THE APPLICATION OF BIOLOGIGAL ASPECTS IN THE MANAGEMENT OF TUNA AND TUNA-LIKE SPECIES IN THE KENYAN WATERS

BY

EDWARD WAFULA KIMAKWA, BSC, MSC

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DECLARATION

This thesis is my original piece of work and has not been presented in any other University.

Signed Kimakwa Edward Wafula Date 18/07/2022

Reg. No. I80/50065/2015

This thesis has been submitted for examination with our approval as the University Supervisors.

Signed Prof. Micheni Japhet Ntiba Date 19/7/2022

Signed Prof. Agnes Muthumbi Date 20/07/2022

Signed Dr. Mohanyi Akunga Date 25/07/2022

DEDICATION

To my lovely wife Ruth and our beloved children Sammy, Wendy and Innocent for their encouragement, moral and financial support. Above all glory and honour to our God the Almighty.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ACLME	Agulhas Current Large Marine Ecosystem.
AIS	Automatic Identification System.
ANCOVA	Analysis of Covariance.
ANOSIM	Analysis of Similarities.
AU-IBAR	African Union - Interafrican Bureau for Animal Resources.
BMU	Beach Management Unit.
BRPs	Biological Reference Points.
CCRF	Code of Conduct for Responsible Fisheries.
CCSBT	Commission for the Conservation of Southern Bluefin Tuna.
cm	centimeter.
COMRED	Coastal & Marine Resource Development.
CSO	Civil Society Organization.
CPUE	Catch Per Unit Effort.
DWFN	Distant Water Fishing Nations.
EACC	The East Africa Coastal Current.
EAF	Ecosystem Approach to Fisheries.

EEZ	Exclusive Economic Zone.
ELEFAN	Length-based Growth Rate Estimator.
ERS	Economic Recovery Strategy.
F	Fishing Mortality.
FADs	Fish Aggregating Devices.
FAO	Food and Agriculture Organization of the United Nations.
FIPs	Fishery Performance Indicators.
FISAT	FAO-ICLARM Stock Assessment Tools.
FL	Fork Length.
GDP	Gross Domestic Product.
HCR	Harvest Control Rules.
ICCAT	International Commission for the Conservation of the Atlantic Tunas.
IO	Indian Ocean.
IOC	Indian Ocean Commission.
IOTC	Indian Ocean Tuna Commission.
ISSF	International Seafood Sustainability Foundation.
ITCZ	Inter-Tropical Convergence Zone.

IUU	Illegal, Unreported and Unregulated.
K	The rate of growth of individual fish based on von-Bertalanffy.
KeFS	Kenya Fisheries Service.
Kg	Kilogram.
KMFRI	Kenya Marine and Fisheries Research Institute.
Kshs.	Kenya Shillings.
L	Length.
LFDA	Length-Frequency Distribution Analysis.
LJFL	Lower Jaw Fork Length.
LME	Large Marine Ecosystem.
LPR	Limit Reference Point.
M	Natural Mortality.
MANOVA	Multivariate Analysis of Variance.
MCS	Monitoring, Control and Surveillance.
MSY	Maximum Sustainable Yield.
Mt	Metric tons.
NEM	Northeast Monsoon.

NGO Non- Governmental Organization.

NEPAD New Partnership for Africa's Development.

NMDS Non-Metric Multi-Dimensional Scaling.

NMK National Museums of Kenya.

NPOA National Plan of Action.

PERMANOVA Permutational Analysis of Variance.

Ph.D Doctor of Philosophy.

RFBs Regional Fisheries Management Bodies.

RFMOs Regional Fisheries Management Organizations.

RTTP-IO Regional Tuna Tagging Project in the Indian Ocean.

SC Somali Current.

SCLME Somali Current Large Marine Ecosystem.

SEM Southeast Monsoon.

SIMPER Similarity Percentage Analysis.

SIMPROF Similarity Profile Analysis.

SRA Strategy for Revitalization of Agriculture.

SWIO South West Indian Ocean.

SWIOFC	South West Indian Ocean Fisheries Commission.
SWIOFP	South West Indian Ocean Fisheries Project.
TAC	Total Allowable Catch.
TAE	Total Allowable Effort.
TL	Total Length.
TRP	Target Reference Point.
UNCLOS	United Nations Convention on the Law of the Sea.
UNDP	United Nations Development Programme.
UNFSA	United Nations Fish Stock Agreement.
VMS	Vessel Monitoring System.
VPA	Virtual Population Analysis.
WCPFC	Central Pacific Fisheries Commission.
WCS	Wildlife Conservation Society.
WIO	Western Indian Ocean.
WIOMSA	Western Indian Ocean Marine Science Association.
WoRMS	World Register of Marine Species (WoRMs).
WWF	World Wide Fund for Nature.

Z	Total Mortality.

DEFINITION OF KEY TERMS AND CONCEPTS

Artisanal fishery

This is small-scale fishery whereby fishing operations employ traditional, low cost technologies and low capital investment both for local consumption and commercial purpose.

Declared Catch

This is the nominal catch that was declared by licensed Distant Water Fishing Nations (DWFN) fleets to the Kenya Fisheries Service (KeFS) for the period February 2012 to March 2017. For the purpose of this study, the focus is on the logbook data of the 24 longliners that was made available to me by the Kenya Fisheries Service for the said period.

Demersal fisheries

These are bottom dwelling fish species usually inhabiting and feeding on / near the bottom of seas.

Exclusive Economic Zone (EEZ)

This is provided for in Article 55 of the United Nations Convention Law on the Sea (UNCLOS) defines EEZ as area adjacent and beyond territorial sea to a distance of 200 nautical miles.

Fisheries Governance

This is the sum of the legal, social, economic and political arrangements used to manage fisheries. It has international, national and local dimensions. It includes legally binding rules, such as national legislation or international treaties as well as customary and social arrangements (http://www.fao.org/fishery/topic/12271/en).

Fishing Mortality

This is the loss of fish from a population due to fishing operations.

Growth overfishing

This is a case of fishing where young individuals are captured before they reach the size to the level that is required to maximize yield per recruit.

Input controls

Putting some restrictions and or limitations on the level of fishing effort, type and size of fishing gears and vessels, fishing season and fishing area in a given fishery.

Maximum Sustainable Yield (MSY)

Highest amount of fish catch annually that may be removed from a fishery stock indefinitely. A constant MSY over a long time is not realistic though it is assumed to be a hypothetical equilibrium between stock and fishing operations.

Natural mortality

The loss of fish from a population resulting from natural causes including predation, old age and diseases.

Neritic tuna

These are tuna and tuna-like fish species inhabiting or resident to the coastal waters within the boundaries of national jurisdiction of any country. They include kawakawa, longtail, striped bonito, bullet and frigate tuna. They do not move a lot and are non-migratory.

Output controls

Putting some limitations and or restrictions on the amount of catch to be harvested, size to be landed, sex and reproductive status of the fish to be harvested, which may employ such tools as quotas, landing size slot and outlawing catching berried/ spawning individuals.

Pelagic fisheries

These are fish species usually inhabiting the column of water not close to the bottom nor nearshore in lakes, coast and open sea. This include species such as tuna, swordfish, mackerel and sardines.

Recruitment overfishing

Occurs when the adult stock is reduced to the extent that recruits are not able to replenish those that have been harvested.

Reef fisheries

These are fish species that inhabit and or spawn in coral reefs. They include among others snappers, emperors, groupers and parrot fish.

Shared and highly migratory fish stocks

These are fish species that move across Exclusive Economic Zones (EEZs) of several coastal states and into the high seas which are open waters that do not fall under the jurisdiction of any country.

Sustainable fisheries

Fishery sustainability is "the balance of fishery resource conservation with human needs" (FAO, 1999).

Target reference point

It is one of the biological reference points that sets the level of optimal biomass and fishing effort that would permit optimal yield or harvest.

Total Allowable Catch (TAC)

This refers to the maximum catch that is allowed to be harvested from any given fishery based on the management plan.

Total Allowable Effort (TAE)

This is the maximum level of fishing effort that is allowed to a fish stock within a given period as provided for in the fishery management plan for a particular area. This can be defined in terms of limits and or some level of restrictions on the number, type and size of fishing vessels and gears, the number of fishers and fishing days.

Tunas

Tuna and tuna-like species comprise of true tunas (of the sub-group *Thunnini* and the family of Scombridae, further classified into four genera, namely, Thunnus, Euthynnus, Katsuwonus, Auxis and Allothunnus), billfishes (marlins, sailfish, spearfish and swordfish) and tuna-like species (namely wahoo, bonitos and mackerel) (Nakumura, 1985; Majkowski, 2007). For the purpose of this particular study, tuna and tuna-like fish species will be collectively referred to as tunas and will be used interchangeably throughout this document. Figure 1 below are pictures of Skipjack tuna (*Katsuwonus pelamis)* and yellowfin tuna *(Thunnus albacares).* Other details about tunas are provided in the preceding pages of this thesis.

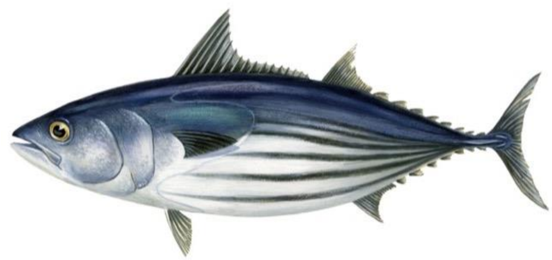
	
Thunnus albacares (Yellowfin tuna) (Source:https://en.wikipedia.org/wiki/Yellowfin_tuna)	*Katsuwonus pelamis* (Skipjack tuna) (Source:https://fish-commercial-names.ec.europa.eu/fish-names/species_en?sn=19511)

Figure 1. **Photographs of yellowfin and skipjack tunas, the most abundant species in the Indian Ocean.**

ABSTRACT

Fisheries, including tunas play, a significant role in contributing to the national economy, however, the paucity of information and knowledge on this fishery remains a challenge. The main objective of this study was to examine the scientific robustness of the fisheries policy and legal framework on tuna management in Kenya. Fish samples were collected monthly from August 2015 to December 2016 from five landing sites at the Kenyan coast; Amu (Lamu), Shella (Malindi), Mnarani (Kilifi), Watamu and Old Town (Mombasa). Historical catch data from 24 foreign flagged longline tuna fishing vessels licensed to fish in Kenya's EEZ for the period February 2012 to March 2017 was obtained from KeFS. These data sources were complemented by literature reviews, interviews and field visits. The data/ information collected was analyzed and used to assess the temporal and spatial variation in fish catch rates, species composition and distribution, size distribution, growth parameters and mortality rates for some artisanal tunas. A total of 2686 individuals of tunas weighing 31,672 Kg representing 15 species, 13 genera and three families (Scombridae, Istiophoridae and Xiphiidae) from artisanal fishery were sampled. The results of this study revealed that *Thunnus albacares, Xiphias gladius* and *Scomberomorus* spp significantly contributed to the coastal fishery in Kenya, accounting for 40%, 27.7% and 8%, respectively, of the total catch of tunas sampled. Fish catch rates varied amongst sites with Amu recording the highest CPUE of 23.7 $KgFisher^{-1}Trip^{-1}$, closely followed by Mombasa with 19.16 $KgFisher^{-1}Trip^{-1}$. Fish catch rates varied monthly, highest CPUE of 21.6 $KgFisher^{-1}Trip^{-1}$ was recorded in the month of August 2015 while the lowest, 3.0 $KgFisher^{-1}Trip^{-1}$, was observed in December of the same year. Highest landings were recorded during the South East Monsoon (SEM) between May to October. The results of the 24 longline tuna vessels flagged to six countries (China, Taiwan, Oman, Seychelles, Spain and Mauritius) fishing in Kenyan EEZ indicate that a total of 1833 individuals of tunas weighing 1,519,398 Kg were harvested. *Thunnus albacares, Katsuwonus* *pelamis and Thunnus obesus* dominated the catch, accounting for 43%, 29% and 17% of the total catch, respectively. Vessels flagged to Mauritius recorded the highest CPUE of 42,000 $KgVessel^{-1}Trip^{-1}$ followed by Spain with 5,392.6 $KgVessel^{-1}Trip^{-1}$. The results of the analysis for the size distribution, growth parameters, mortality and exploitation rates indicated that over 90 % of *Thunnus albacares* and *Xiphias gladius* sampled in artisanal fishery were juveniles. Exploitation rates were also above the optimal indicating that the two fisheries are experiencing growth overfishing. A review of the Kenya fisheries policy and legislative framework reveals that it is coherent with the regional and international law with focus to scientific aspects, however, the challenge is with effective implementation. Information generated by this study will certainly broaden the scientific knowledge and understanding about tunas in Kenya and inform policy for their effective conservation and management.

Key words: Kenya, SWIO, Tunas, distribution, mortality, exploitation, management, conservation.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Study Background

The marine environment and ecosystems in Kenya have rich biodiversity and resources therein including fisheries. Marine fisheries resources play an important role in contributing to the national economy, food security and livelihood. Kenya has a coastline of 640 Km which extends from 5° 25'S to the border with Tanzania and to 1° 30'S with the Somali border. The country has an Exclusive Economic Zone (EEZ) of some 200 nautical miles and a continental shelf covering approximately 6500 km^2 (Government of Kenya, 2017; Kimani *et al.,* 2018). Kenya lies in the South-West Indian Ocean region which is rich in tuna fish resources (Kimani *et al.,* 2018; Campling, 2012). Tunas are the most important and highly valued commercial offshore pelagic fishery. Yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus), albacore tuna (Thunnus alalunga)*, skipjack tuna (*Katsuwonus pelamis*) and swordfish (*Xiphias gladius*) are the key species occurring in Kenya EEZ and that of the respective coastal states as well in the high seas (Kimani *et al*., 2018; Mueni *et al.*, 2018; ISSF, 2020). The coastal fisheries comprise of neritic tunas such as kawakawa (*Euthynnus affinis*), bullet tuna (*Auxis rochei*) and frigate tuna (*Auxis thazard*) among others (IOTC, 2020). Mackerels (*Scomber* spp) and Kingfish (*Scomberomorus commerson*) and Wahoo (*Acanthocybium solandri*) found along the continental shelf also constitute tuna-like species that are important to the artisanal fisheries in Kenya.

The potential of marine fisheries resources in Kenya has been estimated at 150,000 – 300,000 Metric tons (Mt) per year (State Department of Fisheries, 2013). Since the 1970s, the reported commercial marine fish landings in Kenya on the average have ranged from 5,000 to 8,000 Mt per annum, with highest production recorded during the Northeast Monsoon (NEM) season (Mueni *et al.,* 2019). Demersal and reef fisheries account for 45% of the total marine fish production, closely followed by pelagics (including tunas) contributing about 35% of the total catch (KMFRI, 2018). State Department of Fisheries (2013) reported that tunas contributed approximately 6% of the total marine fish production in 2012, estimated at 8,865 Mt. In 2018 some 2000 Mt of tuna were landed by two Kenyan flagged longline vessels (KMFRI, 2018). The main fishing ground for small-scale marine fishery include the Malindi- Ungwana Bay, the North Kenya and Malindi Banks, and to the south of Lamu Archipelago (KMFRI, 2018). Industrial commercial harvesting of tunas is done in the Kenyan EEZ (KMFRI, 2018).

The management and development of the fisheries sector in Kenya is under the State Department of Fisheries, Aquaculture and Blue Economy (SDF&B) and the Kenya Fisheries Service (KeFS). The Indian Ocean Tuna Commission (IOTC) oversee the management of tuna fisheries in the Indian Ocean region. Kenya joined IOTC in 2004 and is bound by its decisions on tuna conservation and management measures. This study examined among others tuna fisheries catch rates, species composition, distribution, growth parameters, mortality rates as well as the contribution of science in informing tuna fisheries conservation and management in Kenya. Formulating effective and appropriate fisheries management policies and regulations is only one step in the right direction, the challenge however lies in their implementation. When fisheries management frameworks are weak, fisheries resources are more prone to overexploitation and mismanagement.

The Fisheries Management and Development Act, 2016 is the main law governing fisheries activities in Kenya. The Act provides, more specifically, for the management and development of the fisheries sector with a view to contributing to improved socio-economic benefits to the local communities who depend on fisheries for their livelihood and other related purposes (Kimani *et al.*, 2018; Government of Kenya, 2017; Republic of Kenya, 2016).

The National Oceans and Fisheries Policy was developed and formally launched by the Government of Kenya for implementation in 2009. The policy (now under review) provides guidance for managing and developing the fisheries sector in Kenya. In 2013, the Government of Kenya, through a stakeholder consultative process, developed the Kenya Tuna Fisheries Development and Management Strategy (2013 – 2018). The strategy, which is now under review, is to help Kenya develop and tap on the highly valuable shared tuna and tuna-like resources in the Indian Ocean area managed by the IOTC.

Kenya, as a sovereignty, has subscribed to several regional and global fisheries management frameworks/regimes as provided for in the Kenya Constitution of 2010 (Article 2 (5)) and the Treaty Making and Ratification Act No. 45 of 2012 (Rev. 2014). Article 2 (5) of the Kenya Constitution stipulates that any Treaty or Convention ratified by the Government of Kenya automatically forms part of the country's law (www. treaties.mfa.go.ke). The Treaty Making and Ratification Act lays down the procedure for making and ratifying treaties and conventions by Kenya. The United Nations Convention on the Law of the Sea (UNCLOS), which was signed and adopted in 1982, was the first of its kind to provide a comprehensive global legal and legislative framework for improved marine governance. The United Nations Fish Stock Agreement (1995) recognized the need for collaboration by states through some form of regional coordination mechanism to manage fisheries inside and outside their respective Exclusive Economic Zones (EEZ). The FAO Compliance Agreement (1994) paid more attention to the challenge of reflagging by states with a view to improving flag state responsibilities and compliance (Cochrane, 2002; AU-IBAR & WWF, 2013). There are many other non-binding tools and instruments including the

FAO Code of Conduct for Responsible Fisheries (1995) and FAO Plans of Actions (NPOAs) such as the International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated (IUU) fishing (2001) and the International Plan of Action for the Management of Fishing Capacity (1999).

This thesis contains the results of a study which was undertaken between August 2015 and December 2016 in five landings sites at the Kenya coast, namely, Lamu (Amu), Mombasa (Old Town), Kilifi (Mnarani), Malindi (Shella) and Watamu (Watamu). The main objective of this study was to examine the scientific robustness of the policy and legal frameworks for managing and developing tuna fisheries resources in Kenya, with focus on some of the biological aspects. This study was to evaluate the existing national policy and legal framework for tuna management and tuna-like fisheries in Kenya and ascertain if they are supported by adequate biological data and scientific knowledge of the tunas in Kenya waters. Sound knowledge and scientific information about tuna fishery is critical to the success of effective fisheries management and conservation measures. Biological sampling and secondary sourcing of data for tunas was undertaken to determine the trend in catch rates, species composition and distribution of artisanal and offshore tunas in Kenya waters based on the tuna fisheries catch data from small-scale fishers and longline foreign fishing fleets that were licensed to fish in Kenyan waters for the period 2012 - 2017. The study further determined the size distribution, growth parameters and mortality rates for some of the tunas from artisanal catches. The findings of this study will certainly make an important contribution to the scientific knowledge and better understanding of the tuna and tuna-like fishery in Kenya waters to support policy and decision making for improved governance and sustainability of these fisheries resources.

1.2 Problem Statement

FAO (2016) estimated that 58.1% of the global marine fisheries were fully exploited and about 31.4% were overexploited. It is estimated that only 10.5% of the fisheries are considered as not fully exploited while the amount of catch of marine fisheries resources is on the declining trajectory. Tuna catches in the Indian Ocean are on a declining trajectory (Pillai & Satheeshkumar, 2012). The assessment of yellowfin tuna in the Indian Ocean by the IOTC Scientific Committee indicated that the stock was overfished and recommended rebuilding measures by the parties (IOTC, 2017; IOTC, 2016; ISSF, 2016; IOTC, 2018).

The fish catches from the nearshore waters in Kenya is declining (Fisheries Department, 2012) suggesting that the reef fisheries are overharvested and being depleted fast (State Department of Fisheries and Blue Economy, 2016; Winter, 2009). Munga *et al.* (2012) reported that artisanal fishing is contributing to the declining catches, changing fish community structure and composition in the inshore waters. The coastal ecosystems are threatened by unsustainable fishing practices (AU-IBAR & WWF, 2013). Fishing effort on nearshore marine fisheries in Kenya is on the rise, including the number of fishers and crafts (State Department of Fisheries and Blue Economy, 2016; Winter, 2009), while overfishing and use of destructive fishing practices are on the rise (McClanahan *et al.*, 2005; Winter, 2009).

Illegal, Unreported and Unregulated (IUU) fishing is on the rise globally, and the Indian Ocean region as well as Kenya have not been spared (AU-IBAR & WWF, 2013). AUC-NEPAD (2014) reported that some 11- 26 million Mt of fish valued at about US$ 10- 23.5 billion was lost annually through illegal fishing activities. AUC-NEPAD (2014) further reported that Africa loses about US$2-US$5 billion annually resulting from poor governance of the fisheries sector of which some

US$1 billion was from Sub-Saharan Africa (AUC-NEPAD, 2014). It has been reported that Kenya is losing some KShs 10 billion annually due to IUU fishing (Kenya Fisheries Service, 2020). IUU fishing not only contributes to over-fishing, but also distorts markets as well as putting strain to governance structures and economic lose specially to developing states.

Scientific and biological information on many fish species in Kenya, including tuna is grossly lacking (Tuda *et al*., 2016; KMFRI, 2018). Few studies for some species have been conducted (Fondo *et al*., 2015). Tunas are highly migratory and shared stocks which require a collective and regional approach for their management and stock sustainability. There are also some tunas which are resident (neritic) in coastal waters of a given country (IOTC, 2016; IOTC, 2014). However, there is limited information in the public domain regarding the biological and growth related parameters of the tunas in the Indian Ocean (IOTC, 2016; IOTC, 2014). The IOTC Scientific Committee (2014) expressed concern with the low sampling rate and discrepancies in catch, effort and size data (IOTC, 2014). It is acknowledged that the data on the status of the tuna fish stocks in the IOTC area is mainly an approximation (IOTC, 2018; IOTC, 2019). There is also a problem of under-reporting (Barnes *et al*., 2011; IOTC, 2014). The catches are not disaggregated to the species level (State Department of Fisheries, 2013; IOTC, 2013; IOTC, 2014). IOTC member states, including Kenya, have not been effectively implementing tuna conservation and management measures that they adopt at IOTC level as evidenced in the various performance reviews (Anon, 2009; IOTC; 2015).

The knowledge and information with regard to the status of tuna and tuna-like fish stocks in the Kenyan waters is very limited (KMFRI, 2018; Ruwa *et al.*, 2003). In 2012, the Fisheries Department estimated that the potential of marine fisheries resources in Kenya at about 150,000 – 300,000 Mt per year. Ruwa *et al.* (2003) reported that small pelagics have the potential to contribute at least 18,000 – 20,000 Mt, annually. However, this potential is not well utilized and or tapped by the national fleet. Most of the fishing opportunities in the Kenya's Exclusive Economic Zone (EEZ) is taken by foreign Distant Water Fishing Nations fleets (DWFN) who pay some fee for access, with an estimated annual catch of over 50,000 Mt which is conservative (Fisheries Department, 2012). In 2009, piracy in the Somali basin affected the number of vessels seeking for fishing license in Kenyan waters (Wetangula, 2013). On average some 30 – 40 DWFN fleets were licensed to fish in Kenya waters between 2010 – 2015 (KMFRI, 2018, State Department of Fisheries, 2016). Compliance by DWFN in submitting quality data and information about their declared catch has been poor due to weak Monitoring, Control and Surveillance (MCS) system.

A good understanding and knowledge of the fishery, including its distribution, biology and population dynamics is critical to inform sustainable development and management of tuna and tuna-like fisheries resources at national, regional and global level. Sound scientific knowledge and information about the fishery is important and critical to inform effective and appropriate policies and decision-making processes for tuna management, sustainable use and development.

The information and knowledge generated from this study will certainly inform sustainable management and exploitation of the tunas in Kenya and entire Indian Ocean region. A scientifically robust management plan for tunas that is effectively implemented will contribute to healthy fish stocks that are profitable to the coastal fishing communities and business people as well as the economies of both coastal and market states.

1.3 Justification

Tuna and tuna-like species are highly valued resources of commercial importance. They are very important socio-economically and contribute significantly to food and nutritional security. Some 7.4 million tons of tunas were produced in 2013, representing over 9 % of total global marine capture fisheries production in the same year (FAO, 2016). Galland *et al.* (2016) reported that global tuna was worth some US$ 42 billion in 2014. Annual global tuna production continues to increase, from less than 0.6 million Mt in 1950 to about 7.9 million Mt in 2018 due to high demand that is continuously increasing (FAO, 2020).

Kenya has not maximized on the potential of this highly valuable tuna fishery which remains underdeveloped. The coastal artisanal fisheries in Kenya is near depletion because of increasing fishing effort, particularly fishers and fishing crafts (State Department of Fisheries, 2016). Tuna industry is expected to make a significant contribution in making Kenya a middle-income status country as envisaged in Kenya's Vision 2030 (State Department of Fisheries, 2013). Tunas accounted for only 3% and 6% of marine fish production in Kenya in 2011 and 2012, respectively (Fisheries, Department, 2012; State Department of Fisheries, ,2013). Therefore, sustainable investment in the tuna fishery will certainly enhance the sub-sector's contribution to Kenya's national economy and livelihoods for the local communities who depend on marine resources.

Offshore marine fisheries resources in Kenya have great potential though least exploited by the national fleet/fishers (Fondo *et al.,* 2014). The potential of marine waters in Kenya was estimated to be 150,000 – 300,000 Mt (State Department of Fisheries, 2013). Hydro-acoustic surveys conducted by KMFRI in 2017 projected an annual yield of 240, 000 Mt from Kenya's EEZ at 20% extraction (KMFRI, 2018). Small pelagics on the other hand has the potential of about 18,000 –

20,000 Mt, annually (Ruwa *et al*; 2003). The marine fisheries production in Kenya is estimated at 5,000-8,000 Mt, annually, with the highest landings reported in Northeast Monsoon (NEM) months (FAO, 2016; Hoofs & Steins, 2017). An average of 147,916 Mt of fish was landed from Kenyan waters in 2016 of which 24,709 Mt came from the artisanal marine sector (State Department of Fisheries and Blue Economy, 2016).

The major fishing grounds for marine fisheries in Kenya (including tunas) are located in Lamu archipelago, offshore areas near Tana River mouth, the Malindi - Ungwana Bay, Northern Kenya Banks, Shimoni, Vanga and Funzi (Munga *et al.*, 2012).

With increasing demand for tuna, the intensity of fishing has remained on the increasing trajectory which has subsequently contributed to overfishing of yellowfin tuna in the Indian Ocean (IOTC, 2019). Intensification of fishing pressure on the tunas would certainly contribute to depletion of the tuna stocks unless effective conservation and management measures are put in place urgently.

This, therefore, calls for collective and collaborative approach to sustainable management and development of the tuna fishery informed by science. Whereas many tunas are shared highly migratory stocks, there are also some neritic tunas that are resident in coastal waters of some countries, including Kenya and would require to be identified, managed and utilized in a sustainable way (IOTC, 2014; IOTC, 2016).

Different data sets and information including catch, effort, mortality rates, length-weight frequency and growth rates are critical in the assessment of tuna stocks to inform management. It is envisaged that the data and information produced by this study will contribute to improved knowledge and science of tuna and tuna-like fisheries in the Kenya waters to support policy and improved management of the fishery in the country.

1.4 Key research questions

The study responded to the following key research questions:

1. How does the fishing effort, catch trends, species composition for artisanal and industrial tunas vary over time and space in Kenya waters?

2. What is the composition and temporal distribution of tuna and tuna-like fish species in the artisanal and industrial catches in the Kenyan waters?

3. What are the length-weight distributions, length-frequency, growth parameters and mortality rates for coastal tunas in Kenya?

4. Is the policy and legislative framework for managing and developing tuna fisheries resources in Kenya supported by science?

1.5 Objectives of Study

The main objective of this study was to examine the scientific robustness of the Kenya national fisheries policy and legal framework for managing and developing tuna and tuna-like fisheries in the country.

The specific objectives of this study were to:

1. Determine the trends in catches, Catch Per Unit Effort (CPUE) of the tuna and tuna-like fish species in coastal and EEZ waters in Kenya.

2. Determine composition and temporal distribution of tuna and tuna-like fish species in the artisanal and industrial catches in the Kenyan waters.

3. Determine size distribution and growth parameters of the tuna and tuna-like species from artisanal catches in the Kenyan waters.

4. Evaluate the contribution of science in informing policy and legal framework for sustainable management and development of the tuna fishery in Kenya.

1.7 The Scope and Limitation of the Study

The scope of this study was confined to the biological aspects of the tuna and tuna-like fish species including growth parameters, length frequency distribution and mortality rates which are critical elements in understanding population dynamics, fish recruitment and stock status. These elements are key ingredients that support the formulation of effective policies and plans for managing tuna fisheries in a more sustainable way in Kenya waters. Further, this study focused on understanding how the science has contributed to the policy and legislative framework for developing and managing tunas, specifically on the input and output controls that requires biological data about the fishery.

Data on catches from foreign fishing vessels in Kenya waters was not readily available due to fishing vessels not declaring their catch and thus creating gaps in the data. Biological data including the length, and sex of the individuals was not provided for in the logbook entries. Length-frequency data was not captured as required by the IOTC. There were a number of incidences where the information in the logbooks was not recorded to species level and lacked some consistency. For instance, in one of the logbooks, the species landed was recorded as “whitetuna”. This wasn’t clear about which type of tuna species that was being referred to. Similar concerns on the quality of data have been raised by the Indian Ocean Tuna Commission (IOTC, 2020; Fiorellato *et al.,* 2018). There was also glaring evidence of under reporting. For instance, one of the fishing vessels was in the sea for four days and managed to catch only 11 individuals of yellowfin tuna. Nevertheless, the data provides very interesting information on the DWFN longline fishery in the Kenya waters.

Insecurity in Amu (Lamu), one of the sampling sites became an issue. This was brought about by the insurgency of Al-Shabaab extremists. Many incidences of attack to the people and property became rampant with loss of life on several occasion. Sampling in Amu had to be discontinued in April 2016, and instead started sampling in Mnarani in Kilifi County the very month. This was to ensure that the number of sampling sites are maintained and representative of tuna landings. Further information on the security situation in Lamu can be found on the following links; https://www.nation.co.ke/counties/lamu/Shabaab-attacks-rise-Lamu/3444912-4272008-15bghb9z/index.html,https://www.youtube.com/watch?v=9w-OuY8tT3s, https://youtu.be/SSeL6LPpPoc, https://youtu.be/8Zkzt5q8lkA.

The main limitation of this study was that there were few Kenyans who had knowledge and a clear understanding of the geo-political dynamics, conservation and science of tunas in the country and the region. This is a gap that need to be addressed with a view to building the capacity of Kenya fisheries experts on tuna related aspects including science, fisheries access, trade and development.

1.8 The structure and layout of the Thesis

This thesis is organized and structured into Eight chapters as described below.

Chapter 1: Provided the context of the study including the background information, problem statement, objectives, key research questions as well as the scope and limitation.

Chapter 2: provides a review of the literature about tunas from national to global perspectives, including the ecology, biology, distribution and the state of knowledge and science of the fishery. The economic importance of tunas, governance and management of the tunas from national, regional and global context is highlighted.

Chapter 3: Presents methodology. The study area is defined and described.

Chapter 4: Presents objective one which focus on catch rate trends of tunas in the Kenyan waters.

Chapter 5: Presents objective two. This focus on species composition and temporal distribution of tuna and tuna-like species in the artisanal and industrial catches in the Kenyan waters.

Chapter 6: Presents objective three with focus on the size distribution and growth parameters of tunas sampled from artisanal catches in the Kenyan waters.

Chapter 7: Presents objective four. The focus is on the contribution of science in informing policy and legislative framework for managing and developing the tuna fishery in Kenya.

Chapter 8: Provides general discussions, conclusions and recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This section reviews available information on tunas from secondary sources in the public domain. The production of principal commercial tuna and tuna-like species from global, regional and national (Kenya) perspectives is examined. The scientific knowledge and studies undertaken on tuna and tuna-like species from national (Kenya), regional (Indian Ocean) and global perspective is reviewed. Further, the section highlights the ecology, biology and distribution of tunas in the Indian Ocean, tuna fisheries governance frameworks local to global, and the contribution of the tunas in the national economy. The challenges facing the tuna sector are also highlighted.

2.2 Production of Tuna and Tuna-like Fish Species: Global to Local Perspectives

Coastal and marine ecosystems are important for ecological and socio-economic purposes, most importantly fisheries resources. It is estimated that 99% of fisheries, globally, are found in the EEZ, which makes it important for the countries to work together to conserve the oceans living resources and its environment (FAO, 2018).

The world fisheries production in 2016 and 2018 was estimated at 171 million Mt and 179 million Mt respectively. In 2016 capture fisheries contributed about 91 million Mt while some 80 million Mt came from Aquaculture (FAO, 2018) and this figure of capture fisheries increased to 96.4 Million Mt by 2018 (FAO, 2020). Capture fisheries from marine sources was about 79 million tons while inland waters contributed 12 million Mt (FAO, 2018). The supply from capture fisheries remained steady compared to 2014 catches of about 94 million Mt with some slight decline to 84.4 Mt in 2018 (FAO, 2020; FAO, 2014).

Tunas are distributed widely across the globe, especially in the tropics and temperate. The principal commercial species are *Kastuwonus pelamis* (skipjack tuna), *Thunnus albacares* (yellowfin tuna), *Thunnus obesus* (bigeye tuna), *Thunnus alalunga* (albacore), *Thunnus macoyii* (Southern Bluefin tuna) and *Thunnus thynnus* (Northern Bluefin tuna) (ISSF, 2016; Pillai & Satheeshkumar, 2012). Production of tunas globally has experienced steady and rapid increase for the last 50 years (Fig.2), from about 0.6 million Mt in 1950 to some 7.9 million Mt in 2018 (FAO, 2020), worth some US$ 40.8 billion in 2020 (Pew, 2020).

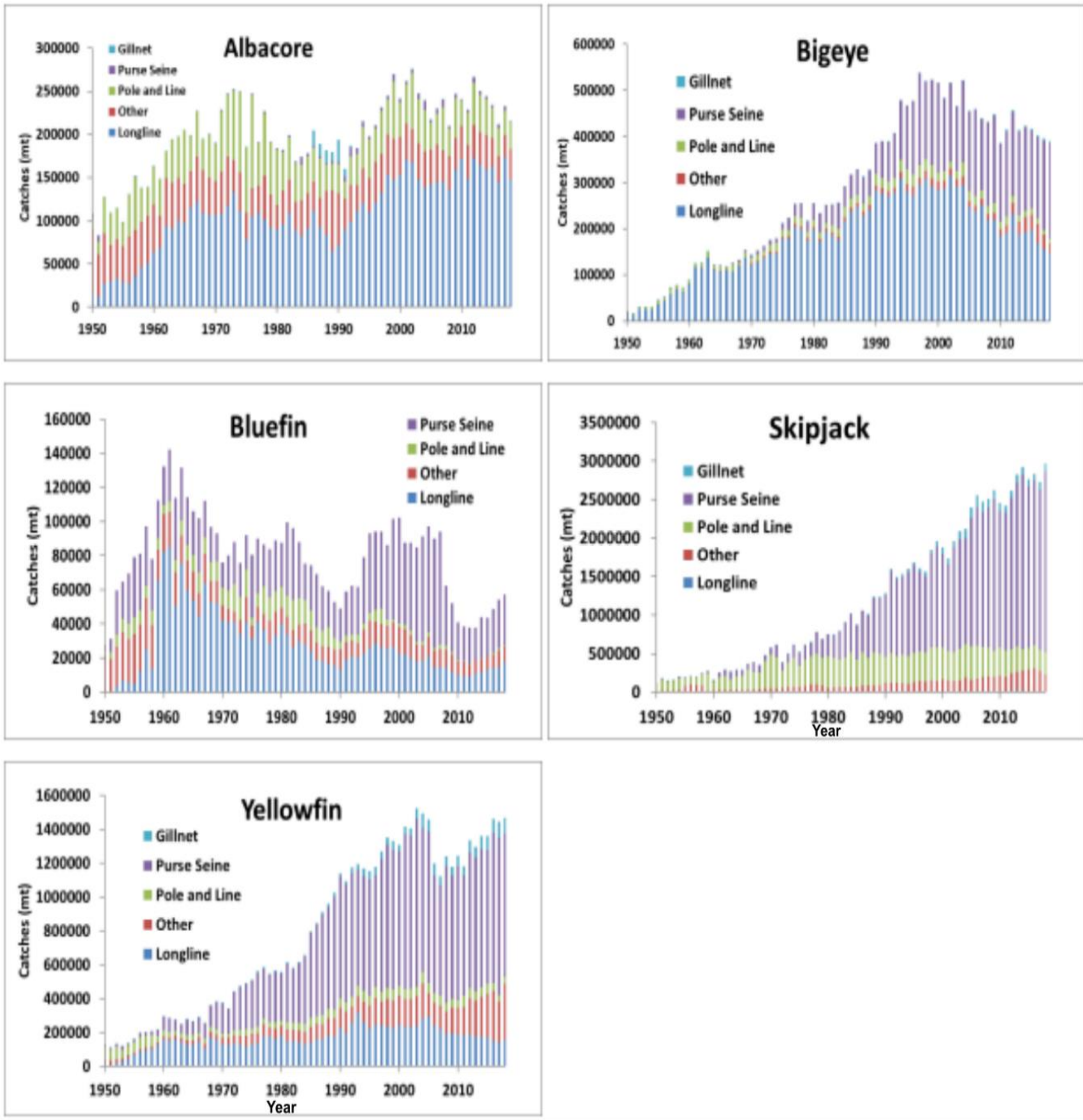


Figure 2. Trends in global production of the principal commercial tunas (Mt) from 1950 to 2018 (Source: ISSF, 2020).

Global combined catch for albacore, bigeye, bluefin, yellowfin and skipjack tunas was estimated at 5.2 million Mt in 2018, which corresponded to some 5% increase compared to 2017 (ISSF, 2020). Skipjack tuna contributed about 58% of the total catch globally in 2018, closely followed by yellowfin tuna (29%), bigeye (8%), albacore tuna (4%) and bluefin tuna (1%) (ISSF, 2020).

Various fishing gears and methods are deployed to catch tunas including purse seining (66%), longline (10%), pole and line (8%), gillnets (4%) and others (12%) (ISSF, 2020; IOTC, 2020).

The Indian Ocean (IO) region contributed about 21% of the global catch in 2018, making it the second largest producer of tunas globally (ISSF, 2020). In 2019, some 1,047,653 Mt of tropical tunas were landed in the Indian Ocean, of which 427,240 Mt, 547,248 Mt and 73,165 Mt were yellowfin, skipjack and bigeye tunas, respectively (IOTC, 2020). Over the past four decades, the landing of tunas has increased rapidly in the Indian Ocean (Pillai & Satheeshkumar, 2012; ISSF, 2016). For instance, tuna catches increased from 237,986 Mt to 654,754 Mt in 1980 and 1995, respectively (Pillai & Satheeshkumar, 2012). Some decline in tuna catches has been reported since 2005 when approximately 1.2 Mt tuna was landed, but this increased substantially from 2013 (Fig. 3).

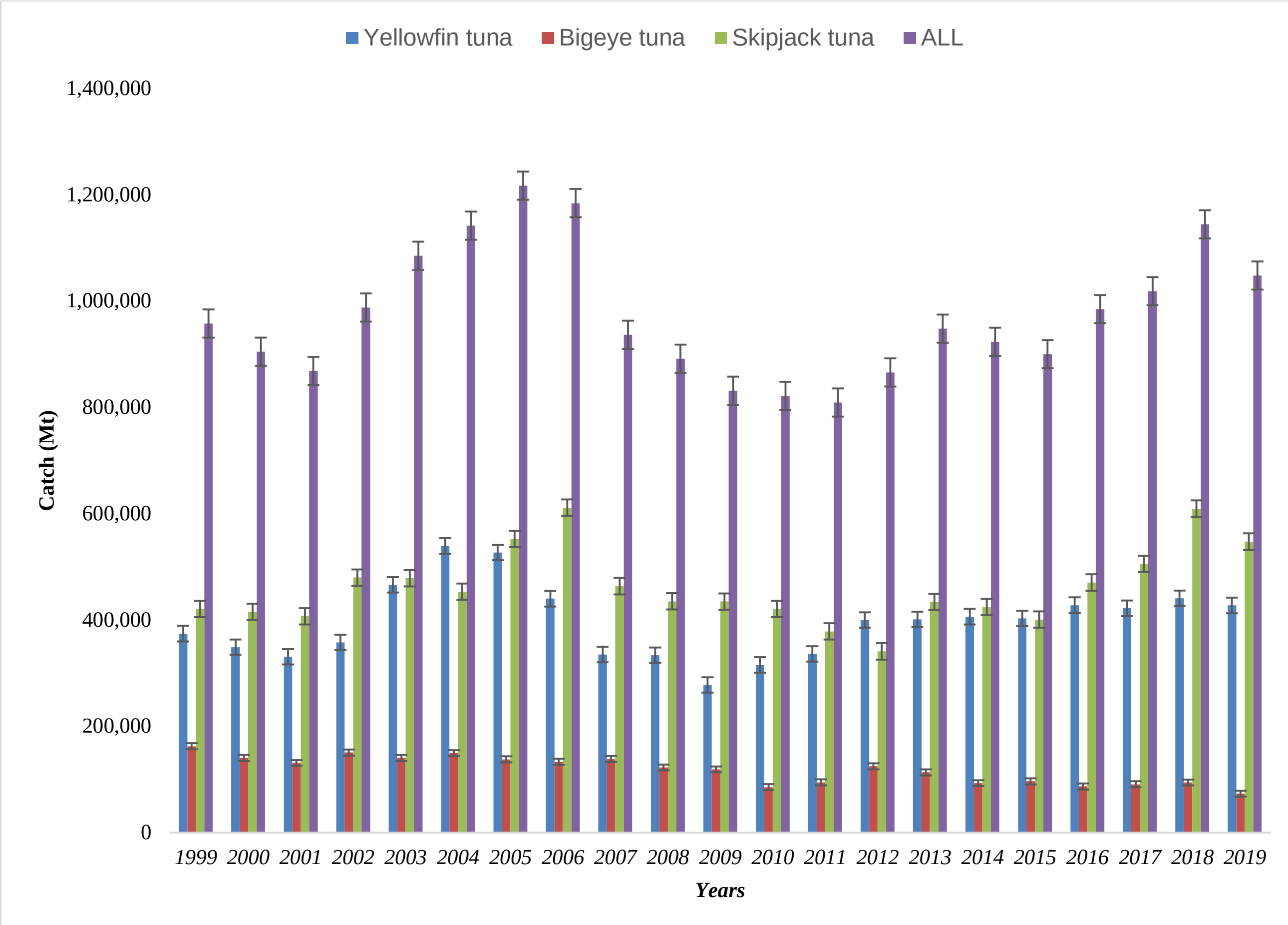


Figure 3. **Trends in the production of principal tunas in the Indian Ocean between 1999 and 2019 (Data source: IOTC, 2020).**

In 2014, skipjack, yellowfin and albacore catches combined were estimated at 1,003, 400 Mt, representing a 2% increase compared to 2013 records (ISSF, 2016). Pooled data (2006 – 2010) show that skipjack dominated the catch contributing about 38% of the total catch in the Indian Ocean, whereas yellowfin, kawakawa, bigeye, albacore and bluefin tunas contributed 26%, 10%, 9%, 3% and 1%, respectively (Pillai & Satheeshkumar, 2012). In 2019, skipjack tuna contributed about 47.7% of the total global catch of tropical tunas, followed closely by yellowfin tuna with 41. 6% and bigeye tuna at 8.7% (IOTC, 2020). Artisanal tuna is increasingly becoming significant accounting for about 40% of the tuna catch landed in the IOTC area in 2019 (IOTC, 2020).

Kenya's EEZ is strategically positioned within the rich tuna migration route (Fig. 4) in the South-West Indian Ocean (SWIO) within the upwelling highly productive Somali basin (State Department of Fisheries and Blue Economy, 2016; Kaplan *et al.*, 2014; Hoof & Steins, 2014).

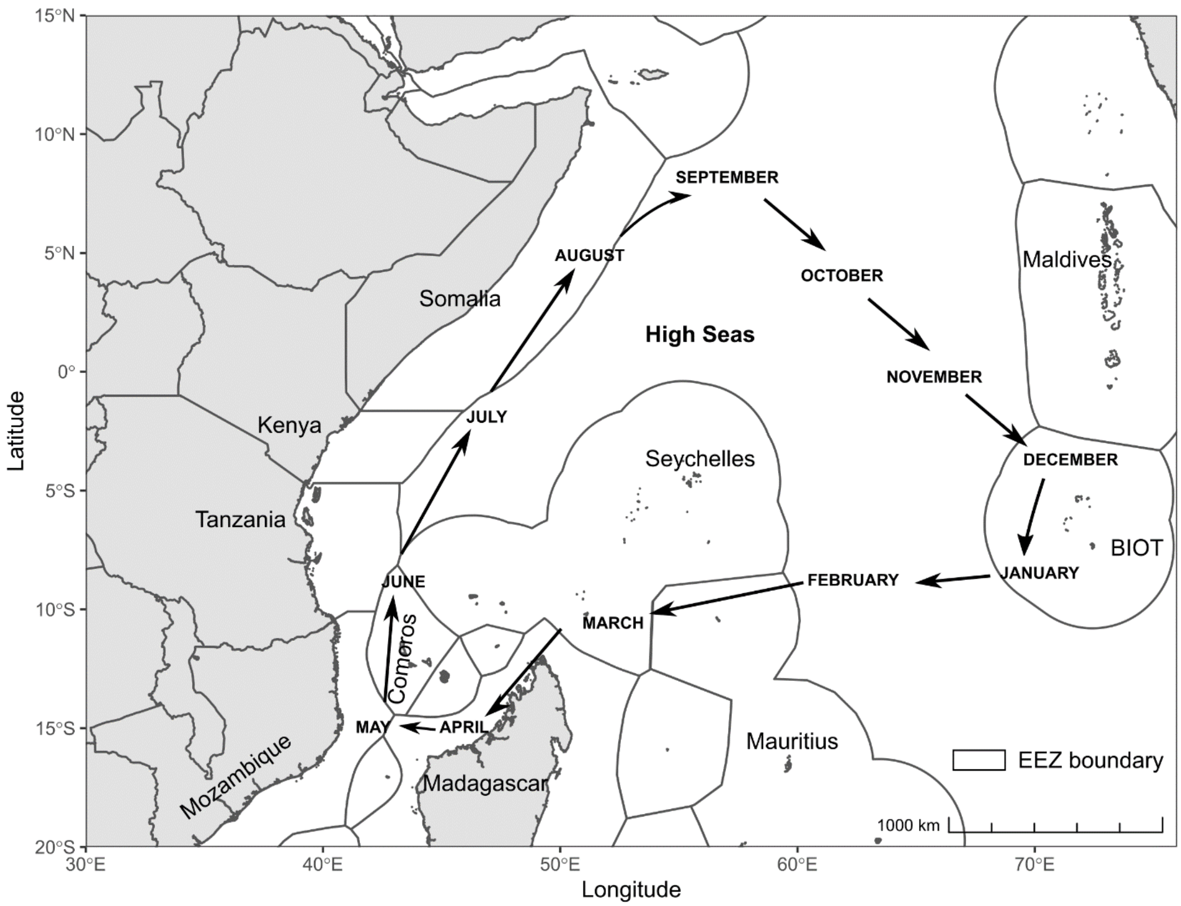


Figure 4. **Seasonal migration routes for tunas in the Western Indian Ocean (adapted from Campling, 2012).**

The main commercial tuna fish species found in the Kenya waters are *Katsuwonus pelamis* (skipjack tuna), *Thunnus albacares* (yellowfin tuna) and *Thunnus obesus* (bigeye tuna) (State Department for Fisheries and Blue Economy, 2016). The coastal tuna fisheries (neritic) comprise of frigate tuna (*Auxis thazard),* little tunny (*Euthynnus alleteratus*), Kawakawa (*Euthynnus* *affinis*), longtail tuna (*Thunnus tonggol*), wahoo (*Acanthocybium solandri*), Mackerels (*Scomberomorus* spp) and Kingfish (*Scomberomorus commerson*) found along the continental shelf are important to the artisanal fisheries (Ndegwa & Okemwa, 2017; Ndegwa & Macharia, 2015).

According to the Food and Agriculture Organization of the United Nations (FAO), the potential of marine waters in Kenya was estimated to be 150,000 – 300,000 Mt (State Department of Fisheries, 2013). Ruwa *et al* (2003) reported that the potential of small pelagics was about 18,000 – 20,000 Mt, annually. Marine fisheries production in Kenya has stagnated since 1970s at about 5,000-8,000 Mt annually, with the highest landings reported in Northeast Monsoon (NEM) months (FAO, 2016; Hoofs & Steins, 2017). In 2016, an average of 147,916 Mt of fish was landed from Kenyan waters of which 24,709 Mt came from the artisanal marine sector (State Department of Fisheries and Blue Economy, 2016). Marine fisheries production is dominated by demersal, pelagics as well as reef based fish harvested from nearshore waters (State Department for Fisheries and Blue Economy, 2016; Kaplan *et al.*, 2014; Fisheries Department 2012). Approximately 80% of marine fisheries landing in Kenya is from nearshore waters, while only 20% is from offshore fishing (Fondo, 2004, Fisheries Department, 2012). Most of the Kenya EEZ fisheries resources are harvested by Distant Water Fishing Nations (DWFN) who pay license fee to fish. Barnes *et al.* (2011) reported that Kenya earned some US$ 8,155,120 from longlines and US$ 1,162,625 from purse seines fishery which does not commensurate with the real value of the tunas.

There are about 414 – 800 artisanal fishing crafts operating within the 3- 5 nautical miles in Kenya waters targeting tunas (State Department of Fisheries and Blue Economy, 2016; Hoof & Steins, 2017). Most fishers target reef/coastal inshore fisheries (within the 5 nautical miles) due to lack of appropriate fishing vessels and gears to venture in to deep sea fishing (Hoof & Steins, 2017).

The fishers employ a range of fishing gears to catch the tunas, the most common being longline hooks, handline, trolling lines and gillnets (Tuda *et al.*, 2016; State Department of Fisheries and Blue Economy, 2016; IOTC, 2017).

Although this data for tunas is available in the Kenya Fisheries Service (KeFS), it is not disaggregated to the species level and are lumped together in the Scombridae family. These catches for the Scombridae family from the artisanal fishers increased from 522 Mt to 1,215Mt and finally to 1,798 Mt from 2014 to2015 and 2016, respectively (Fig.5).

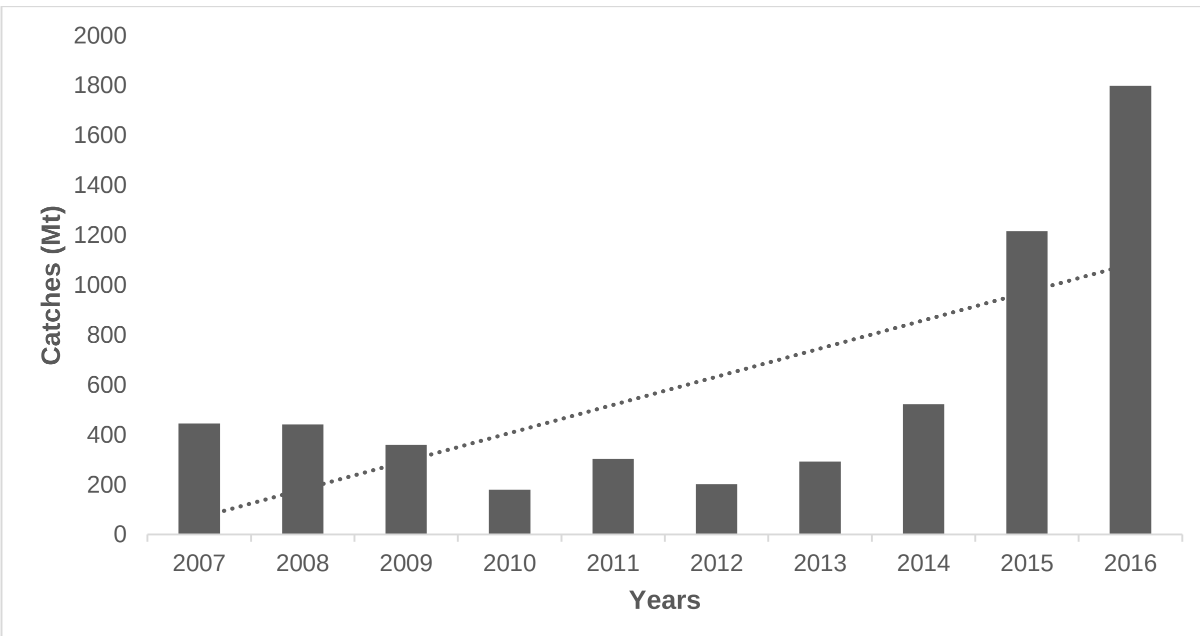


Figure 5. Artisanal tuna catches in Kenya waters from 2007 – 2016
(Source of Data: Kenya Fisheries Department)

This indicates that in 2016, tunas accounted for about 7% of the total landing from capture fisheries in marine waters in Kenya compared to 6% in 2013 (State Department for Fisheries and Blue Economy, 2016). IOTC (2017) reported that 6,815 Mt, 8,265 Mt and 3,431 Mt of Scombridae were harvested by artisanal fishers in the Kenya coastal waters in 2014, 2015 and 2016, respectively. These discrepancies in some data and some inconsistences in the reporting of the artisanal tuna catches could be attributed to poor data collection and reporting system (Ndegwa & Geehan, 2017). Hoof and Steins (2017) reported that some 2,362 Mt of pelagics are landed by artisanal fishers annually.

2.3 The Ecology, Biology, Distribution and Status of Stocks for the Principal Tunas in the Indian Ocean

Tropical and temperate tuna and tuna-like fish species are highly migratory and widely distributed across the world. There are broadly classified as tropical or temperate tunas due to the differences in the temperatures in which they thrive well (ISSF, 2016). Tropical tuna species are usually found in areas with temperatures above 18^{o}C whereas the temperate species occur in areas with temperatures below 10℃ (ISSF, 2020). Tropical tunas among others include bigeye, yellowfin and skipjack. The temperate tunas include Southern albacore, bluefin, North Atlantic bluefin and Pacific bluefin tuna (ISSF, 2020). Tunas are also classified as oceanic and neritic. Most of the principal commercial tunas including skipjack, yellowfin, bluefin, bigeye and albacore are described as oceanic and highly migratory, capable of travelling long distances. They are fast swimmers with the capacity to move at a speed of about 4 to 6 knots and burst speed of approximately 13 to 14 knots (Mbendo, 2011; Chassot *et al.*, 2019). They migrate in search of food to sustain their energy and locate breeding grounds (Pillai & Satheeshkumar, 2012; Chassot *et al.*, 2019). Tunas are top predators preying on several food items including sardines, mackerels, anchovies, squid, octopus, prawns (Pillai & Satheeshkumar, 2012; Chassot *et al.*, 2019).

The Indian Ocean Tuna Commission (IOTC) considers the Indian Ocean tuna stocks as single stocks of the respective species (Chassot *et al*., 2019), however, some studies have shown that there are some sub-populations (Suman *et al.*, 2013; Menezes *et al*., 2012). Suman *et al.* (2013) suggests that they are two sub-populations for bigeye tuna in the Indian Ocean, namely those in Sumatra and Java/ Nusa. The Sumatra population is regarded as the original stock while the one at Java and Nusa may have originated from the Pacific (Suman *et al*., 2013). Menezes *et al*. (2012) suggests that there are four sub-groups of skipjack tuna in the India coastal waters.

The Western Indian Ocean (WIO) is defined by two Large Marine Ecosystems (LME). These LME are the Agulhas Current Large Marine Ecosystem (ACLME) and the Somali Current Large Marine Ecosystem (SCLME). The ACLME extends from the northern end of the Mozambique Channel, characterized by the warm Agulhas Current. The SCLME on the other hand stretches from Comoros Island and the northern part of Madagascar up to the Horn of Africa. The SCLME region is characterized by the Somali Current influenced by the monsoon winds (UNDP, n.d). These two LME are complex with diverse marine life of which some of them are endemic to the region. The marine resources in the LME include fisheries, coelacanth, dugong, turtles, cetaceans and many other living resources in aquatic environment (Ruwa; 2011). These resources underpin the livelihood security and economy of the local coastal communities and the respective SWIO range states (Ruwa, 2011).

The climatic, oceanographic, physical and biological characteristics of the Indian Ocean region is under the influence of the reversing South-East Monsoon (SEM) and the North-East Monsoon (NEM) Monsoon winds (KMFRI, 2018; Chassot *et al*., 2019). This monsoon system is influenced by the oscillation of the Inter-Tropical Convergence Zone (ITCZ), which is a low pressure zone, South or to the North of the Equator relative to the sun (Chassot *et al*., 2019; KMFRI, 2018; Government of Kenya, 2017).

The South Equatorial Current, the East Africa Coastal Current (EACC) and the Somali Currents (SC) have some influence on how the tunas are distributed in the Indian Ocean (Mbendo, 2011; Chassot *et al*., 2019). The EACC flows from the south across the Equator along the Somali basin into the Arabian Sea with the influence of the Southeast Monsoon (SEM) winds occurring between June to September (Chassot *et al.*, 2019). The EACC is weakened and diverted to the east to meet with the Somali Current flowing to the south in the NEM season occurring between December and March (Chassot *et al*., 2019). When these two currents meet, they cause upwelling and mixing of nutrients which enhances productivity (KMFRI, 2018; Chassot *et al.*, 2019, Pillai & Satheeshkumar, 2012). These productivity and seasonal changes influence the abundance and migration of the tunas.

Global climate change has been attributed to low primary production in the Western Indian Ocean (WIO) region (Chassot *et al*., 2019). Change in climate results to reduction of food substances in the environment (Mo *et al*., 2014), degradation of fish habitats (Olden *et al.*, 2007), reduction in the number and abundance of zooplanktons and phyto-planktons (Huang *et al.*, 2021) and alters the growth of individual fish (Kadri *et al*., 2013). The change in climate need to be addressed in order to minimize the negative impacts to the environment and marine ecosystems (Chassot *et al*., 2019). The movement of tunas to the west and north is influenced by the South Equatorial Current (Mbendo, 2011; Chassot *et al*., 2019).

Tunas are abundant along the Coast of East Africa and Mozambique Channel during the SEM season peaking between July and August. Tunas are surface water spawners. They prefer warm temperatures of above 24°C during spawning (Pillai & Satheeshkumar, 2012). They have schooling behavior and each individual fish release about 100,000 eggs in the open waters during each spawning session (Mbendo, 2011; Chassot *et al*., 2019; Pillai & Satheeshkumar, 2012). Spawning takes place in the Equatorial area 0° North and 10° South between December to June with some variations in the different species (Zudaire *et al.*, 2010). Spawning for yellowfin tuna occurs between November and April, bigeye tuna spawns between January and March while skipjack spawns all the year round peaking in December and March (Pillai & Satheeshkumar, 2012). Albacore spawns between January and July (IOTC, 2010). Tuna consume about 15% of their body weight in order to have enough energy for successful spawning (Mbendo, 2011). Known spawning and feeding grounds for tunas are the Mozambique channel, Somali basin, the Bay of Bengal, Sri Lanka and Australia (Pillai & Satheeshkumar, 2012; Chassot *et al*. 2019; Druon *et al*., 2017). These spawning grounds provide conducive environment for breeding, including warm temperatures above 24°C and rich in nutrients (Reglerot *et al*., 2014; Tew & Marsac, 2010). Richards & Simmons (1971) reported that the larvae of bigeye and yellowfin tunas move up to the surface of water daytime. Skipjack larvae on the other hand migrate to the surface at night.

Tunas in the Indian Ocean are experiencing fishing pressure and their conservation status against MSY indicate that yellowfin tuna has been overfished (Table 1).

Table 1. **Summary of stock status for the principal tunas in the Indian Ocean (Source IOTC, 2020 and IOTC, 2018).**

Species	**Recent average catches (Mt)**	**MSY (Mt)**	**Stock status**
Katsuwonus pelamis (Skipjack tuna)	506,555 (2015 – 2019)	470,020	Not overfished and neither subject to overfishing .
Thunnus albacares (Yellowfin tuna)	424,103 (2015 – 2019)	403,000	Overfished.
Thunnus obesus (Bigeye tuna)	88,303 (2015 – 2019)	87,000	Not overfished though subject to overfishing .
Thunnus alalunga (Albacore tuna)	36,004 (2013- 2017)	38,800	Not overfished though subject to overfishing .
Euthynnus affinis (Kawakawa)	148,084 (2015 – 2019)	148,825	Not overfished and neither subject to overfishing.
Xiphias gladius	31,712 (2015-2019)	33,000	Not overfished and neither subject to overfishing .

The principal tunas including their biology, distribution and stock status are summarized in the sections below:

2.3.1 Skipjack tuna (*Katsuwonus pelamis.* Linnaeus, 1758)

Skipjack tuna is a highly migratory species inhabiting tropical and fairly warm temperate waters (Fishbase, 2019). The species is distributed within the geographical range between 55^{o} – 60^{o} N and 45^{o} – 50^{o} S (ISSF, 2016). Skipjack tuna has high fecundity and spawns throughout the year, which makes it more resilient and easily withstands fishing pressure (ISSF, 2016; Pillai & Satheeshkumar, 2012). It usually forms free swimming schools in surface waters, and is also associated with debris and objects that float in water as well as Fish Aggregating Devices (FADs) (Fishbase, 2019; IOTC, 2018; ISSF, 2016).

It is harvested mainly by purse seining, use of gillnets as well as pole and line (IOTC, 2018). Handlines are used in artisanal fisheries. In 2016, some 446,723 Mt of skipjack tuna were landed in the IOTC area (IOTC, 2017) and this figure increased to 607,701 Mt in 2018 which is 29% above the catch limit of 470,029 Mt for the period 2018 to 2020 (Fig. 6) (ISSF,2020).

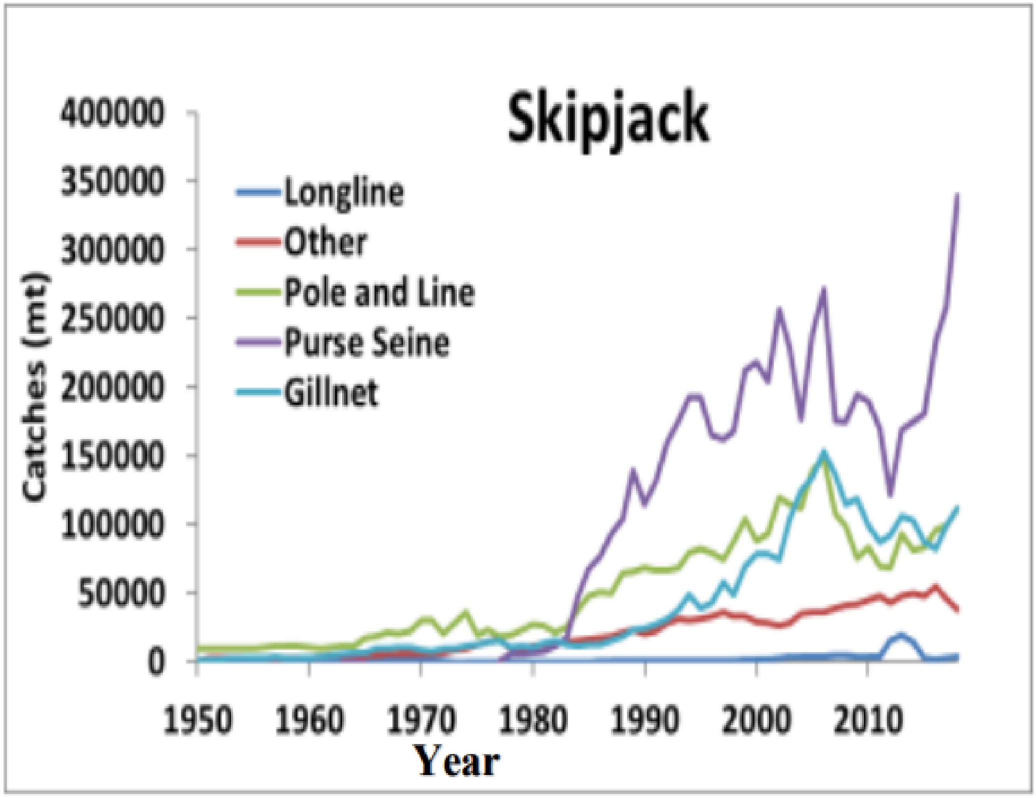


Figure 6. **Indian Ocean skipjack tuna catches by gear type from 1950 – 2018. (Source: ISSF, 2020)**

The catch increased to 547,248 Mt in 2019 (IOTC, 2020). The average catch for the period 2015 – 2019 was 506,555 Mt which is slightly above the Catch Limit of 470,029 Mt (IOTC, 2020). Nevertheless, the 2019 catch is within the estimated MSY range (500,131 Mt – 767,012 Mt) (IOTC, 2020) suggesting that Skipjack tuna is in healthy status.

2.3.2 Yellowfin tuna (*Thunnus albacares*. Bonnaterre, 1788)

Yellowfin tuna is found in tropical waters between 45° – 50° N and S (ISSF, 2016). This species is highly migratory and forms free or associated schools with other tunas (Fishbase, 2019; FAO 2007). Yellowfin is usually caught using various gears namely handline, purse seine, gillnet, longline, ringnet, pole and line (IOTC, 2018; ISSF, 2020).

Its stock in the IOTC area is under extreme fishing pressure and is overfished (IOTC, 2018; IOTC, 2020) leading to decline in catches by about 20% from 530,000 Mt in 2004 to 432,400 Mt in 2018 (ISSF, 2020) though have started increasing for some fisheries in particular purse seining (Fig. 7).

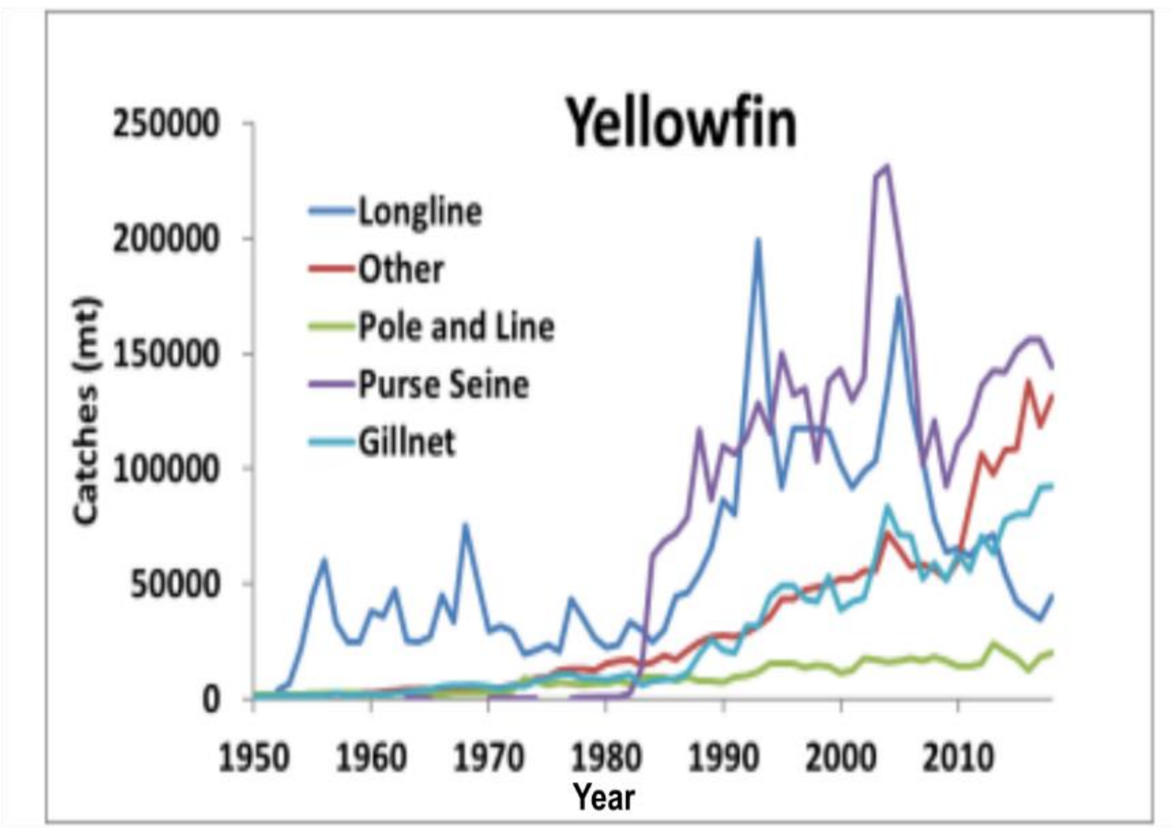


Figure 7. Indian Ocean yellowfin tuna catches by gear type from 1950 – 2018 (Source: ISSF, 2020)

Yellowfin tuna catches were about 432,400 Mt in 2018, representing a 3% increase compared to 2017 levels (ISSF,2020). In 2019, yellowfin tuna catches were estimated at 427,240 Mt against the MSY of 403,000 Mt with average catches for 2015 - 2019 standing at 424,103 Mt (IOTC, 2020). The 2019 catches are higher than MSY suggesting that the yellowfin tuna stock is overfished (IOTC, 2020). Similar observations and concerns have also been raised by other authors (ISSF, 2016; Pillai & Satheeshkumar, 2012).

2.3.3 Bigeye tuna (*Thunnus obesus*. Lowe 1839)

Bigeye tuna inhabits the tropical and sub-tropical waters in the Pacific and the Indian Oceans (ISSF, 2016). They occur between 55^{o} – 60^{o} N and 45^{o} – 50^{o} S (ISSF, 2016). Bigeye are highly migratory. They have high fecundity and spawn throughout the year (Fishbase, 2019; ISSF, 2016). Juveniles and small sized individuals inhabit surface waters while adults inhabit deep waters (Fishbase, 2019; IOTC, 2018; IOTC, 2004). The species forms schools in association with skipjack and yellowfin tunas. The common methods used to harvest the species are purse seine, handline and ringnet. Its adults, which are always found in the deeper waters, are principally harvested using longline (IOTC, 2018; ISSF, 2016).

Bigeye tuna catches in 2018 were estimated at 93,500 Mt, representing a 3% increase from 2017 catches (ISSF, 2020) (Fig. 8). IOTC (2020) reported that bigeye tuna catches in 2019 (73,165 Mt) were lower than the average (88,303 Mt) for 2015 – 2019 period but within the MSY (75,000 Mt – 108,000 Mt) indicating that the stock is being fished within allowable catches (IOTC, 2020).

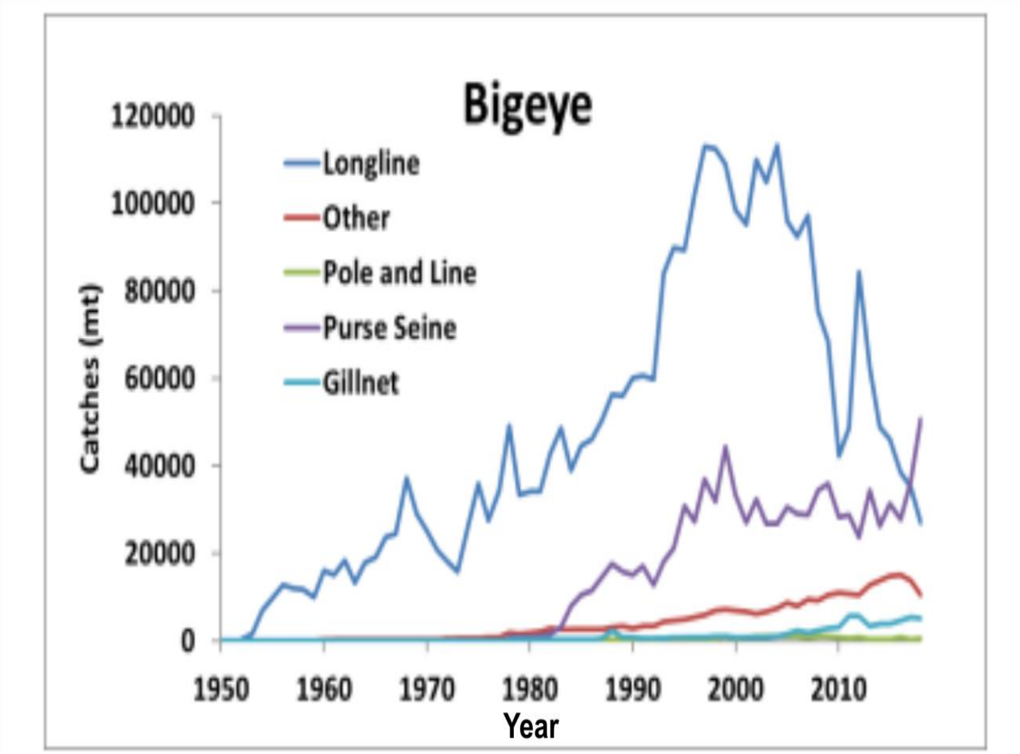


Figure 8. **Indian Ocean bigeye tuna catches by gear type from 1950 – 2018. (Source: ISSF, 2020).**

2.3.4 Albacore tuna (*Thunnus alalunga.* Bonnaterre, 1788)

Albacore is one of the tuna species that inhabits tropical and temperate waters. In the Indian Ocean, the species is found within the range of 5^{o} N and 40^{o} S (ISSF, 2016; Pillai & Satheeshkumar, 2012). The species is highly migratory, swimming in schools for considerably long distances (ISSF, 2016; Pillai & Satheeshkumar, 2012). Unlike the tropical tunas, albacore tuna is not associated with floating objects (ISSF, 2016).

Albacore tuna are mainly caught using longline. Free swimming schools are also harvested using purse seiners. Catches of albacore in the IOTC area have increased significantly since 2007 (IOTC, 2018; IOTC, 2020). It is estimated that some 38,347 Mt of albacore were harvested in the IOTC area in 2017 against the MSY range of 33,900 Mt to 43,600 Mt (IOTC, 2018). The average catch between 2013 to 2017 was estimated at 36,004 Mt, against MSY of 38,800 Mt indicating that the albacore stock is fished within allowable catches (IOTC, 2018) (Fig. 9).

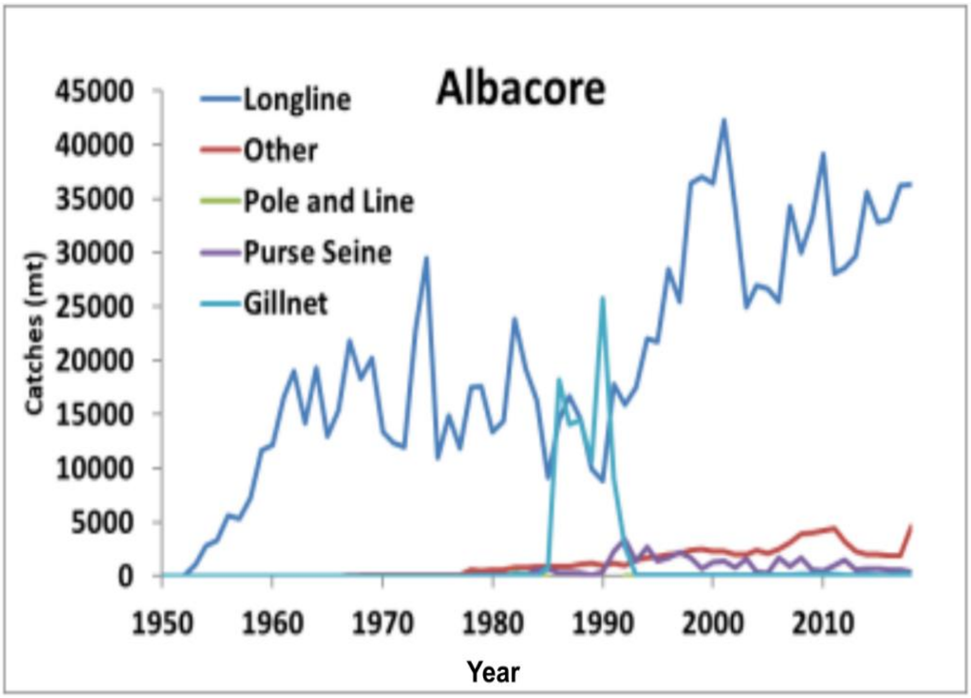


Figure 9. **Indian Ocean albacore tuna catches by gear type from 1950 – 2018. (Source: ISSF, 2020).**

IOTC acknowledged that limited data and biological information of the species exists and hence uncertainty of the assessment hence recommends precautionary approach in the harvesting of albacore tuna and limiting catch at MSY (IOTC, 2018).

2.3.5 Kawakawa (*Euthynnus affinis.* Cantor, 1849)

Kawakawa is one of the tropical neritic tunas that inhabits nearshore areas, sometimes is found in the open waters. The species is highly migratory and forms schools usually based on the sizes with other tunas in the range of 100 to over 5000 individuals (Fishbase, 2019; Pilai & Satheeshkumar, 2012). Kawakawa is commonly found in association with other tunas including yellowfin, frigate and skipjack tunas.

The fishing of kawakawa is mainly by gillnets, trolling and handlines (IOTC, 2018), many of them also caught using purse seines. Other gears used to harvest kawakawa in the Indian Ocean waters include, ringnet, hook & line, fish traps, pole & line (Al-Kiyumi *et al.*, 2013). In the IOTC area, some 128,042 Mt were landed in 2019 with an average of 148,084 Mt for the period 2015 – 2019 against the MSY of 148, 825 Mt (IOTC, 2020) (Fig. 10).

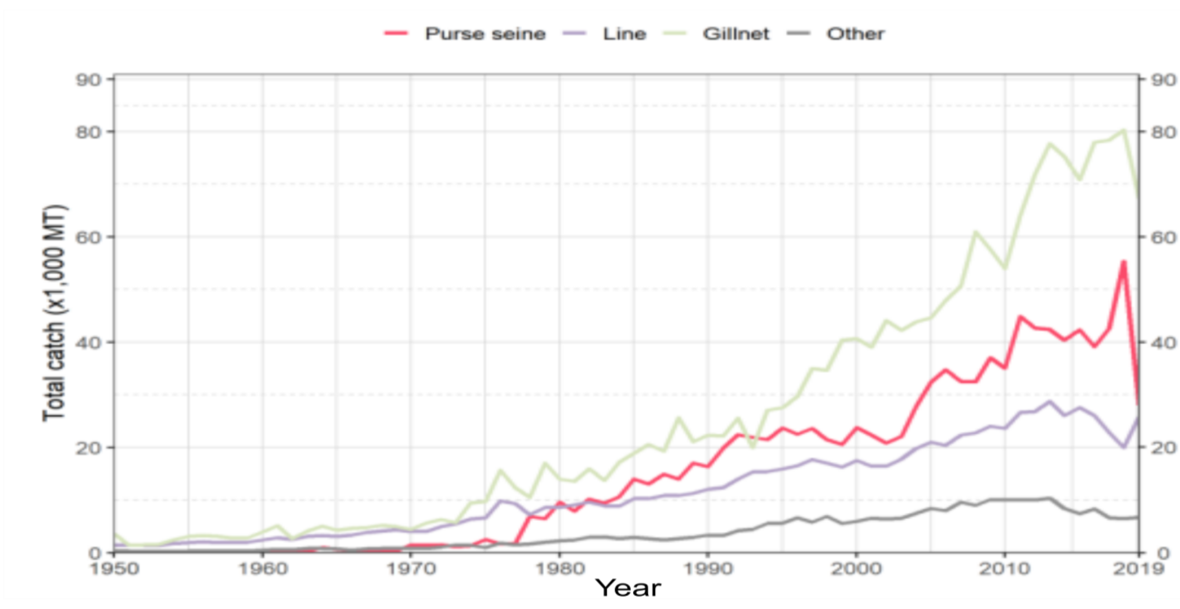


Figure 10. Indian Ocean kawakawa catches by gear type from 1950 – 2019. (Source: IOTC, 2020)

The IOTC (2020) indicated that kawakawa stock in the Indian Ocean area of competence has not been overfished although the estimate of total catch and stock structure is uncertain. The landing for the last 11 years have exceeded the MSY and measures should be put in place to reduce fishing pressure.

2.3.6 Swordfish (*Xiphias gladius*. Linnaeus, 1758)

Swordfish occurs within the range of 65^{o} N - 50^{o} S to 180^{o} E (Fishbase, 2019) and is highly migratory fish that is widely distributed widely in temperate and tropical waters (Fishbase, 2019; IOTC, 2017). The species usually is oceanic inhabiting deeper waters though occasionally is found in coastal waters (Fishbase, 2019; IOTC, 2017). In the Indian Ocean area, swordfish is mainly harvested by longliners. The species takes long to mature and is long-lived making it more vulnerable to overfishing though it spawns throughout the year (IOTC, 2017; Fishbase, 2019). The species is prone to overfishing because once the large individuals are harvested, it takes longtime for the stock be replenished resulting to recruitment overfishing. Some studies have shown that large and long-lived fish species are vulnerable to overfishing. Further, the species accumulate more deleterious mutations than small and short-lived individuals (Roland *et al.*, 2020).

The swordfish stock in the Indian Ocean is neither overfished nor subjected to overfishing (IOTC, 2020; IOTC, 2018; FAO, 2007) though catches seem to be on the decline compared to the 1990s levels (Fig. 11). It is estimated that 32,671 Mt of swordfish were harvested in 2019 with an average of 31,712 Mt for the period 2015 – 2019 against the MSY of 33,000 Mt (IOTC, 2020).

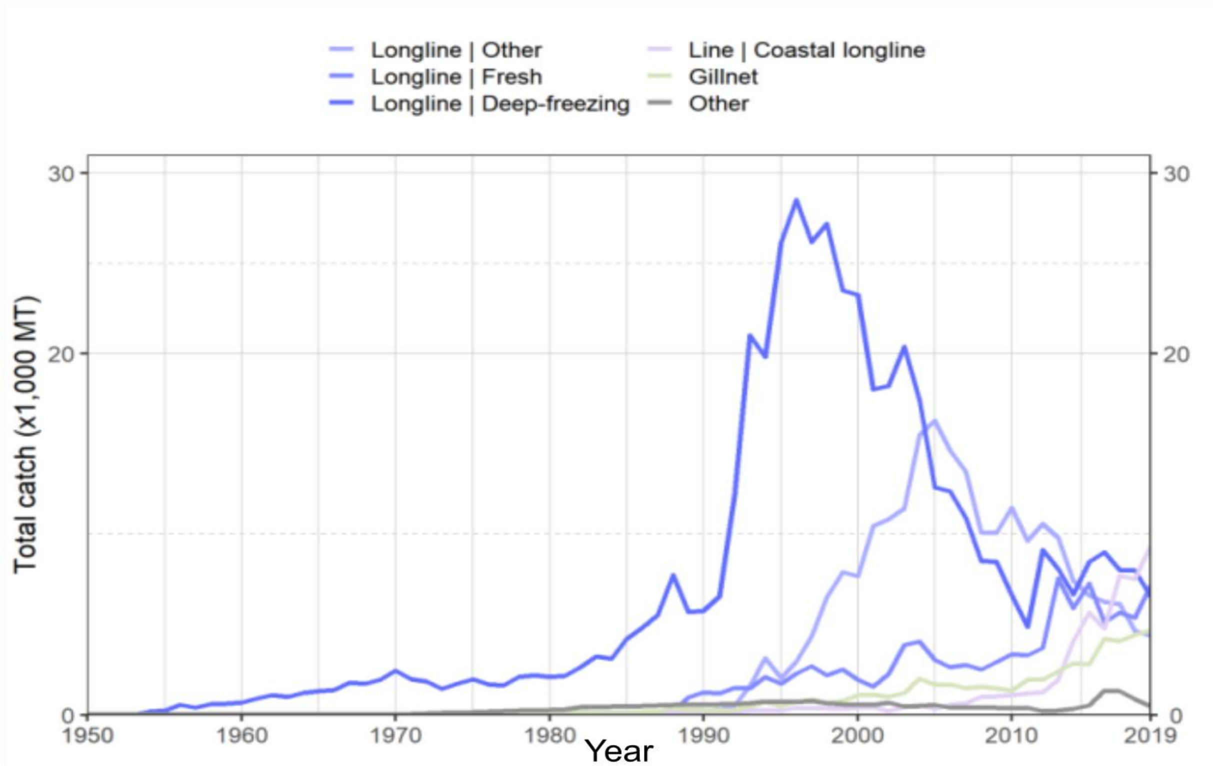


Figure 11. **Indian Ocean swordfish catches by gear type from 1950 – 2019 (Source: IOTC, 2020)**

2.4 The State of Knowledge and Study of Tunas in Kenya and the Indian Ocean Region

Tunas are highly migratory species and effective management requires good understanding of their abundance and distribution. Tuna and tuna-like species belong to the family of Scombridae which has some 54 species representing 15 genera (Fishbase, 2019). Tunas occur in the tropical and temperate waters within 45^{o} North and South of the Equator.

Several studies on tuna and tuna-like fisheries have been undertaken across the world including the Indian Ocean region. The scientific committee of the IOTC spearheads periodic assessment of tuna and tuna-like fish stocks in the Indian Ocean. However, biological data for most of the tunas is inadequate; catch-effort data is limited, incomplete or not available and length-frequency data is poor (IOTC, 2020). Tunas are important fisheries in in coastal states. For instance, 2014, neritic tuna accounted for 68% of the tuna catches landed in the Northwest region of India (Rohit *et al.*, 2015). Kawakawa (*Euthynnus affinis)* and longtail tuna *(Thunnus tonggol)* are dominant catches among the neritic tunas. Longtail tuna occur all year round with maximum landing reported in the months of October and November. The size ranges seem to follow the same trend, with largest in the post monsoon month. Rohit *et al.* (2015) established that longtail tuna stock in the coastal waters of India was in health state.

Itano (2000) studied the reproduction and biology of yellowfin tuna (*Thunnus albacares*) in Hawaii as well as the Western Tropical Pacific Ocean waters, and established that the length at first maturity for females ranged from 108 – 112.5 cm. Kar *et al*. (2012) studied the aspects of growth and parameters related to the population of yellowfin tuna in the Andaman and Nicobar waters in India, the results indicated the fishery was experiencing high fishing mortality rates (0.83/year). Natural mortality and exploitation rates were approximately 0.5/year and 0.62/year, respectively. Suman *et al*. (2013) established that the exploitation of kawakawa fishery in the Indian Ocean at the Western part of Sumatera Island in Indonesia was unsustainable and recommended a reduction of fishing effort by 30%.

In 2004, a regional tuna tagging programme was conducted by IOTC in the Indian Ocean, including Mozambique, Tanzania and Kenya (IOTC, 2004). More than 200,000 tunas were tagged and released, some 31,500 tags (15.7%) were recovered. IOTC (2010) reported that some 78,326 and 54,687 individuals of skipjack and yellowfin tunas were tagged in the SWIO region including Kenya, Seychelles, Tanzania and Mozambique waters. A total of 12631 (16.1%) of skipjack tuna were, recovered mostly (over 90%) by the Seychelles and European purse seine vessels fishing within the IOTC area of competence. About 9,739 individuals of yellowfin tuna tagged were recovered (17.8%) and most (over 90%) of them by the purse seine fishing vessels flagged to the European member states and Seychelles (IOTC, 2012; Pillai & Satheeshkumar, 2012). The study generated valuable data which was used to inform stock assessment for yellowfin tuna and skipjack tuna in 2007 and 2011, respectively (Murua *et al.*, 2015; IOTC, 2015). The tagging study provided some insights on the status, population characteristics, biological aspects and the distribution of the principal three tuna species studied, namely, yellowfin, bigeye and skipjack. For instance, some fish that was tagged in the United Republic of Tanzania were retrieved in Indonesia, the Arabian sea and the South Atlantic (Murua *et al.*, 2015; Hallier & Fonteneau, 2012). Further, the results suggested that there was one yellowfin tuna stock in the Indian Ocean (IOTC, 2012).

The review of scientific information and research on fisheries reveals paucity of data and limited studies on tunas in Kenya. Most of the studies have extensively covered non-tuna species, namely the reef-based fisheries and small pelagics (Fondo *et al*, 2014), and recently medium-to-large pelagics (KMFRI, 2018). Ndegwa & Macharia (2015) studied spatial and temporal distribution of Kingfish (*Scomberomorus commerson*) catches in Kenya from artisanal fishers. The catch rates depicted seasonal variations, with lowest being in May and highest in March. A rapid fact finding mission conducted by the State Department of Fisheries and WWF in 2012 confirmed the occurrence of considerable quantities of tuna catches from artisanal fishers in Kenya (Kimakwa & Kabubu, 2012).

Ndegwa and Okemwa (2017) conducted a land-based survey for six months at Vanga, Gazi and Takaungu to inform the development of the ring net fishery. The growth parameters, mortality estimates, selection analysis, yield models and species-gear-site combinations were determined for some of the pelagic species, including *Sphyraena jello, S. flavicauda, S. obtusata, Hemiramphus* and *Rastrelliger kanagurta*. The results showed fairly low fish catch rates (CPUE) for the different gears, namely; Ring net: 296.5 ± 38.3 kg/vessel^{-1}day^{-1}; Seine (Reef): 55.1 ± 7.7 kg/vessel^{-1} day^{-1} and varied significantly ($p < 0.05$) among the different fishing grounds. The study also established fishing mortality rates and MSY for these species. The results of the study indicated that *Sphyraena jello* and *S. obtusata* were overfished and efforts should be directed to reduce fishing pressure (Munga *et al.*, 2016). No assessment was done specifically for the tunas.

KMFRI, as part of their routine research work, recently monitored the landings of tunas from two (2) Kenya flagged longliners and also did some hydro-acoustic surveys in the EEZ off in Lamu, Kwale and Kilifi counties (KMFRI, 2018). The results from the acoustic surveys indicate that the Kenya EEZ had some significant fish biomass of about 2.2 Million Mt with an estimated value of Ksh 134 billion at an exploitation rate of 20% (KMFRI, 2018). This probably maybe a confirmation of previous estimates which indicated that Kenya has the potential of 150,000 – 300, 000 Mt of fish annually from its EEZ (Hoof & Steins, 2017; KMFRI, 2018). However, the target strength from the acoustic surveys for marine fish species in Kenya waters is yet to be determined to enable accurate estimation, and therefore the fish biomass estimates need some ground truthing (Njiru *et al.*, 2021).

2.5 The Contribution of Tunas to the Economy

The fisheries sector plays an important role in the national economy for many countries. The sector contributes to foreign exchange earnings, revenue, income to the local communities, food and nutritional security. World Bank (2004) reported that fisheries contribute over 3-13% of the Gross Domestic Products (GDP) to maritime countries. In Kenya, for instance the sector contributes about 0.5% to the GDP (KMFRI, 2018; Hoof & Steins, 2017) and 8 - 20% in Seychelles (Republic of Seychelles, 2017). Some 50 million people globally are involved in the marine fisheries sector out of which 95% are from developing countries (World Bank, 2004). FAO (2018) reported that some 60 million people globally are directly employed in the capture fisheries sub-sector. The State Department of Fisheries and Blue Economy (2016) reported that the fisheries sector in Kenya offered source of livelihood and income to approximately 1.1 million people, both directly and indirectly.

The demand for seafood in the world has steadily increased in the last ten years and this trend will continue in order to meet the food needs for about 9 billion people by the year 2050 (FAO, 2018). The demand for seafood was 91.3 Mt in 1997 and was expected to increase to about 127.8 Mt in 2020 (Delgado *et al*., 2003). It is estimated that over 80% of the fish produced globally is used for feeding 3.2 billion people globally who rely on seafood (FAO, 2018).

Fisheries are the most traded products worldwide and developing countries are increasingly playing a big role. Seafood exports from developing countries rose from US$ 3.7 billion in 1980 to some US$ 18 billion in 2000 (World Bank, 2004). In 2016, total exports in fish and fisheries products were valued at about US$ 143billion (FAO, 2018). In 2017, global tuna exports were 1.6

Million Mt with Thailand contributing the largest share of some 483,000 Mt. Seychelles and Mauritius contributed some 59,547 Mt and 67,104 Mt, respectively, to the tuna exports in 2017, exporting mainly to the European Union (Lallemand, 2019).

Fishing in Kenya is mainly artisanal using gill nets, traps, handlines and beach seines. The results of the Kenya marine frame survey (Fisheries Department, 2012) show that fishing effort in the coastal/marine waters is rapidly increasing. The number of fishers for instance increased from 9,017 in 2004 to about 13,417 in 2016, representing a 48.8 % increase over a span of 12 years (State Department of Fisheries, 2016). The number of crafts reduced slightly from of 3,090 in 2012 to 2, 9174 in 2016 (State Department of Fisheries, 2016).

2.6 The Governance and Management of Tunas from Global to Local Perspectives in Kenya

There are over 20 stocks of some Seven (7) principal commercial tunas globally that are under the management of Regional Fisheries Management Organizations (RFMOs) (FAO, 2018). The UN Convention on the Law of the Sea of 1982 (UNCLOS) was the first of its kind to establish a comprehensive global legislative framework for orderly governance and improved management of living resources in the marine environment, including fisheries. Maritime zones were established by UNCLOS, namely the 12 nautical mile territorial waters and the 200 nautical mile Exclusive Economic Zone (EEZ). The coastal states, Kenya included, have sovereign rights to access, explore, exploit, conserve and manage the living resources in their respective EEZ

(UNCLOS, 2010). The coastal states have the power to exercise their sovereign rights to conserve and implement measures including enforcement and regional cooperation through regional and international frameworks like the IOTC.

The United Nations Fish Stocks Agreement (1995) operationalized UNCLOS that facilitated the creation of mechanisms and frameworks at regional level for effective conservation and management of highly migratory and shared fish stocks (AU-IBAR & WWF, 2013). The coastal states and non-coastal states whose citizen engage in fishing operations in the region cooperate and collaborate directly and or indirectly through appropriate international organizations with a view to ensuring conservation and promoting the objective of optimum utilization of such species, both within and beyond the Exclusive Economic Zone of the respective countries. There are currently Five Regional Tuna Fisheries Management Organizations (RFMOs), namely; the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Western and Central Pacific Fisheries Commission (WCPFC), the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) and the Indian Ocean Tuna Commission (IOTC) (FAO, 2018).

In the Indian Ocean region, the management of tunas is under the Indian Ocean Tuna Commission (IOTC), a body that was established in 1996 by Food and Agriculture Organization of the United Nations under Article XIV (FAO, 2018). The IOTC provides a regional framework and coordination mechanism for the management of tunas in the Indian Ocean region delineated as FAO statistical areas 51 and 57 and the adjacent waters (FAO, 2018). By February 2021, IOTC had 31 members (contracting parties) comprising of coastal states, Distant Water Fishing Nations

(DWFN) or flag states, and the market states. Kenya joined IOTC in 2004. There are two Cooperating Non-Contracting Parties (https://www.iotc.org/about-iotc/structure-commission)

The Scientific Committee of the IOTC and other working parties periodically assess the performance and status of the tunas in the Indian Ocean (IOTC, 2016). Some concerns on the catches of yellowfin tuna were raised by the 19th Session of the IOTC Scientific Committee (IOTC, 2016). The average catch for yellowfin tuna for the period 2011 to 2015 (estimated at 390,186 Mt) was below the MSY estimated at 422,000 Mt (IOTC, 2016). This prompted the IOTC during their 20th Session held in La Reunion in 2016, to adopt a resolution on an interim rebuilding plan for the yellowfin tuna stock that was effected on the 1st of January 2017 (IOTC, 2016). IOTC member states have not been complying effectively with the tuna management and conservation measures that they adopt. This led to IOTC performance reviews in 2009 and 2015 which came up with a raft of measures for improving the effectiveness of IOTC in meeting its mandate (IOTC, 2015). However, the tuna stocks under the IOTC management are still facing some challenges. For instance, the harvesting of skipjack tuna in 2018 were 29% above the set catch limits, bigeye tuna catches in 2018 were 3% higher compared to 2017 levels while yellowfin catches declined by some 29% compared to 2004 estimates.

Marine fisheries resources in Kenya are managed and governed by relevant national, regional and global policy and legislative institutional frameworks. The Constitution of Kenya is the supreme law that lays the foundation for the management of natural resources in the country (Republic of Kenya, 2010). Article 69 of the constitution of Kenya provides the basis for the government to ensure that the environment and natural resources therein in are utilized and managed in a sustainable manner while at the same time considering equity in sharing of benefits. The Fisheries Management and Development Act (2016) (Republic of Kenya, 2016) which replaced the

Fisheries Act Cap 378 of 1991 is the principal law guiding the fisheries sector in Kenya, supported by the Fisheries (General) Regulations, 1991 (CAP 378), Fisheries (Foreign Fishing Craft) Regulations, 1991, Fisheries (Foreign Fishing Craft) Regulations, 1991, the Maritime Zone Act 1989 (Cap 371) and the Wildlife (Conservation and Management) Act (2013). New fisheries regulations are being drafted. The Fisheries (Beach Management Unit) Regulations, 2007 have been revised.

The Fisheries Management and Development Act (2016) is the legislative framework that guides the fisheries sector to ensure that fisheries resources are utilized, conserved, managed and developed sustainably in Kenya. The National Oceans and Fisheries Policy of 2008 (now under revision) provides a coordinated framework that addresses the challenges that face the fisheries sector in Kenya aligned with Vision 2030. The Kenya's Tuna Fisheries Development and Management Strategy (2013-2018) main goal is to aid the country in developing and managing tuna resources in a more sustainable way to profitably contribute to the blue growth pathways. This is to help the country enhance the contribution of the fisheries sector in the economy and securing the livelihood of the local fishing communities.

The Kenya Fisheries Service (KeFS) has the national mandate to manage the fisheries resources in the country. The State Department of Fisheries, Aquaculture and Blue Economy (SDF&B) provide policy guidance by working closely with the parent Ministry of Agriculture, Livestock, Fisheries and Cooperatives. Fisheries research to inform policy and decision making for improved management of fisheries resources is undertaken by the KMFRI.

Lack of accurate and reliable data to help in formulating sustainable tuna fisheries management policy and legislation in Kenya and the entire Indian Ocean region remains a challenge (IOTC, 2017). Rapid increase in the catches of tunas in the Indian Ocean has been experienced in the last four decades (IOTC, 2017). Poor quality and unreliable data undermines tuna stock assessments, and consequently resulting to ineffective measure to conserve and manage tunas in Kenya and the Indian Ocean region. The data and information generated by this study certainly will contribute to the scientific knowledge about tunas, including catch and effort, size frequency distribution, growth and biological parameters, mortality rates, seasonal and temporal distributions which are critical ingredients for stock assessment to inform policy. The indices generated by this study, namely CPUE, size frequency distribution, mortality and exploitation rates can form the baseline to aid monitoring of coastal tuna and tuna-like fisheries in order to detect any changes in their stocks.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Study sites

The study was conducted in coastal Kenya (Fig. 12). Fish samples were collected from the catches of artisanal fishers monthly from August 2015 to December 2016 from five landing sites; Amu (Lamu), Old Town (Mombasa), Mnarani (Kilifi), Shella (Malindi) and Watamu (Watamu).

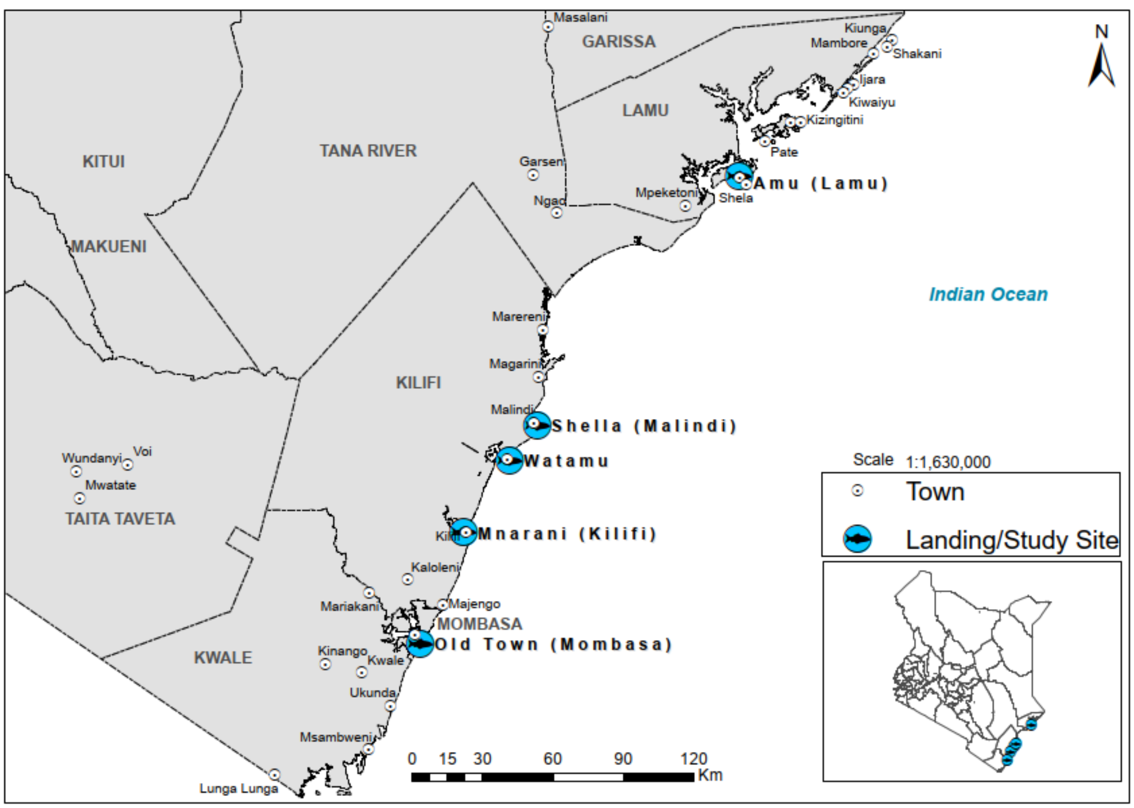


Figure 12. Study sites (Fish landing sites) along the Kenya Coast

3.1.2 Characterization of the Study Area

Fishing in the study area is influenced by coastal climatic and oceanographic conditions brought about by the reversing monsoons, the Northeast Monsoon (NEM) and the Southeast Monsoon (SEM) winds (KMFRI, 2018., Chassot *et al.*, 2019). The NEM occur between November and mid-March, mid-March to the end of March as a transition period and the Southeast Monsoon (SEM) between April and mid- September with transition period mid-September to mid- November (Government of Kenya, 2017). The two seasons are locally referred to as *Kazi kazi* and *kusi*, respectively. The sea is usually calm during the NEM as opposed to SEM when it is rough. The oceanographic conditions of the sea affect the fishing operations, especially that of artisanal fishers who employ simple fishing vessels and gears and fish within the nearshore.

3.1.3 The choice of the study sites

The objectives and purpose of this study as well as the degree of representativeness of the target population in the sample guided the selection of the sites for this research. To arrive at this, some preliminary survey and scoping work was undertaken to have some insights on fish landing sites, the structure of the fishing vessels and the species composition of the catch landed. This was further informed by reviewing the relevant literature, fisheries related reports including the frame surveys report of 2014 (State Department of Fisheries, 2014). The frame survey report provided useful information on the type of fishing gears that were deployed by the artisanal fishers, the different species that were being targeted, and their spatial distribution as well as the landing sites along the Kenya coastline. According to the Frame Survey report of 2014, there were about 197 fish landing sites at the Kenyan coast in that year (State Department of Fisheries, 2014; KMFRI,

2018) though tuna/tuna-like species are landed in only a few of them. The artisanal fishery frame survey report (2014 reported that there are 262 artisanal longline fishers at the Kenyan Coast of which 4% and 5% of them targeted tuna and kingfish, respectively. The report indicated that Kilifi, Mombasa and Lamu were important areas where fishers employed longline fishing targeting large pelagics including tunas and sharks. The annual fisheries statistical bulletin 2013 published by the State Department of Fisheries indicated that significant amounts of pelagics including tunas were landed in Lamu, Mombasa and Kilifi.

Some informal interactions and consultations with the staff from KMFRI, the Kenya Fisheries Service (KeFS), local Beach Management Units (BMU) Leaders, local fishers, local NGOs and CSO working on marine fisheries related issues on the ground provided invaluable information on the local situation, fishing dynamics and the fishery.

Last but not least, a number of other factors including accessibility to the sites, safety and security while in the field played some role in the selection of the sampling sites.

It was on this basis that the study sites, namely, Amu (Lamu), Mnarani (Kilifi), Shella (Malindi) and Watamu (Watamu) were selected. However, security became an issue in Lamu and had to discontinue sampling in Amu in April 2016, and instead started sampling in Mnarani in Kilifi County that very month. This was to ensure that the number of sampling sites were maintained and representative of tuna landings. Further information on the security situation can be found on the following links; https://www.nation.co.ke/counties/lamu/Shabaab-attacks-rise-Lamu/3444912-4272008-15bghb9z/index.html,https://www.youtube.com/watch?v=9w-OuY8tT3s, https://youtu.be/SSeL6LPpPoc, https://youtu.be/8Zkzt5q8lkA

3.2 Research Approach and Development of Data Collection Tools

The study employed a three-pronged research approach which entailed literature review, biological sampling and interviews. Desk top study, literature review and interviews were employed to address objective four which related to the evaluation of the contribution of science to inform policy and decision making for improved tuna fisheries governance. A questionnaire guide (Appendix 1) was developed and administered to the various respondents, including fisheries managers, scientists, policy makers and local fishing communities. Informal consultations and focused group interviews were also undertaken to compliment secondary data/information. A biological sampling form that was adapted from IOTC format was used to collect the data (Appendix 2). Various length measurements for the tuna and tuna-like species were undertaken (Appendices 3 & 4). Collecting of biological parameters including length and weight measurements of the tunas were made possible through sampling of key artisanal tuna fish catches at the fish landing sites.

Field reconnaissance studies and interviews were undertaken for ground truthing which helped to confirm the study areas and sampling sites. In addition, this was necessary to confirm the various fisheries management interventions on the ground/practice as provided for in the national fisheries policy and legislation as well as management plan, with specific reference to the tunas.

3.3 Study Design and Sampling Procedure

3.3.1 Biological sampling

Fish samples were collected from the catches of artisanal fishers, operating mainly longlines, trolling lines and handlines. The boat was the Primary Sampling Unit (PSU) and the fishing trip was the Secondary Sampling Unit (SSU) while the fish catch was the Tertiary Sampling Unit (TSU). Effort was made to maintain the same fishing landing sites, fishers, fishing gears, methods and timing throughout the sampling period. In order to minimize variations in the population samples, this standardized sampling approach was undertaken. Fish samples were collected on a monthly basis for 17 months to determine trends, patterns and temporal variations. It was necessary to collect samples for over a period of 12 months in order to minimize inter-annual variability. Samples were collected at least 10 days in each month, consecutively.

3.3.2 Literature review

Desktop study and literature review was done, including relevant reports, strategic and policy documents and scientific publications by the Kenya Fisheries Service, KMFRI, University of Nairobi Library, online access of various journals, FAO, IOTC, International Sustainable Seafood Foundation (ISSF). Historical catch data for foreign licensed longline fishing vessels in the Kenya EEZ was obtained from the Kenya Fisheries Service (KeFS) Headquarters in Nairobi. Data was also obtained from the IOTC and FAO databases/ websites.

3.3.3 Interviews

These were done through email correspondences, telephone and physical interviews with the target audience who included fisheries managers, fisheries scientist and experts as well as fisherfolk from relevant fisheries management and research organizations including KMFRI, KeFS, universities, fisher associations, fishing industry as well as Non-Governmental Organizations (NGOs)/Civil Society Organizations (CSOs).

3.3.4 Field observations

Field visits were conducted to the landing sites, fish markets, fishing boats and relevant government offices where observation of different fisheries related activities including fishing operations, law enforcement and licensing were noted.

3.4 Details on the Methodology

The specific details on the methodology for each of the study objectives are provided in the corresponding chapters, Four (4), Five (5), Six (6) and Seven (7).

CHAPTER FOUR

4.0 TRENDS IN TUNA FISH CATCH RATES IN KENYA MARINE WATERS

4.1 Introduction

Fishery resources are dynamic and understanding about the fishing effort and knowledge of fish stock is critical to sustainable management and development of at least some of the fisheries resources on the long-term. Consistent collection of catch and fishing effort data and periodically analyzing it provides pertinent information on fish stocks health as well as effectiveness of management measures.

In this chapter, the focus is on objective one (1) of the study, i.e determining catch rates and trends for both artisanal and offshore (EEZ) tunas in the Kenyan waters. Catch Per Unit Effort (CPUE) is usually used as a proxy index for abundance of a given fishery on temporal and spatial scale (Kaplan *et al.,* 2014; Worm & Tittensor, 2011; Myers &Worm, 2003). CPUE is defined as the weight of fish landed per unit of fishing effort deployed to catch it (Harley *et al*., 2001). In the application of CPUE, the assumption here is that the changes in CPUE is a reflection on the changes in the status and health of the respective fish stock, the individuals of fish in the population have the same behavour, the population of fish stock is homogeneous (evenly distributed in the same area) and that fleets have full access to all the fishing grounds (Arreguín-Sánchez 1996).

4.2 Materials and Methods

4.2.1 Data collection and sampling for artisanal tunas

Fish samples were collected from the catch landed by artisanal fishers in Amu (Lamu), Shella (Malindi), Watamu (Watamu), Mnarani (Kilifi) and Old Town (Mombasa). The sampled fish were sorted accordingly and using various identification guides/keys were identified to the lowest taxa. The identification guides were by Lieske & Myers (2001), Anam & Mostard (2012), Richmond (eds) (1997), Smith & Heemstra (1995), Regional Tuna Tagging Project in the Indian Ocean (RTTP-IO) (2004), Itano (2005), IOTC (2013), World Register for Marine Species (WoRMs, 2016) and Fishbase. Individual fish was weighed using a weighing scale (electronic) to the nearest Kilogram (Kg). The Fork Length (FL), the Lower Jaw Fork Length (LJFL) for swordfish as well as the Total Length (TL) of the individual fish were measured to the nearest whole centimeter (cm) using a flexible tape measure (Appendices 3 & 4). The fishing gear type, the fishing vessel, the number of fishing crew per boat and the price of fish per Kg, the time the fishing trip started and when the fishers landed the catch were recorded in a biological sampling form. The data was then keyed in excel spreadsheet and cleaned of errors before it was subjected to the analyses.

4.2.2 Historical catch data collection for EEZ longline tunas

Historical and time series catch data for tuna and tuna-like fish species in the Kenyan Exclusive Economic Zone (EEZ) was compiled from the Logbooks provided by 24 longliners flagged to Six countries, namely, Seychelles, Taiwan, Mauritius, China, Spain and Oman that declared their catch to the Kenya Fisheries Service (KeFS). The logbooks provided were for the period February 2012

– March 2017 and had the details of the fishing vessel, including the owner of the vessel, name of the vessel, date of entry to the fishing ground, date of departure from fishing ground, name of the species landed, number of pieces of the individual species landed, the total weight of each of the species landed (Kg) as well the by-catch species. The position of the vessel (longitude and latitude) during its fishing trip was also recorded. Biological data including the length, weight and sex of the individuals was not provided for in the logbook entries. The data was then keyed in in excel spreadsheets and cleaned of errors before it was subjected to the analyses. QGIS (v 2.18) was used to plot the distribution of landed weights per species.

4.3 Data Analyses

4.3.1 Trends in artisanal Tuna and Tuna-like species catch rates

Catch Per Unit Effort (CPUE) was calculated for each species in each of the sampling site over the sampling period to establish trends. The nominal Catch Per Unit Effort (CPUE) was calculated by dividing the average total catch (Kg) and the average fishing effort (E) using the formula below:

$$CPUE_t = C_t/E_{t,}$$

Where;

C_t is the mean total catch at time t and $E_{t,}$ is the mean fishing effort deployed at the time t.

The CPUE was expressed as Kg of fish per Trip ($KgTrip^{-1}$) and Kg of Fish per Fisher Per Trip ($KgFisher^{-1}Trip^{-1}$). $KgTrip^{-1}$ refers to the total catch of fish for every fishing trip whereas

$KgFisher^{-1}Trip^{-1}$ refers to the proportion of the catch to the individual fisher for every fishing trip. The data was summarized and used to plot the graphs and charts to give a visual impression of the results. Simple linear regression was performed to show the relationship between fish catches and fishing effort. The assumption here was that all fishers had equal opportunity to catch the fish.

The catch and effort data was analyzed by applying non-parametric and simple descriptive statistical procedures with *Statistica* Software version 7. Spearman Rank Order Correlation analysis was done to establish if there was any significant relationship between fish catches (weight of fish), fishing effort (crew), species, Length (both Total and Fork), months and sites. The relationship between the variables was described as significant at $P < 0.05$.

Multiple Regression analysis was performed to establish the relationship between the dependent and independent variables. The dependent variables were species and fish catches (weight of fish) while independent variables were months, site, boat, fishing gear, fish length, price of fish and the fishing effort (crew). The influence of the independent variables to the dependent variable was described as significant at $P< 0.05$.

Descriptive statistics was undertaken to establish the mean and variability of the fish catches (weight), species of fish sampled, fishing effort (crew) during the sampling period in the different sites. The results of these analysis were presented in graphs, charts and figures.

4.3.2 EEZ Tuna and Tuna-like fish species

Multiple Regression analysis was performed to establish the relationship between the dependent and independent variables. The dependent variables were the catches of the individual tuna and tuna-like species, namely *Katsuwonus pelamis, Thunnus albacares, Thunnus alalunga*, *Thunnus obesus, Xiphias gladius,* Sharks and others (unidentified species). The independent variables were the month of fishing, fishing vessel, location for the vessel (both latitude and longitude). The influence of the independent variables to the dependent variable was described as significant at $P < 0.05$. Descriptive statistics was undertaken to establish the mean and variability of the weight of catch (Kg) for each of the species.

For spatial distribution of catches, QGIS (v 2.18) was used to plot the distribution of landed weights per species. Coordinates of vessels fishing locations were used to generate point shape files that were further colored based on the flag of the country of origin for the vessel and sized proportionally depending on the weight landed to 5 classes whose boundaries are defined by natural jenks. Landings, both weight (kg) and species counts of tuna and tuna-like species aggregated per fished location, per day and per vessel, were analyzed using various multivariate techniques.

4.4 Results

4.4.1 Artisanal tuna fishing gears, effort and catch rates

A total of 31,672 Kg of tunas were caught during the sampling period, with a mean catch rate (CPUE) of 11.62 $KgFisher^{-1}Trip^{-1}$. Fishers deployed different fishing gears to harvest tunas. Main fishing gears encountered in this study were trolling line, handline, longline and gillnet. Trolling was used by most of the fishers to harvest tuna, accounting for 46% of the fisher days and 38% of the total catch sampled. About 30% fisher days were attributed to the handline. Longline accounted for 35% of the catch sampled and 20% of the fisher days. Handline and gillnet accounted for 25% and 2% of the catch sampled, respectively (Fig. 13 & Table 2).

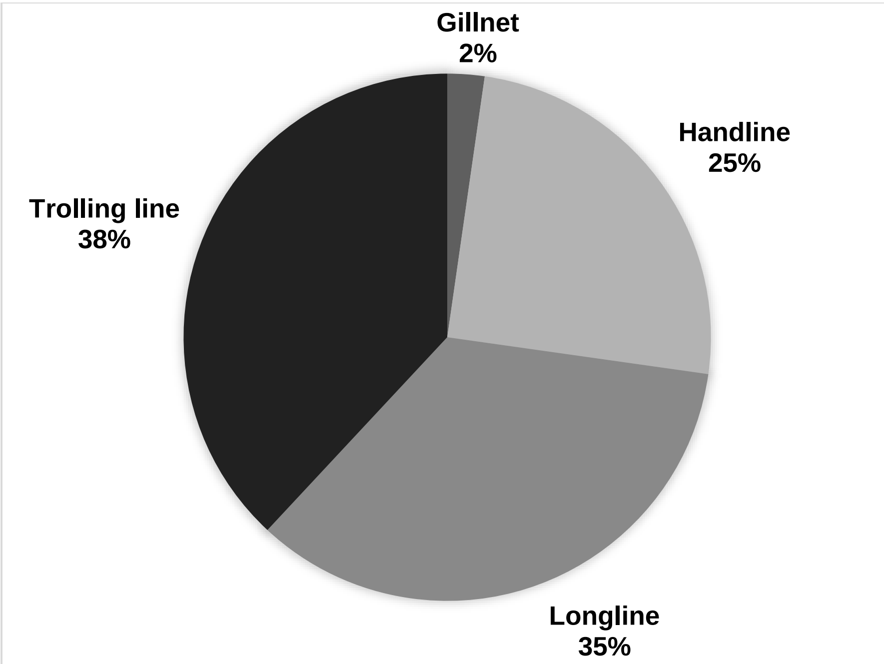


Figure 13. **Proportion of tuna catch rates by gear types.**

Longline recorded the highest catch per fisher, 20.8 $KgFisher^{-1}Trip^{-1}$. Hand line, trolling line and gillnet recorded 11.09 $KgFisher^{-1}Trip^{-1}$,9.5 $KgFisher^{-1}Trip^{-1}$ and 6.4 $KgFisher^{-1}Trip^{-1}$, respectively (Table 2). Longline accounted for 92.9% of the catch sample landed at Old Town. At Watamu, trolling line accounted for 99.5% of the catch sampled. Hand line contributed to 56.6% of the catch sampled at Shella (Malindi). Whereas Mnarani (Kilifi) had all the main fishing gears encountered in this research work, trolling line was responsible for harvesting 87.3% of the fish sampled (Table 2). The results of this study indicate that fishing effort was highly concentrated at Shella and Watamu. A total of 2718 fisher days was recorded in this study with Shella accounting for 33.8% (920 fisher days). Approximately 61.19% of fishers at Shella deployed hand line to catch tunas. Watamu accounted for 25.9% (704) of fisher days, with 99,28% (699) of the fishers deploying trolling line (Table 2).

Table 2. **Artisanal tuna fish catch rates and fishing effort across sites by gear types**

Gears/Site	Sum of Catch ($KgTrip^{-1}$)	Proportion of catch ($KgTrip^{-1}$) per gear per site (%)	Average Catch ($KgFisher^{-1}Trip^{-1}$)	Sum of Fishing Crew (Fisher Days)
Amu				
Gillnet	480	13	26.49	18.0
Handline	3220	87	23.53	142.0
Total	**3700**	**100**	**23.76**	**160.0**
Mnarani				
Gillnet	181	10	2.79	64.0
Handline	15	0.8	2.50	6.0
Longline	31	1.7	7.33	5.0
Trolling line	1570	87.4	6.91	236.0
Total	**1797**	**100**	**6.21**	**311.0**
Old Town				
Handline	828	7.02	9.68	87.0
Longline	10962	92.9	21.12	536.0
Total	**11790**	**100**	**19.17**	**623.0**
Shella				
Gillnet	59	0.9	2.23	29.0
Handline	3807	56.6	7.10	563.0

Gears/Site	Sum of Catch ($KgTrip^{-1}$)	Proportion of catch ($KgTrip^{-1}$) per gear per site (%)	Average Catch ($KgFisher^{-1}Trip^{-1}$)	Sum of Fishing Crew (Fisher Days)
Trolling line	2862	42.5	8.71	328.0
Total	**6728**	**100**	**7.53**	**920.0**
Watamu				
Handline	36	0.5	7.20	5.0
Trolling line	7621	99.5	11.13	699.0
Total	**7657**	**100**	**11.10**	**704.0**
Grand Total	**31672**		**11.62**	**2718.0**

Yellowfin tuna (*Thunnus albacares),* swordfish *(Xiphias gladius)* and kingfish *(Scomberomorus* spp*)* accounted for 40%, 27.7% and 8% of the catch, respectively. Details on gear selectivity and interactions with these three selected fisheries are reported in Chapter Six (6) of this thesis.

4.4.2 Temporal Variations in Tuna Fish Catch Rates

4.4.2.1 Temporal Variation in Mean Catch Rates of Artisanal Tunas

Pooled data for all the tunas sampled shows variation in fish catch rates over the sampling period (Fig. 14).

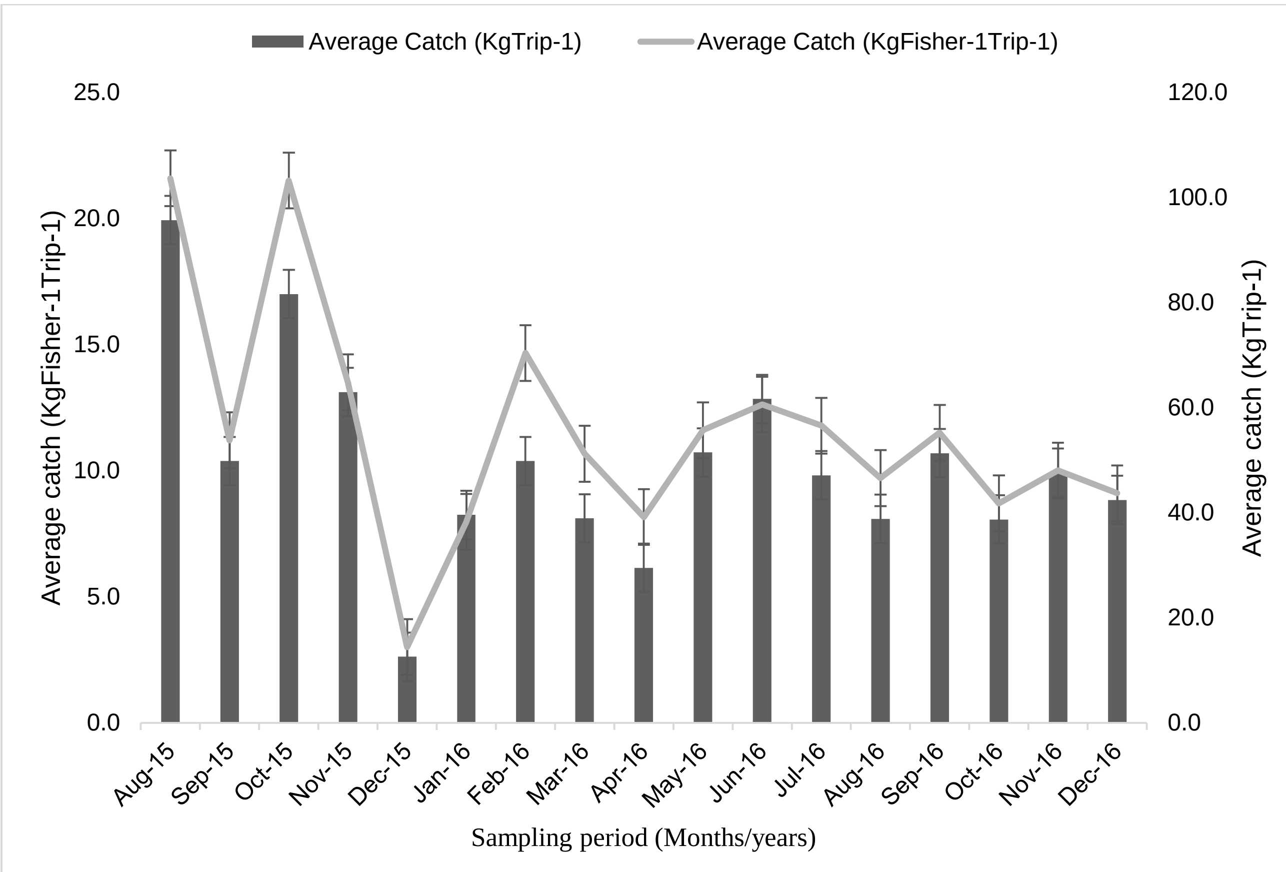


Figure 14. Mean catch rates for the tunas sampled from August 2015 to December 2016.

The months of August – November 2015 and May – November 2015 recorded high catch rates. Relatively low catch rates were reported in the months of December 2015 to April 2016. The month of August 2015 recorded the highest CPUE of 21.6 $KgFisher^{-1}Trip^{-1}$ while December of the same year recorded the lowest, 3.0 $KgFisher^{-1}Trip^{-1}$. The results indicate that most of the tuna and tuna-like fish species were landed during the South East Monsoon (SEM) between May to October.

The mean Catch Per Unit Effort (CPUE) for the six most abundant tuna and tuna-like fish species indicate that there were monthly variations (Fig. 15) with the highest monthly average CPUE being 9.6, 4.23, 3.71, 2.16, 2.08 and 1.29 $KgFisher^{-1}Trip^{-1}$ for *Xiphias gladius*, *Thunnus albacares*, *Scomberomorus* spp, *Katsuwonus pelamis*, *Euthynnus affinis* and *Sarda* spp, respectively.

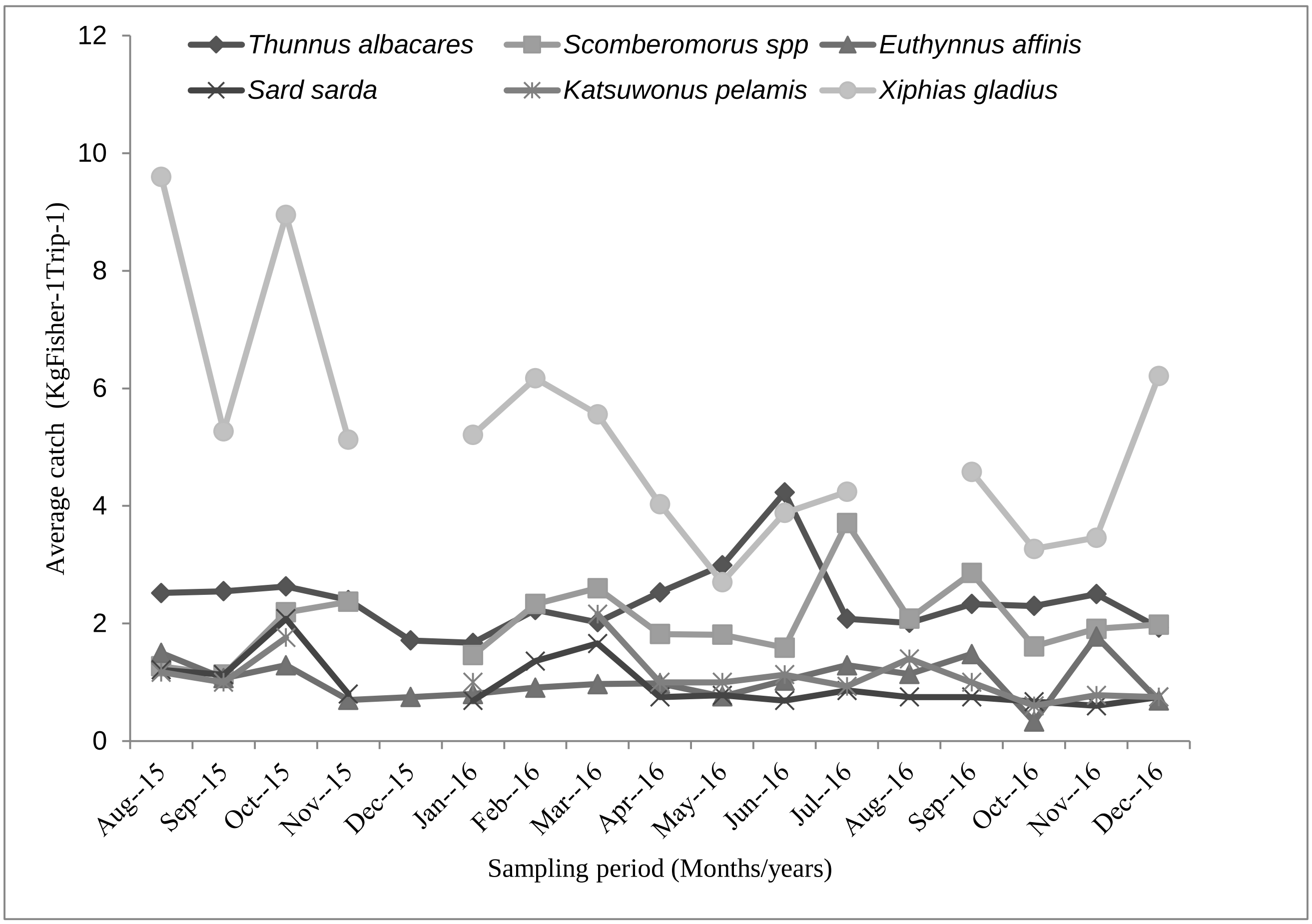


Figure 15. **Monthly catch rates for the six most abundant tuna and tuna-like species caught during the sampling period.**

4.4.2.2 Temporal Variations in EEZ Tuna Catch Rates

Catch rates and composition of the tunas harvested by the 24 longline fleets that declared their catch for the period February 2012 to March 2017 is presented in Fig. 16.

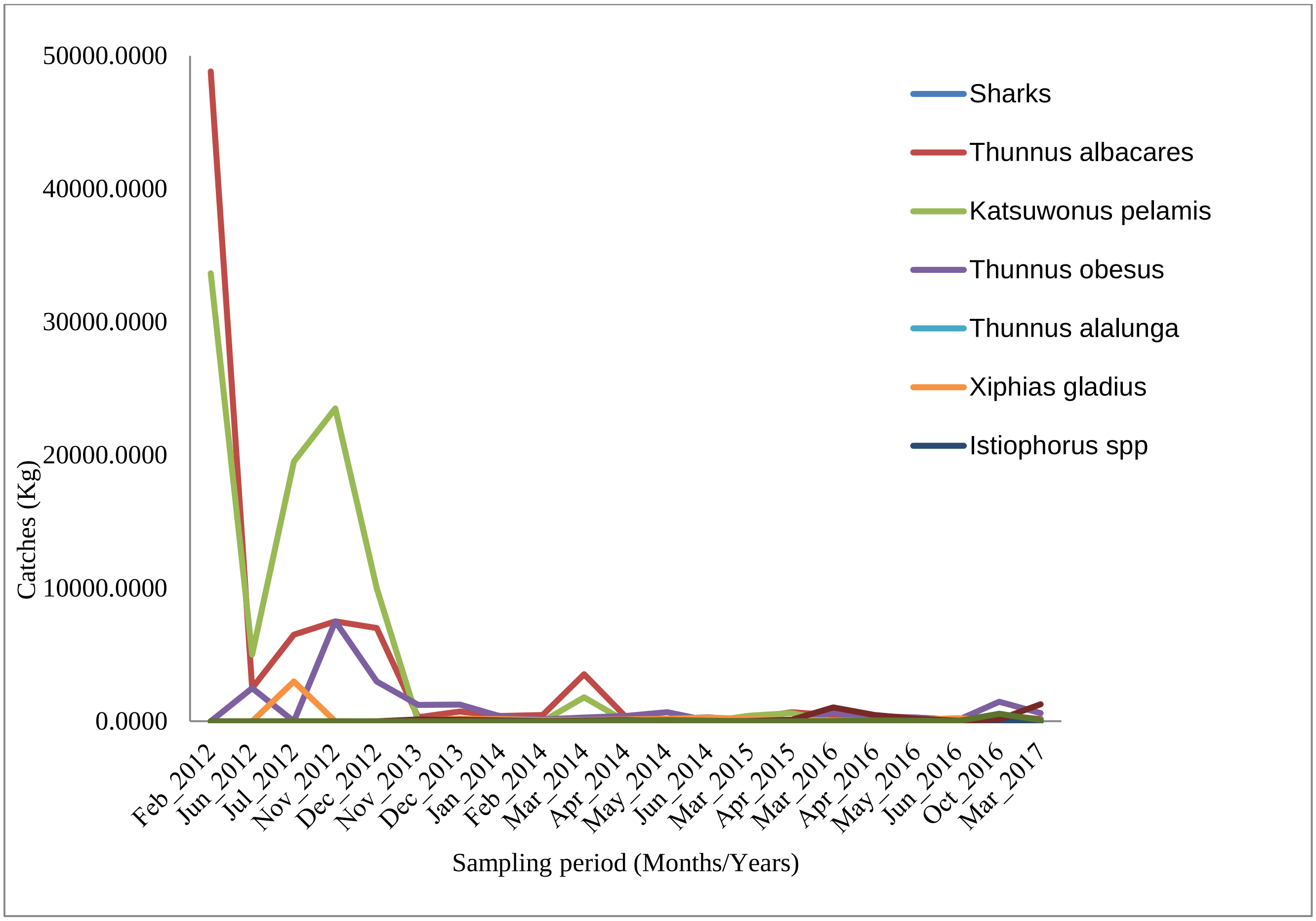


Figure 16. **Catches of tunas harvested in Kenya EEZ by all longline fleet in February 2012 – March 2017.**

Highest catches were reported in the month of February 2012 accounting for 39.7% of the fish harvested. July and November 2012 accounted for 13.95% and 18.5% of the catch. February 2014 and March 2015 reported the lowest catch, accounting for 0.34% and 0.39%, respectively.

It is evident from the results that longline fleets access Kenyan waters for only selected months within a given year depending on the type of license requested and issued to the respective vessel.

Fleet dynamics indicate that 48% of the catch (728,000 Kg) was attributed to Spain and all was harvested in 2012. Two countries, Spain and Seychelles harvested 75% of the catch (Fig. 17).

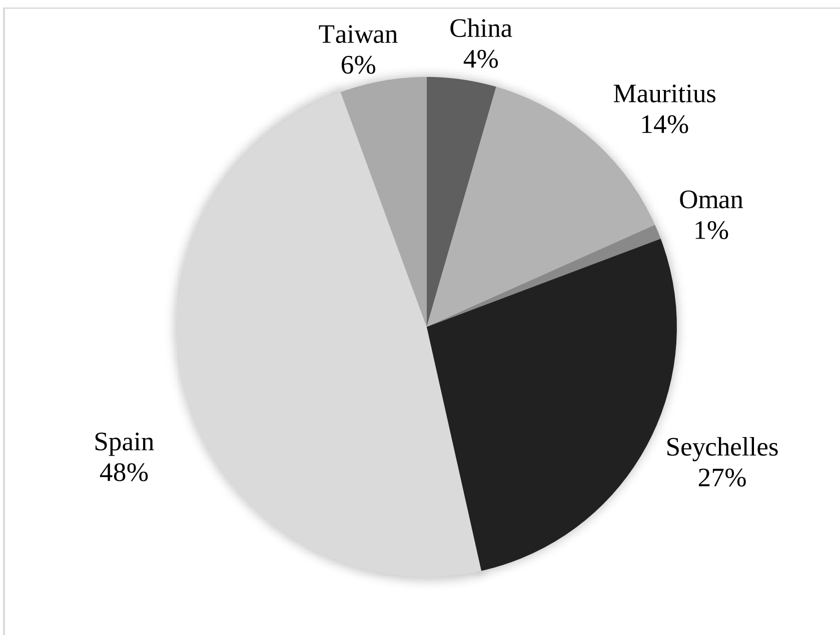


Figure 17. Longline tuna catches (Kg) by flag states.

Catch Per Unit Effort (CPUE) for the 24 tuna longliners flagged to six states licensed to fish in Kenya waters for the period February 2012 – March 2017 that declared catch to the Kenya Fisheries Service is shown in Table 3.

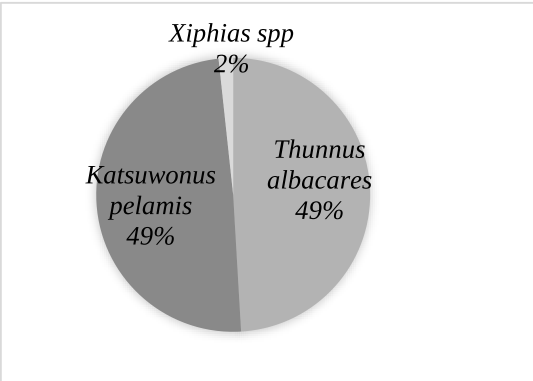
Table 3. **Catch Per Unit Effort (CPUE) by Tuna Longliners licensed to fish in Kenya EEZ for the period February 2012 – March 2017.**

Flag state	Total catch (Kg)	Number of fishing trips	Number of vessels	CPUE - $KgVessel^{-1}Trip^{-1}$
China	68,135	72	5	189.26
Spain	728,000	15	9	5,392.60
Seychelles	413,806	185	6	372.79
Mauritius	210,000	5	1	42,000.00
Taiwan	84,930	32	2	1,327.03
Oman	14,527	11	1	1,320.00
Total	**1519398**	**320**	**24**	**197.80**

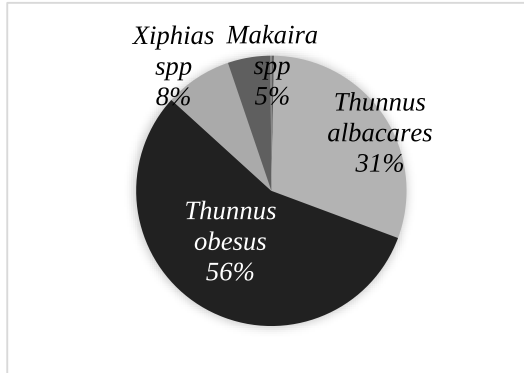
Mauritius and Spain reported high CPUE of 42,000 $KgVessel^{-1}Trip^{-1}$ and 5,392.6 $KgVessel^{-1}Trip^{-1}$, respectively. On average, the results indicate a CPUE of 197.8 $KgVessel^{-1}Trip^{-1}$.

During this study period, a total of 1, 519,398 Kg of the catch was harvested by the fleets.

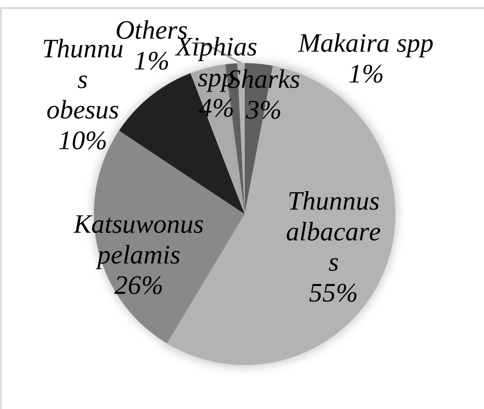
The results of this study suggest that the composition of the tuna catch harvested from the Kenya EEZ varied across the years (Fig. 18).



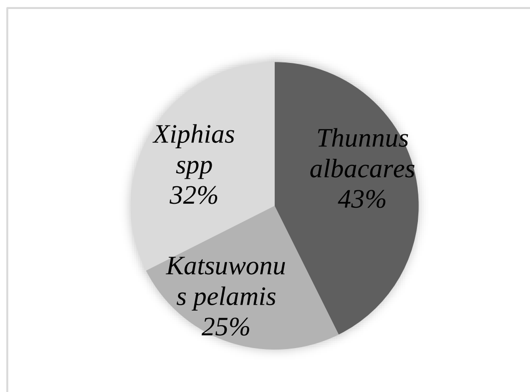
2012



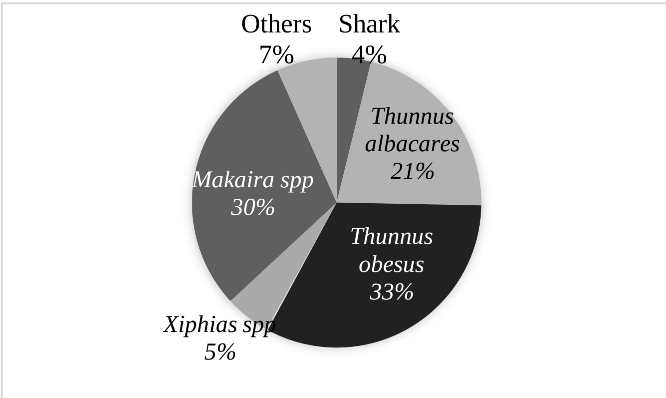
2013



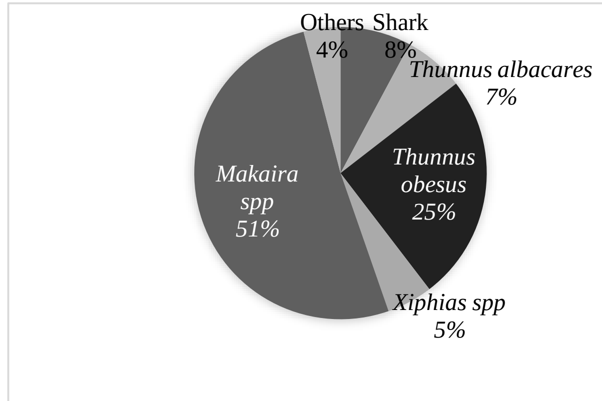
2014



2015



2016



March 2017

Figure 18. Longline tuna catch composition by weight per year from 2012 to 2017.

For instance, in 2012, *Thunnus albacaress* dominated the catch by weight, each contributing 49% of the total catch of tunas landed. In 2013, *Thunnus obesus* and *Thunnus albacares* dominated the catch contributing 56% and 31% of the catch, respectively. *Thunnus obesus*, *Thunnus albacares* and *Makaira* spp were most abundant in 2016.

i) *Thunnus albacares*

The results show that a total of 648,970 kg with mean catch of 1870.23 Kg of *Thunnus albacares* were harvested by the longline fleets that had declared their catch from February 2012 – March 2017 (Fig. 19).

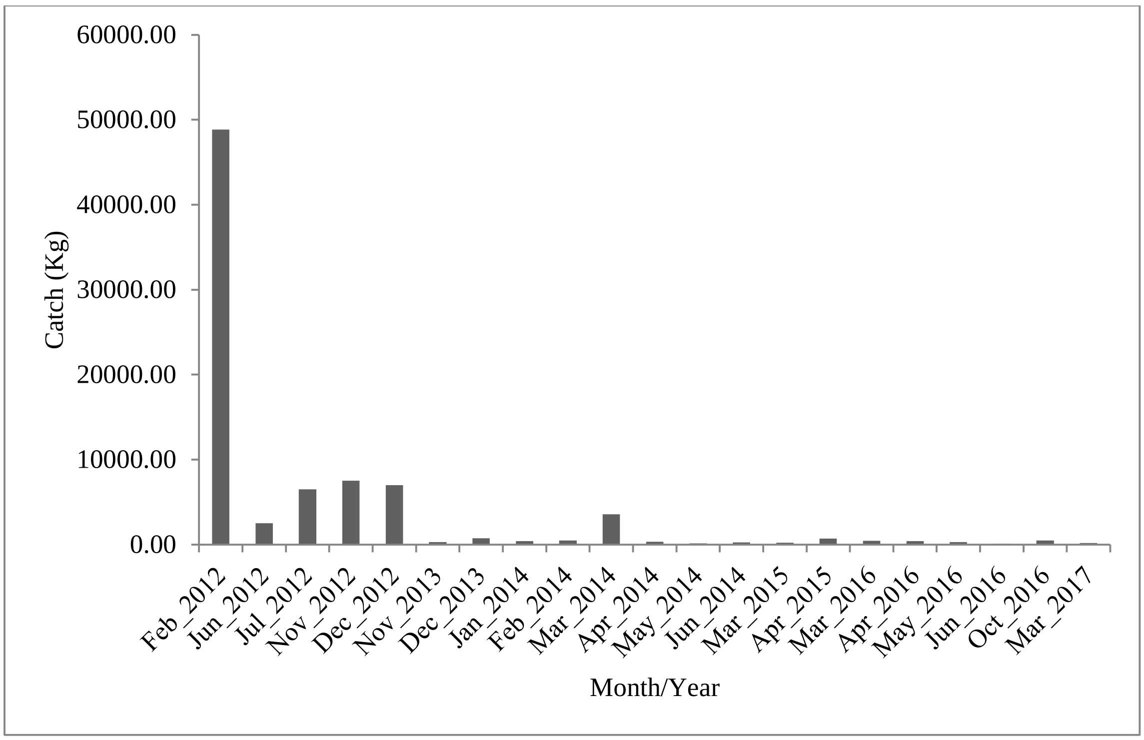


Figure 19. Monthly catch of *Thunnus albacares* (Kg) by the longline fishing vessels in Kenya waters for the period February 2012 – March 2017.

Highest catches of 48,833 Kg were reported in the month of February 2012. This was closely followed by the month of November 2012 with 7,500 kg. The lowest catch of 109 kg was reported in the month of June 2016. A linear projection indicates declining trend in yellowfin tuna catches from 2012 to 2017.

ii) *Katsuwonus pelamis*

A total of 435, 481 Kg of *K. pelamis* with a mean monthly catch of 1254.99 Kg was landed from February 2012 to March 2017 (Fig. 20).

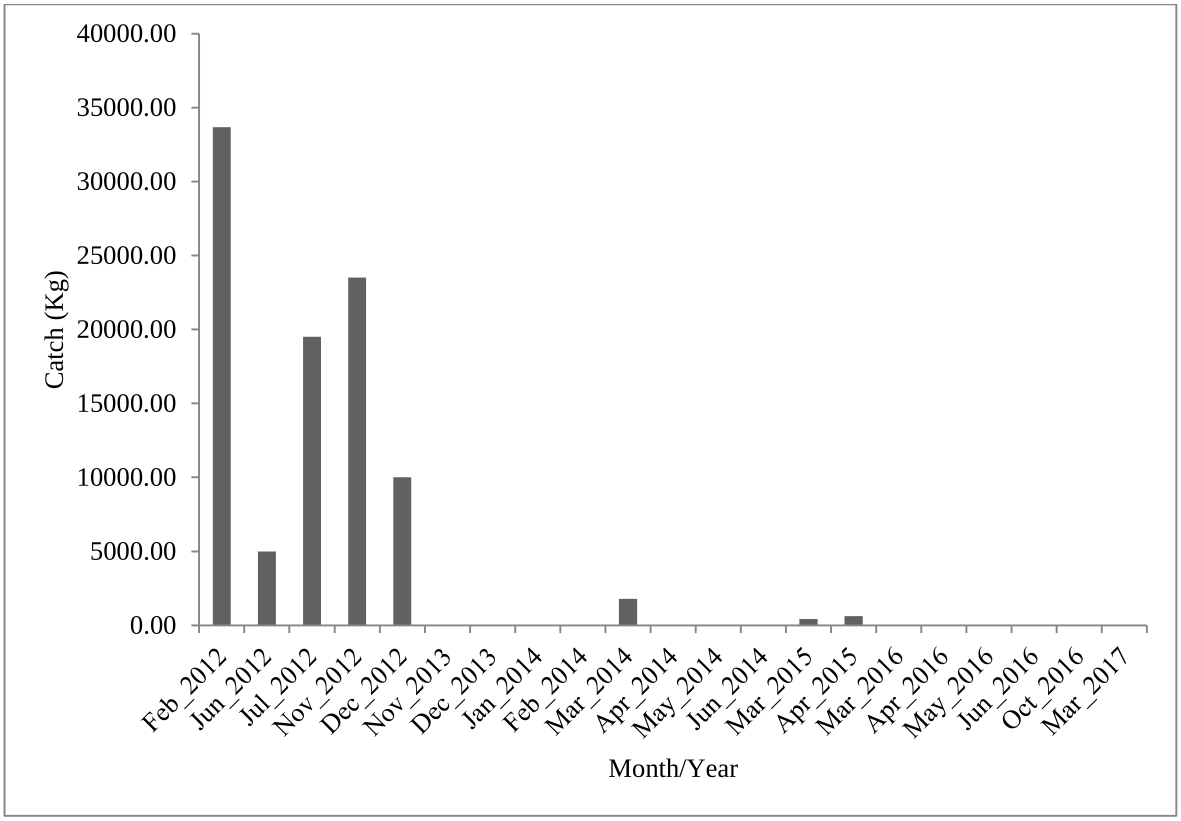


Figure 20. **Monthly catch of *Katsuwonus pelamis* (Kg) by the longline fishing vessels for the period February 2012 – March 2017.**

February and November 2012 reported high catches, 33,667 Kg and 23,500 Kg, respectively. Catch rates per month declined to 1791.67 Kg and 611 Kg in March 2014 and April 2016, respectively. A linear projection depicts declining catches over this period.

iii) Thunnus obesus

A total of 255, 919 Kg of *Thunnus obesus* was harvested in Kenya waters in 2012 to 2017 (Fig. 21).

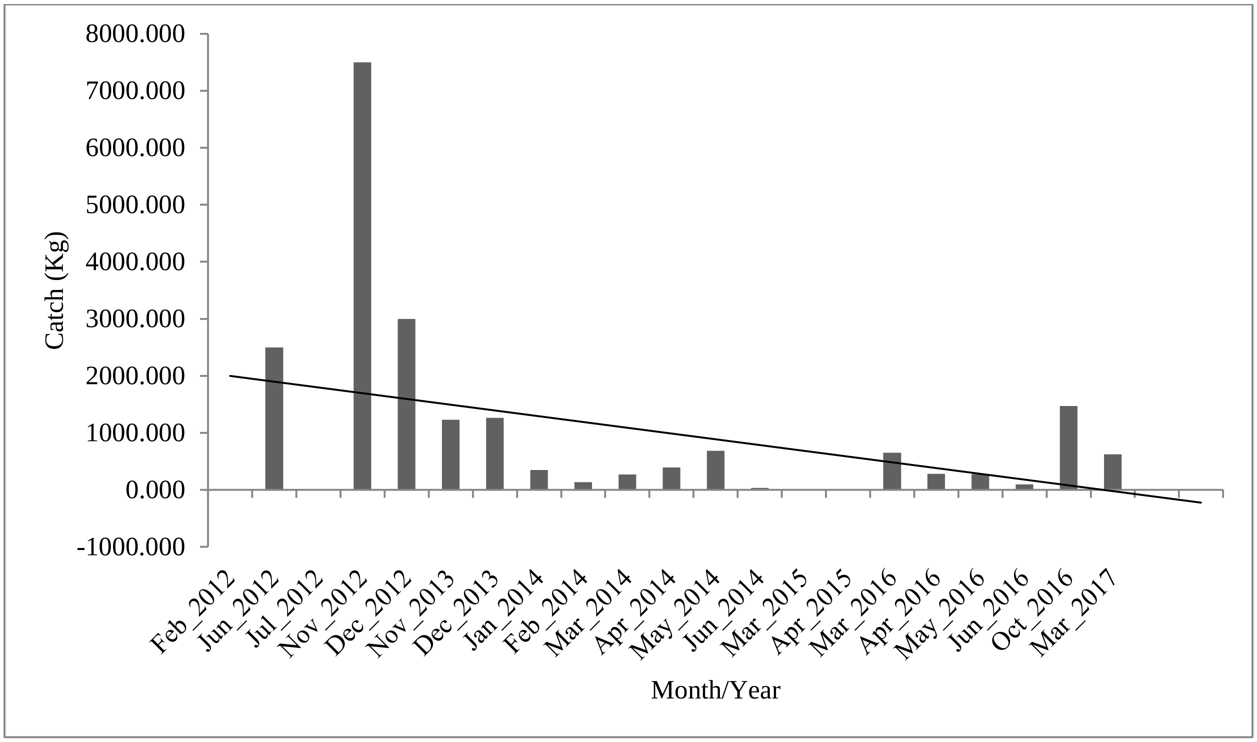


Figure 21. Monthly catch of *Thunnus obesus* (Kg) by the longline fishing vessels for the period February 2012 – March 2017.

Highest catches were reported in the month of November 2012. The months of June and December 2012 recorded 2500 Kg and 3000 Kg of *T. obesus*, respectively. A linear projection of the catches shows a declining trend during the period of this study.

v) Xiphias gladius

A total of 54, 816 Kg with mean of 157.97 Kg per month of *Xiphias gladius* were harvested during this reporting period (Fig. 22).

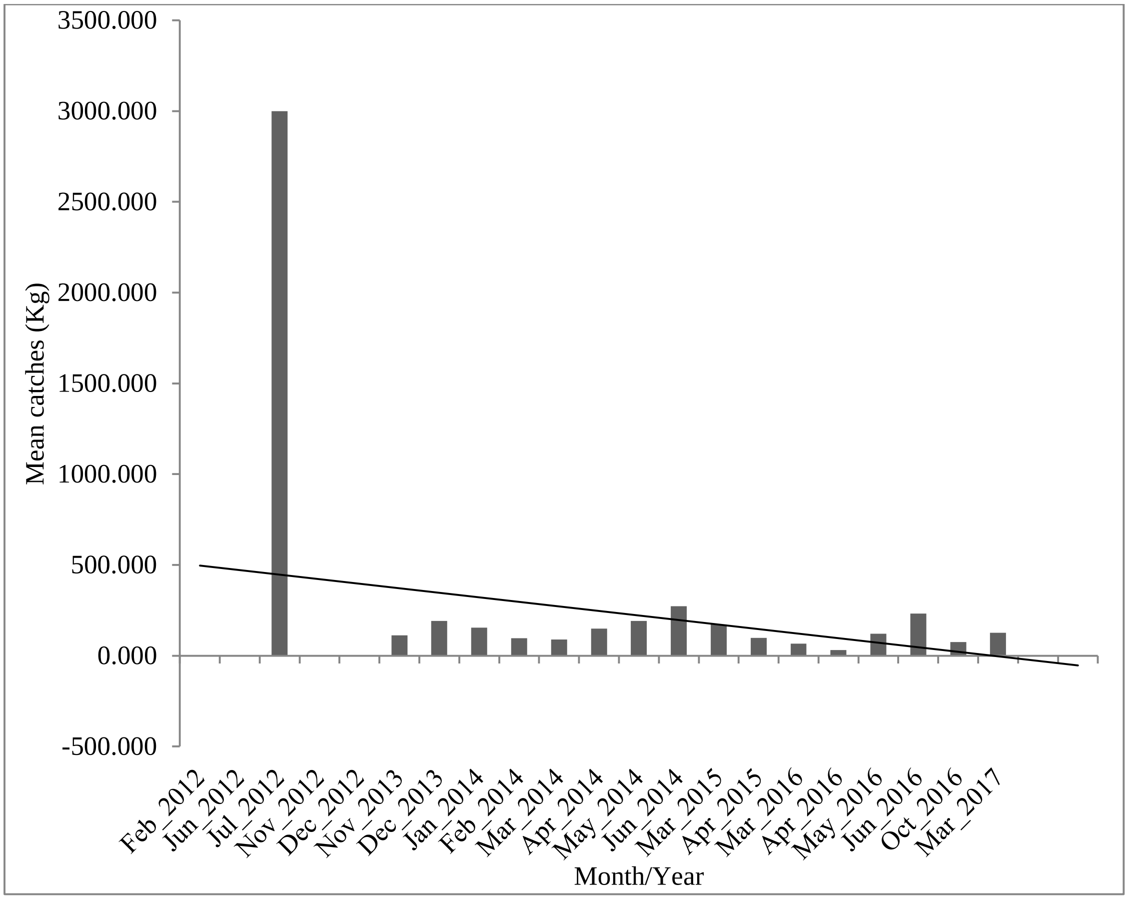


Figure 22. Monthly catch of *Xiphias gladius* (Kg) declared by the longline fishing vessels for the period February 2012 – March 2017.

The month of July 2012 reported the highest catch of 3000 Kg. Some 274 Kg and 232 Kg were recorded in the months of June 2014 and June 2016, respectively. Linear projection shows a declining trend in catch rates during this period of study.

vii) *Makaira* spp

The vessels harvested a total of 86,407 Kg *Makaira* spp with a mean catch of 249.012 Kg (Fig. 23).

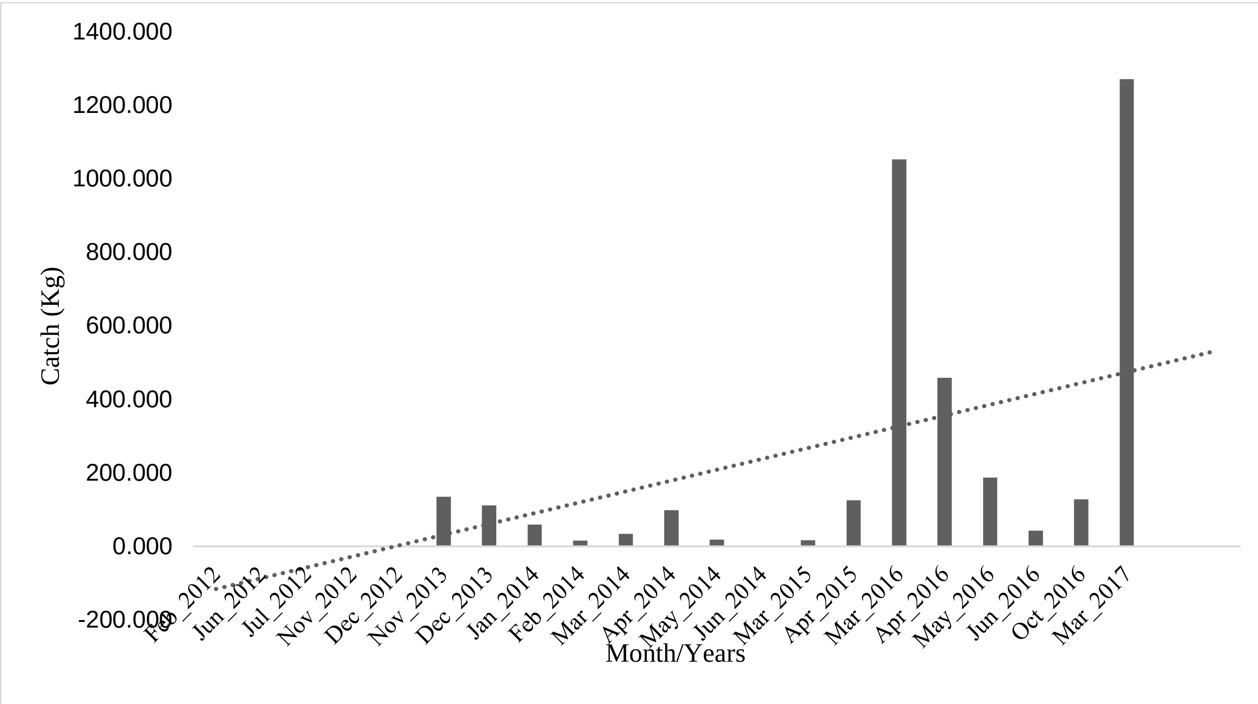


Figure 23. **Monthly catch of *Makaira* spp (Kg) by the longline fishing vessels for the period February 2012 – March 2017.**

Highest catch was reported in March 2017 estimated at 1271.28 Kg. This was closely followed by March 2016 with an estimate of 1052.07 Kg of the catch. Linear projection indicates increasing fish landings.

vii) Thunnus alalunga

Low catches of *Thunnus alalunga* were reported by the longline fleets during the fishing period. A total of 415 Kg with an average catch of 1.19 Kg was reported (Fig. 24).

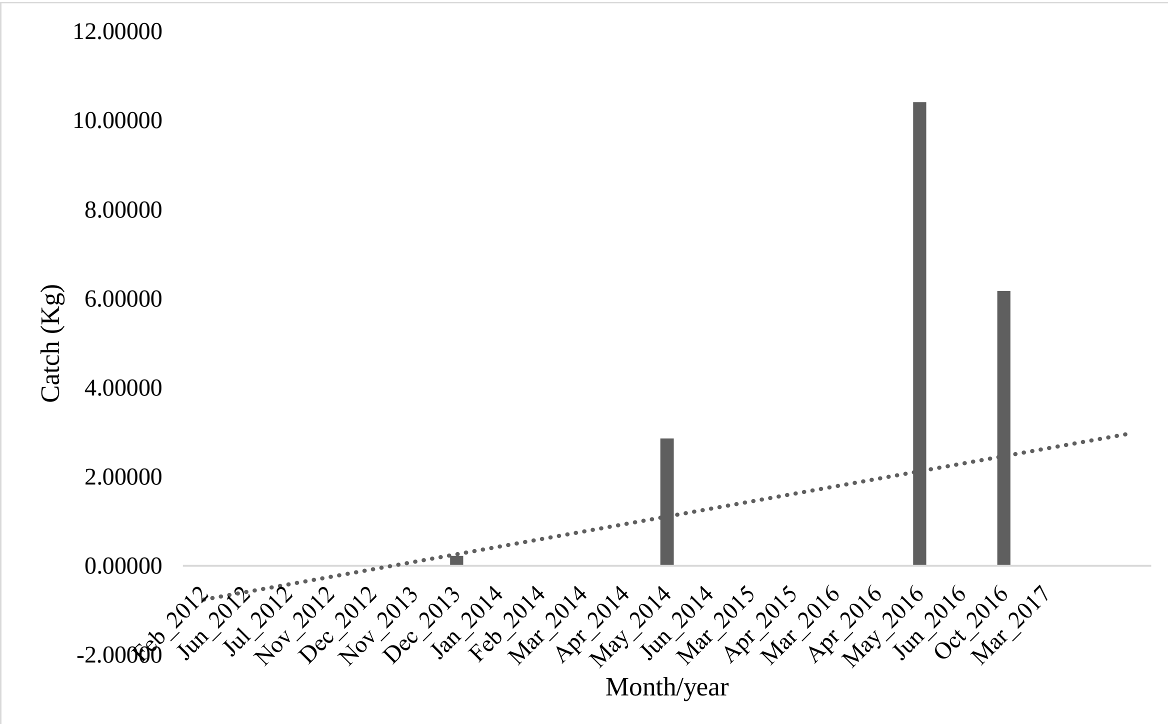


Figure 24. Monthly catch of *Thunnus alalunga* (Kg) by the longline fishing vessels for the period February 2012 – March 2017.

Fish catches were reported only in May 2014 and 2016, and October 2016. Linear projection indicate increase in the fish catches.

viii) *Istiophorus* spp

A total of 406 Kg of *Istiophorus* spp with an average catch of 1.17 Kg was reported during this sampling period (Fig. 25). It may not be conclusive to discuss trend**.** Fish catches were reported only in the months of May 2014 and 2016 and October 2016.

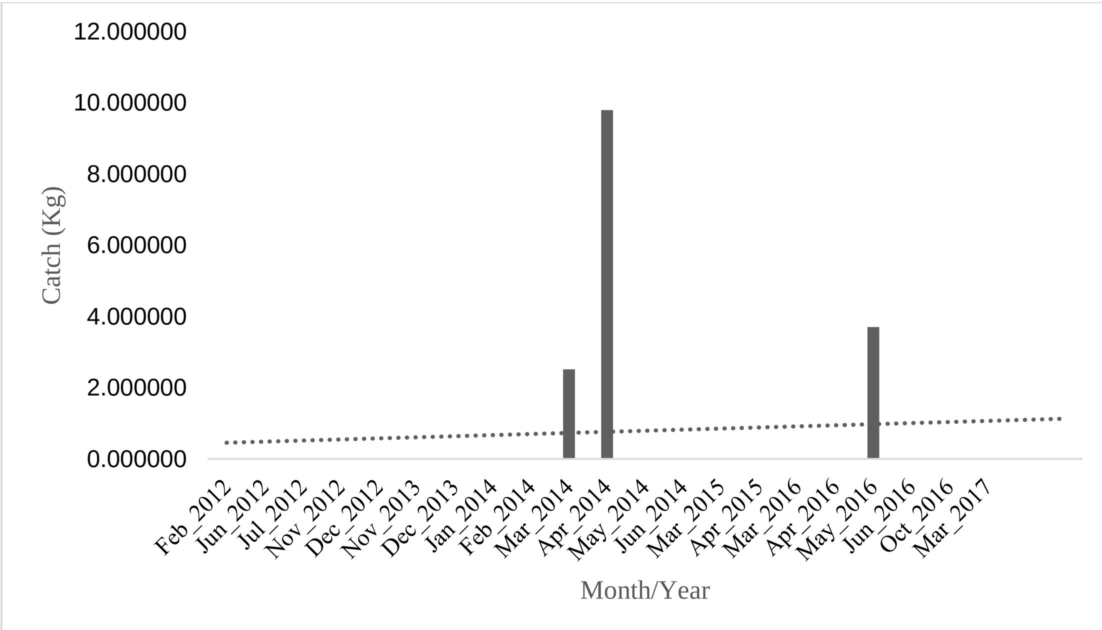


Figure 25. **Monthly catch of *Istiophorus* spp (Kg) by the longline fishing vessels for the period February 2012 – March 2017.**

4.4.3 Spatial variations in tuna fish catch rates

4.4.3.1. Spatial variation in artisanal tunas catch rates

The results indicate spatial variation of fish catch rates between the study sites (Fig. 26).

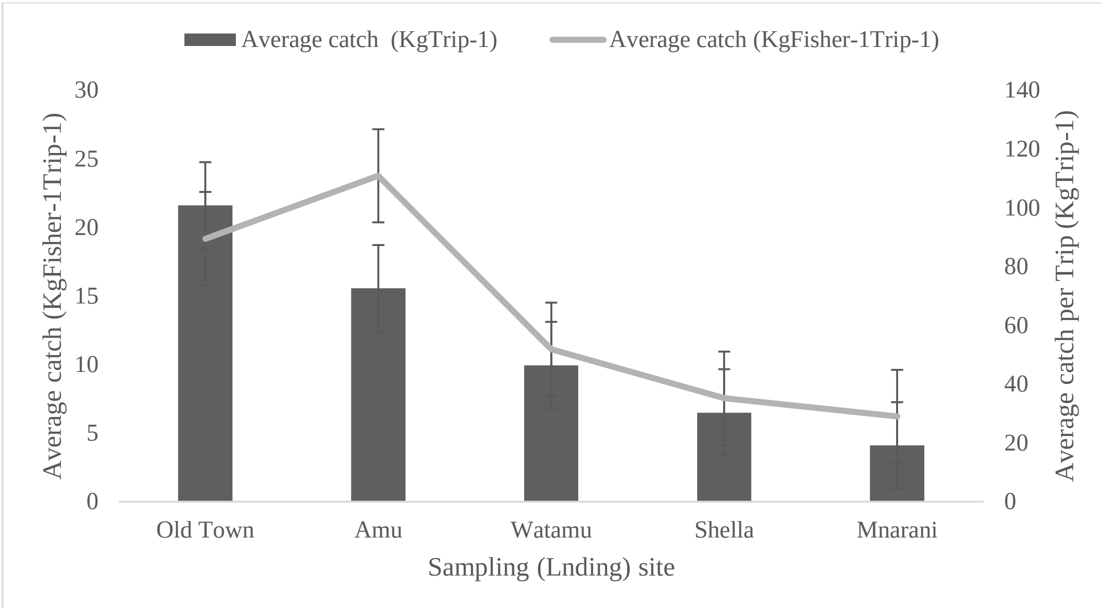


Figure 26. Spatial variation of fish catch rates in the different sampling (landing) sites.

Old Town (Mombasa) recorded the highest average catches rate per trip (100.8 $KgTrip^{-1}$) whereas Mnarani (Kilifi) recorded the lowest (19.11 $KgTrip^{-1}$). Old Town, Watamu, Shella, Amu and Mnarani recorded a total catch of 11,790 Kg, 7,657 Kg, 6728 Kg, 3700 Kg and 1,797 Kg, respectively. The Catch Per Unit Effort (CPUE) recorded at Amu (Lamu), Old Town, Watamu, Shella (Malindi), and Mnarani was 23.7 $KgFisher^{-1}Trip^{-1}$, 19.16 $KgFisher^{-1}Trip^{-1}$, 11.1 $KgFisher^{-1}Trip^{-1}$, 7.5 $KgFisher^{-1}Trip^{-1}$ and 6.2 $KgFisher^{-1}Trip^{-1}$, respectively.

4.4.3.2 Spatial variation in mean catch rates for EEZ tuna and tuna-like species

i) Yellowfin tuna (*Thunnus albacares*)

A total of 648.914 Mt of yellowfin tuna was declared by the longline fishing vessels in the Kenya EEZ waters during this reporting period. The highest landing of *Thunnus albacares*, 145 Mt were reported at 3.63° S and 43.43° E (Fig. 27).

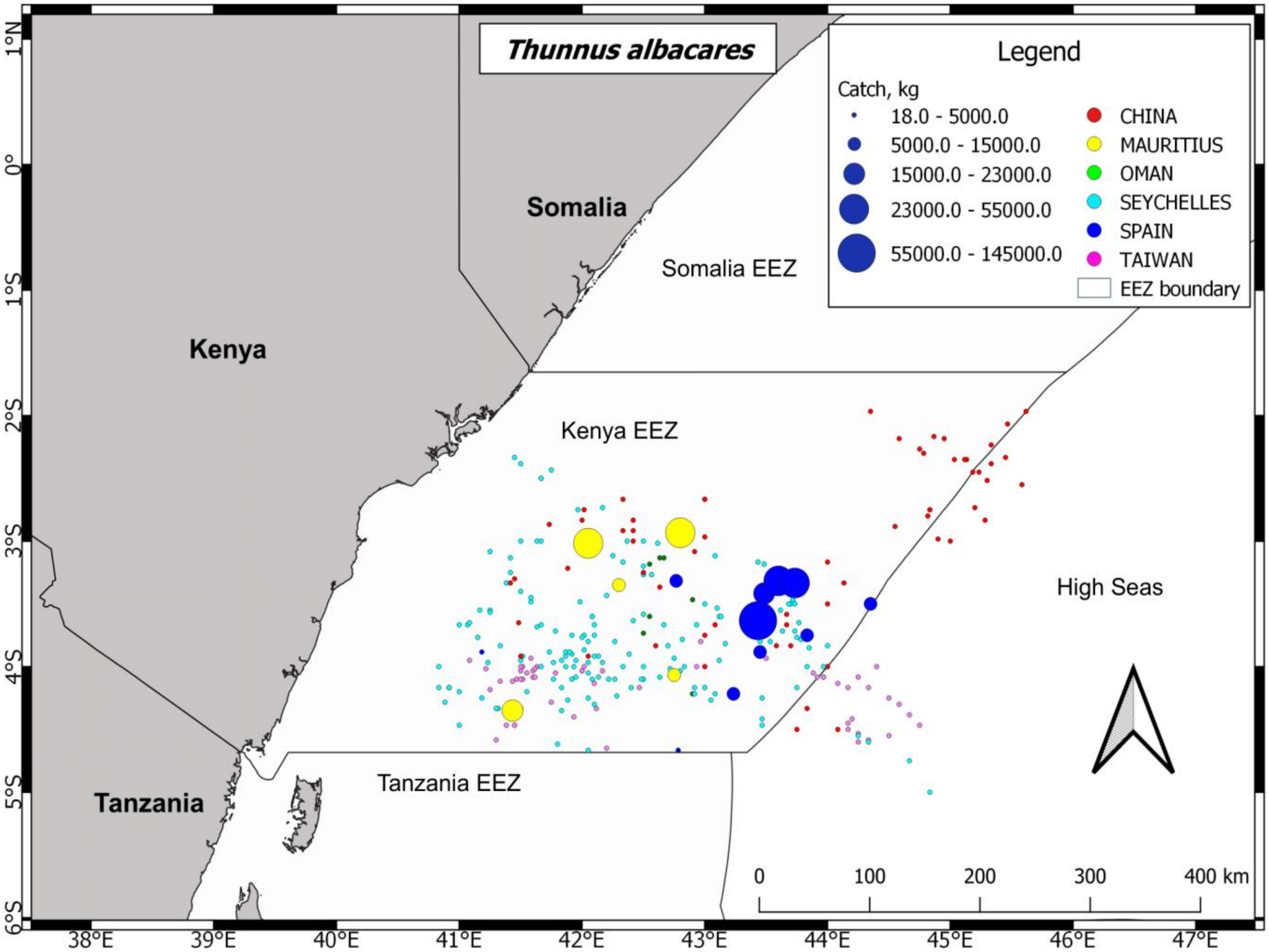


Figure 27. **Time-area catches of *Thunnus albacares* by flag states in the Kenyan EEZ for the period February 2012 – March 2017.**

The results show that high landings were associated with the vessels originating from Spain. The lowest catch, 18Kg of yellowfin tuna were reported at 4.16º S and 42.91º E linked to a vessel from Seychelles. There is evidence of China flagged vessels fishing in the Kenya EEZ towards the boarder with Somalia.

ii) Skipjack tuna (*Katsuwonus pelamis*)

A total of 435.481 Mt of *K. pelamis* was landed from the longline vessels originating from Spain, Mauritius and Seychelles that declared their catch during this reporting period (Fig. 28).

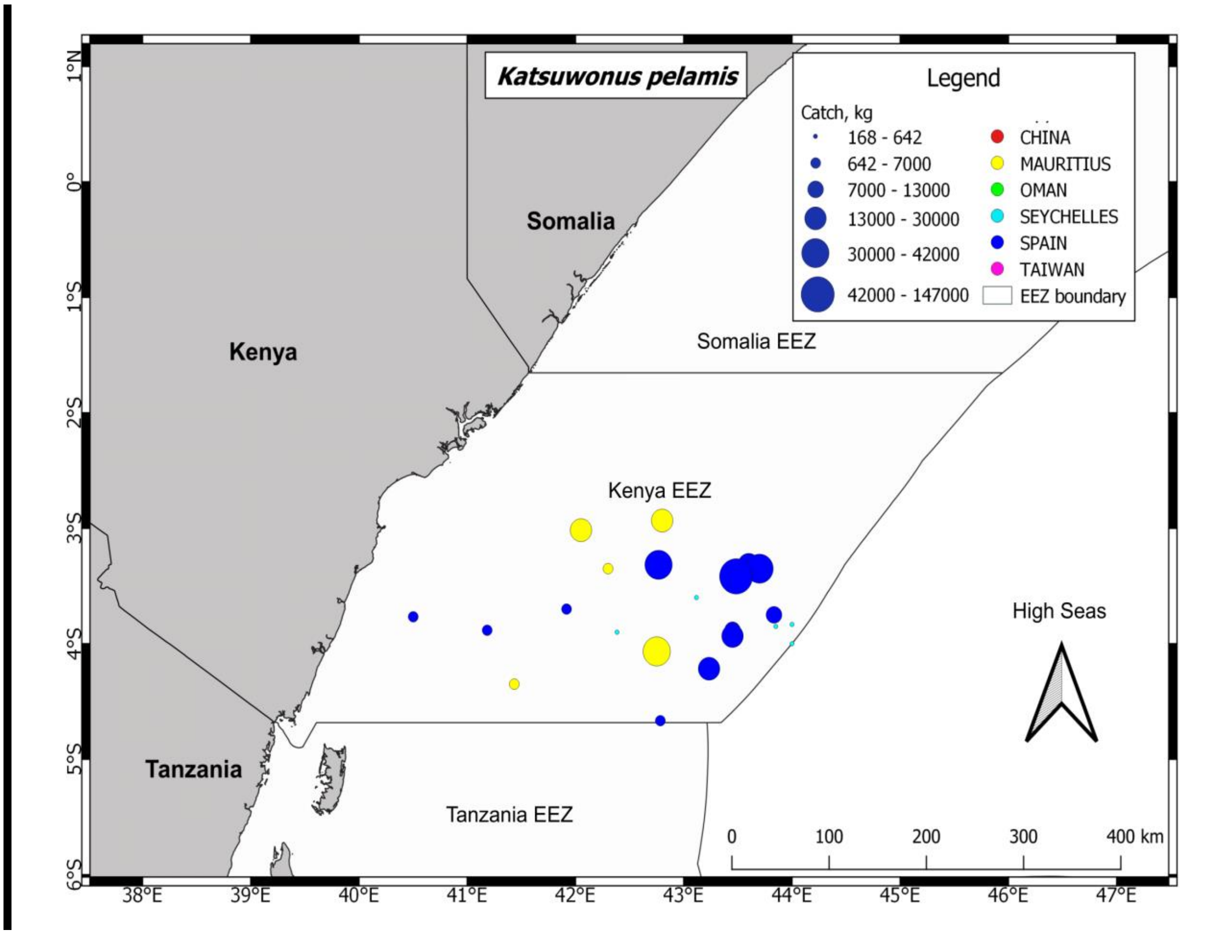


Figure 28. Time – area catches of *Katsuwonus pelamis* in the Kenyan EEZ waters.

The results show that the highest catch of 147 Mt was associated with vessels from Spain, reported at 3.41° S and 43.48° E. The lowest catch of 0.168 Mt reported at 3.83° S and 44.0° E.

iii) Bigeye tuna (*Thunnus obesus*)

A total of 269.708 Mt of bigeye tuna were recorded during this reporting period, with highest catches of 18 Mt reported at 3.5º S and 44.35 º E (Fig. 29).

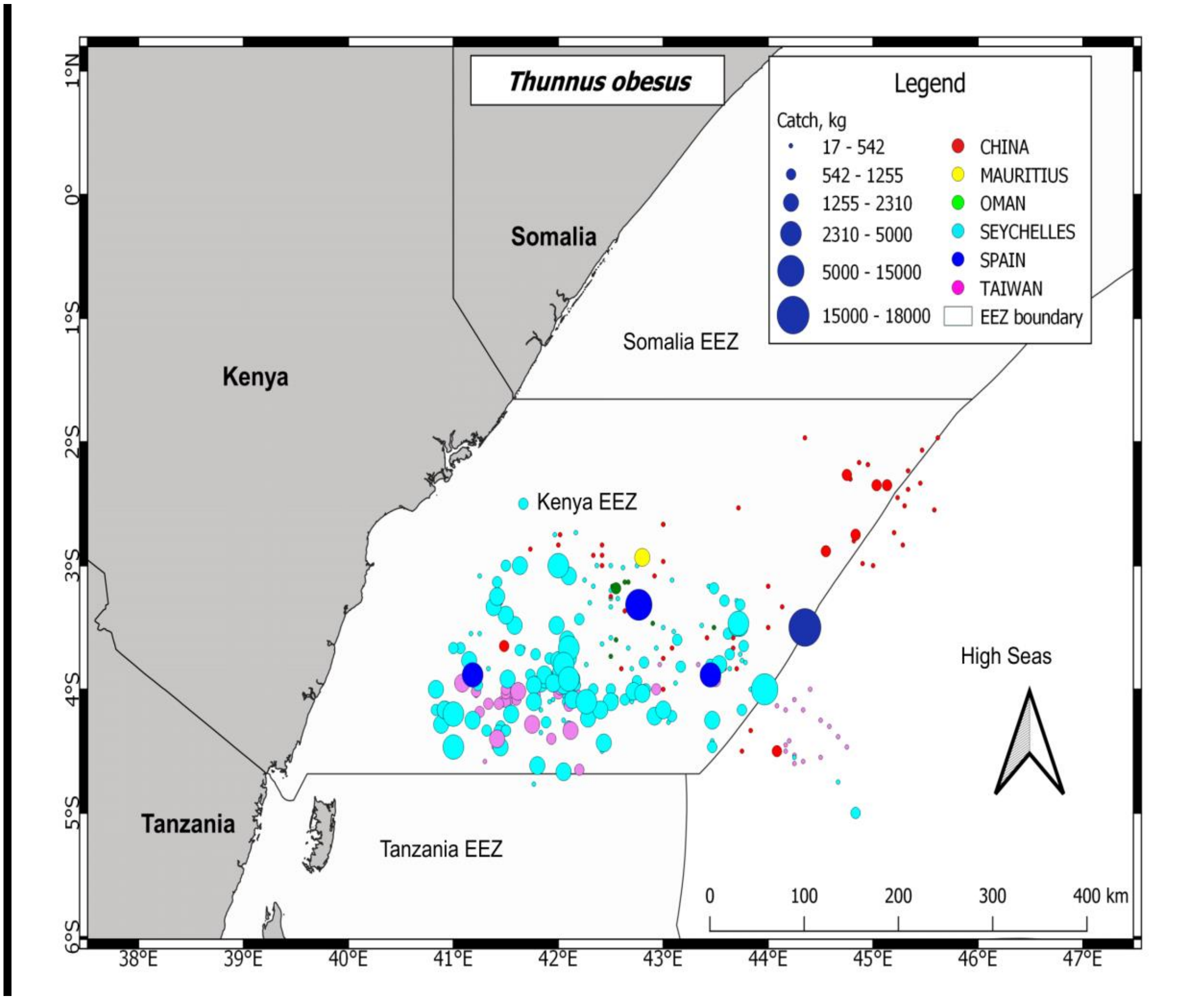


Figure 29. Time-area catches of *Thunnus obesus* in the Kenyan EEZ waters.

The results show that most of the landings of *Thunnus obesus* were associated with Seychelles flagged vessels, with over 5 Mt harvested on the Kenya EEZ boundary. Vessels originating from Spain harvested over 15 Mt on the Kenya EEZ boundary and the high seas.

iv) Swordfish (*Xiphias gladius*)

Some 54.44 Mt of *Xiphias gladius* (swordfish) were landed during this reporting period, with highest catches (12.1 Mt) associated with a Spanish flagged vessel recorded at 4.6º S and 42.78 º E (Fig. 30).

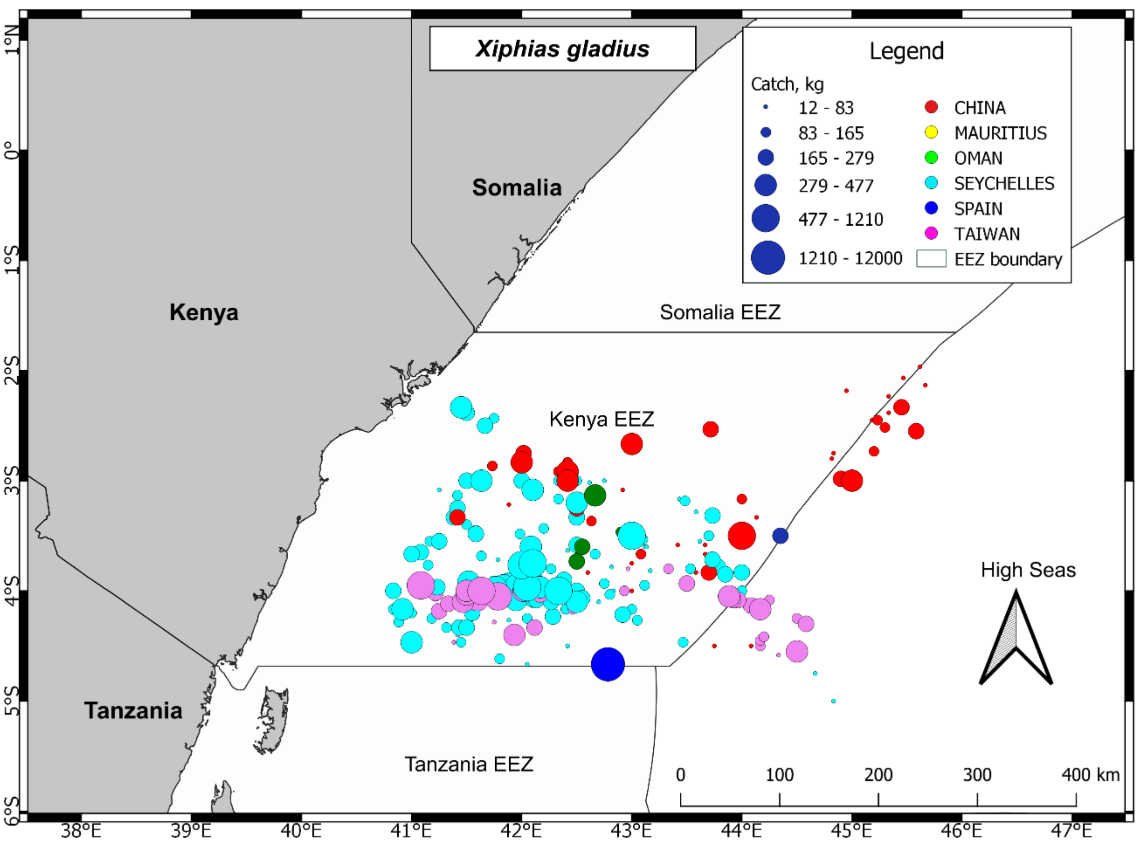


Figure 30. Time-area catches of *Xiphias gladius* in the Kenyan EEZ waters.

Lowest catches of 0.012 Mt were reported at 4.5º S and 44.08 º E. The results indicate that 22% of the catch was landed by a Spanish flagged vessel. Over 1.21 Mt of swordfish was landed by a vessel originating from Spain fishing on the boundary of Kenya and Tanzania EEZ. The Chinese flagged vessels evidently fished mainly in the Kenyan EEZ towards Somalia.

Pooled catch data declared by the 24 longline vessels flagged to six countries show that Spain recorded most of the landings (Fig. 31).

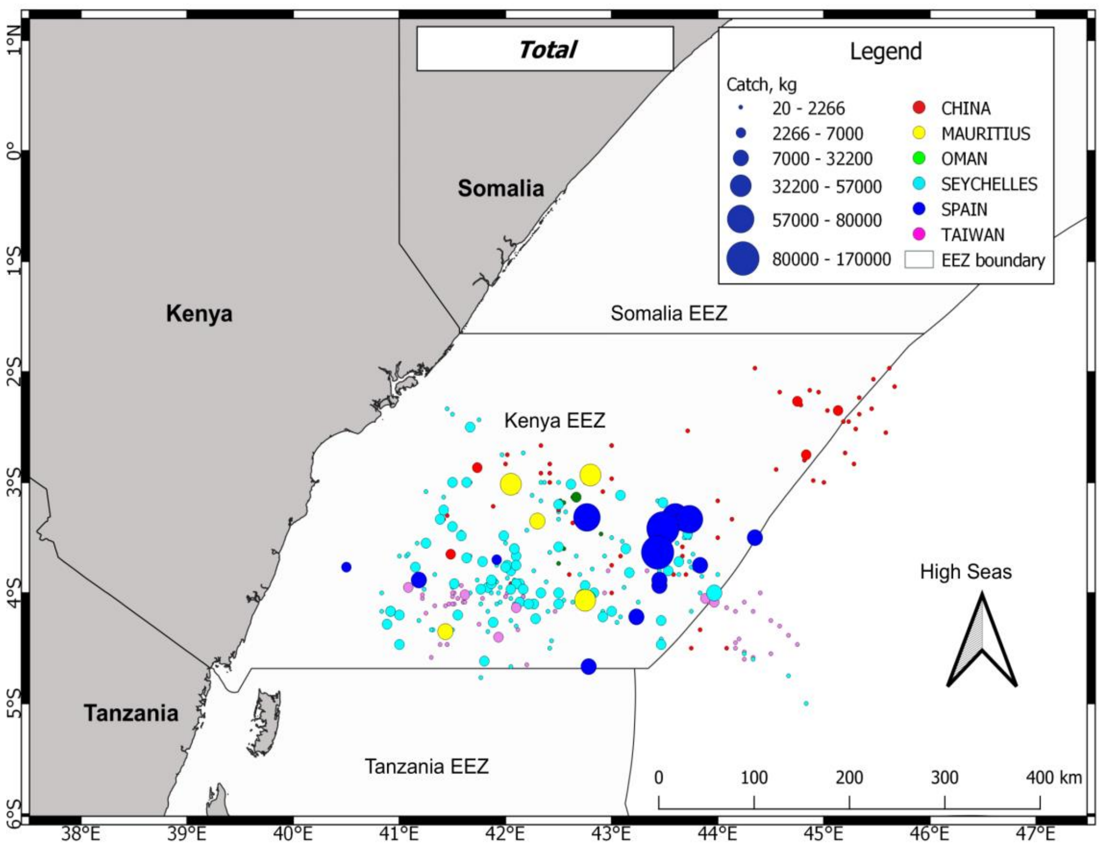


Figure 31. **Time-area catches of tunas in the Kenyan EEZ waters by Flag states.**

The total catch landed was above 30 Mt per location for vessels originating from Spain and Mauritius. Despite having fewer records per location, Spain and Mauritius flagged vessels recorded on average higher catches by weight than the other countries. The catches were dominated by *Thunnus albacares and Katsuwonus pelamis*. Spain and Mauritius flagged vessels recorded the highest landings for *Thunnus albacares and Katsuwonus pelamis*. Catches for Seychelles flagged vessels were moderate i.e.~ 2 - 7 Mt per location and widely distributed within Kenya's EEZ. Catches for vessels flagged to china, Taiwan and Oman were generally below 2 Mt at each location. Chinese vessels were mostly recorded fishing in the Kenyan EEZ towards the Somalia border.

4.5 Discussions

There is evidence from this study of temporal variation in the catch rates of tuna and tuna-like fish species landed by small-scale fishers and industrial longliners. Fish catch rates significantly varied between the months with high fish catches recorded during the South East Monsoon (SEM) season which occurs between the months of April to September with a transition period in mid-September to November (Fig. 14). Relatively low catch rates were reported in the months of December 2015 to April 2016, occurring mostly within the Northeast Monsoon (NEM) season. In 2016, abundance of tuna catches peaked in the month of July.

This temporal variation observed in fish catch rates could be partly attributed to several factors including the type and quality of the habitat, availability of food, selectivity and catchability by the different fishing gears, sex and size of the individual fish, migratory nature of the tunas as well as spawning (Tuda *et al*., 2016; Herrmann *et al*., 2018; Kaplan *et al*., 2014; Lan *et al*., 2014; Abdel-

Barr *et al*., 2012; Kar *et al.*, 2012; Ward & Elscot, 2000). The Somali basin has been known to have high primary production especially from July to October (Kaplan *et al.;* 2014; Chassot *et al.*, 2019) with known upwelling (Chassot *et al*., 2019; Schott *et al*., 2009) and this probably could be an explanation as to why there were high catch rates for tunas around this period because of abundance of food. Tunas prey on small fish including anchovies, mackerels, free swimming crabs, shrimp, spirula, cephalopods, among others (Hemphil, 1995; Potier *et al*., 2002).

The results indicate that the monsoon seasons had influence on the distribution and abundance of the tunas. Tunas are highly migratory species that respond to seasonal changes (Boggs, 1994). The monsoon climatic season and the inter- tropical convergence zone experienced at the Kenya coast have some influence on the abundance of tunas in the Kenya coastal waters (Koido & Suzuki, 1989; Nzioka, 1990; Zudaire *et al.,* 2013). Fairly low catch rates for tunas recorded between December to April (occurring within the Northeastern Monsoon –NEM) could be partly attributed to the movement of some tunas outside the study area for natural migration and/or spawning purposes (Ministry of Agriculture, Livestock and Fisheries, 2013; Campling, 2012). Peak spawning activities for some of the tunas, namely, *Thunnus albacares* in the Indian Ocean region have been reported to take place between November and May (IOTC, 2003; Zhu *et al.,* 2008). Similar observations of seasonal distribution of longline tuna catches in the EEZ of North Madagascar and Seychelles were reported by Kaplan *et al*. (2014).

According to the results of this study, tuna catches peaked in July which compares very well with the results of other studies in the area (Kaplan *et al*., 2014; KMFRI, 2018). There is also evidence from this study that abundance peaks in September, November to February for some of the tunas, which is in agreement with other studies (KMFRI, 2018). Similar observations were reported by other authors (Mueni *et al*., 2019; State Department of Fisheries and Blue Economy, 2016; Lan *et* *al.*, 2014). However, swordfish catches were high between August to March. The high abundance for swordfish seem to coincide with the spawning season of this species in the Indian Ocean which is in October through to April (Lan *et al*., 2014; IOTC, 2017).

Tuna and tuna-like fish species catches from artisanal fisheries were recorded throughout the sampling period with distinctive peak and low seasons (Fig. 15). These findings indicate that some individuals of tuna fish were resident to the Kenya coastal waters with restricted movements, hence referred to as neritic tunas (IOTC, 2019). Neritic tunas make significant contribution to coastal fisheries and include among others kawakawa (*Euthynnus affinis*), longtail tuna (*Thunnus tonggol*), bullet tuna (*Auxis rochei*), frigate tuna (*Auxis thazard*), bonito (*Sarda spp)* and kingfish *(Scomberomorus* spp*) (*IOTC, 2020). Similar trends in temporal variation in catch rates were also observed in the EEZ catches that were declared by the tuna longliners (Fig. 16).

This study revealed that Distant Water Fishing Nations (DWFN) seem to have preference fishing for certain months of the year. There are a number of reasons which may have contributed to the observed trend. Most importantly this must have been linked to the abundance and availability of the tunas and tuna-like fish species, fleet dynamics, species targeted, licensing regime and piracy in the Somali basin. Kenya Fisheries Law has a provision for licensing fishing in some specific months or the whole year (State Department of Fisheries, 2016) which explains why some fishing vessels reported catch only in certain months. The increase of the License Fee and the Somali piracy may have also contributed to the decline in fish catches over the study period (Hoofs & Steins, 2017; POSEIDON *et al.,* 2014). The Somali piracy resulted to shifting of fishing fleets to the Eastern Indian Ocean.

Most of the catch was harvested by vessels flagged to Spain and Seychelles (Fig.17). Mauritius and Spain had the highest CPUE of 42,000 $KgVessel^{-1}Trip^{-1}$ and 5,392.6 $KgVessel^{-1}Trip^{-1}$, respectively. CPUE seem to correlate with trips, the fewer the trips, the higher the fish catch rates (CPUE). Similar trends were observed when the number of vessels were reduced. For instance, the CPUE was very high for Mauritius who deployed only one vessel in this respect. This could be associated with the capacity, gross tonnage and hooking density of the fishing vessels although these details were not captured in the logbook of most of these vessels. This could be probably associated with the proximity to tuna fish processing cannery and port facilities in Seychelles and Mauritius. Most of the Asian flagged vessels (about 50%) transship their catch through Port Louis in Mauritius which has also two major tuna canning factories, namely, Thon des Mascareignes and Princes Tuna (POSEIDON *et al.*, 2014). The Indian Ocean Tuna Cannery with the processing capacity of 70,000 – 80,000 Mt annually is located in Seychelles (POSEIDON *et al.*, 2014). The Seychelles and Mauritius canaries also process tunas from the European fleets including Spain, United Kingdom and Italy (Lecomte *et al*., 2017). The European Union, mainly France, the United Kingdom, Spain and Italy are the main markets for these canneries accounting for over 75% of exports (quantities) and 84% (value) (Lecomte *et al*., 2017).

Significant amount of unidentified sharks (1.3% of the catch) are landed by the longliners targeting tunas in the Kenya EEZs either as by-catch or targeted fishery. Some of the sharks in Kenya and entire Indian Ocean are targeted (Kiilu & Ndegwa, 2013; Kiilu & Ndegwa, 2018), for instance in this study, sharks accounted for 13% of the catch by the Taiwan flagged vessels. Sulaiman *et al*. (2018) reported that sharks accounted for 8.5% of tuna longline catches that were landed in Cilacap Port in Indonesia. Some of the species of sharks landed are categorized according to the IUCN listing as vulnerable and or threatened, namely blue shark (*Prionace glauca*), shortfin mako sharks

(*Isurus oxyrinchus*), thresher sharks (*Alopias* spp), Oceanic whitetip shark (*Carcharhinus longimanus*). Bycatch of sharks in tuna fishing vessels in the Indian Ocean region is an issue of concern by the Government of Kenya and the IOTC (Kiilu & Ndegwa, 2018; Mueni *et al.*, 2018; Mueni *et al.*, 2019; IOTC, 2020). However, sharks are not under the direct management of the IOTC (IOTC, 2020). The Government of Kenya with the support of partners is currently formulating the national Plan of Action for Sharks and Rays.

It is evident from this study that the quantity of the tuna catches varied with years and the different vessels flagged by various countries (Fig. 18). Catch Per Unit Effort (CPUE) which was defined in form of the number of fish caught per vessel per trip ($KgVessel^{-1}Trip^{-1}$) varied with fishing effort (Table 3).

There is evidence from this data of declining catch rates of tunas from the Kenyan EEZ over the study period (Figures 19 - 25). However, this should be taken with caution in drawing this conclusion because of a number of reasons including under-reporting, non-compliance with the reporting requirement, inadequate data collection and data gaps as well as illegal fishing activities. Similar concerns of declining catches have been reported by other authors (IOTC, 2020; WIOMSA, 2015; POSEIDON *et al.*, 2014). The stock of *Thunnus albacares* in the Indian Ocean is overfished whereas *Katsuwonus pelamis, Thunnus obesus*, *Thunnus alalunga* and *Euthynnus affins* are being harvested closer to their respective MSY limits due to increased fishing effort (IOTC, 2020). There have been some efforts by IOTC to rebuild the stock for yellowfin tuna in the Indian Ocean, however, this is yet to yield any tangible results. On the contrary, IOTC (2020) reported that yellowfin tuna catches have increased by 10% for the period 2014 to 2019 (IOTC, 2020).

Artisanal tuna catch rates varied across the landing sites (Fig. 26) with Old Town (Mombasa) recording the highest mean catch per trip ($KgTrip^{-1}$) compared to the other sites. However, Amu recorded the highest catch per fisher trip ($KgFisher^{-1}Trip^{-1}$). The type, size, selectivity of fishing gear and number of fishing crew may have influenced the spatial variation in catch rates (Tuda *et. al*, 2016; Maunder *et. al.,* 2006; Rijisdorp *et al.,* 2000; Farley *et al.,* 2016). Longline was predominantly used by fishers who landed their catch at Old Town. The vessels are fairly larger and have the capacity to venture into the deep sea to catch large sized fish as opposed to trolling line which were predominantly used by fishers in Watamu and Mnarani landing sites. Interviews with the fishers indicated that most of them hardly go to fish beyond the 5 nautical miles. This is because of the artisanal nature of their fishing vessels which cannot withstand high turbulence and rough conditions in the deeper waters. This limits the potential for small-scale fishers to enhance sustainable production of tuna resources in Kenya waters. There is great potential of developing small to medium scale coastal fishery, especially the handline targeting yellowfin tuna in the coastal waters of Kenya. This would only be realized through implementation of effective tuna fisheries conservation and management measures, including yellowfin tuna stock rebuilding plan adopted by IOTC in which Kenya is party to (IOTC, 2021). This would significantly contribute to the improved socio-economic benefits to the local communities and national economy.

The species and size of fish being targeted by fishers also seem to have contributed to spatial variation in the catch rates. Large sized individuals of fish were targeted by fishers who landed their catch at Old Town in particular swordfish (*Xiphias gladius*) and yellowfin tuna (*Thunnus albcares).*

The fishing effort as defined by the number of fishing crew employing different gear types with varying sizes may also have contributed to the observed difference in fish catch rates (CPUE) across the different sites. Cumulatively there were some 2718 fisher days with total sample catch of approximately 31,672 Kg of tunas. Most of the fishing effort was concentrated at Shella (33.8% of the fisher days) with a corresponding CPUE of 7.5 $KgFisher^{-1}Trip^{-1}$. Over 60% of the fishers at Shella deployed handline to harvest tunas. Trolling was the dominant (99.2%) fishing gear at Watamu accounting for the 25.9% of the fisher days. Therefore, the fish catch rates correlated with the level of fishing effort as well as the type of fishing gear (Herrmann *et al*., 2018; Tuda *et al*., 2016).

Analysis of time-area catches confirms the distribution of tunas spatially from industrial longliners in the Kenya EEZ (Figures 27 – 31). The quantities of tunas landed varied spatially with species and the flag of vessels. Vessels flagged to Spain accounted for most of the landings (48%) and closely followed by those with Seychelles and Mauritius flags at 27% and 14%, respectively. Oman, China and Taiwan also got significant tuna catches which were below 6%. Spain, Seychelles and Mauritius accounted for 89% of the longline tuna catches in the Kenya EEZ for the period 2012 to 2017.

Highest abundance of tunas is concentrated in Kenya's EEZ closer to the high seas (Fig. 31). This could be associated with the upwelling areas which are highly productive and provide abundant food for the tunas (Chassot *et al.,* 2019; Kaplan *et al*.; 2014; Chassot *et al.,* 2019; Schott *et al*., 2009). Fishing at the boundary between Kenya and Tanzania EEZ by Spanish fleets was evident. The Chinese flagged vessels fished in the Kenyan EEZ towards the Somalia border. It is evident that vessels aggregated on the borders of EEZ of Tanzania and Somalia and some of them crossing to the high seas and back. These results shows that the northern part of the Kenya EEZ is a major fishing ground and the Government of Kenya should closely monitor fishing operations in this area to deter any illegal activities and minimize ecosystem impacts as well as economic losses.

Kenya and many other countries within the South West Indian Ocean (SWIO) region have limited capacity to venture into deep sea fishing in their Economic Exclusive Zones (EEZ). They have not invested in procuring improved and modern fishing technology, including purse seiners and longliners. Most of their fishing equipment are artisanal in nature, hence offers access to Distant Water Fishing Nations (DWFN) through some form of licensing and or partnership agreements (Hoof & Steins, 2017; Barnes, 2015; POSEIDON *et al.*, 2014; Barnes *et al.*, 2011). Some 31 – 36 foreign fishing fleet were authorized to fish in Kenyan EEZ between 2010 – 2014, by paying US$ 50,000 license fee for each of the vessel per annum (KMFRI, 2018). Investing in the offshore tuna fishing requires building a national fleet and putting in place the necessary support infrastructure which most of the SWIO coastal states have not invested in except Seychelles and Mauritius.

4.6 Conclusions and Recommendations

4.6.1 Conclusions

This study is the most comprehensive one in Kenya to review and analyze logbook catch data for tuna from foreign longline tuna fleets fishing in Kenya EEZ to establish their catch rates. The study has revealed that on average, the CPUE for the fleets as follows China (189.26 $KgVessel^{-1}Trip^{-1}$), Spain (5,392.6 $KgVessel^{-1}Trip^{-1}$), Seychelles (372.79 $KgVessel^{-1}Trip^{-1}$), Mauritius (42,000 $KgVessel^{-1}Trip^{-1}$), Taiwan (1,327.03 $KgVessel^{-1}Trip^{-1}$) and Oman (1,320 $KgVessel^{-1}Trip^{-1}$)

There are significant catches of artisanal tuna fishery in coastal waters of Kenya. The quantity of the catch and species composition vary over time and space. This study has been able to establish

CPUE indices for artisanal tunas in Kenya coastal waters at Amu (23.8 $KgFisher^{-1}Trip^{-1}$), Old Town (Mombasa) (19.16 $KgFisher^{-1}Trip^{-1}$), Watamu (11.1 $KgFisher^{-1}Trip^{-1}$), Shella (Malindi) (7.5 $KgFisher^{-1}Trip^{-1}$) and Mnarani (6.2 $KgFisher^{-1}Trip^{-1}$). These catch rates may be an underestimation though due to under-reporting.

Tuna and tuna-like fish species are more abundant during the South East Monsoon (SEM) season though the sea conditions are rough and most of the artisanal fishers are poorly equipped to venture in the deep sea.

Tuna fishery in coastal waters of Kenya is artisanal in nature, multi-species, multi-gear, with handline, longline, gillnet and trolling as the main fishing gears. Fishers, both artisanal and industrial deploy different gears targeting specific species and sizes of the individual fish. Industrial long liners target deep/ subsurface dwellers, large sized and mature individuals of yellowfin, bigeye, albacore, swordfish, billfishes and sharks.

Species composition for artisanal and offshore tuna catches didn't vary much suggesting that they all harvest tuna fish from the same stock. Yellowfin, swordfish and kingfish dominated the artisanal landings. Offshore longline fishery was dominated by yellowfin, skipjack, bigeye, swordfish, sharks and billfishes. Yellowfin and skipjack were the most dominant in offshore longline catches.

Monsoon seasons, quality of the habitat, availability of food, gear type, size and selectivity, migratory nature of tunas, sex, size and condition of individual fish as well as spawning partly influenced catch rates and relative abundance of tunas in both artisanal and offshore waters although this study didn't asses these environmental and physical factors except fishing gears to some extent.

Aggregation of longline vessels along the EEZ borders between Kenya, Somalia and Tanzania was evident, especially those flagged to Seychelles, China, Spain and Taiwan. Spanish and Chinese flagged vessels fished near the EEZ between Kenya and Somalia. Fishing in the high seas and crossing back to Kenya was also evident for the vessels flagged to Taiwan, China, Seychelles and Spain. This is an area that may require further investigation.

The catch declared by the Distant Water Fishing Nations (DWFN) fleets (1,519.39 Mt) by 24 long liners over a period of Five years suggests under-reporting of the catch. It is highly likely that some catches were not declared/ reported. It is possible that the vessels were declaring the catch somewhere else. This has consequence on the quality of data and implications on managing tuna stocks sustainably as well as catch allocations and granting fishing opportunities in the future.

The quality of data declared by foreign vessels licensed to harvest fish in Kenya waters was poor. The length-frequency and catch-effort data is not collected as advised by IOTC. Some species were lumped together hence difficult to ascertain the type of genus or species being reported, particularly the sharks and the billfishes. Whereas it is a legal requirement for all the licensed foreign fishing vessels to submit catch data as provided for in the national fisheries legislation and in line with the IOTC reporting requirement, compliance was very low. This was an issue of great concern and efforts should be directed to enforce relevant legislation to ensure compliance.

Consistent time series data for both artisanal and EEZ tuna was lacking. The biological data for both coastal and EEZ tunas was not readily available. This presents a challenge of estimating length-weight relationships, growth parameters and mortality rates which are essential in informing sustainable fisheries management. This concern has been raised by IOTC. Most of the data used in stock assessment by IOTC is approximated because many of its members, including Kenya have a challenge in complying with the catch reporting requirement.

Kenya Fisheries Service (KeFS) has been collecting fisheries data since the 1950s. Most of the data sets existed in hard copies until 2000 when the department started capturing the catch data in both hard and soft copies. Nevertheless, the data was not analyzed to inform fisheries policy and decision making for improved fisheries governance and development.

4.6.2 Recommendations

In order to improve on the quality of data from both artisanal and offshore tuna fisheries, and make it more readily available to inform policy and decision making, this study recommends the following;

i. Three species, *Thunnus albacares* (yellowfin tuna), *Xiphias gladius* (swordfish) and *Scomberomorus* spp *(*kingfish) accounted for over 76% of the catch sampled from the artisanal tuna fishers. This overemphasizes the importance of tunas in the coastal fishery in Kenya. Efforts should be directed at developing a sustainable small-scale tuna fishery in Kenya with a view to enhancing the socio-economic and ecological benefits of this fishery to the country and local communities. This is possible if the country will put into place effective and efficient tuna conservation and management measures in compliance with IOTC decisions.

ii. The relevant government agencies should enforce compliance and reporting requirements for all fishing vessels licensed to fish in Kenyan waters unless otherwise, a fishing vessel that doesn't submit the data as required by law should not be considered for licensing in the subsequent years and penalized accordingly.

iii. In order to address this, challenge of non-compliance with reporting by DWFN, the study recommends the development and placement of scientific observers on all fishing vessels, in particular those operating in offshore waters (EEZ). Use and scaling out of low cost data collection and monitoring system including mobile phone technology and attaching tracking devices on artisanal fishing boats is desirable. This would help geo-reference the fishing grounds for the small-scale fishers.

iv. Aggregation of longline vessels along and across the EEZ borders of the different countries need to be closely monitored in compliance with the national fisheries legislation and regional/global instruments including Port States Measures Agreement (PSMA) and IOTC conservation and management measures. Detailed study of offshore vessel fishing activities through analysis of Vessel Monitoring and Satellite Automatic Identification System (AIS) data is recommended.

v. The relevant national fisheries management and research organizations should regularly collect and analyze the data and provide management advice to inform policy and decision making for improved tuna fisheries governance. KMFRI, has been monitoring the landings of tunas from two (2) Kenya flagged longliners. KMFRI also did some hydro-acoustic surveys in the EEZ off in Lamu, Kwale and Kilifi counties (KMFRI, 2018). The acoustic survey results indicated that the Kenya's EEZ had some significant fish biomass estimated at 2.2 Million Mt, at an exploitation rate of 20% (KMFRI, 2018). However comprehensive fish stock assessment as well as studies on ecosystem and ocean dynamics should be conducted by the relevant research institutions.

CHAPTER FIVE

5.0 SPECIES COMPOSITION AND TEMPORAL DISTRIBUTION OF TUNA & TUNA-LIKE FISH SPECIES IN THE ARTISANAL AND INDUSTRIAL CATCHES IN KENYAN WATERS

5.1 Introduction

Coastal and marine ecosystems are facing unprecedented pressure from anthropogenic and natural sources. Tunas, which are high predators, play an important role in the trophic structure in the marine ecosystem (Sardenne *et al.*, 2016). Tunas have been known to be good indicators of changes induced by human and the changing climate in the marine environment due to the modification of their population and trophic structures (Chassot *et al.,* 2018). Knowledge on species composition, diversity and distribution is pertinent to sustainable development and management of coastal and marine biodiversity including tuna and tuna-like fisheries resources.

5.2 Materials and Methods

5.2.1 Catch and Species Composition for Artisanal Tunas

Fish samples were collected from the catch landed by artisanal fishers in Amu (Lamu), Shella (Malindi), Watamu (Watamu), Mnarani (Kilifi) and Old Town (Mombasa) were sorted accordingly and identified to the lowest taxa using various identification guides/keys, namely, Lieske & Myers (2001), Anam & Mostard (2012), Richmond (eds) (1997), Smith & Heemstra (1995), Regional Tuna Tagging Project in the Indian Ocean (RTTP-IO) (2004), Itano (2005), IOTC (2013), World Register for Marine Species (WoRMs, 2016) and Fishbase. Individual fish was weighed using a weighing scale (electronic) to the nearest Kilogram (Kg). The Fork Length (FL), Lower Jaw Fork Length (LJFL) for swordfish as well as the Total Length (TL) of the fish were measured to the nearest whole centimeter (cm) using a flexible tape measure (Appendices 3 & 4). The fishing gear type, the fishing vessel, the number of fishing crew per boat, the time the fishing trip started and when the fishers landed the catch were recorded in a biological sampling form. The data was then keyed in excel spreadsheet and cleaned of errors before it was subjected to the analyses.

5.2.2 Catch and Species Composition for Tunas caught in Kenya EEZ

Catch data for tuna and tuna-like fish species in the Kenyan Exclusive Economic Zone (EEZ) was compiled from the Logbooks provided by 24 longliners flagged to Six countries, namely, Seychelles, Taiwan, Mauritius, China, Spain and Oman that declared their catch to the Kenya Fisheries Service (KeFS). The logbooks had the details of the fishing vessel, including the owner of the vessel, name of the vessel, date of entry to the fishing ground, date of departure from fishing ground, name of the species landed, number of pieces of the individual species landed, the total weight of each of the species landed (Kg) as well the by-catch species. The data was organized, keyed in in excel spreadsheets and cleaned of errors before it was subjected to the analyses.

5.3 Data Analyses

5.3.1 Artisanal Tuna Species Composition and Diversity

Spatial variation in artisanal tuna and tuna-like fish species composition was analyzed by estimating relative percentage abundance for the species aggregated per site from the total counts as well as weight. Relative percentage abundance was calculated by dividing the sum of each species of fish in the sample with the sum of individuals of fish species sampled multiplied by 100. The species diversity for each of the sites was then established using the Shannon-Weiner's diversity index (H') and species richness.

Observed species/taxa counts for each gear per sampling day were pooled by site, month and year of sampling. The pooled species counts were divided by the total observations and then the data was square root transformed to increase the sensitivity to detect differences driven by species/taxa of intermediate abundance. Non-metric multidimensional scaling (NMDS) based on Bray-Curtis similarity measures was used to examine variability in catch composition between gears and sites. ANOSIM and PERMANOVA tests were conducted to investigate whether the catch composition was significantly different between sampled gears and sites. Pairwise PERMANOVA tests were conducted to reveal combinations of gears and sites that differed significantly in their catch composition. Based on these results SIMPER analysis helped to identify the species/taxa that was important in driving the trends in EEZ tuna catch rates.

5.3.2 EEZ Tuna and Tuna-Like Fish Species

For spatial distribution of catches, QGIS (v 2.18) was used to plot the distribution of landed weights per species. The coordinates of vessels fishing locations were used to generate point shape files that were further colored based on the flag of the country where the vessel originated and sized proportionally according to the weight landed to 5 classes whose boundaries were defined by natural jenks or clusters.

The landings (both weight (kg) and species counts) of tuna and tuna-like species were aggregated per fished location, per day and vessels and analyzed using various multivariate statistical techniques. The landings were log (x + 1) transformed to down-weight the influence of dominant species and Bray-Curtis similarity matrices were produced and subsequently used for all multivariate analysis Non-Metric Dimensional Scaling (nMDS) plots were used to describe the landings captured by vessels from various flag states (Clarke, 1993). One-way analysis of similarities (ANOSIM) and Permutational Analysis of Variance (PERMANOVA) tests were used to test for differences among landings of vessels by various flag states (Anderson 2001). Similarity Percentage Analysis (SIMPER) was used to identify species that contribute to the dissimilarities across flags states. Similarity Profile Analysis (SIMPROF) clustering based on Bray Curtis similarities and wards minimum variance cluster linkage method was performed on landed weights to determine the number of significant clusters (Clarke *et al*., 2008). All multivariate analyses were based on 999 permutations by Anderson (2001), a new method for non-parametric multivariate analysis of variance.

5.3 Results

5.3.1 Artisanal Tuna Species and Catch Composition

A total of 2686 individuals of tunas representing 15 species, 13 genera and three (3) families were sampled. The three families are Scombridae, Istiophoridae and Xiphiidae. *Thunnus albacares* was the most abundant accounting for 48% of the individuals sampled (Fig. 32).

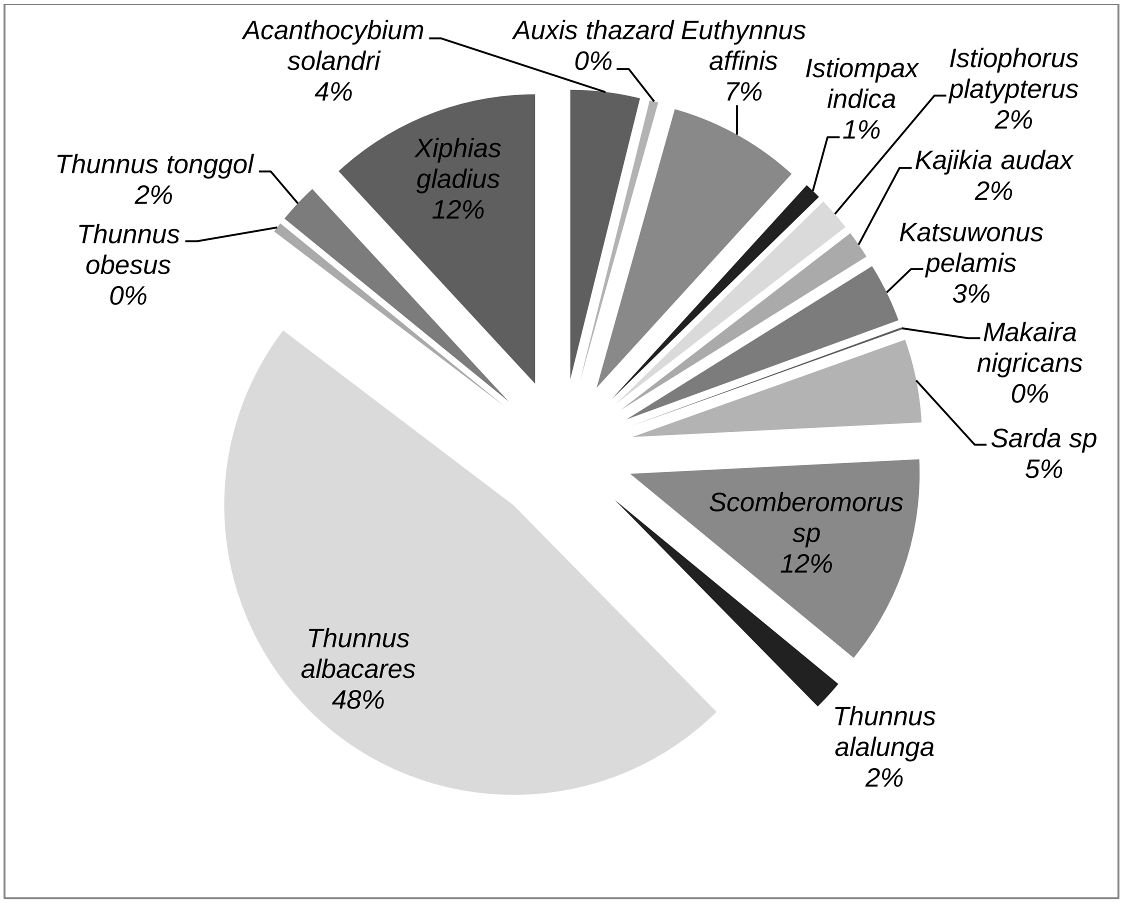


Figure 32. Abundance in numbers of the species sampled (%) from the artisanal tunas.

This was closely followed by *Xiphias gladius* (swordfish) and *Scomberomorus* spp *(*kingfish) at 12% each. *Euthynnus affinis* (kawakawa), *Sarda* spp (Bonito) and *Acanthocybium solandri* (wahoo) accounted for 7%, 5% and 4%, respectively. Other species were 3% and below.

A total of 31,672 Kg of fish were sampled. *Thunnus albacares* accounted for 40% of the total catch. *Xiphias gladius* and *Scomberomorus* spp contributed 28% and 8%, respectively (Fig. 33).

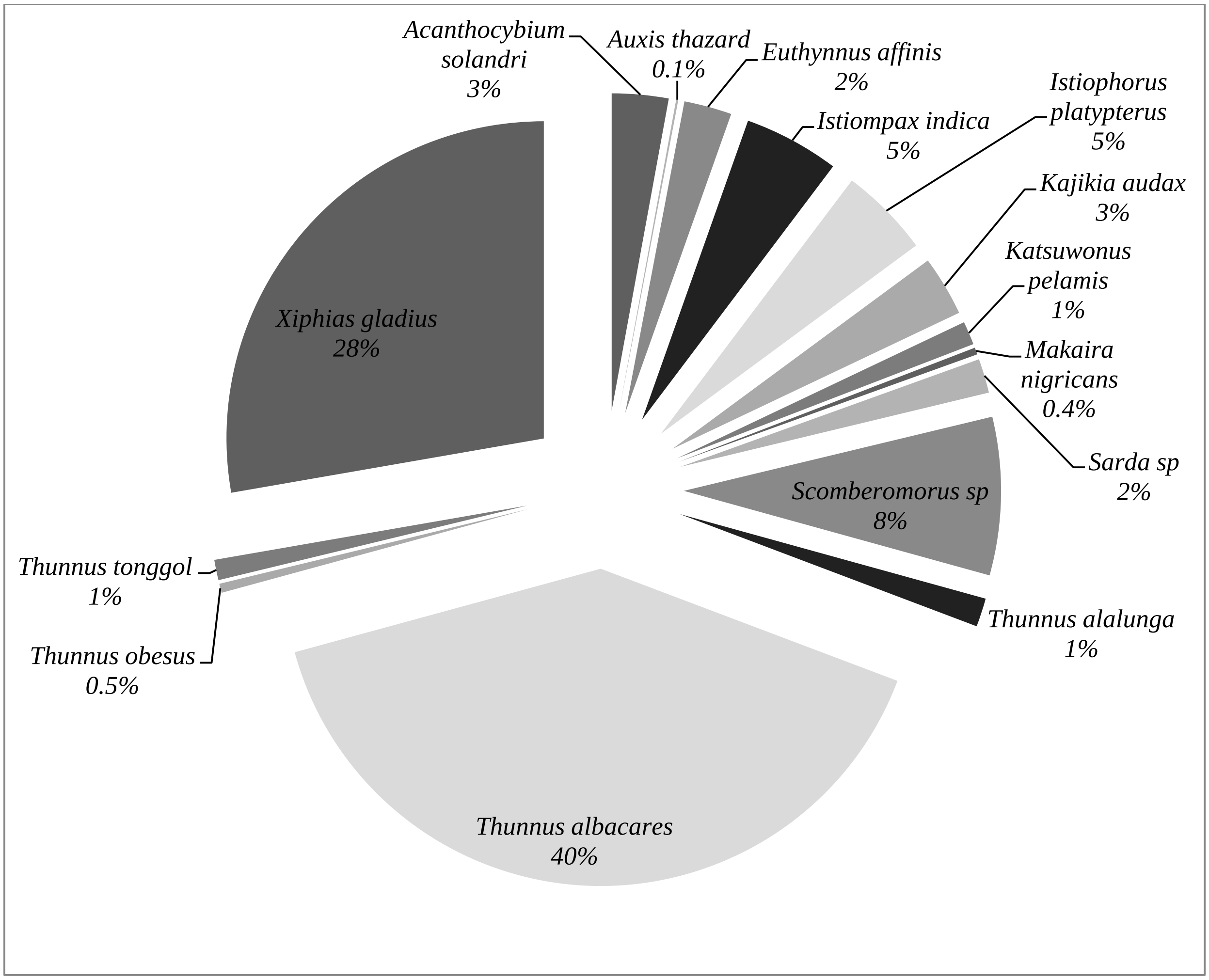


Figure 33. **Abundance by weight (Kg) by species (%) from artisanal tuna fishery during the sampling period.**

These results showed that the three species make an important contribution (76%) to the catch from artisanal sources.

5.3.2 Spatial variation in artisanal tuna catch composition

Species composition varied with sites (Fig. 34).

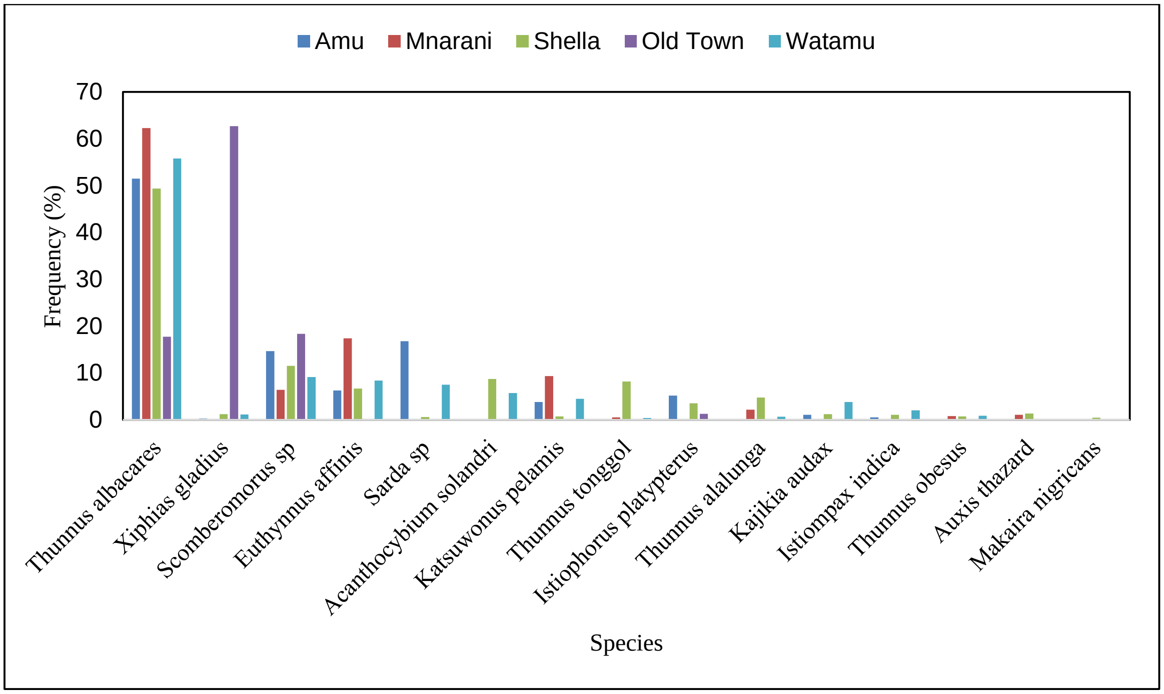


Figure 34. **Catch composition for the artisanal tuna and tuna-like species (Kg) per site during the sampling period.**

Thunnus albacares dominated the species composition in most of the sites, namely; Mnarani (62%), Watamu (56%), Amu (51%) and Shella (49%). *Xiphias gladius* dominated the species composition at Old Town (63%). *Sarda* spp, *Euthynnus affinis and Scomberomorus* spp were second dominant; 17%, 17%, 12% and 8% at Amu (Lamu), Mnarani (Kilifi) and Shella (Malindi), respectively. *Thunnus albacares and Scomberomorus* spp were equally dominant at Old Town, each with 18%.

Watamu recorded the highest number of individuals accounting for 29% of the fish sampled. This was closely followed by Shella (Malindi) and Old Town (Mombasa) with 25% and 18%, respectively. Amu (Lamu) and Mnarani (Kilifi) recorded 14% each. This variation in species composition could be associated with gear selectivity as well as the characteristics of water and substrate.

The results of the Non-Metric Multidimensional (NMDS) ordination plot (Fig.35) associated the tuna species with the different sites. *Xiphias gladius* was associated with Old Town while most of the other species were associated with Mnarani, Shella and Watamu.

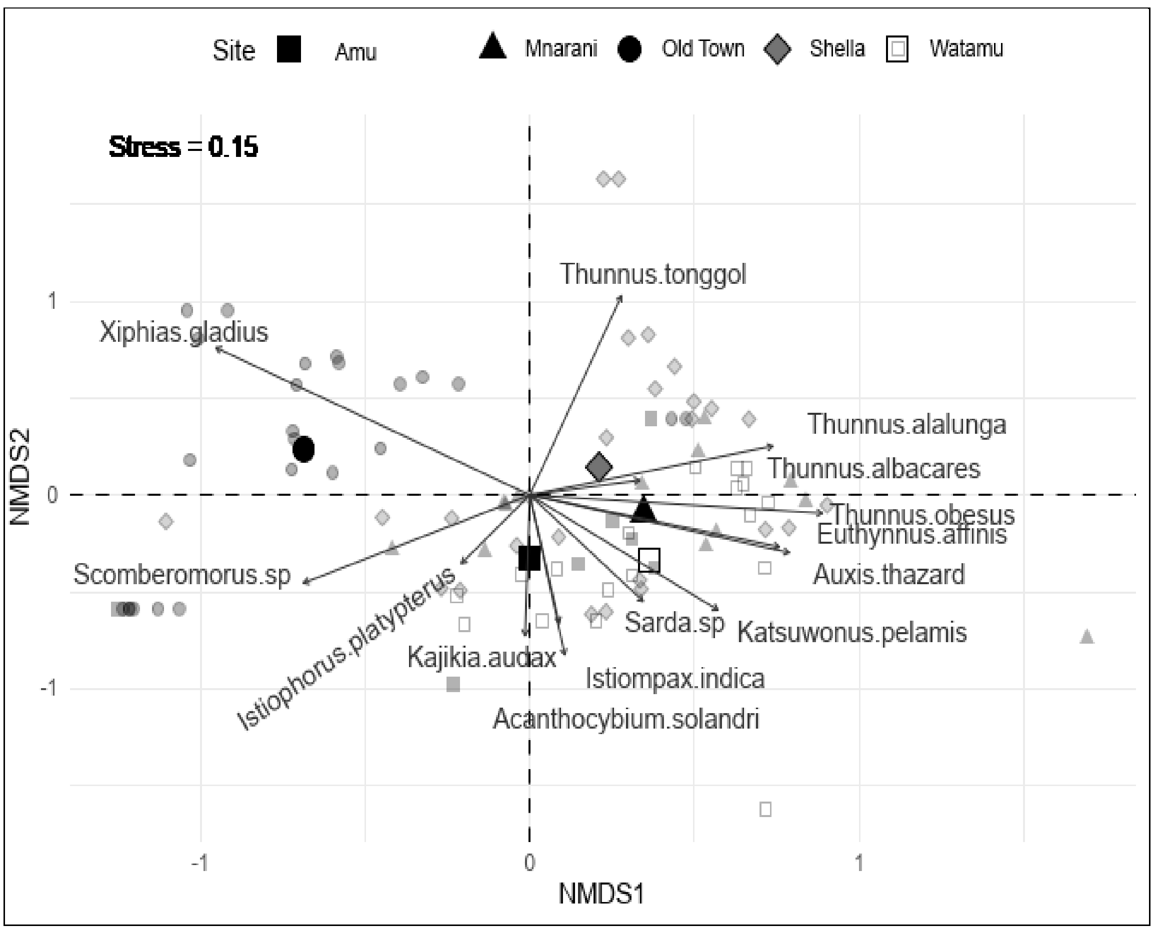


Figure 35. **Non-Metric Multidimensional (NMDS) ordination plot showing association of tuna species across the different sites.**

5.3.3 Species Diversity and Richness

Species diversity based on the Shannon – Wiener Diversity Index ($H^{'}$) across the four sampling sites is shown in Fig. 36.

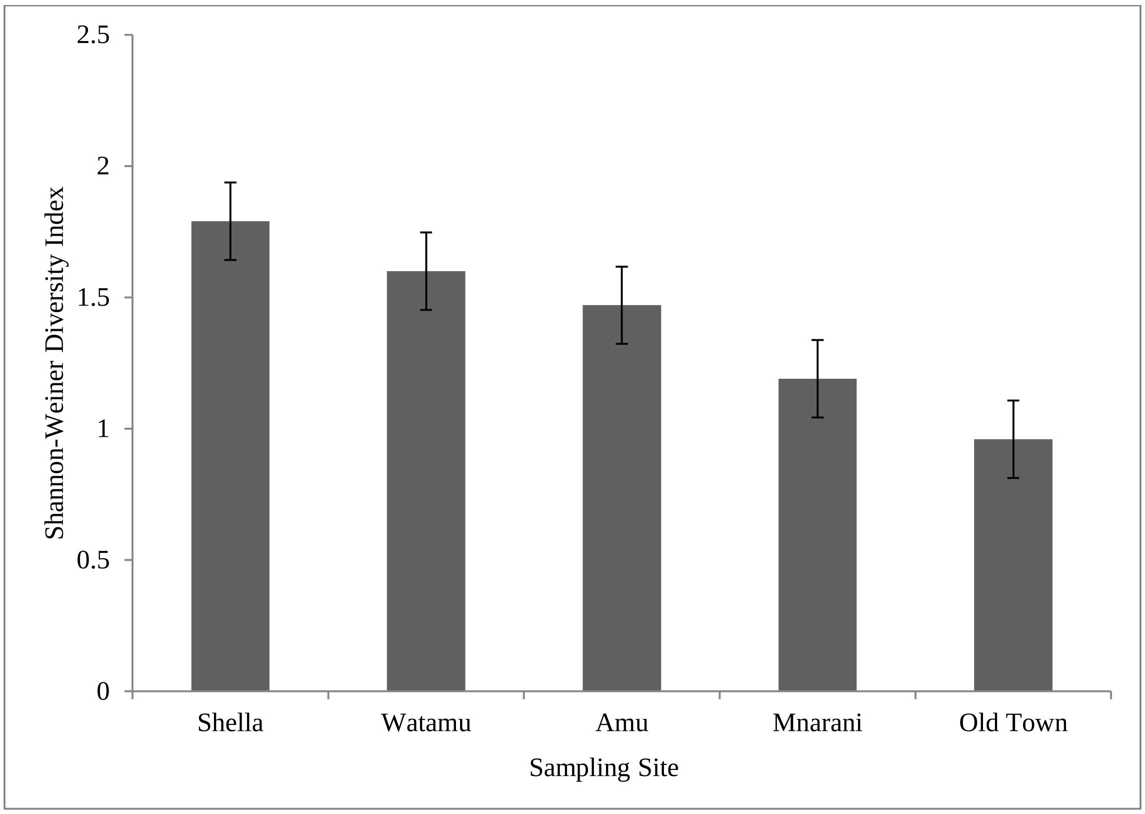


Figure 36. The Shannon – Wiener Diversity Index ($H^{'}$) of the tunas sampled in the different sites.

The results indicated that Shella (Malindi) recorded the highest diversity with $H^{'}$= 1.79, with Watamu following closely with $H^{'}$ = 1.6. Old Town registered the lowest diversity of tunas with $H^{'}$ = 0.96.

These diversity indices for the different sites are indicative and may not necessarily reflect the situation in the fishing ground considering that the fishing gears were selective of different fish size ranges targeted by the fishers. A total of 15 species were encountered in this study (Table. 4).

Table 4. **Spatial variation in artisanal tuna species richness where 1 denoting the presence and 0 absence of species in the site.**

Species	**Family**	**Sampling Sites**				
		Amu	**Mnarani**	**Shella (Malindi)**	**Old Town**	**Watamu**
Thunnus albacares	Scombridae	1	1	1	1	1
Xiphias gladius	Xiphiidae	1	0	1	1	1
Scomberomorus spp	Scombridae	1	1	1	1	1
Euthynnus affinis	Scombridae	1	1	1	0	1
Sarda spp	Scombridae	1	0	1	0	1
Acanthocybium solandri	Scombridae	0	0	1	0	1
Katsuwonus pelamis	Scombridae	1	1	1	0	1
Thunnus tonggol	Scombridae	0	1	1	0	1
Istiophorus platypterus	Istiophoridae	1	0	1	1	1
Thunnus alalunga	Scombridae		1	1	0	1
Kajikia audax	Istiophoridae	1	0	1	0	1
Istiompax indica	Istiophoridae	1	0	1	0	1
Thunnus obesus	Scombridae	0	1	1	0	1

Species	Family	Sampling Sites				
		Amu	Mnarani	Shella (Malindi)	Old Town	Watamu
Auxis thazard	Scombridae	0	1	1	0	0
Makaira nigricans	Istiophoridae	0	0	1	0	0
Species richness		**9**	**8**	**15**	**4**	**13**

Shella (Malindi) recorded the highest species richness of 15. This was closely followed by with Watamu where 13 species were recorded. Old Town registered the lowest species richness, 4. The presence of species in any of the sites seem to have been greatly influenced by the fishers' preference, vulnerability of the individual fish to capture by the fishing gears as well as the selectivity of the gears. This species richness may not be a true reflection of the species richness in the fishing round however is indicative of the key species that are landed by small-scale fishers in those respective landing sites.

5.3.4 Artisanal Tuna Species Catch Similarity

A two-dimensional nMDS (non- metric dimensional scaling) plot showed a significant separation of species caught by the different gears and across sites (2D stress 0.15). Analysis of similarity tests (ANOSIM) results detected significant differences between artisanal tuna species composition by gears (R= 0.37, p = 0.001, 999 permutations) and across sites (R= 0.32, p = 0.001, 999 permutations) Permutational analysis of variance tests (PERMANOVA) also indicated differences in the catch composition between the different fishing gears (F=9.50, p= 0.001, 999 permutations) and across sites (F=9.11, p= 0.001, 999 permutations). A pairwise PERMANOVA test was conducted to assess fishing gears and sites that differed significantly in their catch composition. Species contributing to dissimilarities across gears and sites were confirmed using a one-way SIMPER analysis (Table. 5).

Table 5. **One- way SIMPER analysis of artisanal tuna and tuna-like landings by different fishing gears for species cumulatively contributing up to 70% of the observed differences between fishing gears.**

a) Longline vs Trolling line

Taxa	**Average dissimilarity**	**Contribution (%)**	**Cumulative (%)**	**Mean a**	**Mean b**	**P value (999 permutations)**	**Overall dissimilarity**
Xiphias gladius	0.21	29.62	29.62	0.71	0.01	0.001	0.71
Thunnus albacares	0.11	16.33	45.95	0.42	0.70	0.62	
Scomberomorous spp	0.08	12.27	58.21	0.19	0.27	0.98	
Euthynnus affinis	0.07	10.41	68.62	0	0.24	0.09	
Acanthocybium solandri	0.04	5.67	74.29	0	0.15	0.34	

b) Gillnet vs Longline							
Taxa	**Average dissimilarity**	**Contribution,%**	**Cumulative,%**	**Mean a**	**Mean b**	**P value (999 permutations)**	**Overall dissimilarity**
Xiphias gladius	0.26	33.65	33.65	0	0.71	0.001	0.80
Thunnus albacares	0.17	21.6	55.25	0.46	0.42	0.007	
Thunnus tonggol	0.13	17.21	72.46	0.34	0	0.002	
c) Handline vs Longline							
Taxa	**Average dissimilarity**	**Contribution,%**	**Cumulative,%**	**Mean a**	**Mean b**	**P value (999 permutations)**	**Overall dissimilarity**
Xiphias gladius	0.23	31.85	31.85	0.05	0.71	0.001	0.73
Scomberomorous spp	0.14	19.94	51.79	0.41	0.19	0.003	
Thunnus albacares	0.13	18.51	70.3	0.46	0.42	0.06	
d) Gillnet vs Trolling line							
Taxa	**Average dissimilarity**	**Contribution,%**	**Cumulative,%**	**Mean a**	**Mean b**	**P value (999 permutations)**	**Overall dissimilarity**
Thunnus albacares	0.14	20.74	20.74	0.46	0.70	0.08	0.69
Thunnus tonggol	0.11	16.34	37.08	0.34	0.03	0.01	
Scomberomorous spp	0.10	14.69	51.77	0.17	0.27	0.68	

Euthynnus affinis	0.07	11.17	62.94	0.06	0.24	0.14	
Sarda spp	0.04	6.91	69.84	0.07	0.12	0.09	
e) Handline vs Trolling line							
Taxa	**Average dissimilarity**	**Contribution,%**	**Cumulative,%**	**Mean a**	**Mean b**	**P value (999 permutations)**	**Overall dissimilarity**
Scomberomorous spp	0.11	18.58	18.58	0.41	0.27	0.48	0.61
Thunnus albacares	0.11	18.45	37.04	0.46	0.70	0.79	
Euthynnus affinis	0.07	12.37	49.41	0.14	0.24	0.007	
Thunnus tonggol	0.05	8.42	57.83	0.16	0.03	0.69	
Acanthocybium solandri	0.04	7.98	65.81	0.08	0.15	0.005	
Katsuwonus pelamis	0.04	7.08	72.9	0.06	0.13	0.003	

These results indicate that *Xiphias gladius*, *Thunnus albacares and Scomberomorous* spp. significantly contributed to the catch and were more abundant compared to the rest of the species. Longline gear significantly contributed to the harvesting of *Xiphias gladius*.

5.3.5 EEZ tuna species and catch composition

Pooled historical catch data for the EEZ tunas (as percentage) for the period 2012 – 2017 is shown in Fig. 37.

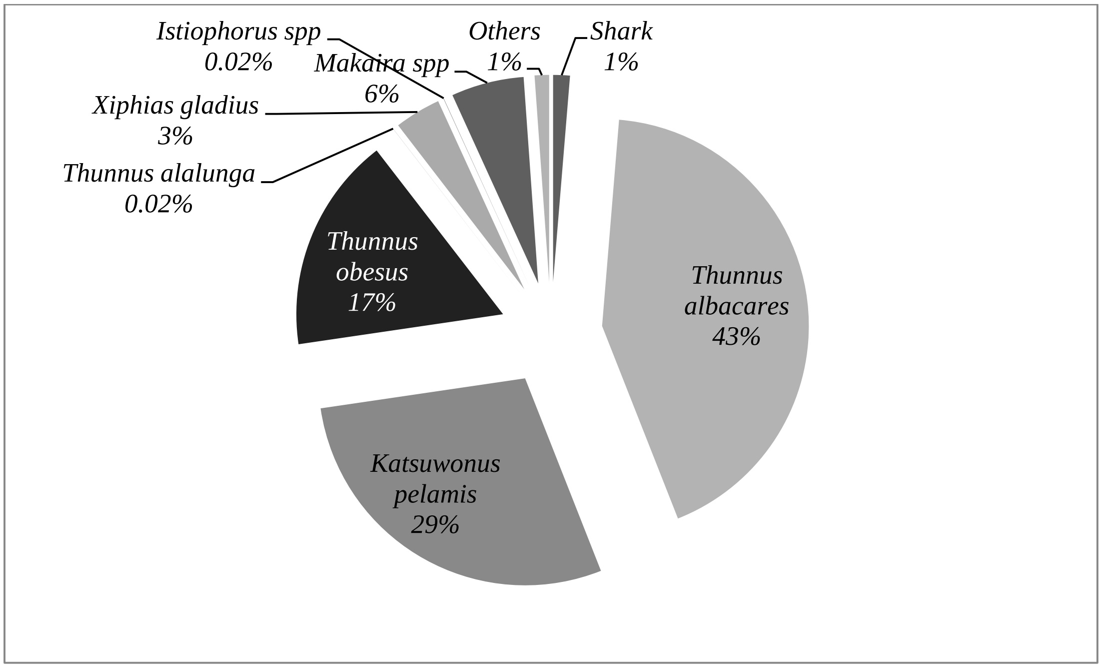


Figure 37. Catch composition of the tunas harvested by longline fleets in Kenya EEZ in 2012-2017.

The catch composition is based on the weight of the individual species landed over the reporting period.

These results show that a total of 1833 individuals of tunas weighing about 1,519,398 Kg were harvested by the 24 longliners from six foreign countries that submitted data to the Kenya Fisheries Service. The catch was dominated by *Thunnus albacares, Katsuwonus pelamis* and *Thunnus* *obesus a*ccounting for 43%, 29% and 17%, respectively. The three species contributed to 89% of the total catch. *Thunnus alalunga* and *Istiophorus* spp for less than 1%. The results indicate that yellowfin, skipjack and albacore tunas are the main target species by the industrial tuna fishing vessels. The yellowfin tuna stock has been overfished and more efforts are now being directed at stock rebuilding by the IOTC members (IOTC, 2021).

5.3.6 Tuna Species Catch Similarity by Flag States

One-way SIMPER analysis of tuna and tuna-like species landings in the Kenyan EEZ waters by vessels from different flag states indicate some dissimilarities (Table 6).

Table 6. One-way SIMPER analysis of tuna and tuna-like landings in the Kenyan EEZ waters by vessels from different flag states.

Species	**Mean abundance**		**Average dissimilarity**	**ratio**	**Cumulative contribution (%)**	**P(999 permutations)**	**Overall dissimilarity**
1. Oman vs. Spain	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	
Katsuwonus pelamis	0.00	3.63	0.19	1.94	0.25	0.001	0.78
Thunnus obesus	2.29	0.76	0.12	2.19	0.40	0.001	
Thunnus albacares	2.38	3.08	0.11	1.55	0.55	0.001	
Shark	2.06	0.00	0.10	1.97	0.68	0.001	
Xiphias gladius	1.72	0.27	0.09	1.82	0.79	0.01	

Species	Mean abundance		Average dissimilarity	ratio	Cumulative contribution (%)	P(999 permutations)	Overall dissimilarity
2. China vs. Spain	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	**Overall dissimilarity**
Katsuwonu pelamis	0.00	3.63	0.22	2.06	0.29	0.001	0.77
Thunnus albacares	2.23	3.08	0.13	1.88	0.46	0.001	
Thunnus obesus	2.14	0.76	0.13	2.26	0.62	0.001	
Makaira spp	1.83	0.00	0.11	1.63	0.76	0.001	
3. Taiwan vs. Spain	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	**Overall dissimilarity**
Katsuwonus pelamis	0.00	3.63	0.22	2.07	0.29	0.001	0.75
Thunnus obesus	2.52	0.76	0.14	2.23	0.48	0.001	
Thunnus albacares	2.30	3.08	0.13	1.75	0.65	0.001	
Xiphias gladius	1.73	0.27	0.11	1.67	0.79	0.001	
4 Oman vs. Mauritius	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	**Overall dissimilarity**
Katsuwonus pelamis	0.00	4.10	0.20	4.33	0.28	0.001	0.72
Thunnus obesus	2.29	0.66	0.10	2.28	0.42	0.03	
Thunnus.albacares	2.38	4.30	0.10	1.94	0.56	0.06	
Shark	2.06	0.00	0.09	2.05	0.69	0.001	
Xiphias gladius	1.72	0.00	0.08	1.94	0.79	0.17	
5.Seychelles vs. Spain	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Katsuwonus pelamis	0.07	3.63	0.23	1.93	0.31	0.001	0.72

Species	Mean abundance		Average dissimilarity	ratio	Cumulative contribution (%)	P(999 permutations)	Overall dissimilarity
Thunnus obesus	2.50	0.76	0.14	1.82	0.51	0.001	
Thunnus albacares	2.49	3.08	0.13	1.43	0.69	0.001	
Xiphias gladius	1.56	0.27	0.10	1.49	0.83	0.001	
6.China vs. Mauritius	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Katsuwonus pelamis	0.00	4.10	0.23	5.78	0.32	0.001	0.71
Thunnus albacares	2.23	4.30	0.12	2.24	0.49	0.01	
Thunnus obesus	2.14	0.66	0.11	2.24	0.64	0.02	
Makaira spp	1.83	0.00	0.10	1.72	0.78	0.01	
7.Taiwan vs. Mauritius	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	**Overall dissimilarity**
Katsuwonus.pelamis	0.00	4.10	0.23	5.96	0.33	0.001	0.70
Thunnus obesus	2.52	0.66	0.12	2.18	0.50	0.01	
Thunnus albacares	2.30	4.30	0.11	2.03	0.67	0.01	
Xiphias gladius	1.73	0.00	0.09	1.76	0.80	0.01	
8.Seychelles vs. Mauritius	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Katsuwonus.pelamis	0.07	4.10	0.23	4.43	0.35	0.001	0.66
Thunnus obesus	2.50	0.66	0.12	1.80	0.54	0.01	
Thunnus albacares	2.49	4.30	0.11	1.57	0.70	0.02	
Xiphias gladius	1.56	0.00	0.09	1.55	0.83	0.04	

Species	Mean abundance		Average dissimilarity	ratio	Cumulative contribution (%)	P(999 permutations)	Overall dissimilarity
9. Seychelles vs. Oman	**ava**	**avb**	**average**	**ratio**	**cumsum**	**P**	**Overall dissimilarity**
Shark	0.17	2.06	0.09	1.84	0.23	0.001	0.39
Others	0.27	1.50	0.07	1.67	0.40	0.001	
Makaira spp	1.59	1.30	0.07	1.13	0.57	1.00	
Xiphias gladius	1.56	1.72	0.05	0.99	0.70	0.97	
10.China vs. Oman	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Shark	0.36	2.06	0.09	1.69	0.25	0.00	0.35
Makaira spp	1.83	1.30	0.06	1.10	0.42	1.00	
Others	0.90	1.50	0.05	1.28	0.57	0.08	
Xiphias gladius	1.50	1.72	0.05	1.03	0.72	0.98	
11.Seychelles vs. Taiwan	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Makaira spp	1.59	0.86	0.08	1.21	0.22	0.64	0.35
Shark	0.17	1.20	0.07	1.14	0.40	0.00	
Xiphias gladius	1.56	1.73	0.06	1.01	0.58	0.95	
Thunnus obesus	2.50	2.52	0.05	0.89	0.73	1.00	
12.China vs. Taiwan	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Makaira spp	1.83	0.86	0.08	1.30	0.22	0.32	0.35
Shark	0.36	1.20	0.06	1.17	0.41	0.00	

Species	Mean abundance		Average dissimilarity	ratio	Cumulative contribution (%)	P(999 permutations)	Overall dissimilarity
Xiphia gladius	1.50	1.73	0.06	1.12	0.57	0.99	
Others	0.90	0.59	0.05	1.09	0.73	0.00	
13.Seychelles vs. China	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Makaira spp	1.59	1.83	0.08	1.14	0.22	0.79	0.34
Xiphias gladius	1.56	1.50	0.06	1.08	0.40	0.99	
Thunnus obesus	2.50	2.14	0.06	1.01	0.58	0.93	
Others	0.27	0.90	0.05	1.02	0.73	0.00	
14.Taiwan vs. Oman	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Shark	1.20	2.06	0.07	1.27	0.21	0.01	0.32
Others	0.59	1.50	0.06	1.39	0.39	0.03	
Makaira spp	0.86	1.30	0.05	1.13	0.56	1.00	
Xiphias gladius	1.73	1.72	0.05	0.94	0.71	0.98	
15.Spain vs. Mauritius	**ava**	**avb**	**average**	**ratio**	**cumsum**	**p**	**Overall dissimilarity**
Thunnus.albacares	3.08	4.30	0.11	0.79	0.44	0.03	0.24
Katsuwonus pelamis	3.63	4.10	0.06	0.65	0.70	0.13	

In these results the focus is on species contributing 70% of the observed differences between flags states. SIMPER analyses indicated an overall dissimilarity between vessel flag states of 54%, however, Mauritius and Spain were highly dissimilar (66 - 78 %) from the other groups. Taiwan, Oman, China and Seychelles were ~65% similar in their catch composition.

A two dimensional Non-metric dimensional scaling (NMDS) ordination revealed a clustering of the catch composition by weight of the vessel flag states into two distinct groups at 50% similarity with a stress value of 0.16 (Fig. 38).

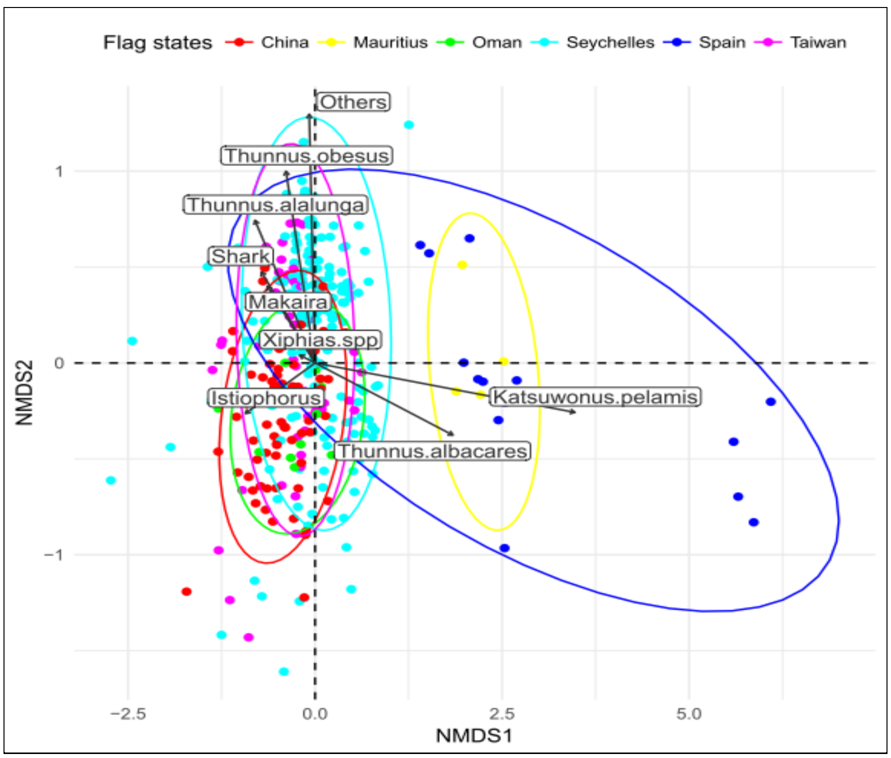


Figure 35. **Non-Metric Dimensional Scaling (NMDS) of tuna landings in the study area associated with flags licensed to fish in the Kenyan EEZ waters.**

Spain and Mauritius formed one group while China, Taiwan, Oman and Seychelles formed the second group (Fig. 39)

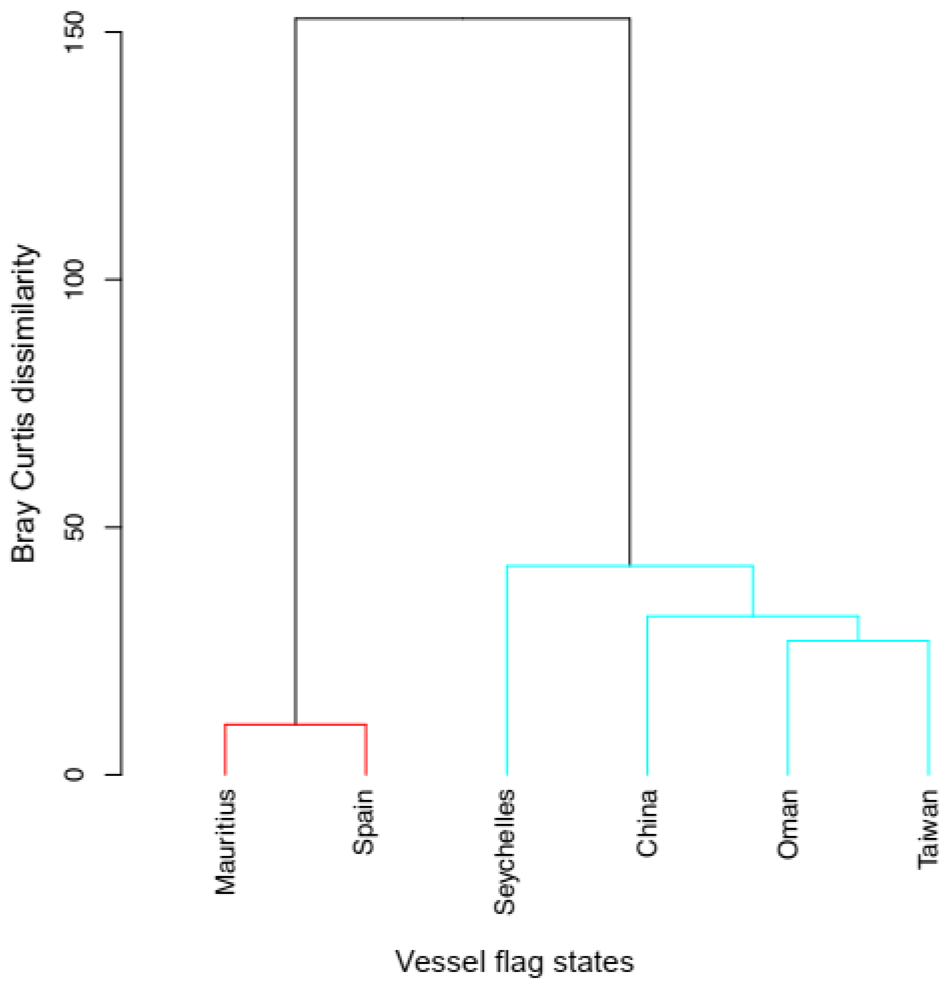


Figure 39. Similarity cluster of flag states.

Analysis of similarities (ANOSIM) of the catch composition by weight found a significant difference between vessel flag states catches (Global R= 0.26, p = 0.01, 999 permutations). Permutational analysis of variance tests (PERMANOVA) also indicated differences between the flag states (F=29.30, p= 0.001, 999 permutations). Pairwise permanova tests based on the weight composition of fish landed revealed significant differences between vessel flag states. There were no significant differences between catch composition of Spain and Mauritius (F: 0.63, p: 1) as well as between Taiwan and Oman (F: 3.63, p: 0.08) (Table 7).

Table 7. **Pairwise PERMANOVA results of tuna and tuna-like landings in Kenyan EEZ waters.**

Pairs	**F statistic**	**R2**	**p (unadjusted)**	**p.adjusted (bonferronni)**
China vs Spain	38.11	0.32	0.001	0.015
Taiwan vs Spain	35.78	0.33	0.001	0.015
Seychelles vs Spain	32.93	0.15	0.001	0.015
Seychelles vs China	22.36	0.08	0.001	0.015
Oman vs Mauritius	21.51	0.61	0.001	0.015
Oman vs Spain	20.68	0.46	0.001	0.015
China vs Mauritius	19.30	0.22	0.001	0.015
Taiwan vs Mauritius	18.68	0.23	0.001	0.015
Seychelles vs Mauritius	14.80	0.07	0.001	0.015
China vs Taiwan	10.94	0.08	0.001	0.015
Seychelles vs Taiwan	8.85	0.04	0.001	0.015

Pairs	F statistic	R2	p (unadjusted)	p.adjusted (bonferronni)
Seychelles vs Oman	6.74	0.03	0.001	0.015
China vs Oman	4.70	0.06	0.002	0.03
Taiwan vs Oman	3.63	0.05	0.005	0.075
Spain vs Mauritius	0.63	0.03	0.684	1

Katsuwonus pelamis, Thunnus albacares and Thunnus obesus cumulatively contributed > 50% of the dissimilarities between Mauritius and Spain on the one hand and the rest of the vessel flag states on the other. Generally, *Katsuwonus pelamis* and *Thunnus albacares* were greater in abundance in the catches of the two (2) flag states while *Thunnus obesus* was lower. *Thunnus albacares and Katsuwonus pelamis* accounted for 59% and 41% in the Mauritius catch respectively. The two species contributed about 49% each of the Spain fleet.

5.4 Discussions

A total of 2686 individuals of tunas representing 15 species, 13 genera and Three (3) families were encountered in this study. The three families are Scomboridae, Istiophoridae and Xiphiidae. Scomboridae family was the most abundant with *Thunnus albacares* (yellowfin tuna) frequently encountered, accounting for 48% of the individual fish sampled (Fig. 32) and contributed to 40% of the total catch in weight (Fig. 33). *Thunnus albacares*, *Xiphias gladius* and *Scomberomorus* spp accounted for 76% of the total catch indicating their significant importance in the artisanal fisheries sector in Kenya. Tropical tunas *Thunnus albacares*, *Thunnus alalunga*, *Thunnus obesus*; the neritic tunas, namely *Euthynnus affinis* (kawakawa), *Auxis thazard* (Frigate tuna) and *Thunnus tonggol* (Longtail tuna); tuna-like species namely *Xiphias gladius*, *Sarda* spp, *Acanthocybium solandri, Katsuwonus pelamis*, *Istiophorus platypterus*, *Kajikia audax, Istiompax indica* and *Makaira nigricans* form an important commercial artisanal fishery.

It is evident from this study that abundance of artisanal tuna, species richness and diversity varied across the sampling sites (Fig. 34). The observed differences in species composition, species diversity and richness across the different sites could be attributed to the type and size of fishing gears. This is confirmed by the results of the One- way SIMPER analysis which indicated that the observed difference in the artisanal tuna and tuna-like species composition is associated with the fishing gears. Pairwise combination of longline and trolling line revealed that *Xiphias gladius* significantly contributed to the observed difference in species composition (P = 0.001) with over 90% and 3% of the individuals captured by longline and trolling line, respectively. Similar observations were noted with a combination of gillnet and longline where *Xiphias gladius* contributed to over 33% of the observed difference (P = 0.001). Most of the fishers (86%) who landed their fish catch at Old Town (Mombasa) deployed longlining gears in their fishing operations mainly targeting large sized fish including swordfish (*Xiphias gladius*) and yellowfin tuna (*Thunnus albacares*). This explains why *Xiphias gladius* is associated with Old Town as indicated in the Non-Metric Multidimensional (NMDS) ordination plot (Fig.35) which suggest that different tuna and tuna-like species were associated with different landing sites. Other species including *Thunnus albacares, Scomberomorus* spp, *Sarda* spp were associated with other sites, Mnarani, Shella and Watamu.

It is clear from this study that Shella (Malindi) and Watamu had the highest species diversity based on Shannon – Wiener Diversity Index, $H' = 1.79$ and $H' = 1.6$ (Fig. 36), respectively. It was also observed that the two sites had high species richness compared to the other sites (Table 4). These differences could have been attributed to the type, size and selectivity of the fishing gears used. Most of the fishers in Shella (Malindi) and Watamu deploy different gears including trolling, gillnet and handline which are highly selective to small sized tuna and tuna-like fish species (Table5). Old Town (Mombasa) had the lowest diversity of tunas because the longline gears are highly selective to large sized fish. The frequency of sampling may have also contributed to observed variation in species composition across different sites. Although Mnarani fishers used diverse gear combinations, species composition was fairly low. Similar observations were noted in Lamu (Amu). This is because relatively few fish samples were taken from the two sites compared to other sites. The species richness and diversity reported in this study may not be a true reflection of the actual situation of the number of individual species of tunas in the respective fishing grounds because fishers seemed to have preference of certain sizes and types of fish, hence highly selective and therefore these figures should be treated as indicative.

The catch by weight for the EEZ tunas was dominated by *Thunnus albacares*, *Katsuwonus pelamis* and *Thunnus obesus* (Fig. 37) Some 24 longline vessels flagged to six states fishing in Kenyan EEZ showed some dissimilarities in the catch landed (Table 6). The results revealed some clustering of the catch composition by weight of the fish per vessel flag states into two distinct groups (Fig. 38). Spain and Mauritius formed one group while China, Taiwan, Oman and Seychelles formed the second group (Fig. 39). Permutational analysis of variance tests (PERMANOVA) (Table 7) based on the weight composition of fish landed revealed significant differences in the catches between vessel flag states ($F=29.30$, $p= 0.001$, 999 permutations).

However, there was no significant differences between fish catch composition in vessels flagged to Spain and Mauritius (F: 0.63, p: 1) as well as Taiwan and Oman (F: 3.63, p: 0.08).

The difference between the species composition of the catches between Spain and Mauritius and other countries could be attributed to the type and weight of the species of fish landed. For instance, the two species, yellowfin tuna and skipjack tuna contributed about 59% and 41% of the catch landed by Spain and Mauritius flagged vessels, respectively. The two species contributed about 49% each of the catch by the fleet flagged to Spain.

Species diversity, composition and richness of tunas recorded across the different sites including the EEZ was influenced to some extent by various factors including size and type of fishing gears (IOTC, 2013; King, 1995; Herrmann *et al.,* 2016; Tuda *et al*., 2016; Kaplan *et al*., 2014; Maunder *et al.,* 2006), type of fishing methods (King, 1995; IOTC, 2013), the species being targeted (King,1995; IOTC, 2013; Tuda *et al*., 2016), how the individuals are distributed in the environment (King, 1995; IOTC, 2013), the kind of season and conditions of the habitat (King, 1995; McClanahan, 1988; Tuda *et al.*, 2016) and how the sampling was undertaken (King, 1995). The larger the size of the fishing hook, the higher the probability of catching a large sized and heavier individual, and the lower the chances of capturing a small sized individual (Ingolfsson *et al.*, 2017; Herrmann *et al.,* 2016; Kar *et al*., 2012).

The results of this study has revealed that different fishing gears and tunas are associated with different sites and can inform site specific tuna fisheries management measures to avoid overfishing.

5.5 Conclusions and Recommendations

5.5.1 Conclusions

Species and catch composition for both artisanal and offshore tuna catches varied with seasons, the types of fishing gear and methods as well as the fishing ground. This is because artisanal and industrial longline fishers target specific species and sizes of the tunas of their preference. The amount of tuna catches varied between months. May to October (South East Monsoon- SEM) reported high catch rates whereas relatively low catch rates were reported in December to April during the North East Monsoon (NEM) season.

Yellowfin, skipjack and bigeye dominated catch for the offshore tunas by weight. Yellowfin, swordfish and kingfish on the other hand were dominant in the artisanal catches by weight. These results show the importance of these fisheries to the local and national economy.

Longline vessels flagged to Spain, Seychelles and Mauritius accounted for most (89%) of the tuna catches in the Kenya EEZ for the period 2012 to 2017. These could be associated with the proximity of the cannery facilities in Seychelles and Mauritius where the vessels have to supply raw tuna for processing.

There was evidence of aggregation of longline vessels along and across the EEZ borders between Kenya, Somalia and Seychelles, especially those flagged to Seychelles, China, Spain and Taiwan. Spanish and Chinese vessels fished in the Kenya EEZ towards Somalia.

The logbook data provided by the longliners had some of the species lumped together which made it difficult to ascertain the type of genus or species being reported, particularly, for the sharks and the billfishes. This could be attributed to the challenges of taxonomy and species identification which the Government of Kenya can address through targeted training.

Considerable amounts of unidentified sharks were landed by the longliners either as by-catch and or targeted fishery. Although the sharks are not directly under the management of IOTC, they interact with tuna fishing operations and every effort should be made to conserve them.

5.5.2 Recommendations

This study proposes the following recommendations in view of its findings on the species and catch composition of tunas both in coastal and EEZ waters.

i. Since the data on by-catch by the longliners is poor, national fisheries management authorities and research institutions should conduct scientific assessment of the by-catch in the tuna fishery landed by longliners from the Kenya EEZ in order to effectively manage the tuna fishery in Kenyan waters. The catch data collection and reporting system should incorporate collection of by-catch species in both coastal and offshore tuna fishing operations. This should inform the development of a comprehensive by-catch reduction and mitigations strategy in Kenya. Currently there is no by-catch strategy in the country.

ii. The scientific knowledge, taxonomy and tuna species identification in Kenya and the entire South West Indian Ocean region is limited. Relevant national and regional institutions should conduct short term courses and training on tuna and tuna-like species identification which should be integral to comprehensive fisheries statistical programme at national level. The IOTC species identification guides should be translated into Kiswahili and other local languages to enhance and sharpen the skills of local fishers and data collectors on species identification.

iii. Fishing activities in the Kenyan EEZ should be closely monitored and compliance with data reporting requirement enforced. This is to ensure that the vessels provide quality data timely and in the right format that is easily analyzed and used to inform policy and decision making.

CHAPTER SIX

6.0 SIZE DISTRIBUTION AND GROWTH PARAMETERS OF ARTISANAL TUNAS IN THE KENYAN WATERS

6.1 Introduction

Fisheries resources are dynamic hence complex to develop and manage without adequate sound knowledge on the health and condition of the fish stocks. Knowledge of fish population structure and the status of fish stocks is essential for policy makers and stock managers to provide a clear plan for sustainable fisheries management and conservation. A comprehensive fisheries conservation and management and monitoring plan should be able to identify fishery pattern changes and issues such as ecosystem and habitat destruction, predation and optimal exploitation rates. Fisheries population dynamics and growth parameters such as length frequency distribution, growth, age and mortality rates are necessary to inform reliable and effective stock assessments, and to ensure a sustainable exploitation of the fisheries (Kaymaram *et al.,* 2013).

Stock assessment is informed by reliable, credible and adequate data on the fishery including length frequency distribution, length-weight frequency, growth parameters and mortality rates. The information generated by science and fish stock assessment is important to inform fisheries policy and decision making with a view to improving tuna governance for improved socio-economic benefits.

Length-based and growth parameters approaches are effective and efficient approaches for evaluating the status of data poor fisheries, especially the small-scale where data collection is a challenge. A range of approaches to be used this context include application of growth parameters, biological reference points, harvest control rule.

In this chapter, the focus is on objective three of the study, the size distribution and growth parameters of tunas sampled from artisanal catches in the Kenyan waters. For the purpose of this chapter, the focus is on three species which accounted for over 67% of the total catch composition by weight. These species were *Thunnus albacares* (yellowfin tuna), *Xiphias gladius* (swordfish*) and Euthynnus affinis (*kawakawa). The choice of these species was based on the representativeness of the species during the sampling period and the relative contribution to the overall catch. *Thunnus albacares* (yellowfin tuna) was the most abundant species and accounted for 48% of the sum of fish species sampled. *Xiphias gladius* (swordfish) accounted for 12% while *Euthynnus affinis* (kawakawa) contributed 7% of the catch.

6.2 Materials and Methods

Fish samples were collected from the catch landed by artisanal fishers in Amu (Lamu), Shella (Malindi), Watamu (Watamu), Mnarani (Kilifi) and Old Town (Mombasa) were sorted accordingly and identified to the lowest taxa using various identification guides/keys, namely, Lieske & Myers (2001), Anam & Mostard (2012), Richmond (eds) (1997), Smith & Heemstra (1995), Regional Tuna Tagging Project in the Indian Ocean (RTTP-IO) (2004), Itano (2005), IOTC (2013), World Register for Marine Species (WoRMs, 2016) and Fishbase. Individual fish was weighed using a weighing scale (electronic) to the nearest Kilogram (Kg). The Fork Length

(FL), Lower Jaw Fork Length (for Swordfish) as well as the Total Length (TL) of the fish were measured to the nearest whole centimeter (cm) using a flexible tape measure (Appendices 3 & 4). The fishing gear type, the fishing vessel, the number of fishing crew per boat, the time the fishing trip started and when the fishers landed the catch were recorded in a biological sampling form. The data was then keyed in excel spreadsheet and cleaned of errors before it was subjected to the analyses.

Data was analyzed to determine the length frequency, size distribution, probability of capture and estimation of growth parameters including maturity, spawning potential ratio, fishing mortality and exploitation rate.

6.3 Data Analyses

6.3.1 Length – Weight Relationship

The Fork Length (FL), to the nearest centimetre (cm), and weight (W) to the nearest Kilogramme (Kg), were used to plot length/weight relationship curves, thus a regression line producing values ***a*** and ***b***. The formula below was then used to calculate the relationship between length and weight;

W = aL^b (Le Cren, 1951)

Where;

W is Total body weight (g)

L is Fork Length (cm)

a is a growth coefficient or condition factor (a constant) b is the relative growth rate (exponent)

The degree of association between the length and weight was calculated by the determination coefficient, R^2, estimated through a regression model. In order to verify if the b value for each fish species was statistically different from the assigned prediction, the student t-test was performed to data sets. The weight-length estimates were log transformed, and outliers removed. One sample t-test was conducted to test for the deviation of the slope from 3. The growth was described as positive allometric growth where $b > 3$, and negative allometric growth where $b < 3$, $p < 0.05$.

6.3.2 Length-Frequency Distribution

The length frequency data was categorized by month and binned in 6 cm intervals for individual gears and gear combination). The FISAT (ELEFAN) and von-Bertalanffy were used to analyze Length-Frequency and gear selectivity data. The length frequency distribution graphs and catch curves were then prepared using the length measurements. The length and weight measurements were used in combination to determine length-weight relationship and Virtual Population Analysis (VPA) to determine the coefficient of growth, growth parameters, mortality and exploitation rates. VPA is used to estimate the present and historical fish abundance and fishing mortality rate by analyzing the catch of year classes (cohorts) over a period of time to generate an estimate of year-class size over time (Jennings *et al.*, 2001). Generally, VPA follows each year class retrospectively from its terminal abundance. This is estimated by using the relationship where the numbers in a cohort the previous year are equal to the numbers in the cohort in the current year less deaths caused by natural and fishing mortalities.

6.3.3 Estimation of Growth Parameters

ELEFAN 1 (Pauly, 1987) routine in FISAT II (Gayanilo *et al*., 1994) were used to estimate the von Bertalanffy growth function (VBGF) asymptotic length (L_∞) and the growth coefficient (K). The mean annual water surface temperature of 26^{o}C (for species in the tropics) was used in the analyses.

The Response Surface Analysis routine was used to identify the combination of the growth parameters that would give the best fit when a range of L_∞ and K values and a fixed starting point (SS) and starting Length are given. The following length based VBGF formula (Sparre &Venema, 1998) was fitted to the data:

$$Lt = L_\infty(1-\exp(-K(t-t0)))$$

Where L_∞ is the asymptotic length, K is the von Bertalanffy growth coefficient, t_0 is the theoretical age at length zero and L_t is the length at age t.

The growth performance index (ϕ') (Pauly & Munro, 1984) was estimated following the equation:

$$\phi' = \log(K) + 2\log(L_\infty).$$

6.3.4 Estimation of Mortality Rates

Total mortality rate (Z) was calculated using a linearized length converted catch curve (Pauly, 1983; 1984) on pooled data and supplied with the estimates of growth parameters, namely the Asymptotic Length (L_∞) and Von Bertalanffy constant (K).

The following equation was used:

$$\text{Log}_e(N_i / \Delta t_i) = a + bt_i$$

Where N is the number of fish in length class *i*, Δt is the time required for the fish to grow through length class *i*, t is the age corresponding to the midlength of class *i*, and where *b*, with sign changed, is an estimate of total mortality coefficient (Z).

Natural mortality rate (M) was estimated using indirect methods following (Pauly, 1980) empirical relationship expression:

$$\text{Log } M = -0.0066 - 0.279 \text{ 1og } L_\infty + 0.6543 \log K + 0.4634 \log T$$

Where M is the instantaneous natural mortality rate, L_∞ is the asymptotic length, T is the mean surface temperature at 26°C and K refers to the VBGF growth rate coefficient.

Fishing mortality rate (F) was calculated using the relationship (Gulland, 1971) as follows;

$$F = Z - M$$

Where Z is the instantaneous total mortality rate and M is the instantaneous natural mortality rate.

The exploitation rate (E) was calculated as a ratio of the fishing mortality(F) to the total mortality (Z):

$E = F/Z$

6.3.5 Fishing Gear Selectivity

Gear selection parameters at 25%, 50% and 75% of L_{max} (L_{c25}, L_{c50}, L_{c75}) were analyzed based on the logistic curve assuming that selection to be symmetrical or nearly so based on the following logistic curve equation:

$$Ln((1/P_L)-1) = S1 - S2 \cdot L$$

where P_L is the probability of capture for length L, and

$L_{25} = (Ln(3)-S1)/S2$

$L_{50} = S1/S2$

$L_{75} = (Ln (3) +S1)/S2$

This is in accordance with the methods described by Pauly, 1984a; 1984b and 1990.

6.3.6 Virtual Population Analysis (VPA)

Virtual Population Analysis (VPA) using FISAT II was performed to show losses and survivors of individuals due to natural and fishing mortalities.

6.4 Results

6.4.1 Length-Weight Relationships

6.4.1.1 *Thunnus albacares* (Yellowfin tuna)

The relationship between the length and weight of yellowfin tuna harvested in the coastal waters of Kenya is shown in Fig. 40).

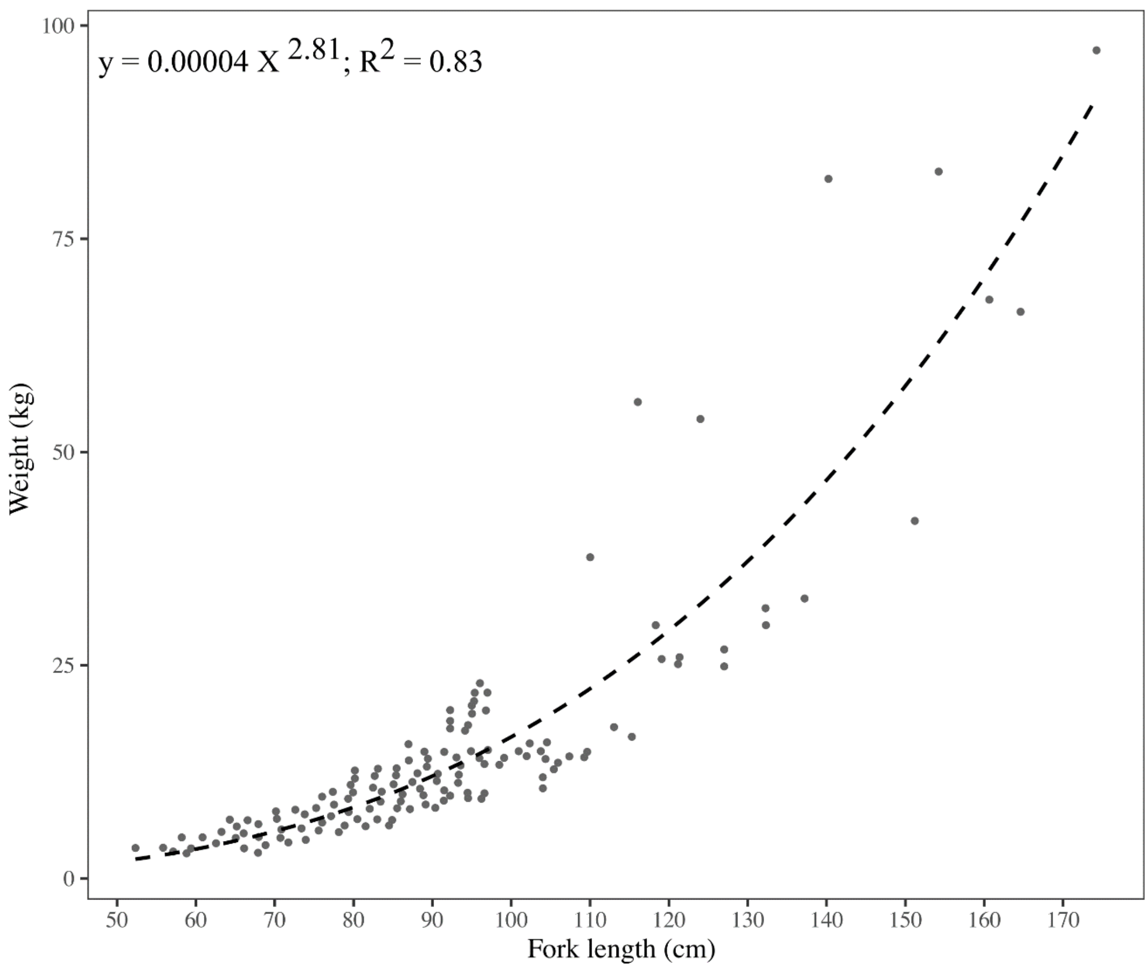


Figure 40. Length-Weight relationship of *Thunnus albacares.*

The relationship function was $W= 0.00004L^{2.81}$ with a coefficient of determination, $R^2 = 0.83$. This indicated that the growth was negatively allometric since the “b” value of 2.5 is less than 3. The coefficient of determination (R^2) is fairly low. The results suggest positive correlation between the weight and the length of the fish, however, the gain in weight was not proportionally direct to the increase in the length of the fish.

6.4.1.2 *Xiphias gladius* (Swordfish)

The relationship between the length and the weight of *Xiphias gladius* harvested in the coastal waters of Kenya is shown in Fig. 41.

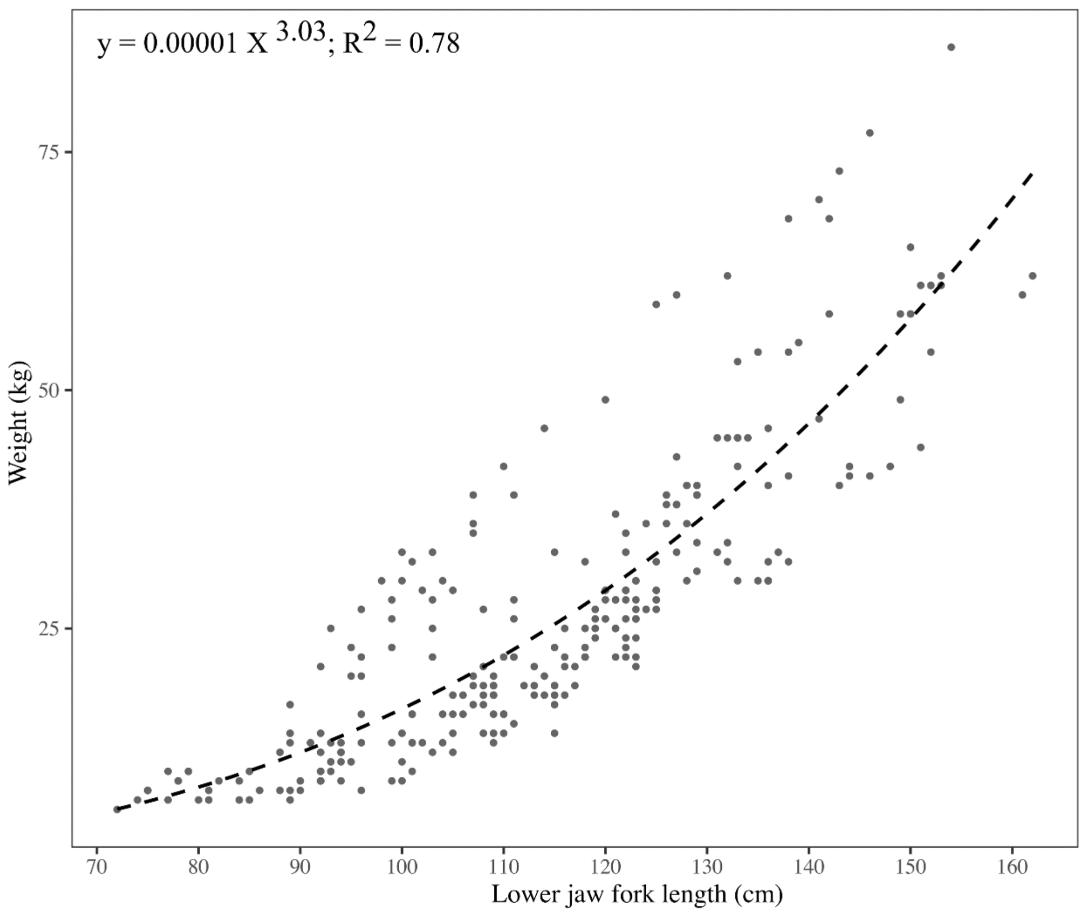


Figure 41. Length-Weight relationship of *Xiphias gladius.*

The relationship function was W = $0.00001L^{3.03}$ and the coefficient of determination, $R^2 = 0.78$. This indicated that the growth was positively allometric since the "b" value of 3.03 is greater than

3. However, the b values are within the range of 2.5 – 3.5. The coefficient of determination is slightly low. The results suggest positive correlation between the weight and the length of *Xiphias gladius*. The gain in weight is proportionally direct to the increase in the length of the fish.

6.4.1.3 *Euthynnus affinis* (Kawakawa)

The relationship between length and the weight of *Euthynnus affinis* harvested in coastal waters of Kenya is shown in Fig. 42.

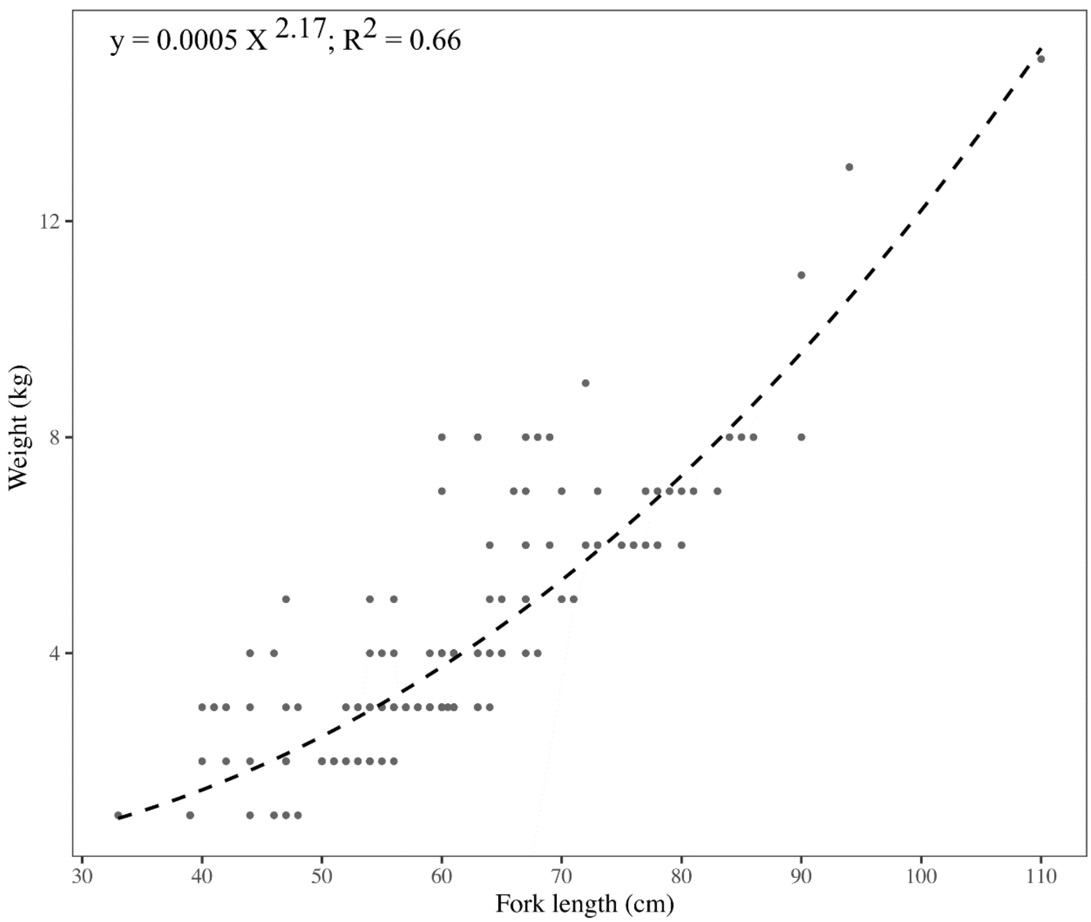


Figure 42. Length-Weight relationship of *Euthynnus affinis*.

The relationship function was $W = 0.0005L^{2.17}$ and the coefficient of determination, $R^2 = 0.66$. This indicated that the growth was negatively allometric since the “b” value of 2.17 is less than 3. The coefficient of determination is also low. The results suggest positive correlation between the weight and the length, however, the gain in weight was not proportionally direct to the increase in the length of fish.

6.4 2 Length-Frequency Distribution

6.4 2.1 Length-Frequency Distribution for *Thunnus albacares*

The length frequency distribution for *Thunnus albacares* is shown in Fig. 43.

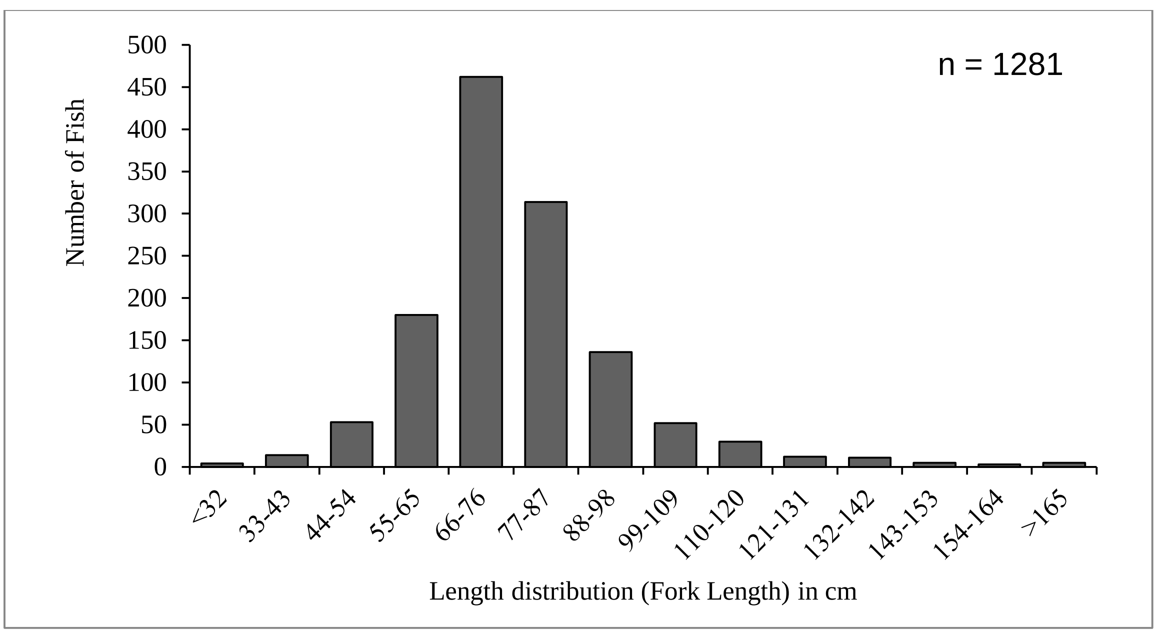


Figure 43. Length frequency distribution of *Thunnus albacares* in the coastal waters of Kenya for the period August 2015 to December 2016.

The length ranged from 11 cm to 205 cm with most of the individuals (36%) in the length class of 66 cm -76 cm. Some 91% of the individuals sampled were below 100 cm, which is length at maturity for *Thunnus albacares.* The results indicate that the yellowfin tuna landed by artisanal fishers at the Kenya coast were juveniles (under-size), i.e below the length of first maturity.

6.4 2.2 Length-Frequency Distribution for *Xiphias gladius*

The minimum and maximum Jaw Fork Length (LJFL) of the swordfish sampled were 68 cm and 234 cm, respectively (Fig. 44) with an average length of 118.68 cm.

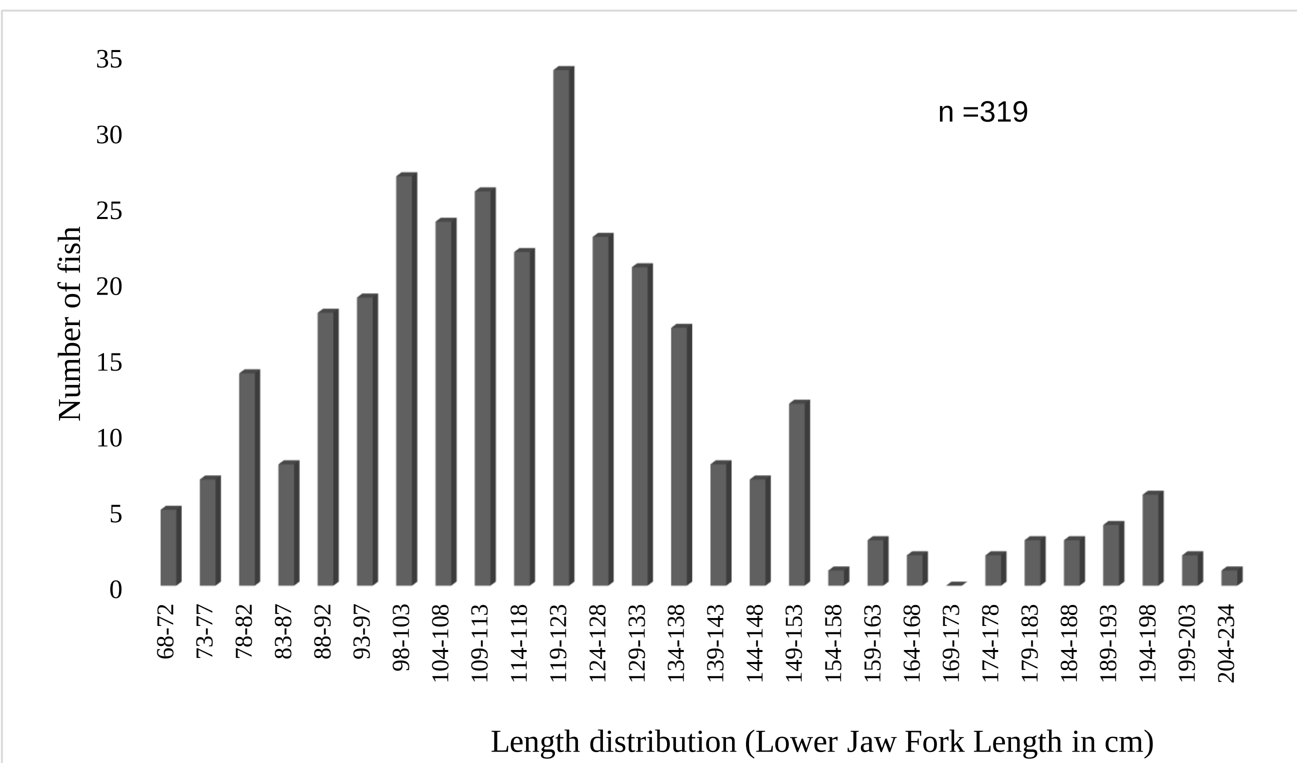


Figure 44. **Length-frequency distribution for *Xiphias gladius* sampled in the coastal waters of Kenya between August 2015 - December 2016.**

Most of the individuals were within 68 cm – 153 cm size range. The modal length range recorded was 119 cm – 123 cm. There is evidence of three length classes from this analysis, i.e. 68 cm – 153 cm, 154 cm – 168 cm and 169 cm – 234 cm. This could be attributed to the different gears employed by the fishers that target specific size ranges. Over 91% of the swordfish sampled were below 212 cm which is the length at maturity (L_{m50}) reported by Fishbase (2019). Age at first maturity ranges from 2- 10 years (IOTC, 2010; Alicli *et al.*, 2012). The results indicate that most of the swordfish caught by artisanal fishers at the Kenya coast are young individuals (juveniles).

6.4 2.3 Length-Frequency Distribution for *Euthynnus affinis*

The size of kawakawa encountered in the sample ranged from 33 cm – 110 cm Fork length (Fig 45).

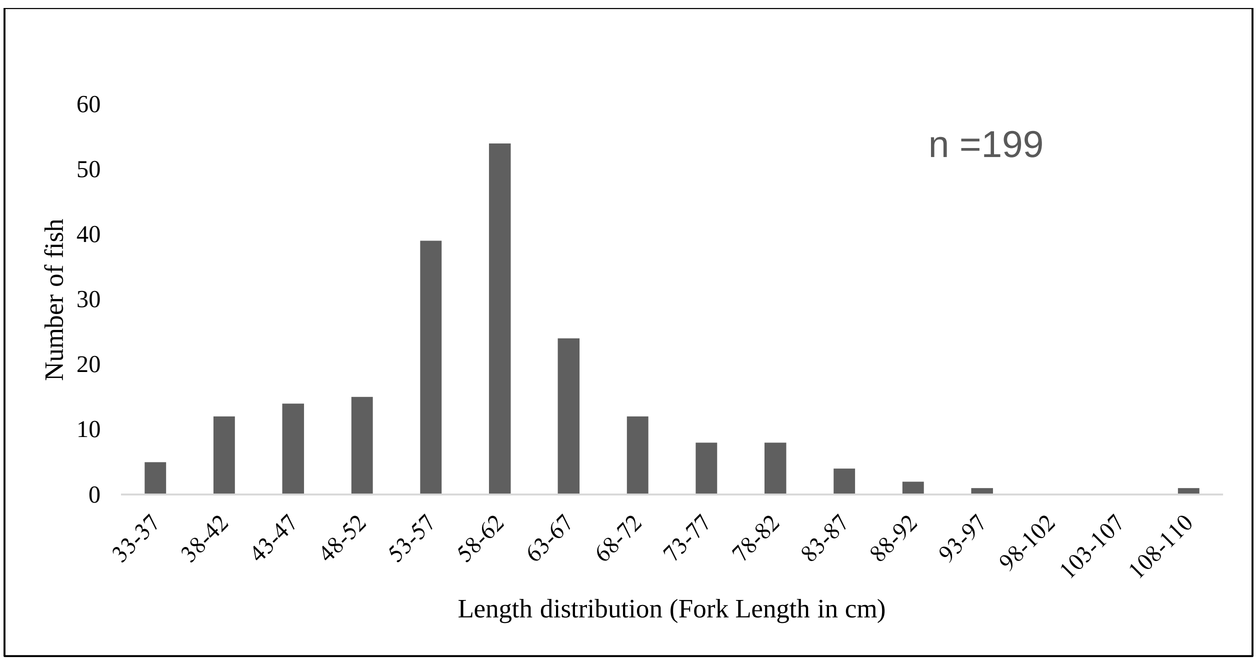


Figure 45. **Length-frequency distribution for *Euthynnus affinis* sampled in the coastal waters of Kenya between August 2015 and December 2016.**

The average length was 59.32 cm. The modal length range was 58 cm – 62 cm. Over 58.8% of the individuals of fish captured were within the size range of 53 cm – 67 cm. The length at first capture according to this study was L_c 50.7 cm. The length at first maturity for kawakawa (Lm 50) ranged from 37.7 cm to 42.3 cm (Fishbase 2019; Ahmed *et al*., 2015). Age at first maturity was estimated at 2.1 years (Ahmed *et al.*, 2015)

6.4.3. Growth Parameters

6.4.3.1 *Thunnus albacares*

Growth parameters for *Thunnus albacares* based on the pooled data were as follows;

The Asymptotic Length (L_∞) = 195 cm, Von Bertalanffy constant (K) = 0.43/ year, t_0 = 0.82 and Growth Performance Index (ϕ) = 4.21.

6.4.3.2 *Xiphias gladius*

Growth parameters for *Xiphias gladius* estimated from the pooled data from this study were as follows; the Asymptotic Length (L_∞) = 208 cm, Von Bertalanffy coefficient (K) = 0.28/ year, t_0 = 0.18 and Growth Performance Index (ϕ) 4.08.

6.4.3.3 *Euthynnus affinis*

Euthynnus affinis growth parameters from the pooled data from this study were as follows; the Asymptotic Length (L_∞) = 93 cm, Von Bertalanffy coefficient (K) = 0.7/ year, $t_0 = 0.20$ and Growth Performance Index (ϕ) 3.79.

6.4.4. Mortality Rates

6.4.4.1. *Thunnus albacares*

Thunnus albacares mortality and exploitation rates are as follows; Total mortality rate (Z) was 2.59/ Year, Natural Mortality (M) with mean annual water surface temperature of 26 ^{o} C was estimated at 0.59/ Year, Fishing Mortality (F) was 2.00/Year and Exploitation Rate (E) 0.77/ Year worked out from the length – converted catch curve of the species (Fig. 46).

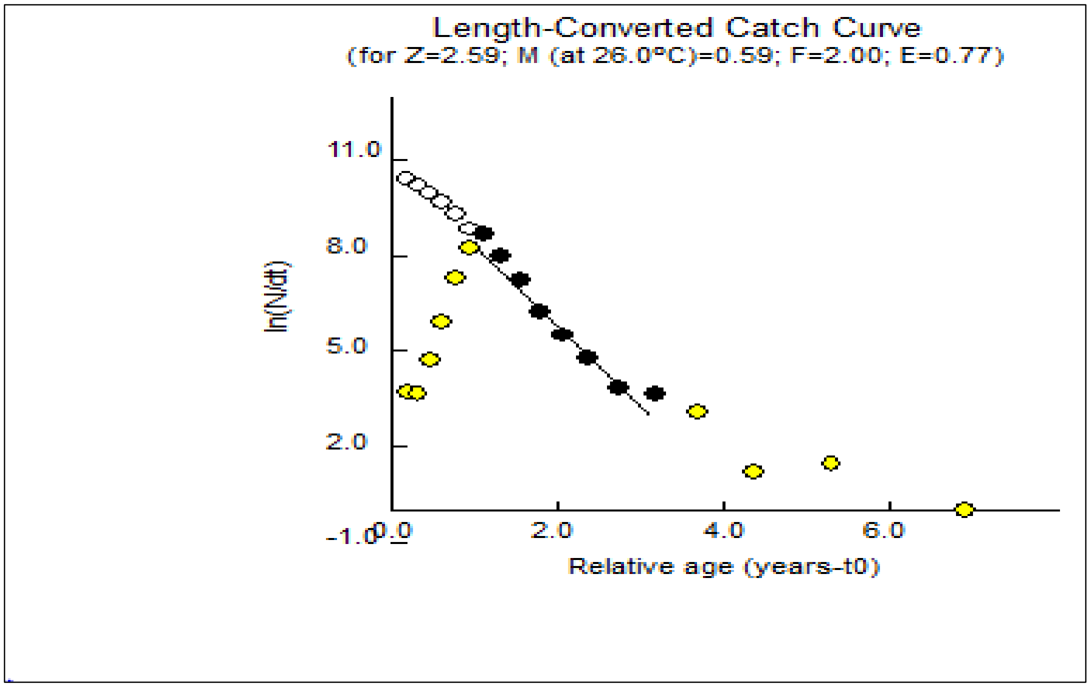


Figure 46. Length – Converted Catch Curve of *Thunnus albacares*.

6.4.4.2. *Xiphias gladius*

Mortality rates for swordfish in this study were estimated as follows; Total mortality (Z) was 1.13/ Year, Natural Mortality rate (M) was estimated at 0.44/ Year, Fishing Mortality (F) was 0.69/Year and Exploitation Rate (E) 0.61/ Year derived from the catch curve that was length-converted (Fig. 47).

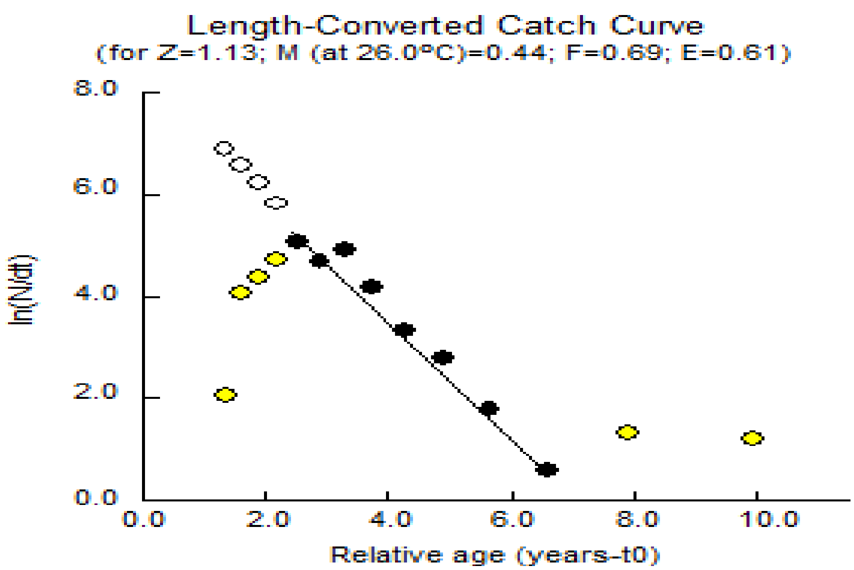


Figure 367. Length –Converted Catch Curve showing mortality and relative age for *Xiphias gladius* in the Kenya coastal waters.

The average annual temperature of 26 ℃ at the water surface was used. The results indicate that fishing pressure was high and exploitation rate is higher than the optimal at 0.5 per year.

6.4.4.3. *Euthynnus affinis*

Mortality rates for *Euthynnuss affinis* were estimated as follows; Total mortality (Z) was 1.83/Year, Natural Mortality (M) was 0.99/ Year, Fishing Mortality (F) was 0.87/Year and Exploitation Rate (E) 0.47/ Year based on the catch curve that was length-converted (Fig. 48). The average annual temperature of 26 ^{O}C at the water surface was used.

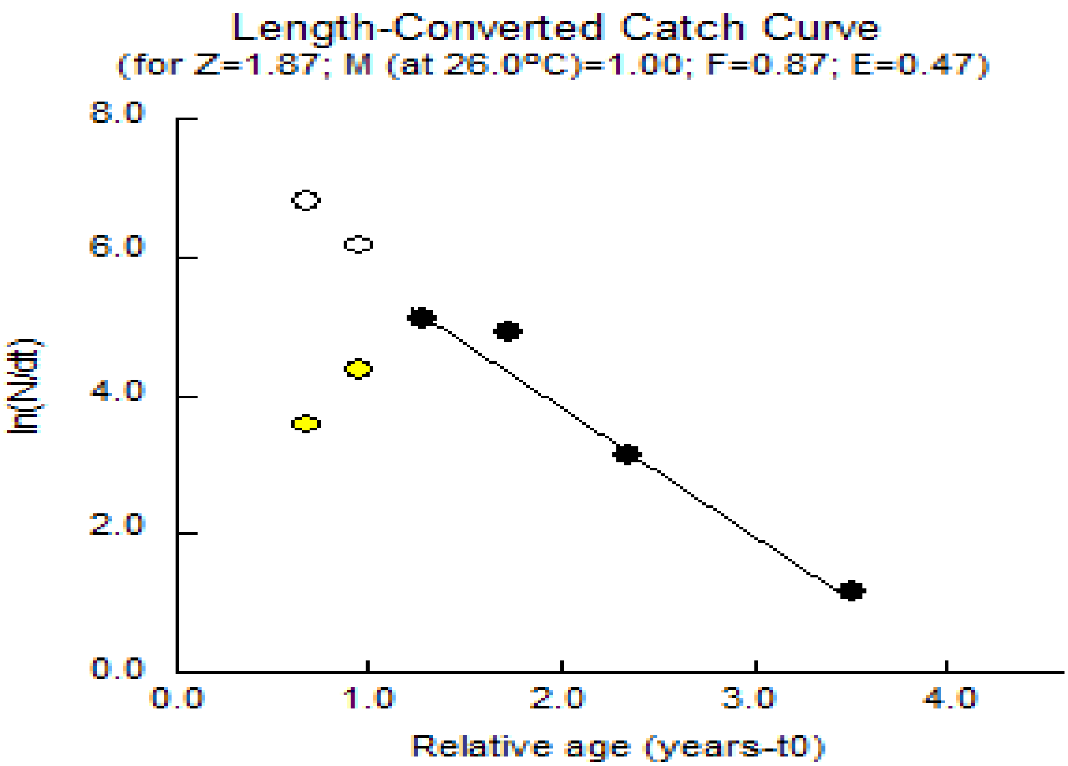


Figure 378. Length –Converted Catch Curve showing mortality and relative age for *Euthynnus affinis* in the Kenya coastal waters.

6.4.5 Fishing Gear Selectivity

6.4.5.1. *Thunnus albacares*

Fishing selectivity of yellowfin tuna varied with gears (Table 8).

Table 8. **Selectivity parameters of *Thunnus albacares* from length converted catch curve and the probabilities of capture.**

Parameter	All gears combined	Longline	Trolling line	Handline
Total Mortality (Z)	2.59	1.11	3.9	3.9
Fishing Mortality (F)	2.00	0.52	3.3	3.4
Exploitation rate (E)	0.77	0.47	0.85	0.85
$L_{c\ 25}$	58.9			
Length at first capture $L_{c\ 50}$	65.4	93.3	68.9	75.6
$L_{c\ 75}$	71.9	102.4	74.7	81.8
$L_{c\ 95}$	80.66	115.9	83.7	91.4

The average length at first capture (L_{c50}) for the combined gears was 65.4 cm. However, (L_{c50}), in main individual gears; longline, handline and trolling was 93.3 cm, 75.6 cm, and 68.9 cm, respectively. The mean length at which 95% of the individual fish were retained in the fishing gear was 80.66 cm for different gear combination, 115.9cm for longline, 91.4cm for handline and 83.7 cm for trolling line. The results indicate that longline gear captured fairly large size individuals compared to the other gears and that is the reason why the fishers deploy specific gears to target certain size of individuals.

6.4.5.2. *Xiphias gladius*

Fishing gear selectivity and length at first capture (L_{c50}) varied with the type and size of the fishing gear involved (Table 9). The mean length at first capture (L_{c50}) for combined gears was 98.3 cm and 99.66 cm for longline.

Table 9. Selectivity of *Xiphias gladius* from length converted catch curve and the probability of capture.

Parameter	**All gears combined**	**Longline**
Total Mortality (Z)	1.13	1.29
Fishing Mortality (F)	0.69	0.85
Exploitation rate (E)	0.61	0.66
$L_{c\ 25}$	89.9	91.4
Length at first capture $L_{c\ 50}$	98.3	99.6
$L_{c\ 75}$	106.7	107.9
L_{c95}	117.2	117.8

The size of most of the individuals sampled ranged from 68 cm – 153 cm. Most of the fish landed (89%) were captured by longline (Fig. 49). Length at first capture for swordfish is estimated at 212 cm though ranges from 156 cm – 250 cm (Fishbase, 2019). The results suggest that swordfish landed by artisanal fishers in Kenya waters were below the reported age at first maturity (212 cm).

The results suggest that specific gears are deployed by fishers targeting certain size of the target fish species.

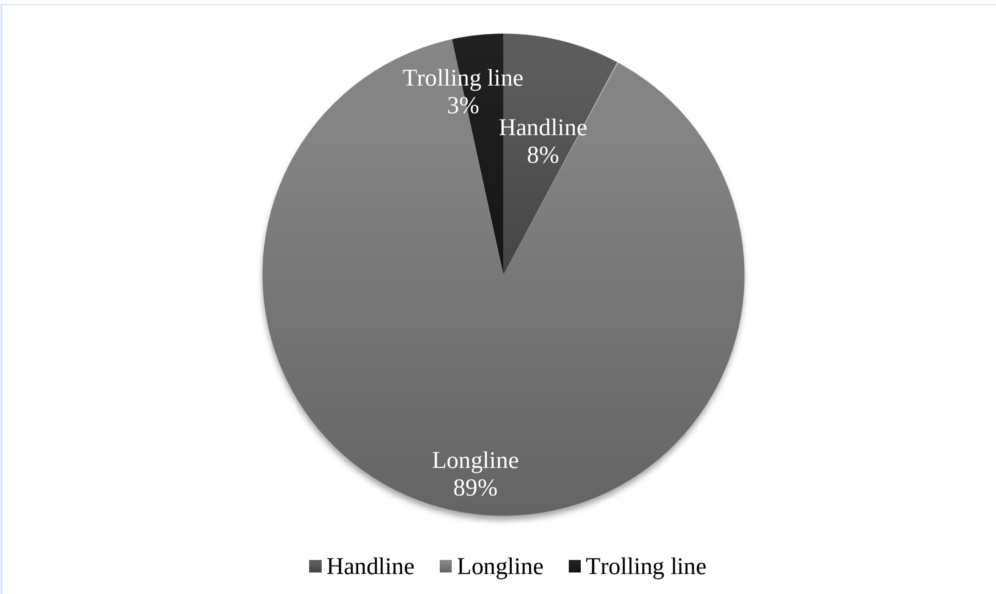


Figure 389. Proportion of swordfish landed by different gears.

6.4.5.3. *Euthynnus affinis*

Length at first capture L_{c50} for *Euthynnus affinis* was estimated at 50.7 cm by this study (Table 10).

Table 10. Selectivity of *Euthynnus affinis* from length converted catch curve and the probability of capture.

Parameter	**All gears combined**	**Trolling**
Total Mortality (Z)	1.87	1.94
Fishing Mortality (F)	0.87	0.94
Exploitation rate (E)	0.47	0.49
Length at first capture $L_{c\ 50}$	50.7	50.7
$L_{c\ 75}$	54.8	54.8
L_{c95}	60.9	60.9

The fishing gear were highly selective to the individuals that ranged in size from 53 cm - 67 cm. Length at first capture (L_{c50}) for Euthynnus affinis ranged from 40 cm - 65 cm. According to this study, 83.4% of the individuals sampled were above L_{c50} of 50 cm and over 95% L_{c50} of 40 cm based on Fishbase (2019). The results indicate that nearly all the individuals sampled were mature. The fishing gears were targeting specific size of kawakawa.

6.4.6 Virtual Population Analyses

6.4.6.1 *Thunnus albacares*

Virtual Population Analysis (VPA) for *Thunnus albacares* indicate that the individuals were vulnerable to capture by gears (fishing mortality) and natural mortality at size 15 cm mid-length (Fig. 50).

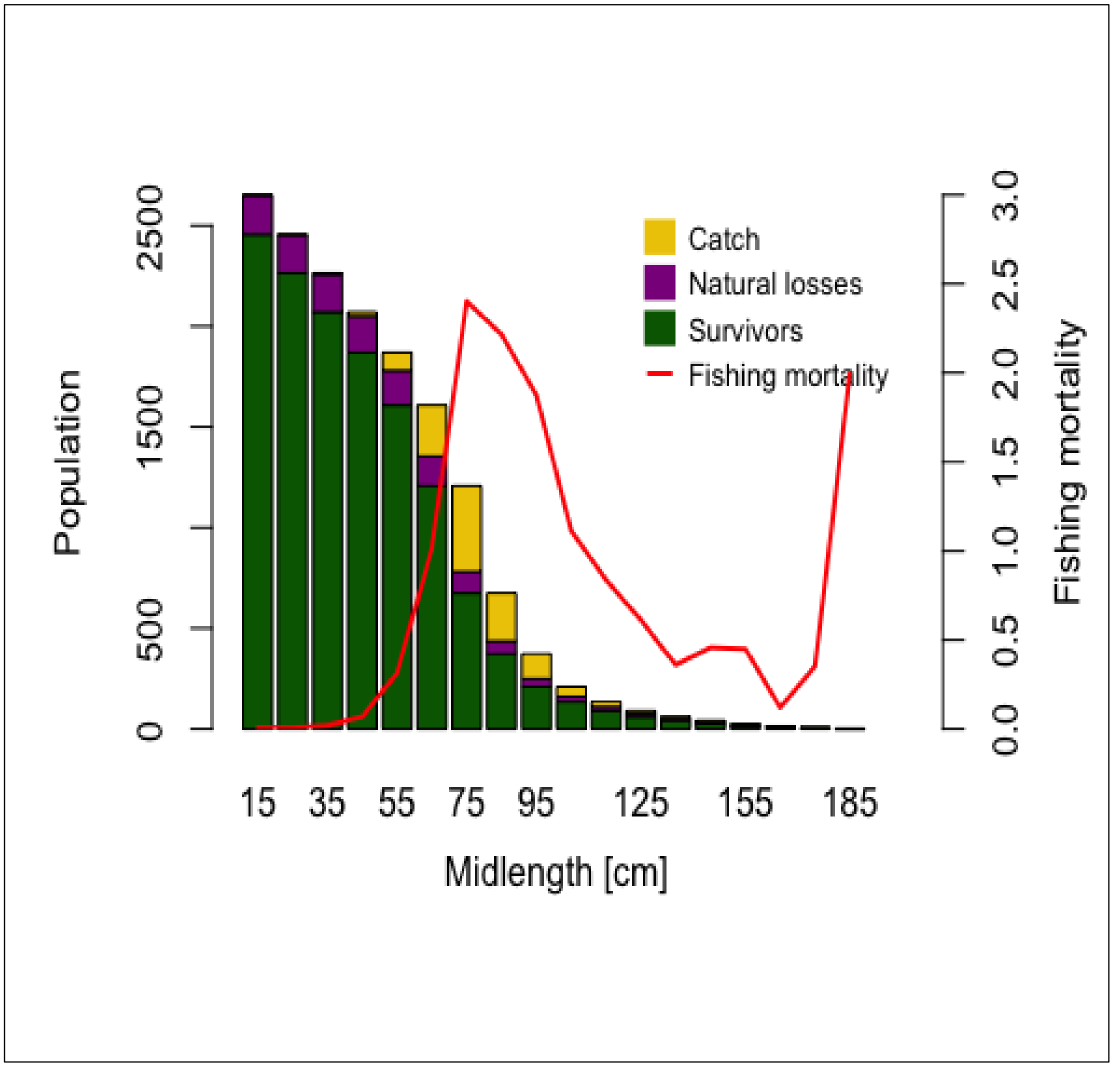


Figure 50. Virtual Population Analysis for *Thunnus albacares* in coastal waters of Kenya.

Mortality caused by natural losses was up to 35 cm mid-le length whereas mortality due to fishing pressure was experienced between 55 cm – 115 cm mid- lengths. It is evident that the highest fishing pressure was experienced between 65 cm – 85 cm mid-length.

6.4.6.2. *Xiphias gladius*

The Virtual Population Analysis for *Xiphias gladius* sampled (Fig. 51) indicate that swordfish losses due to natural mortality was more pronounced at mid-length 65cm – 85 cm.

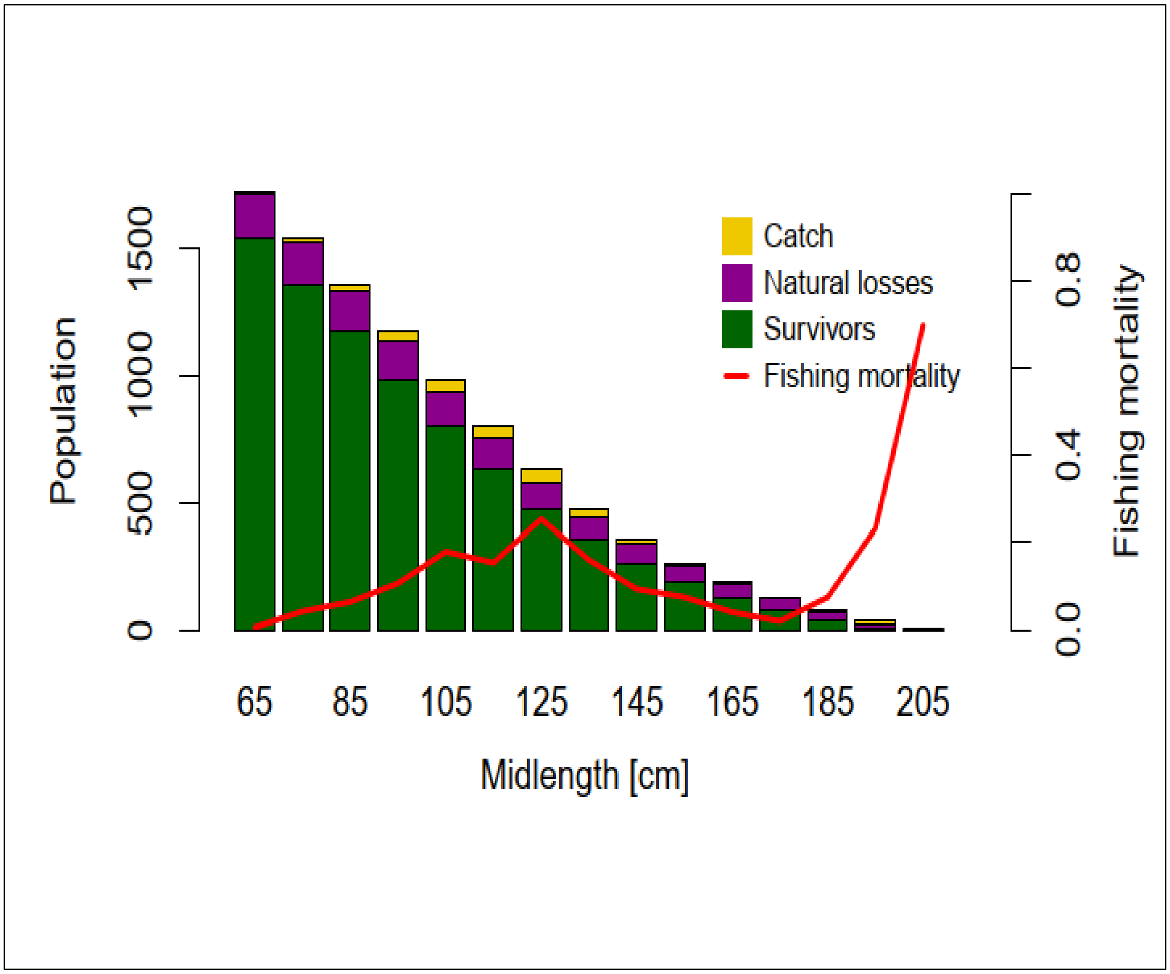


Figure 51. Virtual Population analysis for *Xiphias gladius* in coastal waters of Kenya.

Losses due to fishing pressure (Fishing mortality) started at 85 cm mid-length and peaking at 125 cm mid-length. It is evident that highest fishing mortality was experienced between 105 cm – 135 cm mid-length.

6.4.6.3 *Euthynnus affinis*

The results of the Virtual Population Analysis (VPA) for *Euthynnus affinis* (Fig. 52) shows that losses due to natural mortality was evident at mid-length 32.5 cm – 37.5 cm.

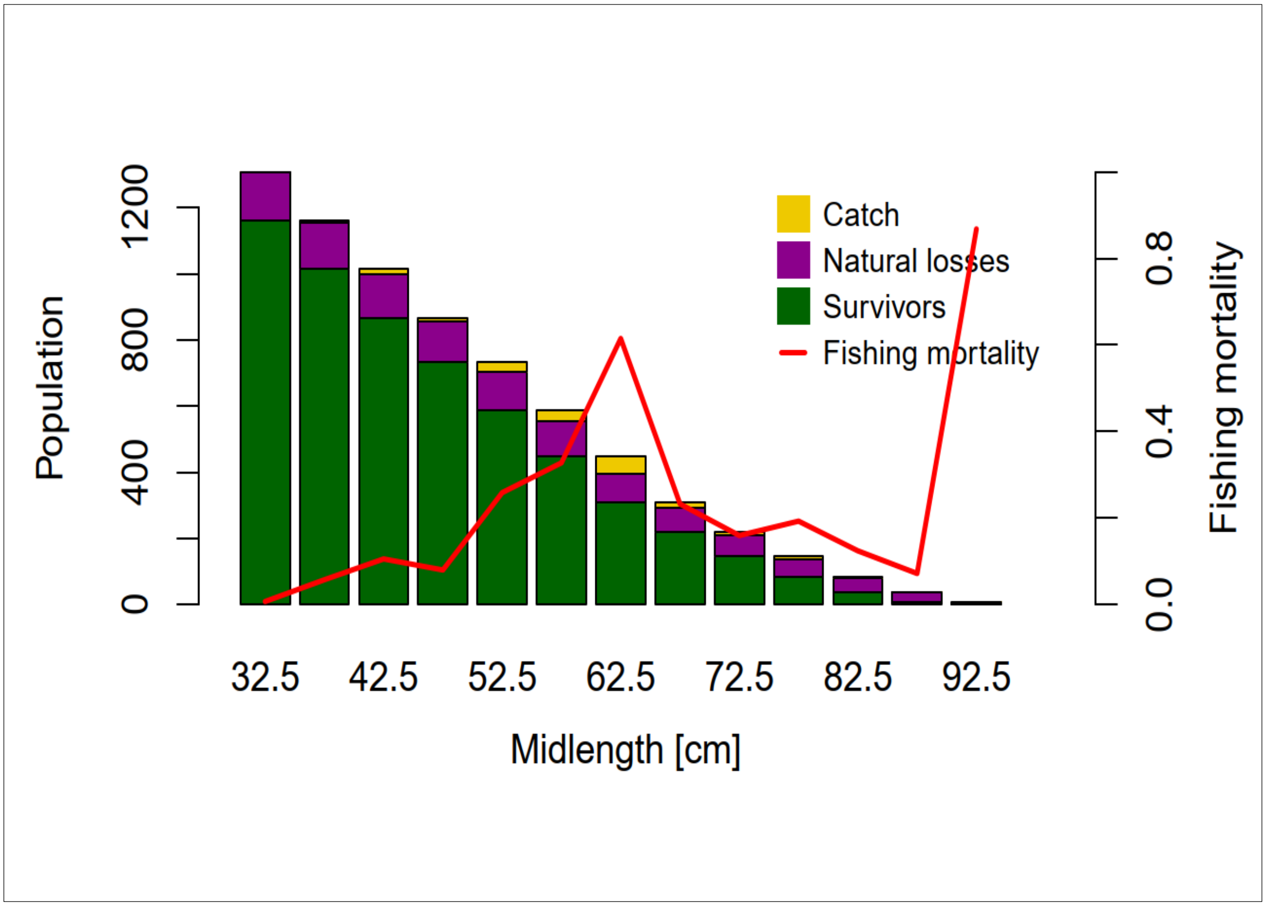


Figure 52. Virtual Population Analysis for *Euthynnus affinis* in coastal waters of Kenya.

Losses due to fishing mortality started at mid-length 42.5 cm and peaking at mid-length 62.5 cm. The results show that juvenile and adult fish were more vulnerable to natural mortality and fishing mortality respectively.

6.5. Discussions

Analysis of length-weight relationship for yellowfin tuna (Fig. 40), swordfish (Fig. 41) and kawakawa (Fig. 42) revealed negative allometric growth for the two species encountered in this study except swordfish. The “b” values for yellowfin, swordfish and kawakawa were 2.81, 3.03 and 2.17 respectively. They were less than 3 for kawakawa and yellowfin tuna indicating that growth was not isometric based on the definition by Carlander (1977). The results reported in this study suggest that there was a positive correlation between the weight and the length of yellowfin and kawakawa fish sampled, however, the gain in weight for the individual fish was not proportionally direct to the increase in the length. The gain in weight on the other hand for swordfish was proportion to the increase in length indicating positive allometric growth. Despite this study reporting negative allometric growth for yellowfin and kawakawa, the results are not very far from other studies, especially for yellowfin tuna. Kaymaram *et al.* (2014) reported some negative allometric growth for *Thunnus albacares* in the Oman Sea where “b” value was 2.8 for males and 2.7 for females. Silas *et al*. (1985) estimated “b” value of 2.6 for *Thunnus albacares* in the Arabian sea in the longline fishery. Stequert *et al*. (1996) reported “b” value of 2.75 for *Thunnus albacares* in the Indian Ocean longline fishery. The “b” value for kawakawa in the coastal waters of Tanzania was estimated at 2.9 for males and 3.31 for females (Johnson & Tamatamah, 2013). In the Sri Lankan waters, Herath *et al.* (2019) reported “b” value of 3.0 – 3.4 for kawakawa. Swordfish “b” values in the Indian waters according Varghese *et al*. (2013) was 3.3 whereas in the Mediterranean Sea was 3.4 (Alicli *et al.*, 2012). Swordfish b values from other authors are comparable to the results of this study which recorded b value of 3.03.

The length-weight relationship observed in this study may have been influenced by a number of factors including the type and size of gears used, gear selectivity, maturity status of the fish, condition of the individual fish, the time of sampling and the fishing environment (Tserpes *et al*., 2008; Tserpes *et al*., 2003; Froese, 2006; Beverton, 1966). Different types of gears and sizes were selective to specific sizes of fish which may have introduced some bias. Longline gear for instance was highly selective to large sized individuals as opposed to handline and trolling lines. According to the results of this study, there was a high proportion of juveniles in the sample, especially for yellowfin tuna and swordfish, which could have contributed to the "b" values observed. The condition of fish also influenced the b values. Depending on the location of the fishing ground, fish lost some weight by the time it was landed. However, to remove the biasness, the study adopted the "a" and "b" values in fishbase (2018) for yellowfin, swordfish and kawakawa.

Analysis of length-frequency distribution for yellowfin and swordfish show that their respective catch was dominated by young individuals. The estimated size at maturity for yellowfin tuna is at 100 cm (Viera, 2005; Stequert *et al.,* 1996; Itano, 2000; Kaplan *et al*., 2014). Most of the individuals of yellowfin tuna were within the size range of 66 – 76 cm FL (Fig. 43). The results of this study compares with studies reported by other authors. IOTC (2016) reported that artisanal yellowfin tuna catches ranged from 70 – 85 cm FL. However, some variations were observed between the length-frequency distribution in artisanal and industrial tuna fisheries. Kar *et al*. (2012) reported the size range of 48 – 169 cm FL from the longline fishery in the Andaman and Nicobar Islands EEZ while Langley *et al.* (2008) reported a length range from 30 cm to 180 cm FL. Size range of 37 – 172 cm FL was reported from the gillnet fishery in the sea of Oman (Kaymaram *et al.* (2014).

Swordfish sampled were in various size ranges, with most of them ranging from 68 – 153 cm Lower Jaw Fork Length (JFL) (Fig. 44). About 91% of swordfish were below 212 cm FL which is the length at first maturity (Fishbase, 2019; Taylor and Murphy, 1992; Wang *et al.,* 2003).

Similar observations of landing large proportions of young individuals of swordfish in the catch have been reported by other authors (FIRMS, 2016; Alicli *et al.*, 2012; Oceana, 2016). The landing of juveniles in the Mediterranean Sea raised some concern to International Commission for the Conservation of Atlantic Tunas (ICCAT) which resulted to the adoption of Minimum Landing Size (MLS) as management measure of the fishery. The MLS was set at 90 cm LJFL and 142 cm LFJL adopted as a reference size of length at first maturity in 2011 (ICCAT, 2013; Oceana, 2016). ICCAT further established a total allowable catch (TAC) for swordfish and capped it at 13,700 Mt annually for the period 2014 – 2016 (ICCAT, 2013).

The size of kawakawa sampled varied, ranging from 33 cm – 110 cm FL (Fig. 45), with most of the individuals within the size range of 53 cm – 67 cm FL. Over 95% of kawakawa sampled was above 39.8 cm FL, the estimated size at first maturity (Fishbase, 2019) indicating that Kawakawa harvested by artisanal fishers in the Kenya waters had attained sexual maturity. According to Fishbase (2019), the size at first maturity for kawakawa is estimated at 39.8 cm FL. Ahmed *et al*. (2015) reported size at first maturity for kawakawa at 37.7 cm FL with size range of 14 cm – 80 cm FL. Similar results were reported by other researchers. Johnson and Tamatamah (2013) reported a size range of 31 – 85 cm FL in Tanzania coastal waters, Mudumala *et al.* (2018) in North West Coast of India reported 33 – 75 cm FL while the IOTC (2020) reported 20 – 55 cm FL.

The recent results suggest that the size of individuals of a particular species landed varied with the type and size of gears, gear selectivity and size of the fish being targeted. Similar observations were reported by other authors (Tuda *et al.*, 2016; Alicli *et al*., 2012), sex, season, sampling time, food, temperature (Johnson &Tamatamah, 2013; Froese, 2006).

It is evident from this study that yellowfin and swordfish landed by artisanal fishers in Kenya waters are juveniles. This suggests that growth overfishing is occurring in these two fisheries (Sparre & Venema, 1998). This may not be conclusive since the study didn't assess gonads to ascertain the maturity status. Length-frequency distribution has implications on the recruitment and population structure. Length-frequency distribution would help detect changes in the fishery such as overfishing and depletion of fish stocks (King, 1995; Ward & Elscot, 2000; Konstantinos *et al*., 2003). Overfishing has contributed to reduction of average length of most fish species globally (Swain *et al.*, 2007; Baudron *et al*., 2014; Hunter *et al.,* 2016).

Analyses of growth parameters for *Thunnus albacares* (yellowfin), *Xiphias gladius* (swordfish) and *Euthynnus affinis* (kawakawa) indicated that different species grow at different rates. The growth parameters for *Thunnus albacares* estimated in this study; the asymptotic Length (L_∞) , 195 cm; Von Bertalanffy constant (K), 0.43/ year; temperatures at age Zero (t_0), - 0.82 and the Growth Performance Index (ϕ) 4.2. The results from this study compares with other studies contacted elsewhere. Kayamaram *et al.* (2014) estimated L_∞ = 183.3 cm, K = 0.45/year and ϕ = 4.21 for *Thunnus albacares* in the Oman Sea. Studies contacted by other authors show variations in the ranges of growth parameters for yellowfin tuna in different waters, L_∞ (165.07 cm – 195 cm), K (0.3 – 0.67/year), t_0 (0.099 – 0.82/year) and ϕ (4.07 – 4.21). The growth coefficient (K) estimated at 0.43/year was found to be higher than 0.34 suggesting that yellowfin tuna encountered in the coastal waters of Kenya is a fast growing species. Kaymaram *et al.* (2014), John (1995) and Chantawong (1998) suggested similar growth rates in accordance to the results of their studies of yellowfin tuna in the Oman sea, Indian waters and Eastern Indian Ocean, respectively. The results from other studies have suggested that there are two growth rates for yellowfin tuna depending on the age. Yellowfin tuna grow at a lower rate when juvenile and faster rate when adults (Marsac &

Lablache, 1985; Marsac, 1991; Lumineau, 2002). Kar *et al*. (2012) has reported growth rate of 1.3 – 2.9 cm and 2.5 – 4.8 cm per month for yellowfin tuna of size <60 cm and > 60 cm, respectively. Therefore, there are three divergent schools of thought with regard to the growth rate of yellowfin tuna; that the species is fast, slow and a combination of both fast and slow growing depending on the size. Nevertheless, the growth rate of the individual may vary due to a number of factors, namely availability of food, water temperature, diseases and the general conditions of the fish (Zhu *et al*. 2011).

There are limited studies on swordfish growth in Kenya. Most of the studies have been conducted elsewhere including the Australia (Young & Drake, 2004), New Zealand, India (Varghese *et al.*, 2013) and the Mediterranean Sea (Alicli *et al*., 2012). In this study, the growth parameters of *Xiphias gladius*; the asymptotic Length (L_∞) , 208 cm; Von Bertalanffy constant (K), 0.28/ year; temperatures at age Zero (t_0), - 0.18 and the Growth Performance Index (ϕ) 4.08. Growth rate for Swordfish has been reported to vary from one region to the other and the sex of the individual fish (Jose, 2001; Wang *et al*., 2003; Lan *et al*., 2014; Varghese *et al*., 2013). Varghese *et al*., 2013 reported (for females) Length (L_∞) , 311.11 cm; Von Bertalanffy constant (K), 0.17/ year; temperatures at age Zero (t_0), - 0.53 and (for males) Length (L_∞) , 243.79 cm; Von Bertalanffy constant (K), 0.22/ year; temperatures at age Zero (t_0), - 0.37 for the swordfish in India waters. Jose (2001) reported pooled data for both males and females as; Length (L_∞) , 327 cm; Von Bertalanffy constant (K), 0.126/ year; temperatures at age Zero (t_0), - 2.59 for swordfish in the Southern Pacific off Chile. Female swordfish grow faster and attain bigger size compared to their male counterparts (Varghese *et al.*, 2013; Young & Drake, 2004). Some studies have reported that swordfish grow very fast reaching 100 cm and above within a period of one year, and growing to a maximum age of 15- 20 years (Megalofonou *et al*., 1995; Young & Drake, 2004; Griggs *et al*., 2005; Varghese *et al*., 2013). Griggs *et al.* (2005) suggests that both male and female individuals of swordfish grow at the same rate up to the age of six years. Berkley and Houde (1983) observed that female swordfish grow faster and attain bigger size within a period of 4 years. The results of this study indicate that swordfish growth rate reported in the coastal waters of Kenya varied from what had been reported elsewhere in other regions, including the Southern and Western Pacific, Mediterranean Sea and the wider Indian Ocean (Young & Drake, 2004; Varghese *et al*., 2013; Jose, 2001). This could be attributed to the type and size of gears and the age of individuals (Alicli et al., 2012; Tuda *et al*., 2016). For instance, the growth parameters estimated in other regions was based on the catches in the industrial fleet using large size gears and targeting mature individuals, whereas in this study the focus was on artisanal swordfish fishery employing small sized gears. Some studies have shown that there are several stocks of swordfish in different oceans and regions with distinctive growth parameters, including the Mediterranean Sea, East Indian Ocean, Western Indian Ocean, India, Australia (Varghese *et al*., 2013; Alicli *et al*., 2012; Ehrhardt, 1992; Ching-Ping Lu *et al*., 2006). Ching-Ping Lu *et al*. (2006) reported that swordfish from Madagascar and Bay of Bengal were genetically different. It is highly likely that the coastal Kenya swordfish could be a different stock and or localized population from that of the entire Indian Ocean region, however genetic studies should be undertaken to confirm this.

Growth parameters for *Euthynnus affinis* (Kawakawa) as per this study was estimated as follows; asymptotic Length (L_∞), 93 cm; Von Bertalanffy constant (K), 0.7/ year; temperatures at age Zero (t_0), - 0.20 and the Growth Performance Index (ϕ) 3.79. The results of this study are similar to other studies conducted elsewhere, in particular the Arabian and Indian seas. Mudumala *et al.* (2018) reported asymptotic Length (L_∞), 67.86 cm, growth coefficient (K) of 0.7/year, (t_0) - 0.20 for Kawakawa in the West Coast of India. Johnson & Tamatamah (2013) estimated growth coefficient (K) at 0.78/year and (L_∞), 89.25 cm for kawakawa in the coastal waters of Tanzania. Fishbase (2019) reported Growth Performance Index (ϕ) of 3.75, asymptotic Length (L_∞), 79.2 cm and growth coefficient (K) of 0.9/year. In this study, the growth coefficient of 0.7/ year is higher than 0.34 indicating that kawakawa inhabiting Kenya coastal waters is a fast growing species. The species grows rapidly at the initial stages of life, reaching a length of about 50cm – 65 cm within the age of three (3) years with estimated longevity of 9 years (IOTC, 2015).

Growth rates estimates for the yellowfin tuna, swordfish and kawakawa that were recorded in this study may have been influenced partly by a number of factors which include among others water temperatures (Jorgensen, 1992; Daufresne *et al*., 2009, Ward *et al.,* 2009; Baudron *et al.,* 2014;), general condition of the fish (Zhu *et*, *al*. 2011), the availability of food (Lorenzen & Enberg, 2002; Overholtz, 1989; Hunter *et al*., 2016), the selectivity of fishing gears (Tuda *et al.*, 2016; Conover & Munch, 2002; Erzini *et al*., 2003; Enberg *et al*., 2012), genetic factors (Hunter *et al.,* 2016; Ching-Ping Lu *et al*., 2006) and the sex of the individual fish (Wang *et al*., 2003; Varghese *et al*., 2013; Lan *et al*., 2014).

There are few studies and limited information in the public domain on the population and growth parameters of tuna and tuna-like species in the Kenya marine waters and to some extent the entire Indian Ocean region. The information that has been generated in this study provides further insight in advancing the science in this particular field. This also serves as baseline for indicators to assist in monitoring the growth performance of fisheries from artisanal sources.

Fisheries stocks are dynamic making it complex to manage. It is quite critical for the purpose of managing a fishery to understand the rate at which individuals of fish are being recruited and or removed from the population. The results of the analyses of mortality rates for yellowfin, swordfish and kawakawa indicated that fish species experience various mortality rates. This study shows that total mortality (Z) for *Thunnus albacares* was 2.59/ Year. The natural mortality (M) was estimated at 0.59/ Year. Fishing Mortality (F) was 2.00/Year and Exploitation Rate (E) 0.77/ Year (Fig. 46). The results of this study on yellowfin tuna mortality rates compares with other studies in the Indian Ocean. For instance, value for Natural Mortality (M) in the present study was 0.59/year. Natural mortality (M) for yellowfin tuna was estimated by different authors as follows; Pillai *et al.* (1992) = 0.54/year, Pillai *et al.* (1993) = 0.52/year, John (1995) = 0.60/year and Kaymaram *et al.* (2000) = 0.6/year. Kaymaram *et al.* (2014) estimated exploitation rate (E) of 0.76/year and total mortality (Z) of 2.04/year which compares to 0.77/year and 2.59/year respectively, in the present study.

It is evident from this study that fishing mortality rate (F) is fairly higher than natural mortality rate (M). This suggests that fishing pressure is causing more losses of yellowfin tuna from the population as opposed to natural mortality. The higher exploitation rate (E) of 0.77/year is an indication of high fishing pressure on the yellowfin tunas in the nearshore waters in Kenya. Noting that most of the individuals being harvested by artisanal fishers are less than 100 cm (Juveniles) this implied that growth overfishing was occurring on this fishery. The IOTC (2018) report indicated that yellowfin tuna in the Indian Ocean was overfished and recommended reduction of fishing pressure on the stock by implementing the stock rebuilding plan.

Mortality rates for *Xiphias gladius* (swordfish) were estimated in this study as follows; total mortality (Z) was at 1.13/ Year, natural mortality (M) was 0.44 / Year, Fishing Mortality (F) was 0.69/Year and the Exploitation Rate (E) was estimated at 0.61/ Year (Fig. 47). Most studies on swordfish mortalities have been done elsewhere, very in Kenya. The results of this study is comparable to similar studies contacted elsewhere, for instance, in the New Zealand waters, Griggs *et al*. (2005) estimated total mortality (Z) at 0.25 – 0.28/year and Natural Mortality (M) at 0.21 – 0.28/year for those individuals within the 5-6 years' age bracket, which was found to be low. FAO (1981) reported total mortality (Z) at 0.16 – 0.59/year. The results of fishing mortality and exploitation rates reported in this study (F = 0.69/Year and E = 0.61/year) is higher than the optimal (0.5/ Year). This suggests that that the fishing pressure on the artisanal swordfish fishery in Kenya waters was high. The study further shows that over 91% of the swordfish landed by the artisanal fishers in coastal waters of Kenya are juveniles i.e below 156 cm Fork Length. Alicli *et al.* (2012) reported similar observations in the Mediterranean Sea where over 50% of the catches of Swordfish were juveniles. Length at first maturity is 212cm with a range of 156 – 250 cm FL (Fishbase 2019; Wang *et al*., 2003; Taylor & Murphy 1992; Poisson & Fauvel 2009). Some studies have reported length at maturity for female and male swordfish ranging from 87 – 188.5 cm and 99 – 161 cm respectively (Alicli *et al.*, 2012).

Some 31,628 Mt of swordfish was landed in 2018, slightly above the MSY of 31,590 (IOTC, 2019). In Kenya, pooled data indicate that some 158 Mt and 160 Mt of swordfish were landed by artisanal fishers in Kenya waters in 2015 and 2016, respectively (State Department of Fisheries and Blue Economy, 2016). IOTC (2018) reported that fishing mortality for swordfish fishery in the Indian Ocean harvested by commercial fleets was below the estimated target reference points and the limit reference points F_{MSY} 1.4/year and describes the fishery to be in health status. IOTC didn't conduct swordfish assessment in 2018 and 2019, the estimates are based on the 2017 assessment hence uncertainty on the stock status (IOTC, 2020). Further IOTC has not conducted assessment of swordfish in the artisanal fishery. Some concerns have been raised by the IOTC Working Party on Billfish of a possible localized depletion of the fishery in the western Indian Ocean (IOTC, 2011; Van der Elst & Everett, 2015).

Mortality rates for *Euthynnus affinis* (kawakawa) as estimated in this study were as follows; total mortality (Z) was at 1.87/ Year, natural mortality (M) was 1.00 / Year, Fishing Mortality (F) was 0.87/Year and Exploitation Rate (E) 0.47/ Year (Fig. 48). The findings of this study compares with the results of other kawakawa studies conducted elsewhere. Rohit *et al.* (2012) estimated total mortality (Z) at 1.68/ year, Fishing Mortality at 0.75/year and Natural Mortality (M) at 0.93/year and the Exploitation rate (E) was 0.36/year in the coastal waters of Indian. Johnson &Tamatamah (2013) estimated total mortality (Z) at 1.78/ year and Natural Mortality (M) at 1.09/ year and fishing Mortality (F) at 0.69/year in the coastal waters of Tanzania. Mudumala *et al.* (2018) while investigating the age, growth and mortality rates for kawakawa in the Northwest coast of India found comparable results, where total mortality (Z) was estimate at 1.48/year, Fishing mortality (F) at 0.62/year and Exploitation rate (E) at 0.42/year.

This study shows that fishing mortality (F) is higher than the optimal (0.5/year) suggesting that fishing pressure is causing significant loss to the kawakawa stocks and the harvesting of this fishery in the coastal waters of Kenya is not sustainable. The study reveals that 97.5% of the Kawakawa in the sample had attained sexual maturity, L_{50} = 37.7 cm – 50 cm (Fishbase, 2019, IOTC 2015). This suggests that the fishery maybe experiencing recruitment overfishing where sexually mature individuals are being removed from the population, and unless checked could lead to the collapse of the fishery. However, this is not conclusive and can only be confirmed with further studies on the reproductive biology of the species in the Kenya coastal waters.

IOTC (2018) classify this kawakawa fishery as not overfished. However due to the paucity of data cautions that there was a 96% chance that the stock biomass was below MSY levels and 100% probability that fishing pressure was above optimal levels (2018). IOTC recommended reduction of fish catches by 20% based on the 2013 levels (IOTC, 2018).

It is evident from this study that fishing mortalities for yellowfin, swordfish and kawakawa were above the optimal indicating that these fisheries under intense fishing pressure and are experiencing overfishing. Measures should be put in place by the Kenya Fisheries Service to reduce fishing effort, including restrictions on gear size, minimum size landing restrictions, closed areas and seasons for coastal fisheries.

The small-scale fishers at the Kenya coast are involved in fishing activities that entail multi-gear and multi-species interactions (Tuda *et al.*, 2016; Mangi & Roberts, 2007). The deployment of different gears by the fishers is dependent on the species targeted, the fishing areas and the season (Tuda *et al.*, 2016; Mangi & Roberts, 2007).

The probability of capture and selectivity of *Thunnus albacares*, *Xiphias gladius* and *Euthynnus. affinis* revealed that size of the fish landed was dependent in part on the design, size and type of gear, species of the target fish and fishing ground. The longline captured larger individuals of the same species at $L_{C\ 50}$ compared to the handline and trolling line. At L_{c50} Longline, handline and trolling captured *Thunnus albacares* of 98.2 cm, 90.3 cm and 68.2 cm, respectively (Table 8). With all gears combined, selectivity was estimated at 65.4 cm. Swordfish was predominantly caught using longline (Fig. 49) with gear selectivity at L_{C50} capturing larger individuals of fish (Table 9). There was no significant difference in the gear selectivity for longline and trolling at L_{c50}, both gears captured *Euthynnus affinnis* (Table 10).

The use of different gear combinations increased the probability of capture and selectivity. Although this study didn't collect the data on the sizes of hooks and mesh that were deployed by the fishers, an interview with the fishermen revealed that most of them use the hooks and nets of different sizes to target different types and sizes of fish species to maximize on returns. The size of the hook, bait and net had some influence on the size and type of fish species that were captured (Ingolfsson *et al.*, 2017). Increasing the size of the hook and net increased the probability of capturing larger individuals and reducing the capture of smaller individuals and or juvenile fish (Ingolfsson *et al.*, 2017; Hermann *et al.*, 2016). The type and method of fishing had some influence on the selectivity and type of fish landed. An interview with some of the fishermen in Malindi, Watamu and Mombasa revealed that fishing methods and deployment of gears influenced the type and size of the individuals landed. The fishers who landed their catch at the Old Town landing site (Mombasa) employed active longlining (drifting) and while those in Watamu most of them engaged in trolling. This observation by fishers reinforces the results of this study which revealed that the sizes of individuals landed at Old Town captured by drifting longline were larger and dominated by swordfish as opposed to other sites where smaller individuals were caught using trolling, gillnet and handline. Similar observations were reported by Munga *et al*., 2014 while studying selectivity of gears-mode of propulsion. Munga *et al.* (2014) established that mashua-gillnet combination captured largest individuals of coastal finfish species whereas mashua-handline landed more of pelagic species. The results suggest that the selectivity of the gears depend on the size and population characteristics of the fish that was targeted (Erzini *et al.*, 2003; Maunder *et al.*, 2006), the fishing ground as well as the type and size of fishing gear deployed by the fishers (Tuda *et al.*, 2016).

The results of the Virtual Population Analyses reveal that the highest fishing mortality (F) of *Thunnus albacares* was experienced between 65 cm – 85 cm mid-length (Fig. 50), *Xiphias gladius* between 105 cm – 135 cm mid-length (Fig. 51) and *Euthynnus affinis* between 52.5 cm – 62.5 cm mid-length (Fig. 52) The results suggest that fishing mortality rate is specific to the size of the individuals encountered as well as the selectivity of the gear (Amponsah *et al*., 2017; Kar *et al*., 2012). Small and large sized individuals are vulnerable to low and high fishing mortality rates, respectively. Individuals of yellowfin tuna in the 15 cm mid-length group experienced highest natural mortality (M) compared to those in the >85 cm mid-length group. VPA for swordfish shows that individuals less than 65 cm mid-length experienced high natural mortality as opposed to those above 105 cm mid-length. Individuals less than 32.5 cm mid-length were more vulnerable to natural mortality compared to those in the mid-length above 52.5 cm for kawakawa. These results clearly indicate that juvenile fishes are more vulnerable to natural mortality than mature individuals because they are easily preyed on by predators and adverse changes on the environment.

6.6 Conclusions and Recommendations

6.6.1 Conclusions

Yellowfin tuna, swordfish and kawakawa make a significant contribution to the artisanal fishery in Kenya. Small-scale fishery in Kenya is multi-species and multi-gear. Gillnets, handline, trolling and longlines are mainly deployed by small-scale fishers to catch tunas in the nearshore waters in Kenya. The deployment of different gears by the fishers was dependent on the species targeted, the fishing areas and the season. Technical measures and appropriate regulations defining the fishing gear type and size restrictions for different fishing grounds would enhance stock sustainability of the target species and minimize the capture of juvenile fish and non-target species.

Fish catch rates varied with season and sites. The variations in catch rates is influenced partly by the type and size of fishing gears as well as fishing methods and selectivity, the fishing ground, the type, size and condition of fish, seasonality and the migratory nature of tunas.

Most individuals of yellowfin tuna and swordfish (over 90%) harvested by artisanal fishers in the Kenya coastal waters are below the estimated length at first maturity (Juveniles). Fishing mortality rates are higher than the optimal (0.5/year) suggesting that these fisheries are under intense fishing pressure suggesting growth overfishing, especially for tuna and swordfish.

The study further reveals that 97.5% of the kawakawa encountered in this study had attained sexual maturity. However, fishing mortality was extremely high suggesting that the fishery maybe experiencing recruitment overfishing where sexually mature individuals are being removed from the population. This need to be addressed by the relevant national fisheries management authorities. Unless checked this could lead to the collapse of the fishery. However, this is not conclusive and can only be confirmed with further studies on the reproductive biology of the yellowfin tuna, swordfish and kawakawa species in the Kenya coastal waters.

Some studies have shown that there are several stocks of swordfish in different oceans and regions with distinctive growth parameters. The coastal Kenya swordfish could be a different stock and or localized population from that of the entire Indian Ocean region. The study has established that overfishing for swordfish could be happening in the Kenya coastal waters. Noting the concerns raised by the IOTC Working Party on Bill fishes on possible localized depletion of swordfish stock in the Western Indian Ocean region.

Virtual Population Analyses reveal that small and large sized individuals are vulnerable to low and high fishing mortality rates, respectively. Juveniles of are more vulnerable to natural mortality compared to mature individuals.

Sound knowledge and good understanding of the distribution, seasonal abundance, growth parameters, size distribution and gear selectivity is important for sustainable conservation and management of the tuna fishery resources in Kenya and the region.

6.6.2 Recommendations

i. This study therefore recommends a more comprehensive research on the growth and genetic analyses for yellowfin tuna, swordfish and kawakawa species in Kenya and the Indian Ocean region to provide more conclusive information on the growth rates and population structure of these fisheries

ii. This study recommends precautionary approach in managing and developing the swordfish fishery in Kenya and the entire region until comprehensive studies on stock status and structure have been undertaken.

iii. The results of this study indicate that yellowfin tuna, swordfish and kawakawa from coastal fisheries are under intense fishing pressure. National fisheries management authorities should closely monitor the trends and catches, fishing effort and length-frequency data in order to avoid overfishing.

iv. Precautionary measures should be applied before comprehensive studies are done to establish maturity status and stock structure for yellowfin and swordfish fisheries. The Kenya Fisheries Service and the IOTC should consider introducing Minimum Landing Size (MLS) for the swordfish fishery to ensure stock sustainability.

v. There is evidence of harvesting of juveniles for yellowfin and swordfish from the artisanal fishery. Development of technical measures and appropriate regulations defining the fishing gear type and size restrictions for different sites and zones is desirable. This would enhance stock sustainability of the target species and minimize the capture of juvenile fish and non-target species.

CHAPTER SEVEN

7.0 EVALUATE THE CONTRIBUTION OF SCIENCE IN INFORMING POLICY AND LEGAL FRAMEWORK FOR SUSTAINABLE MANAGEMENT AND DEVELOPMENT OF THE TUNA FISHERY IN KENYA

7.1 Introduction

This chapter focuses on the study's fourth (4) objective, which is to evaluate the contribution of science in informing sustainable management and development of Kenya's tuna fishery resources. The Fisheries Management and Development Act of 2016 replaced the Kenya Fisheries Act Cap 278 of 1991 as the primary law for governing and managing fisheries resources in Kenya (Republic of Kenya, 2016). There are also other relevant laws and policies that support the fisheries sector, namely, the Maritime Zones Act Cap 371 (1989). Kenya's National Oceans and Fisheries Policy of 2008 provides a framework for managing and developing the country's fisheries resources. The Government of Kenya in 2014 launched the Tuna Fisheries Development and Management Strategy (2013 -2018). The goal of the strategy is to offer direction and a framework for managing and developing the country's tuna fisheries resources in order to spur socioeconomic growth (Ministry of Agriculture, Livestock and Fisheries, 2013).

Kenya has also ratified a number of international tools, treaties, and instruments relevant to the fisheries sector, including the United Nations Convention on the Law of the Sea (UNCLOS), the United Nations Fish Stock Agreement (UNFSA), the FAO Code of Conduct for Responsible Fisheries (CCRF), the Indian Ocean Tuna Commission (IOTC), and the South West Indian Ocean Commission (SWIOFC) (Republic of Kenya, 2020; Ruwa, 2011). As previously stated, worldwide capture of marine fisheries resources are diminishing (FAO, 2016; Myers & Worm, 2005).

Furthermore, tuna and tuna-like fish stocks in the Indian Ocean are on the declining trajectory (IOTC, 2015; 1OTC 2016, IOTC, 2020), with yellowfin tuna being overfished in particular (IOTC, 2020; IOTC, 2018; IOTC, 2017; IOTC, 2016; ISSF 2016; IOTC, 2015; Pillai & Satheeshkumar, 2012). Kenya's coastal fisheries are likewise on the decline (Fisheries Department, 2012; Winter, 2009; Munga *et al*., 2012).

The Kenya Fisheries Service (KeFS) is in charge of the governance and management of Kenya's inland and marine fisheries resources (Republic of Kenya, 2016). The State Department of Fisheries, Aquaculture, and Blue Economy provides strategic guidance and policy direction to the key actors in the country's fisheries sector, including aquaculture. The Kenya Marine and Fisheries Research Institute (KMFRI) was established with a national mandate to conduct marine and fisheries research in Kenya in collaboration with relevant national, regional, and international agencies, such as the Indian Ocean Tuna Commission (IOTC) (KMFRI, 2018). Kenya cooperates and collaborates with other competent national, regional, and international organizations to conduct research and put conservation and management measures in place for tuna fisheries (Kimani *et al.,* 2018; Republic of Kenya, 2020; Ministry of Agriculture, Livestock and Fisheries, 2013). The management of tunas in the Indian Ocean is under the Indian Ocean Tuna Commission (IOTC) which was created in 1996 under FAO Article XIV (IOTC, 2016). IOTC is a management body and its decisions are binding to all members (IOTC, 2019). Kenya became a member of the IOTC in 2004 (Republic of Kenya, 2020).

This chapter focuses on objective four of the study, which is about how science has contributed in informing policy and legislation for the management and development of tunas in Kenya. The evaluation focuses on both empirical evidence of the application of science in the formulation and implementation of Kenya's fisheries policy and legislation.

7.2 Methodology

7.2.1 Study Design

The study used a systematic review and descriptive survey design to collect, collate, analyze, and interpret publicly available data and information on how science has influenced the development and implementation of Kenya's national fisheries policy and legal framework for sustainable tuna fisheries development and management.

The study analyses relevant national fisheries policy and legal documents, describes how the different regional and global instruments are domesticated, and looks at how policies and regulations are implemented. The focus here was on how science and biological information has helped the formulation and implementation of Kenya's fisheries policy and regulations in order to manage tuna resources sustainably.

7.2.2 Data Collection

The study used a two-pronged methodological approaches that included secondary and primary sourcing of data and information as well as informal consultations with pertinent respondents using a questionnaire guide.

7.2.2.1 Secondary Data Collection

Desktop study and literature review on the topic of study were conducted by accessing the websites of major organizations and institutions involved in research and management of marine fisheries resources at the national, regional, and global levels.

Literature review of relevant policy, legal, and strategic documents, as well as reports, was conducted to identify empirical evidence on the use of science to formulate and implement tuna management policy and legislation in Kenya. This was preceded by an examination of how regional and international policy instruments have been domesticated in national fisheries policy and regulation, with an emphasis on science-based approaches to tuna resource management in Kenya. The Kenya National Oceans and Fisheries Policy 2008, the Fisheries Management and Development Act 2016, and the Kenya Tuna Fisheries Development and Management Strategy (2013-2018) were among the strategic reports and policy documents reviewed, as well as international instruments and tools such as the Indian Ocean Tuna Commission (IOTC) Agreement and the United Nations Convention on the Law of the Sea (UNCLOS) and the United Nations Fish Stock Agreement (UNFSA).

The information and data were sourced from relevant organizations including the Ministry of Agriculture, Livestock, Fisheries and Cooperatives, the Kenya Fisheries Service (KeFS), the Kenya Marine and Fisheries Research Institute (KMFRI), the Indian Ocean Tuna Commission (IOTC), Food and Agriculture Organization of the United Nations (FAO), the University of Nairobi Library, Wildlife Conservation Society (WCS), the International Seafood Sustainability Foundation (ISSF) and other relevant national, regional, and global organizations involved in research and sustainable management of marine fisheries resources.

The data was gathered by visiting the institutes listed above and looking through relevant reports, publications, journals, scientific papers, and unpublished literature. The majority of the research was conducted via going to these institutions' websites and accessing their databases and/or information repositories via the internet and their websites.

This entailed searching for the relevant records using key words such as fisheries study, the study of tuna, tuna-like species , Catch Per Unit Effort (CPUE) for tunas, fisheries research and study, fish distribution, composition, abundance, growth parameters of tunas, the biology of tunas, the growth and population dynamics of tunas, the biology and growth of swordfish, yellowfin tuna reproductive biology and growth; the biology and growth of skipjack tuna, kawakawa, yellowfin tuna, albacore tuna, longtail tuna, bonitos; the study of neritic/ coastal tunas in the Western Indian Ocean region/Kenya, gear selectivity of tuna and tuna-like species, length-weight relationship for the yellowfin tuna, swordfish, kawakawa; Virtual Population Studies for the yellowfin tuna, swordfish and kawakawa; the management of shared Indian Ocean tuna resources, tunas research in the Indian Ocean region/Kenya, science and tuna management, science based tuna fisheries management, Kenya tuna fishery resources, tuna strategy, fisheries policy, Kenya fisheries legislation, tuna harvest strategy, biological reference points, fisheries international treaties/ tools, Nairobi Convention, FAO fisheries, IOTC.

The literature/information was screened for relevancy before being downloaded and saved as softcopies of reports, papers, articles, and books. The relevant institutions loaned hard copies of the materials, such as thesis, reports, and books. Documents were borrowed and returned in circumstances when the evaluation was done in libraries.

The documents were rated and assessed based on their relevancy, with a special focus on tuna and tuna-like species science and research in Kenya over the last ten years.

7.2.2.2 Primary Data Collection

This included using a questionnaire guide to conduct informal consultations with the appropriate responders. Before being administered to the respondents, the questionnaire guide was pre-tested, and fine-tuned. The questions were designed to capture important scientific aspects of sustainable tuna resource management, such as the Total Allowable Catch (TAC), Maximum Sustainable Yield (MSY), biological reference points, harvest strategy and control rules, fisheries data collection and analysis to inform policy and decision making, and fish landing size restrictions, nautical mile restrictions and fishing gear restrictions. The respondents were also asked to provide information on the policy, legal, and institutional framework, as well as the involvement of the IOTC and local fishing communities in the management of tuna resources in Kenya.

A total of 31 respondents, mostly fisheries experts drawn from fisheries management, research, and academia, as well as fisherfolk in Kenya were interviewed. The respondents were asked a series of questions designed to assess the extent to which science had informed policy formulation and practice in Kenya's tuna fisheries management and development. The replies were scaled from 1 to 3, with 1 indicating the lowest (NO), 2 suggesting partially/intermediate, and 3 representing the greatest (Yes).

Visits to fish landing sites and relevant offices were made for reconnaissance and confirmation of various fisheries management interventions on the ground/practice, as specified in the national fisheries policy and legislation, as well as the tuna fisheries management and development strategy, with a focus on science-based tuna management.

The data gathered was used to answer the following critical questions on how science informed policy, law, and management of tuna and tuna-like species in Kenyan waters:

1. Is science used to inform Kenya's policy and legal framework for the management and development of tuna fishery resources?
2. Does the Indian Ocean Tuna Commission (IOTC) scientific advice inform Kenya's regulatory framework and management of tuna and tuna-like species?
3. To what extent has Kenya's tuna management policy and legal framework internalized relevant regional and international tools, including science-based approaches to fisheries management?
4. What is the present state of science-based practice in the development and management of tuna resources in Kenya, as outlined in the country's national fisheries policy and legislation?
5. What are the gaps in the science-policy interaction for tuna resource management in Kenya, and how can they be addressed?

7.3 Data Analysis

The data and information collected was analyzed for empirical evidence on the use of science in fisheries policy and legislation formulation and practice in Kenya. The analysis was useful in discerning evidence for scientific input in the provisions in the Kenya national fisheries policy, legislation and tuna strategy and against what was currently being practiced. Further the analysis was used to help describe the extent to which the Kenya national fisheries policy and legal framework domesticated and confirmed with the relevant science based provisions in the regional and global instruments and frameworks such as the IOTC and UNCLOS. The data and information analyzed was presented in descriptive, qualitative and essay format describing the relevant provisions of the national, regional and global policy and legal instruments with focus on science and how they are applied in practice in the management of tunas in Kenya.

7.4 Results

7.4.1 Scientific Robustness of the Tuna Fisheries Management Policy and Legal Framework in Kenya

7.4.1.1 The Fisheries Management and Development Act 2016

As detailed in the following sections, a review of the Fisheries Management and Development Act 2016 makes substantial reference to science and research in managing Kenya's fisheries sector.

Section 5. 2 (a) of the Act provides for the allocation and access to fisheries with a view to achieving optimal use and sustainable development of fisheries resources on the long-term. The Fisheries Act explicitly underscores the importance of managing fisheries resources based on available scientific information, more specifically in stock designing stock rebuilding plans in order help fisheries move towards sustainability (Maximum Sustainable Yield – MSY) (Section 5. 2 (h)). Fisheries data collection system and information sharing with the relevant users is critical (Section 5.2(K)). Section 5.2 (0) lays emphasis on conservation measures aimed at controlling fishing effort which implies Total Allowable Effort (TAE).

Section 6 (2b) outlines the functions of the Kenya Fisheries Advisory Council, including the allocation and access to fisheries resources in Kenya. However, the Act does not specify how these fishing opportunities will be allocated. The Kenya Fisheries Service (KeFS) is allowed by Section

9 of the Act to promote scientific study on fisheries-related issues in partnership with the Kenya Marine and Fisheries Research Institute, among other things (KMFRI). Subsection 9(h) mandates the collection and analysis of data on a regular basis in order to inform fisheries policy and management.

Section 27 provides for the creation of a research fund to aid in the development and management of fisheries. As one of the fisheries management measures, Section 30(6) emphasizes research and survey. Section 30(i) mandates the creation of an investor-friendly licensing system, however it is unclear because it does not clearly set a limit or cap on the number of licenses that can be awarded based on the Total Allowable Catch (TAC). Section 39 emphasizes the use of scientific data to support fishery-specific management plans, whereas subsection 3(d) calls for the establishment of a Maximum Sustainable Yield (MSY) based on both biological and socioeconomic data. Section 40 sets limits on the amount of fish caught, the species caught, and the size of individuals, while Section 42 forbids the use of specific fishing gear. To assist sustainable fisheries management and development, Section 52 (1-2) emphasizes fisheries stock assessment, periodic data collection, and analysis. Section 75.1(a) emphasizes the need of keeping data and information related to fisheries research and surveys. Licensed fishing companies are obliged to maintain an easily accessible database to support fisheries management (see Section 81). Industrial fishing is forbidden in closed areas and territorial waters (Section 99.1 (h and k)), and Distant Water Fishing Nations are required to land some bycatch (30%) and sell their catch in the local market at authorized fishing ports in Kenya (Section 99.1 (J and K).

Sections 100 and 102 of the fisheries lays emphasize on the importance of reporting requirements, which include the amount of catch landed, the type of species, and the size of fish. The International Law establishes a framework for fisheries access agreements, and Kenya's fisheries law, section 128 (4-5), refers to the estimated value of fisheries accessed by vessels in the EEZ, which may be determine if fishing levels have negative impacts on stocks and ecosystems. The precautionary approach (section 130.2(b) can also be used to manage fisheries. Vessel Monitoring System (VMS) application and use are critical to fisheries management (parts 136 (6), 147, and 157).

7.4.1.2 The Kenya National Oceans and Fisheries Policy 2008

In 2009, Kenya's government launched the country's first ever comprehensive national oceans and fisheries policy. The policy establishes an overarching framework that guides the development and management of Kenya's marine and fisheries sectors. There are seven chapters in the policy document. This review focused on chapters two, three, four, five, and six which were more relevant for this topic. Chapter Two outlines challenges and opportunities in Kenya's fisheries sector; Chapter Three highlights policy guidelines and objectives; Chapter Four presents policy statements; and Chapter Five outlines the strategies. The implementation framework is presented in Chapter 6.

In Chapter Two, the challenges facing the marine fisheries sector are listed, as well as policy objectives. Increased fishing effort, unsustainable fishing techniques, and degradation of the fishing ecosystem are among the challenges facing marine fisheries sector in Kenya. The Kenya National Oceans and Fisheries Policy's overarching objective is to increase the contribution of the fisheries sector to the national economy, including food and nutritional security, job development, and long-term prosperity. The policy emphasizes the use, development, and management of fisheries resources in a way that is informed by science and the precautionary principle.

The policy framework's main thrust is found in Chapters 4, 5, and 6. The policy declarations in Chapter Four include, among other things, encouraging fisheries research and surveys, monitoring, control, and surveillance (MCS), the development of fisheries infrastructure, public engagement, and long-term investment in the Kenyan fisheries industry. In Chapter Five, the strategies to be pursued in order to attain the intended policy objectives are detailed. These strategies include, but are not limited to, the use of scientific information (Clause 5.1.3), engaging with local fishing communities (Clause 5.2.4), regional collaboration and cooperation for managing shared and highly migratory stocks like tuna and tuna-like species (Clause 5.5.3), and sustainable investments that take into account stock sustainability (Clause 5.9.2). Perhaps the most intriguing clause is 5.1.3 which emphasizes the significance of gathering data and information in order to enable effective and long-term fisheries management.

7.4.1.3 The Kenya Tuna Fisheries Development and Management Strategy (2013-2018)

The Government of Kenya launched the Tuna Fisheries Development and Management Strategy in 2014 (Government of Kenya, 2017). The strategy lays forth a plan for Kenya to tap into profitable tuna and tuna-like resources within her EEZ in order to boost the contribution of marine fisheries to the economy. Yellowfin, skipjack, bigeye, kawakawa, frigate tuna, swordfish, and marlins are the main tuna and tuna-like species found in Kenyan water as outlined in the Strategy. The Strategy acknowledges the role of the Indian Ocean Tuna Commission (IOTC) in tuna management in the IOTC's area of competency. Kenya became a Contracting Party of the IOTC in 2004.

In Section 2.5, the challenges and issues facing the tuna fishery in Kenya are outlined, including limited data and knowledge on the stocks, insufficient research, and a lack of quota allocation.

Chapter 3 of the Strategy recognizes the migratory nature of the tunas, the role of science and research, the precautionary and ecosystem approach, as well as regional/global cooperation in managing tunas.

In Chapter 4, the key issues, objectives and strategies for managing tunas in Kenyan waters are outlined. The management and/or restoration of tuna stocks above and/or maintaining them at the IOTC reference points is underpinned on strategic objective 1 and strategy 3. The potential of the tuna sector to contribute to the national economy is emphasized. Strategic objective 3 underscores the importance of science and research in guiding decision-making in the management of Kenya's tuna resources.

The tuna strategy's implementation framework is detailed in Chapter 5. Tuna stock assessments, harvest control rules adoption and implementation, effort restrictions and limits, and domestication of international tools are some of the strategic actions highlighted in the tuna Strategy.

7.4.2 A Review of Relevant Regional and Global Legal and Policy Instruments that govern Fisheries Resources in Kenya

The goal is to see how the Kenyan fisheries policy and legal framework are aligned to the regional and global tools/instruments for fisheries management and development, particularly science-based approaches to fisheries management. The following documents were examined for the purposes of this study:

i. The United Nations Convention on the Law of the Sea (UNCLOS, 1982)
ii. The United Nations Fish Stock Agreement (1995).
iii. FAO Code of Conduct for Responsible Fisheries (1995). The year 2020 marked 25 years that the FAO Code of Conduct for Responsible Fisheries has provided services to the human fraternity and the environment (FAO, 2020).
iv. The Agreement for the establishment of the Indian Ocean Tuna Commission (IOTC) and related structures.

7.4.2.1 The United Nations Convention on the Law of the Sea (UNCLOS, 1982)

The United Nations Convention on the Law of the Sea (1982) was the first worldwide framework for the orderly use, management, and conservation of live marine resources, including fisheries, in the Exclusive Economic Zone (EEZ). (UN, 2018; UNCLOS, 1982; AU-IBAR & WWF, 2013; Winter, 2009). The Convention was first made available for signature in 1982, and it became legally binding in 1994. (UN, 2018; Woke *et al*; 2020).

The UNCLOS contains 320 articles and annexes (UN, 2018; UNCLOS, 1982). The relevant provisions of UNCLOS were examined in the context of research and science in order to demonstrate how they contributed to the conservation and management of fisheries resources in this study.

Part V of the UNCLOS establishes the legal framework and rights that coastal states have in their respective EEZs. Article 56 (1) (a) grants coastal states sovereign rights to explore, utilize, protect, and manage living resources in the EEZ, as well as to conduct scientific research to inform management (Article 56 (1) b) (ii). The United Nations Convention on the Law of the Sea

(UNCLOS) sets procedures for coastal states to collaborate in the management of shared and highly migratory species (Article 64).

Coastal states are under obligation to design appropriate measures to conserve and manage living resources in the high seas (Article 119) (1. a), such as establishing allowable catch levels based on the best scientific evidence available in order to harvest, maintain, and restore stocks at levels that produce Maximum Sustainable Yield (MSY). Article 119 (1) (b) takes into account ecosystem concerns about the impact of fishing operations on both target and non-target species in order to ensure that their population are not depleted. Sharing of scientific data and information by the relevant national, sub-regional, regional, and global organizations and experts is encouraged (Article 119). (2).

Part XIII of the UNCLOS (Articles 238 – 265) explicitly provides for rules and procedures for Marine Scientific Research. Whereas UNCLOS fails to provide concrete definition of Marine Scientific Research (Woke *et al*, 2020; Yu, 2020), the Convention makes general provisions on how marine research should be conducted (Article 240). Coastal states have a right to consent and approve any research that is to be undertaken in their territorial and EEZ waters (Articles 245 - 246). Coastal states have a right to access data and results for the scientific research in their waters (Articles 248 – 249). All coastal states have the right to conduct research in the water column within their respective EEZs and beyond, according to Articles 256 and 257.

7.4.2.2 The UN Fish Stock Agreement (UNFSA, 1995)

The UN Fish Stock Agreement was up for signature in 1995, and it went into effect in 2001. This legally binding agreement establishes a framework for governments to work together to implement the UNCLOS, with a focus on the conservation and management of straddling and highly migratory fish species (UN, 2020; Winter, 2009; UN, 1995).

The conservation and management of straddling and highly migratory fish stocks is addressed in Part II of the Agreement. Article 5(b) mandates that coastal governments protect and manage fish stocks in accordance with scientific evidence in order to ensure Maximum Sustainable Yield (MSY). The agreement contemplates a situation in which data and information on a particular fishery are insufficient or unavailable, and it makes provisions for the use of precautionary measures (Article 6).

Article 6 lays emphasis on the use of scientific data to support fisheries management, as well as a precautionary approach if such data/information is unavailable. Article 6 (3) lays forth the procedures for putting the precautionary approach into action, as well as steps to restore depleted fish stocks. Coastal states are expected to design, develop, and implement comprehensive fisheries data collection and research programs that include both target and non-target species. The Agreement provides for the imposition of a catch and effort cap in order to realize long-term sustainability of fish stocks (Article 6), (6).

All coastal states have the right to conserve and manage fisheries resources in their territorial waters and high seas (Article 7), in compliance with UNCLOS requirements (Article 7 (2)). Article 7 (2)(d) emphasizes the use of biological parameters in fish stock management. Regional Fisheries

Management Organizations (RFMOs) play a critical role in stock assessment and scientific advice, which informs conservation and management measures (Article 10) (d & g).

The agreement calls for regional cooperation in gathering data and undertaking scientific research to inform stock assessment and decision-making (Article 14).

7.4.2.3 FAO Code of Conduct for Responsible Fisheries (I995)

The FAO Conduct for Responsible Fisheries (CCRF) was approved by the FAO Conference in 1995, and it offers a fundamental foundation for national and international efforts to sustainably utilize and manage living aquatic resources. The CCRF is a voluntary and non-binding soft law (Yona, 2011; CCRF, 1995; AU-IBAR & WWF, 2013). Article 7 of the CCRF stipulates the objectives of fisheries management informed by science to ensure stock sustainability (Article 7.2.1) and outlines procedures for data collection and adoption of scientific advice (Article 7.4) as well as precautionary approach (Article 7.5).

The CCRF emphasizes the importance of research and scientific information in supporting policy and decision-making for better fisheries management (Article 12). A number of research interventions are prescribed including gear selectivity, monitoring stock status and impact of fishing on the environment, socio-economic valuation. Coastal states are encouraged to analyze the information generated by scientific research and utilized it in setting the management objectives, reference limits and criteria for fisheries performance (Article 12 (2 and 13).

7.4.2.4 The Agreement for the Establishment of the Indian Ocean Tuna Commission (IOTC)

The Indian Ocean Commission (IOTC) was founded in 1996 as an FAO body under Article 14 vide the IOTC Agreement (Article 1), which is in compliance with UNCLOS and UNFSA. On 25th of November 1993, the Indian Ocean Tuna Commission (IOTC) was established as an FAO body, and became effective on the 27th of March 1996 (Republic of Kenya, 2020; IOTC, 1996).

IOTC coastal states have sovereign rights to utilize, conserve, and manage highly migratory tuna resources in their respective EEZs (Articles XVI). The IOTC, currently, has 33 member states (IOTC, 2020), including coastal states and DWFNs (Article IV (1)). (a). Kenya joined IOTC in 2004 (Republic of Kenya, 2020).

As stated in Article V (i), the objective of the IOTC is to promote regional cooperation in the management, development, and conservation of tuna and tuna-like species in the Indian Ocean. IOTC's functions include gathering, analyzing, and sharing scientific information on tuna trends and status in the IOTC's area of competence (Article V (2) (a), coordinating research-related initiatives (Article V(2)(b), and adopting tuna conservation and management measurers based on scientific advice (Article V (2) (c)).

The IOTC has formed subsidiary entities such as working parties, sub-commissions, and a permanent scientific committee (Article XII) (5) to assist it in achieving its goals and fulfilling its mandate. The scientific committee works closely with the relevant working groups to conduct stock assessments, conduct research, and provide scientific advice to tuna conservation and management measurers (Article XII (4 a – e)).

7.4.3 Perceptions of Fisheries Experts, Resource Managers, Scientists and Fishers on the Application of Some Scientific Aspects in Conservation and Management of Tunas in Kenya

Scaling of the perceptions by the different respondents drawn from the fisheries managers, researchers and fisherfolk are presented in Figure 53.

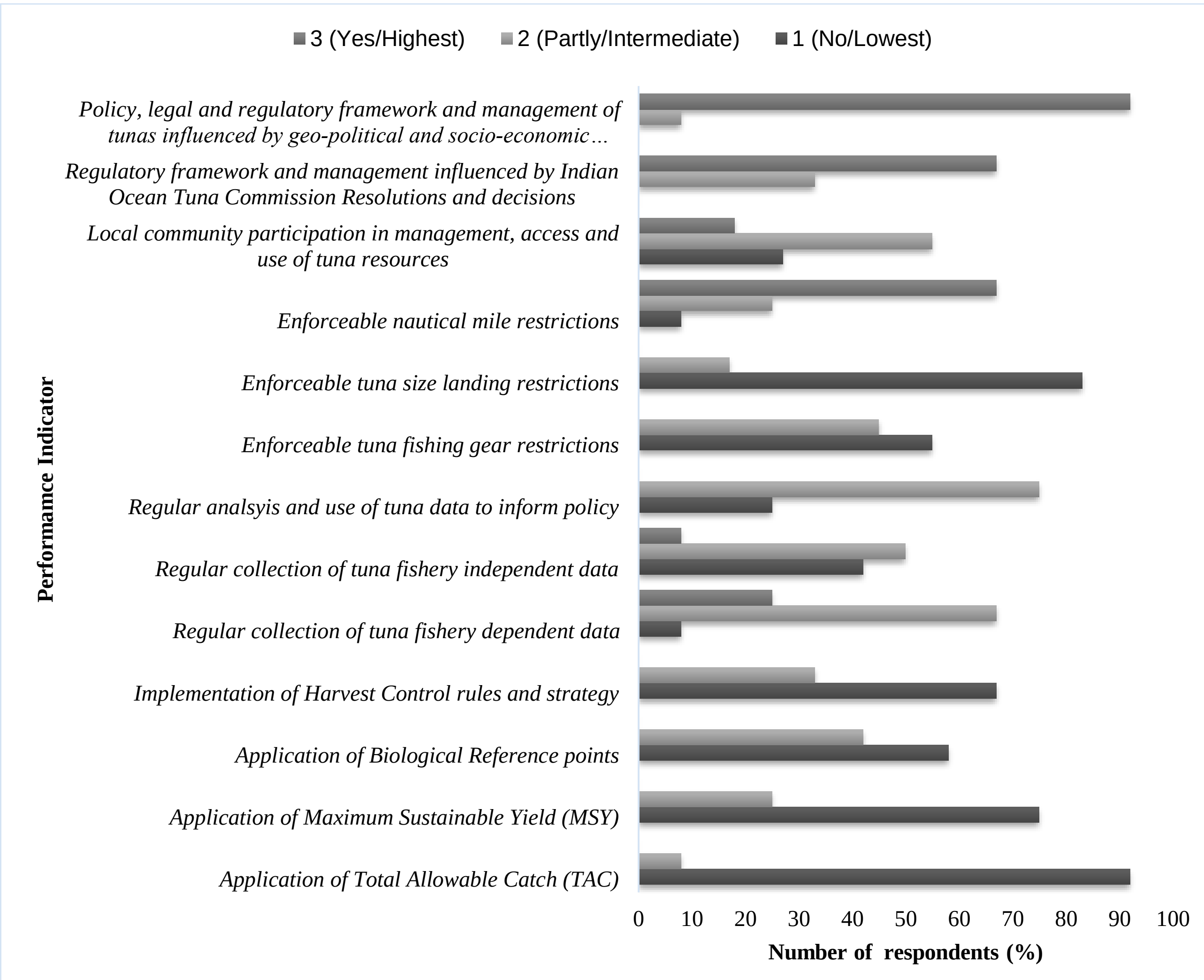


Figure 53. **Expert opinions on science-based management and governance of tuna resources in Kenya from fisheries managers, research scientists, academia, and fisher folk (values scaled from 1 to 3).**

Some 92% of the respondents scaled lowest the application of Total Allowable Catch (TAC) in the management of tunas in Kenya. About 8% of the respondents scaled 2 (intermediate). None of the respondents scaled 3 (Highest). Approximately 75% of the respondents scaled lowest the application of Maximum Sustainable Yield (MSY)and none rated 3. On application of biological reference points, about 58% and 42% of the respondents scaled lowest and intermediate, respectively. Harvest control rules and strategy was scaled lowest by approximately 67% of the people that were interviewed. None of them scaled 3 (Highest). About 67 % of the respondents (scaled 2) were on the opinion that tuna fishery dependent data was regularly collected from the fisherfolk whereas 50% had the same view for the fishery independent data.

Although tuna fisheries data was collected regularly, about 75% of the respondents felt that the data was not used to inform policy for improved tuna management. Fish landing size, fishing gears and nautical mile restrictions are some of the approaches employed in the conservation and management of fisheries resources. Some 55% of the respondents scaled lowest (1) on fishing gear, 83 % scaled lowest on landing size restrictions and 67% scaled 3 (highest) on nautical mile restrictions. The management of shared tuna stocks was influenced by local populations, the Indian Ocean Tuna Commission (IOTC), geopolitical, and socioeconomic factors. In terms of local community engagement in sustainable tuna fisheries, 55% of respondents gave a score of 2 (moderate), compared to 18% who gave a score of 3. IOTC was rated as having a 3 (highest) influence by 67% of the respondents. Over 90% of respondents rated geopolitical and socioeconomic factors as important in the management and development of tuna resources in Kenya, and indeed the entire Indian Ocean region, on a scale of 1 to 3.

Consultations with fisheries experts found that the management of tuna and tuna-like species in Kenyan waters was heavily influenced by the Indian Ocean Tuna Commission's (IOTC) decisions, geopolitical dynamics, and socioeconomic factors.

The results indicate that Kenya is yet to implement all science based tuna fisheries management and conservation measures as per the IOTC decisions aligned to international fisheries management instruments.

7.3.4 Scientific Studies On Tunas in Kenya to Inform Policy and Management

There is limited data and studies on growth, population dynamics, mortality and exploitation rates of tunas in Kenyan waters. Most of the studies have extensively focused on non-tuna species ranging from the biology, distribution, species diversity, gear selectivity and composition (Fondo *et al.*, 2014). Aura *et al.* (2011) studied length-based relationship for nine deep sea fish species of Kenya coast. The species studied belonged to 8 families, namely Bempropsidae, Rajidae, Squalidae, Squantinidae, Triglidae and Sycliorhinidae. Munga *et al.* (2014) conducted ecological and socio-economic assessment of the artisanal trawl fishery in the Malindi –Ungwana Bay. The trawl fishery was dominated by Sciaenidae, Mullidae and Sillaginidae. Some studies have been undertaken to establish fish catch rates for non-tuna species (Munga *et al.*, 2014, McClanahan *et al.*, 2008).

Kenya recently procured a research vessel (RV-Mtafiti) and have started conducting some research on tunas in the EEZ spearheaded by the Kenya Marine and Fisheries Research Institute (KMFRI). KMFRI and Kenya Fisheries Service are also monitoring catches on Kenya flagged longline vessels. The information gathered will provide a precise estimate of tuna stocks and other fisheries resources in Kenya's Exclusive Economic Zone (EEZ) (KMFRI, 2018).

Details about the knowledge and science of tunas in Kenya and the region have been discussed in Section 2.4 of this thesis.

Effective tuna fisheries management and conservation measures require an evidence-based and science-based strategy, as well as the availability of catch-effort data and biological parameters on tuna and tuna-like species. This study identified some gaps in the management of Kenya's tuna fishery resources from scientific point of view and made recommendations on how to resolve the issues.

7.5 Discussions

The Fisheries Management and Development Act 2016, which repealed the Kenya Fisheries Act Cap 278 of 1991, governs the management of fisheries resources in Kenya. The Act provides for the protection, conservation, management and development fisheries resources.

A review of the Kenyan fisheries policy, legislation, regulations, and tuna management strategy revealed that they were compliant with the provisions of relevant regional and global agreements, including UNCLOS, UNFSA, and the Indian Ocean Tuna Commission (IOTC) Agreement. The Treaty Making and Ratification Act of 2012 establishes procedures for making and ratifying treaties in Kenya (Republic of Kenya, 2012; IOTC, 1996; IOTC, 2018). On March 2, 1989, Kenya ratified the United Nations Convention on the Law of the Sea (UNCCLOS). Kenya was granted sovereignty rights under the UNCLOS to cooperate with relevant countries and agencies in the development and management of tunas in the EEZ, whether bilaterally or multilaterally. The United Nations Fish Stock Agreement (UNFSA) and the Agreement for the Establishment of the Indian Ocean Tuna Commission (IOTC) were ratified by Kenya in 2004 (Republic of Kenya, 2020). The FAO Code of Conduct for Responsible Fisheries (CCRF), which was signed in 1995 and entered into force in 2001 with the goal of promoting sustainable development and management of fisheries resources, was recently amended after 25 years of service to the world (FAO, 2020). In 1995, Kenya ratified the CCRF (Republic of Kenya, 2020). The CCRF is not legally binding because it is voluntary.

Kenya has also ratified other relevant treaties and agreements, such as the UN FAO Port State Measures Agreement, 2009 (PSMA), which aims to prevent, deter, and eliminate IUU fishing. The FAO compliance agreement has yet to be ratified by Kenya. Kenya has also joined a number of regional fisheries management organizations, including the South West Indian Ocean Commission (SWIOFC) and the Lake Victoria Fisheries Organization (LVFO). Kenya collaborates and cooperates with the African Union, the Indian Ocean Commission (IOC), the Southern African Development Commission (SADC), the Eastern African Community (EAC), and the Inter-Governmental Authority on Development (IGAD) and other bodies for improved coordination and management of shared and highly migratory species. The domestication of these regional and global fisheries related agreements is through the Kenya Fisheries Management and Development Act, 2016, the Maritime Zones Act, Cap. 371, and Legal Notices on Foreign Fishing Fleets. These agreements are coordinated at the national level by the State Department for Fisheries, Aquaculture, and Blue Economy. Kenya Fisheries Service (KeFS), Kenya Marine and Fisheries Research Institute (KMFRI), and Kenya Maritime Authority (KMA) are the major national institutions responsible for implementing these agreements in accordance with their legislative mandates (Republic of Kenya, 2020).

Marine fisheries and their associated ecosystems are diverse, complex, and dynamic, making management difficult (Nilsson, *et al.*, 2019). Scientific data and information that is credible, adequate, and correct are essential for the sustainable and effective management of fisheries resources (Nilsson *et al.*, 2019; Ndegwa & Okemwa, 2017). Lack of or insufficient use of research in fisheries management has been linked to declining fish stocks and mismanagement of marine resources (Nilsson *et al.*, 2019). UNCLOS Article 61 (2); UNFSA Article 5 (b); CCRF Article 7.2.1; IOTC Article V (1) require coastal States to manage and conserve marine living resources in their respective Exclusive Economic Zones (EEZ) based on the best available scientific evidence to avoid over-exploitation (UNCLOS Article 61 (2); UNFSA Article 5 (b); CCRF Article 7.2.1; IOTC Article V (1)).

The coastal states, as appropriate, have to cooperate bilaterally, collectively and with other relevant national, regional and global institutions to undertake scientific research to inform policy. The Kenya Fisheries Development and Management Act, 2016 underpins the principle of using the best available scientific evidence to inform fisheries management and conservation in the waters under her jurisdiction in conformity with the international law (Kenya Fisheries Law, Article 5 (2); Kenya Fisheries Policy Article 4.2.1 and National Tuna Strategy Chapter 3). In exercising this obligation and taking into account that tuna and tuna-like species are highly migratory, Kenya has to cooperate with other coastal states under the framework of the Indian Ocean Tuna Commission (IOTC) and the South West Indian Ocean Fisheries Commission (SWIOFC).

According to IOTC (2020) compliance report, a large number of members, including Kenya, have not been consistent with complying with the IOTC conservation and management measures. Kenya's compliance has been varying since 2010, with a low of 31% in 2012 and a high of 66% in 2015. In 2017 and 2018, the percentages fell to 42% and 39%, respectively. Compliance increased to 87% in 2019 (IOTC, 2020). In terms of sustaining consistently high compliance, much more is desirable. Coastal states have the obligation to put in place measures to sustain and/or restore stocks at levels that provide Maximum Sustainable Yield (MSY), such as quota allocation, landing size restrictions, and limit reference points.

The maximum quantity of annual catch of fish that can be extracted from a fisheries stock indefinitely is known as the Maximum Sustainable Yield (MSY) (Caddy & Mahon, 1995; WWF, 2011). Though it is believed to represent a hypothetical equilibrium state between stock and fishing activities, a constant MSY through time is not feasible. Coastal States are required by UNCLOS Article 61 (3) to design fisheries management and conservation measures that ensure species are harvested at levels that meet Maximum Sustainable Yield. According to UNCLOS, any coastal harvest below the MSY is considered a surplus (Caddy & Mahon, 1995). The UN Fish Stock Agreement (Article 5(b)) and the FAO Code of Conduct for Responsible Fisheries (Article 7.2.1) reinforce UNCLOS provisions requiring coastal states to develop science-based conservation and management measures to maintain or restore fish stocks at levels capable of producing MSY while taking economic and environmental factors into account. The Indian Ocean Tuna Commission

(IOTC) applies MSY in the management of some of the stocks under its management. For instance, the MSY for some of the species are; yellowfin, 403,000 Mt; bigeye, 87,000 Mt; skipjack, 601,088 Mt (IOTC, 2020). The MSY for yellowfin has been exceeded while that of bigeye, kawakawa, albacore and swordfish are very close to being exceeded as was shown in Table 1.

Chapter 3 of the Tuna Strategy of Kenya lays out the general principles for long-term development and management of the country's tuna resources. The use of biological and economic reference points in tuna fisheries management in Kenya is stated explicitly in Section 3 I of the Kenya tuna strategy. Chapter 4 section 4.1 of the Strategy lists strategic issues, defines objectives, and outlines strategies to promote stock sustainability. More specifically, strategic objective 1 (one) is to guarantee that tuna stocks are maintained at sustainable levels while causing the least amount of negative impacts to the marine environment. The specific management objectives for the Kenya National Oceans and Fisheries Policy (2008) section 3.3.1, is to promote long-term stock viability by putting in place appropriate resource conservation and management measures guided by science. MSY is not explicitly mentioned in this policy document, but it is implied. The Kenya Fisheries Management and Development Act, 2016, Section 39 (3)(d), lays out the methods for establishing MSY, which must be based on biological and socioeconomic data. The Director General of the Kenya Fisheries Service develops and issues guidelines for the construction of fisheries management plans (Section 3), including creating MSY, after consulting with county governments and relevant stakeholders. The process of determining MSY for a specific fishery and or fish stock requires the application of scientific and biological data. Catch, effort and length frequency data is critical. Interaction with the Kenya fisheries managers and scientists revealed that MSY for various tuna and tuna-like species, as provided for in the IOTC conservation and management measures has not been effectively implemented by the member states.

The Total Allowable Catch (TAC) is the maximum amount of fish that can be harvested from a certain fishery based on the management plan. The United Nations Convention on the Law of the Sea allows coastal governments to establish the amount of total permissible catch (TAC) (UNCLOS, 1982). Article 6 of the UNFSA outlines procedures for implementing a precautionary approach to avoid over-exploitation of living resources. Article 6 (3)(b) provides guidelines in Annex II for determining and establishing stock-specific reference points that must not be exceeded. The guidelines specify two types of precautionary reference points: conservation (limit reference) and management (target reference). The limit reference points define boundaries that allow stocks to be harvested safely within their biological limits which would result in Maximum Sustainable Yield (MSY). On the other side, target reference points are used to achieve management objectives. The IOTC adopted Harvest Control Rule for bigeye tuna in 2016, setting a TAC of 513, 572 Mt annually for the period 2021-2023 (IOTC, 2020).

Establishing TAC is a technical procedure that requires scientific information, including an understanding of the mortality rates and stock dynamics. There is therefore need to train fisheries officers and scientists adequately to undertake these tasks. The absence of the Total Allowable Catch (TAC) at national and regional level remains a challenge. Similar concerns were raised by the Kenya fisheries experts.

Total Allowable Effort (TAE) is the maximum amount of fishing effort that a fish stock can receive in a given period, as determined by the fishery management plan for that location. This can be expressed in terms of quotas and/or restrictions on the number of fishers, the size and number of fishing vessels and gears, and the number of fishing days. States are responsible for taking necessary fisheries management measures to reduce and/or eliminate overcapacity, in line with the FAO Code of Conduct for Responsible Fisheries, Chapter 7 (General Fisheries Management), section 7.1.8. This is to ensure that fishing effort is proportional to available fishing opportunities, in accordance with conservation and management methods for fisheries resources.

The Kenya Fisheries Management and Development Act of 2016 (Section 5. 2 (a)) provides for the allocation and access to fishing opportunities in order to achieve long-term sustainable development of fisheries resources. The application of TAE is implied in Section 5.2 (o), which lays emphasis on conservation measures aimed at reducing fishing effort, and Section 30(i), which mentions a friendly licensing system.

Whereas the national fisheries policy, tuna strategy and legal framework provides for the application of Total Allowable Effort (TAE), interview with the fisheries managers, fishers and other stakeholders in Kenya marine sector indicate that the current practice for licensing both industrial and artisanal tuna fishers in Kenya waters is not based on TAE. It is an open access system. Decisions to issue a fishing license is not based on any data nor science but other considerations which are not informed by science. Usually, the fishers apply for license and after some form of due diligence and vetting, they are issued the document. Vetting for artisanal fishers is done by the Beach Management Units (BMU) in their respective areas of jurisdiction upon whose recommendation, The Kenya Fisheries Service (KeFS) issues them with a fishing license.

Licensing for offshore fishing vessels is approved by the licensing board constituted by the Director General of the Kenya Fisheries Service.

The UNFSA, in Article 6, exclusively focuses on the precautionary principle in managing fisheries resources where scientific data or information is not available. The Agreement outlines the procedure for implementation of precautionary approach and measures to rebuild overfished stocks in Article 6 (3). Such management measures have to take into consideration uncertainties with regard to the sizes, productivity, reference points and condition of the stock relative to the reference points, mortality rates and impact on non-target species as well as prevailing socio-economic and environmental aspects. One of the primary guiding principles in managing and conserving Kenya's fisheries resources is the precautionary approach. This is covered by the fisheries law's section 5(2)(i), the Kenya Tuna Fisheries Development and Management Strategy's section 3.2, and the Oceans and Fisheries policy's section 3.2 (iv).

The review of scientific information on fisheries, it appears that there is limited data and information on tuna and tuna-like species in Kenya, including their biology, distribution and management (Ministry of Agriculture, Livestock and Fisheries, 2013; Ndegwa & Okemwa, 2017; Republic of Kenya, 2020). The Indian Ocean Tuna Commission (IOTC) compliance committee had expressed concern on the quality of data submitted by Kenya (IOTC, 2020). Kenya had not reported on the size frequency, catch and effort the nearshore fisheries, sharks and longlines in line with the IOTC standards (IOTC, 2020). An examination of the catch data declared to the Kenya Fisheries Service (KeFS) by Distant Water Fishing Nations (Longliners) for the period 2012 to 2016 suggests that there is significant under reporting. Similar observations were made by KMFRI

(Kimani *et al.,* 2018; Hoof & Steins, 2017). It is highly likely that some vessels didn't submit the data or declared in another country (Temple *et al*., 2018), although this should be investigated. Consultations with fisheries managers and fisheries scientists indicated that tuna fisheries related data was not adequately and consistently collected to inform policy and legal framework for sustainable tuna management and development in Kenya. The limited capacity for Kenya to collect tuna related data in the required format has been associated with inadequate funding to support scientific research (Republic of Kenya, 2020; Ministry of Agriculture, Livestock and Fisheries, 2013).

Consultations with fisheries managers and scientists revealed that data on tuna fisheries was not adequately and consistently collected to inform the policy and legislative framework for sustainable tuna management and development in Kenya. This is because there was limited capacity to collect tuna-related data in the required format linked to inadequate funding for scientific research (Republic of Kenya, 2020; Ministry of Agriculture, Livestock and Fisheries, 2013).

The challenges associated with data collection in the IOTC area of competency affects the quality of the stock assessment. For instance, IOTC requires only 5% observer coverage for the longliners (above 24 M Overall Length) to monitor catches and collect scientific data while other tuna RFMOs like the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Inter-American Tropical Tuna Commission (IATTC) have 100% coverage (IOTC, 2020; McCluney *et al.,* 2019). The quality of data submitted to IOTC member states is of poor quality, incomplete and less accurate (Pillai & Satheeshkumar, 2013; IOTC, 2020; Sinan & Bailey, 2020).

Most of the tuna catch in the Indian Ocean is from coastal fisheries (40 – 50%) and is not properly reported and IOTC has to estimate the landings (Sinan & Bailey, 2020; Pillai & Satheeshkumar, 2013).

While concerns have been made about dwindling tuna stocks in the Indian Ocean, management of tuna fisheries in the IOTC area of competency through TAC, has been a mirage. This prompted a process in the IOTC Area of Competence to establish a quota system for the management of yellowfin and bigeye tuna (IOTC, 2010). This process, which started way back in 2010 in Busan, South Korea, is nowhere near conclusion (IOTC, 2020; IOTC, 2010). The plan was for the IOTC adopt the quota system by 2012 (IOTC, 2010). The quota allocation discussions have been ongoing spearheaded by the Technical Committee on Allocation Criteria (TCAC) within the framework of IOTC and Kenya is actively involved. This process has been moving slower than envisaged and a number of factors could be attributed to this. There are competing interests between developing coastal states and DWFN, particularly over who owns the fish obtained in coastal waters' Exclusive Economic Zones (EEZs) (Abolhassani, 2017; Sinan & Bailey, 2020). The fish belongs to the owners of the vessels that are permitted to fish in coastal seas, but the coastal states believe that the fish was captured in their waters. The dispute over who owns the fish has yet to be addressed. Another factor for the delay relates to the uncertainty of the status of stocks.

There is limited data on stocks. It is estimated that 40 – 50% of the tuna catches in the Indian Ocean are from small-scale fisheries, and yet it is not reported to IOTC (IOTC, 2019; Sinan & Bailey, 2020). The data reported by the industrial fisheries is of poor quality. Ardill *et al*. (2011) reported that about 40 – 70% of the data on neritic tuna is of poor quality. The IOTC 2019 report on compliance indicated that about 72% of the nominal catches for industrial fleet were either partially or fully complete. Political and economic considerations is another factor that is contributing to the delay of this process. Some of the coastal states, including Kenya, are keen to develop their own national fleets so that they can enhance the flow of socio-economic benefits to their respective countries (Sinan & Bailey, 2020) and also control the collection and archiving of data. This view was quite evident during the consultation with the Kenya fisheries experts and managers.

The IOTC adopted Harvest Control Rules (HCR) for skipjack tuna in 2016 and set a limit of 513,572 Mt annually for the years 2021-2023 (IOTC, 2020). IOTC has implemented other conservation measures to limit the catches of yellowfin tuna through stock rebuilding plan and reduction of catches for bigeye tuna (IOTC, 2005; IOTC, 2016). Kenya is yet to implement such measures and should start doing so in earnest. In Kenya, the DWFN fleets have been accessing fishing opportunities in the EEZ through some form of licensing. Annually, 30 - 40 purse seiners and 4 - 9 longliners are licensed to fish in Kenya's Exclusive Economic Zone (Kimani *et al.,* 2018). Kenya is no longer licensing foreign fishing fleets, according to personal communication with some Kenya Fisheries Service (KeFS) officials. The country is now building its own fleet, and three longliners and six purse seiners have been flagged and are currently fishing for tuna in the Kenya EEZ (Pers.com, 2021). Kenya filed its National Fleet Development Plan to the Indian Ocean Tuna Commission (IOTC) in 2016 with a total of 73 vessels (55 longliners and 18 purse seiners) (Republic of Kenya, 2016) in accordance with IOTC Resolutions 03/01, 05/01, and 12/11 (IOTC, 2012; IOTC, 2005; IOTC, 2003). However, it is unclear whether this figure was based on science or available fishing prospects in Kenya's Exclusive Economic Zone. Interviews with fisheries managers and other industry stakeholders suggest that socio-economic factors have a significant impact in this regard. In 2020, the Kenya Marine and Fisheries Research Institute (KMFRI) began conducting fish stock assessments to ascertain the status of fish stocks, which will help estimate the TAE and TAC for better management of the tuna fishery in Kenya.

The Kenya Fisheries Development and Management Act of 2016, as well as the Kenya Tuna Fisheries Development and Management Strategy and the Oceans and Fisheries Policy, lay emphasis on a precautionary approach in the management of Kenya's fisheries resources, particularly where data is uncertain. Kenya also recognizes that data and scientific knowledge on tuna fishery in Kenya is very limited as quoted in the Kenya tuna fisheries development and management strategy section 2.5.3 on governance, “data and quality fishery dependent data of tuna fisheries is inadequate due to limited staff, lack of species categorization of catch by local vessels, and lack of observers on-board the DWF vessels. There is limited research information on the tuna fishery in Kenya, including on stock abundance, distribution and behavior” (Ministry of Agriculture, Livestock and Fisheries, 2013). Section 3 of the tuna strategy (General principles) is very explicit about the application of precautionary approach in the management and development of tuna fishery where scientific information and knowledge is inadequate (Ministry of Agriculture, Livestock and Fisheries, 2013). Interactions and interviews with fishers, senior fisheries managers and fisheries scientist revealed that precautionary approach is not being applied in the management of tuna fisheries, both nearshore and offshore. These are matters that Kenya needs to build capacity in order to address them.

7.6 Conclusions and Recommendations

7.6.1 Conclusions

Kenya has established both policy and legislative framework for the management of tuna and tuna-like species fisheries resources. These include the Fisheries Management and Development Act of 2016, the Kenya Tuna Fisheries Management and Development Strategy (2013-2018) and the National Oceans and Fisheries Policy (2008). The Kenya Fisheries Service (KeFS) is in charge of tuna and tuna-like species management in Kenya. Policy direction is provided by the State Department of Fisheries, Aquaculture, and Blue Economy. The Kenya Marine and Fisheries Research Institute (KMFRI) is mandated with conducting national marine and fisheries research.

Kenya's national policy and legal framework for fisheries resource management is compliant with international law, such as the United Nations Convention on the Law of the Sea (UNCLOS), the United Nations Fish Stock Agreement (UNFSA), and the FAO Code of Conduct for Responsible Fisheries (CCRF). Tuna and tuna-like species are highly migratory fish populations whose management is under the Indian Ocean Tuna Commission (IOTC) at the regional level, as outlined in UNCLOS, UNFSA, and the IOTC Establishment Agreement. Kenya is a member of IOTC since 2004 and is bound by the IOTC tuna fisheries conservation and management decisions/ measures. Kenya's compliance with IOTC conservation and management measures has been fairly low over the past years, but it has lately improved.

Science-based management of marine living resources is emphasized in Kenya's fisheries policy and legislation, as well as international law. In the event that there is insufficient data and science to support fisheries policies and decisions, a precautionary approach has to be applied. The management objectives of tuna fisheries management in Kenya include sustainable development and management of tuna and other highly migratory fishery species based on the best available scientific data and information.

In Kenya, there is a scarcity of scientific data and knowledge about tuna and tuna-like species, including their biology, distribution, and management. The majority of the research has been on non-tuna fishery resources such as lobster, shrimp, and reef-based finfish. Kenya has been collecting fisheries catch statistics (annual statistical bulletins) for many years, including tunas. However, the data isn't analyzed on a regular basis to support fisheries management. The difficulty of gathering tuna data in Kenya has been linked to limited expertise and resources to implement a comprehensive tuna research program. By obtaining an offshore research vessel (RV-Mtafiti), the Kenyan government has made some headway in building scientific capability for marine and fisheries research by procuring an offshore research vessel (RV- Mtafiti), but this is insufficient.

It is clear from this study that the importance and application of science, available data, indigenous knowledge, and a precautionary approach in the management of fisheries resources are all highlighted in Kenya's fisheries policy, legislation, regulations, and tuna strategy. Kenya specifically makes reference to the development and implementation of Maximum Sustainable Yield (MSY), the control of fishing effort (Total Allowable Effort – TAE), the limit on the amount of catch (Total Allowable Catch – TAC), the type of species and size of individuals to be harvested, and gear restrictions in the policy and legislative frameworks. While this may be true for other species, no proof exists that tuna conservation and management methods, such as licensing and providing fishing access in Kenyan waters (both artisanal and offshore), are based on scientific data. For both neritic and oceanic tunas, there are no MSY, Total Allowable Catch (TAC), and or Total Allowable Effort (TAE) restrictions on fishing gears. The development of all fish landing sites, as well as the enforcement of the requirement that all fish captured be landed in Kenya, will go a long way toward fixing this problem.

The finding of this study takes into account current tuna fisheries management practices in Kenya, as well as science in the context of data availability, Maximum Sustainable Yield, Total Allowable Catch, Non-target species, and the use of a precautionary strategy for data-poor fisheries. These performance metrics were chosen because they demonstrate how science may be used to inform sound fisheries management decisions. This research, therefore, demonstrates that the policy and legal framework for tuna management in Kenya makes reference to science, although, the application of science based performance metrics including MSY, TAC, TAE is yet to be effected.

7.6.2 Recommendations

In light of the foregoing, the following suggestions and recommendations are made to assist in the development and implementation of science-based tuna fisheries management in Kenyan waters.

i. In collaboration with other partners, the Kenya Marine and Fisheries Research Institute (KMFRI) should develop a comprehensive and long-term tuna research program to generate reliable data for sustainable tuna development and management in Kenya waters, including establishing reference points and developing harvest strategy and control rules, particularly for coastal tunas.
ii. Kenya should improve its compliance with the Indian Ocean Tuna Commission's conservation and management measures for tuna fisheries. Strengthen and improve catch and scientific data collection systems for both nearshore and offshore tuna resources, including the employment of low-cost tools such as mobile phone data collection, crew-based and electronic monitoring.

iii. There should be regular analysis of annual fisheries catch statistical data to inform policy and decisions making for improved tuna management. Effort data should also be collected.

iv. Enforce reporting requirement and catch declaration by offshore fishing vessels.

v. Enhance funding for marine fisheries research and surveillance of the Kenya EEZ. This will ensure availability of data to inform policy and curbing of Illegal, Unreported and Unregulated (IUU) fishing activities in the Kenya EEZ.

vi. Review the national Oceans and Fisheries Policy and the Kenya Tuna Fisheries Management and Development Strategy, a process that is long overdue.

vii. The Government of Kenya should consider developing a comprehensive Ocean and Marine Policy, legislation and framework to harness the potential for marine living resources.

CHAPTER EIGHT

8.0 GENERAL CONCLUSSION AND RECOMMENDATIONS

8.1 General conclusions

This work is one of the most comprehensive study to generate scientific knowledge and consolidate information about tunas in Kenya, especially from the artisanal fisheries.

There are few studies and limited information in the public domain on the population and growth parameters of tunas in the Kenya marine waters and to some extent the entire Indian Ocean region. This study has generated information on growth parameters for *Thunnus albacares* (yellowfin), *Xiphias gladius* (swordfish) and *Euthynnus affinis* (kawakawa) from artisanal fishery. This study has established mortality rates and exploitation rates for yellowfin tuna, kawakawa and swordfish in the coastal waters of Kenya. The results suggest that yellowfin tuna and swordfish are experiencing high fishing pressure from artisanal fishers and strategies should be put in place to provide solution to this problem. The growth parameters, mortality rates and recruitment can assist in developing and defining biological and target reference points for the yellowfin tuna, swordfish and kawakawa in coastal waters.

The management of coastal tunas has been limited by inadequate data on length-frequency distribution and catch effort data. This has been of concern to the national fisheries management authorities in Kenya and the Indian Ocean Tuna Commission (IOTC). This study has established the CPUE for the six most abundant coastal tunas encountered in this study. The six species are for *Xiphias gladius*, *Thunnus albacares, Scomberomorus spp, Katsuwonus pelamis*, *Euthynnus affinis* and *Sarda* spp. The CPUE estimated in this study can serve as baseline to monitor the trends which can aid in detecting changes in the way the fishery is performing with time.

This study has revealed that over 90% of the yellowfin tuna and swordfish caught by artisanal fishers in Kenya coastal waters are pre-adults. These are clear indications that growth overfishing is occurring on the coastal tuna fishery. The concerns raised by the Indian Tuna Ocean Commission (IOTC) that yellowfin stocks in the Indian Ocean are overfished is reinforced by the results of this study. Tunas are top predators and overfishing of this fishery is likely to change the trophic and community structure of the coastal waters.

The deployment of different gears by the fishers is dependent on the species targeted, the fishing areas and the season. This study estimated the selectivity of longline, trolling and gillnet targeting swordfish, yellowfin tuna and kawakawa in the artisanal fishery.

The findings of this study show that amongst the oceanic tunas, yellowfin tuna species are resident in the Kenya coastal waters throughout the season.

The size and weight at first capture (Lc_{50}) of yellowfin tuna, swordfish and kawakawa varied with the type of fishing gear and across the sampling sites. The size of fish landed partly depended on the design, type and size of fishing gears involved, the characteristics of the fishing ground and the method of fishing.

Aggregation of longline vessels along and across the EEZ borders between Kenya, Somalia and Seychelles was evident, especially those flagged to Seychelles, China, Spain and Taiwan. The activities of the vessels need to be closely monitored in compliance with the relevant national and international laws, including the coastal, flag and Ports States measures as well as Indian Ocean Tuna Commission (IOTC) decisions.

Whereas it is a legal requirement for all the licensed foreign fishing vessels to submit catch data as provided for in the national fisheries legislation, compliance seem to be very low. A close examination of the declared catch data suggests some level of underreporting, the case of one of the fishing vessels that was in the sea for four days and managed to catch only 11 individuals of yellowfin tuna.

The quality of the catch data that was declared by the foreign fishing longline vessels that were licensed to fish in Kenya waters during the reporting period was poor. The length frequency data during the reporting period was not collected. Some species were lumped together which made it difficult to ascertain the type of genus or species being reported, particularly the sharks and the billfishes.

A review of the Kenya fisheries policy, legislation and tuna strategies indicate that they are aligned to the international law. They overemphasize science based fisheries management. They lay emphasis on managing fisheries based on Maximum Sustainable Yield (MSY), controlling fishing effort, limitation on the amount of catch, type of species and size of individuals to be harvested. Whereas this may apply to other species, there is no evidence that the current fisheries management practice for the tunas, including the licensing and granting fishing access in the Kenya waters (both artisanal and offshore) are informed by scientific data. The tuna fishery management performance metrics as Total Allowable Catch (TAC), Total Allowable Effort (TAE), MSY, restriction on fishing gears for both neritic and oceanic species are yet to be put into practice.

8.2 General Recommendations

i. Close monitoring of the fishery and precautionary approach is recommended to avoid depletion of the coastal tuna and swordfish fisheries, and introducing size and gear restrictions should be piloted by the Kenya Fisheries Service.

ii. The nearshore/coastal waters are critical habitats and foraging grounds for yellowfin tuna hence the need to put in place appropriate strategies and measures to conserve and protect these important ecosystems.

iii. The data and information generated from this study can inform the development of technical measures and appropriate regulations defining the fishing gear type and size restrictions for different sites and zones. This would enhance stock sustainability of the target species and minimize the capture of juvenile fish, undersize and by-catch.

iv. The structure and status of tuna stocks in the Kenya waters is not very clear. Comprehensive genetic studies on the tunas in the coastal waters of Kenya would be necessary to establish whether the resident tunas are of the same stock with that of the entire Indian Ocean or localized populations.

v. Detailed study of the offshore vessel fishing activities, through analysis of Vessel Monitoring and Satellite Automatic Identification System (AIS) data, is recommended.

vi. The relevant national agencies should enforce the conditions attached to the reporting requirement. Unless otherwise, a fishing vessel that doesn’t submit the data as required by law may not be considered for licensing in the subsequent years.

vii. Consistent time series data is lacking. Secondary biological data for all the species sampled (both coastal and offshore tunas) was not readily available at the Kenya Fisheries Service records. This presented a challenge of estimating the length-weight relationships, growth parameters and mortality rates which are essential in supporting sustainable fisheries management policy and decisions. In order to address these, the study recommends the placement of scientific observers on fishing vessels, in particular those operating in offshore waters (EEZ). Use of low cost data collection system including mobile phone technology and crew based could be more effective.

viii. Kenya Fisheries Service (KeFS) has been collecting data since the 1950s. Most of the data sets exists in hard copies until 2000 when the defunct Department of Fisheries started capturing the catch data in both hard and soft copies. The data is not analyzed to inform fisheries policy and decision making for improved fisheries governance and development. This data should be analyzed regularly in order to support fisheries management.

ix. A comprehensive and long-term tuna research programme to generate reliable data to inform sustainable development and management of tunas in the Kenya waters, including establishing reference points and developing harvest strategy and control rules especially for coastal tunas should be established.

x. A comprehensive study to monitor mortality and fishing catch rates at gear level that takes into consideration type and size of vessel and fishing gears.

xi. The national Oceans and Fisheries Policy and the Kenya Tuna Fisheries Management and Development Strategy should be revised by the relevant authorities through and all-inclusive process since they are over 10 years old.

xii. The Government of Kenya should consider developing a comprehensive Ocean &Marine Policy and legislative framework to harness the potential of marine living resources, in particular the tunas.

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APPENDICES

Appendix 1. Questionnaire guide for assessing the scientific robustness of the policy and legal framework for the management and development of tuna fisheries in Kenya

Preamble

I Edward Kimakwa, I'm currently pursuing my Ph.D studies at the University of Nairobi, School of Biological Sciences. As part of the fulfillment of the requirements for this Ph.D program, I am doing a research to assess the scientific robustness of the policy and legal framework for managing and developing tuna fisheries in Kenya. This research is primarily for academic purposes for the University of Nairobi. However, the study findings could be used by the relevant fisheries management and research organization, academia and other stakeholders in an effort to mage and develop the fisheries sector in Kenya, more specifically tuna and tuna-like species in more sustainable way for increased socio-economic returns to the country.

Below are the questions that I would like to explore with you. The information you provide will be treated with high anonymity. Your cooperation is highly appreciated.

Objective

The main objective of this study is to evaluate the scientific robustness of the policy and legislation that govern tuna fishery in Kenya. The focus here will be on the policy and legal framework as well as the practice.

Key research questions

The following key research questions have been designed to assess the extent of how science has informed policy, legislation and management of tuna and tuna-like stocks in Kenya waters.

1. Is science used to inform Kenya's policy and legal framework for the management and development of tuna fishery resources?
2. Does the Indian Ocean Tuna Commission (IOTC) scientific advice inform Kenya's regulatory framework and management of tuna and tuna-like species?
3. To what extent has Kenya's tuna management policy and legal framework internalized relevant regional and international tools, including science-based approaches to fisheries management?
4. What is the present state of science-based practice in the development and management of tuna resources in Kenya, as outlined in the country's national fisheries policy and legislation?
5. What are the gaps in the science-policy interaction for tuna resource management in Kenya, and how can they be addressed?

Methodology

In this study, a number of approaches have been proposed as follows;

1. A review of the existing relevant policy, legal and strategic documents for evidence and scientific robustness on tuna related matters. The documents include among others the Kenya National Ocean and Fisheries Policy 2008, Kenya’s Tuna Fisheries Development and Management Strategy 2013-2018, the Fisheries Development and Management Act 2016; The United Nations Convention on the Law of the Sea (UNCLOS), the United Nations Fish Stock

Agreement (UNFSA), The Agreement for the establishment of Indian Ocean Tuna Commission (IOTC) and the FAO Code of Conduct for Responsible Fisheries.

2. Interviewing senior fisheries managers, scientists, the fishing industry and fisher folk on the current policy practice and application of science in the management of tunas in Kenya
3. A review of the scientific information available on tunas in Kenya and elsewhere to inform policy and decision making for improved fisheries governance, management and development.

Interview questionnaire guide

A. Personal Information

1. Your name

2. Age? Tick one please: 15-20 21-25 26 – 34….. 35-40 41-50 Above 50

3. Level of Education: Tick One please: Informal Primary…..Secondary ……Tertiary/College……University

4. Marital status: Single……..Married……..Divorced Other (Please specify………………

5. Employed

6. If employed, list the Name of your organization and your position

Rating scale: 1 No 2. Partly 3 Yes

S/N	Question	Rating		
		1	2	3
1	Are tuna and tuna-like species in the Kenya waters harvested through an enforceable system of Total Allowable Catch (TAC), and the TAC that is never exceeded?	☐	☐	☐
2	Are tuna and tuna-like species harvesting in the Kenya waters based on the Maximum Sustainable Yield (MSY)?	☐	☐	☐
3	Is there a biological reference point to guide management objectives of the tuna fishery in Kenya to avoid overfishing?	☐	☐	☐
4	Does Kenya have in place and or implement harvest control rules for the tuna fishery?	☐	☐	☐
5	Is tuna fishery dependent data (catch, landing, and effort information) regularly collected in Kenya?	☐	☐	☐
6	Is the tuna fishery independent data (research/surveys) regularly collected in Kenya?	☐	☐	☐
7	Is the fishery data (both dependent and independent) regularly analyzed and used to inform policy formulation, decision making and sustainable tuna fishery management in Kenya?	☐	☐	☐
8	Are there enforceable gear restrictions for tuna harvesting in Kenya in Kenya?	☐	☐	☐
9	Are there enforceable restrictions in the size of the individual tuna harvested in the Kenyan waters?	☐	☐	☐

S/N	Question	Rating		
		1	2	3
10	Is there enforceable nautical mile restriction in tuna fishing in Kenya waters?	☐	☐	☐
11	Do the local fishing communities have influence in the way tuna and tuna-like fisheries resources are managed, governed and accessed in the territorial waters and Exclusive Economic Zone (EEZ) in Kenya?	☐	☐	☐
12	Is the regulatory framework and management of tuna fishery in Kenya influenced by the Indian Ocean Tuna Commission (IOTC) decisions and resolutions?	☐	☐	☐
13	Is the policy, legal and regulatory framework of the management of tuna fishery in Kenya influenced by geo-political and socio-economic considerations?	☐	☐	☐

Thank you very much for your time and cooperation

Please return this questionnaire to kimakwa2001@gmail.com

Respondents

Respondents to be interviewed will come from but not limited to the following institutions,

1. Kenya Fisheries Services (KeFS)
2. The State Department of Fisheries and Blue Economy

3. Kenya Marine Fisheries and Research Institute (KMFRI)
4. Fisheries Departments in the respective County Governments
5. NGOs working on marine and fisheries related issues in Kenya (namely the COMRED, WCS, CORDIO, East African Wildlife Society, the Nature Conservancy, Tuna Fisheries Alliance of Kenya)
6. Academia (namely universities who have local presence and understanding of tuna fisheries related aspects on the ground, policy and regional levels including Pwani University, the University of Eldoret, Technical University of Mombasa)
7. The industry (Kenya Fish Processors and Exporters Association of Kenya – AFIPEK)
8. Representatives of the fisher folk (The Beach Management Unit (BMU)Network, fishers especially those targeting tunas in the study sites)
9. Regional fisheries management bodies where Kenya is a party to (the Indian Ocean Tuna Commission (IOTC), the South West Indian Ocean Fisheries Commission, African Union)

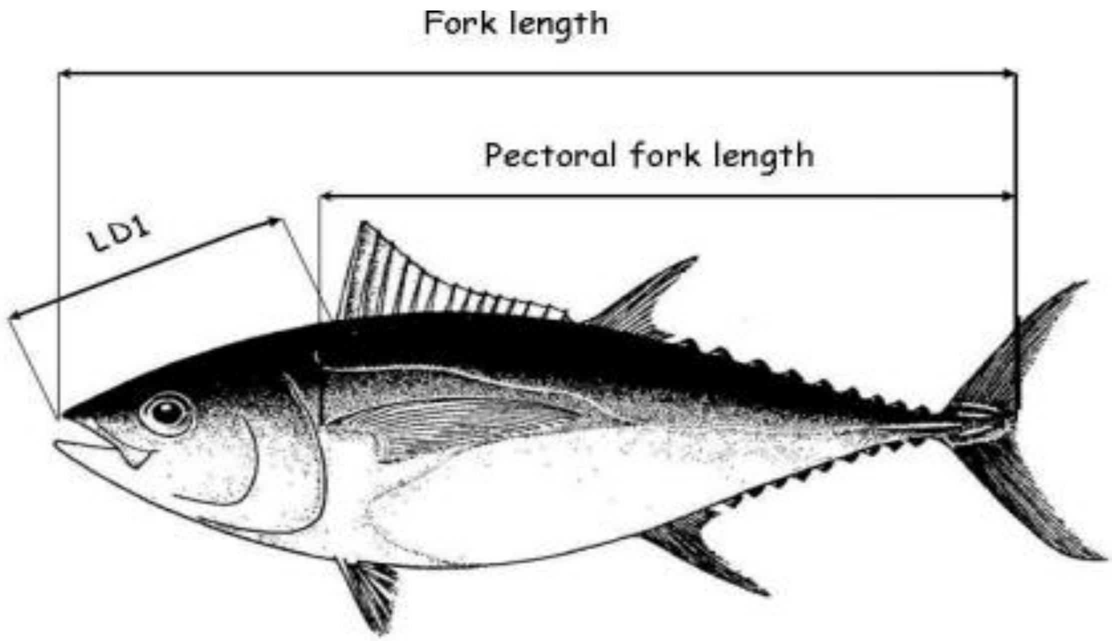
   Do you have any question for me?

Thank you very much for your time and cooperation.

Appendix 2. The Biological Sampling Form for Artisanal Tunas in the Kenya Coastal Waters

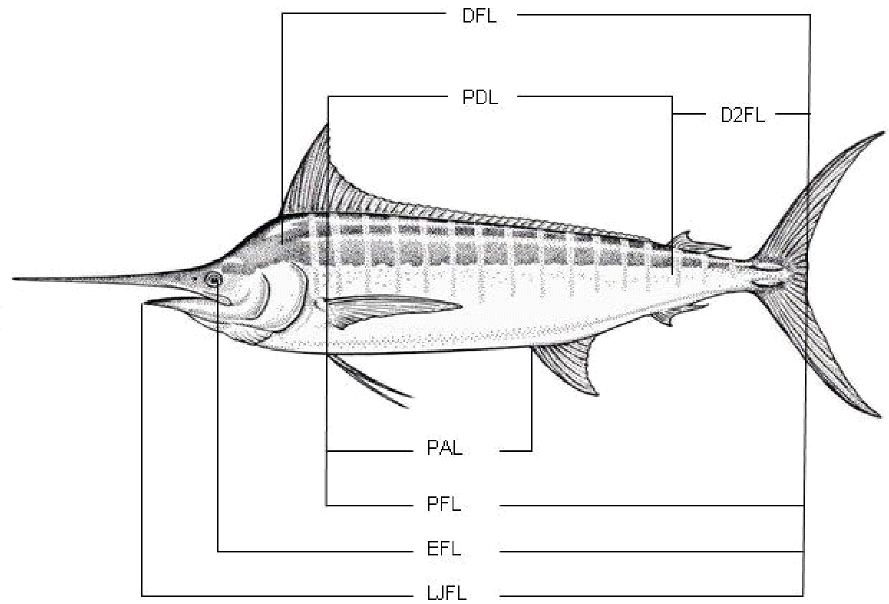
Name of Landing Site:		Location:		Name of County:	
Sampler's Name		Date of Sampling:		Date of Arrival of fishing boat/ Fish landing	
Name of fishing boat (if any)/		Name of Owners: No. of Crew members: No of Female Crew: No of Male Crew:		Type of fishing gear/ Method	
Species	Weight (Kg)	Condition	Length (cm) Total Length	Length (cm) Fork Length	Average Price/Kg

Appendix 3. Type of measurements for Tunas



LD1 = First Predorsal Length

Appendix 4. Type of measurements for billfishes



DFL = Dorsal Fork Length
D2FL = Second Dorsal Fork Length
PDL = Pectoral Dorsal Length
PAL = Pectoral Anal Length
PFL = Pectoral Fork Length
EFL = Eye Fork Length
LJFL = Lower Jaw Fork Length

In this study, Lower Jaw Fork Length (LJFL) was measured.