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African Journal of Marine Science

ISSN: 1814-232X (Print) 1814-2338 (Online) Journal homepage: https://www.tandfonline.com/loi/tams20

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To cite this article: BK Kiilu, B Kaunda-Arara, RM Oddenyo, P Thoya & JM Njiru (2019) Spatial distribution, seasonal abundance and exploitation status of shark species in Kenyan coastal waters, African Journal of Marine Science, 41:2, 191-201

To link to this article: https://doi.org/10.2989/1814232X.2019.1624614

African Journal of Marine Science 2019, 41(2): 191–201
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AFRICAN JOURNAL OF MARINE SCIENCE
ISSN 1814-232X EISSN 1814-2338
https://doi.org/10.2989/1814232X.2019.1624614

Spatial distribution, seasonal abundance and exploitation status of shark species in Kenyan coastal waters

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Efforts to conserve and manage shark populations are often hampered by a lack of basic data, such as species-specific landings and distribution ranges. We bridge this gap in coastal East Africa by providing data on the distributions, catch rates, morphometrics, and exploitation status of shark species in Kenyan coastal waters. Data were collected from artisanal fishers and from bycatch taken by shallow-water (10–50 m) prawn trawlers from Malindi-Ungwana Bay and demersal research trawlers (10–150-m depth) along the ~640-km coastline, over a 12-month period (June 2012 to May 2013). A total of 1 893 individual sharks (representing 20 species and 11 families) were sampled from the artisanal fishery (*n* = 1 610) and the trawlers (*n* = 283). The demersal trawl bycatches were dominated by the African angelshark *Squatina africana* (2.39 kg h^{-1}), shortnose spurdog shark *Squalus megalops* (1.48 kg h^{-1}) and African spotted catshark *Holohalaelurus punctatus* (0.11 kg h^{-1}). Catches of the scalloped hammerhead shark *Sphyrna lewini* (0.73 kg h^{-1}), smooth hammerhead shark *Sphyrna zygaena* (0.60 kg h^{-1}) and grey reef shark *Carcharhinus amblyrhynchos* (0.77 kg h^{-1}) dominated in the prawn trawlers. Only a few species (*S. lewini, C. amblyrhynchos*, and blacktip reef shark *Carcharhinus melanopterus*) showed a coast-wide distribution in the artisanal fishery. Artisanal fishers harvested mostly immature specimens of *S. lewini*, *C. melanopterus* and blacktip shark *Carcharhinus limbatus*, suggesting that the fishery might be unsustainable in the long-term. The Endangered *S. lewini* is the most vulnerable to overexploitation on the Kenyan coast, with most specimens landed (>90%) being below the size at maturity. Data are also presented on morphometric relationships and observed or estimated exploitation reference points (maximum observed length L_{max}, asymptotic length $L\infty$, mean length at first maturity L_m, and optimum length L_{opt}) for the commonly landed species. A more comprehensive coast-wide National Plan of Action is recommended for the management of shark populations in Kenya.

Keywords: artisanal harvest, bycatch, conservation, growth overfishing, life-history traits, *Sphyrna lewini*, western Indian Ocean

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Introduction

Sharks, as apex predators, are now widely acknowledged to play a key role in maintaining ecosystem health, diversity and stability (Heithaus et al. 2008; Baum and Worm 2009). However, they are continuously threatened by harvesting as bycatch in, for example, longline pelagic fisheries, and also as targeted catch in directed fisheries (Worm et al. 2013). As a result of exploitation pressure, it is estimated that one-quarter of a globally distributed lineage of 1 041 chondrichthyan fishes (sharks, rays and chimaeras) are threatened with extinction (Dulvy et al. 2014). This situation is aggravated by the unique life-history traits of sharks that limit their potential to sustain high fishing mortality (Musick 2000; Dulvy et al. 2014). For most shark species, little is known about their exploitation status, distribution range or biology (Fowler et al. 2005; Dulvy et al. 2008), but such information is necessary for management of stocks and conservation initiatives. In developing countries, wide latitudinal spread in fishing pressure, a low level of surveillance and year-round fishing in small-scale artisanal fisheries have made it difficult to monitor the status of fisheries (Berg et al. 2002; van der Elst et al. 2012).

Levels of exploitation might be underestimated due to possible under-reporting of catches and the socioeconomic importance of sharks, but little biological information exists at the species level and neither are there data on fisheries−shark interactions in coastal East Africa or elsewhere in the western Indian Ocean (WIO) region (Berg et al. 2002; van der Elst et al. 2012). Data on landed catches, including species composition, for slow-growing species such as sharks and rays are important for stock management as these species can be replaced by smaller, fast-growing species, with no apparent changes in landing volumes (Dulvy and Forrest 2010). Furthermore, removal of large sharks from coastal habitats may allow their prey, which may include mesopredators, to increase in abundance, with subsequent changes in trophodynamics and ecosystem structure (Heithaus et al. 2008). Due to poor management protocols and lack of relevant expertise, chondrichthyan landings in WIO countries are often lumped as 'sharks and rays' in fisheries statistics (Kaunda-Arara et al. 2003; van der Elst et al. 2012). The lack of species-specific

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information has made it difficult to evaluate the effects of fisheries on individual species.

It is estimated that about 3 100 artisanal fishing vessels operate in the territorial waters of Kenya (Kenya Marine Frame Survey Report 2016). About 600 of these vessels target small- and medium-sized pelagic species and reef fishes, with incidental catches of sharks taken mostly in gillnets. Shark bycatch in the artisanal fishery is retained. Considerable quantities of a number of shark species are also landed as bycatch in the semi-commercial prawn-trawl fishery on the north coast of Kenya (Munga et al. 2014). In this study, we aimed to provide species-level information relating to catch composition and rates, spatial distribution and morphometric relationships, in addition to a rapid assessment of the exploitation status of shark species in coastal Kenya. The data were obtained from three sources: from artisanal fisher catches and from shark bycatch taken in both the prawn-trawl fishery and coast-wide trawl surveys for demersal fish resources. It is anticipated that the results will help with the formulation of a National Plan of Action (NPOA) for shark management in Kenya, as called for internationally by the Food and Agriculture Organization of the United Nations (FAO 1999, 2007), with a wider application in the WIO region.

Materials and methods

Study area and fisheries

The study was carried out between June 2012 and May 2013 at selected fish-landing sites along the ~640 km Kenyan coastline (Figure 1) and on trawl vessels. The Kenyan coastline and fisheries activities are influenced by both the northeasterly and southeasterly monsoon winds. Respectively, these trade winds occur during the northeast monsoon season (NEM, November–March), which is a period of calm seas, elevated temperatures and higher salinities, and during the southeast monsoon season (SEM, April–October), which is characterised by rough seas, cooler weather and lower salinities (Kaunda-Arara et al. 2009). Well-developed fringing reef systems are present all along the coastline except where major rivers (e.g. the Tana and Athi/Sabaki rivers; Figure 1) discharge into the Indian Ocean. Artisanal fishing activities are generally concentrated on the inner continental shelf, between the shore and these reefs; however, at Kipini (a site with high shark landings) the reefs are patchy due to the influence of discharge from the Tana River, and fishers operate considerable distances from the shore (Kaunda-Arara 2016), increasing the possibility of landing more-oceanic species.

Much of the Kenyan coastal fishery is artisanal (small scale). This fishery predominantly uses multifilament gillnets, traps, monofilament nets (mostly nylon), handline hooks and longlines. The fishery is operated by dugout canoes that are engine-(6–10 Hp) or wind-propelled. There is also a semi-industrial trawl fishery for prawns in the relatively productive Malindi-Ungwana Bay on the north coast (2°30′–3°30′ S, 40°00′–41°00′ E; Figure 1). The bay is the only shallow-water trawlable ground on the Kenyan coast with a narrow continental shelf extending ~60 km offshore, with shallow fishing grounds ranging between 12 and 18 m deep in areas between 2.8 and 11.1 km from shore (Fulanda et al. 2011).

Field sampling

Shark landings, species composition and distribution data were collected from three sources: (i) the inshore artisanal fishery, (ii) inshore prawn-trawl fishery, and (iii) trawl surveys for demersal resources. Shark landings data from the artisanal fishery were collected at six active sites (Shimoni, Msambweni, Ngomeni, Kipini/Ziwayu Island and Kiwayu Island; Figure 1) spread along the Kenyan coastline and excluding sites known to have a low occurrence of sharks in the landings. These data were collected with the help of trained field enumerators from the State Department of Fisheries (SDF) and the Kenya Marine and Fisheries Research Institute (KMFRI). The field enumerators had been trained in species identification using various field guides (e.g. Compagno 2005; Musick and Bonfil 2005; IOTC 2012) and in methods of measuring shark morphometrics (following Branstetter and Stiles 1987). Standard data collection sheets and shark identification charts were provided to the enumerators. In addition, all specimens were photographed for later confirmation of identity. Data from each landing site were usually collected for two continuous weeks in each month, from June 2012 to May 2013.

Trawl-based data were collected in 2012, for two weeks per month during July, August, October and November, by two trained scientific observers. One observer was deployed on board a semi-commercial prawn trawler, the MV *Roberto*, operating within the Malindi-Ungwana Bay area (between Malindi and Kapini; Figure 1). Prawn trawlers fish in shallow waters of <70 m and land sharks as bycatch. Another observer collected data from the MV *Vega* during a 2-week scientific trawl survey in November 2012 that was funded by the Southwest Indian Ocean Fisheries Project (SWIOFP). This trawler surveyed the distribution of demersal fish along the Kenyan coast at depths of 10–150 m. Details of the trawling methods used in the prawn fishery are provided by Fulanda et al. (2011) and Munga et al. (2012), and those in the scientific survey by Kaunda-Arara et al. (2016). Briefly, for the research trawl vessel, the percentage area of each depth stratum in a geographical zone (north, south or mid-coast) was used to determine the proportion of sampling time to be allocated to the depth strata in each zone during the sea-days. A total of 27 trawls yielded catches. The transects per depth stratum were run parallel to the shore in order to remain within the stratum as much as possible, while avoiding very shallow areas as well as coral and rocky areas. The geographical coordinates of the start and end positions of each transect were determined using a GPS. Trawling was conducted during daytime, from 06:00 to 18:00, and each trawl lasted for one hour (unless aborted), at a speed of 2.5–3.0 knots. Scientists and observers on the trawlers recorded: coordinates of the fished areas, water depth, catch of target species and retained bycatch, tow and haul durations, and the number of hours fished each day. As shark species were relatively few in the hauls, these were measured separately.

Landed shark specimens (caught both by the artisanal fishers and trawlers) were weighed (to nearest g) using an automatic top-loading balance for smaller sharks and a spring balance for specimens ≥5 kg. Total length (TL, cm)

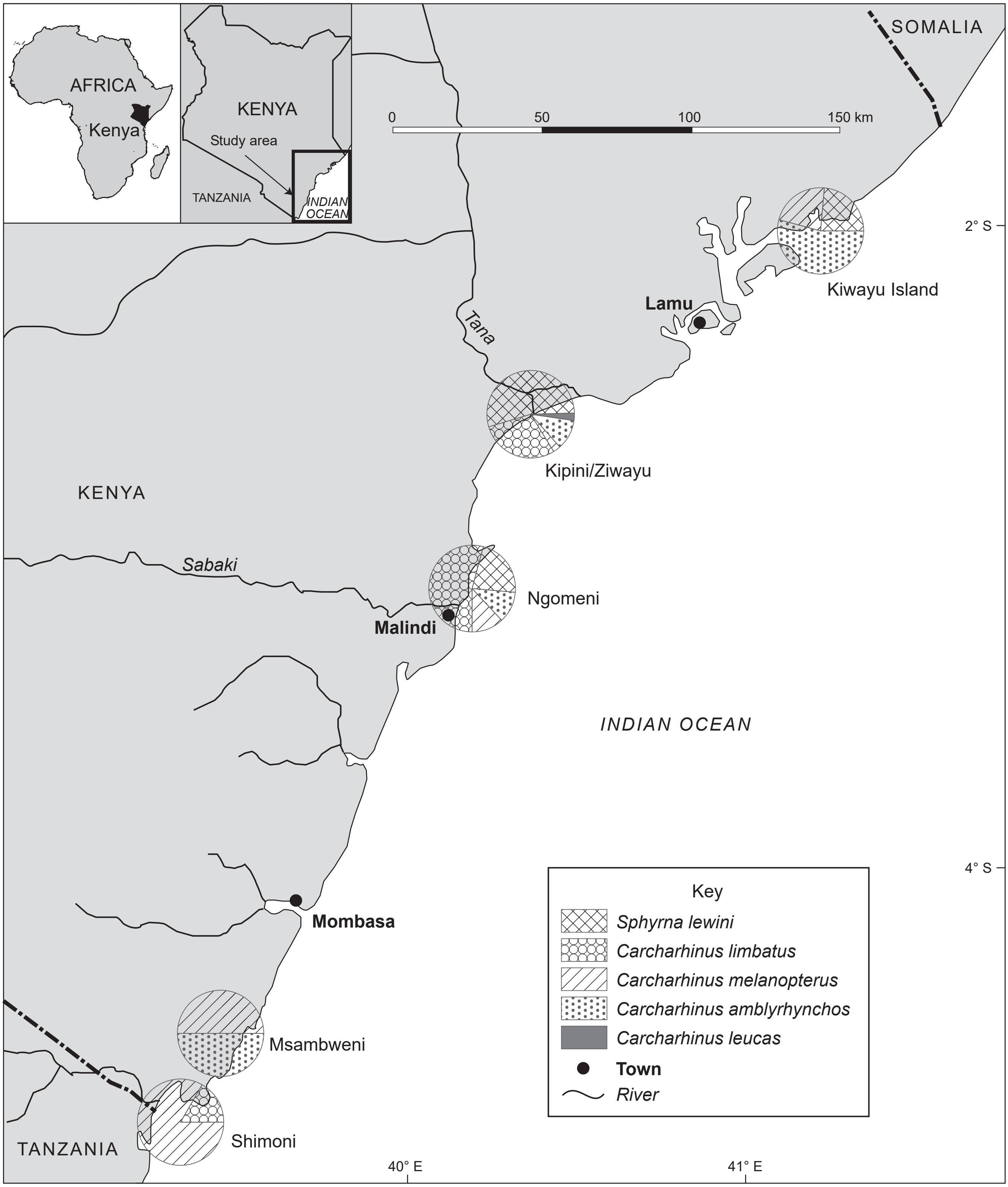

Figure 1: Map of the Kenyan coastline showing the main landing sites of the artisinal fishery (Shimoni, Msambweni, Ngomeni, Kipini/Ziwayu and Kiwayu Island) that were sampled for sharks, and the bycatch composition by weight of the main species landed at each site

was measured as the distance from the tip of the snout to a point on the horizontal axis intersecting a vertical line extending downward from the tip of the upper caudal lobe to form a right angle, while fork length (FL) was measured as the straight-line distance from the tip of the snout to the fork of the tail (Branstetter and Stiles 1987). The fins that local fishers commonly utilise for sale (first dorsal fin, both pectoral fins, and the complete caudal fin [rather than the lower caudal-fin lobe only]) were removed by the fishers on shore or by the crew members on board the vessels and then weighed on an electronic balance.

Data analyses

Morphometrics and catch rates

Data from artisanal shark landings were used to describe length-frequency distributions and length–weight, length–length and body-weight to fin-weight relationships. The data were also used to derive catch rates (catch per unit effort [CPUE]) for the landings from both the artisanal and the trawl fisheries. CPUE was expressed both as the weight of sharks landed per fisher per day (kg fisher^{-1} day^{-1}) and as the annualised number landed (number fisher^{-1} y^{-1}) for the artisanal fisheries, or as the amount of sharks caught by a trawler per hour of trawling (kg h^{-1}). Transects that lasted less than one hour (aborted trawls) were excluded from the analyses. The CPUE of shark species from the artisanal fishery was compared between the NEM and SEM seasons, using Welch's *t*-test (the unequal variances *t*-test) (Zar 1999), and between months, using one-way ANOVA on log $(x + 1)$ transformed data.

Simple linear regressions of FL against TL of the form $\text{FL} = a + b\text{TL}$ were derived for the landed species for purposes of conversions between the different length measurements. The relationship between TL and body weight (W) was derived from the equation $W = a\text{TL}^b$, where a (scaling constant) and b (allometric growth coefficient) are regression constants obtained from $\log W = \log a + b \log \text{TL}$. Length–weight relationships were derived separately for the sexes and the length exponents (b) were compared using ANCOVA. Data were pooled where no significant difference existed. The relationship between W and fin weight (FW), useful for estimating discarded carcass mass, was described by $\text{FW} = a + bW$.

Length-frequency distributions of males and females of each species were compared using a two-sample Kolmogorov–Smirnov test (Zar 1999), and a Chi-squared goodness-of-fit test was used to test whether the sex ratio of a species differed from unity.

Length-frequency distributions and exploitation status

A rapid evaluation of the exploitation status of the most frequently landed species in the artisanal fishery was performed from a simple length-frequency framework developed by Froese and Binohlan (2000) for data-deficient fisheries and provides a first approximation of population parameters in these fisheries. The data used for this analysis were obtained from shark landings sampled in 2014–2015 at Kipini (the site with the highest shark landings in Kenya: Kaunda-Arara 2016). Sample sizes were larger than those from 2012–2013 and included one additional species, the silky shark *Carcharhinus falciformis*, not sampled in the previous year. The length-frequency framework uses empirical relationships between the asymptotic length ($L\infty$, cm), the mean length at first maturity (L_m, cm), and the length corresponding to the mean age in years at maximum possible yield per recruit, known as the optimum length (L_{opt}, cm). For estimation of the relationship between L_m and $L\infty$, Froese and Binohlan (2000) used pairs of values of L_m and $L\infty$ from the MATURITY and POPGROWTH tables in FishBase (Froese and Pauly 2018). The MATURITY table contains about 2 600 records of length or age at first maturity for more than 1 100 species. In total, 467 pairs of L_m and $L\infty$ values, encompassing a wide variety of fish species, including sharks, were used in regression analyses to yield the empirical relationship between these parameters, as described below. To estimate the relationship between $L\infty$ and maximum observed length L_{max}, Froese and Binohlan (2000) used data from the POPGROWTH and POPCHAR tables in FishBase that yielded 563 pairs of $L\infty$ and L_{max} values, and these were similarly used to determine the empirical relationship between these two parameters.

The following empirical relationships from Froese and Binohlan (2000) were used to estimate $L\infty$, L_m and L_{opt}:

Asymptotic length ($L\infty$) was estimated from the maximum observed length (L_{max}) using the equation $\log L\infty = 0.044 + 0.9841 \log L_{max}$.

Length at first maturity (L_m) was estimated from $L\infty$, as follows:

Unsexed: $\log L_m = 0.8979 \log L\infty - 0.0782$ (SE = 0.127)
Female: $\log L_m = 0.9469 \log L\infty_{(female)} - 0.1162$ (SE = 0.122)
Male: $\log L_m = 0.8915 \log L\infty_{(male)} - 0.1032$ (SE = 0.147)

where standard error (SE) provides a measure of variability around the regression coefficient.

Length at maximum possible yield per recruit (L_{opt}) was estimated from L_m for unsexed fish, as follows: $\log L_{opt} = 1.053 \log L_m - 0.0565$.

The derived growth parameters ($L\infty$, L_m and L_{opt}) were then indicated on the length-frequency distributions of the species to evaluate the exploitation status and sustainability of sharks caught in the artisanal fishery.

Results

Species distribution and catch composition

A total of 1 893 individual sharks were collectively sampled from the artisanal fishery (n = 1 610) and the trawlers (n = 283). The sharks comprised 19 species from 10 families (Tables 1 and 2). The five most-common species in the artisanal fishery (scalloped hammerhead *Sphyrna lewini*, blacktip reef shark *Carcharhinus melanopterus*, grey reef shark *C. amblyrhynchos*, blacktip shark *C. limbatus* and bull shark *C. leucas*) were more abundant in the middle of the north coast area (the Malindi-Ungwana Bay area; see Figure 1 for species distributions). Proportionally less *S. lewini* and *C. melanopterus* were landed at the northernmost site of Kiwayu (Figure 1). The south coast sites recorded proportionally more *C. melanopterus* (at Msambweni and Shimoni) and *C. amblyrhynchos* (at Msambweni), with no catches of *S. lewini* recorded on this part of the coast. Proportionally less *C. limbatus* was recorded at the south coast landing site of Shimoni, and none at Msambweni (Figure 1). Only *C. melanopterus* was

Table 1: Composition and characteristics of the shark species caught by semi-industrial prawn and demersal research trawlers in Kenyan coastal waters during 2012–2013. CPUE = catch per unit effort; TL = total length

Type of fishery	Family	Species caught	No. of individuals	TL, range (cm)	Total weight (kg)	Mean CPUE (SD) (kg h^{-1} $trawl^{-1}$)
Semi-industrial prawn trawl	Sphyrnidae	*Sphyrna lewini*	78	46–63.7	77.1	0.73 (1.6)
	Carcharhinidae	*Carcharhinus amblyrhynchos*	83	25–186	80.6	0.77 (1.99)
	Carcharhinidae	*Carcharhinus melanopterus*	2	113–144	27	0.26 (1.05)
	Carcharhinidae	*Carcharhinus leucas*	1	156	20	–
	Sphyrnidae	*Sphyrna zygaena*	69	47–69	66.2	0.6 (1.07)
	Stegostomatidae	*Stegostoma fasciatum*	3	33–36.4	2.5	0.24 (0.112)
	Carcharhinidae	*Carcharhinus galapagensis*	2	40–42	2.94	0.028 (0.16)
	Carcharhinidae	*Galeocerdo cuvier*	1	80	1.45	–
	Squalidae	*Squalus acanthias*	7	62–97	21.8	0.21 (1.9)
	Pseudocarchariidae	*Pseudocarcharias kamoharai*	3	55–98	7.1	0.1 (0.4)
	Carcharhinidae	*Carcharhinus longimanus*	1	93	3.6	–
Demersal research trawl	Carcharhinidae	*Carcharhinus amblyrhynchos*	2	38.8–40	2	0.19 (0.32)
	Centrophoridae	*Centrophorus moluccensis*	1	71	2	–
	Carcharhinidae	*Carcharhinus sealei*	1	69.7	0.7	–
	Scyliorhinidae	*Holohalaelurus punctatus*	12	25–45.5	1.2	0.11 (0.12)
	Scyliorhinidae	*Scyliorhinus capensis*	1	40	0.4	–
	Sphyrnidae	*Sphyrna zygaena*	1	72.5	1.5	–
	Squalidae	*Squalus megalops*	9	45–80	15.8	1.48 (2.56)
	Squatinidae	*Squatina africana*	4	35.4–87.5	25.5	2.39 (4.14)

Table 2: Catch rates of the shark species landed by the artisanal fishery in Kenyan coastal waters during 2012–2013. NEM = northeast monsoon season; SEM = southeast monsoon season. Numbers of fishers: 244 in NEM, 750 in SEM. Total fishing days: 125 in NEM, 147 in SEM. CPUE = catch per unit effort; TL = total length

Family	Species	Total catch (no.)		TL, range (cm)	Total catch (kg)		CPUE (no. $fisher^{-1}$ y^{-1})		CPUE (weight) (kg $fisher^{-1}$ day^{-1})	
		NEM	SEM		NEM	SEM	NEM	SEM	NEM	SEM
Sphyrnidae	*Sphyrna lewini*	237	640	28.8–92.5	233.0	435.1	2.84	2.12	1.86	2.96
Carcharhinidae	*Carcharhinus amblyrhynchos*	70	78	30–56.1	61.6	64.4	0.84	0.26	0.49	0.44
	Carcharhinus melanopterus	8	48	28–78.8	9.9	21.9	0.10	0.16	0.08	0.15
	Carcharhinus leucas	10	21	36.6–85.5	60.0	16.5	0.12	0.10	0.48	0.11
	Carcharhinus limbatus	237	250	28.2–90.1	159.5	99.5	2.84	0.83	1.28	0.68
Lamnidae	*Carcharodon carcharias*	0	1	379.2	–	600.0	–	–	–	2.21
Total		562	1 048	–	87.3	206.2	6.73	3.47	0.84	1.23

represented at all the landing sites coast-wide, whereas *C. leucas* was encountered only at Kipini on the north coast, perhaps due to the proximity of that site to the Tana River estuary (Figure 1).

Catches from the trawlers (Table 1) had higher species richness (n = 17) relative to the artisanal fishery (n = 6) (Table 2). The species composition of sharks from the research trawl survey was different from the compositions of the shallow-water prawn trawl and the artisanal fisheries. Catches in the demersal research trawls (Table 1) were dominated numerically by the African spotted catshark *Holohalaelurus punctatus*, African angelshark *Squatina africana* and shortnose spurdog *Squalus megalops*. *Carcharhinus amblyrhynchos*, *Sphyrna lewini* and smooth hammerhead shark *S. zygaena* dominated catches numerically in the semi-industrial prawn fishery (Table 1), whereas *S. lewini*, *C. limbatus* and *C. amblyrhynchos* dominated the artisanal landings (Table 2).

Canonical correspondence analysis, based on relative abundance of the species in the three landing categories (Figure 2), showed that the requiem sharks *Carcharhinus* spp. were associated most with the artisanal fishery, whereas the shallow-water prawn trawl fishery had a shark bycatch assemblage that was distinct from that of the deeper research trawl samples, and included species with a broad depth range (e.g. crocodile shark *Pseudocarcharias kamoharai*, Galapagos shark *C. galapensis* and oceanic whitetip shark *C. longimanus*) and species mostly associated with shallower water (e.g. *S. zygaena*, *S. lewini* and zebra shark *Stegostoma fasciatum*). Some species of ray (e.g. shovelnose guitarfish *Rhinobatos productus*, bowmouth guitarfish *Rhina ancylostoma* and giant guitarfish *Rhynchobatus djiddensis*) were caught by the prawn trawlers, whereas specimens of the Critically Endangered common sawfish *Pristis pristis* were caught by the research trawl vessel (Figure 2). An uncertain record of a yellowspotted catshark *Scyliorhinus capensis*, recorded during the research trawl survey (Table 1), could not be validated because the specimen was not retained.

Seasonally, in the artisanal fishery there were higher catch rates (kg $fisher^{-1}$ day^{-1}) during the NEM season for

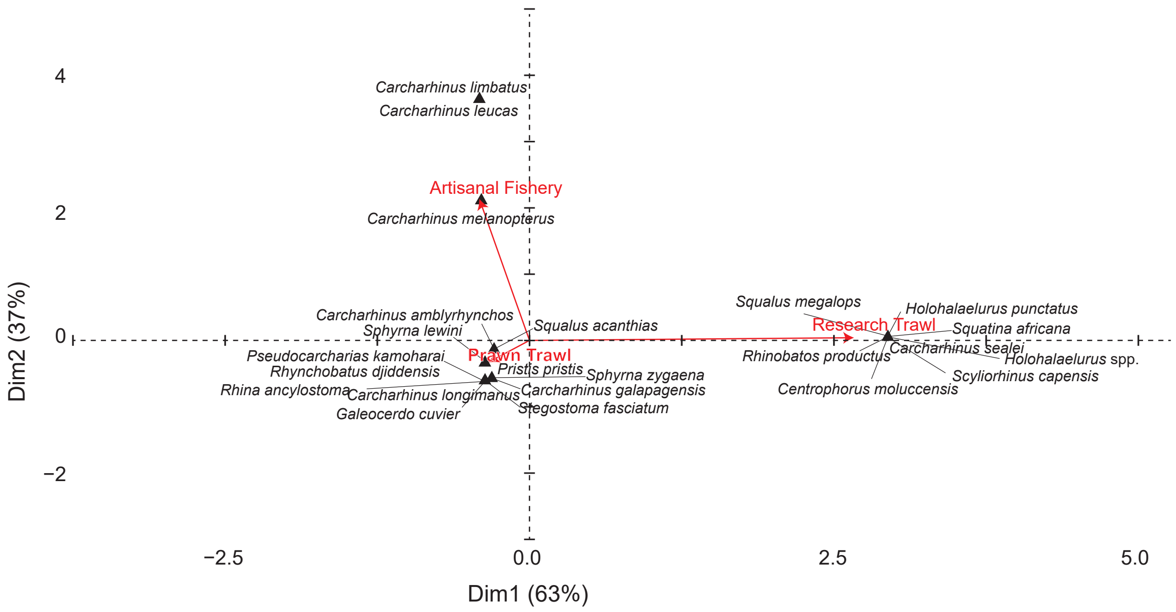

Figure 2: Canonical correspondence analysis biplot of the association of shark and ray species with catches in the artisanal fishery and the prawn and research trawls on the Kenyan coast during 2012–2013

C. amblyrhynchos, *C. limbatus* and *C. leucas*, and during the SEM season for *S. lewini* and *C. melanopterus* (Table 2). Annualised average numbers of sharks caught per fisher were generally very low, ranging between 0.10 and 2.84 for the common species, and showed *S. lewini* and *C. limbatus* to be the most frequently landed in both seasons (Table 2). The overall mean catch rates by weight for the artisanal fishery were not significantly different between seasons: NEM 0.84 (SD 0.73) kg fisher^{-1} day^{-1} vs. SEM 1.23 (SD 1.17) kg fisher^{-1} day^{-1} ($t = 2.26$, df = 9, $p > 0.05$).

Although seasonal differences were minimal, there were monthly variations in the occurrence of shark species in the landings. *Sphyrna lewini* had peak catch rates during the NEM months of November 2012 and January 2013, and *C. amblyrhynchos* during the SEM months of March and April 2013 (Figure 3a, b), although there were some landings of *S. lewini* throughout the year. Catch rates of *C. limbatus* peaked during October (SEM), November and December (both NEM) of 2012 (Figure 3c), whereas those of *C. melanopterus* were distributed from February to September, with a peak in the SEM months of April and May (Figure 3d). Catch rates of *C. leucas* peaked during the rainy SEM month of April (Figure 3e). Overall, catch rates were generally higher during the NEM months of November to March, although high catch rates extended into April, at the beginning of the SEM.

Morphometric relationships

Length–weight relationships derived for 1 495 individual sharks belonging to the five major species landed by the artisanal fishery (mostly at Kipini, see Figure 1) are provided in Table 3. The values of the length exponent (b) indicated that the relationships showed negative allometry for *C. leucas* ($b = 1.6$), with the other species exhibiting isometric growth ($b \approx 3$). However, the samples of *S. lewini, C. limbatus* and *C. leucas* did not include mature individuals. The largest specimen of all sharks landed by the artisanal fishers was a white shark *Carcharodon carcharias*, with a total length of 379.2 cm, less than the maximum length of >500 cm reported in FishBase (Froese and Pauly 2018). Fork length (FL) to total length (TL) relationships derived for the five shark species are presented in Table 4.

Fin weight comprised 7.4% of the body weight in *S. lewini* ($n = 337$), and 5.7% in *C. limbatus* ($n = 428$). The linear relationships between fin weight (y, kg) and body weight (x, kg) were significant for *S. lewini* ($y = 0.053x + 0.011$, $r^2 = 0.80$, $p = 0.041$) and *C. limbatus* ($y = 0.043x + 0.004$, $r^2 = 0.75$, $p = 0.033$), the species for which data were available, suggesting that fin weight (with fins being traded commercially) is a good predictor of body or carcass weight in these two species, and likely in the other species as well.

Length-frequency distributions and exploitation status

Data for the estimation of exploitation status based on length-frequency distributions were obtained from sharks caught at Kipini (Figure 1). The distributions for male and female *C. amblyrhynchos* were asymmetrical ($D = 0.261$, $p = 0.001$) and hence were plotted separately (Figure 4a, b). Females had a weakly bimodal distribution, with an indistinct mode at 40–80 cm TL and a more distinct mode at 110 cm TL (Figure 4a), whereas males had a more distinct bimodal distribution with peaks at 40–60 cm TL and 130 cm TL (Figure 4b). Bimodal length-frequency distributions suggest the likely presence of different cohorts in the landings, most of which were caught in gillnets. Males and females of *S. lewini* had symmetrical length-frequency distributions ($D = 0.076$, $p = 0.596$) and the length data were therefore pooled; hence, for this species there was a single mode at 60 cm TL

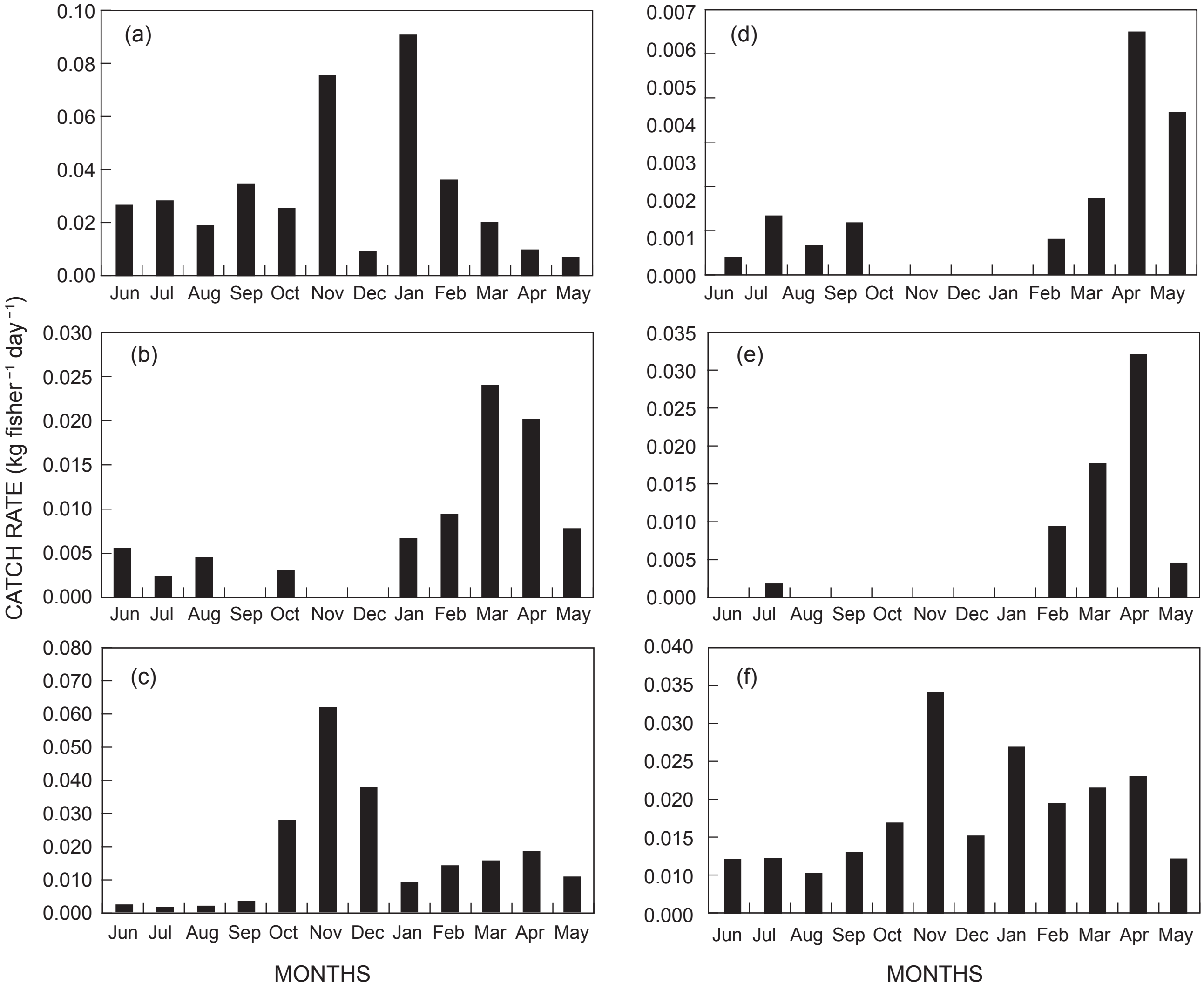

Figure 3: Monthly catch rates of the common shark species caught in the artisanal fishery along the Kenyan coast between June 2012 and May 2013: (a) *Sphyrna lewini*, (b) *Carcharhinus amblyrhynchos*, (c) *Carcharhinus limbatus*, (d) *Carcharhinus melanopterus*, (e) *Carcharhinus leucas*, and (f) these five species combined

Table 3: Length-weight relationships ($W = a\mathrm{TL}^b$) of five shark species commonly landed by artisanal fishers in Kenyan coastal waters during 2012–2013. TL = total length; *W* = body weight

Species	*n*	Mean TL (SD) (cm)	TL, range (cm)	Mean weight (SD) (kg)	Weight, range (kg)	*a*	*b*	r^2
Sphyrna lewini	773	55 (10.1)	37.3–92.1	0.8 (0.9)	0.013–3.6	0.0000236	2.6	0.71
Carcharhinus limbatus	487	48.1 (11.4)	16.1–90.1	0.5 (0.48)	0.02–4.6	0.0000067	2.9	0.85
Carcharhinus amblyrhynchos	148	51.8 (15.6)	30–89.5	0.8 (0.84)	0.12–2.9	0.000005	3.0	0.91
Carcharhinus melanopterus	56	50.5 (13.5)	32.3–78.8	0.6 (0.44)	0.15–2.5	0.0000102	2.8	0.92
Carcharhinus leucas	31	54 (15.4)	26.4–65.5	2.6 (0.9)	0.82–3.9	0.0047	1.6	0.8

(Figure 5a). Similar symmetrical distributions between the sexes were found for *C. melanopterus* ($D = 0.235$, $p = 0.119$; Figure 5b), with a single mode at 60 cm TL, and for *C. falciformis*, with a broad unimodal peak contained within the interval 100–120 cm TL ($D = 0.426$, $p = 0.743$).

Empirical relationships adopted from Froese and Binohlan (2000) were then used to estimate various growth parameters of shark species landed in the artisanal fishery at Kipini (Table 5). To evaluate the exploitation status of the species, the estimated growth parameters were transposed onto length-frequency distributions (Figures 4 and 5).

A number of the sharks landed in the artisanal fishery were smaller than the size of maximum possible yield per

Table 4: Length–length relationships (FL = *a* + *b*TL) of five shark species commonly landed by artisanal fishers in Kenyan coastal waters during 2012–2013. FL = fork length; TL = total length

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

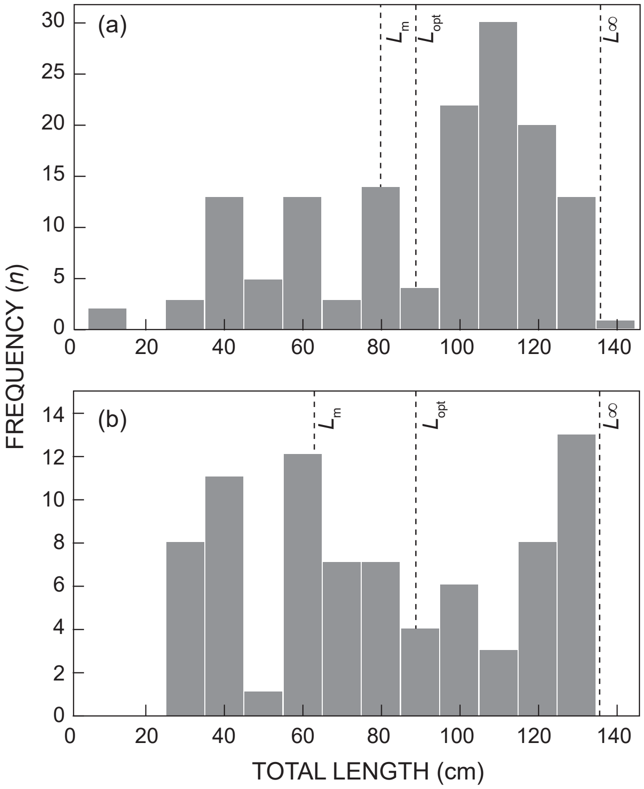

Figure 4: Length-frequency distributions of (a) females (*n* = 143) and (b) males (*n* = 80) of *Carcharhinus amblyrhynchos* landed in the artisanal fishery in Kenyan coastal waters between October 2014 and November 2015. L_m = length at first maturity; L_{opt} = optimum length; $L\infty$ = asymptotic length

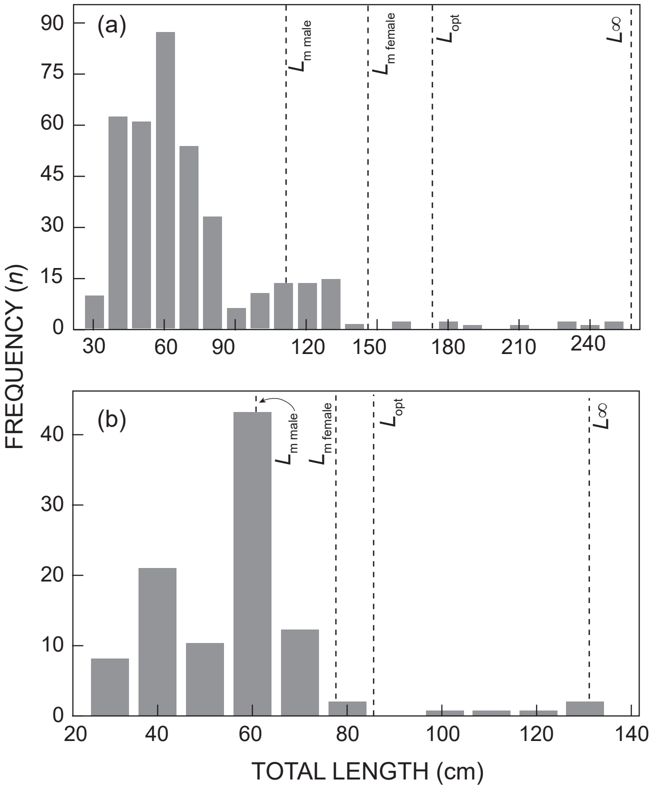

Figure 5: Length-frequency distributions of (a) *Sphyrna lewini* (*n* = 397) and (b) *Carcharhinus melanopterus* (*n* = 101) landed in the artisanal fishery in Kenyan coastal waters between October 2014 and November 2015. L_m = length at first maturity; L_{opt} = optimum length; $L\infty$ = asymptotic length

recruit (L_{opt}) (Table 5). These included 36% of females and 63% of males of *C. amblyrhynchos* (Figure 4a, b); 98% of *S. lewini* landed were smaller than L_{opt} (Figure 5a), and 95% of *C. melanopterus* were less than L_{opt} (Figure 5b).

The length at maturity (L_m) for *C. amblyrhynchos* was estimated at 80.3 cm TL for females and 63 cm TL for males, with 31% of females and 40% of males landed being below L_m (Figure 4a, b). *Sphyrna lewini*, the species landed in largest numbers, had the largest value of L_m for both females and males, at 146 cm TL and 111 cm TL, respectively, with 98% of females and 87% of males landed being below L_m (Table 5; Figure 5a). The species with the lowest L_m was *C. melanopterus*, at 77.2 cm TL and 60.7 cm TL for females and males, respectively, with 92% of females and 50% of males caught being below L_m (Table 5; Figure 5b). Asymptotic length ($L\infty$) was largest for *S. lewini* at 257.4 cm TL, and lowest for *C. melanopterus* at 130.6 cm TL (Table 5; Figure 5).

Discussion

The study documented 6 species of sharks in the artisanal fisheries and a total of 17 species caught by the trawlers. These numbers are likely not representative of the entire shark species assemblage in Kenyan coastal waters. However, we know of no documented comparative account of the diversity of shark species in East African coastal waters. Consequently, this study should serve as

Table 5: Estimated growth parameters for shark species landed by the artisanal fishery in Kenyan coastal waters during 2014–2015; the parameters were estimated using the empirical equations of Froese and Binholan (2000). $L_{\max}$ = maximum observed length; $L\infty$ = asymptotic length; L_m = mean length at first maturity; L_{opt} = length at maximum possible yield per recruit; $<L_{opt}$ = proportion less than length at maximum possible yield per recruit

Species	n	$L_{\max}$ (cm)	$L\infty$ (95% CI) (cm)	L_m female (95% CI) (cm)	L_m male (95% CI) (cm)	L_{opt} (95% CI) (cm)	$<L_{opt}$ (%)
Sphyrna lewini	397	254	257.4 (217.1–305.2)	146.7 (110.6–194) (140–273)[a]	111 (79.2–155.9)	172.9 (146.2–204.6)	98
Carcharhinus amblyrhynchos	223	133	136.2 (114.8–161.5)	80.3 (60.6–106.3) (96–142)[a]	63 (44.9–88.4)	89.1 (75.3–105.4)	46
Carcharhinus melanopterus	101	127.5	130.6 (110.2–154.9)	77.2 (58.3–102.2) (91–120)[a]	60.7 (43.3–85.1)	85.5 (72.1–100.9)	95

[a] Length at maturity range for unsexed specimens as reported in FishBase (Froese and Pauly 2018)

a baseline for more work focused on the abundance and distribution of shark species in the region. The Kenyan artisanal fishery exploits a number of shark species that are assessed as globally Near Threatened (*C. limbatus* and *C. amblyrhynchos*), Vulnerable (*S. zygaena* and *C. falciformis*) or Endangered (*S. lewini* and *H. punctatus*) as a result of overexploitation, according to the IUCN Red List of Threatened Species (www.iucnredlist.org). Additionally, a specimen of yellowspotted catshark *Scyliorhinus capensis*, known to have a restricted distribution in Namibian and South African waters (Compagno et al. 2004), and the shortnose spurdog *Squalus megalops*, not known to occur locally (Compagno 2003), were found in the deepwater trawl samples off Kenya. Such an occurrence might be evidence of a wider geographical distribution of these species than previously thought but this will require further validation by more-targeted expeditions and taxonomic resolution, especially of the problematic *Squalus* complex (Last and Stevens 1994; Compagno 2003). The study has also documented some species of rays (Batoidea), including *Rhinobatos productus*, *Rhina ancylostoma*, *Rhynchobatus djiddensis* and the Critically Endangered common sawfish *Pristis pristis*, which is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, https://cites.org/eng/app/appendices.php). These species were recorded from the prawn trawl catches and not from the artisanal fishery, which might be explained by a combination of gear layout (artisanal nets are suspended in the water column and rarely touch the bottom) and the known preference of these rays for sandy and muddy substrates (Michael 1993). More-targeted studies on rays will be required in order to determine their status, catch rates and distributions.

The rapid stock assessment method indicated that Kenya's artisanal fishery exploits a large proportion of juvenile sharks. Species are therefore exploited at less than optimum size, which might result in reduced recruitment into the fishery, with potentially serious long-term population effects (Froese and Binohlan 2000). Although these results are preliminary and useful for data-deficient situations (Froese and Binohlan 2000), continuous monitoring of species-specific catch rates and landings, coupled with an appropriate regulatory framework and effective surveillance, are necessary to avoid the risk of overexploitation. However, enforcement of a minimum size is unlikely to be effective because of poor governance structures and because few captures are released in artisanal tropical fisheries where the entire catch tends to be retained for subsistence use (Allison and Ellis 2001). The Endangered *S. lewini* appears to be at greatest risk of overexploitation on the Kenyan coast, with the greatest proportion of the catch being below L_m. The introduction of management measures such as seasonal closure to fishing in inshore pupping grounds is required to mitigate the likely overexploitation of juveniles. This measure, among others, has been proposed previously for the global conservation and management of shark populations (Worm et al. 2013).

Only *C. melanopterus* exhibited a fully coast-wide distribution, with most of the other sharks being caught in the Malindi-Ungwana Bay area on the north coast. The bay has a high biological productivity facilitated by riverine inputs (Munga et al. 2012, 2014), making it a likely nursery and feeding ground for elasmobranchs on the Kenyan coast. However, *S. lewini* and *C. amblyrhynchos* also displayed relatively wide distributions. This implies that, although area-focused conservation and management programmes for sharks in Kenya might address short-term goals, a more comprehensive coast-wide National Plan of Action (NPOA) for sharks (FAO 1999, 2007) will be beneficial in the long-term.

The growth parameters $L_{\max}$, $L\infty$ and L_m observed or derived for the commonly landed species were found to have considerably lower values than those reported in FishBase for other regions (Froese and Pauly 2018). Additionally, other studies from the WIO region reported a higher L_m for *S. lewini* (females = 244.4 cm, males = 216.0 cm) off KwaZulu-Natal, South Africa (de Bruyn et al. 2005), and for *C. amblyrhynchos* (males = 135.2–162.7 cm) from the Arabian Gulf (Jabado et al. 2016). Differences between the growth parameters reported for species in this study and those in FishBase and elsewhere might be partially due to region-specific environmental influences or to other factors such as phenotypic responses to variable fishing pressure (Locham et al. 2014), but, for some species, the differences are probably due primarily to the small number, or absence, of mature specimens in this study. Nonetheless, the unsustainable nature of shark fisheries in Kenya as a result of the predominant harvesting of juveniles is supported by similar findings from the Arabian Gulf (Jabado et al. 2016), indicating high fishing pressure in pupping grounds.

In conclusion, this study provides baseline information on the species composition, distributions and exploitation status of shark species in Kenya, which could form an important reference point for future studies in East African coastal waters and for conservation initiatives in the larger WIO region. Globally, there is a general lack of species-specific data regarding shark catches (Worm 2013). Hence, many challenges face fisheries conservation and management efforts directed at sharks, particularly in data-limited fisheries such as those of the WIO region. Consequently, the results of this study could provide a basis for estimating species-specific management reference points, and for formulating a national framework for managing shark populations in Kenya. Such a framework should consider the need to provide seasonal protection of inshore pupping grounds, regulate and enforce minimum catch sizes and institute long-term monitoring programmes. The development of a more comprehensive coast-wide NPOA is recommended for the management of shark populations in coastal Kenya.

Acknowledgements — We thank data collectors from the Kipini Beach Management Unit (A Bwanaheri and A Mubarak), field staff from the State Department for Fisheries and the Blue Economy (SDF&BE) and from the Kenya Marine and Fisheries Research Institute (KMFRI). B Orembo and R Anam (KMFRI) helped with on-board sampling on the trawl vessels, and A Achieng (University of Eldoret, Kenya) helped with aspects of data analysis. We thank the three anonymous reviewers for constructive criticisms and useful comments. This work was funded by the Southwest Indian Ocean Fisheries Project (SWIOFP) fellowship support to BKK, and a US Fish and Wildlife Service–Endangered Species Program grant to BKA.

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Manuscript received April 2018 / revised April 2019 / accepted April 2019