DISTRIBUTION, ABUNDANCE AND SOME GROWTH ASPECTS OF SHARK SPECIES (PISCES: CHONDRICHTHYES) ON THE KENYAN COAST

BY

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DECLARATIONS

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DEDICATION

a) *TO SELF*

I dedicate this thesis first to myself;

And to a few others, who always encouraged I open another chapter in life;

To my parents, all I can say is a very big thank you, which is not enough;

And to Susan, my accomplished wife, who was there throughout my study, ever patient and encouraging;

And the trio of my little boys;

And to my University supervisors, for their unwavering guidance and patience;

God bless you all.

b) *TO THE FISHES*

"Here lies the concept, MSY,

It advocated yields too high, and didn't spell out how to slice the pie,

We bury it with the best of wishes, especially on behalf of the fishes.

We don't know yet what will take its place, but we hope it is just as good for mankind".

By: P.A. Larkin, 1977, 'An epitaph for the concept of maximum sustainable yield'

Abstract

In Kenya and most of the Western Indian Ocean (WIO) region, substantial amounts of shark landings occur as by-catch in artisanal fisheries, prawn trawls and longlines. However, the species structure, distribution, catch rates and levels of fisheries-shark interactions are not well studied. This information is, however, necessary to assess exploitation levels of shark species and for setting regulatory, conservation and management frameworks. This study therefore aimed at filling this information gap. Data were collected from fisher landings at various sites along the Kenya coast and by observers on commercial and scientific trawl surveys. Landings at six fish landing sites were inspected for sharks for 2-weeks in a month for 12 months (June 2012 to May 2013). Specimens were identified to species level and sex, length and weight recorded for each shark landed or trawled as by-catch. Results indicated that the catches are mainly dominated by hammerhead sharks (*Sphyrna lewini*, 53.7%), blacktip sharks (*Carcharhinus limbatus,* 33.7%), and grey reef sharks (*Carcharhinus amblyrhynchos*, 5.5%). Catch rates of species show spatial and seasonal variation, with higher catch rates in the middle coast (Malindi-Ungwana bay). Size-frequency distributions show mostly juveniles in the catches indicating fishers are probably exploiting nursery grounds. Fin weight was found to be 7.4% of body weight in *S. lewini* and 5.7% in *C. limbatus*. The sex ratios were significantly different in *S. lewini* (χ^2= 36.62; df= 1; p= 0.00), *C. limbatus* (χ^2= 7.03; df= 1; p= 0.008) and *C. melanopterus* (χ^2= 34.77; df= 1; p= 0.00). In all three cases the female sex was dominant. The ratios for the other species assessed were close to unity. The study also provided length-weight and length-length relationships of the common shark species. Growth and mortality parameters are provided, for the first time, for the five common shark species in coastal Kenya. The results are discussed in relation to overfishing threats and behavioural ecology of the species. There is need to continuously monitor the distribution and abundance of sharks in Kenya and the WIO region for purposes of conservation, and an urgent need to set up a national plan of action to manage the shark stocks is recommended.

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LIST OF ACRONYMS

BMU	Beach Management Units
CCSBT	Commission for the Conservation of Southern Blue fin Tuna
CITES	Convention on International Trade in Endangered Species
CoP	Conference of parties
ELEFAN	Electronic Length Frequency Analysis
FADs	Fish Aggregating Devices
FiSAT	FAO ICLARM Stock Assessment Tools
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
IPOA	International Plan of Action
IUCN	International Union for Conservation of Nature
IUCN SSG	IUCN Shark Specialist Group
IUU	Illegal, Unreported and Unregulated
KMFRI	Kenya Marine and Fisheries Research Institute
MCS	Monitoring, Control and Surveillance
NMFS	National Marine Fisheries Service
NPOA	National Plan of Action
RFMO	Regional Fisheries Management Organization
SDF	State Department of Fisheries
SWIOFP	South Western Indian Ocean Fisheries Project
UNEP	United Nations Environmental Programme
WCPFC	Western and Central Pacific Fisheries Commission
WIO	Western Indian Ocean

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CHAPTER ONE

INTRODUCTION

1.1. Background information

Sharks are fished worldwide for their fins, liver oil and cartilage and are often caught as by-catch in tuna and tuna-like fisheries. Direct and indirect shark fishing has caused serious declines in shark populations in many areas of the world (Baum *et al*., 2003; Burgess *et al*., 2005) and in the Western Indian Ocean (WIO) countries including Kenya (Rudy van der Elst *et al*., 2012).

Sharks are top apex predators with low fecundity, slow growth rate and late maturity, hence are vulnerable to both growth and recruitment overfishing (Stevens *et al*., 2000) resulting into cascading effects associated with top predator removals (e.g. fishing down the food web; *sensu* Pauly *et al*., 1998). The loss of these top predators has effects on trophic interactions associated with resultant increases in lower-level predators, such as rays, skates and smaller sharks. The prevailing view is that it is important to control directed shark fisheries and shark by-catch (Baum *et al*., 2003). The IUCN red list (www.**iucnredlist**.org) indicates a number of shark species as being threatened, including all hammerhead sharks (*Sphyrna* spp.), the angel shark (*Squatina squatina*), thresher sharks (*Alopias* spp.), gulper sharks (*Centrophorus* spp.), oceanic whitetip shark (*Carcharhinus longimanus*) amongst others. Despite this scenario, few countries manage their shark fisheries and there are no national or trans-boundary management systems in place for chondrichthyan populations in the WIO region including Kenya (Rudy van der

Elst *et al*., 2012). However, some initiatives such as the International Plan of Action (IPOA) for sharks aim to conserve shark populations (FAO, 2000).

Although many sharks and rays have been of lower economic value in fisheries (FAO, 2009), the economic impact of stock collapse may be similar to that of more productive fish species because population recovery of sharks last much longer (Musick, 1999). Well-documented cases of collapsed shark fisheries includes the porbeagle (*Lamna nasus*) fishery in the North Atlantic, the tope or soupfin shark (*Galeorhinus galeus*) fishery off California and Australia, various basking shark (*Cetorhinus maximus*) fisheries, the spiny dogfish (*Squalus acanthias*) fisheries both in the North Sea and off British Columbia (Holden, 1968; Ketchen, 1986; Hoff and Musick, 1990), and the large coastal shark fishery off the east coast of the United States of America (reviewed in Musick *et al*., 1993).

Despite this over-exploitation scenario, there is a paucity of scientific information on the populations of sharks and other top predators in the WIO and their effects on ecosystem functions (Rudy van der Elst *et al*., 2003). More specifically, there exists no adequate information on the landing statistics and ecology of sharks in Kenya. However, the information on landing statistics and species ecology are necessary for stock assessment and for conservation plans. This study therefore aims to contribute to the database on shark populations in Kenya and the WIO region for purposes of management and conservation. The study describes, for the first time in Kenya, the catch rates, distribution, abundance, composition, growth and mortality parameters of some selected shark species.

1.2. Problem statement

In Kenya substantial amounts of shark landings occur as by-catch in artisanal gillnet and longline fisheries, and in prawn trawls. Relatively large quantities of sharks are landed from the artisanal fishery on the north coast of Kenya especially in Kipini and Ziwayuu Island in Tana River County. In the year 2011, 306 tons of sharks were landed from the artisanal fishery alone, with Tana River County contributing 34% of the sharks (Fisheries Department Annual Report, 2011). This artisanal shark fishery also supports 411 fishers (out of a total of 13,000 fishers coast wide) (Marine Frame Survey Report, 2014). In addition, the extent to which inshore prawn trawlers, offshore commercial long liners and purse seiners catch sharks is not known but may be significant. Despite this level of exploitation and the ecological importance of the fishery, the species composition and distribution, catch rates, biology and levels of fisheries-shark interactions are not known in Kenya and most of the WIO (Rudy van der Elst *etal*., 2012). This information is, however, necessary to assess exploitation levels of species and for setting conservation and management frameworks.

1.3. Justification for the study

Species-specific catch statistics are lacking from most shark fishing countries, although data may be available for species aggregated in some higher groups (orders or families) (Lack and Sant, 2009). This paucity of data on sharks is also evident from the Kenyan fishery where sharks are landed as part of the artisanal catches. Species catch data aggregated into higher groups, as happens in Kenya (where they are grouped as sharks and rays), can easily mask declines of individual species within the groups. Larger species which grow at slower rates can be replaced by smaller species which grow at faster rates, with no apparent changes in landings data for the group (Dulvy and Forrest, 2010). Whereas directed fisheries have been the cause of stock collapse in many species of elasmobranches, capture in mixed fisheries and non-target catch in fisheries directed towards more productive teleosts are the biggest global threats to elasmobranch stocks (Musick, 1999), making it important to document species specific catch rates. Additionally, fisheries biology studies are a useful tool for rational management of stocks (Gulland, 1978). This is because information on parameters like reproduction and growth are useful for determining the recruitment potential and sustainable yield levels of a species (Pitcher and Hart, 1982). Despite the importance of such biological data, there is little information on biology of sharks from Kenya compared to the teleostean species (Murdoch *et al*., 2008; Kaunda-Arara and Ntiba, 1997). This study therefore aimed to contribute data on the fishery of the commonly harvested shark species including data on the distribution, abudance and some growth parameters of selected species. The information will be useful for developing management plans and will provide an initial scientific database on the elasmobranchs in Kenya.

1.4. Objectives of the Study

The main objective of the study was to provide data and information on the distribution, abundance and some growth aspects of shark populations in coastal Kenya.

The specific objectives of the study were:

1. To determine the composition and distribution of the shark species caught as by-catch or in directed artisanal fisheries, and in prawn trawl fisheries in coastal Kenya.

2. To describe the morphometric relationships of selected shark species landed in coastal Kenya.

3. To determine growth and mortality parameters, and exploitation rates of the common shark species in the landings useful for modelling the stock dynamics.

4. To perform a retrospective analysis on shark landings to determine current and historical trends in the landings from coastal Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1. General overview on sharks

Sharks and their relatives (the batoids and chimaeras) comprise the chondrichthyan fishes, a group of more than 1,100 species, of which more than 400 are sharks (Compagno, 2005). Most of the chondrichthyans are elasmobranchs (sharks, skates and rays of the subclass Elasmobranchii) that have slow rates of growth, late age-at-maturity and low fecundity compared with bony fishes (Cortes, 2004; Musick, 2005). These life history parameters result in low intrinsic rates of population growth and a limited ability to withstand fishing pressure (Smith *et al.*, 1998). In addition, the history of most directed shark fisheries around the world has been one of over-harvest, rapid stock decline, and collapse, with limited recovery (Dulvy *et al*., 2014; Worm *et al*., 2013; Bonfil, 1994).

Because of the low economic value attached to sharks and rays, few resources have been put into the collection of fisheries landings data (FAO, 2009). This has been compounded by illegal, unreported and unregulated (IUU) fishing, particularly in regard to shark fins (FAO, 2009). Catch per unit effort (CPUE) trends from either fisheries or fisheries-independent data are available for only a handful of stocks, and most recent CPUE analyses of elasmobranch stocks have shown declines (Dulvy and Forrest, 2010). Formal stock assessment models have been produced for even fewer stocks. Notable exceptions include- but are not limited to- those for blue and mako sharks in the North Atlantic (Babcock and Nakano, 2008), the piked dogfish assessment in the Northwest Atlantic

(Rago and Sosebee, 2009), and others such as the Australian gummy shark assessment (Walker, 1998). Regardless, most shark and ray populations are being fished without established fishery yield targets or limits, or without any sort of management (Dulvy and Forrest, 2010). For many elasmobranch species the question is no longer about fishery sustainability, but rather extinction risk (Musick, 2005). The International Union for the Conservation of Nature (IUCN) Shark Specialist Group recently completed assessments of the conservation status of all recognized chondrichthyans (1,044 species) (IUCN, 2010). Of these, almost half did not have sufficient data to make an assessment. Of the remainder, 37% were assessed in threatened categories: 23% as Vulnerable; 9% as Endangered; and 5% as Critically Endangered (IUCN, 2010). Fisheries mortality was identified by the group as the major cause of decline in virtually all of the threatened species and hence the need to derive this index for stocks.

Sustainable fisheries for sharks are possible, particularly for the smaller, faster-growing species such as the Australian gummy shark (*Mustelus antarcticus*), which has been managed through size-selective gillnet regulations for several decades (Stevens, 1999). Even slower-growing species can be harvested sustainably, but must be very closely managed with small yields relative to standing stocks, particularly the reproductive portion of the stock (Simpfendorfer, 1999). Two previously decimated spiny dogfish stocks (in Northeast Pacific and Northwest Atlantic) for which fishing mortality was severely curtailed have recovered and are being fished sustainably albeit at much lower levels (Wallace *et al.*, 2009). This recovery has been instructive because spiny dogfish have among the lowest rebound potentials known for any shark species (Smith *et al.*, 2008).

Globally, 67 species of sharks are listed as Critically Endangered or Endangered and are on the IUCN red list (Simpfendorfer *et al*., 2011). A recent study by Simpfendorfer *et al.* in 2011 to determine the global conservation status of 64 species of pelagic sharks and rays reveals that 32% are threatened with extinction, primarily due to overfishing, according to the IUCN criterion. Of 57 species of epipelagic sharks (0-200 m depth), 35 percent face the risk of extinction (www.iucnredlist.org).

Sharks are deliberately targeted, or at least considered to be economically valuable by-product when captured in tuna fisheries (FAO, 2000). Some of the commonly caught species of sharks within the tuna fisheries are the silky, blue, shortfin mako, porbeagle, oceanic whitetip and hammerheads (FAO, 2000). In most cases, a general lack of data on shark catch, abundance, distribution, life history and interactions within Regional Fisheries Management Organizations (RFMO) hinders an accurate estimation of shark bycatch levels and the associated population-level impacts (FAO, 2000). Moreover, in some regions, many shark species are captured at levels comparable to target species within the tuna RFMOs (FAO, 2000). Shark bycatch has been discussed by the tuna RFMOs, some seeking to address the problem for many years, particularly where sharks are characteristically caught in substantial numbers. For example, the Inter-American Tropical Tuna Commission (IATTC) started collecting shark bycatch statistics in 1992 (IATTC, 2009) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) in 1995. In 2008, the Commission for the Conservation of Southern Blue fin Tuna (CCSBT) adopted a recommendation requiring the use of conservation measures of other area-based RFMOs in relation to bycatch of sharks (CCSBT, 2008). The Indian Ocean

Tuna Commission (IOTC) has been tagging sharks in the Western Indian Ocean (WIO) and using telemetry to track their movements and behavior, especially juvenile Silky sharks (*Carcharhinus falciformis*) associated with Fish Aggregating Devices (FADs) (IOTC, 2010). It has also banned the fishing, retention and landing of endangered species.

2.2. Biology and conservation status of sharks

As in most other fish, the rate of growth of a shark decreases continually as the shark ages. Thus, as Hoenig and Gruber (1990) argue, a single parameter is insufficient to describe growth rate of a species. For example, Porbeagles, *Lamna nasus*, grow faster than dusky sharks, *Carcharinus obscurus*, at early age but by age 17 both species are almost the same size (roughly 250 cm). At ages greater than about 10 years, the annual growth of dusky sharks is greater than that of porbeagles. In terms of total increase in length or weight per unit of time, a shark at almost any age will increase in size faster than a stickleback (*Gasterosteus* spp.), because sticklebacks attain such a small size (Hoenig and Gruber, 1990).

The spatial ecology of elasmobranchs is an area of increasing interest, driven largely by the rapid miniaturization and increasing sophistication of tags and tracking arrays (Simpfendorfer *et al*., 2011). Studies of the broader spatial scale movements as well as the details of fine-scale habitat use has revealed considerable surprises over the past decade, such as ocean-crossing transits in white shark (Bonfil *et al*., 2005). Research that identifies areas (e.g. nursery or mating areas), times (e.g. pupping seasons) or habitats (e.g. estuaries close to human settlements) in which species are more vulnerable to human impacts will contribute significantly to the development of spatial management approaches

(Simpfendorfer *et al*., 2011). For many years, there has been recognition that sharks are likely to play an important role in the functioning of ecosystems (Stevens *et al*., 2000), and that this is one important reason for the development of conservation management. However, there has been very limited empirical analysis of what happens (both directly and indirectly) when sharks or rays are excluded or reduced in an ecosystem (Heithaus *et al*., 2008).

There is also mounting evidence of widespread and ongoing declines in the abundance of shark populations worldwide, coincident with marked rises in global shark catches in the last half-century (Stevens *et al*., 2000; Lack and Sant, 2006; 2009). In some cases, these declines have been linked to resultant trophic cascades (Stevens *et al*., 2000; Myers *et al.*, 2007). Consequently, overfishing of sharks is now recognized as a major global conservation concern (Barker and Schluessel, 2005), with increasing numbers of shark species added to the International Union for the Conservation of Nature's list of threatened species (IUCN, 2010). However, our knowledge of the status of many shark populations is limited due to lack of, or ambiguous data (Cavanagh *et al*., 2003; Ricard *et al*., 2012).

On coral reef areas, apex predators, including medium-sized reef sharks, can make up a large proportion of fish biomass in the absence of fishing (DeMartini *et al*., 2008; Sandin *et al*., 2008). Food web models suggest that they also are strongly interacting and they have relatively large influence on other species in the community (Bascompte *et al*., 2005). However, evaluating population trends for reef shark species, like that of many sharks, is complicated by several factors that make trends in reported catch and catch rate data unreliable indicators of fishing mortality or abundance. Firstly, many countries with significant coral reefs do not have extensive and reliable reporting of total catches and fishing effort (Fowler *et al*., 2005), both of which are required to obtain fisheries-based indices of abundance. Indeed, even where catch and effort data are available, there is often little information about covariates needed to standardize the catch-effort relationship, such as changes in gear types or targeting behavior of the fishery (Fowler *et al*., 2005). Secondly, a large proportion of the global catch consists of illegal (and therefore unreported) shark finning: a recent estimate based on fin-trade data identified 75% of the global shark catch as illegal and unreported (Clarke *et al*., 2006). Reef sharks are a small, but acknowledged part of such catches (Salini *et al*., 2007). Thirdly, sharks may be caught as bycatch in fisheries targeting other species. Often these sharks are not reported at the species level (Lack and Sant, 2009), or are killed and discarded at sea, and not recorded as catch (Bromhead *et al*., 2005). Finally, robust inference of population trends from catch data requires lengthy time series, precluding timely use when decades of high-quality catch records are unavailable (Ellis, 2005).

2.3. Shark finning

The practice of “finning”, understood as the removal of the fins from the shark and discarding the rest of the body is an age-old custom among fishers. It was carried out in many different places of the world, in both developed and developing countries (Hareide *et al*., 2007). Although in the last few decades these practices have been substantially reduced in many regions or fully eradicated by many fleets, some fleets still engage in this practice with operational limitations aimed at the preservation of shark bodies on board (Mejuto *et al*., 2009). The interest to determine the fin to carcass weight ratios is that these ratios are used in the regulations on finning. The average ratio of 5% often used in most RFMOs' conservation and management measures (CMMs) is controversial (Fowler and Séret, 2010; Biery and Pauly, 2012). These ratios may sometimes be useful in defining thresholds as a measure to control landings in order to avoid the undesirable practice of finning in the fleets or vessels that are still engaged in this practice (Lorenzo *et al*., 2010). Therefore, in addition to being of unquestionable scientific value, these ratios may also provide legislators with a foundation on which to base the definition of realistic thresholds adapted to the fishery practices of the respective fleets (Lorenzo *et al*., 2010).

The international shark fin market distinguishes several commercial categories of fins: the first choice or "primary set" is constituted by the first dorsal fin, both pectoral fins and the lower lobe of the caudal fin; the secondary set is constituted by the other fins: the second dorsal fin, the pelvic fins, the anal fin and the upper lobe of the caudal fin (Séret *et al.*, 2012). The price of the fins is also a function of their size: generally, larger fins have higher prices. Also, the fins of some species are more valuable because they contain more fibres (the vermicelli-like component that is extracted from the fins to prepare the famous shark-fin soup) (Séret *et al.*, 2012).

2.4. Age, growth and mortality in sharks

Fish age and growth are critical correlates with which to evaluate many other biological (and physiological) processes, such as productivity, yield per recruit, prey availability, habitat suitability, and even feeding kinematics (Campana, 2001; Robinson and Motta, 2002). Age determination in elasmobranchs is often more challenging than it is in teleosts because of the absence of otoliths in the former (Campana and Thorrold, 2001). As a result, the implementation of modern age determination methods for elasmobranchs has tended to lag well behind that of teleosts. Many studies have been carried out on elasmobranch age determination, including methods for interpreting spines (Irvine *et al*., 2006), whole vertebrae (MacNeil and Campana, 2002), sectioned vertebrae (Natanson *et al*., 2002), amongst others. A comprehensive summary of more modern ageing methods for elasmobranchs has not yet been published, although the paper by Cailliet and Goldman (2004) makes that attempt.

Mortality is an essential parameter in understanding the dynamics of any population including that of sharks. Without knowledge of how fast shark individuals are removed from a population, it is difficult to model the population dynamics or estimate sustainable rates of exploitation or other useful management parameters (Simpfendorfer *et al*., 2011). A commonly used indirect method of estimating natural mortality was described by Pauly (1980). He related natural mortality to von Bertalanffy growth parameters (L_∞ or W_∞ and K) and mean environmental temperature. This method assumes that there is a relationship between size (measured in either length or weight) and natural mortality. This relationship is quite weak on its own, but the inclusion of mean environmental temperature increases the fit as an animal living in warmer water will have higher mortality rates than an equivalent animal living in cooler water (Pauly, 1980). The relationships developed were based on natural mortality and ambient temperature data for 175 fish stocks, only two of which were sharks (*Cetorhinus maximus* and *Lamna nasus*). There is need to derive more mortality indices for shark stocks as a measure of fishing and natural mortalities.

2.5. The scalloped hammerhead shark (*Sphyrna lewini*: Griffith & Smith, 1834)

The scalloped hammerhead shark (*Sphyrna lewini*) (CITES Appendix II), one of the species studied in this research and the most common in the Kenyan artisanal landings (Kiilu, pers. obs.), is a semi-oceanic species globally distributed throughout tropical and temperate oceans (Compagno, 1984). Characterized by a range of habitats, the young typically occur in shallow bays and estuaries, while adults have been known to frequent continental shelves and adjacent waters to depths of 275m (Compagno, 2005). The abundance and accessibility of *S. lewini* in these areas means that it often comprises a large proportion of elasmobranch catches from commercial fishing activities, such as shrimp trawling (Castro, 1993), longlining (Branstetter, 1987; Chen *et al*., 1988) and gillnetting (Stevens and Lyle, 1989). They have been observed to be highly faithful to particular diurnal core areas (Holland *et al.,*1993) and sometimes form large schools which migrate to higher latitudes in summer (Stevens and Lyle, 1989).

Sphyrna lewini is captured throughout much of its range in the Indian Ocean, including illegal targeting of the species in several areas. The species faces heavy fishing pressure in the Indian Ocean with declines in abundance (Dudley and Simpfendorfer, 2006). Given the continued high fishing pressure, observed and inferred declines, the species is assessed as endangered in the WIO (Baum *et al.*, 2003). Only a few studies have been made on the growth and age of this shark in the Gulf of Mexico (Piercy *et al*., 2007) and the Pacific Ocean (Anislado-Tolentino and Robinson-Mendoza, 2001) in which the parameters of the von Bertalanffy growth equation for this shark were published. Because of this scarce information, there is a high degree of uncertainty surrounding the population characteristics of this species (Cortés, 2002), requiring interventions in form of more research and conservation management. This research aims to build on this scarce database on the species together with other common species by studying growth in the Kenyan population.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Site

This study was carried out between June 2012 and May 2013 at selected landing sites along the 650 km long Kenya coastline (Fig. 1). The coastline is fringed by coral reefs, which creates a shallow inshore lagoonal zone sustaining artisanal fisheries. About 3.3 million people (8.5% of the Kenyan population) live in the coastal zone (Kenya National Bureau of Statistics, 2009) and a significant portion depends on fisheries for their livelihoods.

The Kenyan coast is influenced by both north-easterly and south-easterly monsoon winds. The northeast monsoon season (NEM, November–March) is a period of calm seas, elevated temperatures and higher salinities, while the southeast monsoon season (SEM, April–October) is characterized by rough seas, cool weather, and lower salinities (McClanahan, 1988; Kaunda-Arara *et al.*, 2009). The continental shelf covers an area of about 19,120 km^2 (UNEP, 1998). Well-developed fringing reef systems are present all along the coastline except where major rivers (e.g. Tana and Athi/ Sabaki rivers) discharge into the Indian Ocean. Patch reefs occur around Malindi and Kiunga in the north, and around Shimoni in the south. Seagrass beds usually associated with reef systems are found growing in shallow lagoons, creeks and bays.

Much of the fishery is artisanal (small scale mostly operated using canoes) with some semi-commercial exploitation of the prawn fishery in the Malindi- Ungwana Bay on the north coast. The near-shore fisheries are being over-exploited along most of the mainland coastline (Kaunda-Arara *et al*., 2009). Thus the coastal environment and its valuable resources are increasingly under pressure from human settlement and related developments.

The fish landing site was taken as the primary sampling unit. Consequently data collection focused mainly on specific but representative fish landing sites chosen along the coastline based on the following criteria:

1. As a first iteration, the choice of the landing sites had to ensure adequate spatial representativeness.

2. Prior reconnaissance and desktop surveys were also done at the onset to determine the main shark landing sites along the coastline.

3. Accessibility throughout the study period was considered.

4. Consideration was also given to fishing craft-gear type combination on each landing site.

Subsequently a total of 6 landing sites were chosen: Shimoni and Msambweni (Kwale County), Ngomeni (Kilifi County), Kipini and Ziwayu Island (Tana River County) and Kiwayu Island (Lamu County). Due to high urban influence on the artisanal fishing and fish landing dynamics (most sharks were landed gutted, finned and beheaded for quick marketing upon landing), no landing site from Mombasa County was chosen.

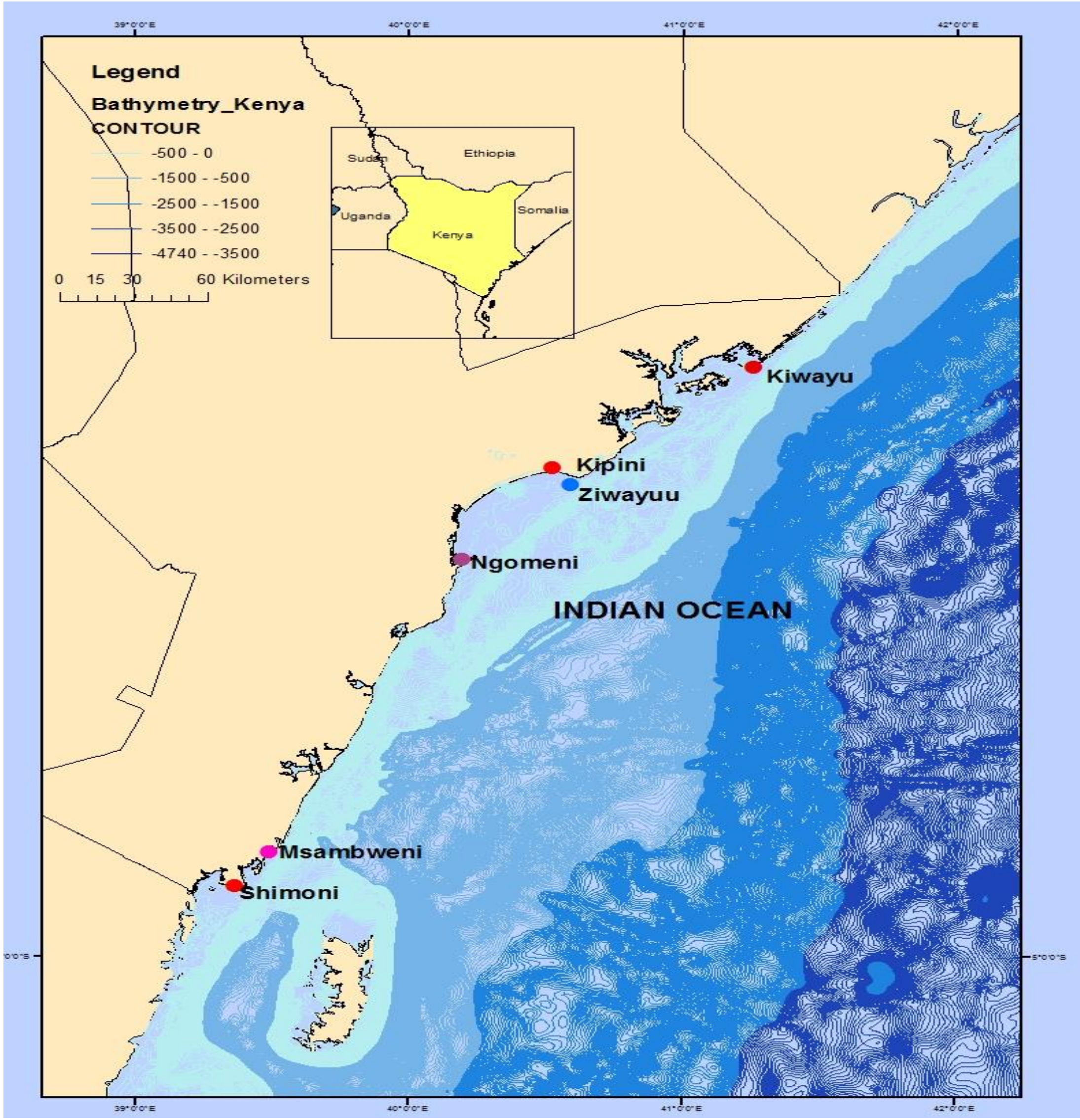

Figure 1: Map of the Kenyan coastline showing the main landing sites (Shimoni, Msambweni, Ngomeni, Kipini, Ziwayuu and Kiwayu Islands) selected for sampling for sharks in this study (Source: Author, 2014).

3.2. Field sampling

The sampling design involved collecting shark samples and data from three main sources. These included:

a) Artisanal catches at selected landing sites along the coast.

b) Observer survey data from the semi-industrial and research prawn trawl vessels.

c) Fisheries landing statistics as recorded by the State Department of Fisheries, Kenya from 1984 to 2011.

Each of these sources are described in the subsequent sections.

3.2.1. Artisanal landings data

Samples from the artisanal fisheries were collected from the landing sites on the south coast (Shimoni and Msambweni), the middle coast/ Malindi-Ungwana bay (Ngomeni, Kipini and Ziwayuu Island) and on the north coast (Kiwayu Island in Lamu) (Fig. 1). Data from these sites were collected with the help of trained field enumerators and field officers from the State Department of Fisheries (SDF) and the Kenya Marine and Fisheries Research Institute (KMFRI). The field enumerators were previously trained by the researcher on species identification using field guides (e.g. Compagno, 2005; FAO, 2007; IOTC, 2012) and on shark morphometric measurements methods following Cruz-Martínez *et al* (2004). Standard data collection sheets (Appendix Ia, b and c) along with shark identification charts were provided to the data collectors. All specimens were additionally photographed for later confirmation of identity and for archiving (Appendix II). Data from each landing site were normally collected for two continuous weeks in a month for one year extending from June 2012 to May 2013.

The weights of the landed specimens were taken to the nearest gramme on an automatic self-loading balance (an Ashton Meyers model that weighs up to 5kg) for smaller sharks and on a spring balance for larger sharks of more than 5kg. Total length (TL) was measured using a plastic measuring tape to the nearest centimeter in a straight line along the body axis with the caudal fin placed in a natural position. This TL was measured as the distance from the snout to a point on the horizontal axis intersecting a vertical line extending down-ward from the tip of the upper caudal lobe to form a right angle (Fig. 2), while fork length (pre-caudal fin length, PCL) was measured as the straight-line distance from the tip of snout to the fork of the tail (Branstetter and Stiles, 1987). The fins (1st dorsal fins, both pectoral fins and the complete caudal fin, Fig. 2) that the artisanal fishers commonly utilize for commercial sale, were removed by the fishers on shore or by the crew members on-board (in the case of observer data) and weighed to the nearest 0.00001 grammes on an electronic balance.

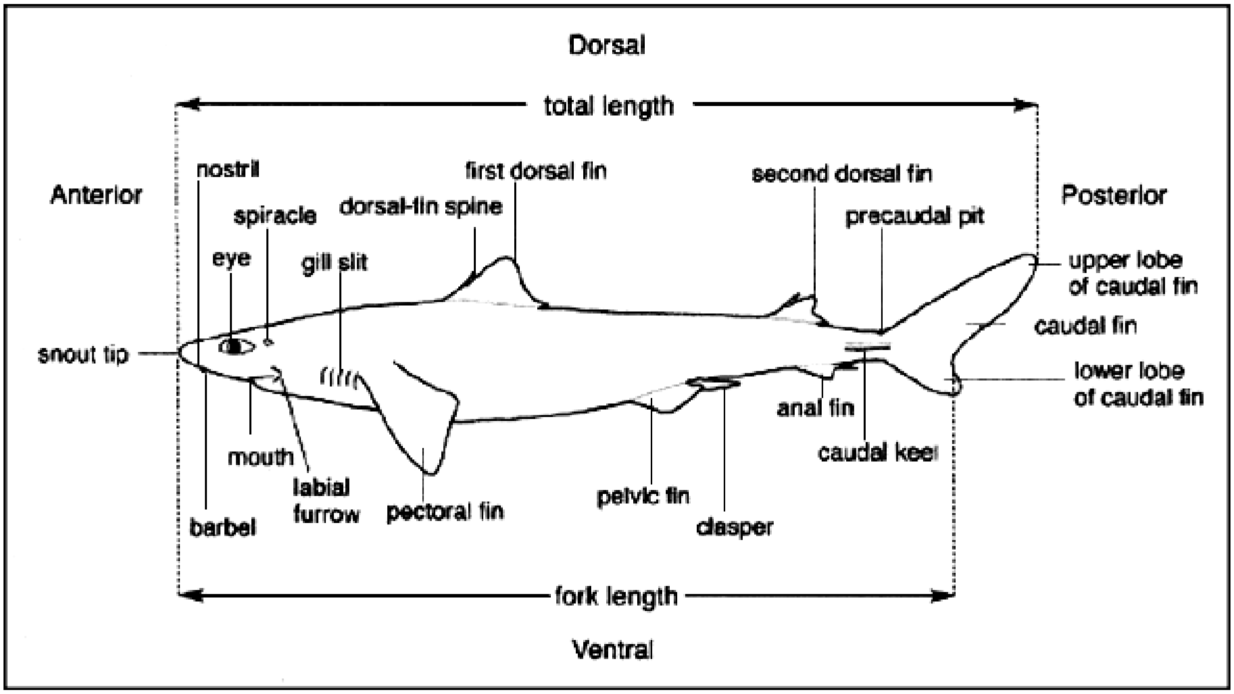

Figure 2: Morphometrics of sharks showing among others, the dimensions of total and fork lengths (Source: FAO, 2005).

3.2.2. Observer data

More data were collected by trained scientific observers deployed on-board a semi-commercial prawn trawler MV Roberto (from 21st July to 2nd August 2012; and 5th October to 17th October 2012) operating within the Malindi-Ungwana bay (the fishing area between Ngomeni and Ziwayuu, Fig. 1) during the study period. Two observers were deployed at different times on the MV Roberto for 2 weeks each during a 3 months trawling period (July, September and October) in 2012. Another observer collected data from the MV Vega that had been acquired for a 2-weeks scientific trawl survey in November, 2012. Shark specimens caught by the trawlers were identified to species level following the keys by Compagno *et al*. (2005), IOTC (2012) and FAO (2007). The specimens were then sexed and measured for their weights and lengths as described in section 3.2.1. The data was used to determine the characteristics of the sharks taken by the trawlers, including species composition and catch per unit effort (CPUE).

3.2.3. Historical landings data

Kenya's marine fisheries data are collected by fisheries personnel (usually Fisheries Assistants and Assistant Fisheries Officers) stationed at fish landing points along the coastline. Some of these landing sites may have fish landing facilities (*bandas*) as purchase points built by the SDF thus making them convenient points to collect data. The fish landings come from the major fishing areas such as the Kiunga coastline, Lamu islands in the north, Tana River mouth, Ungwana Bay and Malindi area including the offshore North Kenya Bank, Shimoni, Vanga, Funzi Island and coral reef areas in the southern border with Tanzania (Fisheries Department Annual Report, 2011). These data are analyzed at the county fisheries headquarters and forwarded to the national fisheries offices to be collated as the National Annual Statistical Bulletins. Data to evaluate long-term trends (1984-2011) in shark landings were obtained from these Annual Statistical Bulletins routinely prepared by the SDF. The data are, however, categorized broadly as “sharks and rays” and lack species level categories.

3.3. Data Analyses

3.3.1. Historical trends in landings

To analyze for long-term trends, the data obtained from the SDF was projected on a time-series of total elasmobranch (sharks and rays) landings for the years running from 1984 to 2011, using a Second Order Polynomial regression of the form;

$$y= a_0+a_1x+a_2x^2+E;$$

where; **y** is the amount of catch in kg (dependent variable), **x** is the time-change in years (independent variable), **a** is the unit of change, and **E** is an unobserved random error. However, data for the years 1989, 2007, 2008, 2009 and 2010 were missing from the Department's records and the points were smoothed by the regression model. This analysis was indirectly used to determine exploitation trends of sharks in Kenya.

3.3.2. Artisanal and observer datasets

3.3.2.1. Catch rates and CPUE

Artisanal shark landings data were used to determine length-frequency distributions for the main species landed and to describe length-weight and, body-weight to fin-weight relationships for the species. The data was also used to determine catch per unit effort (CPUE) (kg/fisher/day) for the species landed by the artisanal fishers. Observer data from the prawn trawlers were used to determine the CPUE as kg/hr. The CPUE of shark species from the artisanal fishery were compared between the NEM and SEM seasons using two-sample t-test (Zar, 1999), and between months using one-way ANOVA on log (x+1) transformed data in order to find out if there were significant seasonal and monthly differences in landings of the commonly landed shark species.

3.3.2.2. Morphometric relationships

Simple linear regressions of fork length (FL) on total length (TL) of the form;

$FL= a + bTL$,

were derived for the landed species for purposes of inter-conversions. The relationship between total length (TL) and body weight (W) of the species were derived from the equation;

$W= aTL^{b}$;

where ***a*** (scaling constant) and ***b*** (allometric growth coefficient) are regression constants obtained from;

$\log W= \log a + b \log TL$.

The relationship between body weight (W) and Fin weight (FW) was similarly described by;

$W= aFW^{b}$.

The length-weight relationships were derived separately for the sexes and the length exponents (**b**) of the sexes compared using ANCOVA before deciding to pool the data when no significant differences existed.

Size-frequency distributions of males and females of species were compared for symmetry using a two-sample Kolmogorov–Smirnov test (Zar, 1999), while Chi-squared goodness-of-fit test (χ^2) was used to examine the hypothesis of unity in sex ratios of the shark species landed.

3.3.2.3. Growth and mortality parameters

Total lengths were measured for the most common shark species in the artisanal fishery and grouped into monthly length-frequencies to analyze for growth and mortality parameters using the FAO ICLARM Stock Assessment Tools (FiSAT II) (Gayanilo *et al*., 1995). The growth parameters (e.g., instantaneous annual growth rate, Kyr^{-1} and the asymptotic length, L_∞ cm) were estimated for the five shark species using the monthly length-frequencies (from June 2012 to May 2013) analysed by routines in the FiSAT II package (Gayanilo *et al*., 1995). The von Baterlanffy growth function (VBGF) (Gayanilo, 1995) was fitted to the length-frequency data following the function;

$$TL_t = TL_\infty\ (1\text{-}e^{\,[-K\ (t\text{-}tx)\text{-}\ (CK/2\pi)\ \sin\ (2\pi\ (t\text{-}\ WP))]});$$

where, TL_t is the total length at age t (cm), TL_∞ is the asymptotic total length (cm), K is the growth coefficient ($year^{-1}$), C is the amplitude of oscillations, t is age (year), t_x are the coordinates of a point through which the curve must pass and WP is the winter point, a period of the year when growth is slowest (the WP in this case was fixed at 0, meaning no significant seasonality).

Analysis of length-frequency data was done using the K-Scan routine in the Electronic Length Frequency Analysis (ELEFAN I) sub-routine in FiSAT II. This routine identifies the peaks in the length-frequency of samples and searches for the best combination of growth parameters (L_∞, K) using a goodness-of-fit index (Rn). The goodness of fit index (Rn) of the growth curves superimposed on the restructured length-frequencies was defined by;

$Rn = 10^{ESP/ASP}/10$;

where the ASP (Available Sum of Peaks) is computed by adding the "best" values of the available "peaks" and the ESP (Explained Sum of Peaks) is computed by summing all the peaks and troughs "hit" by the von Bertalanffy growth curve (Gayanilo *et al*., 1995). Having obtained estimates of the growth parameters (K and L_∞) from ELEFAN II package in FiSATI using the LFA data, estimates were then derived for instantaneous total mortality rate (Zyr^{-1}) from the linearized length-converted catch curves (Sparre and Venema, 1992). Natural mortality coefficient (Myr^{-1}) was derived for the species using Pauly's empirical formula (Pauly, 1984) as;

$\log(M) = 0.0066 – 0.279 \log(L_\infty) + 0.6543 \log(K) + 0.4634 \log(T)$;

where, T is the average annual sea surface temperature, taken as 27 ºC for the Kenyan coast (www.sea-temperature.com/country_water/kenya/61). The fishing mortality, F, was then obtained from the difference between Z and M. The exploitation rate (E) for each of the five species was derived from the ratio, F/Z, (Gulland, 1971). The exploitation rate indicates whether the stock is lightly ($E < 0.5$) or strongly ($E > 0.5$) exploited, based on the assumption that the fish are optimally exploited when $F = M$ or $E = 0.5$ (Gulland, 1971).

From the derived estimates of L_∞ and K, the growth performance index, Φ of the five shark species were calculated by the formula (Pauly and Munro, 1984);

$$\Phi = \log_{10}K + 2\log_{10} L_\infty.$$

Further, by projecting the length-frequency data backward onto the time axis down to zero length, using the von Bertalanffy growth equation and the estimated growth parameters (Pauly, 1982), the recruitment pattern of the five shark species were estimated and generated by the FiSAT II programme.

CHAPTER FOUR

RESULTS

4.1. Historical landings

Landings of elasmobranchs (sharks and rays) by artisanal fishers in Kenya have decreased by about 83% since the peak in 1992 (2,900 MT) to the 2011 level of about 500 MT (Fig. 3). Landings have generally shown a downward trend since the 1992 peak with the second order polynomial regression trend line predicting a gradual but steady decline in catches over time. The actual annual landings show erratic peaks and lows (Fig. 3).

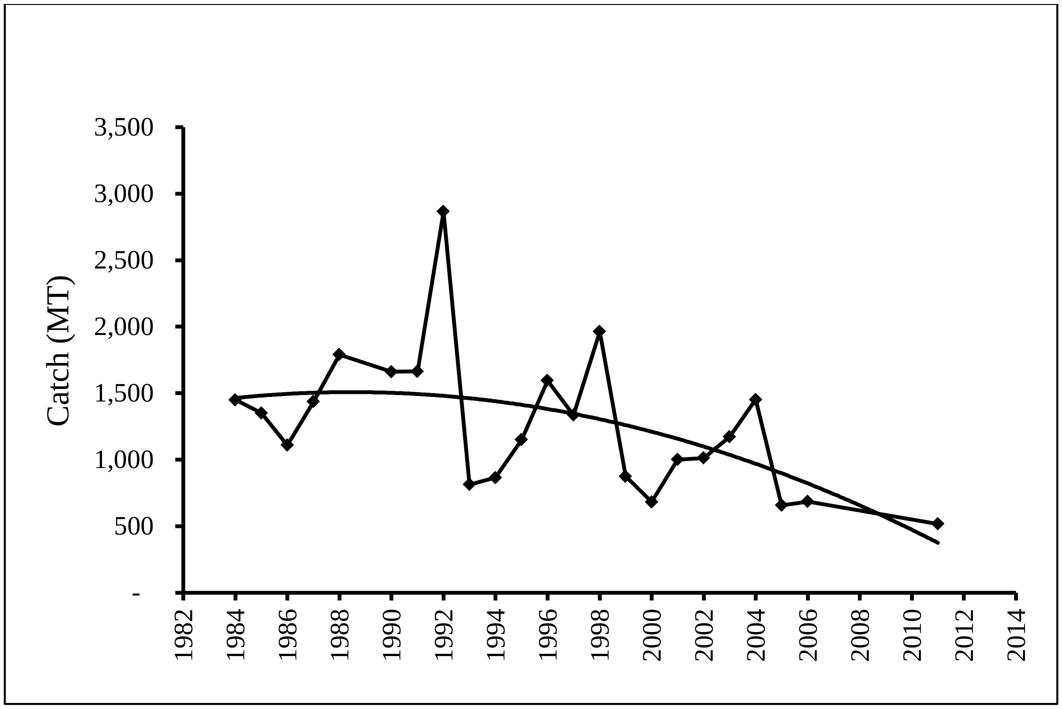

Figure 3: Temporal trends in landings of elasmobranchs in coastal Kenya. The continuous line indicates a second order polynomial trend line (Source: Author, 2014).

4.2. Species distribution and catch composition

The catches of sharks studied comprised 20 species distributed in 11 families (Table 1). A total of 1,883 individual sharks were sampled from the artisanal fisheries, and from both commercial and research trawl fishery sources during the study period.

Table 1: Taxonomic composition of the various shark species caught during the study.

Family	Scientific name	Common name
Carcharhinidae	*Carcharhinus sealei* (Pietschmann, 1913)	Blackspot shark
	Carcharhinus melanopterus (Quoy & Gaimard, 1824)	Blacktip reef shark
	Carcharhinus limbatus (J.P. Muller & Henle, 1839)	Blacktip shark
	Carcharhinus leucas (J.P. Muller & Henle, 1839)	Bull shark
	Charcharhinus galapensis (Snodgrass & Heller, 1905)	Galapagos shark
	Charcharhinus amblyrhynchos (Bleeker, 1856)	Grey reef shark
	Carcharhinus longimanus (Poey, 1861)	Oceanic whitetip shark
	Galeocerdo cuvier (J.P. Muller & Henle, 1837)	Tiger shark
Centrophoridae	*Centrophorous moluccensis* (Bleeker, 1860)	Smallfin gulper shark
Echinorhinidae	*Squalus acanthias* (Linnaeus, 1758)	Spiny shark
Lamnidae	*Carcharodon carcharias* (Linnaeus, 1758)	Great white shark
Pristidae	*Pristis microdon* (Latham, 1794)	Saw fish
Pseudocarcharidae	*Pseudocarcharias kamoharai* (Matsubara, 1936)	Crocodile shark
Scyliorhinidae	*Holohalaelurus punctatus* (Gilchrist, 1914)	African spotted catshark
	Scyliorhinus capensis (J.P. Muller & Henle, 1838)	Yellowspotted catshark
Sphyrnidae	*Sphyrna lewini* (E. Grifith & C. H. Smith, 1834)	Scalloped hammerhead shark
	Sphyrna zygaena (Linnaeus, 1758)	Smooth Hammerhead Shark
Squalidae	*Squalus megalops* (W.J. Macleay, 1881)	Shortnose spurdog
Squatinidae	*Squatina africana* (Regan, 1908)	African angelshark
Stegostomatidae	*Stegostoma fasciatum* (Hermann, 1783)	Zebra shark

The samples comprised 1,600 individual sharks from the artisanal fisheries, 252 from the semi-industrial prawn trawlers and 31 from the demersal research trawl survey (Table 3).

The five most commonly landed shark species in the artisanal fishery (*Sphyrna lewini*, *Carcharhinus melanopterus*, *Carcharhinus amblyrhynchos*, *Carcharhinus limbatus* and *Carcharhinus leucas)* were more abundant in the middle coast area (Malindi- Ungwana bay) landing sites of Ngomeni, Kipini and Ziwayuu Island (Table 2). Smaller numbers of *S. lewini*, *C. melanopterus* and *C. amblyrhynchos* were also landed in the north coast landing site of Kiwayu. Very few specimens of *C. limbatus C. melanopterus* and *C. amblyrhynchos* were encountered in the south coast landing sites of Shimoni and Msambweni. However, only *C. melanopterus* was represented on all the landing sites sampled, while *C. leucas* landings were only encountered in Kipini (Table 2).

Table 2: Distribution of the 5 most common shark species landed from the artisanal fishery in coastal Kenya.

Species/ Landing site	**Shimoni**	**Msambweni**	**Ngomeni**	**Kipini/ Ziwayu**	**Kiwayu**	**Total**
Hammerheads (*S. lewini*)	0	0	4	869	4	877
Blacktip sharks (*C. limbatus*)	1	0	10	476	0	487
Blacktip Reef sharks (*C. melanopterus*)	5	1	2	45	4	57
Grey reef sharks (*C. amblyrhynchos*)	0	1	2	136	9	148
Bullsharks (*C.leucas*)	0	0	0	31	0	31
Total	6	2	18	1557	17	1600

Catches from the semi-industrial prawn trawls had higher species richness (12 species) relative to the research trawl survey (8 species) (Table 3) and the artisanal fishery (6 species) (Table 4). The species composition of sharks from the research trawl survey were different from those of the semi-industrial and artisanal fishery (Table 3 and 4). The demersal research trawl catches (Table 3) were dominated by the African angelshark (*Squatina africana*) with catch rates of 9.55 kg/hr, shortnose spurdog shark (*Squalus megalops*) (5.92 kg/hr) and the smooth hammerhead shark (*Sphyrna zygaena)* at 0.56 kg/hr. The scalloped hammerhead shark, *Sphyrna lewini*, dominated the catches (0.51 kg/hr) in the semi-industrial prawn fishery (Table 3), followed by the smooth hammerhead shark (*S. zygaena*) (0.44 kg/hr) and the grey reef shark (*Carcharhinus amblyrhynchos*) with catch rates of 0.34 kg/hr. The *S. lewini* also dominated the artisanal landings with a catch rate (kg/fisher/day) of 2.46 (Table 4), followed by the great white shark (*Carcharodon carcharias*) at 2.21 and the blacktip shark (*Carcharhinus limbatus*) at 0.95. The artisanal landings had higher catch rates during the NEM season for *C. amblyrhynchos*, *C. limbatus* and *C. leucas*, and higher rates for *S. lewini* and *C. melanopterus* during the SEM season (Table 4). The overall mean catch rates for the artisanal fishery were not significantly different between the NEM ($\bar{x}$= 0.84) and SEM ($\bar{x}$= 1.23) seasons (t= 0.632; df= 2; p= 4.303) (Table 4). A one way-between subjects ANOVA conducted indicated that the catch rates for the most common shark species in the artisanal fishery were not significantly different between the NEM and SEM seasons at the p> 0.05 level ($F_{(1, 11)}$= 0.03; p= 0.87).

Table 3: Sample characteristics of shark species in the semi-industrial prawn and demersal research trawlers in coastal Kenya.

Type of fishery	Species caught	Number of Individuals, n	Total Length Range (cm)	Total Weight (Kg)	Mean Catch Rates (Kghr^{-1})	Standard Deviation of catch rates
Semi-Industrial Prawn Trawl	*Sphyrna lewini*	78	46- 63.7	77.1	0.73	±1.6
	Charcharhinus amblyrhynchos	83	25- 186	80.6	0.77	±1.99
	Carcharhinus melanopterus	2	113- 144	27	0.26	±1.05
	Carcharhinus leucas	1	156	20	0.2	±1.11
	Sphyrna zygaena	69	47- 69	66.2	0.6	±1.07
	Stegostoma fasciatum	3	33- 36.4	2.5	0.24	±0.112
	Charcharhinus galapensis	2	40- 42	2.94	0.028	±0.16
	Pristis pristis	2	70- 95	2.86	0.03	±0.11
	Galeocerdo cuvier	1	80	1.45	0.014	±0.08
	Squalus acanthias	7	62- 97	21.8	0.21	±1.9
	Pseudocarcharias kamoharai	3	55- 98	7.1	0.1	±0.4
	Carcharhinus longimanus	1	93	3.6	0.03	±0.2
Demersal Research Trawl	*Charcharhinus amblyrhynchos*	2	38.8- 40	2	0.19	±0.32
	Centrophorous moluscensis	1	71	2	0.19	±0.32
	Charcharinus sealei	1	69.7	0.7	0.07	±0.11
	Holohalaelurus punctatus	12	25- 45.5	1.2	0.11	±0.12
	Scyliorhinus capensis	1	40	0.4	0.04	±0.06
	Sphyrna zygaena	1	72.5	1.5	0.14	±0.24
	Squalus megalops	9	45- 80	15.8	1.48	±2.56
	Squatina africana	4	35.4- 87.5	25.5	2.39	±4.14

The scalloped hammerhead shark, *S. lewini* and the grey reef shark, *C. amblyrhynchos,* had peak catch rates in the months of November 2012 and January 2013 (NEM season), and March and April 2013 (SEM season), respectively, in the artisanal landings (Fig. 4a and b), however, *S. lewini* was landed throughout the year. *C. limbatus* showed peak catch rates during the SEM- NEM months of October, November and December of 2012 (Fig. 4c), while blacktip reef shark, *C. melanopterus,* had bimodal pattern landing during the SEM months of June to September of 2012 and during the months of February to May of 2013 (Fig. 4d).

Table 4: Sample characteristics of shark species in the artisanal fisheries in coastal Kenya. NEM- north east monsoon season; SEM- south east monsoon season.

Species	Number of individuals, n	Total length range (cm)	Total landed weight (Kg)		Total fishing days		Catch rates (Kg/fisher/day)	
			NEM	SEM	NEM	SEM	NEM	SEM
Sphyrna lewini	877	28.8- 92.5	233.0	435.1	125	147	1.86	2.96
Charcharhinus amblyrhynchos	148	30- 56.1	61.6	64.4	125	147	0.49	0.44
Carcharhinus melanopterus	57	28- 78.8	9.9	21.9	125	147	0.08	0.15
Carcharhinus leucas	31	36.6- 85.5	60.0	16.5	125	147	0.48	0.11
Carcharhinus limbatus	487	28.2- 90.1	159.5	99.5	125	147	1.28	0.68
Carcharodon carcharias	1	379.2	-	600.0	-	272	-	2.21
Overall mean ($\bar{x}$) seasonal landings and catch rates (all species)	-	-	87.3	206.2	104.2	167.8	0.84	1.23

The bull shark, *C. leucas*, catch rates showed a peak during the rainy SEM month of April (Fig. 4e). The catch rates of the shark species in the artisanal fishery in general showed bi-modal peaks that divided into SEM months (March-April) and the NEM months (November-February) with higher peaks in the NEM season (Fig. 4f).

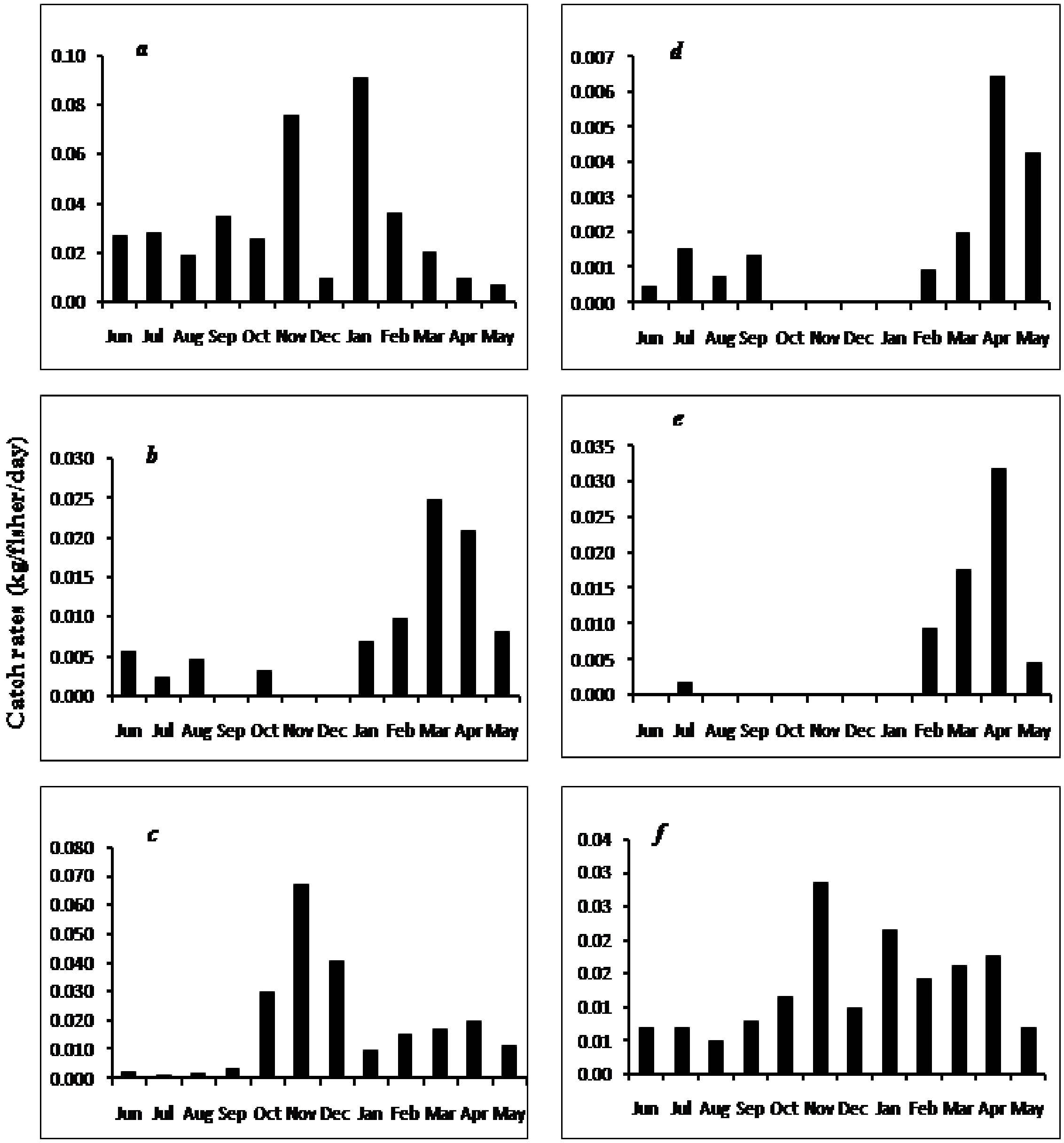

Figure 4: Monthly catch rates of the common shark species in the artisanal fisheries along the Kenyan coast during June 2012 to May 2013. ***(a) Sphyrna lewini (b) Carcharhinus amblyrhynchos (c) Carcharhinus limbatus (d) Carcharhinus melanopterus (e) Carcharhinus leucas (f)*** **All species (Source: Author, 2015).**

4.3. Length- frequency distributions

Length-frequency distributions were derived for 1,596 individual sharks from the most common species landed (*S. lewini*, *C. limbatus*, *C. amblyrhynchos*, and *S. Zygaena*) landed from both the artisanal and trawl fisheries. For the artisanal samples (Fig. 5), the sizes of *S. lewini* ranged from 28.8 to 92.1cm TL, with a modal length class at 50.0 to 54.9 TL cm for both males and females (Fig. 5a). Samples of *C. limbatus* landed by artisanal fishers ranged from 16.1 to 90.1 cm TL, with a modal class at 35.0 to 39.9 cm TL for both males and females (Fig. 5b). The grey reef shark, *C. amblyrhynchos,* had a length range of 30.0 to 89.5 cm TL in the samples and a strong modal class at 35.0 to 39.9 cm TL for females, and a bi-modal length distribution for males at 35.0 to39.9 and 55.5 to 55.9 cm TL (Fig. 5c). All the specimens landed in the artisanal fishery had sizes that were less than the size at maturity as per the Fishbase records (Fig. 5).

The Kolmogorov–Smirnov (K-S) test showed no significant differences in size-frequency distribution between males and females of; *S. lewini* ($D = 0.2$; $p = 0.901$), *C. limbatus* ($D = 0.188$; $p = 0.912$), and *C. amblyrhynchos* ($D = 0.455$; $p = 0.147$) landed by the artisanal fishery.

For the semi-industrial samples (Fig. 6), the *S. lewini* had a length range from 46.0 to 63.7 cm TL, with a modal length class at 52.0 to 53.9 cm TL (Fig. 6a). Compared to the artisanal fishery, the length distribution of this species had a near normal distribution in the semi-industrial samples. Smaller *C. amblyrhynchos* (25.0 to 58.0 cm TL) were landed in this fishery compared to the artisanal fishery, with a modal length class at 40.0 to 42.9 cm

(Fig. 6b). The *S. zygaena* from the semi-industrial samples had lengths ranging from 47.0 to 69.0 cm TL and a modal length class at 53.0 to 55.9 cm TL (Fig. 6c). As in the artisanal fishery, all the shark specimens landed in the semi-industrial fishery were immature (size at maturity indicated by arrow heads).

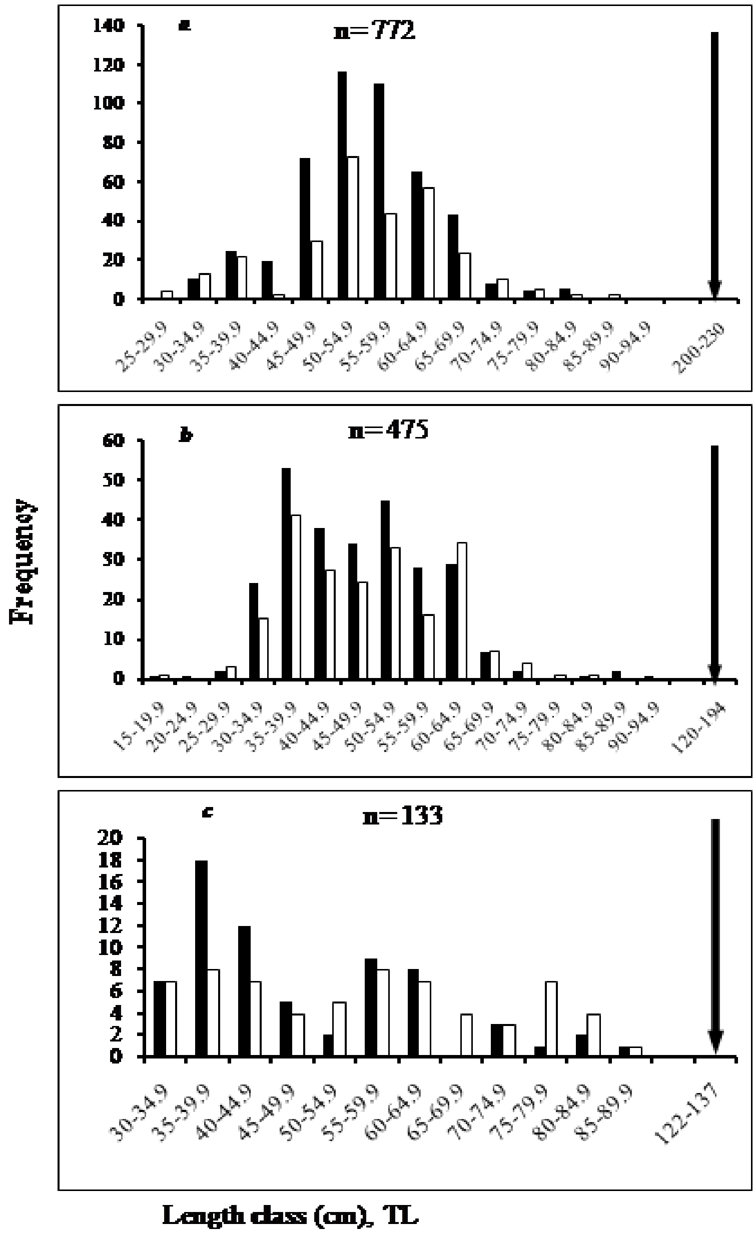

Figure 5: Length- frequency distributions of shark species (sexes combined) from the artisanal fishery of coastal Kenya (males □, females ■): *a*) *Sphyrna lewini*, *b*) *Carcharhinus limbatus* and *c) Carcharhinus amblyrhynchos*. Arrows

indicate length at maturity (Compagno, 1984; www.fishbase.org) (Source: Author, 2015).

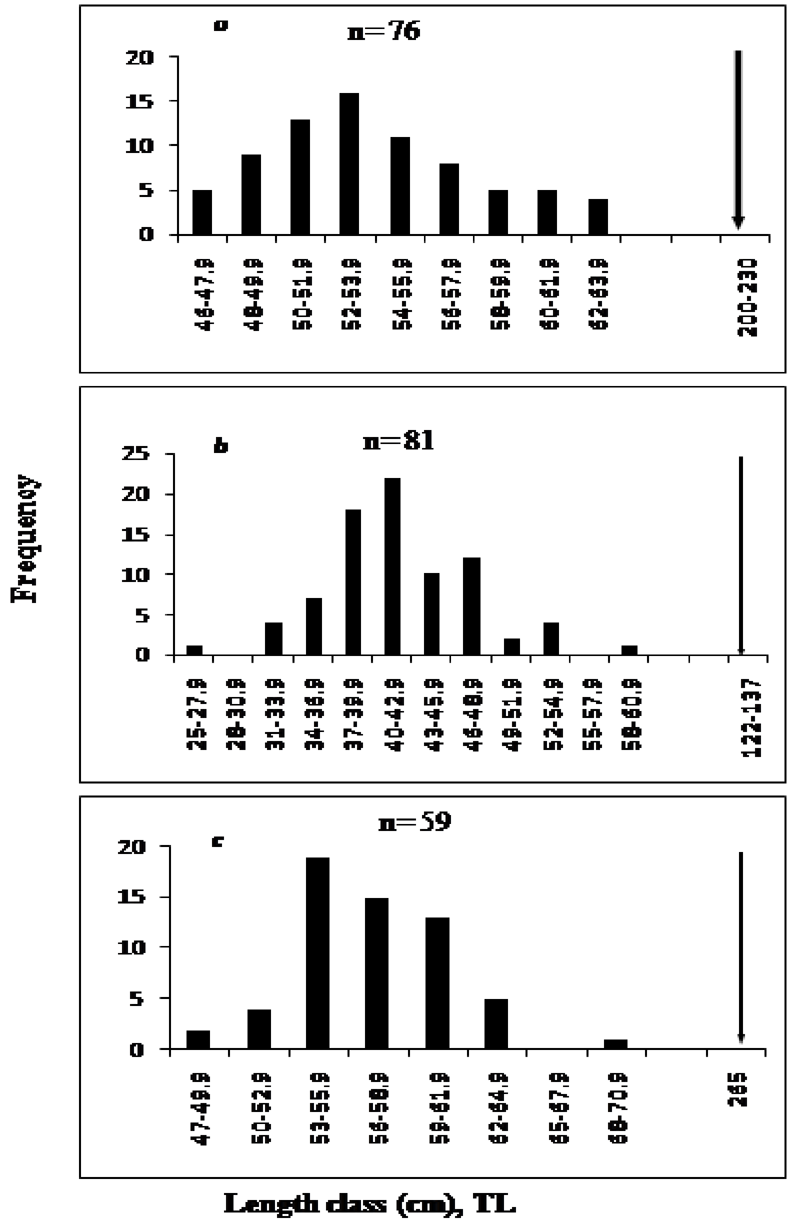

Figure 6: Length- frequency distributions of shark species from semi-industrial prawn trawl fishery in Malindi-Ungwana Bay, Kenya: *a) Sphyrna lewini*;

***b*) *Carcharhinus amblyrhynchos* and *c) Sphyrna zygaena*. Arrows indicate length at maturity obtained from Fishbase (Compagno, 1984; www.fishbase.org) (Source: Author, 2015).**

4.4. Length-weight and length-length relationships

From the derived exponents of the length-weight relations (**b**) of the male and female shark specimens from the artisanal fishery, there was no significant difference following ANCOVA test (Table 5), therefore both sexes of samples derived were pooled for analysis of length-weight relationships.

The length-weight relationships derived for 1,495 sharks belonging to the 5 major species landed from the artisanal fishery are as indicated in Table 6. The hammerhead and the blacktip sharks had the highest sample sizes in the artisanal landings. The 773 specimens of the *S. lewini* used to derive length-weight relationships had a length range of 37.3 to 92.1 cm with a mean length and weight (±S.D) of 55 ± 10.1cm and 0.8 ± 0.45 kg, respectively. For *C. limbatus*, the 487 specimens used to derive the relationships had a length range of 16.0 to 90 cm. The length-weight relationships were significant for all the five species (r^2= 0.71- 0.92) (Table 6). The values of the length exponents (**b**) indicated that the relationships showed negative allometry for *C. leucas* (b= 1.6) with the other species being isometric (b≈3) (Table 6). The largest specimen of all the sharks landed by the artisanal fishers during the sampling period was of the grey *C. carcharias*, with a total length of 379.2 cm, less than the maximum length of > 500 cm reported in Fishbase (www.fishbase.org).

The fork length (FL)- total length (TL) relationships derived for the five shark species were found to be highly correlated (Table 7) providing a basis for inter-conversion using the relationships. The highest correlation was found in *C. leucas* with r^2= 0.99 (Table 6).

Table 5: ANCOVA summary output on test of homogeneity for male and female length-weight exponents ('b') of the 5 common shark species from the artisanal fishery.

Source	SS	df	MS	F	P
Adjusted means	0	1	0	-5.3	NaN
Adjusted error	0	7	0		
Adjusted total	0	8			

Table 6: Length-weight relationships of five shark species commonly landed by artisanal fishers from coastal Kenya.

Species	**n**	**Mean Length (cm)±SD**	**Total Length Range (cm)**	**Mean Weight (kg)±SD**	**Weight Range (kg)**	**$W = aL^b$**		
						a	b	r^2
Sphyrna lewini	773	55± 10.1	37.3- 92.1	0.8± 0.9	0.013- 3.6	0.0000236	2.6	0.71
Carcharhinus limbatus	487	48.1± 11.4	16.1- 90.1	0.5± 0.48	0.02- 4.6	0.0000067	2.9	0.85
Carcharhinus amblyrhynchos	148	51.8± 15.6	30- 89.5	0.8± 0.84	0.12- 2.9	0.000005	3.0	0.91
Carcharhinus melanopterus	56	50.5± 13.5	32.3- 78.8	0.6± 0.44	0.15- 2.5	0.0000102	2.8	0.92

Carcharhinus leucas	31	54± 15.4	26.4- 65.5	2.6± 0.9	0.82- 3.9	0.0047	1.6	0.8

Table 7: Fork length (FL)-Total length (TL) relationships for five species of sharks landed in artisanal fisheries in coastal Kenya based on the relationship, FL = a + bTL.

Species	**n**	**Mean FL (cm)**	**FL Range (cm)**	**Mean TL (cm)**	**TL Range (cm)**	**FL= a + bTL** a	b	r^2
Sphyrna lewini	563	38.7± 5.3	26.1- 73.2	55.9± 7.9	37.3- 92.1	0.06	0.88	0.84
Carcharhinus limbatus	237	35.6± 7.4	19.8- 60.9	49.5± 10.4	23.5- 85.5	-0.05	0.9	0.84
Carcharhinus amblyrhynchos	50	39.1± 10.1	23.5- 69.5	45.3± 8.7	30.7- 59.1	-0.37	1.17	0.62
Carcharhinus melanopterus	19	38.4± 7.5	29.1- 51.2	53.7± 11	39.1- 78.8	0.44	0.66	0.7
Carcharhinus leucas	26	49± 15.7	26.2- 62.2	67.8± 12	36.6- 85.5	-0.26	1.06	0.99

4.5. Fin weight- Body weight relationships

Fin weight comprised 7.4% of the body weight in *S. lewini* for 337 specimens and 5.7% of the body weight for *C. limbatus* in 428 specimens. The fin weight-body weight relationships (Fig. 7) were derived for the two shark species (*S. lewini* and *C. limbatus*) that had significant sample sizes. The linear relationships between fin weight and body weight were significant for *S. lewini* and *C. limbatus* (r^2 = 0.8 and 0.75, respectively; Fig.

7) suggesting that fin-weight (a commercial product) is a good predictor of body or carcass weight in the two species.

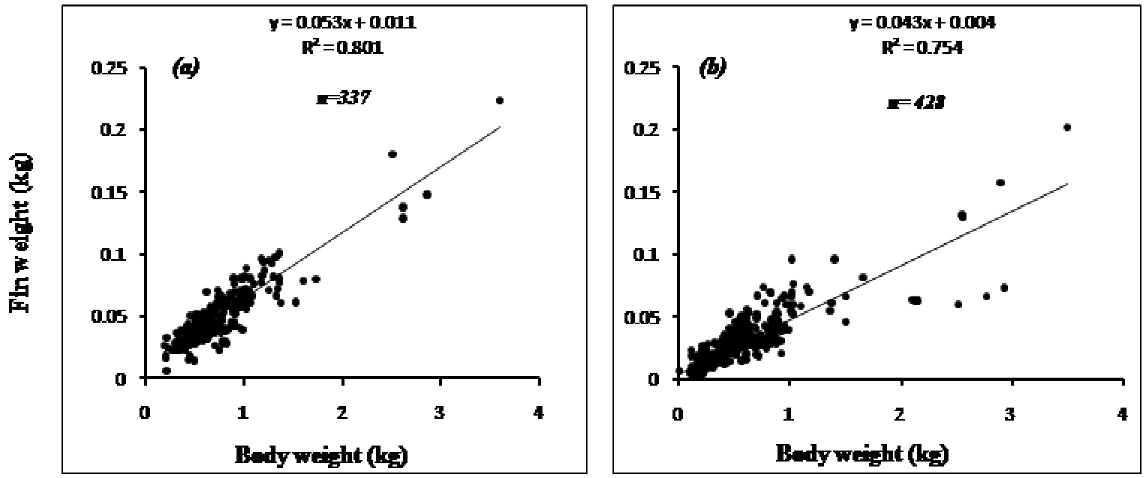

Figure 7: Fin weight-body weight relationships in (a) ***Sphyrna lewini*** **and, (b)** ***Carcharhinus limbatus*** **caught in the artisanal fishery in coastal Kenya (Source: Author, 2015).**

4.6. Sex ratios

There was a significant difference from unity in the sex ratio of *S. lewini* (χ^2= 36.62; df= 1; p< 0.05), *C. limbatus* (χ^2= 7.03; df= 1; p< 0.05) and *C. melanopterus* (χ^2= 34.77; df= 1; p<0.05). The sex ratios of *C. amblyrhynchos* and *C. leucas* were not significantly different from the expected 1:1 ratio (Table 8). All the shark species anlysed had a high number of females compared to males in the landings, except *C. ambyrhynchos*. The females of *C. melanopterus*, *S. lewini* and *C. leucas* were proportionally more in the artisanal landings than those of *C. amblyrhynchos* and *C. limbatus* (Table 8).

Seasonal (SEM and NEM) sex ratio differences were also observed among the shark species (Table 9). For the *S. lewini*, there was no significant difference in the sex ratio during the NEM season (χ^2= 0.004; df= 1; p> 0.05); however the sex ratio differed significantly from unity during the SEM season (χ^2= 47.52; df= 1; p< 0.05). The *C. limbatus* exhibited significant sex ratio differences during SEM (χ^2= 17.315; df= 1; p< 0.05), while no significant differences were observed during NEM for the same species (χ^2= 0.033; df= 1; p> 0.05). There were no significant differences from unity observed for the *C. amblyrhynchos* during both NEM (χ^2= 0.015; df= 1; p> 0.05) and SEM (χ^2= 0.051; df= 1; p> 0.05). However, the *C. melanopterus* exhibited no significant sex ratio differences in the NEM (χ^2= 2; df= 1; p= 0.157), but significant differences were observed in the SEM (χ^2= 32.94; df= 1; p< 0.05). Species of both *C. amblyrhynchos* and *C. leucas* exhibited no significant sex ratio differences during the NEM (χ^2 = 0.015; df= 1; p>0.05) (χ^2= 0.00; df= 1; p> 0.05) and SEM respectively (χ^2= 0.00; df= 1; p>0.05) (χ^2= 1.19; df= 1; p> 0.05). Overall, all the shark species were observed to have no significant sex ratio differences during NEM, while the sex ratios were largely skewed towards female dominance in most of the cases except *C. limbatus* (NEM) and *C. amblyrhynchos* (SEM) (Table 9).

The sex ratio of the most commonly landed species by the artisanal fishers (*S. lewini*) showed monthly variation (Table 10). However, the variation was significantly skewed in favour of the females except in the months of December and January, with significant sex ratio differences in being observed in the months of March, June, July, September and

December (Table 10). The overall sex ratio of males to females differed significantly from unity (χ^2= 36.62; df=1; $p< 0.05$).

Table 8: Overall sex ratios of the common species of sharks landed by the artisanal fishery in coastal Kenya.

Species	Males	Females	Sex ratio (m:f)	χ^2	p- value
Sphyrna lewini	384	571	0.7 : 1	36.62	0.000
Carcharhinus limbatus	218	277	0.8 : 1	7.03	0.008
Carcharhinus melanoptetrus	16	71	0.2 : 1	34.77	0.000
Carcharhinus amblyrhynchos	73	72	1.01:1	0.01	0.920
Carcharhinus leucas	13	18	0.7 : 1	0.81	0.368

Table 9: NEM and SEM season sex ratios of the common species of sharks landed by the artisanal fishery in coastal Kenya.

	NEM SEASON					SEM SEASON				
	Males	Females	Sex Ratio (m:f)	χ^2	p- value	Males	Females	Sex Ratio (m:f)	χ^2	p- value
S. lewini	113	114	0.9:1	0.004	0.947	271	457	0.6:1	47.522	0.00E- 00
C. limbatus	138	135	1.02:1	0.033	0.856	80	142	0.6:1	17.315	3.17E- 05
C. amblyrhynchos	33	34	0.97:1	0.015	0.903	40	38	1.1:1	0.051	8.21E- 01
C. leucas	5	5	1:1	0.000	1	8	13	0.6:1	1.190	2.75E- 01
C. melanopterus	2	6	0.3:1	2.000	0.157	14	65	0.2:1	32.924	1.00E- 08

Table 10: Monthly numbers and sex ratios of the most commonspecies (Sphyrna lewini) landed by artisanal fishers between June 2012 and May 2013 in coastal Kenya.

Months	Male	Female	Total	Sex Ratio (m:f)	χ^2	p- value
June	20	63	83	0.3:1	22.28	2.36E- 06
July	100	165	265	0.6:1	15.94	6.54E- 05
August	74	85	159	0.9:1	0.76	3.83E- 01
September	55	105	160	0.5:1	15.63	7.70E- 05
October	17	29	46	0.6:1	3.13	7.69E- 02
November	6	10	16	0.6:1	1.00	3.17E- 01
December	16	5	21	3.2:1	5.76	1.64E- 02
January	63	57	120	1.1:1	0.30	5.84E- 01
February	28	34	62	0.8:1	0.58	4.46E- 01
March	0	8	8	0:1	8.00	4.68E- 03
April	2	4	6	0.5:1	0.67	4.13E- 01
May	3	6	9	0.5:1	1.00	3.17E- 01
All months	384	571	955	0.7:1	36.62	0.00E- 00

4.7. Growth, mortality and exploitation rates of common shark species

Following the K-Scan routine in the Electronic Length Frequency Analysis (ELEFAN I) in FiSAT II (see section 3.3.2.3), the derived restructured monthly length-frequency data with peaks (shown in black) as positive points and troughs (shown in white) as negative points are shown in Figure 8. The growth parameters generated in ELEFAN I (Table 11) showed *S. lewini* and *C. limbatus* to have similar asymptotic lengths, L_∞ (of 97.07 cm) but with a higher growth rate (K) for *S. lewini* (0.76 yr^{-1}) compared to *C. limbatus* of 0.48 yr^{-1}. The lowest growth rate (0.33 yr^{-1}) was derived for *C. amblyrhynchos* (Table 11). The goodness of fit index (Rn) of the growth lines for the five species was generally low except for *C. leucas* (Rn=0.89) (Table 11). The growth rates of these species from other regions are presented in Table 12 for purposes of comparison. However, no estimates of growth performance index (Φ) were found for the species from other regions.

The length-converted-catch-curves for the estimation of total mortality (Z) were also derived from the ELEFAN I routine and are shown on Figure 9. The mortality rates for the five common sharks derived from the curves are then shown on Table 13. The results indicate that total mortality (Z) and exploitation rate (E) were both highest in *S. lewini* (1.69 yr^{-1} and 0.56, respectively), while *C. ambyrhynchos* had the lowest total mortality at 0.76 yr^{-1}, and *C. limbatus* the lowest exploitation rate at 0.10 (Table 13). Natural mortality (M) was highest in *C. melanopterus* (0.86 yr^{-1}) and lowest in *C. ambyrhynchos* (0.6 yr^{-1}), with *C. limbatus* and *S. lewini* experiencing similar natural mortalities at 075 yr^{-1}. Overall *S. lewini* experienced the highest fishing mortality (F) at 0.94 yr^{-1}, with *C. limbatus* having the lowest (0.08 yr^{-1}). The annual fisheries recruitment pattern plotted for all the five major shark species indicates a year-round recruitment for all the species (Fig. 11), with unimodal peaks for most species, except for *C. melanopterus* with bimodal pattern of recruitment in the fishery (Fig. 10).

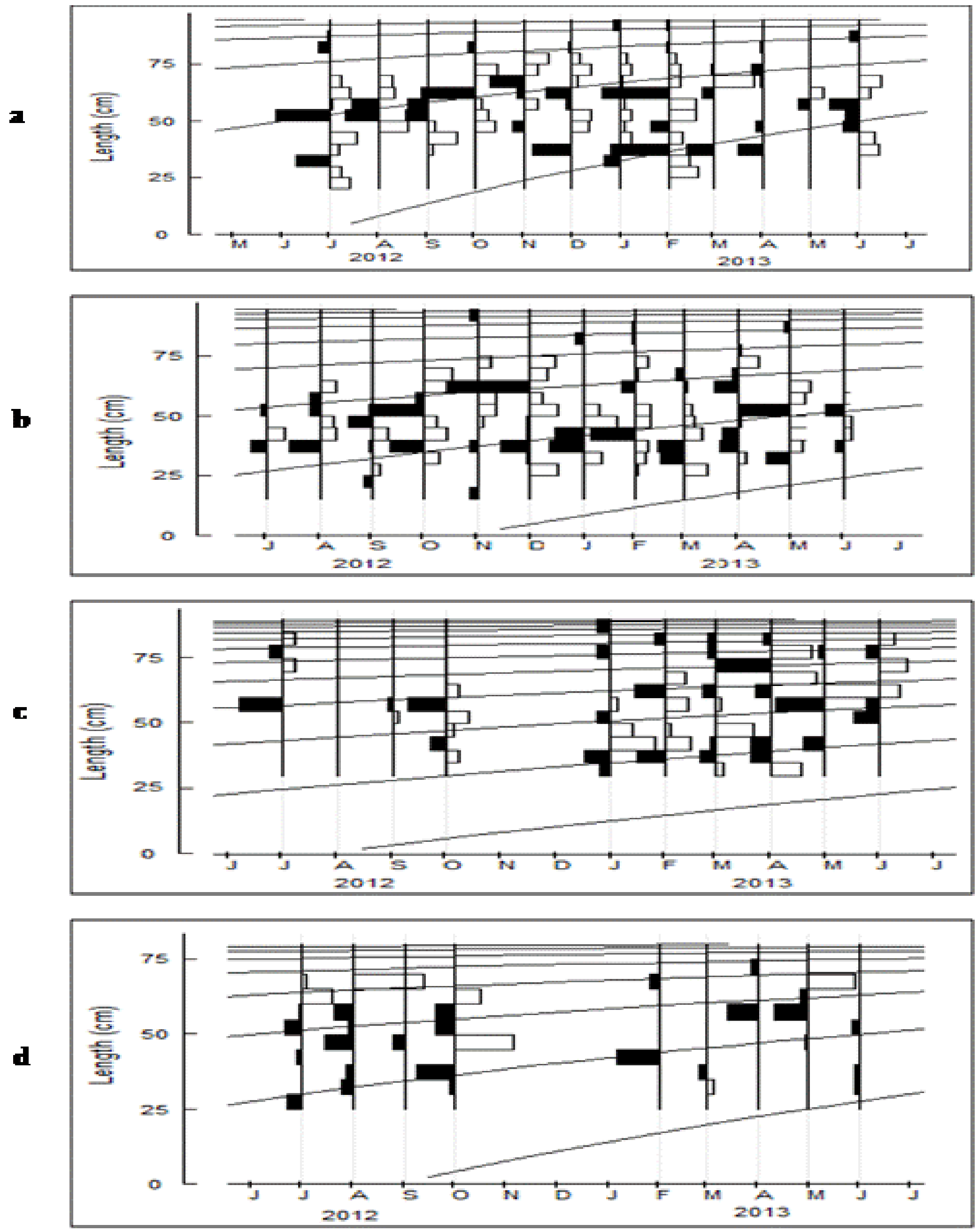

Figure 8: Growth curves of four shark species from Kenya's coastal artisanal fishery superimposed on the restructured length-frequency histograms in (a) *Sphyrna lewini* (b) *Carcharhinus limbatus* (c) *Carcharhinus amblyrhynchos* and (d) *Carcharhinus melanopterus* (Source: Author, 2015).

Table 11: Growth parameter estimation in five shark species using ELEFAN I method in the FiSAT II programme. L_∞= asymptotic length, K= instantaneous annual growth rate, Φ= growth performance index and Rn= goodness of fit index.

Species	L_∞ (cm)	K (yr^{-1})	L_{max} (cm)	Growth Performance Index, Φ'	Goodness of fit index, R_n
Sphyrna lewini	97.07	0.76	92.1	3.9	0.22
Carcharhinus limbatus	97.07	0.48	90.1	3.7	0.17
Carcharhinus amblyrhynchos	91.82	0.33	89.5	3.4	0.30
Carcharhinus melanopterus	81.32	0.54	78.8	3.6	0.28
Carcharhinus leucas	91.82	0.52	85.5	3.6	0.89

Table 12: Growth parameters of the five shark species studied in coastal Kenya as derived in other studies. Growth parameters from coastal Kenya are as derived in Table 11.

Species	L_∞ (cm)	K (yr^{-1})	L_{max} (cm)	Region	Source
Sphyrna lewini	331.2	0.076	430	Sub-tropical (Australia)	Harry *et al.*, 2011; Compagno, 1984
Carcharhinus limbatus	139.40	0.230	275	Warm temperate/ Tropical	Carlson *et al.*, 2006; Compagno, 1984
Carcharhinus amblyrhynchos	-	-	255	Warm temperate/ Tropical	Compagno, 1984
Carcharhinus melanopterus	158.5	0.251	200	Sub-tropical (Australia)	Chin *et al.*, 2013; Compagno, 1984
Carcharhinus leucas	311.9	0.158	360	Tropical and Sub-tropical	Tillett *et al.*, 2011; Compagno, 1984

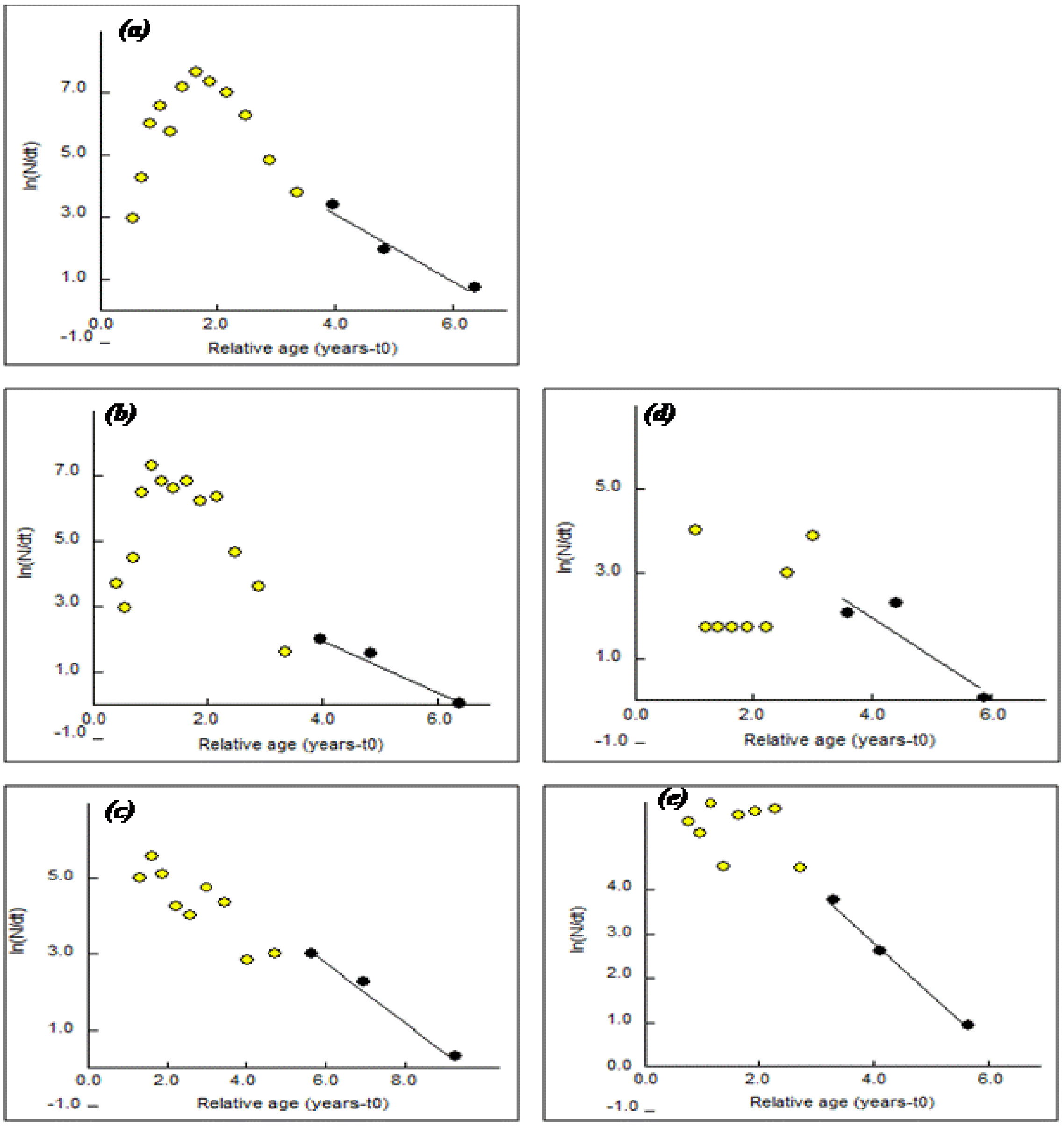

Figure 9: Length- converted catch curves for estimation of total mortality (Zyr^{-1}) of five common species in the artisanal fishery in coastal Kenya. (a) *Sphyrna lewini* (b) *Carcharhinus limbatus* (c) *Carcharhinus amblyrhynchos* (d) *Carcharhinus leucas* and; (e) *Carcharhinus melanopterus* (Source: Author, 2015)

Table 13: Mortality and exploitation rate estimation of five shark species in coastal Kenya derived from ELEFAN I analysis in FiSAT II programme (Total mortality, Zyr^{-1}; Natural mortality, Myr^{-1}; Fishing mortality Fyr^{-1}; and Exploitation rate, E).

Species	Total mortality, Z	Natural mortality, M	Fishing mortality, F= Z-M	Exploitation rate, E= F/Z
Sphyrna lewini	1.69	0.75	0.94	0.56
Carcharhinus limbatus	0.83	0.75	0.08	0.10
Carcharhinus amblyrhynchos	0.76	0.6	0.16	0.21
Carcharhinus melanopterus	1.18	0.86	0.32	0.27
Carcharhinus leucas	0.95	0.81	0.14	0.15

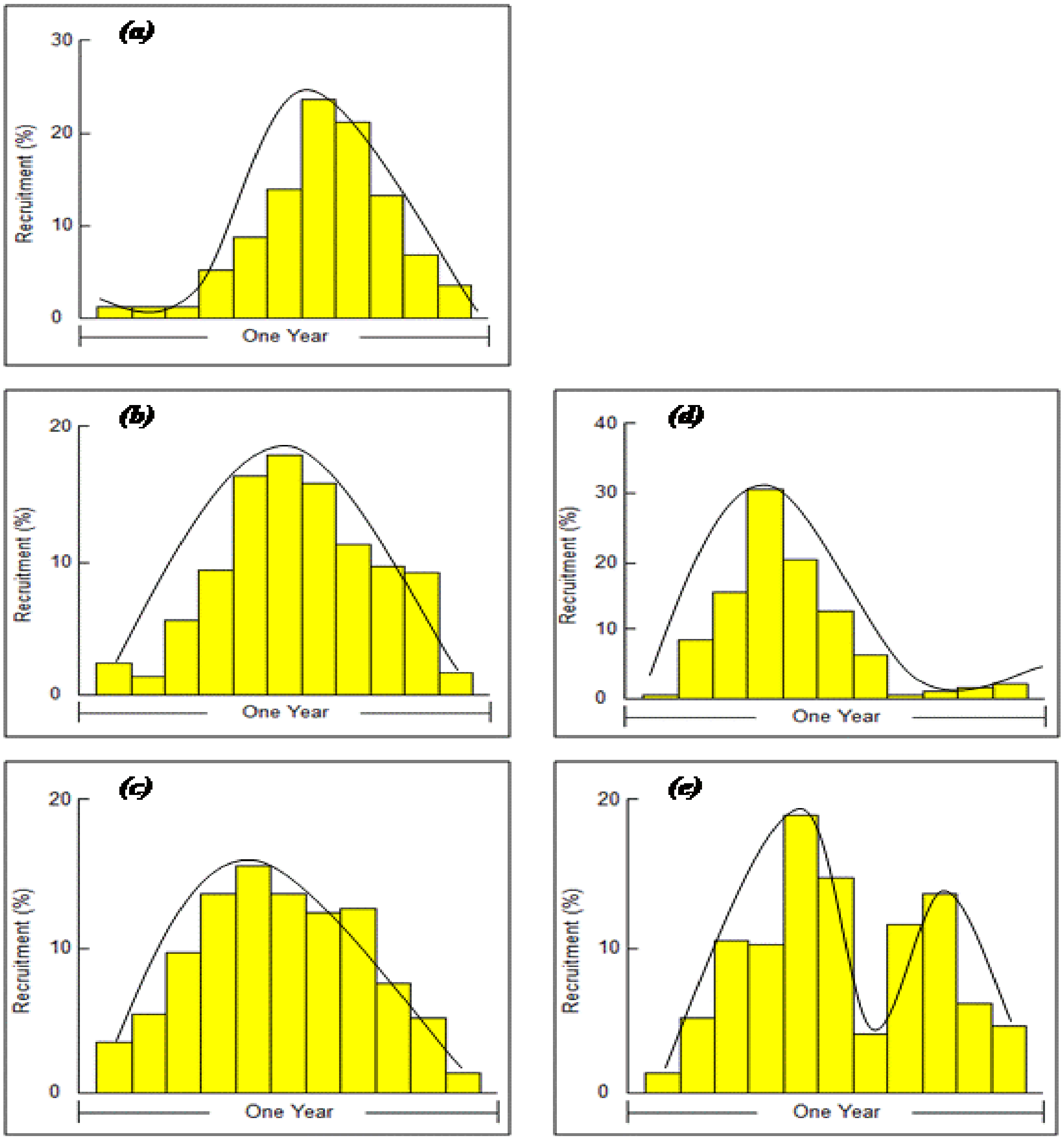

Figure 10: Annual relative recruitment patterns of five shark species in the artisanal fishery of coastal Kenya. (a) *Sphyrna lewini* (b) *Carcharhinus limbatus* (c) *Carcharhinus amblyrhynchos* (d) *Carcharhinus leucas* and; (e) *Carcharhinus melanopterus* (Source: Author, 2015).

CHAPTER FIVE

DISCUSSION

Landing trends, species composition and catch rates

The artisanal elasmobranch (sharks and rays) landings in Kenya have decreased by about 83% between 1983 and 2011. This massive decline poses a serious concern for the sustainability of the fishery because, as apex predators, sharks help to regulate and maintain the health and balance of marine ecosystems (Griffin *et al.*, 2008). Due to overfishing, it is likely that the shark landings in Kenya are currently sustained by the Malindi-Ungwana bay stocks which are believed to be the richest (Fulanda *et al.*, 2013). Despite this source, more conservation measures including gear restrictions, closed seasons and catch-quota limitations are required to stem the monotonous decline in catches since the peak of 1992.

All the sharks landed by artisanal fishers were caught using gillnets and longline hooks, with gillnets contributing over 90% of the catches (Kiilu, pers. obs.). Currently about 500 fishers target sharks along the Kenyan coastline (Marine Frame Survey Report, 2014). However, it is not quite clear whether a strictly artisanal shark-directed fishery exists in Kenya, as most of the shark landings were likely by-catch from the small and medium pelagic fisheries.

The catch composition differed among the fishing methods, with the demersal research trawl surveys catching mostly the African spotted catsharks (*H. punctatus*), the African angel sharks (*A. africana*) and the shortnose spurdog (*S. megalops*). The prawn trawl fishery was largely dominated by species similar to those landed in the artisanal fishery, with differences in species catch rates. The catches from these two fishery sources comprised of the scalloped hammerhead sharks (*S. lewini*), grey reef sharks (*C. amblyrhynchos*) and blacktip reef sharks (*C. melanopterus*). This variation likely reflects differences in the fishing gear and method employed, and effort. In addition, the prawn trawls and the artisanal fishers are known to share the same fishing grounds (often leading to fishing conflicts) (Fulanda *et al*., 2013), hence the similarity in catch composition between the two fisheries.

The observed fishery-specific differences in composition, distribution and catch rates of the various shark species may also have been due to depths at which fishing was conducted, where the research trawls conducted surveys offshore, and therefore at greater depths than those at which the small scale artisanal fishers and inshore prawn trawlers were operating. Other studies have shown that the distribution, catch rates and capture probabilities of different shark species are influenced to a larger extent by abiotic factors like temperature, oxygen and salinity profiles (Bromhead *et al.*, 2012; Heithaus *et al.*, 2008) that may be depth dependent.

Only one shark species, *C. melanopterus*, exhibited a coast-wide distribution, however, major landings were observed in the landing sites along Malindi-Ungwana Bay, a bay which is characterized by fresh water inflows from the Sabaki and Tana rivers. This points to the ecological importance of this ecosystem complex probably as a likely breeding and nursery ground for sharks, and its overall contribution to elasmobranch landings.

Compared to the *C. leucas*, species of *S. lewini, C. melanopterus* and *C. amblyrhynchos* showed a more wider coastal distribution range, indicating that even though area-focused conservation and management programmes for sharks in Kenya might address short term goals, a more comprehensive coast-wide programme will be beneficial in the long term.

As most of the landings of *S. lewini* occurred in the months during the closed season for prawn trawl fishing (November to April) (Prawn Fishery Management Plan, 2010), with a peak during January, this may imply that closing the fishery from prawn trawling was replenishing for the *S. lewini* stocks. During the months of April to August (corresponding to the SEM season), the catches were low likely due to rough sea conditions making it unsuitable for fishing with small, traditional fishing crafts but may also be related to temporal changes in distribution of sharks (Holland *et al*., 1993). The same trend was apparent for the other shark species.

Population structure and size distribution

The sex ratio imbalances that were observed in some of the shark species could have been caused by micro-habitat segregation between the sexes or sex-dependent mortality (Wearmouth and Sims, 2008). These imbalances may lead to differential exploitation of the sexes which is unhealthy for the reproductive success of populations (Wearmouth and Sims, 2008). This may require identification and protection of refugia for the different sexes during periods of sexual segregation.

There was an apparent SEM season dominance by females in most of the shark species. However, majority of the specimens encountered during the study were juveniles making the possibility of pupping minimal. Therefore, this large number of female shark juveniles observed in the Malindi-Ungwana bay fishery during SEM is likely due to maximization of this productive fishery to attain faster growth rates (Sims, 2003).

The significant sex ratio difference in the *S. lewini*, *C. melanopterus* and *C. limbatus* observed in this study, with a high number of females compared to males in the landings may have population dynamics implications. Other studies have found spatial sex segregation in *C. melanopterus* in lagoonal areas of inshore waters (Mourier *et al*., 2013). Variable sex ratios have also been reported for *S. lewini* (Chen *et al.*, 1988; Stevens and Lyle, 1989), but such variations are thought to be highly dependent on the degree to which inshore and offshore waters are fished (White *et al.*, 2008). Studies in Indonesia have found a 1:1 sex ratio in *C. limbatus* (White *et al.*, 2008), while this study found a significant difference from unity for this species in Kenya. Overall, sexual segregation as a feature of shark populations remains to be investigated in the majority of species (Wearmouth and Sims, 2008), and this study contributes to this scarce database.

The present study has demonstrated significant length-weight relationships in the shark species. The *S. lewini* showed negative isometric length-weight relationship, indicating that this species becomes slimmer with increasing length, while *C. limbatus* grew more plump with increase in length, indicative of positive isometry as also described in Duncan and Holland (2006) and Lowe (2002).

The size-frequency distribution of the sharks landed in the artisanal fishery showed that the artisanal fishers are harvesting juveniles, likely pups. This scenario, together with the known high natural mortality in juvenile *S. lewini* (Duncan and Holland, 2006), suggests that the species landed in the artisanal fishery are susceptible to growth overfishing (*sensu* Pauly *et al*., 1998) which may lead to stock collapse. Adult *S. lewini* are known to congregate around sea mounts during the day, moving into pelagic waters at night (Klimley *et al*., 1988). Large females generally come inshore to give birth, but the juveniles remain in coastal waters for a number of years (Branstetter, 1987). These movement patterns could account for the exclusive dominance of juveniles in the nearshore artisanal fishery found in this study. The results of the present study are also consistent with findings from other studies such as Clarke (1971) and, Duncan and Holland (2006) where pupping for *S. lewini* was found to occur in shallow inshore waters and juveniles stay in nursery environments for up to one year or more. Conservation efforts are therefore required to address the continued exploitation of these juveniles by artisanal fishermen in Kenya.

Shark fin-body weight relationships and ratios

In this study, fin weight-bodyweight ratio for *S. lewini* calculated as 7.4% (n= 479) and that of *C. limbatus* as 5.7% (n=280), is slightly higher than the universally used threshold ratio of 5%, thereby validating the notion that the ratio will vary between species.

The fin-weight to body-weight linear relationships obtained for *S. lewini* and *C. limbatus* in this study suggest that fin-weight (a commercial product) is a good predictor of body weight in the two species. This under-scores the importance of describing the fin-body weight ratios as these have been shown to differ amongst species and fishery regions

(IOTC, 2007). The interest to determine the fin to carcass weight relationships and ratios is that these ratios are used in the regulations on finning (fins cut on board of the fishing vessel and discard of the carcass) (IOTC, 2007).

A number of studies on ratios and biometric relationships between the weight of the different fin sets and the bodies of sharks have also been conducted to estimate or indirectly verify the catches of different species (Santos and García, 2008). The fin weight-body weight ratios are useful in defining retained shark fins and carcass weight thresholds as a measure to control landings in order to avoid the undesirable practice of finning in the fleets or vessels (Mejuto *et al.,* 2009). Therefore, these ratios may also provide legislators with a foundation on which to base the definition of realistic thresholds adapted to the fishery practices of the respective fleets (Lorenzo *et al.*, 2010). The average fin weight-body weight ratio of 5% often used is controversial (Biery and Pauly, 2012).

Growth, mortality, exploitation rates and recruitment patterns of sharks

This study has generated, for the first time, growth parameters of some shark species in the WIO region. These parameters are important for modeling stocks (Beverton and Holt, 1957) and for comparative analysis of stock performance between regions (Munro, 1979). Estimates of age, growth, and exploitation rates for the sharks were different from those reported in several other studies outside the WIO region. The von Bertalanffy growth parameters (L_∞ and K) obtained for the five most commonly caught species indicate a higher growth rate for *S. lewini* in coastal Kenya compared to other regions, however, other species showed lower growth rates in coastal Kenya with all the Kenyan species recording lower asymptotic sizes relative to other studied regions. This could be attributed to the high rate of growth-overfishing of sharks in the Malindi- Ungwana bay, from where most of the specimens were recorded.

In this study, *S. lewini* total mortality, Z, was much higher (1.69 yr^{-1}) than the 0.56 yr^{-1} mortality rate observed by Liu and Chen (1999) for the species in Northwestern Pacific. The high total mortality of *S. lewini* in Kenya is likely related to the juvenile composition of the specimens in the landings that could eventually lead to growth overfishing, and the overall fishing mortality. Juveniles are likely to be more vulnerable to predation and fishing pressure than adults (Branstetter, 1990). The *S. lewini* in this study were also found to be exploited beyond optimum levels (E= 0.6), indicating that increasing fishing pressure on its fishery is not sustainable for the species in the long run. The other species seem to be exploited below optimum levels (E< 0.5). This notion of low exploitation rates for these species is reinforced by the low fishing mortality levels derived for the species except for *S. lewini*. The *S. lewini* is also one of the most affected species by overfishing and finning globally, and the IUCN Red List considers it as both threatened and endangered (www.iucnredlist.org). The juveniles are vulnerable to the gill nets and longline hooks of artisanal fishermen who fish close to the shore in the estuaries and bays, and this may lead to the danger of growth overfishing (*sensu* Pauly *et al.*, 1998) and stock collapse.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The shark landings in artisanal fisheries were largely dominated by the Sphyrinidae, with *S. lewini* contributing over 50% of the total shark biomass landed. The Sphyrinidae are typically common in shallow coastal habitats (Clarke, 1971) such as the studied Malindi-Ungwana Bay. Size-frequency distributions of the five dominant species in the catches of both artisanal and semi-industrial fisheries indicates that the sharks caught by these fisheries are predominantly juveniles. This is of concern, as any fishery resulting in considerable mortality levels of non-adult age classes will likely severely impact the local population. A management plan is required to reduce this pressure on juveniles and to allow stocks to build adult biomass. The results also indicate that the artisanal fishery is likely concentrated on nursery and parturition grounds, specifically the estuarine Malindi-Ungwana Bay.

In the present study, it was also determined that there is largely a negative isometric relationship (Beverton, 1992) between length and weight of the sharks investigated, implying that the shark species become slimmer with increasing length (Wootton, 1998). While some descriptions of such relationships for some shark species have been published (White *et al.*, 2008; Fabio *et al.*, 2000) for other regions, few descriptions exist from the WIO. This study has contributed to the scarce database on shark species morphometrics from the WIO region.

While the fins harvested-to-carcass ratios are useful in defining thresholds for controlling landings in order to avoid the undesirable practice of finning in the fleets or vessels (Lorenzo *et al*., 2010), these ratios may also provide legislators with a foundation on which to base the definition of realistic thresholds that can be adapted to different shark fisheries and fleets. In this study the fin-weight to body-weight ratios for *S. lewini* (7%) and *C. limbatus* (5.7%) derived differed with the average global ratio of 5%, and this implies that species and region-specific ratios need to be considered in future to aid in shark fisheries management actions.

Previous authors have suggested that mortality rates for juvenile sharks are highest in the first year of life (e.g. Manire and Gruber, 1993), and the results presented here support these conclusions. Therefore the protection of the Malindi- Ungwana bay nursery areas (fished by artisanal fishers) would be of significant conservation value to the juvenile populations. In addition, the growth performance indices estimated from this study will allow for interspecific comparison of growth rates among sharks, when estimates for other species become available.

Recommendations

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

1. For effective management of the elasmobranch fishery in Kenya, the State Department of Fisheries should consider that majority of the sharks harvested in the Kenyan fishery are juveniles, especially in view of the substantial numbers of this development stage taken in Ungwana Bay waters and the large proportion that are

below the sizes at maturity reported in this study. Fishing gear regulations on gillnets, fishing hooks, seinenets and monofilaments are therefore recommended.

2. In addition, because the results of this study indicate a high likelihood of pupping ground for in the Malindi-Ungwana bay, fishery management measures need to include closed seasons when there is a high pupping intensity. In addition to this, future research needs to include a more detailed examination of the current level of exploitation of the juvenile sharks and the development of appropriate but simple models to determine sustainable effort and catch levels.

3. The findings from this study on body weight-fin weight relationships of two shark species (*S. lewini* and *C. limbatus*) need to be considered in the development and implementation of sound management measures for the shark species, and during the development of the National Plan of Action for sharks (NPOA-Sharks) in Kenya.

4. To enable continuous and informed management advice for the fishery, research will be needed to obtain a time series of annual catch and effort data (to capture variability in CPUE or abundance) at species level, and of size structure in the populations.

5. An integrated management plan should be developed for the whole Malindi-Ungwana Bay (Sabaki/ Tana Delta estuary) complex with the highest catch rates of sharks, establishing resource-user community agreements on effort control and well

coordinated Monitoring, Control and Surveillance (MCS) actions to ensure compliance.

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APPENDIXES

APPENDIX I a : GENERAL SHARK RESEARCHSAMPLING PROTOCOLS

Name of Recorder……………………………………Type of Boat………………
Date…………………………Type and Amount of fishing gear………………………
Name of Boat……………………………… Number of hours/ days fishing……………
Name of Landing site………………………… Fishing ground………………………
Number of fishermen…………………………Total shark landings (kg)…………………

No.	Species Name	Total Length	Weight (kg)	Weight of Fins	Sex (M/F)	Observations

Appendix I b: SEMI-INDUSTRIAL FISHERY

Name of Data Collector ………………………………… Date………………………
Name of Trawler…………………………………… Type of Trawl Net………………
Name of Fishing Area…………………………… Coordinates………………………
Haul Number………………………Number of Hours Fished…………………….
Total shark landings (kg)…………………

No.	Species Name (Species, English or Local names)	Total No. of males of the species	Total No. of females of the species	Total Weight of the Species (kg) in the haul	Observations
HAUL NUMBER 1: Duration of Trawl (hrs) ………………… Total shark landings (kg)………..					
HAUL NUMBER 2: Duration of Trawl (hrs) ………………… Total shark landings (kg)………..					
HAUL NUMBER 3: Duration of Trawl (hrs) ………………… Total shark landings (kg)………..					
HAUL NUMBER 4: Duration of Trawl (hrs) ………………… Total shark landings (kg)………..					
HAUL NUMBER 5: Duration of Trawl (hrs) ………………… Total shark landings (kg)………..					

Appendix I c: SHARK BOTTOM/ DEMERSAL TRAWL RESEARCH SAMPLING PROTOCOL

Date……………………………… Name of Recorder……………………………………
Name of Boat …………………………………….. Trawling speed (Knots)…………
Width of trawl net mouth opening (m) …… Height of trawl net mouth opening (m) …..
Name of fishing ground/ coordinates …………………………………

No.	Species Name (Species, English or Local names)	Total No. of males of the species	Total No. of females of the species	Total Weight of the Species (kg) in the haul	Observations
HAUL NUMBER 1: Duration of Trawl (hrs) ………………… Total shark landings (kg)…………					
HAUL NUMBER 2: Duration of Trawl (hrs) ………………… Total shark landings (kg)…………					
HAUL NUMBER 3: Duration of Trawl (hrs) ………………… Total shark landings (kg)…………					
HAUL NUMBER 4: Duration of Trawl (hrs) ………………… Total shark landings (kg)…………					
HAUL NUMBER 5: Duration of Trawl (hrs) ………………… Total shark landings (kg)…………					

APPENDIX II: SHARKS IDENTIFICATION PHOTOS

Sphyrna lewini juveniles

Carcharhinus amblyrhynchos juvenile

A juvenile *Carcharhinus leucas*

Carcharhinus limbatus juveniles

Juvenile *Carcharhinus melanopterus*

Great white shark, *Carcharodon carcharias*