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Temporal variation, population and growth parameters of swordfish (*Xiphias gladius* Linnaeus, 1758) in the nearshore waters of Kenya

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Abstract

Swordfish (*Xiphias gladius)* is a pelagic species found in the tropical waters. The species is an important fishery. The scientific knowledge, stock structure and distribution of the fishery in Kenya is limited. The objective of this study was to investigate the temporal variation in catch rates and growth parameters for swordfish. Data was collected between August 2015 and December 2016 from five sites. The Length-Frequency data and gear selectivity were analyzed using FISAT (ELEFAN) and von-Bertalanffy. Catch rates were also determined. Virtual Population Analysis using FISAT II performed to estimate survivors and mortalities. Size ranged between 68 cm and 234cm Lower Jaw Fork Length (LJFL). The growth parameters were as follows; L_∞ = 208 cm; K = 0.28/ year; t_0 = 0.18; and ϕ = 4.08. Mortality rates were; Z = 1.13/ Year; M = 0.44/Year; F = 0.69/Year; E = 0.61/Year. Over 91% were below sexual maturity (L_{50}). Fishing mortality rate (*F*) of 0.69/Year is higher than the optimal (0.5/Year). A comprehensive study to establish the stock structure and maturity status of this fishery is recommended to avoid localized depletion.

Keywords: *Kenya, Swordfish, Distribution, Mortality, Growth, Management*

1. Introduction

Swordfish (*Xiphias gladius)* is a highly migratory species that forms an important fishery globally including Kenya. In the Indian Ocean the fishery is usually targeted by both artisanal and industrial long line fishers (IOTC, 2019; and Mueni *et al.*, 2019). In 2015 and 2016, some 158 tons, 160 tons of Swordfish were landed by artisanal fishers in Kenya, respectively (Ministry of Agriculture, Livestock and Fisheries, 2016). In 2019, swordfish catch in the Indian Ocean was estimated at 32, 671 Mt compared to some 31, 628 Mt, and 34, 782 Mt caught in 2019 and 2018 respectively **(**IOTC, 2020; IOTC, 2019; and IOTC, 2018**).** In all these cases the catches were very close to the Maximum Sustainable Yield (MSY) of 33, 000 Mt, and slightly above the lower limit of the MSY range of 27, 000-40,000 Mt (IOTC, 2020). Swordfish is usually caught by longliners and gillnets in both nearshore and offshore waters. In 2019 for instance in the Indian Ocean Tuna Commission (IOTC) area of competency, 60% of the catch was from offshore longliners while nearshore longliners accounted for 22% of

the total catch (IOTC, 2020). Swordfish catches in the Indian Ocean region have been reported by fishing fleets flagged to Indonesia, Japan, Taiwan, Iran, India, Pakistani, Spain, Sri Lanka, Mauritius, Seychelles and Reunion (IOTC, 2016; and IOTC, 2017). Sri Lanka, Taiwan, China, India, EU/Spain contributed over 63 % of the catch in the period 2015 – 2019 (IOTC, 2020).

Swordfish is one of the highly migratory pelagic species that is found in the tropical, sub-tropical and temperate waters (IOTC, 2019; Alicli *et al.*, 2012; and Ward and Elscot, 2000). The species is distributed within the range of 65°N - 50°S to 180°E according to Fishbase (2019). Swordfish is found in deep oceanic waters though on some occasions it is found in coastal waters (Mueni *et al.*, 2019; IOTC, 2017; and Varghese *et al.*, 2013). Swordfish grows rapidly especially at its early stages of growth (Young and Drake, 2004; and Alicli *et al.*, 2012). The species spawns all year round (IOTC, 2017).

The Swordfish fishery in the South West Indian Ocean region is not well studied, especially lengthen and size distribution, sexual maturity, growth and mortality rates (Van der Elst and Everett, 2015). There are few studies on swordfish fishery in Kenya. Most of the studies have been conducted elsewhere including Australia, New Zealand, South Africa and Mediterranean Sea (Alicli *et al.*, 2012; Young *et al.*, 2006; and Varghese *et al.*, 2013).

In this paper, we investigate the temporal variation in fish catch rates, length frequency distribution, growth parameters, mortality rates, maturity and fishing gear selectivity and Virtual Population Analysis (VPA) for the swordfish (*Xiphias gladius*) fishery in Kenya coastal waters. The findings of this study contribute to the scientific knowledge of the Swordfish fishery in Kenya coastal waters that will provide support to policy and decision making for improved management and Swordfish stock sustainability for increased socio-economic benefits to the local fishing communities and the national economy.

2. Materials and methods

2.1. Study areas

The study was undertaken in five landing sites at the Kenyan coast, namely Amu (Lamu), Mombasa Old Town (Mombasa), Mnarani (Kilifi), Shella (Malindi) and Watamu (Figure 1).
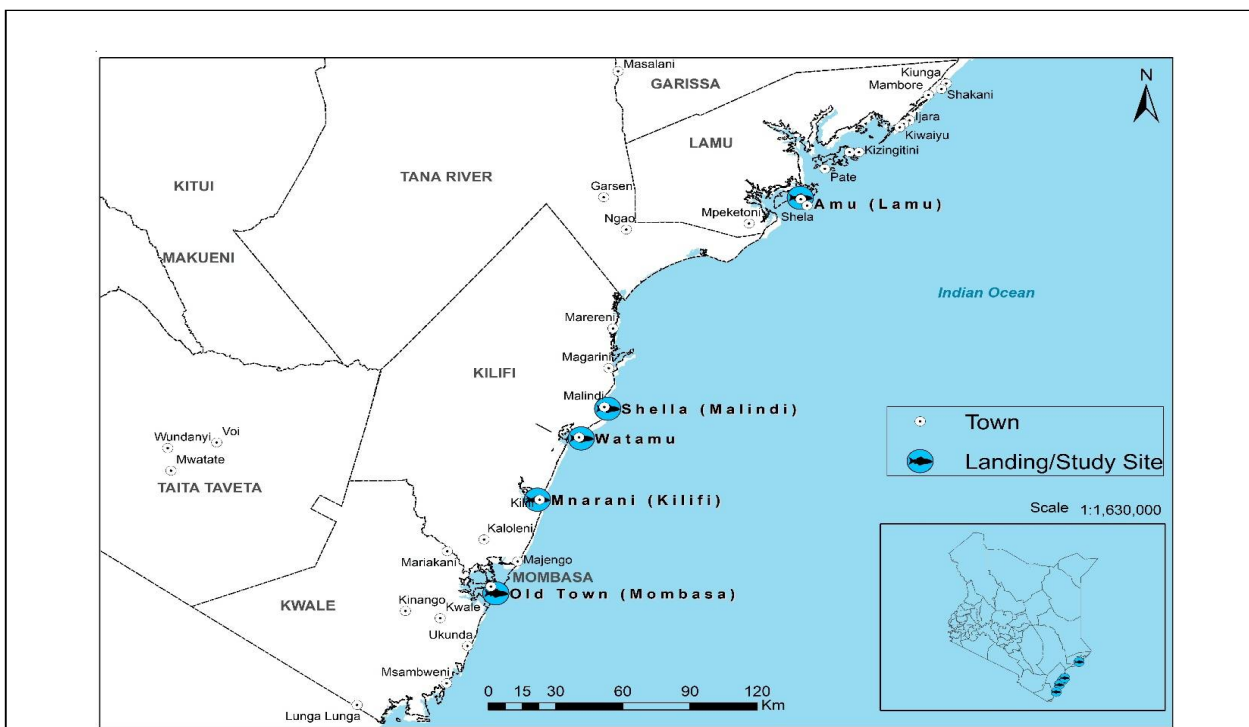

Figure 1: Artisanal Swordfish fishery landing sites used as study sites

2.2. Sampling and collection of data

The study was conducted between the months of August in 2015 and December 2016. Fish samples were collected for 10 days in every month from catches landed by artisanal fishers using a range of fishing gears, namely the longline, handline and trolling line. The fish landing site was the stratification while the vessel was the Primary Sampling Unit and the fishing trip was the secondary sampling unit. The swordfish catch was the tertiary sampling unit. The fish samples were identified to the species level using identification guide by Smith and Heemstra (1995), Richmond (Eds.) (1997) and Anam and Mostarda (2012). Fish samples were weighed to the nearest Kilogram (Kg) using a weighing scale. The total length (TL) and the Lower Jaw Fork Length (LJFL) of the individual fish were measured to the nearest whole centimeter (cm) using a measuring tape. The type of fishing gear and boat, number of fishers per boat, date and time of departure and arrival from fishing, name of the landing beach/site, the price of fish per Kg were recorded in a data collection form for tuna and tuna-like species based on the IOTC template. The data was entered in the excel spreadsheet, cleaned and organized before it was analyzed.

3. Data Analyses

3.1. Catch Per Unit Effort (CPUE)

Mean Catch per Unit Effort (CPUE) was calculated by dividing mean weight of fish caught (Kg) with the mean number of fishers per fishing trip as shown below.

$CPUE = C_y/E_y$

Where C_y is Catch at time y, E is the fishing effort that was deployed at time y.

3.2. Length-Frequency Distribution

The data from the different sites and gears was pooled and binned in 5 cm intervals and the Length-Frequency data and gear selectivity analyzed using the von-Bertalanffy and the FISAT (ELEFAN). The length - frequency distribution data was used to prepare graphs and catch curves. The length and weight measurements were used to determine length-weight relationship and Virtual Population Analysis (VPA) to estimate growth coefficient, growth parameters, mortality rates and exploitation rates.

3.3. Estimation of Growth Parameters

Electronic Length Frequency Analysis (ELEFAN 1) (Pauly, 1987) routine in Fish Stock Assessment Tool (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 $26^{\circ}C$ was used for the tropical species.

The combination of growth parameters that would give the best fit given a range of the values of L_∞ and K and a fixed starting point (SS) and the starting Length were identified using the Response Surface Analysis routine. Length based VBGF formula (Sparre and Venema, 1998) shown below was fitted to the data.

$L_t = L_\infty(1 - \exp(-K(t - t_0)))$

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 and Munro, 1984) was estimated using the following equation:

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

3.4. Estimation of mortality rates

Total mortality rate (Z) was calculated using length converted linearized catch curve (Pauly 1983 and 1984) , the Asymptotic Length (L_∞) and Von Bertalanffy constant (K).

The equation below was used;

$Ln(N_i/\Delta t_i) = a + b\Delta t_i$

Where;

N is the number of fish in length class *i*,

Δ_t is the time required for the fish to grow through length class *i*,

t is the age corresponding to the mid-length of class *i*,

b, with sign changed, is an estimate of total mortality coefficient (*Z*).

Mortality rate due to natural losses (*M*) was estimated using the following indirect methods with empirical relationship expressed by Pauly (1980);

Log M = –0.0066 – 0.279 1og L_∞ + 0.6543 log K + 0.4634 log T

Where;

M is natural mortality rate,

L_∞ is the asymptotic length,

T is the mean surface temperature at $26°C$;

K is the coefficient of growth rate of the Von Bertalanffy (VBGF)

In order to calculate Fishing mortality (F), the following relationship was used (Gulland, 1971);

$F = Z – M$; Where *Z* is the total mortality rate and *M* is the natural mortality rate.

The rate of exploitation (*E*) was computed by dividing Fishing (*F*) mortality with total mortality (*Z*) as shown below;

$E = F/Z$

3.5. Fishing gear catch selectivity

The logistic curve was used to analyze fishing gear catch selectivity at various levels; 25%, 50% and 75% of L_{max} (Lc_{25}, Lc_{50}, Lc_{75}). One of the assumption here was that selectivity was symmetrical or close based on the below logistic curve equation and methods as described by Pauly (1984a; 1984b and 1990).

$Ln((1/P_L)–1) = S_1 – S_2 \cdot L$

Where;

P_L is the probability of capture for length *L*,

$L_{25} = (Ln(3) – S_1)/S_2$

$L_{50} = S_1/S_2$

$L_{75} = (Ln(3) + S_1)/S_2$

3.6. Virtual Population Analysis (VPA)

Virtual Population Analysis (VPA) was performed with the use of FISAT II. This analysis showed survivors and the loss of individuals due to natural and fishing related mortalities.

4. Results

4.1. Temporal variations of swordfish catch rates

There is evidence of temporal variation of Swordfish catch rates (Figure 2). Highest Catch rate of 64 kgFisher[-1]Trip[-1] was reported in the month of October 2015. This was closely followed by November 2015 with catch rate of 57 KgFisher[-1]Trip[-1]. High catches of swordfish were recorded between August 2015 and March 2016. Low catches on the average were recorded in the months of April to October 2016, ranging from 7 – 13 KgFisher[-1]Trip[-1]. The results indicate that seasonality influenced the catch rates of Swordfish in the Kenyan coastal waters.
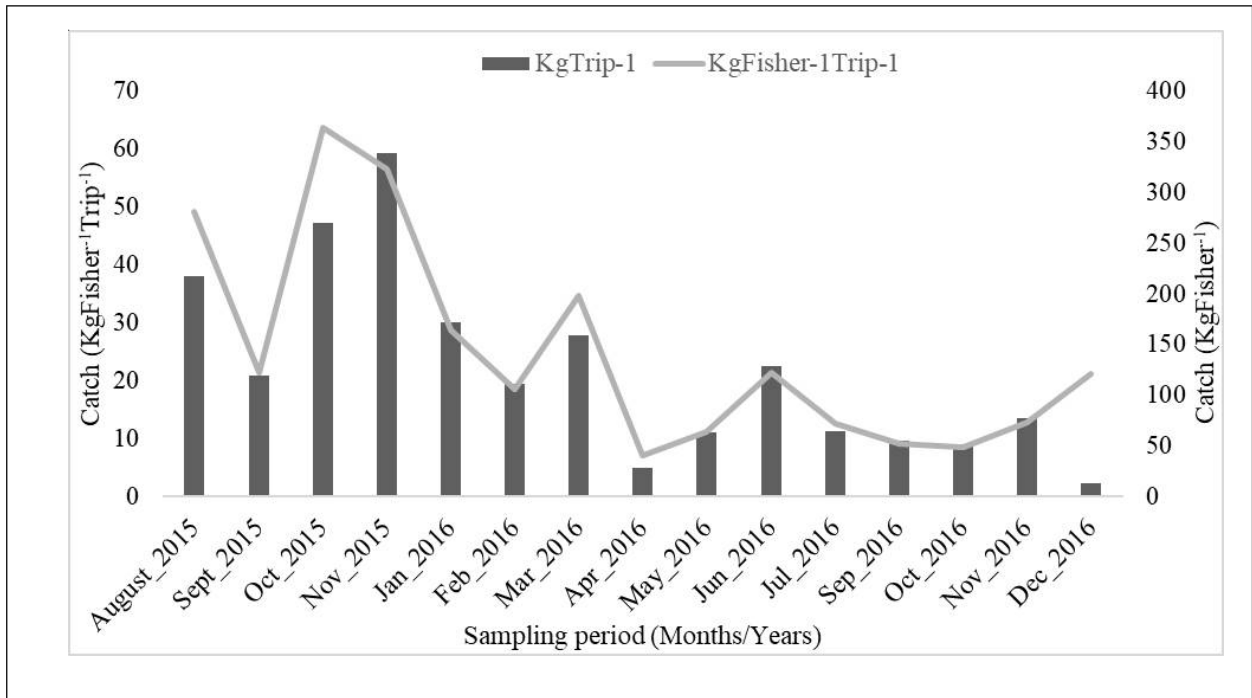
Figure 2: Monthly variation of Swordfish mean catch rates (KgFisher^{-1} and KgFisher^{-1}Trip^{-1}) from the coastal waters of Kenya for the period August 2015-December 2016

4.2. Length-Frequency Distribution

The minimum and maximum fork length of the swordfish encountered in the sample were 68 cm and 234 JFL cm respectively (Figure 3). The average length was 118.68 cm. Most of the individuals captured were within the size range of 68 cm-153 cm. The modal length range was 119 cm-123 cm. Three length classes are evident from this analysis; 68 cm-153 cm, 154 cm-168 cm and 169 cm-234 cm.
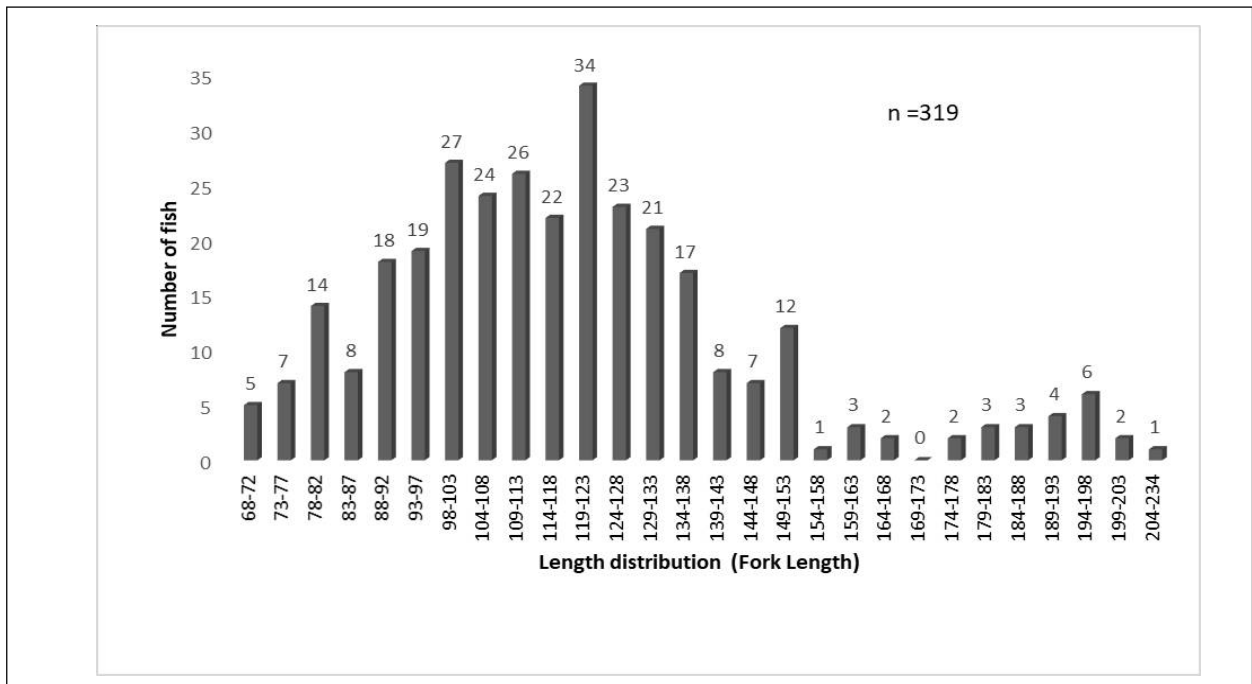

Figure 3: Length-frequency distribution for *Xiphias gladius* sampled in the coastal waters of Kenya between August 2015 and December 2016

4.3. Growth Parameters

Growth parameters of *Xiphias gladius* from the pooled data in 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.

4.4. Mortality rates

In this study swordfish mortality rates were estimated as follows; Total mortality (Z) was 1.13/Year, Natural Mortality (M) at 0.44/Year and Fishing Mortality (F) was 0.69/Year. Exploitation Rate (E) was estimated at 0.61/Year. The mean annual water surface temperature of 26°C was used (Figure 4). The results indicate that the exploitation rate was fairly high than the optimal of 0.5/Year.
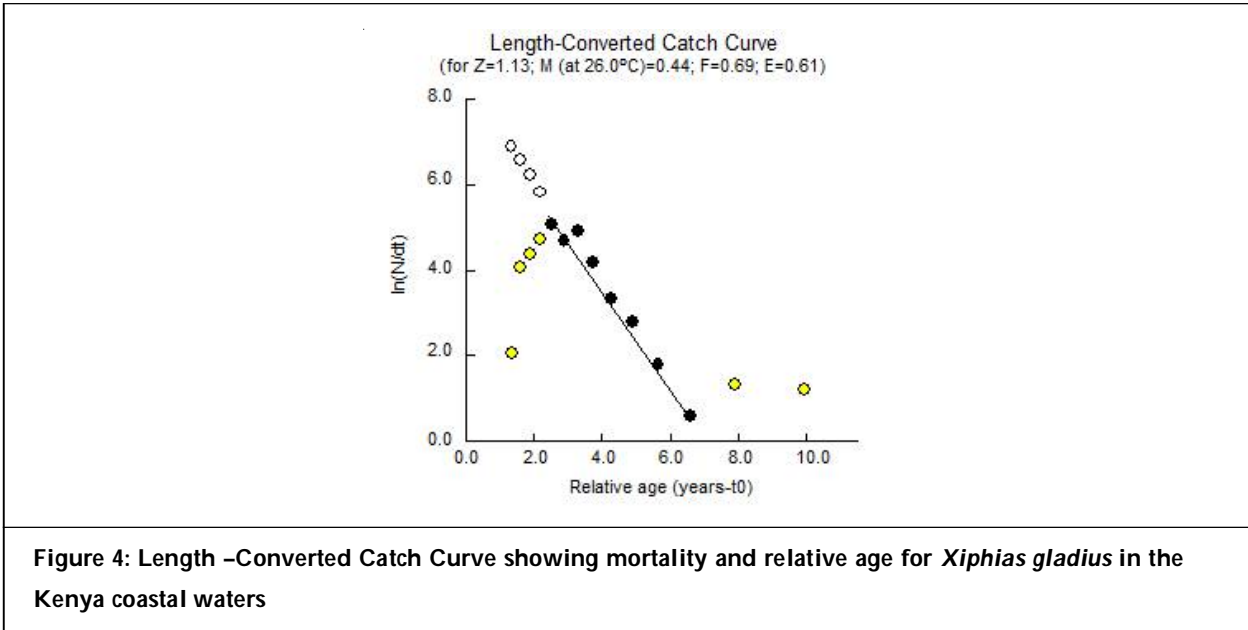

Figure 4: Length –Converted Catch Curve showing mortality and relative age for *Xiphias gladius* in the Kenya coastal waters

4.5. Gear selectivity and length at first capture

Length at first capture (L_{50}) and fishing selectivity for swordfish varied with the type and size of fishing gear (Table 1). The mean length at first capture (L_{50}) for the pooled data from different gear combination was 98.3 cm and 99.66 cm for longline. Most of the individuals encountered in the sample ranged from 68 cm-153 cm. Length at first capture for swordfish is 221 though range from 156 cm-250 cm (Fishbase, 2019). The results indicate that swordfish encountered in this study were below the reported age at first maturity. 89% of the total weight of the swordfish sampled were captured using longline (Table 2). The results suggest that specific gears are employed by fishers targeting certain size of the target species. However, this study didn't collect the

Table 1: Selectivity and mortality rates 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

Table 2: Proportion of swordfish landed by different gears deployed by artisanal fishers in Kenya coastal waters

Gear Type	No. of individual fish	Catch (Kg)	Kg/Fisher/Trip	Fishing crew
Handline	18	694	166	35
Longline	290	7790	1480	399
Trolling line	11	301	80	26
Total	**319**	**8785**	**1726**	**460**

data on the sizes of hooks that were deployed by the fishers. Increasing the size of the hook increased the probability of capturing larger individuals and reducing the capture of smaller individuals and or undersize fish (Ingolfsson *et al.*, 2017; and Hermann *et al.*, 2018).

A total of 319 individuals of swordfish from artisanal catches were sampled during this study. The main fishing gears used by fishers to target swordfish are longline, handline and trolling line (Table 1). Longline contributed over 91% of the individuals and 88% of the total catch by weight. Handline and trolling line accounted for 6% and 3% of the individual fish caught respectively. Cumulatively there were 460 fishing crew (fisher days) with an average of 6 fishers per boat. The total catch during the sampling period was 8785 Kg with an average CPUE of 19.09 Kg/Fisher. Longline recorded the highest catch (7790 Kg) accounting for 88.7% of the total catch with a total catch rate (CPUE) of 1480 KgFisher^{-1}Trip^{-1}. This was closely followed by handline which recorded cumulatively catch rate (CPUE) of 166 KgFisher^{-1}Trip^{-1} and trolling line with 80 KgFisher^{-1}Trip^{-1}.

4.6. Virtual Population Analysis (VPA) and standing biomass

The VPA for *Xiphias gladius* sampled was performed to show total population, catches, fishing mortality, natural mortality and survivors (biomass) per length group (Figure 5). The results indicate that swordfish losses due to natural mortality was more pronounced mid-length 65cm-85 cm. Losses due to fishing pressure (Fishing mortality) started at 85 cm mid-length and peaking at 125 cm mid-length. The highest fishing mortality range was observed between 105 cm-135 cm mid-length.
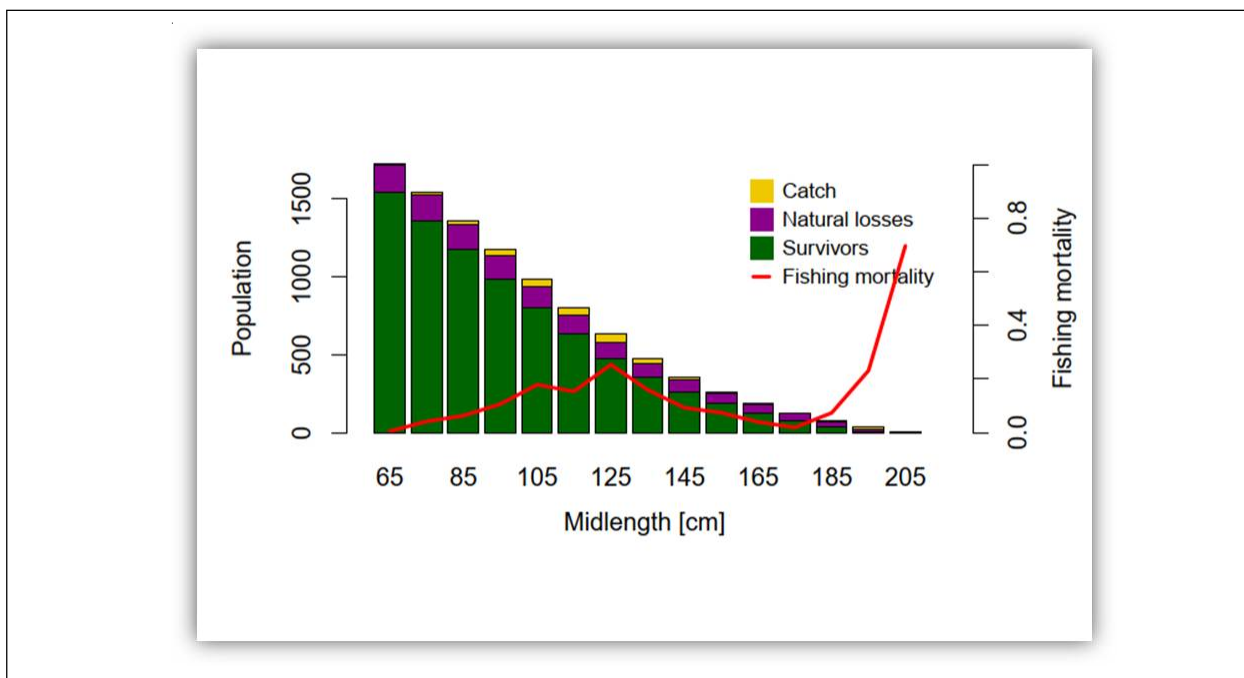

Figure 5: Virtual Population Analysis for *Xiphias gladius* in coastal waters of Kenya

5. Discussion

5.1. Temporal variation in Swordfish catches

Swordfish was encountered throughout the sampling period with clear evidence of temporal variation in catch rates (Figure 2). Pooled data indicate that average catch rates for swordfish were high between the months of August 2015 to March 2016, ranging from 19-64 KgFisher^{-1}Trip^{-1}. Low catch rates ranging from 7-13 KgFisher^{-1}Trip^{-1} on the other hand were reported from April to October 2016. The results indicate that seasonality partly influenced the catch rates of swordfish in the Kenyan coastal waters. This temporal distribution of the swordfish catches and abundance could be partly attributed to the seasonal changes in the temperature of the sea water, sex and size of the individual fish, and availability of food in the environment (Mueni *et al.*, 2019; Lan *et al.*, 2014; and Ward and Elscot, 2000) and the type of fishing gears (Herrmann *et al.*, 2018; and Tuda *et al.*, 2016). The high catch rates seem to coincide with the spawning season (October through to April) for swordfish in the Indian Ocean (Lan *et al.*, 2014; and IOTC, 2017). Sound knowledge and good understanding of the distribution and seasonal abundance of the swordfish fishery is important for sustainable conservation and management of the fishery. More effort should be directed to a comprehensive study in order to understand better the stock structure and distribution of the swordfish fishery in Kenya and indeed the entire Indian Ocean region.

5.2. Length – frequency distribution

Length-frequency analysis for the 319 individuals' show that swordfish sampled were in various sizes ranging from 68 cm-234 cm (Figure 3), most of them were within the size range of 68 cm-153 cm. There is evidence from this study of three length classes; 68 cm-153 cm, 154 cm-168 cm and 169 cm-234 cm. The modal length ranged from 119 cm-122 cm. These length classes could be attributed to the different types and sizes of gears deployed by the fishers, gear selectivity and the specific size of individual fish targeted (Alicli *et al.*, 2012; and Tuda *et al.*, 2016).

Nearly all the Swordfish sampled (over 91%) were below sexual maturity (L_{50}) hence regarded as juveniles. Mature individuals are 221 cm FL, though can range from 156-250 cm FL (Fishbase 2019; Wang *et al.*, 2003; Taylor and Murphy, 1992; and Poisson and Fauvel, 2009). Some studies have reported length at first maturity for female and male swordfish ranging from 87-188.5 cm and 99-161 cm, respectively (Alicli *et al.*, 2012). The results of this study compare with other authors who have reported dominance of young individuals of swordfish in the catch (FIRMS, 2016; Oceana, 2016; Alicli *et al.*, 2012; Tserpes *et al.*, 2001; and Di Natale, 1990). For instance, in the Mediterranean Sea over 50% of the swordfish landed are juveniles (Oceana, 2016; and FIRMS, 2016). The landing of juveniles was a concern to most of the countries in the Mediterranean region under the International Commission for the Conservation of Atlantic Tunas (ICCAT) leading to the introduction of Minimum Landing Size (MLS) set at 90 cm LJFL and adoption of 142 cm LJFL as the reference as size at first sexual maturity (L_{50}) for the Atlantic swordfish in 2011 (ICCAT, 2011; and Oceana, 2016). In 2013, ICCAT set Total Allowable Catch (TAC) at 13,700 tons for 2014, 2015 and 2016 (ICCAT, 2013). The Indian Ocean Tuna Commission (IOTC) is yet to set TAC for swordfish as a management measure.

The length- frequency distribution affects recruitment and population structure of the fishery and may be used to detect changes in the stock such as overfishing and depletion of the stocks where effective fisheries management measurements are wanting (Ward and Elscot, 2000; Konstantinos *et al.*, 2003; and King, 1995). It is evident from this study that the swordfish fishery harvested by artisanal fishers in the coastal waters of Kenya is comprised of young individuals suggesting growth overfishing (Sparre and Venema, 1998). However, this may not be conclusive since this study did not investigate maturity status of the individuals sampled based on the assessment of the gonads. More research on maturity status based on sexing and gonadal development is necessary to ascertain whether the small-sized individuals of swordfish encountered in this study were mature and contributed to stock recruitment.

Over the years fishing pressure and environmental changes has resulted to the general decline in length for most of the fish species globally (Hunter *et al.*, 2016; Baudron *et al.*, 2014; Swain *et al.*, 2007; and Cheung *et al.*, 2012). Close monitoring of the swordfish fishery in Kenya coastal waters should be a priority for the national fisheries management authorities and research to establish the trends in the size changes over time which could give an indication of the status of the stocks. As precautionary measure before conclusive studies to

establish maturity status and stock structure of the artisanal swordfish fishery, national fisheries management authorities should put in place Minimum Landing Size (MLS) of the swordfish as part of the technical measures to ensure the sustainability of the stocks.

5.3. Growth parameters

Studies on the swordfish growth in the Kenya marine waters are very limited. Most of the research on swordfish fishery have been conducted in other parts of the world, namely Australia (Young *et al.*, 2006), New Zealand, India (Varghese *et al.*, 2013) and the Mediterranean Sea (Alicli *et al.*, 2012). The results of this study indicate that swordfish growth rate in the coastal waters of Kenya varied from that reported in other regions including the Mediterranean Sea, India, Southern Pacific and wider Indian Ocean (Cerna, 2001; Young and Drake, 2004; Varghese *et al.*, 2013) (Table 3). The results suggest that probably the Kenya swordfish could be of a different stock or localized population from that of the entire Indian Ocean and genetic studies should be undertaken to confirm this. Ching-Ping Lu *et al.* (2006) reported that swordfish samples from Madagascar and the Bay of Bengal were genetically different suggesting that the two were distinct groups. Studies have shown that there are several stocks of swordfish fishery with distinct life history, growth and maturity parameters, namely the Atlantic, Australian, New Zealand, Indian, South Pacific, Mediterranean, Eastern Indian Ocean, Western Indian Ocean stocks (Alicli *et al.*, 2012; Varghese *et al.*, 2013; Ehrhardt, 1992; and Tserpes and Tsimenides, 1995).

The asymptotic length (L_∞) in this study was slightly lower than the other regions. It is highly likely that the observed difference in L_∞ and overall growth rate could be attributed to gear selectivity. The growth parameters from other regions were based on catches from commercial offshore fishing longliners who were targeting fairly larger individuals of swordfish while in this study the focus was on artisanal swordfish fishery using smaller sizes of hooks.

Other factors which may have contributed to the differences in the growth rate of swordfish observed in Kenya waters and other regions relate to variations in water temperatures (Baudron *et al.*, 2014; Jorgensen, 1992; Daufresne *et al.*, 2009, and Ward *et al.*, 2009), food availability (Overholtz, 1989; Lorenzen and Enberg, 2002; and Hunter *et al.*, 2016), gear selectivity (Erzini *et al.*, 2003; Conover and Munch, 2002; Enberg *et al.*, 2012; Tuda *et al.*, 2016) and genetic makeup and heredity (Ching-Ping Lu *et al.*, 2006; Hunter *et al.*, 2016; and Chow *et al.*, 1997).

Table 3: Growth parameters for swordfish stocks in different countries and oceans

Region	L_∞	K	t_0	Authors
Australian waters	296.0 (F)	0.08 (F)	–3.7 (F)	Young and Drake, 2004
Australian waters	224.2 (M)	0.13 (M)	–3.0 (M)	Young and Drake, 2004
Indian Ocean	323.40 (F)	0.081 (F)	–3.413 (F)	Young and Drake, 2004
Indian Ocean	260.47 (M)	0.1096 (M)	–3.3808 (M)	Young and Drake, 2004
India waters	311.11 (F)	0.17 (F)	–0.53 (F)	Varghese *et al.*, 2013
India waters	243.79 (M)	0.22 (M)	–0.37 (M)	Varghese *et al.*, 2013
Mediterranean Sea	185.57 (F)	0.219 (F)	–1.968 (F)	Valeiras et al., 2008
Mediterranean Sea	263. 559 (M)	0.119 (M)	–2. 27 (M)	Valeiras *et al.*, 2008
Kenya coastal waters	208	0.28	–0.18	In this study

Note: F = Female; and M = Male.

Growth rate of swordfish also varies with sex of the individual fish (Wang *et al.*, 2003; Lan *et al.*, 2014; and Varghese *et al.*, 2013). Female swordfish tend to grow faster and attain bigger size compared to their male counterparts (Kume and Joseph, 1969; Berkley and Houde, 1983; Young and Drake, 2004; 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. Some studies have reported that swordfish grow very fast reaching 100 cm and above

within a period of one year, and living to a maximum age of 15-20 years (Megalofonou *et al.*, 1995; Young and Drake, 2004; Griggs *et al.*, 2005; and Varghese *et al.*, 2013). However, in this study, sex for the individuals was not determined.

Environmental factors, genetic makeup and gear selectivity may have contributed to the growth rates estimated in this study. However more comprehensive study and genetic analyses of the swordfish fishery in Kenya waters and entire SWIO region would help provide more conclusive results on the growth rate of swordfish in this region.

5.4. Mortality rates

Studies on the mortality rates of swordfish in Kenya and indeed the SWIO region are very limited. In this study, the mortality rates for *Xiphias gladius* (Swordfish) fishing mortality rate (F) of 0.69/Year is higher than the optimal of 0.5/ Year indicating that the fishing pressure in Kenya coastal waters is fairly high (Figure 4). The fishing mortality for swordfish is considered to be below the estimated target reference point of F_{MSY} and the limit reference points F_{MSY} 1.4/year for the catch by the commercial fleets operating in the IOTC area of competency (IOTC, 2018; and IOTC, 2019). Pooled data for artisanal catches from all gears indicate that some 180 tons, 158 tons and 160.0 tons of swordfish were landed in 2014, 2015 and 2016 respectively in the Kenya waters by artisanal fishers (Ministry of Agriculture, Livestock and Fisheries; 2016). In 2018, the swordfish catch in the Indian Ocean was estimated at 31,628 tons, slightly above the MSY of 31,590 tons (IOTC, 2019). Nevertheless, the Indian Ocean Swordfish stock is described to be in healthy condition and not subject to overfishing (IOTC, 2018; and IOTC 2019). The IOTC didn't carry out swordfish stock assessments in 2018 and 2019, the estimates are based on the 2017 assessment hence uncertainty in the stock status of this fishery. Some concerns on localized overfishing of Swordfish in the Western Indian Ocean have been raised by the IOTC Working Party on Billfish and WIOMSA report (IOTC, 2011; and Van der Elst and Everett, 2015). Moreover, the IOTC has not conducted assessment of the swordfish fishery from artisanal sources. The findings of this study certainly is an important contribution on the mortality rates for swordfish from artisanal fisheries.

Therefore, this study recommends that precautionary measures should be undertaken not to rapidly expand the swordfish fishery in Kenya and the SWIO region until comprehensive assessment is done on the mortality rates to avoid localized depletion of the stocks.

5.5. Fishing gear catch selectivity and size at first maturity

Swordfish sampled in this study varied in sizes depending on the type of fishing gear and site. According to this study, the size at first capture (L_{50}) for the longline was 99.6 cm FL while for the combined gears was 98.3 cm FL (Table 1) indicating that most of the individuals were juveniles. Size at first maturity (L_{50}) for swordfish in the Indian Ocean is estimated at 170 cm for females and 120 cm for males (IOTC; 2017). Fishbase (2019) estimates Length at first capture from 156 cm-250 cm. The study further reveals that longline gear was selective for larger individuals as opposed to the other gears. The probability of capture of juveniles or small-sized individuals is reduced by increase in the size of the fishing gear (Ingolfsson *et al.*, 2017; and Hermann *et al.*, 2016). The data on the sizes of hooks that were deployed by the fishers was not collected in this study. The size of the hook and bait had partly influenced the size and type of species that were captured (Ingolfsson *et al.*, 2017).

The type and method of fishing had some influence on the selectivity and type of fish landed. Over 88% of the total swordfish catch were captured using longline (Table 2) suggesting that the selectivity of the gears depend on the size and population dynamics of the fish targeted (Erzini *et al.*, 2003; and Maunder *et al.*, 2006), the type and size of fishing gear and the fishing ground (Tuda *et al.*, 2016). Erzini *et al.* (2003) while studying the comparative selectivity of fishing gears established that longlines were highly selective to larger individuals compared to gillnets. An interview with some of the fishers in the different sites revealed that fishing methods and deployment of gears influenced the type and size of the individuals landed.

Other authors have confirmed that longline is the main fishing gear for swordfish (Mueni *et al.*, 2019; and Tuda *et al.*, 2016). In 1997, longline accounted for 85% of the global swordfish catches (Ward and Elscot, 2000). The longline fleets accounted for 69%, 70% and 60% of the total swordfish catch in the Indian Ocean in 2018, 2019 and 2020, respectively (IOTC, 2018; 2019 and 2020).

It can therefore be concluded that specific gears are employed by fishers targeting certain size of the target species. Length at first capture (Lc_{50}) is one of the most important input in factors for consideration in the assessment of fish stocks (Wang *et al.*, 2003) with a view to informing policy and decision making for improved fisheries governance. It is highly likely that swordfish being landed by artisanal fishers in Kenya coastal waters are juveniles and would affect recruitment in the short term.

The stock structure of the swordfish in the Western Indian Ocean is not well known and some reports have indicated that the fishery maybe in danger of local depletion (Van der Elst and Everett, 2015). Similar observations were reported in the Mediterranean Sea whereby nearly 50% of the swordfish landed are juvenile (Alicli *et al.*, 2012; ICCAT, 2016; and FIRMS, 2017) hence threatened with overfishing. This prompted the International Commission for the Conservation of Atlantic Tunas (ICCAT) to put in place various management measures including closures and Minimum Size Landings (MLS) of 119 and 125 cm LJFL to avoid the depletion of the fishery in the Atlantic Ocean (FIRMS, 2017). Development of technical measures and appropriate regulations defining the fishing gear type and size restrictions for different sites and zones for the swordfish fishery in Kenya coastal waters is recommended. Precautionary approach in the absence of more comprehensive data on the stock structure and maturity status of the swordfish fishery is highly recommended. This would enhance the sustainability of the swordfish stocks and minimize ecosystem impacts on the non-target species as well as the reduce the capture of juveniles.

5.6. Virtual Population Analysis (VPA)

Virtual Population Analysis for *Xiphias gladius* sampled (Figure 5) indicate that natural mortality(M) loss for Swordfish is more pronounced among the juveniles (mid-length 65 cm-85 cm). Fishing mortality (F) was experienced between 85 cm-205 cm mid-length. Fishing mortality peaked at 125 cm mid-length. The highest fishing mortality range was observed between 105 cm-135 cm mid-length. These results suggest that juveniles are more prone to natural mortality compared to the adults. Mature individuals are highly susceptible to fishing mortality. Fairly larger individuals of swordfish were landed using the longline as opposed to other fishing gears (Table 2). Selectivity of fishing gears determines the size of individuals captured, increasing the size of fishing gears for instance reduces the probability of capture of young individuals (Alos *et al.*, 2008; Tuda *et al.*, 2016; and Herrmann *et al.*, 2018).

6. Conclusion and Recommendations

The findings of this study indicate that swordfish was landed by artisanal fishers throughout the sampling period. However temporal variations in the catches was evident, high catch rates were reported between August and March. The results indicate that seasonality played a big role in determining the abundance and distribution of swordfish in the Kenyan waters.

The study reveals that fishing mortality rate ($F = 0.69$) is higher than natural mortality rate ($M = 0.4$). The estimated exploitation rate (E) of 0.77/year is higher than the expected optimal of 0.5/year. This is a clear indication that fishing pressure on the fishery in Kenya coastal waters is fairly high and growth overfishing is being experienced.

The stock status and structure for swordfish fishery in Kenya and the entire Indian Ocean region is uncertain. The IOTC (2019) swordfish stock status is based on the estimates from the 2017 assessment and concludes that the fishery is in a healthy condition. In Kenya, historical catch data on swordfish from artisanal fishery is grossly lacking. Some concerns have also been raised of localized overfishing of this fishery in the Western Indian Ocean region (Van der Elst and Everett, 2015). Precautionary approach should be applied in the management of the swordfish fishery in the nearshore waters as more genetic and maturity studies are undertaken to ascertain whether the individuals less than 99 cm FL are mature and contribute to the recruitment of the swordfish stock

Over 91% of individuals of swordfish encountered in this study ranged from 68 cm-153 cm (below sexual maturity) hence regarded as juveniles. Mature individuals are within the range of 156-250 cm FL. Development and introduction of technical measures and appropriate regulations defining the fishing gear type and size restrictions for different sites and zones as well Minimum Landing Size (MLS) for the swordfish fishery in Kenya coastal waters is worthy consideration by the fisheries management authorities at national and regional

level. This would enhance the sustainability of the swordfish stocks and minimize ecosystem impacts on the non-target species as well as reduce the capture of young individuals.

There are divergent views on the growth rates of swordfish which seem to vary from sex, age and region. A comprehensive study on the biology, maturity and growth rate for swordfish in the Kenya waters and the Indian Ocean region should be undertaken to improve and broaden the scientific knowledge in these aspects.

It is evident from this study that about 89% of the swordfish catch landed by artisanal fishers were captured by longline. Further the individuals landed by longline were fairly large (99.6 cm FL) as opposed to other gear combinations (98.3 cm FL). The relevant government fisheries management authorities, local fishing communities and other actors should direct their efforts to develop in a more sustainable way a small-scale longline swordfish fishery in Kenya.

The Indian Ocean Tuna Commission (IOTC) and the South West Indian Ocean Fisheries Commission (SWIOFC) member states should develop a regional management strategy for the Swordfish fishery in the SWIO, including consideration for introducing MLS for the fishery on a pilot basis borrowing lessons from other regions and organizations including the ICCAT.

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