GROWTH, MORTALITY AND EXPLOITATION RATES OF SHARK SPECIES CAUGHT AS BYCATCH IN SMALL-SCALE TUNA FISHERIES IN COASTAL KENYA

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SUMMARY

Growth, mortality and exploitation rates in fish are critical correlates with which to evaluate many other biological (and physiological) processes such as productivity, yield per recruit, prey availability, habitat suitability, and even feeding kinematics. Despite the importance of these processes, the implementation of modern methods for determining these parameters for elasmobranchs has tended to lag well behind that of teleosts. Data were collected from artisanal fisher landings at various fish landing sites along the Kenya coast. The landings were inspected for sharks for 2-weeks in a month for 12 months (June 2012 to May 2013). Specimens were identified to species level, and total lengths were measured for the most common shark species landed and grouped into monthly length-frequencies to analyze for growth and mortality parameters using the FAO ICLARM Stock Assessment Tools (FiSAT II). The growth parameters were estimated for three shark species using the monthly length-frequencies (from June 2012 to May 2013) analyzed by routines in the FiSAT II package. Results showed S. lewini *and* C. limbatus *to have similar asymptotic lengths,* L_∞ *(of 97.07 cm) but with a higher growth rate (K) for* S. lewini *(0.76* yr^{-1}*) compared to* C. limbatus *of 0.48* yr^{-1}*. The lowest growth rate (0.33* yr^{-1}*) was derived for* C. amblyrhynchos. *Total mortality (Z) and exploitation rate (E) were both highest in* S. lewini *(1.69* yr^{-1} *and 0.56* yr^{-1}*, respectively), while* C. ambyrhynchos *had the lowest total mortality at 0.76* yr^{-1}*, and* C. limbatus *the lowest exploitation rate at 0.10. The results are discussed in relation to stocks performance and overfishing threats of the shark species. There is need to continuously monitor the populations of sharks in Kenya and the WIO region for purposes of conservation.*

Key words: *By-catch, growth, mortality, exploitation rates, stock performance, conservation.*

1. Introduction

In Kenya substantial amounts of shark landings occur as by-catch in artisanal tuna gillnets and longline fisheries, and in prawn trawls. Relatively large quantities of sharks are landed from the artisanal fishery on the north coast of Kenya especially in the Malindi-Ungwana bay. In the year 2011, 306 tons of sharks were landed from the artisanal fishery alone, with catches from the bay contributing 34% of the sharks (Fisheries Department Annual Report, 2011). The artisanal shark fishery also supports 411 fishers (out of a total of 13,000 fishers coast wide) (Marine Frame Survey Report, 2014). Despite this level of exploitation and the ecological importance of the fishery, the species composition and distribution, exploitation rates, biology and levels of fisheries-shark interactions are not known in Kenya and most of the WIO (Rudy van der Elst *et al*., 2012). This information is, however, necessary to assess exploitation levels of species and for setting conservation and management frameworks.

Species-specific catch statistics are lacking, and the sharks are landed as part of the artisanal catches where they are grouped as merely sharks and rays. This can easily mask declines of individual species within the groups. Larger species which grow at slower rates can be replaced by smaller species which grow at faster rates, with no apparent changes in landings data for the group (Dulvy and Forrest, 2010). Whereas directed fisheries have been the cause of stock collapse in many species of elasmobranches, capture in mixed fisheries and non-target catch in fisheries directed towards more productive teleosts are the biggest global threats to elasmobranch stocks (Musick, 1999), making it important to document species specific exploitation rates.

In addition, fisheries biology studies are a useful tool for rational management of stocks (Gulland, 1978). This is because information on parameters like reproduction and growth are useful for determining the recruitment potential and sustainable yield levels of a species (Pitcher and Hart, 1982). Despite the importance of such biological data, there is little information on biology of sharks from Kenya compared to the teleostean species (Murdoch *et al*., 2008; Kaunda-Arara and Ntiba, 1997). This research therefore focused on contributing data on the fishery of the commonly harvested shark species, including data on some growth parameters of selected species. The information will be useful for developing management plans and will provide an initial scientific database on the elasmobranchs in Kenya. More attention was given to determination of growth and mortality parameters, and exploitation rates of the common shark species in the landings that are useful for modelling the stock dynamics.

2. Materials and methods

2.1. Data collection

This study was carried out between June 2012 and May 2013 at selected fish landing sites along the 650km long Kenya coastline (Fig. 1). The coastline is influenced by both north-easterly (NEM) and south-easterly (SEM) monsoon winds. Much of the fishery is artisanal (small scale mostly operated using canoes) with some semi-commercial exploitation of the prawn fishery in the Malindi- Ungwana Bay on the north coast. The near-shore fisheries are being over-exploited along most of the mainland coastline (Kaunda-Arara *et al*., 2009). Thus the coastal environment and its valuable resources are increasingly under pressure from human settlement and related developments.

The fish landing site was taken as the primary sampling unit. Consequently data collection focused mainly on specific but representative fish landing sites chosen along the coastline based on the following criteria: adequate spatial representativeness, main shark landing sites as determined from reconnaissance and desktop surveys, accessibility, and fishing craft-gear type combination on each landing site. Subsequently a total of 6 landing sites were eventually chosen (Fig. 1).

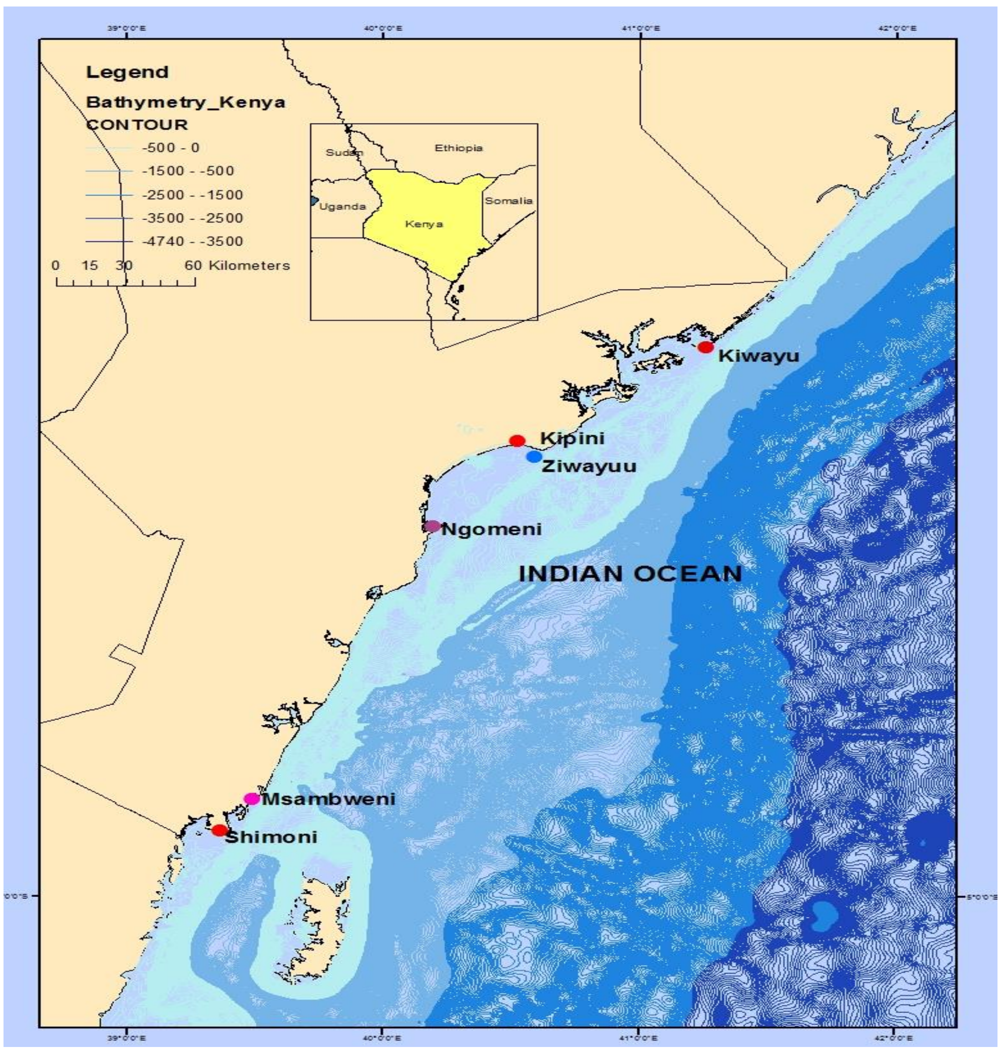

Figure 1: Map of the Kenyan coastline showing the main landing sites (Shimoni, Msambweni, Ngomeni, Kipini, Ziwayuu and Kiwayu Islands) selected for sampling for sharks in this study (Source: Author, 2014).

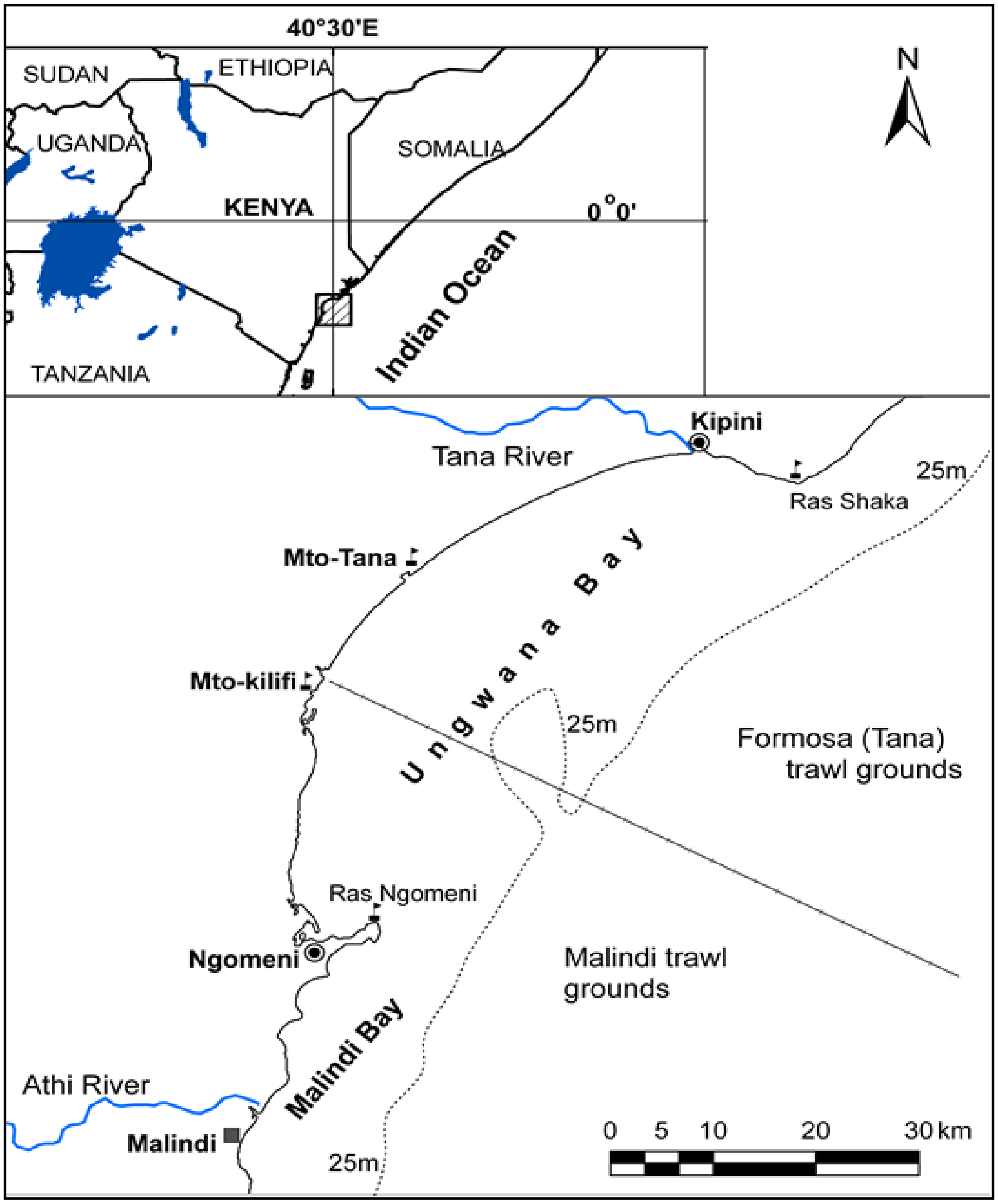

Figure 2: Map showing the Malindi-Ungwana bay where prawn trawling is done and substantial artisanal shark landings were observed (Source: Munga et al., 2012).

2.2. Data analysis

Size-frequency distributions of males and females of species were compared for symmetry using a two-sample Kolmogorov–Smirnov test (Zar, 1999).

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

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

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

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

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

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

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

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

3. Results and discussion

3.1. Length- frequency distributions

Length-frequency distributions were derived for 1,380 individual sharks of *Sphyrna lewini* (772), *Carcharhinus limbatus* (475) and *C. amblyrhynchos* (133) landed from the artisanal fishery.

The sizes of *S. lewini* ranged from 28.8 to 92.1cm TL, with a modal length class at 50.0 to 54.9 TL cm for both males and females (Fig. 2a). Samples of *C. limbatus* landed by artisanal fishers ranged from 16.1 to 90.1 cm TL, with a modal class at 35.0 to 39.9 cm TL for both males and females (Fig. 2b). The grey reef shark, *C. amblyrhynchos*, had a length range of 30.0 to 89.5 cm TL in the samples and a strong modal class at 35.0 to 39.9 cm TL for females, and a bi-modal length distribution for males at 35.0 to 39.9 and 55.5 to 55.9 cm TL (Fig. 2c). All the specimens landed in the artisanal fishery had sizes that were less than the size at maturity as per the Fishbase records (Fig. 2). The Kolmogorov–Smirnov (K-S) test showed no significant differences in size-frequency distribution between males and females of; *S. lewini* ($D = 0.2$; $p = 0.901$), *C. limbatus* ($D = 0.188$; $p = 0.912$), and *C. amblyrhynchos* ($D = 0.455$; $p = 0.147$) landed by the artisanal fishery.

The size-frequency distribution of the sharks landed in the artisanal fishery showed that the artisanal fishers are harvesting juveniles. This suggests that Kenya's artisanal fishery in Malindi-Ungwana bay is susceptible to growth overfishing (*sensu* Pauly *et al*., 1998) which may lead to stock collapse.

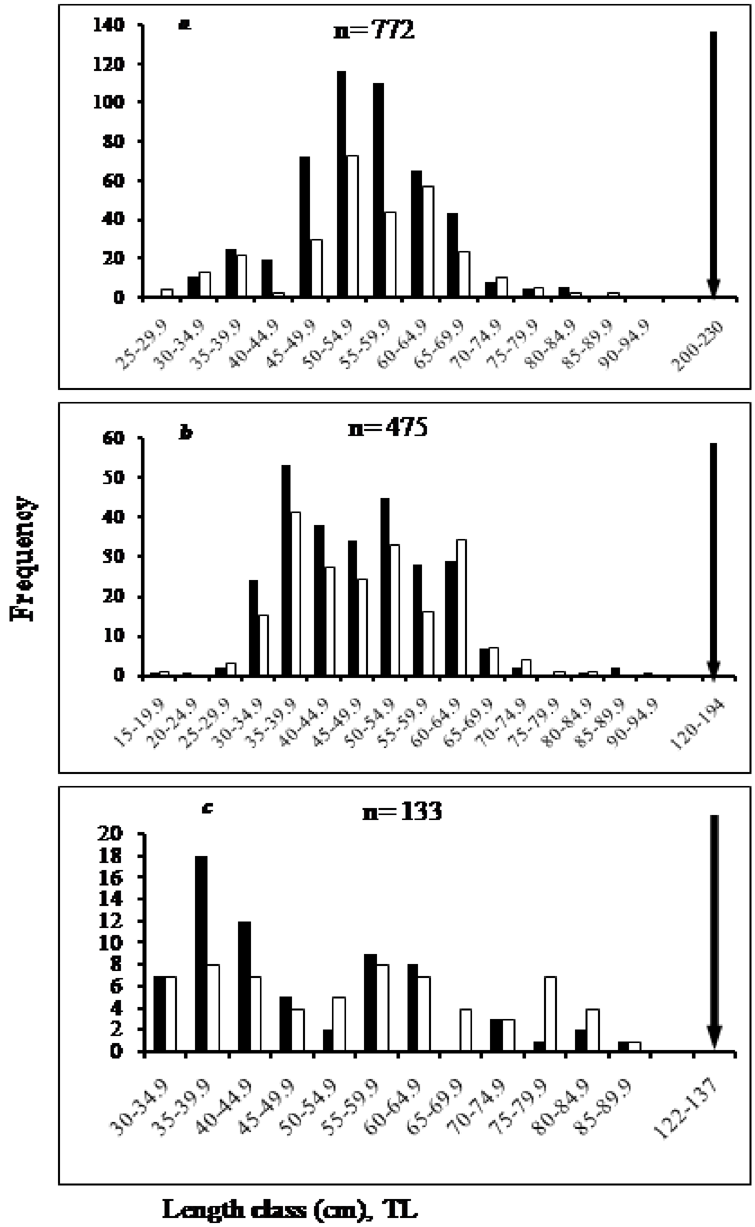

Figure 2: Length- frequency distributions of shark species (sexes combined) from the artisanal fishery of coastal Kenya (males □, females ■): *a*) *Sphyrna lewini*, *b*) *Carcharhinus limbatus* and *c) Carcharhinus amblyrhynchos*. Arrows indicate length at maturity (Compagno, 1984; www.fishbase.org) (Source: Author, 2015).

3.2. Growth, mortality and exploitation rates

Following the K-Scan routine in the Electronic Length Frequency Analysis (ELEFAN I) in FiSAT II (see section 2.2), the derived restructured monthly length-frequency data with peaks (shown in black) as positive points and troughs (shown in white) as negative points are shown in Figure 3. The growth parameters generated in ELEFAN I (Table 1) showed *S. lewini* and *C.*

limbatus to have similar asymptotic lengths, L_∞ (of 97.07 cm) but with a higher growth rate (K) for *S. lewini* (0.76 yr^{-1}) compared to *C. limbatus* of 0.48 yr^{-1}. The lowest growth rate (0.33 yr^{-1}) was derived for *C. amblyrhynchos* (Table 1). The growth rates of these species from other regions are presented in Table 2 for purposes of comparison. However, no estimates of growth performance index (Φ) were found for the species from other regions.

The length-converted-catch-curves for the estimation of total mortality (Z) were also derived from the ELEFAN I routine and are shown on Figure 4. The mortality rates for the three common sharks derived from the curves are then shown on Table 3. The results indicate that total mortality (Z) and exploitation rate (E) were both highest in *S. lewini* (1.69 yr^{-1} and 0.56, respectively), while *C. ambyrhynchos* had the lowest total mortality at 0.76 yr^{-1}, and *C. limbatus* the lowest exploitation rate at 0.10 (Table 3). Natural mortality (M) was highest in *C. melanopterus* (0.86 yr^{-1}) and lowest in *C. ambyrhynchos* (0.6 yr^{-1}), with *C. limbatus* and *S. lewini* experiencing similar natural mortalities at 075 yr^{-1}. Overall *S. lewini* experienced the highest fishing mortality (F) at 0.94 yr^{-1}, with *C. limbatus* having the lowest (0.08 yr^{-1}).

The high total mortality and exploitation rates especially observed in *S. lewini* is likely related to the juvenile composition of the specimens in the landings, and vulnerability to gillnets due to their general body morphology, clearly indicating that more fishing pressure than present is not healthy for the fishery.

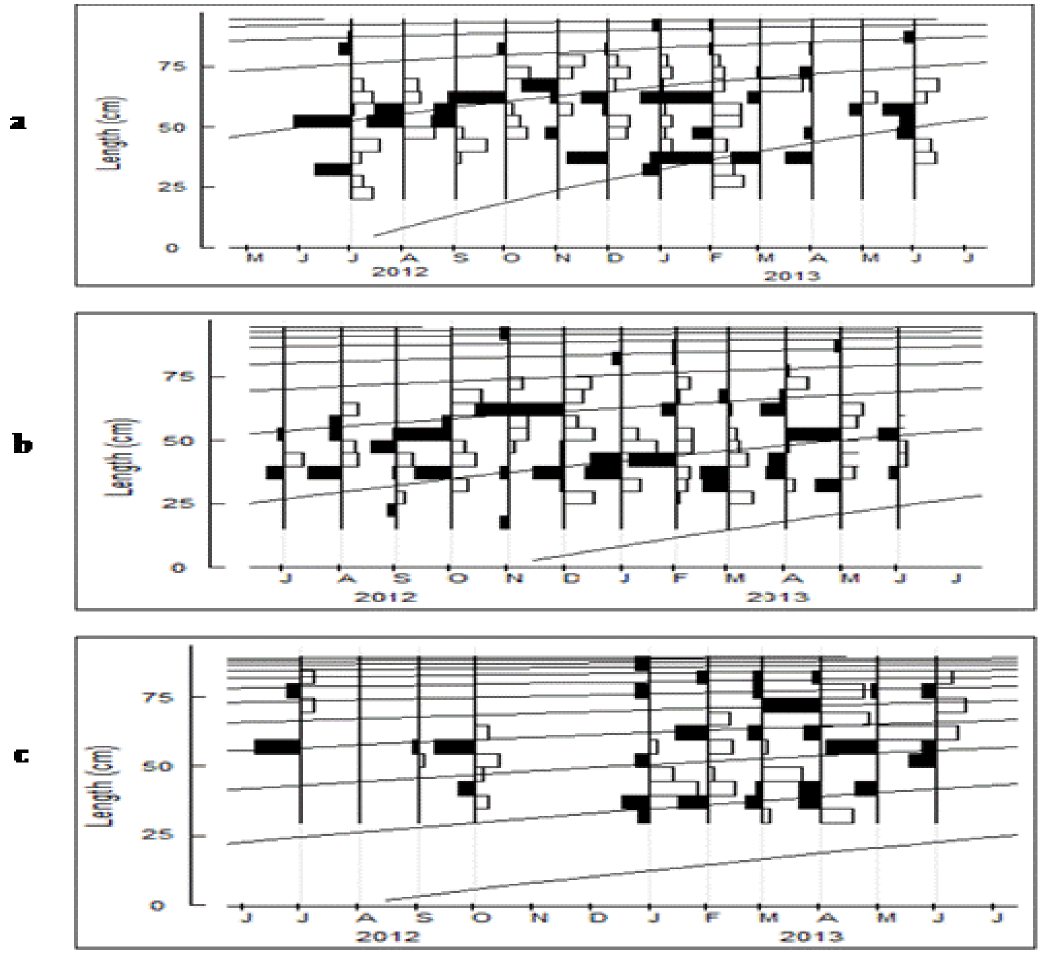

Figure 3: Growth curves of three shark species from Kenya's coastal artisanal fishery superimposed on the restructured length-frequency histograms in (a) *Sphyrna lewini* (b) *Carcharhinus limbatus* (c) *Carcharhinus amblyrhynchos* (Source: Author, 2015).

Table 1: Growth parameter estimation in three shark species using ELEFAN I method in the FiSAT II programme. L∞= asymptotic length, K= instantaneous annual growth rate, Φ= growth performance index and Rn= goodness of fit index.

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

Table 2: Growth parameters of the three shark species studied in coastal Kenya as derived in other studies. Growth parameters from coastal Kenya are as derived in Table 3.

Species	L_∞ (cm)	K (yr^{-1})	L_{max} (cm)	Region	Source
Sphyrna lewini	331.2	0.076	430	Sub-tropical (Australia)	Harry *et al.*, 2011; Compagno, 1984
Carcharhinus limbatus	139.40	0.230	275	Warm temperate/ Tropical	Carlson *et al.*, 2006; Compagno, 1984
Carcharhinus amblyrhynchos	-	-	255	Warm temperate/ Tropical	Compagno, 1984

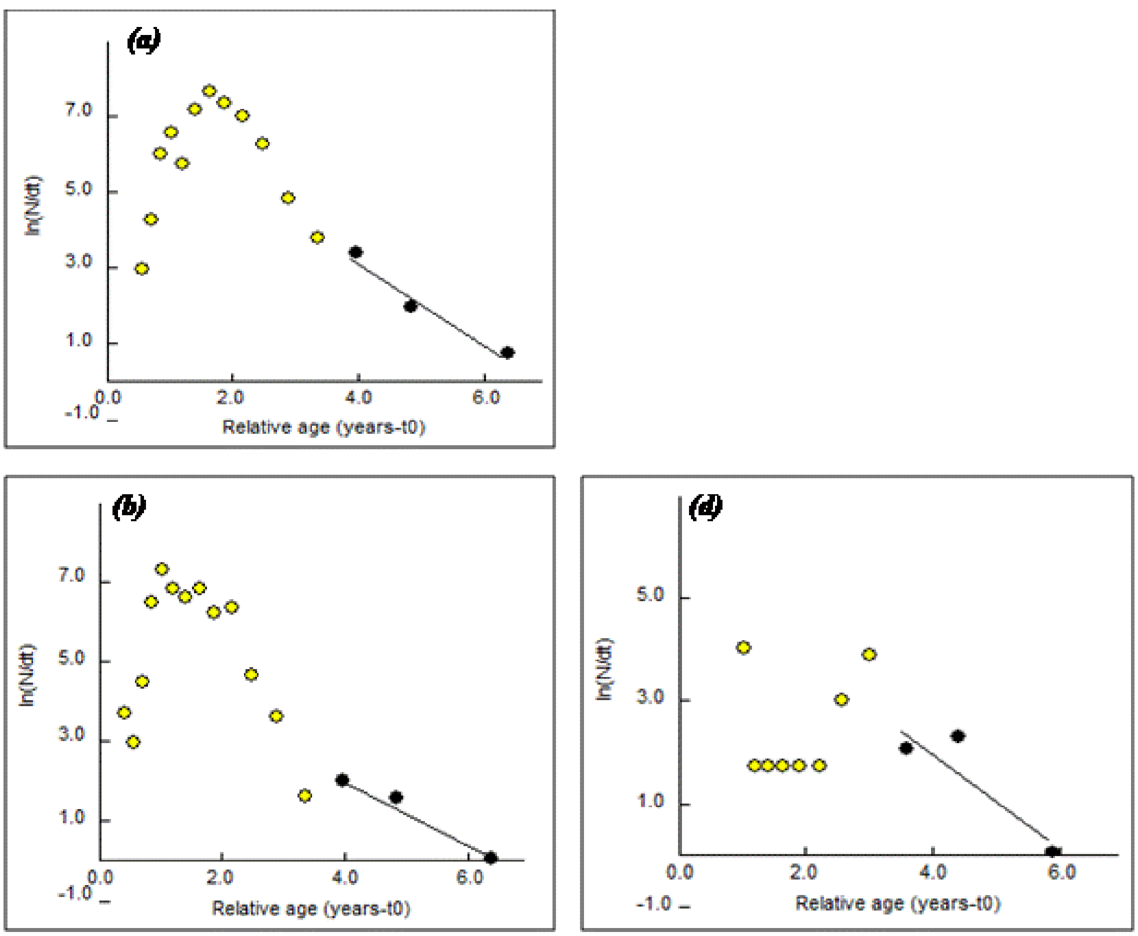

Figure 4: Length- converted catch curves for estimation of total mortality (Zyr^{-1}) of three common species in the artisanal fishery in coastal Kenya (a) *Sphyrna lewini* (b)

Carcharhinus limbatus (c) *Carcharhinus amblyrhynchos* (d) *Carcharhinus leucas* and; (e) *Carcharhinus melanopterus* (Source: Author, 2015).

Table 3: Mortality and exploitation rate estimation of three shark species in coastal Kenya derived from ELEFAN I analysis in FiSAT II programme (Total mortality, Zyr^{-1}; Natural mortality, Myr^{-1}; Fishing mortality Fyr^{-1}; and Exploitation rate, E).

Species	Total mortality, Z	Natural mortality, M	Fishing mortality, F= Z-M	Exploitation rate, E= F/Z
Sphyrna lewini	1.69	0.75	0.94	0.56
Carcharhinus limbatus	0.83	0.75	0.08	0.10
Carcharhinus amblyrhynchos	0.76	0.6	0.16	0.21

4. Acknowledgements

Data collection for this study was funded by the South West Indian Ocean Fisheries Project (SWIOFP). The author also wishes to extend his gratitude to data collectors from Kipini Beach management Unit (Mr. Abubakar Bwanaheri and Mr. Awadh Mubarak), field staff from the State Department for Fisheries and the Blue Economy (SDF&BE) and the Kenya Marine and Fisheries Research Institute (KMFRI), and Prof. Boaz Kaunda-Arara of the University of Eldoret for guidance.

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