In this study, the shrimp abundance was significantly affected by water depth and distance from the shore ($p < 0.05$). All environmental variables except depth showed a positive relationship with the shrimp abundance, that is when water depth increases, the shrimp abundance decreases. Similarly, the results of this study found that the abundances of penaeid shrimps increased significantly with distance from the shoreline.

Table 3.4: Multiple linear regression between the shrimps abundance and environmental variables in Malindi–Ungwana Bay.

Variable	Coefficient	F–Value	*p*–Value
Depth (m)	–6.11	8.03	0.007
Temperature (^{0}C)	15.9	2.36	0.133
Salinity (‰)	0.90	0.01	0.923
Distance from the Shore (m)	0.012	6.98	0.012

Table 3.5: One way ANOVA testing similarity of seasonal environmental variables between sample stations in Malindi–Ungwana Bay.

	Environmental variable							
	Depth (m)		Temperature (^{0}C)		Salinity (‰)		Distance from the Shore (m)	
Station	**NEM**	**SEM**	**NEM**	**SEM**	**NEM**	**SEM**	**NEM**	**SEM**
S1	0.6±0.15^{b}	0.7±0.06^{b}	28.1±0.15^{bcd}	28.8±0.21^{ab}	35.9±0.12^{ab}	33.9±0.27^{de}	3.0±0.50^{b}	3.2±0.21^{b}
S2	1.3±0.15^{b}	1.0±0.10^{b}	27.9±0.27^{cd}	28.2±0.27^{bcd}	35.4±0.15^{ab}	35.0±0.15^{bcd}	7.8±1.04^{b}	6.0±1.11^{b}
S3	1.2±0.15^{b}	0.8±0.06^{b}	27.0±0.20^{e}	28.9±0.12^{a}	35.9±0.25^{ab}	35.5±0.31^{ab}	5.9±2.00^{b}	4.8±1.76^{b}
S4	0.9±0.12^{b}	0.8±0.10^{b}	27.6±0.06^{de}	28.6±0.36^{abc}	33.4±1.19^{e}	34.2±0.21^{cde}	17.7±2.52^{b}	13.3±3.06^{b}
S5	12.1±6.06^{a}	10.9±4.09^{a}	28.1±0.46^{cd}	29.0±0.06^{a}	36.2±0.21^{a}	35.2±0.31^{bc}	5880±940^{a}	5510±699^{a}
S6	1.8±0.57^{b}	1.7±0.40^{b}	27.8±0.24^{d}	28.9±0.14^{a}	36.2±0.13^{a}	35.8±0.40^{ab}	4273±2578^{a}	3658±1891^{a}
R^2 (Adj)	73.84%		85.12%		82.50%		82.13%	
F– Value	11.01		21.28		17.71		17.29	
***p*– Value**	0.0000		0.0000		0.0000		0.0000	

(Sample stations with descriptive habitat type as S1 (Soft Muddy), S2 (Creek/ Sea grass/ Silt), S3 (Creek/ Sand/ Silt), S4 (Soft Muddy/ Fine Silt), S5 (Soft Muddy/ Silt) and S6 (Sand/ Silt/ Fine Silt/ Sea grass); Mean values ± Standard deviations of data collected in each sample station; *p* is probability of significance of the difference at α=0.05)

The environmental variables such as depth, distance from the shore, salinity and temperature are summarized in Table 3.5. In this study, the environmental variables differed significantly between the sample stations ($p < 0.05$). The mean values of water salinities in all the sample stations except S4 were slightly higher during the NEM than SEM seasons. In contrast, the mean values of water temperature remained high throughout the SEM season. In this study, water depths varied between 0.6 – 12.1 m and 0.7 – 10.9 m during the NEM and SEM seasons respectively, while the mean values of distance from the shore varied more in the shallow waters (S5 and S6) than the estuarine sample stations (S1, S2, S3 and S4) during the two seasons.

3.4.4 Sex ratio

This study revealed an overall sex ratio of 1:1.50 in favour of females. A chi-square goodness of fit test was performed and the results showed that the ratio was significantly different from a 1:1 ratio ($\chi^2 = 34.3$, $p < 0.05$) (Table 3.6). The sex ratio deviated significantly during NEM season ($\chi^2 = 30.8$, $p < 0.05$) but remained the same as expected during SEM season ($\chi^2 = 9.2$, $p > 0.05$). The sex ratio of several species such as *M. monoceros, P. canaliculatus, M. japonicus* and *P. monodon* were in favour of females except *P. semisulcatus* which the sex ratio was in favour of males. For *M. japonicus*, however, there were more females than males during NEM season compared to SEM season as opposed to *P. canaliculatus*. For *F. indicus* and *P. monodon* remained relatively the same as the expected sex ratio of 1:1, while *M. monoceros* females were favoured more than males as opposed to *P. semisulcatus* males being favoured more than females in both seasons.

Table 3.6: Chi–Square (χ^2) Goodness–of–Fit Test for sex ratio of penaeid shrimps in Malindi–Ungwana Bay.

Species	**Overall**		**North East Monsoon**		**South East Monsoon**	
	x±S.E.	Contribution to χ^2	x±S.E.	Contribution to χ^2	x±S.E.	Contribution to χ^2
M. monoceros	3.38±1.88	27.120	7.63±6.70	22.418	2.10±0.61	6.195
P. canaliculatus	2.08±1.92	2.201	0.17±0.00	4.517	4.00±0.00	0.035
F. indicus	0.98±0.21	0.055	0.96±0.34	0.001	1.01±0.17	0.103
M. japonicus	1.17±0.23	1.694	1.38±0.16	0.107	0.57±0.00	2.590
P. monodon	1.03±0.33	0.201	1.02±0.23	0.124	1.04±0.82	0.078
P. semisulcatus	0.57±0.19	3.027	0.33±0.33	3.603	0.69±0.23	0.218
χ^2 :	34.298		30.770		9.219	
***p* – Value:**	0.000		0.000		0.101	

(x – Mean sex ratio; ± Standard errors; p is probability of significance of the difference at α=0.05)

3.5 Discussion

3.5.1 Species composition and population abundance

In this study, all economic important penaeid shrimps that were captured in the estuarine waters comprised of the same species as those captured in the shallow waters of Malindi–Ungwana Bay by commercial bottom trawl. Munga *et al.* (2013) reported a similar species composition from an industrial fishery data off the coastal waters of Malindi–Ungwana Bay with slight differences in their species relative abundance as *F. indicus* (31.9%) being dominant, *M. monoceros* (25.8%), *P. semisulcatus* (22.8), *P. monodon* (14.5%) and least abundant species was *M. japonicus* (5.0%). The recruitment of juveniles and high dominance of *Metapenaeus spp.* alongside the adult *M. monoceros* during the two seasons as well as *F. indicus, P. semisulcatus* and *P. monodon* during SEM season suggested that Malindi–Ungwana Bay is as a nursery area for these species. Similarly, Blaber (2009) reported a significant relationship between recruitment to the fishery and juvenile density in the nursery grounds, emphasizing the importance of the juvenile habitat to fisheries production.

Sample stations, S2 and S3 were in the brackish water covered by mangrove ecosystem which provided penaeid shrimp with protection, food and non burrowing habits. In other studies, Rosle and Ibrahim (2017) reported a high abundance of *F. indicus* and *P. monodon* in the mangroves of Kelantan Delta in Malaysia. *M. monoceros* preferred the intertidal sand flats or mud substrates for either predation avoidance or food availability (de Freitas, 1986; Macia, 2004). More similar results to this study on seasonal shrimp abundance were reported by Teikwa and Mgaya (2003) in Tanzania, and Brito and Pena (2007) in Mozambique.

3.5.2 Shrimp sizes

Considering the wide variability in life histories and the range of habitats occupied by different developmental stages of species of penaeid shrimps, it is not surprising that they exhibit rather complex seasonal and spatial life-history patterns (Dall *et al.*, 1990). In this study, some distinct differences were observed in the size distribution patterns of penaeid shrimps in Malindi–Ungwana Bay (Figures 3.2 – 3.7). However, there were differences of area for juvenile and adult inhabitant (Tables 3.2 and 3.3). Some penaeid shrimps caught in this study were dominated by juvenile stages such as *F. indicus* and *M. monoceros* during the two seasons while juveniles of *P. semisulcatus* and *P. monodon* were observed during SEM season. This confirms the role of Malindi–Ungwana Bay as nursery area for penaeid shrimps. This study was in agreement with the findings of Rosle and Ibrahim (2017) that smaller shrimps are normally to be less active swimmers compared to bigger shrimps, and therefore their tendency to be transported to the mangrove edges and mud flats are high.

3.5.3 Environmental parameters and species associations

Penaeid shrimp inhabit for a major proportion of their life cycle in estuarine areas, which are often prone to temperature and salinity fluctuations that occur as a result of tidal and freshwater mixing (Pinto and Maheshwari, 2012; Promhom *et al.*, 2015). In this study, the environmental variables such as salinity, temperature, distance from the shore and depth differed significantly between the sample stations ($p < 0.05$). However, the shrimp abundance was significantly affected by water depth and distance from the shore

($p < 0.05$), while the water temperatures and salinities did not significantly affect the shrimp abundance ($p > 0.05$).

In this study, water temperatures and salinities were ranging from 26.8 – 28.6 ^{0}C and 32.2 – 36.4 ‰ respectively during the NEM season with small variations in the water temperatures (27.9 – 29.1 ^{0}C) and salinities (33.6 – 36.2 ‰) during SEM season. The presence of high number of ovigerous females as well as positive allometric growth ($b > 3$) and good condition factors (K) indicates that water temperature and salinity ranges in the present study are favourable for growth and survival of these penaeid shrimps. This study and other studies elsewhere have shown that growth and survival for penaeid shrimps coincided best at water temperatures of 28 – 30 ^{0}C and salinities of 33 – 40 ‰ (Aktaş and Cavdar, 2012; Chaitanawisuti *et al.*, 2013; Promhom *et al.*, 2015). Juveniles of *M. monoceros, F. indicus, P. semisulcatus* and *P. monodon* seem to prefer most the estuarine waters of Malindi–Ungwana Bay during SEM season when salinity levels slightly dropped within the estuaries, and as such salinity drives recruitment of shrimps in Malindi–Ungwana Bay same as in the estuary of River Pungué to the Sofala Bank in Mozambique (Brito & Pena, 2007).

In this study, water depth showed a negative relationship with the shrimp abundance, that is, when water depth increased, the shrimp abundance decreased (Table 3.4). Additionally, sediments at sample stations may have differed in organic content, and this influenced shrimps distribution and abundance. In the shallow water sample stations at S6 which was less deep than S5, shrimp abundance was high during the two seasons. The substrate type at S6 comprised of diversity of sand, silt, fine silt and sea grass while the substrate of S5 was soft muddy and Silt (Table 3.1). Montoya *et al.* (2014) suggested that organisms of are adapted to exploit and survive in dynamic habitats, and the population persistence for some time, if not most. Probably, this could be one of the reasons for more shrimp abundance at S6 than S5 during the two seasons. Similar results were observed by Munga *et al.* (2016) when looking at species composition of fisheries resources of the Tana and Sabaki Estuaries in the Malindi–Ungwana Bay, Kenya.

3.5.4 Sex ratio

The results of sex ratio showed that the overall combined sex ratio deviated from the expected ratio of 1:1 ($p < 0.05$) with females dominating the total catch (1 male: 1.50 female). Choy (1988) reported that owing to increased reproductive activity such as maturation and mating, catchability in female shrimps is said to be higher than male species. The results of this study on the skewed sex ratio agrees with Kalogirou *et al.* (2017) that showed ovigerous females decreased with increased depths. Despite the dominance of females in the catches, no information on the gear selectivity used in this study was available for the captured penaeid shrimps.

3.6 Conclusion

The findings of this study have shown higher species abundance during SEM than NEM seasons despite proportional decrease with increasing water depths. This study failed to reject the hypothesis that every penaeid shrimp has unequal population abundance in Malindi–Ungwana Bay. The high number of juveniles recruited in the Malindi–Ungwana Bay suggested that this Bay is the nursery area for *M. monoceros, F. indicus, P. semisulcatus* and *P. monodon*. Hence, the management of penaeid shrimp fishery of Malindi–Ungwana Bay requires close monitoring of the catches on monthly basis.

In order to allow coexistence of the artisanal and commercial trawl fleets, an appropriate management goal for the artisanal fleets based on findings of this study should be adopted to thwart growth overfishing in the estuarine area. A review of the Prawn Fisheries Management Plan of 2010 is however, recommended for an effective management of penaeid shrimps fishery in Malindi–Ungwana Bay.

CHAPTER FOUR

4. MORPHOMETRIC LENGTH–WEIGHT RELATIONSHIPS OF WILD PENAEID SHRIMPS IN MALINDI–UNGWANA BAY: IMPLICATIONS TO AQUACULTURE DEVELOPMENT IN KENYA

4.1 Abstract

This study was designed to investigate and describe the morphometric length-weight relationships of penaeid shrimps during the two monsoon seasons, namely Southeast monsoon (SEM) and Northeast monsoon (NEM), in Malindi–Ungwana Bay of Kenya. A total of 1238 penaeid shrimps were randomly collected from six sample stations with four sample stations established within the estuaries while the remaining two in the shallow waters of the Malindi–Ungwana Bay. Penaeid shrimps were identified as *Fenneropenaeus indicus***,** *Metapenaeus monoceros***,** *Penaeus semisulcatus*, *Marsupenaeus japonicus*, *Penaeus monodon* and *Penaeus canaliculatus* with SEM recording more diverse species than the NEM species. The length-weight relationship analyses of the most sampled penaeid shrimps exhibited positive allometric growth significantly different from 3.0 ($p < 0.05$) with strong relationship between lengths and weights of these species. The carapace length at first maturity (L_{50}) of the six penaeid shrimps suggested that their spawning started at different sizes with *P. monodon* achieving the largest size (L_{50} = 54.2 mm CL) while *M. monoceros* at the smallest size (L_{50} = 30.2 mm CL). Large proportions of female *F. indicus, P. semisulcatus* and *M. monoceros* had gonad stages IV and V recorded during SEM than in NEM seasons. The abundance of *F. indicus* and *M. monoceros* with matured gonads in both seasons confirmed the suitability of *F. indicus* and *M. monoceros* for sustainable shrimp culture production in Kenya.

4.2 Introduction

Penaeid shrimps are considered as one of the most valuable fishery resources in Malindi–Ungwana Bay in the northern coast of Kenya (E. Kimani *et al.*, 2018). Nevertheless, wild stocks of penaeid shrimp have declined rapidly in recent years, largely as a result of fishing pressure and habitat loss in the mangrove and estuarine areas (Groeneveld & Everett, 2015). Information on the early life of penaeid shrimps that might be useful for effective management strategies or coastal aquaculture development in Malindi–Ungwana Bay is relatively inadequate. Few studies from the commercial fishery catches on the species composition, distribution patterns, abundance, population structure and recruitment patterns of some penaeid shrimps have been presented by Kimani *et al.* (2011), Mkare *et al.* (2014) and (Munga *et al.*, 2013; 2014).

In fisheries biology, length versus weight and/ or length versus length relationships are important tools as they provide information on growth patterns and the general condition of the fish that can be used in population structure analysis (Guino-o, 2012; Zlateva, 2017; Perdana *et al.*, 2018). The condition factor (*K*) is used to compare the condition such as fatness or wellbeing of fish (Getso, Abdullahi, & Yola, 2017). It is based on the hypothesis that heavier shrimp of a particular length are in a better physiological condition. Penaeid shrimp like any other marine organism is said to exhibit isometric growth when length increases in equal proportion with body weight, the regression coefficient for isometric growth is three ($b = 3$) and values greater than three ($b > 3$) or less than three ($b < 3$) indicates allometric growth (Kaka *et al.*, 2019). However, some differences have been reported among the studies of penaeid species, sexes, sites and seasons for both cultured and wild populations (Pérez-Castañeda & Defeo, 2002).

Despite great economic values of penaeid shrimps in Kenya, there is little information on morphometric length-weight relationships of these species in Malindi–Ungwana Bay. This study was therefore designed to evaluate the relative growths and condition factors of different penaeid shrimps in Malindi–Ungwana Bay for sustainable mariculture programs as well as formulation of sound management strategies for such important fisheries.

4.3 Materials and Methods

4.3.1 Study area

Malindi–Ungwana Bay is located between Malindi (Latitudes: S 03º 10' 00" – S 02º 30' 00") and Ras Shaka, north of Kipini (Longitudes: E 40º 05' 00" – E 40º 30' 00") covering the Ungwana Bay along the Northern Coast of Kenya (Figure 3.1). Malindi–Ungwana Bay is characterized by two major rivers, which discharge into the Bay, with River Sabaki at its southern most limit, while River Tana discharges at its northern most limit. During the spring tides, Malindi–Ungwana Bay has an average depths of 12 m and 18 m at 1.5 nautical miles and 6.0 nautical miles respectively, followed by a sharp depth increase of 100 m after 7.0 nautical miles but generally decreasing northwards (Mwatha, 2002). The Malindi–Ungwana Bay region is influenced by the Southeast monsoon (SEM) winds between April and October and the Northeast monsoon (NEM) winds between November and March (McClanahan, 1988; Munga *et al.*, 2013). The river discharge is highest during SEM season due to heavy rains, while NEM season receives less rain resulting to a reduced river discharge during these months (Omukoto *et al.*, 2015; Kimani *et al.*, 2018). These oceanographic features of the Bay presumably facilitate prawn larval dispersal and mixing, with implications for recruitment patterns and fisheries dynamics.

4.3.2 Data Collection

The study had six sample stations, four of which were located within the estuaries (S1, S2, S3 and S4) while the other two sample stations (S5 and S6) were within the shallow waters (Figure 3.1; Table 3.1). Penaeid shrimps were collected from these sample stations during the two monsoon seasons with SEM season being cooler than NEM season. Every seasonal sampling had two separate surveys of 10 and 13 days duration conducted for sample collections in the estuary and shallow water sites respectively. Random samples were collected from the estuaries of four main artisanal fishing areas (S1, S2, S3 and S4) and two others within the shallow waters trawling grounds (S5 and S6). Establishment of sample stations was based on factors such as frequent use of the sites by artisanal fishermen, presence of high biomass of aquatic vegetation, areas surrounding high influx of fresh water into the ocean, and areas known to be the main trawling grounds by the shallow water shrimp trawlers.

In the estuaries, sampling was done using a 1 inch (25.4 mm) stretched mesh size seine net measuring 20 m long by 1.25 m high. Fishing was undertaken by two people during low tide with eight hauls made per sampling day. While in the shallow waters' trawling grounds, the Fishing Vessel VEGA (measuring 25 m long and with gross register tones of 146) with 496 horsepower engine capacity and a commercial bottom trawler with a fitted 70 mm mesh size towing net (44.3 m long and 45 mm mesh size cod end) was used to conduct the surveys for one hour at a speed of 2.5 knots. Coordinates for every shallow water trawling transect and sampling point in the estuaries were recorded and depths were taken at the start and end of each tow.

For every small reasonable catch (at least 30 specimens), the whole catch was considered as a single sample, sorted out by species, identified and weighted per species; and where the total catch was too large to manage as a single sample, sampling proportion was performed at 10% of the catch with a desired margin of error at the 95% confidence level as the subsample (Tonks, Griffiths, Heales, Brewer, & Dell, 2008). These samples were considered to be representative of the trawl catch and the sampling procedures adopted allowed quantitative comparisons of the samples in relative terms.

The samples were identified morphologically according to Chan (1998). Where the identification of the specimens was difficult, the sample were characterized to the genus level due to lack of distinct characteristics and then subjected to further genetic analysis to identify them to species level. A Vernier caliper was used to measure individuals in each sample for carapace length (CL) and total length (TL) to the nearest 0.1 mm, while body weight (BW) was measured to the nearest 0.1 gram using an electronic weighing balance.

Every population sample was sorted out according to the sex composition of each species. The presence of eggs on female shrimps was recorded and the stages of ovarian maturation were classified on the basis of coloration to five stages; undeveloped (I) and developing (II) stages, nearly ripe (III), ripe (IV) and spent (V) stages as described by Amanat and Qureshi (2011).

4.3.3 Data analyses

The length-weight relationship of penaeid species, such as total length versus shrimp body weight was calculated using the exponential regression formula: $W = aL^b$ (Le Cren, 1951) where, *W* is BW in grams (g); *L* is the length in centimeters (cm); *a* is the constant (intercept); and *b* is the length exponent (slope). The parameters of length-weight relationship '*a*' (intercept) and '*b*' (exponent) were estimated from a linear regression function, $Y = a + bX$, by logarithmically expressing this equation as: $\log W = \log a + b \log L$ where, *W* is BW in grams (g); where *L* is the length in centimeters (cm); *a* and *b* are constants showing the initial growth index and growth coefficient respectively. The isometric ($b = 3$) or allometric (negative allometric when $b < 3$ or positive allometric when $b > 3$) growth patterns, with a confidence level of 95%, was determined according to Froese (2006).

Also the Fulton's condition factor (*K*) for each species in every sample station was determined according to the equation by Froese (2006): $K = \frac{W}{L^3} \times 100\%$ where, *W* is BW in grams (g); *L* is the TL in centimeters (cm); factor 100 is used to bring *K* close to unity. By using female shrimp individuals, gonad maturity stages were categorized into two distinct groups, where I and II as immature and III – V as mature (Amanat and Qureshi, 2011), and the length at first maturity (L_{50}) being determined by calculating the proportion of the mature individuals for each length class (Teikwa & Mgaya, 2003). All statistical analyses were calculated using the program Minitab 17 (Mathews, 2005).

4.4 Results

4.4.1 Penaeid shrimp Length–weight relationships

The analyses of length–weight relationships of penaeid shrimps per season are summarized in Tables 4.1 and 4.2. Both tables show the average total length and body weight values of each penaeid shrimp population sampled per sample station in Malindi–Ungwana Bay. However, there was no penaeid shrimp that was identified to the species level at S1 during the two seasons. The length–weight relationship parameters such as a and b, 95% confidence interval for b as well as the coefficient of determination (R^2) are also presented in same tables. During NEM season, *P. monodon* were recorded as big in size at every site sampled, while *M. monoceros* were smaller sizes in all the sample sites. Most shrimps from various sample stations exhibited positive allometric growth with the values of b being greater than 3 ($b > 3$). There were strong relationships between the lengths and weights of these species judging from the results of regression coefficients in most sample stations except for *F. indicus* from S2 and S4 with the models explaining data variability of 18.1% and 22.2% respectively. However, the b values for most shrimps were significantly different from 3 ($p < 0.05$) during NEM season, same as those from various sample stations during the SEM season.

In a few cases, length–weight relationships estimated in this study showed that penaeid shrimp may be suffering from negative algometric growth during NEM season for *F. indicus* ($b = 0.91$) and *M. japonicus* ($b = 2.64$) in S2, *F. indicus* ($b = 2.12$) in S4, *P. canaliculatus* ($b = 2.\ 64$), *P. monodon* ($b = 2.96$) and *P. semisulcatus* ($b = 2.96$) in S5. During SEM season conditions were more favorable for most species ($b \geq 3.0$) except for *M. monoceros* ($b = 2.59$) and *P. monodon* ($b = 2.48$) in S2 and S6 respectively.

Moreover, the regression coefficients for length–weight relationships were high for most penaeid species in Malindi–Ungwana Bay, which indicated that length increased with the increase in shrimp weight at these sites.

Table 4.1: Summary of seasonal Length–weight relationship parameters of penaeid shrimps from Malindi–Ungwana Bay during Northeast Monsoon season.

Station	Species	n	Total length (mm) x ±S.E.	Body weight (g) x±S.E.	a	b±S.E	R^2	$p < 0.5$
2	*F. indicus*	27	114.11±3.68	6.48±0.38	0.08460577	0.91±0.39	0.181	0.0270
	M. japonicus	42	118.05±1.55	9.24±0.35	0.00002972	2.64±0.24	0.749	<0.0001
3	*F. indicus*	22	121.09±2.03	9.55±0.59	0.00000112	3.32±0.47	0.713	<0.0001
	M. japonicus	34	142.29±3.65	19.18±1.57	0.00000103	3.36±0.11	0.966	<0.0001
4	*F. indicus*	24	153.88±1.32	17.38±0.72	0.00040476	2.12±0.84	0.222	0.0201
	P. monodon	8	208.00±12.14	59.25±11.54	0.00000035	3.53±0.14	0.991	<0.0001
5	*M. monoceros*	29	110.52±4.20	9.76±1.49	0.00000177	3.26±0.15	0.947	<0.0001
	P. canaliculatus	7	156.00±10.26	24.57±4.97	0.00003643	2.64±0.39	0.901	0.0011
	F. indicus	15	150.67±6.74	27.53±4.00	0.00000444	3.10±0.20	0.950	<0.0001
	P. monodon	11	191.91±6.94	49.54±5.30	0.00000848	2.96±0.20	0.964	<0.0001
	P. semisulcatus	30	135.83±3.77	18.50±1.66	0.00000845	2.96±0.11	0.963	<0.0001
6	*M. monoceros*	46	130.07±2.99	16.13±1.04	0.00000071	3.46±0.10	0.965	<0.0001
	F. indicus	58	152.55±2.22	22.59±1.10	0.00000196	3.22±0.18	0.858	<0.0001
	M. japonicus	32	147.97±2.38	21.84±1.24	0.00000229	3.21±0.21	0.888	<0.0001
	P. monodon	44	195.05±3.85	51.45±3.26	0.00000294	3.15±0.09	0.967	<0.0001

(n – species sample size; a and b parameters of length–weight relationship; x – mean value, S.E. – standard error; R^2 – regression coefficient; p is probability of significance of the difference at $\alpha = 0.05$)

Table 4.2: Summary of length–weight relationship parameters of penaeid shrimps from Malindi–Ungwana Bay during Southeast Monsoon season.

Station	Species	n	Total length (mm) x±S.E.	Body weight (g) x ±S.E.	a	b±S.E	R^2	$p < 0.5$
2	*M. monoceros*	25	113.36±1.01	7.88±0.29	0.00003739	2.59±0.74	0.350	0.0018
	P. semisulcatus	20	110.15±3.53	9.85±1.02	0.00000364	3.14±0.19	0.937	<0.0001
3	*F. indicus*	42	118.50±1.04	8.45±0.31	0.00000256	3.14±0.44	0.559	<0.0001
	P. monodon	11	119.00±6.24	11.72±1.64	0.00000183	3.26±0.11	0.990	<0.0001
4	*P. monodon*	5	112.40±2.32	9.20±0.80	0.00000007	3.95±0.99	0.844	0.0275
5	*M. monoceros*	49	129.04±2.19	15.78±0.91	0.00000278	3.19±0.20	0.841	<0.0001
	F. indicus	44	156.68±2.53	23.45±1.58	0.00000016	3.71±0.19	0.903	<0.0001
	P. semisulcatus	49	153.08±2.69	28.41±1.66	0.00000305	3.18±0.12	0.934	<0.0001
6	*M. monoceros*	183	121.45±1.22	12.68±0.49	0.00000022	3.70±0.08	0.914	<0.0001
	P. canaliculatus	5	154.00±3.04	26.80±2.29	0.00000004	4.05±0.64	0.930	0.0080
	F. indicus	188	159.21±0.97	24.55±0.53	0.00000048	3.49±0.09	0.889	<0.0001
	M. japonicus	33	136.39±2.40	18.15±1.18	0.00000259	3.20±0.10	0.970	<0.0001
	P. monodon	49	199.06±4.43	60.06±4.58	0.00010899	2.48±0.25	0.680	<0.0001
	P. semisulcatus	106	136.57±1.50	18.64±0.70	0.00000457	3.09±0.08	0.933	<0.0001

(n – species sample size; a and b parameters of length–weight relationship; x – mean value, S.E. – standard error; R^2 – regression coefficient; p is probability of significance of the difference at $\alpha = 0.05$)

4.4.2 Shrimp condition factors

The results of condition factors (*K*) determined for penaeid shrimps in Malindi–Ungwana Bay are shown in Table 4.3. During NEM season, the highest *K* of 0.74 was recorded from *F. indicus* in S5, while the lowest *K* of 0.45 was from the same species in S2. During SEM season, the highest *K* of 0.76 was recorded from *P. monodon* in S6, while the lowest *K* of 0.5 was from *F. indicus* in S3. The condition factors for penaeid shrimps in the estuarine area (S1, S2, S3 and S3) were very low compared to the shallow water area (S5 and S6) in both seasons. Generally, the condition factors were slightly higher during SEM than NEM seasons.

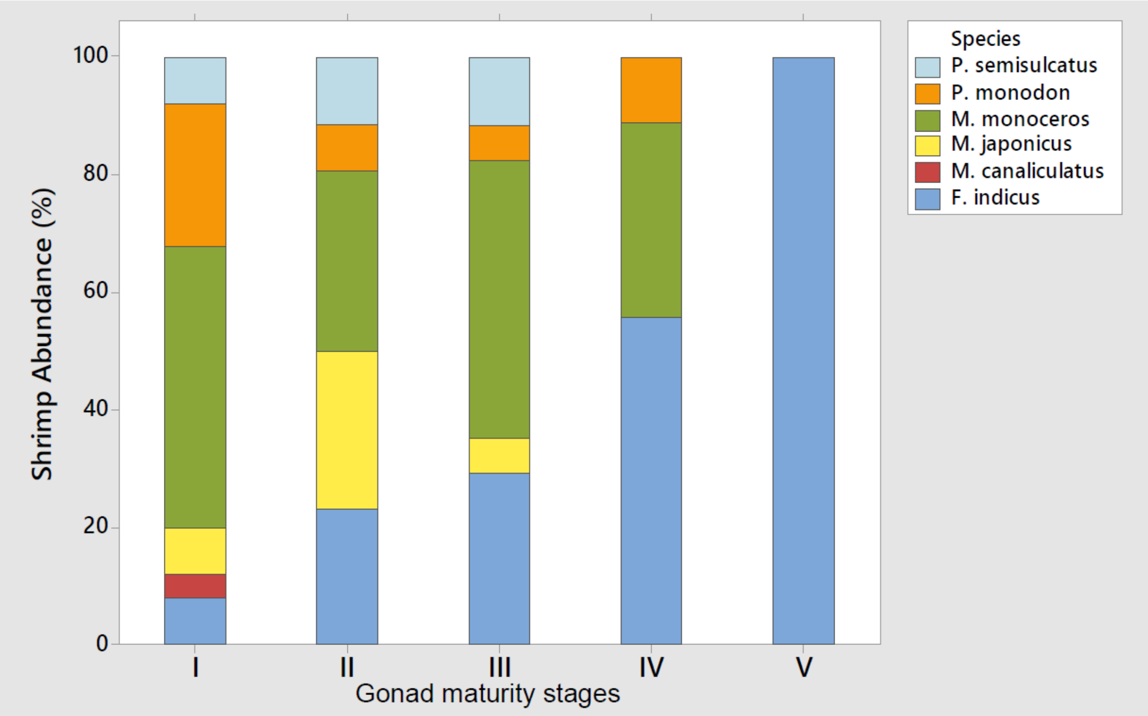
Table 4.3: Seasonal condition factors of penaeid shrimps in Malindi–Ungwana Bay.

Station	**Species**	**Northeast Monsoon**		**Southeast Monsoon**	
		n	***K* ±S.E.**	**n**	***K* ±S.E.**
2	*F. indicus*	27	0.45±0.02	–	–
	M. japonicus	42	0.55±0.01	–	–
	M. monoceros	–	–	25	0.54±0.02
	P. semisulcatus	–	–	20	0.69±0.02
3	*F. indicus*	22	0.53±0.02	42	0.50±0.01
	M. japonicus	34	0.61±0.01	–	–
	P. monodon	–	–	11	0.63±0.02
4	*F. indicus*	24	0.48±0.02	–	–
	P. monodon	8	0.59±0.02	5	0.64±0.03
5	*M. monoceros*	29	0.62±0.02	49	0.70±0.02
	P. canaliculatus	7	0.61±0.03	–	–
	F. indicus	15	0.74±0.02	44	0.57±0.01
	P. monodon	11	0.67±0.01	–	–
	P. semisulcatus	30	0.69±0.01	49	0.75±0.01
6	*M. monoceros*	46	0.67±0.01	183	0.64±0.01
	P. canaliculatus	–	–	5	0.73±0.02
	F. indicus	58	0.61±0.01	188	0.59±0.01
	M. japonicus	32	0.65±0.01	33	0.69±0.01
	P. monodon	44	0.65±0.01	49	0.76±0.08
	P. semisulcatus	–	–	106	0.70±0.01

(n – species sample size; *K* – condition factor; S.E. – standard error)

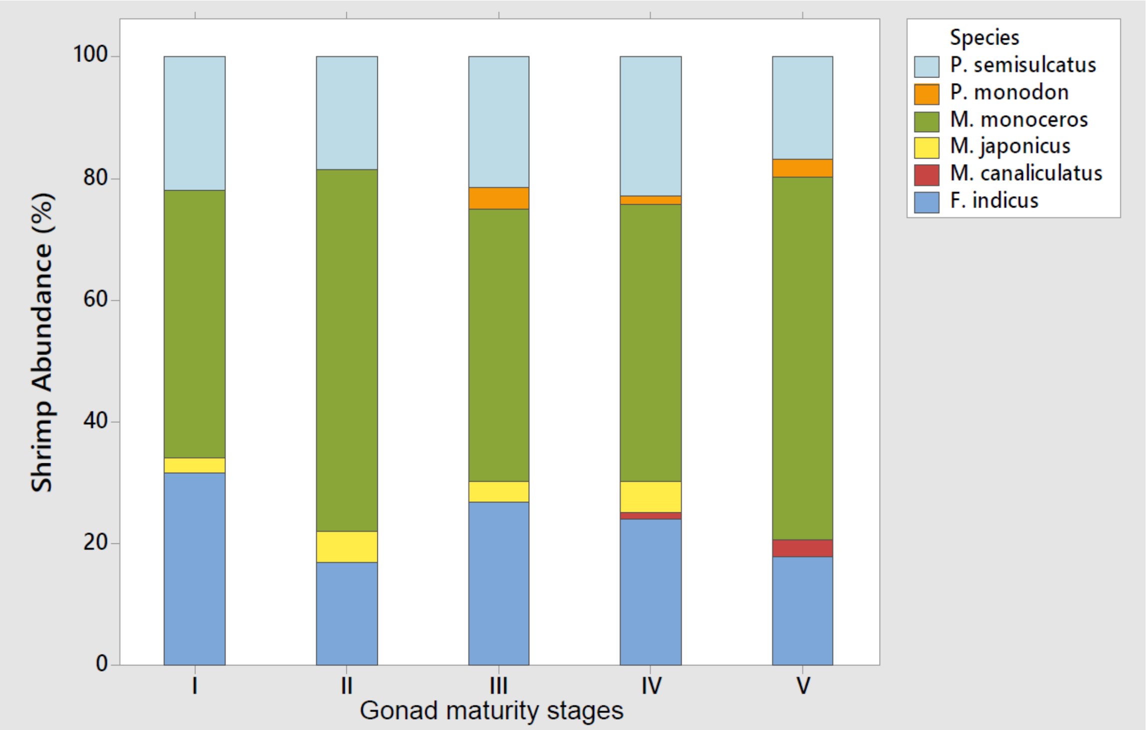
4.4.3 Gonad maturity stages and size at first maturity (L_{50})

The results for seasonal gonad maturity stages of penaeid shrimps showed more diverse female shrimps were either at immature or developing stage during NEM than SEM seasons (Figures 4.1 and 4.2). Large proportion of matured females in gonad stage IV and V was mainly dominated by *F. indicus* during NEM season while *M. monoceros* dominated during SEM season. In both seasons, there were almost the same proportions of similar penaeid shrimps in gonad stage III. Conversely, there were more diverse penaeid shrimps in gonad stage IV during the SEM than NEM seasons. In both seasons, *F. indicus* was the only species found berried with gonads across all maturity stages.



(I – Undeveloped; II – Developing; III – Nearly ripe; IV – Ripe; V – Spent)

Figure 4.1: Gonad maturity stages of Penaeid shrimps during NEM season.



(I – Undeveloped; II – Developing; III – Nearly ripe; IV – Ripe; V – Spent)

Figure 4.2: Gonad maturity stages of Penaeid shrimps during SEM season.

The results of carapace length at first maturity (L_{50}) among penaeid shrimps in Malindi–Ungwana Bay differed according to species (Figures 4.3, 4.4, 4.5, 4.6 and 4.7). In Figure 4.3, *M. monoceros* reached the carapace length at first maturity of L_{50} = 30.2 mm with the smallest females with ripe ovaries recorded at 19.6 mm CL and the largest size at 43.9 mm CL, while in Figure 4.4, *F. indicus* recorded a slight large size of L_{50} = 35.8 mm with the smallest females with ripe ovaries recorded at 24.8 mm CL, and the largest size at 50.3 mm CL. Similarly, the L_{50} for *P. semisulcatus* was 33.7 mm with the smallest females ripe with ovaries recorded at 23.3 mm CL and the largest size at 45.1 mm CL while *M. japonicus* was observed at L_{50} = 37.1 mm with the smallest females with ripe ovaries recorded at 27.8 mm CL and the largest size at 45.9 mm CL (Figure 4.5

and 4.6). Figure 4.7 showed the L_{50} for *P. monodon* was found to be 54.2 mm CL, while the smallest females with ripe ovaries at 37.8 mm CL, and the largest size at 77.5 mm CL.

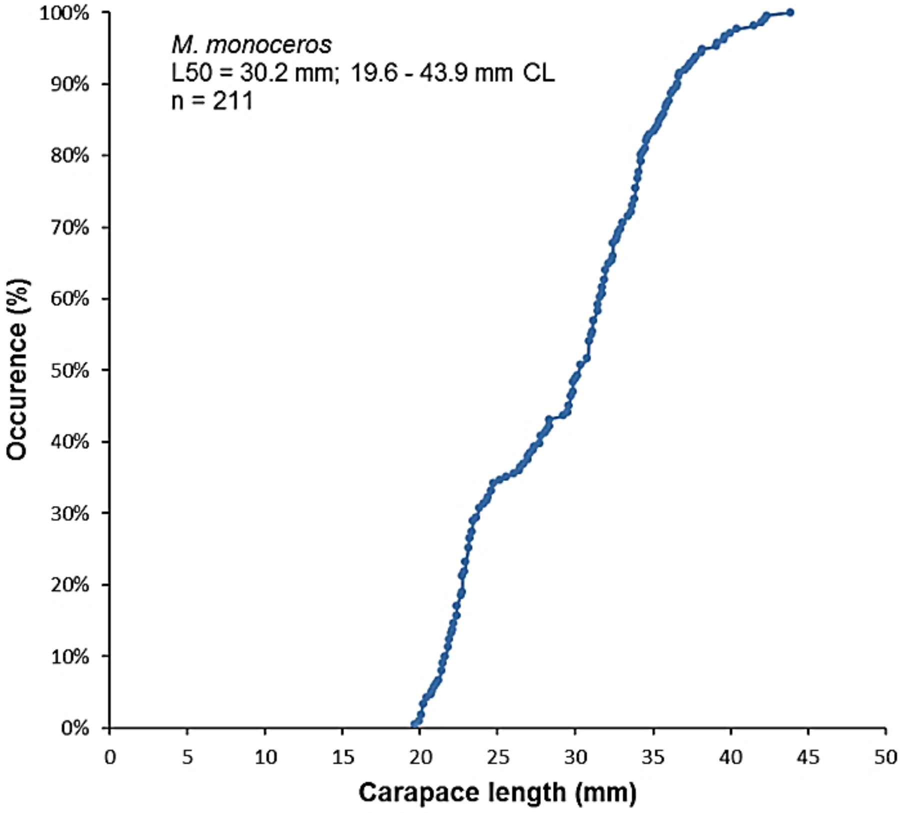


Figure 4. 3: The size at first maturity for *Metapenaeus monoceros* in Malindi–Ungwana Bay.

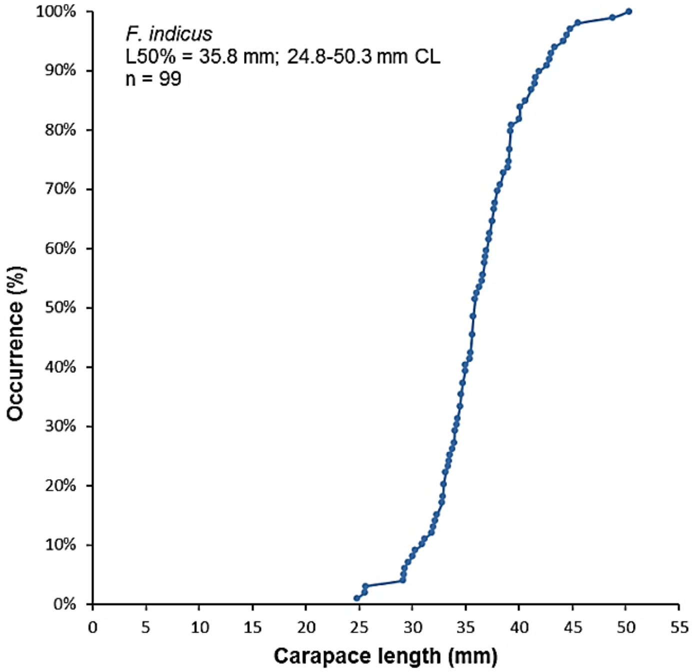


Figure 4.4: The size at first maturity for *Fenneropenaeus indicus* in Malindi–Ungwana Bay.

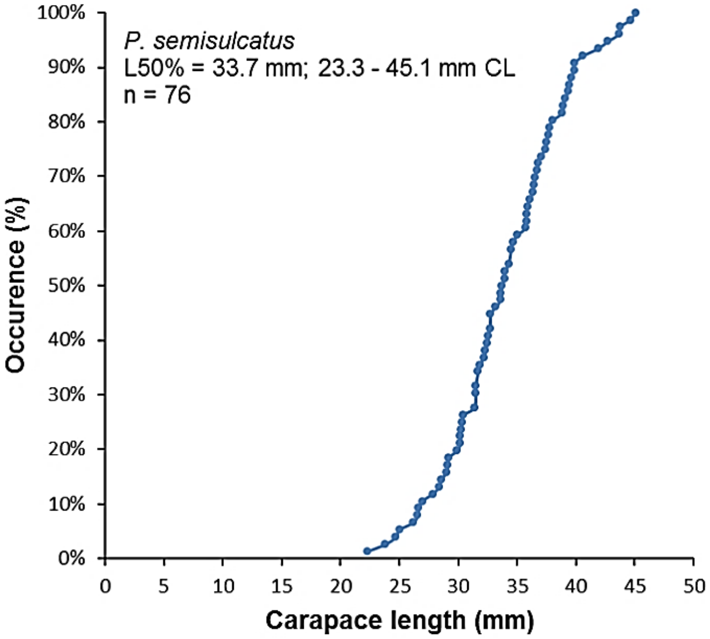


Figure 4.5: The size at first maturity for *Penaeus semisulcatus* in Malindi–Ungwana Bay.

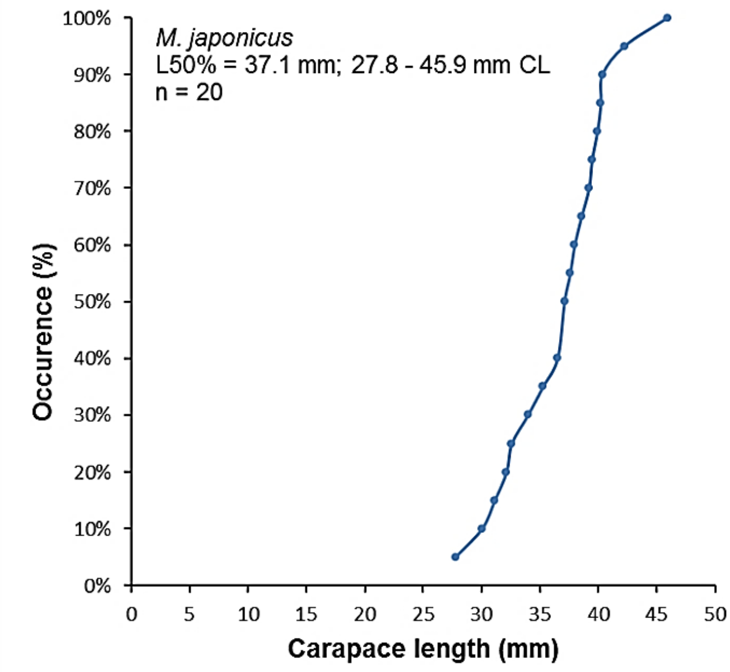


Figure 4.6: The size at first maturity for *Marsupenaeus japonicus* in Malindi–Ungwana Bay.

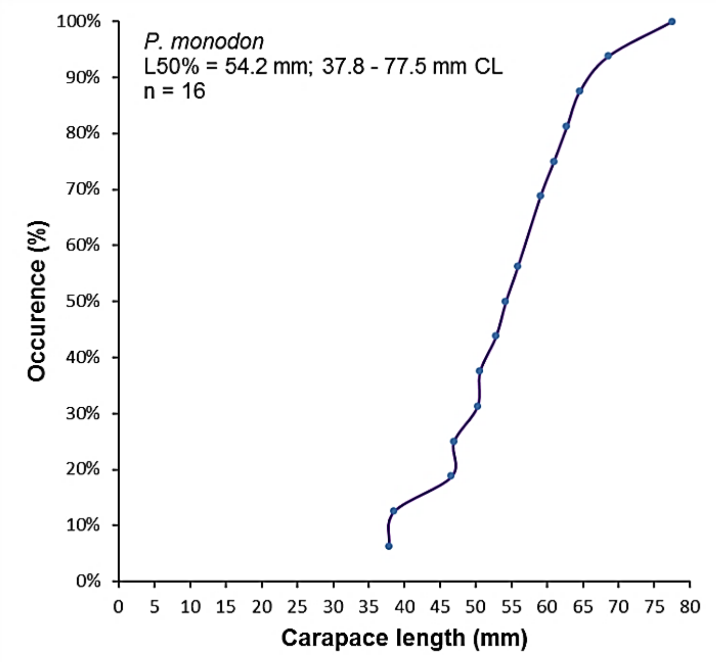


Figure 4.7: The size at first maturity for *Penaeus monodon* in Malindi–Ungwana Bay.

4.5 Discussion

4.5.1 Penaeid shrimp length–weight relationships

The values related to the wellbeing index present the highest values associated to the individuals that present highest weights for a given length. The highest *b* values indicate the inflection of the curve for the asymptotic values, indicating allometric growth, that is, the length becomes an irrelevant variable in relation to the weight (Ndiaye *et al.*, 2015). In this study, the relationship between the length and weight for most penaeid shrimps was significant exhibiting positive allometric growth, while a few observations were made on negative allometric growth patterns. The results for *b* values of *P. monodon* from S4 and S6 during NEM season as well as S3 and S4 during SEM season were in conformity with Maheswarudu *et al.* (2016) who reported positive allometric growth for *P. monodon* cultured in open sea floating cage in the Bay of Bengal with *b* values of 3.08. Similarly, negative allometric growths for *b* value results of this study for *P. monodon* from S6 during SEM season were in conformity with *b* values of 2.49 recorded by Gopalakrishnan *et al.* (2014) for wild shrimp.

Generally, a number of shrimp populations during NEM season recorded negative allometric growth patterns suggesting that the lower *b* values could be attributed to crowding and competition for food as result of a reduced river discharge during these months. However, variations in the value of *b* could also be linked to other factors such as differences in the physiology of different penaeid shrimps, sexes, sensitivity to water quality parameters, weight of the gonads, differences in the observed length ranges of the specimens sampled or behaviour (Getso *et al.*, 2017; Okomoda *et al.*, 2018). These factors inhibit growth, and hence, affect the value of *b* in the length-weight relationship of any species. The regression coefficient (R^2) for length-weight relationships varied among the shrimp populations and was high for most penaeid shrimps in Malindi–Ungwana Bay, which indicated that the length increased with the shrimp weight. This was in agreement with previous studies on different penaeid species from various water bodies (Li *et al.*, 2016; Maheswarudu *et al.*, 2016).

4.5.2 Shrimp condition factors

In this study, the condition factors of the same species have varied seasonally from one locality to another. The difference in condition factors may have been attributed to the presence of ovigerous females in shallow waters (S5 and S6) during the SEM season as compared to during NEM season as females were observed to be heavier than the immature ones of the same total length and body length. Udoinyang *et al.* (2016) reported similar observations in condition factors attributed to the presence of ovigerous females in *P. monodon* from the artisanal shrimp fishery of Iko River Estuary, South Eastern Nigeria. Qureshi and Amanat (2014) observed mature females due to the additional weight of the ovaries constituting up to 13% of the total body weight. Generally, the condition factors were slightly higher during SEM than NEM seasons in Malindi–Ungwana Bay. The SEM season falls within the wet season and at this period, rainfall is high, water levels in the coastal waters increase and food availability is also high. Thus, Olapade and Tarawallie (2014) suggested that SEM seasons provides favourable conditions for spawning to occur. This study and another one conducted by Ndiaye *et al.* (2015) suggest that those shrimps which were in good condition, healthy and will be suitable for mariculture as they provide the producer with information of the specific condition under which organisms are developing.

4.5.3 Gonad maturity stages and size at first maturity (L_{50})

In this study, the spawning season of different penaeid shrimps in the Malindi–Ungwana Bay seems to occur at different periods depending on the growth rates, maturity and proportions of gonads, which were either ripe or spent, and kept changing from one sampling area to another. The results of this study agree with Munga *et al.* (2013) who recorded seasonal patterns in Malindi–Ungwana Bay for *M. monoceros* and *P. monodon* with slight differences in their proportion for female gonads. Villarta *et al.* (2006) showed spawning activity peaks for female *P. semisulcatus* during SEM, which corresponds to our results.

The size at first maturity, L_{50}, of the five penaeid species in this study differed substantially suggesting that the penaeid species spawn at different sizes with *P. monodon* achieving L_{50} at the largest size and *M. monoceros* at the smallest size. Aryani *et al.* (2016) reported that the variations in the condition factor with the increase in length may yield evidences concerning the size at first maturity. The L_{50} values in the present study were within the range of those obtained by Kumlu *et al.* (1999) for *P. semisulcatus* collected off Iskenderun Bay in the North Eastern Mediterranean, Teikwa and Mgaya (2003) for *F. indicus* off Bagamoyo coastal waters in Tanzania, and Munga *et al.* (2013) for all penaeid species except *P. monodon* of Malindi–Ungwana Bay. However, the discrepancy between this study and Munga *et al.* (2013) could be attributed to slight differences in their sampling techniques as Munga *et al.* (2013) collected their samples from trawl areas different this study whereas the results of this study had more samples from the estuaries.

4.6 Conclusion

The findings of the present study provide the first evidence about the growth pattern and condition factors of penaeid shrimp from its in-situ habitat. This study has shown that Malindi–Ungwana Bay is suitable for the survival and reproduction of penaeid shrimps. Following the abundance of *F. indicus* and *M. monoceros* with matured gonads in both seasons, this study recommends the suitability of the two species for sustainable coastal shrimp aquaculture in Kenya. Mariculture practice is gaining momentum with significant information on the seasonal availability of quality seed in the wild taken as breakthroughs in the development of shrimp industry. Since penaeid shrimp is part of the commercially important species of Kenya, this study recommends that it is important to have a record of their length and weight from different habitats for proper management and selection decisions in coastal aquaculture breeding programs.

CHAPTER FIVE

5. MORPHOMETRIC VARIATIONS AMONG POPULATIONS OF THE WILD PENAEID SHRIMPS IN MALINDI–UNGWANA BAY ALONG THE NORTHERN COAST OF KENYA

5.1 Abstract

Intraspecific morphological variation in the penaeid shrimps was studied in four estuarines and two shallow waters study sites in Malindi–Ungwana Bay. Three morphometric characteristics, body length, carapace length and total length describing shape of penaeid shrimps were used. Total Length, the explanatory variable, brings out significant information in shrimps, while groups of population that varied significantly in terms of morphometric variations were easily differentiated ($p < 0.05$) across the sample stations. Generally, Principle Component Analysis dimensions for all shrimps except *Penaeus canaliculatus* showed an inverse correlation between body length and carapace length and a good correlation of carapace length and total length. Several species displayed intraspecific morphological variability where shape variations increased with size and the postlarva were closer to each other than adults along the first axis of Principle Component Analysis. This study concluded that the variability among individual species within each population indicated the presence of high genetic diversity among the populations of different shrimps. This has given rise to genetically panmictic populations within the Malindi–Ungwana Bay.

5.2 Introduction

Morphometric variations are revelations of continuous data derived from a set of measurements in the morphometric studies (Kaouèche, Bahri-Sfar, Hammami, & Hassine, 2017). These measurements are used in fisheries biology to determine similarity or dissimilarity of taxa (Reist, 1985) or relationships among various taxonomic groups (Turan, 1999). The analysis of phenotypic variations forms the basis for identifying stocks as well as evaluating their population structure (Mojekwu & Anumudu, 2015). Despite the use of molecular genetics today, these conventional approaches continue to play important roles in stocks identification (Solomon *et al.*, 2015), while the use of multivariate techniques is thus receiving more attention in delineation of the stocks (Bektas & Belduz, 2009).

All different types of life cycles of the family Penaeidae as described by Dall *et al.* (1990) cover ranges of heterogeneous environment which require different morphological traits that match with local environments (Jørgensen *et al.*, 2008). Any organism adapting in such heterogeneous environment requires to produce sufficient chances for genetic variation (Rajakumaran, Vaseeharan, & Yeshvadha, 2013) as specific genetic variation is needed for a particular adaptation (Lundqvist *et al.*, 2008).

The knowledge of genetic diversity based on morphological traits is fundamental to species conservation, yet understanding of these phenomena, particularly in the management of penaeid shrimp fishery of Malindi–Ungwana Bay, is scantly. Low genetic diversity in penaeid shrimp population of Malindi–Ungwana Bay may have led to its population decline that threatens its evolutionary potential. This study, therefore, evaluated the genetic diversity based on the morphometric variations within and between different penaeid shrimps in Malindi–Ungwana Bay.

5.3 Materials and Methods

5.3.1 Study area

Malindi–Ungwana Bay is located between Malindi and Kipini areas of Kilifi and Tana River Counties respectively (Figure 3.1). The study had six sample stations, four of which were located within the estuaries (S1, S2, S3 and S4), while the other two sample stations (S5 and S6) were within the shallow waters (Kaka *et al.*, 2019). The choice of establishing sample stations was mainly considered on the basis of areas frequently used by artisanal fishers or trawlers as well as the estuarine areas around the river mouths of River Tana and River Sabaki. During survey in the shallow waters, the entire bay was stratified using regular polygons into four zones by depth and distance from shore. The total area of each zone was estimated using ArcGIS area calculator as follows: Zone 1 represented by 137.3 nm^2 in areas less than 10 m depth; Zone 2 represented an area of 234.1 nm^2 for depths of 10 – 20 m; Zone 3 with an area of 136.3 nm^2 for depths of 20 – 40 m; and lastly, Zone 4 represented by 38.7 nm^2 in depths of 40 – 100 m (Kimani *et al.*, 2012; Kaka *et al.*, 2019).

5.3.2 Data Collection

A total of 1364 penaeid shrimps were randomly collected from the six sample stations in the estuaries and shallow waters fishing grounds. Sample collections were carried out in two separate surveys of 10 and 13 days during Northeast monsoon (NEM) and Southeast monsoon (SEM) respectively with SEM being cooler than NEM. In the estuaries stations, 8 hauls were made daily by two people using a seine net of 1 inch mesh size measuring 20 m long by 1.25 m high (Kaka *et al.*, 2019). In the shallow waters, surveys of one hour intervals were conducted at a speed of 2.5 knots using a 496 horsepower Fishing Vessel (FV VEGA) fitted with a 70 mm mesh size towing net of 44.3 m long and 45 mm mesh size cod end. Records for sample stations' coordinates and depths were taken during seasonal sampling periods of 10 and 13 days for estuaries and shallow waters respectively.

Whenever a catch comprised of at least 30 specimens, the whole catch was considered as a single sample, while a catch was too large to manage as a single sample, then a 10% sampling proportion with a desired margin of error at the 95% confidence level (Tonks *et al.*, 2008) was performed as the subsample (Kaka *et al.*, 2019). These subsamples were considered as being representative of the trawl catch and sampling procedures allowed quantitative comparisons of the samples in relative terms. The samples were sorted out by species, identified morphologically according to Chan (1998) and weighted per species. When the identification of the specimens lacked distinct characteristics, they were recognized to the genus level and further subjected to genetic analysis to identify them to species level (Kaka *et al.*, 2019).

The morphometric measurements for body length (BL), carapace length (CL) and total length (TL) were taken to the nearest 0.1 mm using a standard model series 530 Vernier caliper (Figure 5.1). When the abdomen was fully stretched, TL was measured from the end of telson to the tip of rostrum, while BL was measured from the mid dorsal line opposite the posterior orbital margin to the end of telson. The CL measurement was taken from the posterior mid dorsal edge of carapace to the posterior margin of eyestalk, while, BW was measured using an electronic weighing balance to the nearest 0.1 gram.

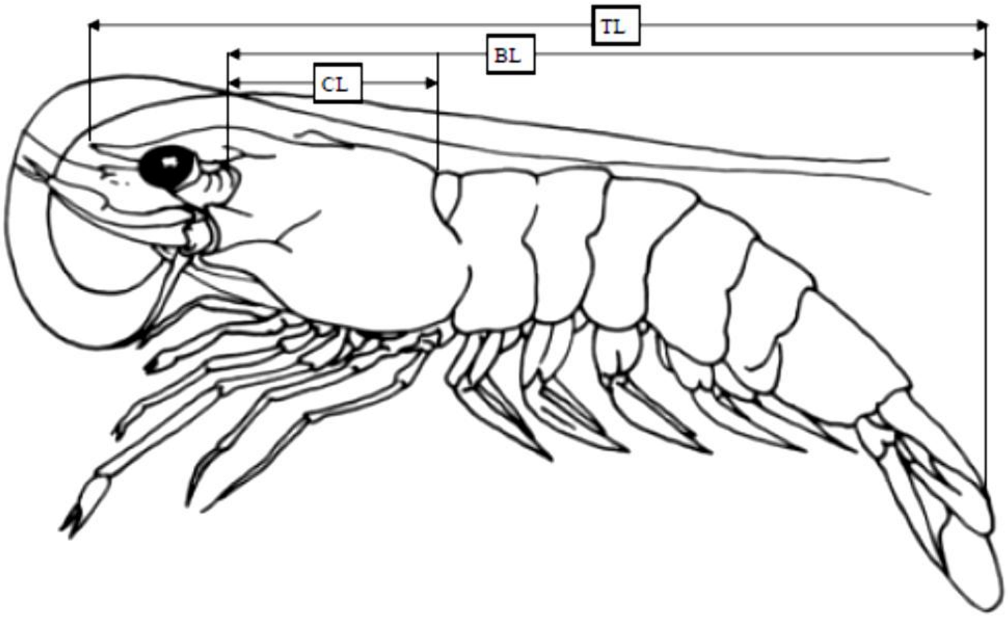


Figure 5.1: Diagrammatic representation of the morphometric characteristics, total length (TL), body length (BL) and carapace length (CL) used for penaeid shrimp.

5.3.3 Data analyses

Measurements which were taken from morphometrics were transformed to BL by growth allometry using Reist (1985) to remove size effect as described in Gunawickrama (2007). The normality distribution of the standardized measurement after removal of size effect was confirmed using Shapiro–Wilk test. The t–test with type I error level was used to determine if there was significant difference between the means of variables (Rice, 1989). A general formula was used by Sani *et al.* (2017) for correction of all morphometric data: $M_S = M_O(L_S / B_L)^b$ by logarithmically expressing this equation as: $\log M_S = \log M_O + b\log L_S - b\log B_L$ where, M_S is the standardized character measurement; M_O is the observed character measurement; L_S is the overall mean BL for all the penaeid shrimps from each sampling site; B_L is the BL of the specimen; b is the slope of the regression of $\log M_O$ on $\log B_L$ for all penaeid shrimps.

Correlation of standardized data against size was carried out to remove size dependence. Since a number of specimens have damaged rostrum, BL was used as the basis of transformation. The correlation coefficient (R^2) between standardized data and BL was determined to verify standardization efficiency. Both univariate and multivariate methods were used to analyse the standardized data. The Analysis of variance followed by Tukey HSD multiple comparison test for unequal sample sizes was also used to determine differences among samples. In order to discriminate shrimp populations, separate principle component analysis (PCA) for each species was used as well as its correlation matrix. The pattern of morphological variations between samples was assessed using discriminant function analysis (DFA). In order to observe relationships among shrimp populations, 95% ellipses of population centroids were produced in DFA scatter diagram to study the relationships (Ola–Oladimeji *et al.*, 2016). The Agglomerative Cluster Dendrogram (ACD) was constructed to classify clusters of penaeid populations based on the similar characteristics. All statistical analyses were performed using program Minitab 17 and XLSTAT 2015 (Mathews, 2005; Addinsoft SARL, 2015).

5.4 Results

Morphometric characters of six populations of penaeid shrimps analysed by normality tests are presented in Table 5.1. The mean values of morphometric variables for each penaeid shrimp differed significantly ($p < 0.05$). However, there was no significant difference in the carapace length (CL) of *P. canaliculatus*, *F. indicus* and *M. japonicus* same as the case in the total length (TL) of *P. canaliculatus* and *M. japonicus* ($p > 0.05$). The results from the Shapiro–Wilk test revealed that among the three morphometric variables, body length (BL) showed as the only variable that does not follow a normal distribution, and hence, show significant differences in all the penaeid species.

Table 5.1: Results of normality tests (Shapiro–Wilk test) of morphometric characters of penaeid shrimps from Malindi–Ungwana Bay.

Species	**N**	**CL**	**TL**	**BL**
M. monoceros	340	0.985*	0.984*	0.733**
P. canaliculatus	12	0.985	0.927	0.640*
F. indicus	420	0.996	0.920**	0.602**
M. japonicus	141	0.984	0.987	0.784**
P. monodon	132	0.963*	0.857**	0.518**
P. semisulcatus	207	0.975*	0.958**	0.492**

N = Number of individuals; CL = Carapace Length; TL = Total Length; BL = Body Length. Note: Means within the same row bearing different superscript differ significantly ($p < 0.05$)

In this study, the results showed that the variability of BL as dependent variable was well explained by two explanatory variables, CL and TL, in all penaeid shrimps (Table 5.2). Although the correlation coefficient of 0.07 between CL and BL was too low in *P. canaliculatus*, there was no significant difference of CL in explaining BL variation ($p < 0.05$). The results of this study also showed a positive relationship between TL and BL while the relationship between CL and BL was negative. The present study showed TL, based on the Type III sum of squares ($P < 0.05$), as the most influential among the two other variables.

Table 5.2: Contribution of two morphometric traits in explaining BL Variation (R^2) in each population assessed using multiple regression analysis.

Species	N	Variables	Type III SS	Predictor Coefficient	R^2	Pr > F
M. monoceros	340	CL	0.644	–0.479	0.655	<0.0001
		TL	6.719	1.394		<0.0001
P. canaliculatus	12	CL	0.011	–0.549	0.069	0.017
		TL	0.095	1.470		<0.0001
F. indicus	420	CL	0.155	–0.288	0.744	<0.0001
		TL	3.440	1.220		<0.0001
M. japonicus	141	CL	0.122	–0.484	0.657	<0.0001
		TL	1.251	1.408		<0.0001
P. monodon	132	CL	0.159	–0.407	0.744	<0.0001
		TL	2.070	1.342		<0.0001
P. semisulcatus	207	CL	1.228	–0.757	0.958	<0.0001
		TL	6.948	1.654		<0.0001

Table 5.3: One–way Analysis of Variance of seasonal morphometric relationships for penaeid species from Malindi–Ungwana Bay.

		F. indicus		*P. canaliculatus*		*P. monodon*		*P. semisulcatus*		*M. japonicus*		*M. monoceros*	
Season		CL	TL	CL	TL	CL	TL	CL	TL	CL	TL	CL	TL
Northeast monsoon	S1	–	–	–	–	–	–	–	–	–	–	–	–
	S2	1.820^{b}	2.071^{c}	–	–	–	–	1.874^{abc}	2.084^{abc}	1.879^{b}	2.082^{c}	–	–
	S3	1.868^{b}	2.096^{c}	–	–	1.994^{ab}	2.202^{b}	–	–	1.955^{a}	2.160^{a}	–	–
	S4	1.982^{a}	2.200^{ab}	–	–	2.118^{a}	2.326^{a}	–	–	–	–	–	–
	S5	1.985^{a}	2.183^{b}	1.998^{a}	2.200^{a}	2.092^{a}	2.291^{ab}	1.937^{bc}	2.139^{b}	–	–	1.844^{a}	2.047^{cd}
	S6	1.983^{a}	2.192^{b}	–	–	2.100^{a}	2.297^{a}	–	–	1.993^{a}	2.178^{a}	1.915^{a}	2.121^{a}
Southeast monsoon	S1	–	–	–	–	–	–	–	–	–	–	–	–
	S2	–	–	–	–	–	–	2.069^{a}	2.001^{c}	–	–	1.854^{a}	2.066^{bc}
	S3	1.844^{b}	2.089^{c}	–	–	1.859^{b}	2.083^{c}	1.838^{abc}	2.053^{bc}	–	–	1.784^{a}	1.996^{de}
	S4	–	–	–	–	1.848^{b}	2.064^{c}	–	–	–	–	1.706^{a}	1.930^{e}
	S5	1.984^{a}	2.206^{ab}	–	–	–	–	1.994^{ab}	2.192^{a}	–	–	1.915^{a}	2.120^{a}
	S6	1.996^{a}	2.213^{a}	2.018^{a}	2.196^{a}	2.112^{a}	2.304^{a}	1.940^{c}	2.144^{b}	1.947^{a}	2.111^{b}	1.880^{a}	2.094^{b}
	R^2	32.5%	67.9%	1.2%	0.2%	30.9%	64.7%	14.1%	57.6%	17.9%	44.0%	4.5%	24.5%
	F	28.29	124.55	0.12	0.02	9.32	38.22	6.59	54.59	9.94	44.51	2.63	18.05
	Pr > F	0.000	0.000	0.732	0.895	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000

(Carapace length (CL); total length (TL); Sample stations (S1, S2, S3, S4, S5 and S6); R^2 – coefficient of determination; F value (Fisher's F-test); Pr > F is probability of significance of the difference at $\alpha = 0.05$. Note: Means that do not share a letter are significantly different)

The results of analysis of variance showed R^2 is better explained by total length (TL) than carapace length (CL) in all penaeid shrimps except *P. canaliculatus* (Table 5.3). The morphometric variable, TL, brings out significant information in every species as well as groups of population that varied significantly in terms of morphometric variations ($p < 0.05$). In *F. indicus*, TL accounted for the 67.9% of variations closely followed by *P. monodon* (64.7%), *P. semisulcatus* (57.6%), *M. japonicus* (44%) and *M. monoceros* (24.5%) while the least variation of 0.2% was accounted in *P. canaliculatus.* However, the results showed that there was significant difference in the morphometric variation of each penaeid shrimp except *P. canaliculatus* (0.895, $p > 0.05$). Although the variability explained by CL was very low in all the penaeid shrimps, the results showed that there was significant difference in every species except *P. canaliculatus* (0.732, $P > 0.05$).

Generally, the principle component analysis (PCA) dimensions for all species except *P. canaliculatus* indicated an inversely correlation between BL and CL and a good correlation of CL and TL (Figures 5.2 – 5.7). In the case of *F. indicus*, 98% of initial data variability revealed three mixed populations that were homogeneously distributed (Figure 5.2). The population groups of *F. indicus* were from S2, S3, S4, S5 and S6 during the NEM season, while S3, S5 and S6 during SEM season. For *M. japonicus*, 98.31% of the total variation in the morphometric characters revealed a distinct population group found in S2 during NEM season being different from other populations during the two seasons. The rest of *M. japonicus*, however, seem to come from the same population but they were homogeneously distributed at S3 during NEM season and S6 during the two seasons (Figure 5.3). The results further revealed that distribution pattern of morphometric characters of *P. monodon* (98.26% of the initial variability of the data) formed a heterogeneous population group which was widely distributed (Figure 5.4). The population group from S6 had similar characteristics during the two seasons with a few outliers observed in them, while those from S3 and S4 during the SEM season seem to come from the same population with those sampled during NEM season. However, there were few cases of outlier were observed in S3 during the two seasons.

Although the PCA dimension of *M. monoceros* was 99.11% of the total variation of the data, five groups of population were revealed as homogenously distributed (Figure 5.5). The five groups of *M. monoceros* population were from S5 and S6 during NEM season, while S2, S5 and S6 during SEM season. The results showed two outliers from S4 during the SEM season possessing unique characteristics different from the rest. S3 seemed to have a population group different from others during SEM season. In the case of *P. semisulcatus*, 99.6% of the variation in the morphometric characters indicated two distinct groups of population, one from S2 during SEM season while the rest were sharing common characteristics during the two seasons (Figure 5.6). The homogeneous population of *P. semisulcatus* included groups of population from S2 during the NEM season, while S3 and S6 during SEM season. There were also observations made to a population from S5 during the two seasons. Lastly, 97.08% of the initial variability in the morphometric characters of *P. canaliculatus* revealed two distinct groups of population, one from S6 with larger BL during SEM than those from S5 dominating NEM seasons (Figure 5.7).

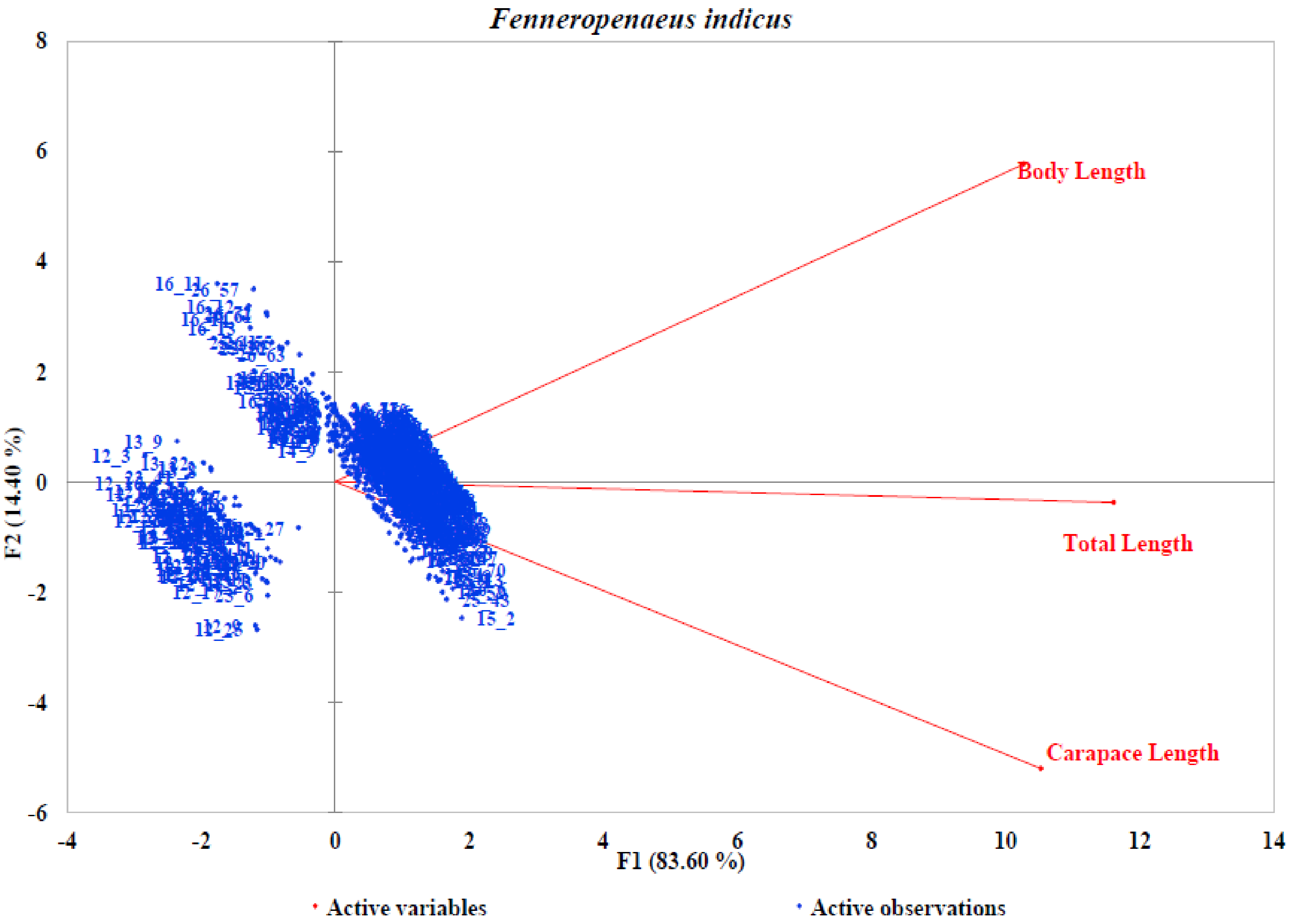


Figure 5.2: Principle Component Analysis Scatter Plot of *Fenneropenaeus indicus*.

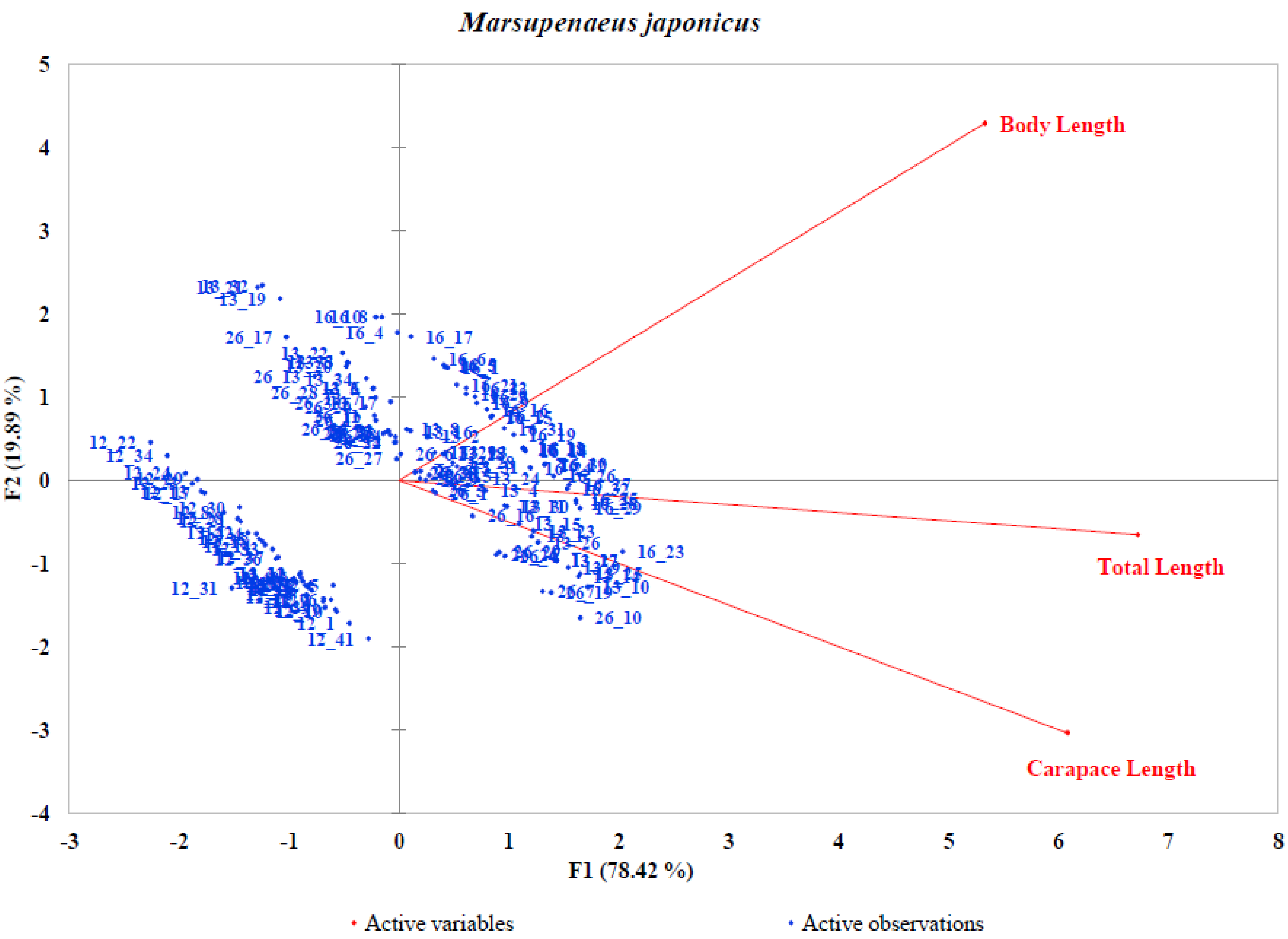


Figure 5.3: Principle Component Analysis Scatter Plot of *Marsupenaeus japonicus*.

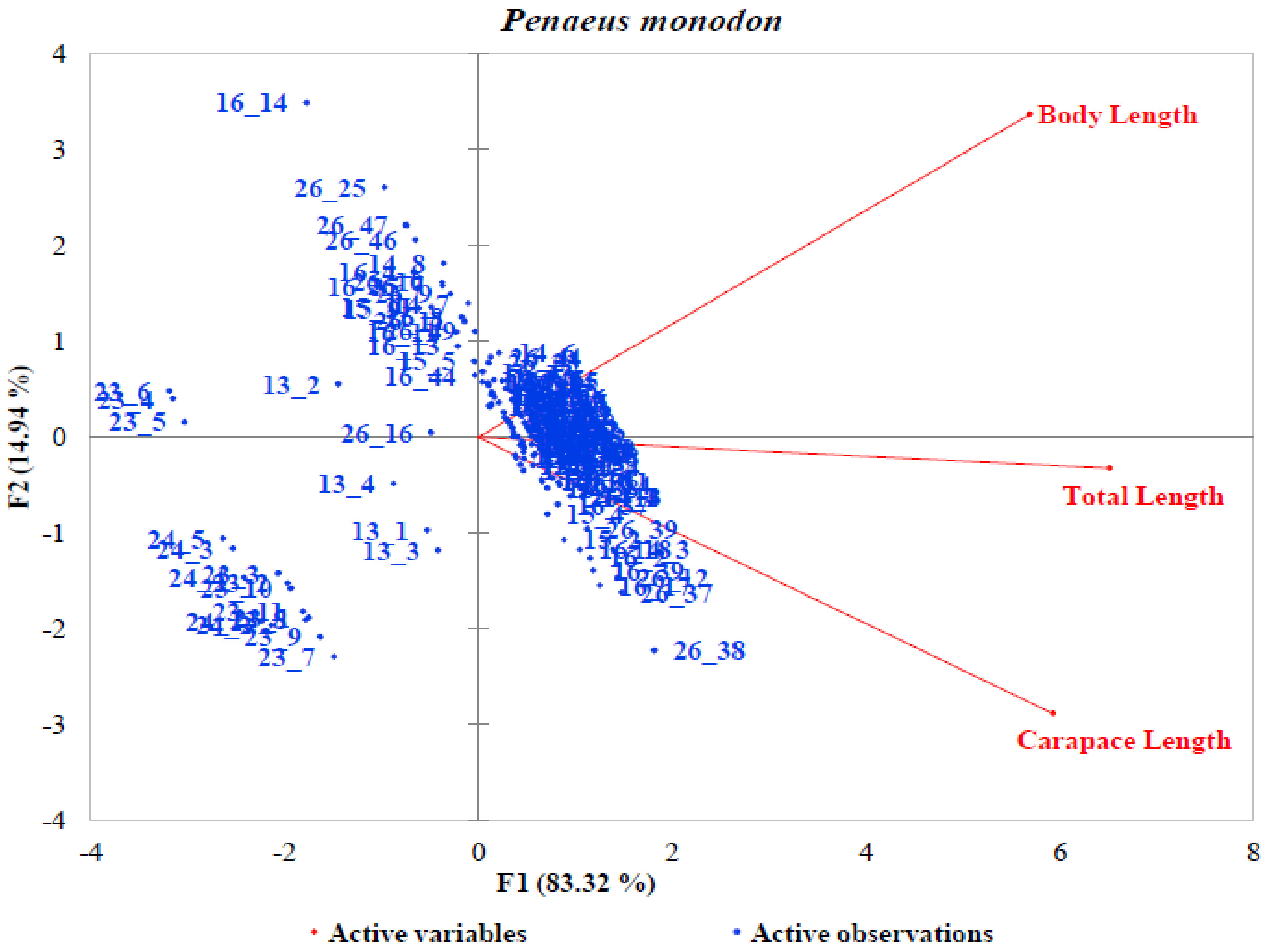


Figure 5.4: Principle Component Analysis Scatter Plot of *Penaeus monodon*.

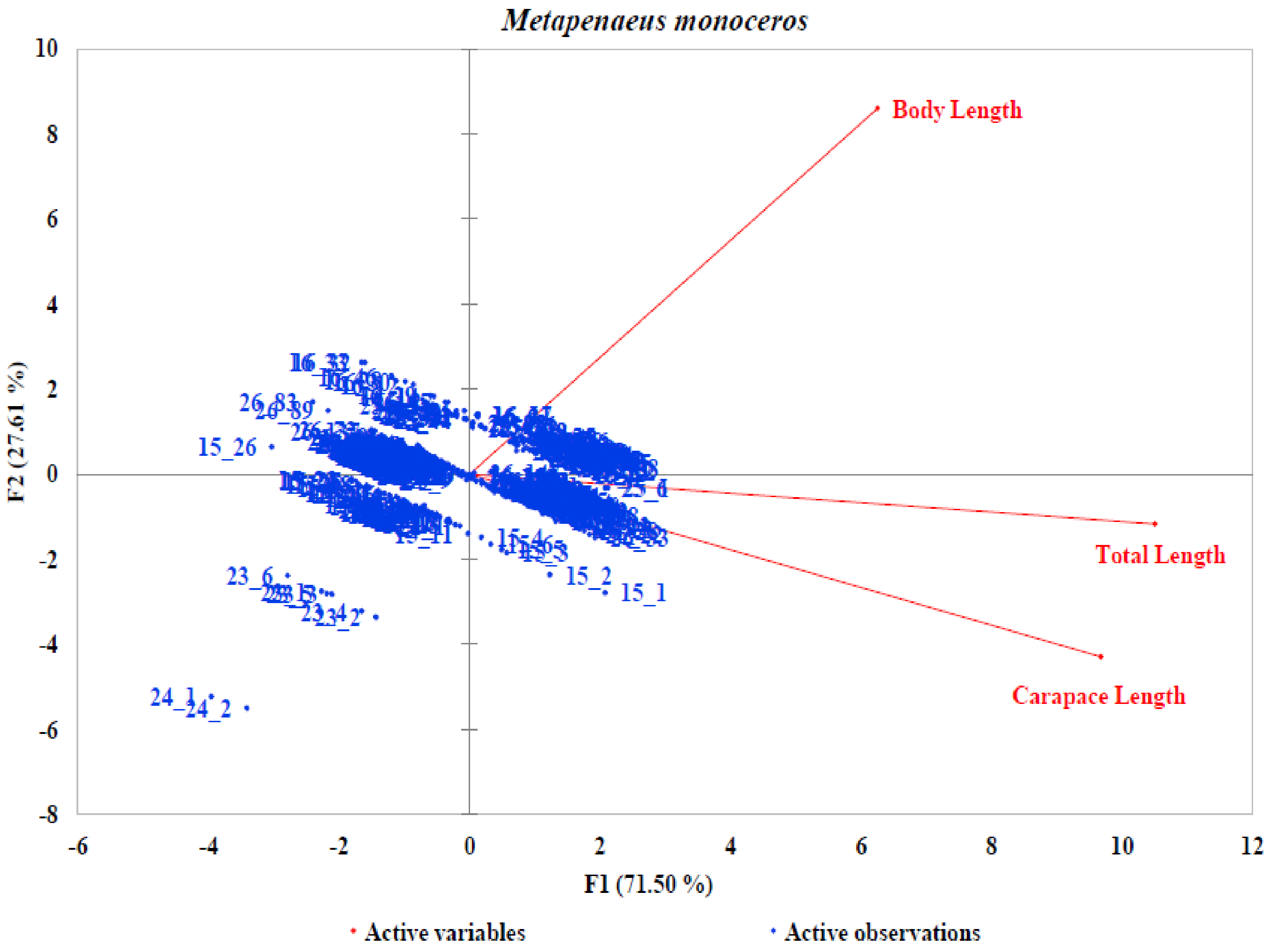


Figure 5.5: Principle Component Analysis Scatter Plot of *Metapenaeus monoceros*.

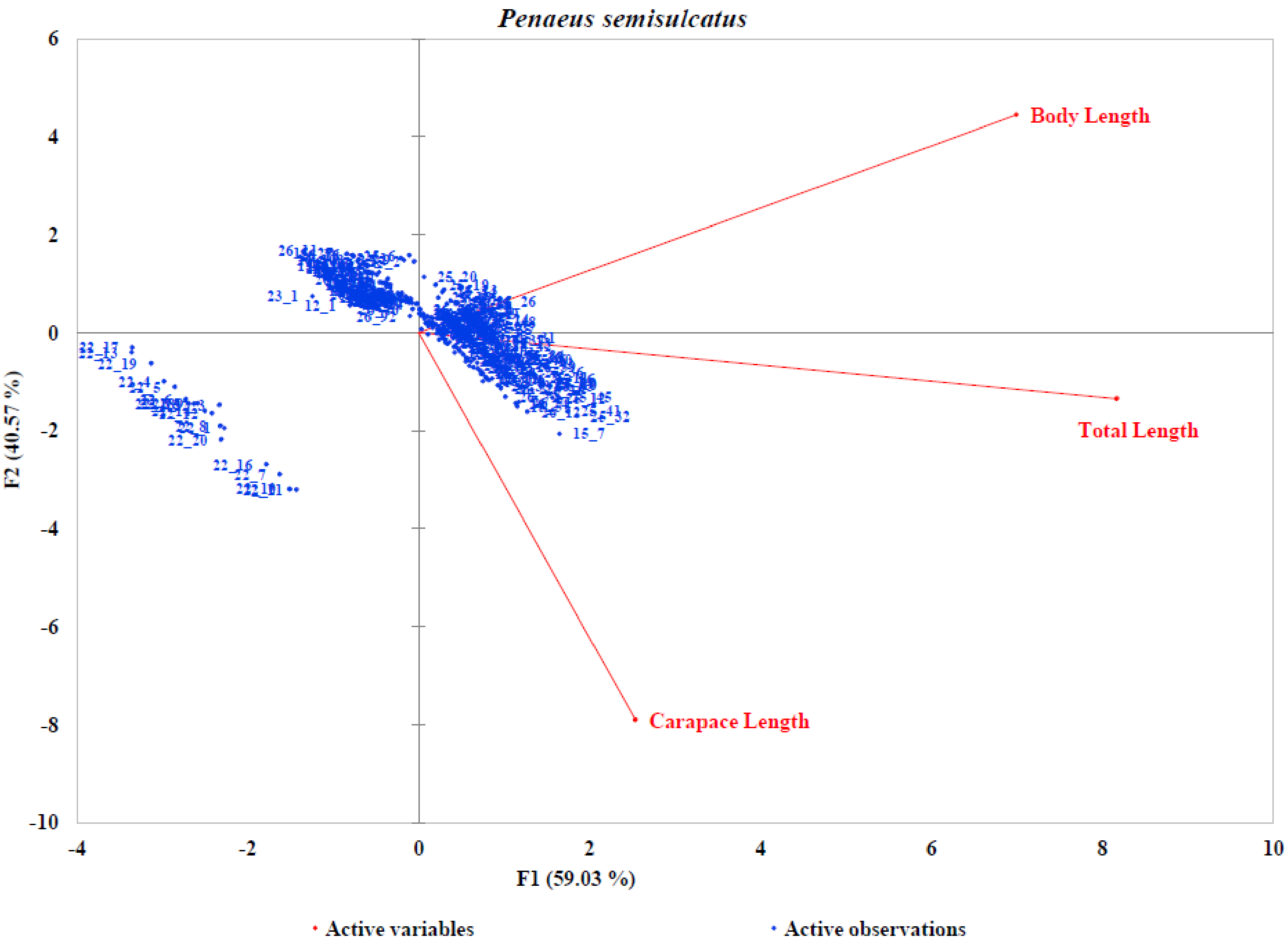


Figure 5.6: Principle Component Analysis Scatter Plot of *Penaeus semisulcatus*.

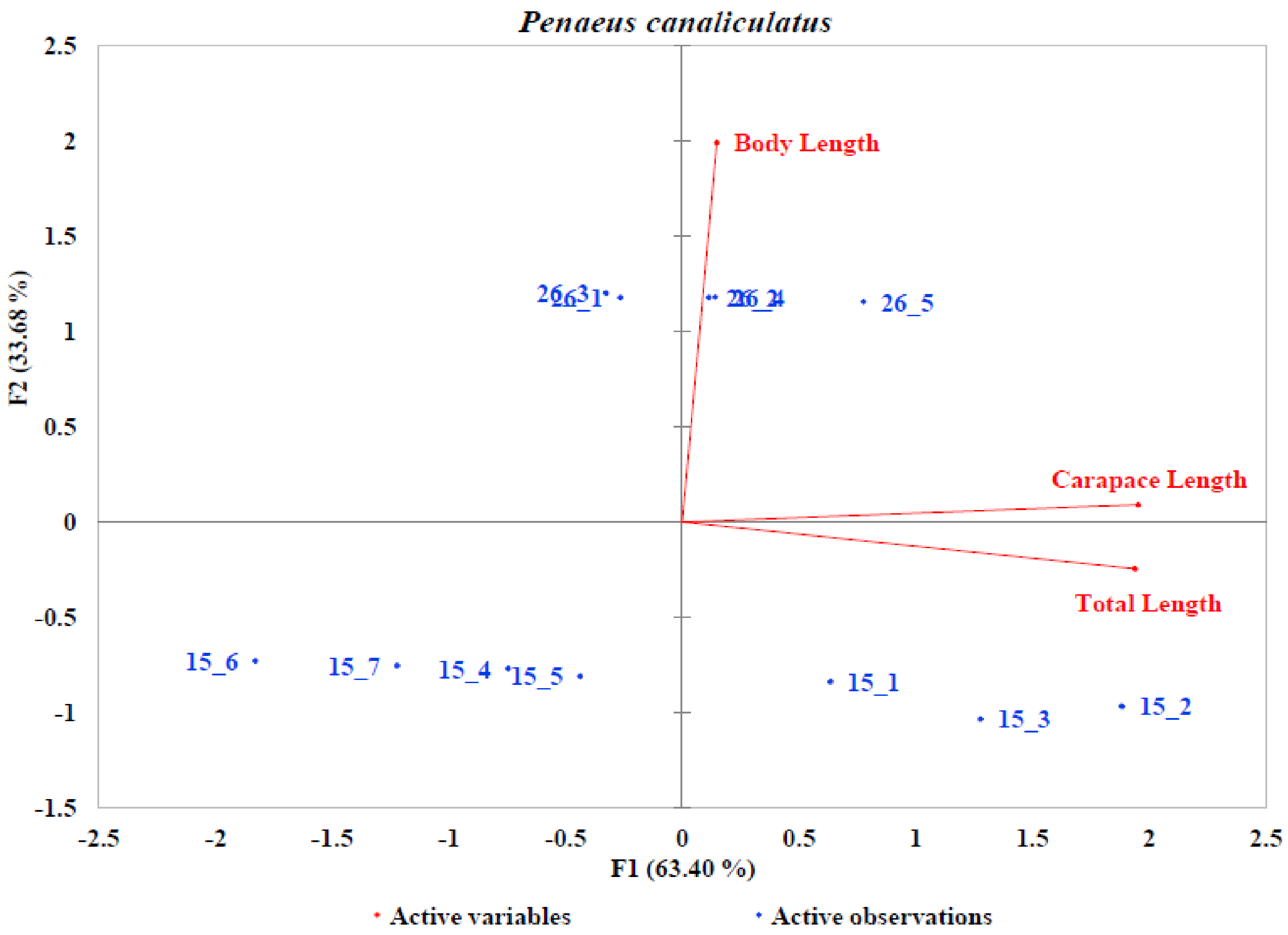
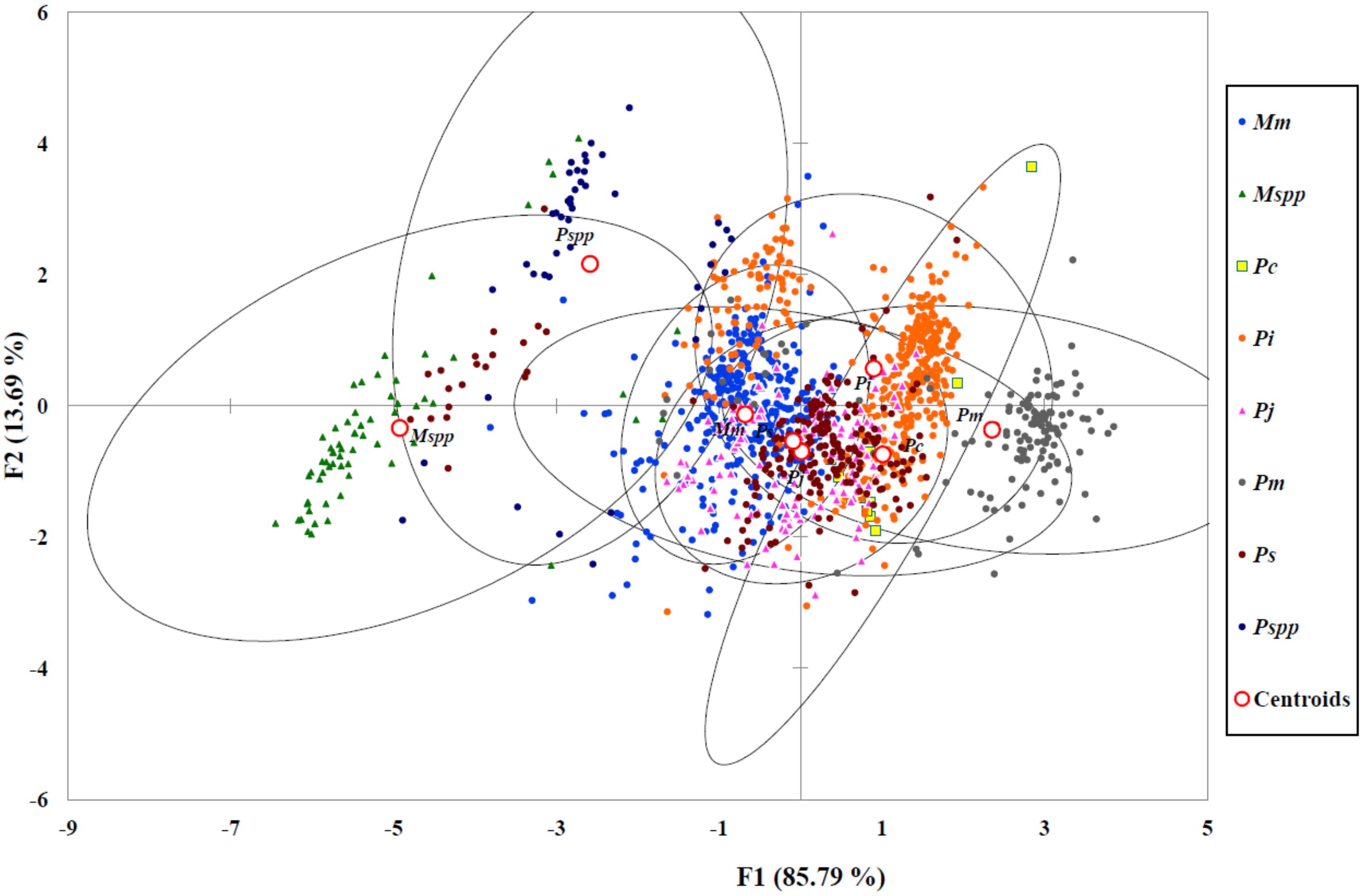


Figure 5.7: Principle Component Analysis Scatter Plot of *Penaeus canaliculatus*.

The Discriminant Function Analysis (DFA) applied to 1361 specimens based on Mahalanobis distances were analyzed after exploratory analysis to remove outliers with predictive classification of individuals for all groups of penaeid shrimp populations (Figure 5.8). The results of this study showed clusters produced overlapped. The results further showed centroids of populations for adult species partitioned closely to each other while the postlarva of *Penaeus spp.* and *Metapenaeus spp*. were classified far apart due to dissimilarities with their adult populations. The two populations of *P. canaliculatus* from S5 and S6 seemed to be different from each other as they were marked with no overlaps in all the evaluated characters. The results also showed that *M. japonicus* and *P. semisulcatus* are more closely related due to similarities with each other than any other species.



(*Mm– Metapenaeus monoceros; Mspp– Metapenaeus spp.; Pc– Penaeus canaliculatus; Pi– Fenneropenaeus indicus; Pj– Marsupenaeus japonicus; Pm– Penaeus monodon; Ps– Penaeus semisulcatus; Pspp– Penaeus spp.*)

Figure 5.8: Discriminant analysis showing penaeid shrimps in Malindi–Ungwana Bay based on Mahalanobis distances.

The Agglomerative Cluster Dendrogram (ACD) of the penaeid shrimps from Malindi–Ungwana Bay is shown in Figure 5.9. During the NEM season, clusters of homogeneous populations based on similar characteristics were observed in *F. indicus* from S4 and S5 as well as *P. monodon* from S5 and S6. A good number of clusters with homogeneous populations during SEM season were observed in *M. monoceros* from S4 and S5, *P. monodon* from S3 and S4, *F. indicus* from S5 and S6, while homogeneous population of *Metapenaeus sp.* was made from S1 and S4. Generally, at the level of similarity increases from 66.7% to 100%, more clusters of heterogeneous or increase in diversity among penaeid shrimp populations were observed across the Malindi–Ungwana Bay during the two seasons. Postlarva which were collected during SEM season were clustered together because of sharing dissimilar characteristics with their adult populations. The present study further revealed *P. canaliculatus* from S5 was well separated from S6 and its group population was classified as the most distant morphologically population in Malindi–Ungwana Bay.

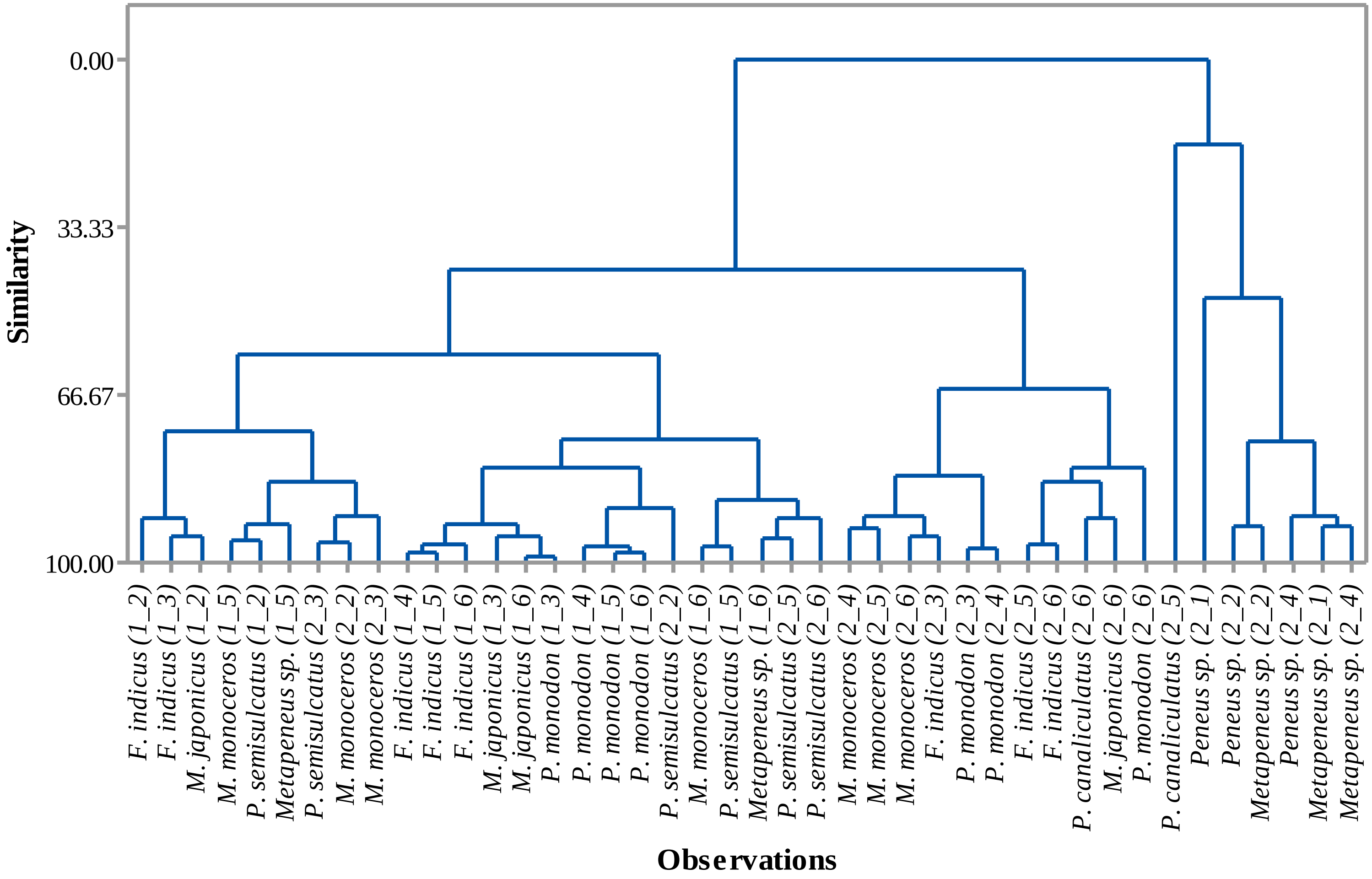


Figure 5.9: Agglomerative Cluster Dendrogram of the penaeid shrimp populations based on morphometric characters collected from Malindi–Ungwana Bay.

5.5 Discussion

The genetic diversity of wild penaeid shrimps from six geographic locations in the Malindi–Ungwana Bay was investigated using morphometric variations. This study revealed significant morphometric variations among groups of population in Malindi–Ungwana Bay which are solely from body shape and not size effects. In other studies, Bagherian & Rahmani (2007) and Lundqvist *et al.* (2008) have considered the shape variation among individuals or populations as a reflection of genetic variation caused by local adaptation. Populations of penaeid shrimps in this study are geographically very close to each other where phenetic differences examined between populations show apparent signs of response to local adaptation on various forms of selection pressures.

Heterogeneity as well as homogeneity in morphology was evident in all populations of penaeid shrimps in Malindi–Ungwana Bay. Among the morphometric variables measured, TL was the most variable and consequently the most suitable for the separation of the populations. The DFA managed to separate distinct populations of individual penaeid shrimps while postlarva of *Penaeus spp.* and *Metapenaeus spp*. were classified far apart due to dissimilarities with their adult populations. In another similar work to this study by Guarneri *et al.* (2014) showed that several species displayed intraspecific morphological variability where shape variations increased with size, while postlarva were closer to each other than adults along the first axis of PCA.

In this study, there were only two distinct clusters of penaeid shrimp that were observed at 22.9% level of similarity. The difference between the populations of these clusters may have been due to local adaption as well as phenotypic plasticity. Plasticity influences the evolution and adaptive responses of organisms, because it can alter the relationship between the phenotype and the genotype (Awodiran & Ogunjobi, 2016). Indeed, the environmental influence is of particular importance during the early development stages of these penaeid shrimps. Wangüemert *et al.* (2010) and Corpuz *et al.* (2013) suggested that population differentiation can be driven by heterogeneity of spawning habitat or larvae retention both geographically as well as at more localized scales. The morphometric variations observed in the samples of this study could also be due to different type of habitats where the penaeid shrimps live or effects of genetic drift caused by intense fishing in the Bay. This study has rejected the hypothesis that low genetic diversity in penaeid shrimp population of Malindi–Ungwana Bay has not led to its population decline that threatens its evolutionary potential. The results of this study indicated that *P. canaliculatus* populations bear a reduced genetic diversity in contrast to other penaeid species shrimps, likely due to the reduction of effective population size arising from fishing. Further, this study is in agreement with findings from Mkare *et al.* (2014) that showed *M. monoceros* has also a reduced genetic diversity due to fishing in the Malindi–Ungwana Bay.

5.6 Conclusion

Generally, this study confirmed that the variability among individual species within each population indicated the presence of high genetic diversity among populations of penaeid shrimps that give rise to genetically panmictic populations in Malindi–Ungwana Bay. This study further suggests that the two separate populations of *P. canaliculatus* could be considered as unique evolutionary taxa for conservation.

CHAPTER SIX

6. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General Discussion

In this study, six penaeid shrimps belonging to three sub–genera of the genus Penaeus were reported during the two monsoon seasons, Southeast monsoon (SEM) and Northeast monsoon (NEM). The six species were Indian white prawn (*Fenneropenaeus indicus* Edwards, 1837)**,** Speckled prawn (*Metapenaeus monoceros* Fabricius, 1798)**,** Green tiger prawn (*Penaeus semisulcatus* De Haan, 1844), Kuruma shrimp (*Marsupenaeus japonicus* Bate, 1888), Giant tiger prawn (*Penaeus monodon* Fabricius, 1798) and Witch prawn (*Penaeus canaliculatus* Olivier, 1811)**.** The most abundant species at 30.8% was *F. indicus* followed by *M. monoceros* (24.9%), *P. semisulcatus* (15.2%), *M. japonicus* (10.3%), *P. monodon* (9.7%) and the least was *P. canaliculatus* (0.9%).

Moreover, the dominance of juveniles recruited in the Malindi–Ungwana Bay is probably an indication that peak recruitment into the estuary takes place, and hence, the Malindi–Ungwana Bay is suggested to be the nursery area for *M. monoceros, F. indicus, P. semisulcatus* and *P. monodon*. Similar species compositions have been reported by Kimani *et al.* (2018), Omukoto *et al.* (2015) and Munga *et al.* (2013) from the coastal waters of Malindi–Ungwana Bay with slight differences in their species relative abundances. The major difference between this study and other studies in Malindi–Ungwana Bay is attributed to slight differences in the sampling techniques. Kimani *et al.* (2018) and Munga *et al.* (2013) had samples mainly from trawl catches which were collected from trawl areas different from this study, while Omukoto *et al.* (2015) collected their samples from the estuaries different this study as well.

The abundance of penaeid shrimp in Malindi–Ungwana Bay is influenced by the seasonal variation of environmental variables. This study has revealed a high relative abundance during SEM than NEM seasons despite its proportional decrease with increasing water depth, suggesting that distance from the shore and water depth strongly influences shrimp catches. In this study, the water temperatures and salinities did not significantly affect the shrimp abundance ($p > 0.05$). The water temperatures and salinities ranged from 26.8 ^{0}C – 28.6 ^{0}C and 32.2 ‰ – 36.4 ‰ respectively during the NEM season with small variations in the water temperatures (27.9 ^{0}C – 29.1 ^{0}C) and salinities (33.6 ‰ – 36.2 ‰) during SEM season. In another study by Chaitanawisuti *et al.* (2013) reported a similar salinity range of 30 – 35 ‰ as ideal for shrimp larval development and temperature range of 25 ^{0}C – 35 ^{0}C as best for growth of shrimp.

The shrimp abundance was higher in the shallow waters at S6 than deep waters at S5 during the two seasons. The substrate type at S6 plays a significant role in defense of shrimps from predation as well as allowing shrimps to burrow into the organic content and feed on other organisms present in the substrate. However, no information on substrate contents which were collected in this study was available for the sampled stations. Several studies have reported on seasonal abundance of shrimps in many parts of the world. In the outer Songkhla Lake of Thailand, Promhom *et al.* (2015) reported high shrimp abundance in the mud flats and sand-flats. Rosle and Ibrahim (2017) observed habitat preferences in relation to the abundance of penaeid shrimps, particularly *Penaeus monodon*, in Kelantan Delta, Malaysia. More similar seasonal shrimp abundance were reported by Teikwa and Mgaya (2003) for both artisanal and commercial bottom trawl shrimp fisheries in Tanzania, and Brito and Pena (2007) for the recruitment of *M. monoceros* and *F. indicus* from the estuary of the Sofala Bank in Mozambique.

Female shrimps were predominant in the overall combined sex ratio, while male shrimps were less abundant in this study ($p < 0.05$, $\chi^2 = 34.298$; Table 3.6). Similar findings were reported in other studies (Choy, 1988; Da Costa *et al.*, 2010; Gerami *et al.*, 2013; Simões *et al.*, 2013; Nyalungu *et al.*, 2014; Kalogirou *et al.*, 2017). Da Costa *et al.* (2010) and Choy (1988) suggested that the sex ratio of females may be related to the greater vulnerability of females to fishing due to their size or increased reproductive activity such as maturation and mating. Gerami *et al.* (2013) suggested that the skewed sex ratio may be due to differences in mortality rates between the two sexes or because of differences in behavioral characteristics such as reproduction migratory pattern. The results of this study on the sex ratio in favour of females agrees with Kalogirou *et al.* (2017) that showed ovigerous females decreased with increased depths. However, no information on the gear selectivity used in this study was available for the captured penaeid shrimps.

The findings of this study provide the first evidence about the growth pattern and condition factors of penaeid shrimp from its in-situ habitat. In all seasons, the relationship between the length and weight for most penaeid shrimps was significant exhibiting positive allometric growth different from $b = 3$ ($p < 0.05$), while a few observations were made on negative allometric growth patterns. Other studies have reported positive allometric growths for some penaeid shrimps such as *P. semisulcatus* (Manasirli *et al.*, 2014). For the results of negative allometric growths, this study agrees with other studies such as Khademzadeh and Haghi (2017), Komi and Francis (2017), Li *et al.* (2016) and Uddin *et al.* (2016) on *P. monodon*, while Manasirli (2014) on *M. monoceros*. The low *b* values reported in this study could also be attributed to fewer berried female shrimps in the catches. Lalrinsanga *et al.* (2012) suggested that the weight of maturing and berried females increases the *b* values. The regression coefficient (R^2) for length-weight relationships was high for most penaeid species, which suggested that body length is the best predictor of shrimp weight. The results of this study were in agreement with several other studies which showed high values of R^2 for length–weight relationships of different penaeid shrimps from various water bodies (Li *et al.*, 2016; Maheswarudu *et al.*, 2016; Udoinyang *et al.* 2016; Khademzadeh and Haghi, 2017; Komi and Francis, 2017; Suryanti *et al.*, 2018; Muhammadar *et al.*, 2019).

The Fulton's condition factor (*K*) an indicator of the environmental suitability for the resource, varied with size and sexes of the shrimp in the population (Oluboba, 2015). In this study, the condition factors of the same species have varied from one locality to another in every season (Kaka *et al.*, 2019). Generally, the condition factors were slightly higher during SEM than NEM seasons. This suggests that these shrimps were in good condition, healthy and will be suitable for mariculture. Li *et al.* (2016) and Lalrinsanga *et al.* (2012) suggested that the mean condition factor is both sex and season dependent, and the differences in condition factors of male and females may be attributed to the presence of gravid females or due to higher weight of the female's gonads, which are lacking in their male counterparts. This study also showed large occurrence of *M. monoceros* and *F. indicus* with matured gonads in both seasons as well as high number of juveniles surviving to different environmental conditions in the estuary making them suitable for development of mariculture in Kenya (Kaka *et al.*, 2019).

The genetic diversity of wild penaeid shrimps from six geographic locations in the Malindi–Ungwana Bay was investigated and revealed significant differences in the morphometric variations among populations. The significant differences between the population groups of the penaeid shrimps in Malindi–Ungwana Bay could be attributed to variations in body shape which is a reflection of genetic variation (Vatandoust, Abdoli, Anvarifar, & Mousavi-sabet, 2014). This study has revealed considerable distinction between the seasonal environmental variables on the local adaptations and their respective shrimp populations of Malindi–Ungwana Bay in terms of morphometric variations.

Based on the DFA results, this study showed the shrimp population structure in sympatric populations of *F. indicus***,** *M. monoceros***,** *P. semisulcatus*, *M. japonicus*, *P. monodon* and *P. canaliculatus*. A similar population structure in sympatric populations of *F. indicus* and *M. monoceros* was reported by Mkare *et al.* (2017) in the Southwest Indian Ocean. However, the DFA managed to separate distinct populations of individual penaeid shrimps while postlarva of *Penaeus spp.* and *Metapenaeus spp.* were classified far apart due to dissimilarities with their adult populations. In another similar work to this study by Guarneri *et al.* (2014) showed that shape differentiation in *Sinanodonta woodiana* populations increased with specimen's size as younger animals appeared to be more similar than older ones.

The results showed high genetic diversity was present among penaeid shrimp populations in Malindi–Ungwana Bay because of several clusters of penaeid shrimp that were observed when the level of similarity was increased to 100% (Figure 5.9). The difference between these clusters could be due to local adaption as well as phenotypic plasticity or genetic differentiation. Awodiran and Ogunjobi (2016) suggested that high genetic diversity within snail populations could be due to the numerous introduction and reintroduction of several gene pools of snails to the study areas by local snail marketers. Similarly, morphometric variations observed among shrimp populations in this study could be due to the effects of genetic drift caused by intense trawl fishing in the Bay. The results of this study indicated that each penaeid shrimp comes from a common population except *P. canaliculatus* which bear a reduced genetic diversity in contrast to others, likely due to the reduction of effective population size arising from intensive trawl fishing or habitat environmental changes. Similarly to this study, Mkare *et al.* (2014) also reported that *M. monoceros* has a reduced genetic diversity due to fishing in the Malindi–Ungwana Bay.

6.2 Conclusions

This study provides a useful assessment of penaeid shrimps in the Malindi–Ungwana Bay along the Northern part of Kenya, focusing on genetic diversity and population abundance of penaeid shrimps with a view of conservation and developing a coastal aquaculture program. The results of this study showed that *F. indicus* and *M. monoceros* with matured gonads, better growth patterns and condition factors were abundantly available throughout the monsoon seasons for the development of sustainable coastal shrimp aquaculture in Kenya.

Moreover, the results indicated that Malindi–Ungwana Bay is the nursery area for *M. monoceros*, *F. indicus*, *P. semisulcatus* and *P. monodon* that requires close monitoring of the catches to avoid growth overfishing in the estuarine area. The two population groups of *P. canaliculatus* seem to be reproductively isolated due to its small effective population size caused by either founder effect or bottlenecks effect. For that reason, *P. canaliculatus* needs to be considered as unique evolutionary taxa for conservation purposes. Generally, this study confirmed that the variability among individual species within each population indicated the presence of high genetic diversity among populations of penaeid shrimps that give rise to genetically panmictic populations in Malindi–Ungwana Bay.

6.3 Recommendations

1. Future postdoctoral research ought to be granted on the molecular studies using very sensitive genetic markers that are desirable to enrich our understanding of genetic variation in all penaeid shrimps of commercial importance from Malindi–Ungwana Bay;
2. There is need for an appropriate policy to be formulated on penaeid shrimp farming in Kenya;
3. This study recommends that strict measures on fishing efforts to be adopted in the estuarine areas between February and July every year while in the shallow waters between March and August every year to improve shrimp fishery in Malindi–Ungwana Bay;
4. Further action plan of a genetic monitoring programme ought to be put in place for conserving genetic diversity of the penaeid shrimps in Malindi–Ungwana Bay; and
5. This study recommends a review of the Prawn Fisheries Management Plan of 2010 to address the imminent changes.

REFERENCES

Abila, R. (2010). Economic Evaluation of the Prawn Fisheries of Malindi-Ungwana Bay Along the Kenya Coast. Kenya Marine and Fisheries Research Institute Technical Report, 66pp.

Adams, D. C., Rohlf, F. J., & Slice, D. E. (2004). Geometric morphometrics: Ten years of progress following the ‘revolution.’ *Italian Journal of Zoology, 71*(1), 5–16. https://doi.org/10.1080/11250000409356545.

Addinsoft SARL. (2015). *XLSTAT 2015*. Paris, FRANCE: Addinsoft. Retrieved from http://www.xlstat.com/en/learning-center/tutorials.html

Aktaş, M., & Cavdar, N. (2012). The combined effects of salinity and temperature on the egg hatching rate, incubation time, and survival until protozoal stages of *Metapenaeus monoceros* (Fabricius)(Decapoda: Penaeidae). *Turkish Journal of Zoology*, *36*(2), 249–253. https://doi.org/10.3906/zoo-1003-144.

Amanat, Z., & Qureshi, N. A. (2011). Ovarian Maturation Stages and Size at Sexual Maturity of *Penaeus indicus* (H. Milne Edwards, 1937) in the Lagoon Water of Sonmiani Bay, Balochistan. *Pakistan J. Zool.*, *43*(3), 447–459.

Anger, K. (2001). *The biology of decapod crustacean larvae*. *Crustacean Issues* (Vol. 14, pp 1–4). Lisse: A.A. Balkema Publishers. https://doi.org/10.1651/0278-0372(2005)025.

Aryani, N., Suharman, I., & Hasibuan, S. (2016). Length-weight relationship and condition factor of the critically endangered fish of Geso, *Hemibagrus wyckii* (Bleeker, 1858) bagridae from Kampar Kanan River , Indonesia. *Journal of Entomology and Zoology Studies*, *4*(2), 119–122.

Auld, J. R., Agrawal, A. A., & Relyea, R. A. (2010). Re-evaluating the costs and limits of adaptive phenotypic plasticity. *The Royal Society*, *277*, 503–511. https://doi.org/10.1098/rspb.2009.1355

Awodiran, M. O., & Ogunjobi, Z. O. (2016). Genetic diversity in two populations of *Limicolaria aurora* (Jay, 1839) from two ecological zones in Nigeria. *African Journal of Biotechnology*, *15*(25), 1306–1314. https://doi.org/10.5897/AJB2015.15154.

Bage, H. (2013). Desk review: The problem of bycatch in shrimp fisheries. Report/Rapport: SF-FAO/2013/13. January/Janvier 2013. *FAO-SmartFish Programme of the Indian Ocean Commission*, 38pp.

Bagherian, A., & Rahmani, H. (2007). Morphological differentiation between two populations of the Shemaya, *Chalcalburnus chalcoides*: a geometrical morphometric approach. *Zoology in the Middle East*, *40*(1), 53–62. https://doi.org/10.1080/09397140.2007.10638204.

Bate, C. S. (1888). *Report on the Crustacea Macrura Collected by H.M.S. Challenger During the Years 1873-76. Report on the Scientific Results ofthe Voyage of H.M.S. Challenger During the Years 1873-76 Under theCommand of Captain George S. Nares, R.N., F.R.S. and the Late Cap*. Edinburgh: Neill and Company. Retrieved from http://ci.nii.ac.jp/naid/10006436565/en/

Beck, S. V., Räsänen, K., Ahi, E. P., Kristjánsson, B. K., Skúlason, S., Jónsson, Z. O., & Leblanc, C. A. (2019). Gene expression in the phenotypically plastic Arctic charr (*Salvelinus alpinus*): A focus on growth and ossification at early stages of development. *Evolution and Development*, *21*, 16–30.

https://doi.org/10.1111/ede.12275.

Bektas, Y., & Belduz, A. O. (2009). Morphological variation among atlantic horse mackerel, *Trachurus trachurus* populations from Turkish coastal waters. *Journal of Animal and Veterinary Advances, 8*(3), 511–517.

Bishop, J. M., & Khan, M. H. (1991). Depth as a factor in abundance and size of juvenile penaeid shrimps in the absence of estuaries and marshes. *Marine Biology*, *114,* 103–104.

Blaber, S. J. M. (2009). Relationships between tropical coastal habitats and (offshore) fisheries. In I. Nagelkerken (Ed.), *Ecological Connectivity among Tropical Coastal Ecosystems* (pp. 533 – 564). Springer Dordrecht, London. https://doi.org/10.1007/978-90-481-2406-0.

Blamires, S. J., Martens, P. J., & Kasumovic, M. M. (2018). Fitness consequences of plasticity in an extended phenotype. *Journal of Experimental Biology, 221*(4), jeb167288. https://doi.org/10.1242/jeb.167288.

Briggs, M., Funge-smith, S., & Phillips, M. (2005). Introductions and movement of two penaeid shrimp species in Asia and the Pacific. *FAO Fisheries Technical Paper. No. 476*, 78.

Brito, A., & Pena, A. (2007). Population Structure and Recruitment of Penaeid Shrimps from the Pungué River Estuary to the Sofala Bank Fishery, Mozambique. *Western Indian Ocean J. Mar. Sci.*, *6*(2), 147–158.

Cao, Y. Y., & Li, Z. B. (2016). Genetic diversity and population structure of *Fenneropenaeus penicillatus* determined by mitochondrial DNA analyses. *Genetics and Molecular Research*, *15*(3), 1–11.

https://doi.org/http://dx.doi.org/10.4238/gmr.15038503.

Carvalho, C. D. E., Keunecke, K. A., & Lavrado, H. P. (2019). Morphometric variation in pink shrimp populations at Rio de Janeiro coast (SE Brazil): are they really similar in closer areas? *Annals of the Brazilian Academy of Sciences*, *91*(2), 1–17. https://doi.org/10.1590/0001-3765201920180252.1.

Castilho, A. L., Pie, M. R., Fransozo, A., Pinheiro, A. P., & Costa, R. C. (2008). The relationship between environmental variation and species abundance in shrimp community (Crustacea: Decapoda: Penaeoidea) in south-eastern Brazil. *Journal of the Marine Biological Association of the United Kingdom*, *88*(1), 119–123. https://doi.org/10.1017/S0025315408000313.

Chaitanawisuti, N., Santhaweesuk, W., & Wattayakorn, G. (2013). The combined effects of temperature and salinity on survival of postlarvae tiger prawn *Penaeus monodon* under laboratory conditions. *Agricultural Sciences*, *4*(6), 53–56. https://doi.org/10.4236/as.2013.46A008.

Chan, T. Y. (1998). In: Carpenter, K.E. and V.H. Niem (Eds). FAO Species Identification Guide For Fishery Purposes. The Living Marine Resources of the Western Central Pacific. Cephalopods, Crustaceans, Holothurians and Sharks. *Food and Agriculture Organization of the United Nations, Rome*, *2*, 687–1396.

Choy, S. C. (1988). The fishery and biology of *Penaeus canaliculatus* (Crustacea: Decpoda: Penaeidae) in Laucala Bay, Republic of Fiji. *Fishbyte*, *6*(1), 21–24.

Corpuz, M. N. C., Camacho, M. V. C., & Ocampo, P. P. (2013). Morphometric and morphomeristic variations in five populations of indigenous Celebes goby *Glossogobius celebius* (Perciformes: Gobiidae) from Southern Luzon, Philippines.

Philippine Agricultural Scientist, *96*(1), 75–85.

Da Costa, R. C., Branco, J. O., MacHado, I. F., Campos, B. R., & Avila, M. G. (2010). Population biology of shrimp *Artemesia longinaris* (Crustacea: Decapoda: Penaeidae) from the southern coast of Brazil. *Journal of the Marine Biological Association of the United Kingdom*, *90*(4), 663–669. https://doi.org/10.1017/S002531540999124X.

Dall, W., Hill, B. J., Rothlisberg, P. C., & Sharples, D. J. (1990). *Advances in Marine Biology*. Academic Express, London.

Davis, A. H., & Townsend, J. P. (2009). Evolving gene expression: from G to E to G x E. *Trends in Ecology and Evolution*, *24*(12), 649–658. https://doi.org/10.1016/j.tree.2009.06.011.

de Freitas, A. J. (1986). Selection of nursery areas by six southeast African Penaeidae. *Estuarine, Coastal and Shelf Science*, *23*(6), 901–908. https://doi.org/10.1016/0272-7714(86)90080-6.

De Haan, W. (1844). Crustacea. In *In: von Siebold, P.F., Fauna Japonica sive Descriptio Animalium, quae in Itinere per Japoniam, Jussu et Auspiciis Superiorum, qui Summum in India Batava Imperium Tenent, Suspecto, Annis 1823-1830 Collegit, Notis, Observationibus et Adumbrationibus Illustr* (pp. 1–55). Lugduni-Batavorum. Retrieved from http://www.marinespecies.org/aphia.php?p=sourcedetails&id=125841

Demetriades, N. T., & Forbes, A. T. (1993). Seasonal changes in the species composition of penaeid prawns on the Tugela Bank, Natal, South Africa. *South African Journal of Marine Science*, *13*(1), 317–322. https://doi.org/10.2989/025776193784287266.

Dwivedi, A. K., & Dubey, V. K. (2013). Advancements in morphometric differentiation: a review on stock identification among fish populations. *Rev Fish Biol Fisheries, 23*, 23–39. https://doi.org/10.1007/s11160-012-9279-1.

Dzoga, M., Simatele, D., & Munga, C. (2018). Assessment of ecological vulnerability to climate variability on coastal fishing communities: A study of Ungwana Bay and Lower Tana Estuary, Kenya. *Ocean and Coastal Management*, *163*, 437–444. https://doi.org/10.1016/j.ocecoaman.2018.07.015.

Edwards, H. M. (1837). *Histoire naturelle des crustacées comprenant l'anatomie, la physiologie, et la classification de ces animaux (1834–1840), Vol 2. Librairie Encyclopedique de Roret*. Paris. https://doi.org/10.1016/s0399-8320(05)80791-2.

Fabricius, J. C. (1798). *Joh. Christ. Fabricii hist. nat. oec. et cameral. p.p.o. societ. Hafn. ... Entomologia systematica : emendata et aucta, secundum classes, ordines, genera, species, adjectis synonimis, locis, observationibus, descriptionibus.* Hafniae : impensis Christ. Gottl. Proft,. Retrieved from https://www.biodiversitylibrary.org/item/82436

FAO. (2016). Fishery and Aquaculture Country Profiles. The Republic of Kenya. *FAO Fisheries and Aquaculture Department*, pp. 1–29.

FAO. (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals*. Food and Agriculture Organization of the United Nations, Rome.

Feng, X., Liu, J., Chiang, Y. C., & Gong, X. (2017). Investigating the Genetic Diversity, Population Differentiation and Population Dynamics of *Cycas segmentifida* (Cycadaceae) Endemic to Southwest China by Multiple Molecular Markers.

Frontiers in Plant Science, *8*, 1–14. https://doi.org/10.3389/fpls.2017.00839.

Froese, B. R. (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology*, *22*, 241–253. https://doi.org/10.1111/j.1439-0426.2006.00805.x.

Fulanda, Bemerd. (2003). Shrimp Trawling in Ungwana Bay A Threat to Fishery Resources. In J. Hoorweg & N. Muthiga (Eds.), *Recent Advances in Coastal Ecology; Studies from Kenya* (pp. 233–242). African Studies Centre, 2300 RB Leiden, Netherlands.

Fulanda, Bernerd, Ohtomi, J., Mueni, E., & Kimani, E. (2011). Fishery trends, resource-use and management system in the Ungwana Bay fishery Kenya. *Ocean and Coastal Management*, *54*(5), 401–414. https://doi.org/10.1016/j.ocecoaman.2010.12.010.

Fynn, J. A., & Mensah, R. S. (2012). Species diversity and relative abundance of fisheries resources found in beach seine along the central Coast of Ghana. *West African Journal of Applied Ecology*, *20*(1), 1–9.

Gammanpila, M. (2015). Economic Viability of small scale shrimp (*Penaeus monodon*) farming in the Northwestern province of Sri Lanka. *United Nations University Fisheries Training Programme*, 49. Retrieved from http://www.unuftp.is/static/fellows/document/menake14prf.pdf

Garcia, S. (1988). Tropical penaeid prawns. In: I.A. Culland (Eds). *Fish Population Dynamics, 2nd Edition*, *150*(0035-3787 (Print)), 3–15. Retrieved from http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_7/b_fdi_51-52/010019707.pdf

Gerami, M. H., Ghorbani, R., Paighmabari, S. yousof, & Momeni, M. (2013). Reproductive season, maturation size (LM50) and sex ratio of *Metapenaeus affinis* (Decapoda: Penaeidae) in Hormozgan shrimp fishing grounds, south of Iran. *International Journal of Aquatic Biology*, *1*(2), 48–54. https://doi.org/10.22034/ijab.v1i2.25.

Getso, B. U., Abdullahi, J. M., & Yola, I. A. (2017). Length-weight relationship and condition factor of *Clarias gariepinus* and *Oreochromis niloticus* of Wudil River, Kano, Nigeria. *Journal of Tropical Agriculture, Food, Environment and Extension*, *16*(1), 1–4.

Gillett, R. (2008). *Global study of shrimp fisheries. FAO Fisheries Technical Paper. No. 475*. Food and Agriculture Organization of the United Nations, Rome. Retrieved from http://www.gbv.de/dms/sub-hamburg/588858374.pdf

Gopalakrishnan, A., Rajkumar, M., Rahman, M. M., Sun, J., Antony, P. J., Venmathi maran, B. A., & Trilles, J. P. (2014). Length-weight relationship and condition factor of wild, grow-out and “loose-shell affected” giant tiger shrimp, *Penaeus monodon* (Fabricius, 1798) (Decapoda: Penaeidae). *Journal of Applied Ichthyology*, *30*(1), 251–253. https://doi.org/10.1111/jai.12269.

Government-of-Kenya. (2011). Prawn Fishery Management Plan L.N. 20/2011. *Government Printer, Nairobi.*

Groeneveld, J., & Everett, B. (2015). Crustacean Deep-water trawl fisheries. A retrospective analysis of their status in the Southwest indian Ocean. In R. van der Elst & B. Everett (Eds.), *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (pp. 67–118). Retrieved from http://cordioea.net/outputs-results/swiofp-offshore-fisheries-report/%5Cnhttp://www.swiofp.net/

Guarneri, I., Popa, O. P., Gola, L., Kamburska, L., Lauceri, R., Lopes-Lima, M., … Riccardi, N. (2014). A morphometric and genetic comparison of *Sinanodonta woodiana* (Lea, 1834) populations: Does shape really matter? *Aquatic Invasions*, *9*(2), 183–194. https://doi.org/10.3391/ai.2014.9.2.07.

Guino-o, R. S. (2012). Length-Weight and Length-Length Relationships and Fulton Condition Factor of Philippine Mullets (Family Mugilidae: Teleostei). *Silliman Journal*, *53*(2), 176–189.

Gunawickrama, K. B. S. (2007). Morphological heterogeneity and population differentiation in the green chromid *Etroplus suratensis* (Pisces: Cichlidae) in Sri Lanka. *Ruhuna Journal of Science*, *2*, 70–81.

Hanif, M. A., Chaklader, M. R., Siddik, M. A. B., Nahar, A., Foysal, M. J., & Kleindienst, R. (2019). Phenotypic variation of gizzard shad, *Anodontostoma chacunda* (Hamilton, 1822) based on truss network model. *Regional Studies in Marine Science*, *25*, 100442. https://doi.org/10.1016/j.rsma.2018.100442.

Hoof, L. van, & Steins, N. A. (2017). Mission Report Kenya; Scoping Mission Marine Fisheries Kenya. Wageningen Marine Research report C038/17. *Wageningen Marine Research*, 136pp.

Ibrahim, M. Y., Nor, M. S. A., & Abukashawa, S. M. A. (2015). Sequence analysis and molecular phylogeny of 16S rRNA gene fragments in four species of the Penaeid shrimps from the Sudanese Red Sea. *International Journal of Marine Science*, *5*(55), 1–9. https://doi.org/10.5376/ijms.2015.05.0055.

Iversen, S. A. (1984). Kenyan marine fish resources in water deeper than 10 m investigated by R/V 'Dr. Fridtjof Nansen". In S. A. Iversen & S. Myklevoll (Eds.), *The Proceedings of the Norad- Kenya Seminar To Review the Marine Fish Stocks and Fisheries in Kenya. Mombasa, Kenya, 13-15 March 1984.* (pp. 22–34). FAO, Rome.

Jamizan, A. R., & Chong, V. C. (2017). Demersal fish and shrimp abundance in relation to mangrove hydrogeomorphological metrics. *Sains Malaysiana*, *46*(1), 9–19.

Jones, B. M., & Robinson, G. E. (2018). Genetic accommodation and the role of ancestral plasticity in the evolution of insect eusociality. *Journal of Experimental Biology*, *221*, 1–11. https://doi.org/10.1242/jeb.153163.

Jørgensen, H. B. H., Pertoldi, C., Hansen, M. M., Ruzzante, D. E., & Loeschcke, V. (2008). Genetic and environmental correlates of morphological variation in a marine fish: the case of Baltic Sea herring (*Clupea harengus*). *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(3), 389–400. https://doi.org/10.1139/f07-177.

Jose, J. (2013). Penaeus. In J. Jose & L. Pillai (Eds.), *Taxonomy and identification of commercially important crustaceans of India* (pp. 45–69). Cochin: C.M.F.R.I. Publications.

Kaka, R. M., Jung'a, J. O., Badamana, M., Ruwa, R. K., & Karisa, H. C. (2019). Morphometric length-weight relationships of wild penaeid shrimps in Malindi-Ungwana Bay: Implications to aquaculture development in Kenya. *Egyptian Journal of Aquatic Research*, *45*(2), 167–173. https://doi.org/10.1016/j.ejar.2019.06.003.

Kalogirou, S., Anastasopoulou, A., Kapiris, K., Maravelias, C. D., Margaritis, M., Smith, C., & Pihl, L. (2017). Spatial and temporal distribution of narwal shrimp *Plesionika narval* (Decapoda, Pandalidae) in the Aegean Sea (Eastern Mediterranean Sea). *Regional Studies in Marine Science*, *16*, 240–248. https://doi.org/10.1016/j.rsma.2017.09.014.

Kaouèche, M., Bahri-Sfar, L., Hammami, I., & Hassine, O. K. Ben. (2017). Morphometric variations in white seabream *Diplodus sargus* (Linneus, 1758) populations along the Tunisian coast. *Oceanologia*, *59*(2), 129–138. https://doi.org/10.1016/j.oceano.2016.10.003.

Khademzadeh, O., & Haghi, M. (2017). Length-weight relationship and condition factor of white leg shrimp *Litopenaeus vannamei* (Boone, 1931) in culture systems of Choebdeh, West-South of Iran. *International Journal of Fisheries and Aquatic Studies*, *5*(1), 298–301.

Kimani, E., Manyala, J., Munga, C., & Ndoro, C. (2011). Shallow-water prawn trawl survey. SWIOFP Component 2 for SWIOFP 2011C201a. *South West Indian Ocean Fisheries Project Survey Technical Report*, (October), 90pp.

Kimani, E. N., Fulanda, B., Wambiji, N., Munga, C., Okemwa, G., Thoya, P., & Omukoto, J. (2012). Spatial mapping of trawl fishery resources of Malindi-Ungwana Bay, Kenya. SWIOFP Components 2 (Crustaceans). *South West Indian Ocean Fisheries Project Survey Technical Report*, (June), 28pp.

Kimani, E., Omukoto, J., Mueni, E., Mirera, D., & Fondo, E. (2018). Status of crustacean fisheries. In E. Kimani, C. Aura, & G. Okemwa (Eds.), *The Status of Kenya Fisheries: Towards the sustainable exploitation of fisheries resources for food* *security and economic development.* (p. 135). Mombasa: Kenya Marine and Fisheries Research Institute (KMFRI).

Kitheka, J. U. (2002). Freshwater and sediment discharge in Ungwana Bay: The Role of the Tana and Sabaki Rivers. *Kenya Marine and Fisheries Research Institute Final Report*, (December), 1–97.

Kitheka, J. U., Obiero, M., & Nthenge, P. (2005). River discharge, sediment transport and exchange in the Tana estuary, Kenya. *Estuarine, Coastal and Shelf Science, 63*(3), 455–468. https://doi.org/https://doi.org/10.1016/j.ecss.2004.11.011.

Komi, G. W., & Francis, A. (2017). Length-weight relationship, condition factor and aspects of growth parameters of the black tiger shrimp (*Penaeus monodon*) in the Andoni River System, Niger Delta, Nigeria. *Global Journal of Science Frontier Research (D), 17*(2), 8–18.

Kristjansson, B. K., Leblanc, C. A., Skúlason, S., Snorrason, S. S., & Noakes, D. L. G. (2018). Phenotypic plasticity in the morphology of small benthic Icelandic Arctic charr (*Salvelinus alpinus*). *Ecology of Freshwater Fish, 27*, 636 – 645. https://doi.org/10.1111/eff.12380.

Kumlu, M., Eroldogan, O. T., & Aktas, M. (2000). Effects of temperature and salinity on larval growth , survival and development of *Penaeus semisulcatus*. *Aquaculture, 188*, 167–173.

Kumlu, Metin, Avşar, D., Eroldŏan, T., & Başusta, N. (1999). Some biological aspects of penaeid shrimps inhabiting Yumurtalik Bight in Iskenderun Bay (North-Eastern Mediterranean). *Turkish Journal of Zoology, 23*(1), 53–59.

Kumlu, Metin, Kumlu, M., & Turkmen, S. (2010). Combined effects of temperature and salinity on critical thermal minima of pacific white shrimp *Litopenaeus vannamei* (Crustacea: Penaeidae). *Journal of Thermal Biology*, *35*, 302–304. https://doi.org/10.1016/j.jtherbio.2010.06.008.

Lalrinsanga, P. L., Pillai, B. R., Mahapatra, K. D., Sahoo, L., Ponzoni, R. W., Nguyen, N. H., … Patnaik, S. (2012). Length–weight relationship and condition factor of nine possible crosses of three stocks of giant freshwater prawn, *Macrobrachium rosenbergii* from different agro-ecological regions of India. *Aquaculture International*, *23*(1), 401. https://doi.org/10.1007/s10499-012-9595-4.

Le Cren, E. D. (1951). The Length-weight relationship and seasonal cycle in gonad weight and condition in the Perch (*Perca fluviatilis*). *Journal of Animal Biology*, *20*(2), 201–219. Retrieved from http://www.jstor.org/stable/1540

Le Manach, F., Abunge, C. A., Mcclanahan, T. R., & Pauly, D. (2015). Tentative Reconstruction of Kenya's Marine Fisheries Catch, 1950–2010*. *Fisheries Centre Research Reports*, *23*(2), 37–52.

Levis, N. A., & Pfennig, D. W. (2016). Evaluating 'Plasticity-First' Evolution in Nature: Key Criteria and Empirical Approaches. *Trends in Ecology & Evolution*, *31*(7), 563–574.

Levis, N. A., & Pfennig, D. W. (2018). *Evolution of Phenotypic Plasticity and Gene Expression during Character Displacement*. *Evolution & Diversity of Life*. Chichester: eLS. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470015902.a0028159.

Levis, N. A., & Pfennig, D. W. (2019). Plasticity-led evolution: evaluating the key prediction of frequency-dependent adaptation. *Proc. R. Soc. B*, *285*, 20182754.

https://doi.org/http://dx.doi.org/10.1098/rspb.2018.2754.

Li, Y., Zhou, F., Ma, Z., Huang, J., Jiang, S., Yang, Q., … Qin, J. G. (2016). Length–weight relationship and condition factor of giant tiger shrimp, *Penaeus monodon* (Fabricius, 1798) from four breeding families. *SpringerPlus*, *5*, 1279. https://doi.org/10.1186/s40064-016-2979-6.

Lind, M. I., Yarlett, K., Reger, J., Carter, M. J., & Beckerman, A. P. (2015). The alignment between phenotypic plasticity, the major axis of genetic variation and the response to selection. *Proceedings of the Royal Society B*, *282*, 20151651. https://doi.org/10.1098/rspb.2015.1651.

Lundqvist, A., Andersson, S., & Lonn, M. (2008). *Genetic variation in wild plants and animals in Sweden: A review of case studies from the perspective of conservation genetics*. The Swedish Environmental Protection Agency, Stockholm.

Macia, A. (2004). Juvenile Penaeid shrimp density, spatial distribution and size composition in four adjacent habitats within a mangrove-fringed bay on Inhaca Island, Mozambique. *Western Indian Ocean Journal of Marine Science*, *3*(2), 163–178. Retrieved from file:///C:/Users/Heather/Downloads/Macia distribution.pdf

Maheswarudu, G., Rao, G. S., Ghosh, S., Ranjan, R., Dash, B., Muthukrishnan, P., & Veena, S. (2016). Experimental culture of black tiger shrimp *Penaeus monodon* (Fabricius, 1798) in open sea floating cage. *Indian Journal of Fisheries*, *63*(2), 47–54. https://doi.org/10.21077/ijf.2016.63.2.46459-07.

Manasirli, M. (2014). Population dynamics of the *Metapenaeus monoceros* (Fabricius, 1798) in North Eastern Mediterranean Sea. *Iranian Journal of Fisheries Sciences*, *13*(4), 955–966.

Manasirli, M., Kiyaga, V. B., & Perker, M. (2014). Reproduction, growth, mortality and exploitation rate of *Penaeus semisulcatus* De Haan, 1844 (Decapoda, Penaeidae) from iskenderun bay (North Eastern Mediterranean). *Crustaceana*, *87*(4), 385–400. https://doi.org/10.1163/15685403-00003290.

Mathews, P. G. (2005). *Design of Experiments with MINITAB*. *The American Statistician* (Vol. 60). American Society for Quality, Quality Press, Milwaukee,Wisconsin. https://doi.org/10.1198/tas.2006.s46.

McClanahan, T. (1988). Seasonality in East Africa’s coastal waters. *Marine Ecology Progress Series*, *44*, 191–199. https://doi.org/10.3354/meps044191.

Mirera, O. D. (2011). Trends in exploitation, development and management of artisanal mud crab (*Scylla serrata* Forsskal 1775) fishery and small-scale culture in Kenya: An overview. *Ocean and Coastal Management*, *54*(11), 844–855. https://doi.org/10.1016/j.ocecoaman.2011.08.001

Mkare, T. K., Groeneveld, J. C., Teske, P. R., & Matthee, C. A. (2017). Comparative genetic structure in two high-dispersal prawn species from the south-west Indian Ocean. *African Journal of Marine Science*, *39*(4), 467–474. https://doi.org/10.2989/1814232X.2017.1402089.

Mkare, Thomas K., Von Der Heyden, S., Groeneveld, J. C., & Matthee, C. A. (2014). Genetic population structure and recruitment patterns of three sympatric shallow-water penaeid prawns in Ungwana Bay, Kenya, with implication for fisheries management. *Marine and Freshwater Research*, *65*(3), 255–266. https://doi.org/10.1071/MF13047.

Mmochi, A. (2015). Mariculture. In J. Paula (Ed.), *The Regional State of the Coast*

Report: Western Indian Ocean (p. 546). Nairobi, Kenya: UNEP and WIOMSA.

Mojekwu, T. O., & Anumudu, C. I. (2015). Advanced techniques for morphometric analysis in fish. *Journal of Aquaculture Research & Development*, *06*(08), 6–11. https://doi.org/10.4172/2155-9546.1000354.

Montoya, J. V., Arrington, D. A., & Winemiller, K. O. (2014). Seasonal and diel variation of shrimp (Crustacea, Decapoda) on sandbanks of a tropical floodplain river. *Journal of Natural History*, *48*(9–10), 557–574. https://doi.org/10.1080/00222933.2013.840398.

Morais, P., Rufino, M., Reis, J., Dias, E., & Sousa, R. (2013). Assessing the morphological variability of *Unio delphinus* SPENGLER, 1783 (Bivalvia: Unionidae) using geometric morphometry. *Journal of Molluscan Studies*, 1–7. https://doi.org/10.1093/mollus/eyt037.

Muhammadar, A. A., Sarong, M. A., Ulfa, M., Putra, D. F., & Zulfahmi, Z. (2019). Length-weight relationship of *Metapenaeus ensis* in Aceh utara waters, lhokseumawe city, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *348*, 012089. https://doi.org/10.1088/1755-1315/348/1/012089.

Munasinghe, D. H. N., & Senevirathna, J. D. M. (2015). Phenotypic plasticity and genetic variation of two wild populations of green tiger shrimp (*Penaeus semisulcatus* De Haan, 1844). *International Journal of Marine Science*, *5*(5), 1–8. https://doi.org/10.5376/ijms.2015.05.0005.

Munga, C. N., Kimani, E., Ruwa, R. K., & Vanreusel, A. (2016). Species composition of fisheries resources of the Tana and Sabaki estuaries in the Malindi-Ungwana Bay, Kenya. In S. Diop, P. Scheren, & F. J. Machiwa (Eds.), *Estuaries of the World*

(Estuaries:, pp. 27–38). Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-319-25370-1.

Munga, C. N., Mwangi, S., Ong ’anda, H., Ruwa, R., Manyala, J., Groeneveld, J. C., … Vanreusel, A. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. *Fisheries Research*, *147*, 93–102. https://doi.org/10.1016/j.fishres.2013.04.013.

Munga, C. N., Mwangi, S., Ong, H., Ruwa, R., Manyala, J., Groeneveld, J. C., … Vanreusel, A. (2014). Fish catch composition of artisanal and bottom trawl fisheries in Malindi-Ungwana Bay, Kenya: A cause for conflict? *Western Indian Ocean J. Mar. Sci.*, *13*(2), 177–188.

Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J., & Vanreusel, A. (2012). Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries Science*, *78*(2), 209–219. https://doi.org/10.1007/s12562-011-0458-0.

Mutagyera, W. B. (1984). Distribution of some deep water prawn and lobster species in Kenya’s waters. In S. A. Iversen, S. Myklevoll, & Kenya (Eds.), *The Proceedings of The NORAD-Kenya Seminar To Review the Marine Fish Stocks and Fisheries in Kenya* (pp. 17–19). Food Agriculture Organization of the United Nations, Rome.

Mwatha, G. K. (2002). Assessment of the prawn fishery, bycatch, resource use conflicts and performance of the Turtle Exclusive Device. In *Current status of trawl fishery of Malindi-Ungwana Bay. Kenya Marine and Fisheries Research Institute Technical Report 12/2002* (pp. 43–64).

Ndiaye, W., Diouf, K., Samba, O., Ndiaye, P., Panfili, J., Marbec, U. M. R., … Bataillon, P. E. (2015). The Length-weight relationship and condition factor of white grouper (*Epinephelus aeneus*, Geoffroy Saint Hilaire, 1817) at the south-west coast of Senegal, West Africa. *International Journal of Advanced Research*, *3*(3), 145–153.

Noble, D. W. A., Radersma, R., & Uller, T. (2019). Plastic responses to novel environments are biased towards phenotype dimensions with high additive genetic variation. *Proceedings of TheNational Academy of Sciences of the United States of America*, *116*, 13452–13461. https://doi.org/10.1073/pnas.1821066116.

Nyalungu, N. P., Hodgson, A. N., Froneman, P. W., Dopolo, M., & Masubelele, M. (2014). Temporal and spatial variability in the abundance, biomass and distribution of *Palaemon peringueyi* (Decapoda: Crustacea) are influenced by biological but not physico-chemical factors in the permanently open Kariega Estuary, South Africa. *African Journal of Aquatic Science*, *39*(4), 435–442. https://doi.org/10.2989/16085914.2014.960792.

Oa, A., Oik, U., & Amadioha, F. (2018). Morphometric characters and meristic counts of black chin tilapia (*Sarotherodon melanotheron*) from Buguma, Ogbakiri and Elechi creeks, Rivers State, Nigeria. *International Journal of Poultry and Fisheries Sciences*, *2*(1), 1–8. https://doi.org/10.15226/2578-1898/2/1/00106.

Okomoda, V. T., Koh, I. C. C., Hassan, A., & Shahreza, S. M. (2018). Length-weight relationship and condition factor of the progenies of pure and reciprocal crosses of *Pangasianodon hypophthalmus* and *Clarias gariepinus*. *Aquaculture, Aquarium, Conservation & Legislation*, *11*(4), 980–987.

Ola-Oladimeji, F. A., Awodiran, M. O., Fagbuaro, O., & Akomolafe, A. O. (2016).

Morphological characterization of wild and cultured *Clarias gariepinus* (Burchell 1822) using principal component and cluster analyses. *Notulae Scientia Biologicae*, *8*(4), 428–436. https://doi.org/10.15835/nsb.8.4.9852.

Olapade, J. O., & Tarawallie, S. (2014). The length-weight relationship, condition factor and reproductive biology of *Pseudotolithus senegalensis* (Valenciennes, 1833) (croakers), in Tumbo western rural district of Sierra Leone. *African Journal of Food, Agriculture, Nutrition and Development*, *14*(6), 2176–2189.

Olivier, A. G. (1811). Palemon : Palaemon. *Encyclopedie Methodique, Ou Par Ordre Des Matieres. Histoire Naturelle. Insectes*, *8*, 652–667. Retrieved from http://ci.nii.ac.jp/naid/10020634860/en/

Oluboba, T. F. (2015). Comparative biology of the pink shrimp, *Penaeus notialis* (Perez-Farfante) and giant tiger shrimp, *Penaeus monodon* (Fabricius), in the Lagos Lagoon, Nigeria. *Journal of Biology, Agriculture and Healthcare*, *5*(17), 97–109.

Omukoto, J. O., Kimani, E. N., Mkare, T. K., Mwakiti, S. M., Mbaru, E. K., Karama, K. S., … Mututa, W. K. (2015). *Malindi-Ungwana Bay small-scale prawn fishery stock assessment. Kenya Marine and Fisheries Research Institute Annual Report 2014-2015*.

Pearson, K. (1934). On a New Method of Determining “Goodness of Fit.” *Biometrika*, *26*(4), 425–442. https://doi.org/10.2307/2331988.

Perdana, A. W., Batubara, A. S., Aprilla, R. M., Nurfadillah, Nur, F. M., & Iqbal, T. H. (2018). Length-weight relationships of three popular fishes from Banda Aceh, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *216*(1), 012053. https://doi.org/10.1088/1755-1315/216/1/012053.

Pérez-Castañeda, R., & Defeo, O. (2002). Morphometric relationships of penaeid shrimps in a coastal lagoon: Spatio-temporal variability and management implications. *Estuaries*, *25*(2), 282–287. https://doi.org/10.1007/BF02691315.

Pinto, A. U., & Maheshwari, B. L. (2012). Impacts of water quality on the harvest of school prawn (*Metapenaeus macleayi*) in a Peri-Urban River System. *Journal of Shellfish Research*, *31*(3), 847–853. https://doi.org/10.2983/035.031.0332.

Promhom, S., Sukree, H., & Reunchai, T. (2015). Species composition and abundance of penaeid shrimps in the outer Songkhla Lake of Thailand. *International Journal of Agricultural Technology*, *11*(2), 253–274. Retrieved from http://www.ijat-aatsea.com

Qureshi, N. A., & Amanat, Z. (2014). Reproductive biology and size at sexual maturity of *Penaeus Merguiensis* (De man, 1887) from the Sonmiani Bay Lagoon, balochistan, Pakistan. *Journal of Animal and Plant Sciences*, *24*(2), 503–511.

Radhakrishnan, E. V, Deshmukh, V. D., Maheswarudu, G., Josileen, J., Dineshbabu, A. P., Philipose, K. K., … Raju, B. (2012). Prawn fauna (Crustacea: Decapoda) of India - An annotated checklist of the penaeoid, sergestoid, stenopodid and caridean prawns. *Journal of the Marine Biological Association of India*, *54*(June), 50–72. https://doi.org/10.6024/jmbai.2012.54.1.01697-08.

Rafinesque, C. S. (1815). *Analyse de la nature ou Tableau de l'univers et des corps organisés*. *Analyse de la nature : or, Tableau de l'univers et des corps organisés /*. Palerme. https://doi.org/ark:/12148/bpt6k98061z.

Rajakumaran, P., Vaseeharan, B., Jayakumar, R., & Chidambara, R. (2014). Conformation of phylogenetic relationship of Penaeidae shrimp based on morphometric and molecular investigations. *Cytology and Genetics*, *48*(6), 357–363. https://doi.org/10.3103/S0095452714060103.

Rajakumaran, P., Vaseeharan, B., & Yeshvadha, V. A. (2013). Molecular characterization of economically important Penaeid populations in South East Coast of India. *International Journal of Aquaculture*, *3*(19), 105–114. https://doi.org/10.5376/ija.2013. 03.0019.

Rao, G. S., Radhakrishnan, E. ., & Jose, J. (2013). *Handbook of Marine Prawns of India*. Kochi: Central Marine Fisheries Research Institute. https://doi.org/10.1016/B978-0-12-800776-1.01001-3.

Rebello, V. T., Joseph, A., & Silvester, S. T. (2016). An Investigation on the Population Structure of Green Tiger Shrimp *Penaeus semisulcatus* (De Hann, 1844) of Kerala Coast. *International Journal of Marine Science*, *6*(5), 1–7. https://doi.org/10.5376/ijms.2016.06.0005.

Reist, J. D. (1985). An empirical evaluation of several univariate methods that adjust for size variation in morpometric data. *Canadian Journal of Zoology*, *63*, 1429–1439.

Rice, W. R. (1989). Analyzing tables of statistical tests. *Evolution*, *43*(1), 223–225.

Rönnbäck, P., Macia, A., Almqvist, G., Schultz, L., & Troell, M. (2002). Do penaeid shrimps have a preference for mangrove habitats? Distribution pattern analysis on Inhaca Island, Mozambique. *Estuarine, Coastal and Shelf Science*, *55*(3), 427–436. https://doi.org/10.1006/ecss.2001.0916.

Rönnbäck, Patrik, Bryceson, I., & Kautsky, N. (2002). Coastal aquaculture development in eastern Africa and the Western Indian Ocean: prospects and problems for food security and local economies. *Ambio*, *31*(7–8), 537–542.

Rosle, S., & Ibrahim, S. (2017). Habitat preferences of shrimp (*Penaeus monodon*) in Kelantan Delta, Malaysia. *International Journal of Fisheries and Aquatic Studies*, *5*(6), 326–330.

Sani, A., Andy Omar, S. Bin, Trijuno, D. D., & Nugroho, E. (2017). Morphometric characteristic of white shrimp *Fenneropenaeus merguiensis* de Man 1888 in South Sulawesi Indonesia. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *33*(2), 248–256.

Sekar, M., Alam, A., Suresh, E., Rao, S., Kathirvelpandian, A., Chaudhari, A., & Krishna, G. (2014). Genetic diversity among three Indian populations of black tiger shrimp (*Penaeus monodon* Fabricious, 1798) using microsatellite DNA markers. *Indian Journal of Fisheries*, *61*(3), 45–51.

Sen, S., Jahageerdar, S., Jaiswar, A. K., Chakraborty, S. K., Sajina, A. M., & Dash, G. R. (2011). Stock structure analysis of *Decapterus russelli* (Ruppell, 1830) from east and west coast of India using truss network analysis. *Fisheries Research Journal*, *112*, 38–43. https://doi.org/10.1016/j.fishres.2011.08.008.

Sharawy, Z. Z., Abbas, E. M., Desouky, M. G., & Kato, M. (2016). Descriptive analysis and molecular identification of the green tiger shrimp *Penaeus semisulcatus* (De Haan, 1844) in Suez Gulf, Red Sea. *International Journal of Fisheries and Aquatic Studies*, *4*(5), 426–432.

Siddik, M. A. B., Hanif, M. A., Chaklader, M. R., Nahar, A., & Fotedar, R. (2016). A multivariate morphometric investigation to delineate stock structure of gangetic whiting, *Sillaginopsis panijus* (Teleostei: Sillaginidae). *SpringerPlus*, *5*, 520. https://doi.org/10.1186/s40064-016-2143-3.

Simões, S. M., D'Incao, F., Fransozo, A., Castilho, A. L., & Da Costa, R. C. (2013). Sex ratio, growth and recruitment of the pelagic shrimp *Acetes americanus* on the southeastern coast of Brazil. *Journal of Crustacean Biology*, *33*(1), 1–9. https://doi.org/10.1163/1937240X-00002108.

Solomon, S. G., Okomoda, V. T., & Ogbenyikwu, A. I. (2015). Intraspecific morphological variation between cultured and wild *Clarias gariepinus* (Burchell) (Clariidae, Siluriformes). *Archives of Polish Fisheries*, *23*(1), 53–61. https://doi.org/10.1515/aopf-2015-0006.

Suryanti, A., Riza, N., & Raza'I, T. S. (2018). Length-weight relationship and condition factor of white shrimp *Penaeus merguiensis* captured in ecosystem mangrove of Bagan Asahan, Tanjungbalai, Asahan, North Sumatra, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *122*, 012108. https://doi.org/10.1088/1755-1315/122/1/012108.

Taugbøl, A., Arntsen, T., Østbye, K., & Vøllestad, L. A. (2014). Small changes in gene expression of targeted osmoregulatory genes when exposing marine and freshwater three spine Stickleback (*Gasterosteus aculeatus*) to abrupt salinity transfers. *PLoS One*, *9*(9), e106894. https://doi.org/10.1371/journal.pone.0106894.

Taylor, M. D. (2016). Identifying and understanding nursery habitats for exploited Penaeid shrimp in Nsw estuaries. In *25th Annual NSW coastal conference* (pp. 1–8). Retrieved from http://www.coastalconference.com/2016/papers2016/Matt Taylor.pdf

Teikwa, E. D., & Mgaya, Y. D. (2003). Abundance and reproductive biology of the Penaeid prawns of Bagamoyo coastal waters, Tanzania. *Western Indian Ocean J.*

Mar. Sci, *2*(2), 117–126. Retrieved from http://www.oceandocs.org/bitstream/handle/1834/960/WIOJ22117.pdf;jsessionid=B311E06703FE3762D4241663FE5DB6E1?sequence=1

Thoya, P., Kaunda-Arara, B., Omukoto, J., Munga, C., Kimani, E., & Omondi, A. (2019). Trawling effort distribution and influence of vessel monitoring system (VMS) in Malindi-Ungwana Bay: Implications for resource management and marine spatial planning in Kenya. *Marine Policy*, *109*, 103677. https://doi.org/10.1016/j.marpol.2019.103677.

Tonks, M. L., Griffiths, S. P., Heales, D. S., Brewer, D. T., & Dell, Q. (2008). Species composition and temporal variation of prawn trawl bycatch in the Joseph Bonaparte Gulf, North Western Australia. *Fisheries Research*, *89*(3), 276–293. https://doi.org/10.1016/j.fishres.2007.09.007.

Turan, C. (1999). A note on the examination of morphometric differentiation among fish populations: the Truss System. *Turkish Journal of Zoology*, *23*, 259–263.

Uddin, S. K. N., Ghosh, S., & Maity, J. (2016). Length weight relationship and condition factor of *Penaeus monodon* (Fabricius, 1798) from Digha coast, West Bengal, India. *International Journal of Fisheries and Aquatic Studies*, *4*(3), 168–172.

Udoinyang, E. P., Amali, O., Iheukwumere, C. C., & Ukpatu, J. E. (2016). Length-weight relationship and condition factor of seven shrimp species in the artisanal shrimp fishery of Iko River Estuary, southeastern Nigeria Udoinyang EP, Amali O, Iheukwumere CC, Ukpatu JE. *International Journal of Fisheries and Aquatic Studies IJFAS*, *4*(2), 109–114. Retrieved from www.fisheriesjournal.com

Uller, T., Moczek, A. P., Watson, R. A., Brakefiel, P. M., & Laland, K. N. (2018).

Developmental bias and evolution: A regulatory network perspective. *Genetics*, *209*(August), 949–966. https://doi.org/https://doi.org/10.1534/genetics.118.300995.

van der Elst, R., & Everett, B. (2015). Offshore fisheries of the Southwest Indian Ocean. *Oceanographic Research Institute. Special Publication*, (10), 448pp. Retrieved from http://cordioea.net/outputs-results/swiofp-offshore-fisheries-report/%5Cnhttp://www.swiofp.net/

Vatandoust, S., Abdoli, A., Anvarifar, H., & Mousavi-sabet, H. (2014). Morphometric and meristic characteristics and morphological differentiation among five populations of brown trout *Salmo trutta fario* (Pisces: Salmonidae) along the Southern Caspian Sea basin. *European Journal of Zoological Research*, *3*(2), 56–65.

Villarta, K. A., Norte-campos, A. G. C., & Campos, W. L. (2006). Some aspects of the population biology of the green tiger prawn *Penaeus semisulcatus* (De Haan, 1844) from Pilar and Capiz Bays, Northern Panay, West Central Philippines. *Science Diliman*, *18*(1), 1–10.

Wangüemert, M. G., Cánovas, F., Ruzafa, A. P., Marcos, C., & Alexandrino, P. (2010). Connectivity patterns inferred from the genetic structure of white seabream (*Diplodus sargus L.*). *Journal of Experimental Marine Biology and Ecology*, *383*(1), 23–31. https://doi.org/10.1016/j.jembe.2009.10.010.

Whetstone, J. M., Treece, G. D., Browdy, C. L., & Stokes, A. D. (2002). Opportunities and constraints in marine shrimp farming. *Southern Regional Aquaculture Center. SRAC Publication*, *July*(2600), 1–8.

Whitman, D. W., & Agrawal, A. A. (2009). What is phenotypic plasticity, and why is it important? In D.W. Whitman & T. N. Ananthakrishnan (Eds.), *Phenotypic Plasticity of Insects: Mechanisms and Consequences* (pp. 1–63). Science Publishers.

Zlateva, I. (2017). Matlab-based length/weight relationship analysis of commercial fishery samples taken from the Black Sea (Bulgaria). *Journal of FisheriesSciences.Com, 11*(4), 4–13. https://doi.org/10.21767/1307-234x.1000135.