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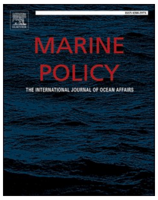

Full length article

Longline pelagic fishery assemblage in Kenya's exclusive economic zone marine waters

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ABSTRACT

Fisheries catch data is important for monitoring and assessing anthropogenic and natural impacts on fish communities. Information on fish assemblages and diversity in the Western Indian Ocean region is limited complicating management of the fisheries. In this study, we determined longline catch rates, species diversity indices, species richness, and species evenness for fish assemblages of Kenya's exclusive economic zone (EEZ) through experimental surveys conducted using a commercial Fishing Vessel (FV) between April and October 2020. A total of 110 sets were conducted where 4217 specimens of 50 species and 23 families were caught. The catches were mainly composed of *Xiphias gladius* (70.2%), *Prionace glauca* (7.8%), and *Thunnus obesus* (4.4%). About 15.0% of the catches were discarded of which 11.3% comprised of fish no commercial value. High levels of endangered, threatened and protected species forming 5.5% of the catches were observed. Catch rates were high for the dominant species in the three zones and differed significantly between months. Species abundance, richness, Shannon-Weiner diversity, and Simpson's diversity indices were highest at the nearshore zone and during August. However, the diversity indices were not statistically different both for the zones and months. The nearshore zone exhibited higher species assemblages and greater species richness compared to other zones. This suggests the importance of prioritizing conservation efforts in the nearshore zone, as it serves as a critical habitat for diverse fish populations. Implementing protective measures can help preserve the biodiversity and sustainability of fish assemblages in the nearshore zone.

1. Introduction

1.1. Background

The marine pelagic community is the largest realm covering about 1370 million cubic kilometers, representing about 71% of the earth by volume [1,2]. The pelagic community supports marine life and supplies more than 80% seafood [3–5]. Furthermore, pelagic systems influence global nutrient recycling, primary and secondary productivity, and climate change [6,7]. Additionally, pelagic fish contribute 20–25% of the total annual global fish catches accounting for about 16% fish trade value [8,9]. However, the global pelagic fish stocks have declined due to continued increase in mechanization and expansion of markets that have led to increased pressure on the stocks [8]. In the Western Indian Ocean, the pelagic stocks equally account for the bulk of the marine catches, with an estimated annual production of about 12.3 million tons. This production form 14.5% of the 84.4 million tons of marine catches globally [9]. At the county level, marine fisheries resources form an important source of nutritional, financial, and economic support for industrial and artisanal fishers in Kenya [10,11].

Kenya marine fisheries resources can be categorized into coastal inshore fisheries and the offshore exclusive economic zone (EEZ) fisheries. The coastal fisheries are localized within 12 nautical miles (nm), covering an area of 9700 km^2 while the offshore EEZ fisheries cover an area of 142, 000 km^2 of the 200 nM extend [11–13]. The inshore fisheries are exploited by about 70% of the coastal communities (artisanal fishers) using non-mechanized vessels, with the communities deriving about 80% of their income from the sub-sector [14]. The EEZ fisheries are generally exploited by distant-water fishing nations (DWFN) operating between 20 and 200 nM offshore [13]. The EEZ has a high fisheries

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potential of about 321,262 Mt [15]. The exploitation levels are estimated at about 977–2096 Mt per annum accounting for 27% of Kenya's marine fish landings [12,16]. Evidently, the offshore fisheries are underexploited but detailed data and information on the fisheries is scanty, even in regional fisheries stock reports [16,17].

Industrial fishing is one of the major threats to pelagic fish stocks. Other threats include toxic pollution, eutrophication, invasive species and climate change among others [18,19]. Fishing impacts heavily on marine biodiversity through the indiscriminate removal of both target and non-target species from the ecosystem [20,21]. Furthermore, fishing alters the distribution, reproduction, stock structure, species composition, and interaction of fish, disrupting diversity [22]. Consequently, knowledge of fish distribution, assemblages, and their variation over space and time is important for the management of any capture fishery [23].

Assemblage information provide details of the association of one or more coexisting species with similar environmental tolerance and trophic relationships, although the species may not be dependent on each other [24]. Pelagic fish assemblage surveys form an important baseline for monitoring fish community composition and assessing the effect of human and natural activities on the diversity of the pelagic fish communities [25].

Ecosystem-based fisheries management approaches (EBFM) requires more detailed data and information including species diversity, instead of simple species-specific indicators to evaluate the status of marine ecosystems [5,26,27]. The diversity of pelagic fish community is formed by different components, hence taking a functional perspective, the ecosystem may not identify not species, but functional trait groups such as body-size categories, and therefore the use of different complementary indices is necessary for describing marine ecosystems [25]. Diversity indices provide information on the number of species in water bodies and act as important indicators of species scarcity and commonality in a community [28].

Studies in fish diversity are conducted through scientific census surveys and the use of scientific observers' data [1,25,29]. However, the latter approach does not give a true reflection of the fish community diversity because the data is fishery-dependent, often selecting for the target sizes and species, and due to changes in fish abundance distribution, which also influences the distribution of fishing effort. The mode of operation of the fleet and skippers' preferences also lead to variation in fishery-dependent information [30]. Changes in catchability coefficient over time do not give consistent results, creating challenges in predicting abundance changes for less fished or non-fished fishing grounds.

Generally, there is limited information about open-sea pelagic fish assemblages due to vast nature of the pelagic ecosystems, limited regular access to the deep sea, and the behavior of pelagic fish spreading over a wide area without aggregating easily [25,31,32]. Furthermore, compared to other coastal ecosystems, data on the pelagic ocean is often lacking, leading to difficulties in decision-making, huddled by the high costs required to conduct surveys [7].

Information on catch composition, abundance and distribution of Kenya's EEZ marine fishes is limited, covering mainly commercial fisheries of the Malindi-Ungwana Bay and the North Kenya Banks [33–35]. Some studies have been conducted on the nearshore fish assemblages including Sigana et al. [36], Sindorf et al. [37] and Kaunda-Arara et al. [38]. However, corresponding studies on the pelagic fish stocks are clearly lacking. The objective of this study was to determine the assemblage of longline pelagic fishes of Kenya's EEZ marine waters. Specifically, the study aimed to determine the assemblage patterns, catch rates, and species diversity of the longline pelagic fisheries in the Kenya EEZ.

2. Materials and methods

2.1. Study area

The study was conducted in Kenya's EEZ waters straddling latitude 3°32' 12.4'' S and longitude 41°47'34'' E, covering an area of 9700 km^2 (Fig. 1). The Kenya EEZ is characterized by inter-annual climate change that arises from the interaction of sea surface temperatures, atmospheric patterns, synoptic weather conditions, and seasonal and intra-seasonal climate change [39–41]. The Kenya EEZ is influences the East Africa Coastal Current (EACC), the Somali Current (SC) and the Equatorial Counter Current (ECC) which are closely linked to the monsoon cycles [42,43]. The monsoon seasons together with the EACC are key drivers of physical parameters including the sea surface temperatures (SST) in the EEZ waters, which range from 27 °C to 28 °C during the NEM season and 24.5 °C to 25.8 °C during the SEM season. However, temperatures can exceed 30 °C in shallow inshore areas during the NEM season [44,45]. The EEZ waters experience swells of different magnitudes with about 80% of the swells originating from the north to the east with a maximum height of 6 m during the NEM season. The waves often grow to heights of 8 m during the SEM season when the swells directions change, flowing in a south-east to south-west direction [41]. During the inter-monsoon season, the swells drop to 2.5 m, and waves presume a southerly approach with swells originating from the northeast direction [41].

2.2. Survey strategy and data collection

Five experimental surveys were conducted during April through October 2020 onboard a Kenyan-flagged longline Fishing Vessel (FV) Seamar II, (Registration number IMO 7902790). The FV Seamar II is 50.74 m long (length overall, LOA), 8.5 m wide, with a gross rated tonnage (GRT) of 580 Mt. The vessel has a fish-holding capacity of 405 m^3 and rated maximum speed of 10–11 knots [46].

The survey employed a parallel stratified transect approach, with 67 points (fishing stations) designated at equal distances, laid West-East to cover the entire EEZ (Fig. 2). Every survey lasted for about 20 to 24 days. This approach prevents overlapping and ensures independent statistical representation of the entire population. For regional comparison of

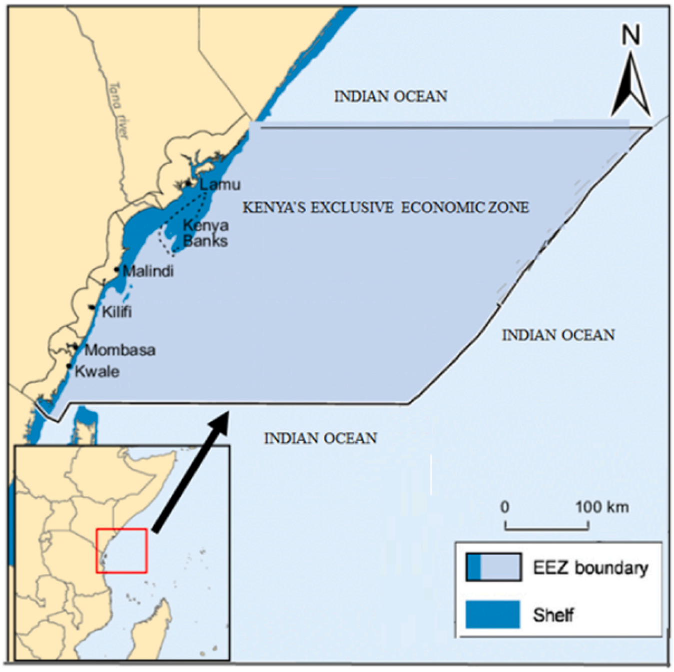

Fig. 1. The exclusive economic zone (EEZ) of Kenya inset shows the location within the broader map of Kenya.

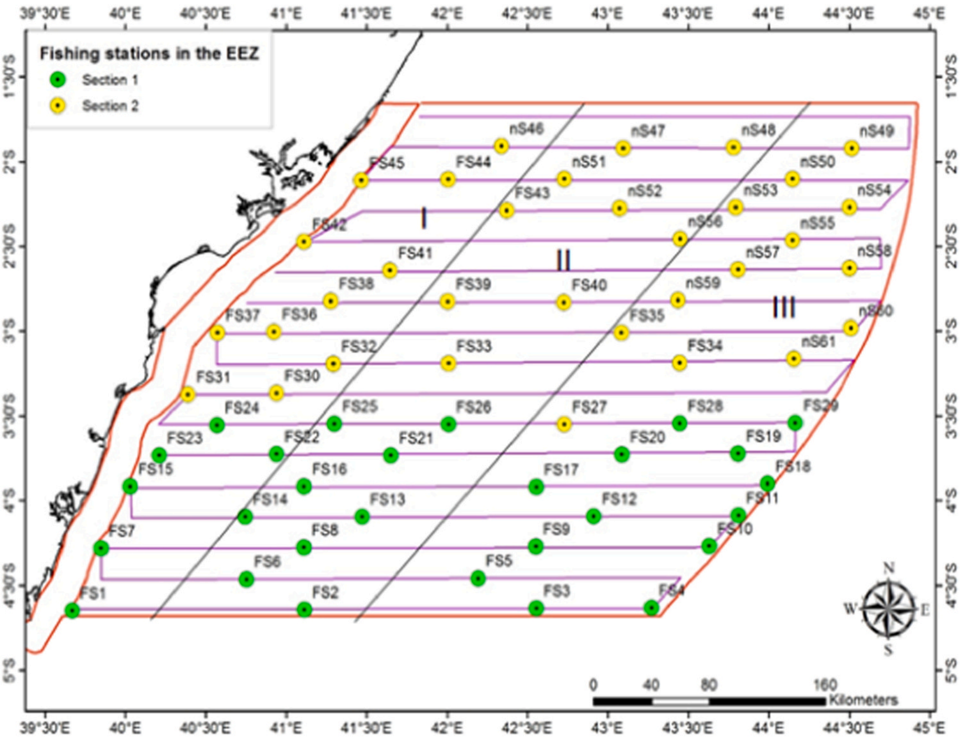

Fig. 2. Fishing sampling stations within the Kenya exclusive economic zone (EEZ) and zones adopted for analysis post prior.

catches, the Kenya EEZ was partitioned into three regions (zones I to III) parallel to the coastline with zone I consisting of the nearshore stations while zone II and zone III covered the mid-EEZ and offshore EEZ stations, respectively.

The study was based on the assumption that all fish were caught while the longline had settled (with no fish caught during the sinking phase of the deployment or during hauling). Secondly, it was noted that large fish could distort the basket shape and the depth of the longline. The longline sampling method was preferred as it is commonly used for pelagic species diversity studies and mainly targets highly migratory pelagic fish stocks such as tunas, billfish, and sharks [25,47].

Deployment of the longline was done in the evening hours at 5:00 p.m., adopting the Japanese longline practice in which synthetic nylon monofilament branch lines (baskets) of at least 84 hooks are set in a series on a single catenary curved (U-shaped) mainline [48,49]. The number of hooks used during the setting ranged from 234 to 346. The branch lines were attached to the mainline by metallic clips and frozen jack mackerel (*Trachurus symmetricus*) baits were attached to the hooks while light sticks were attached to the secondary line to lure fish, respectively. Buoys were attached at the end of every branch line, and the mainline was then suspended in the water column at depths of 30–138 m using floaters and floating lines (Fig. 3). A line-setter was used to regulate the depth of the mainline during setting [50].

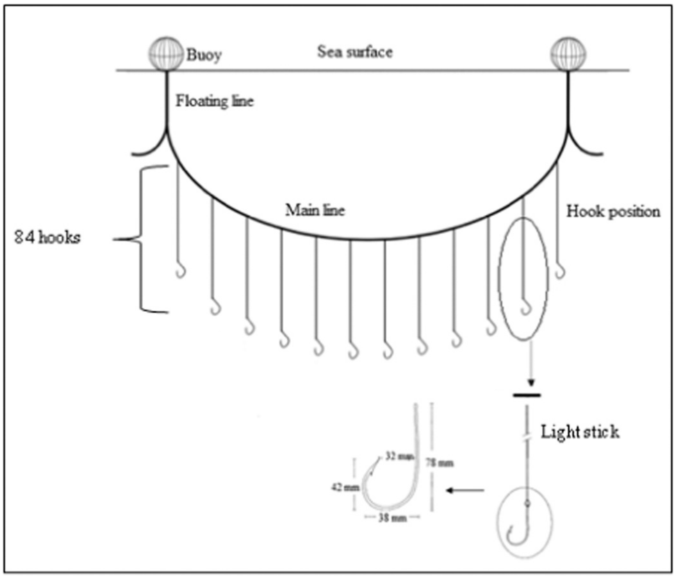

Fig. 3. Design of the Basket used during the longline survey.

Hauling was done in the morning at 6:00 a.m., starting from the last set line deployed on a last-out, first-in principle. After retrieval, the fish were identified to species level using fish identification guides [51,52]. Length for each individual landed was measured to the nearest 0.1 cm using a retractable measuring tape. Depending on the type of species caught, mensurations were done for such as fork length (FL), lower jaw fork length (LJFL), total length (TL) and width disk (WD). Total length was measured from the tip of the snout to the tip of the caudal fin on a straight line by placing the fish on the retractable measuring tape. Following the same approach, FL was measured from the tip of the snout to the middle of the caudal rays of the tail while the LJFL was measured from the lower jaw to the fork of the tail. On the other hand, DW was measured across the widest part of the disc from wingtip to wingtip in a straight line, by placing the ray fish on the measuring tape [53]. Individual weight (kg) was measured to the nearest 100 g using a hanging scale. Data on the number of hooks set and retrieved, depth of shooting, geolocation of shooting and hauling, time when hauling started and ended, count of individuals captured for every species, total length (cm), and weight (kg) of the fish was recorded. Live and dead discards were also recorded during the survey.

2.3. *Data analysis*

The fish catches were categorized into large pelagic (LP, >60 cm length as adult) and medium pelagic (MP, 20–60 cm length) species to determine the assemblage interaction of the two groups within Kenya's EEZ marine waters. The medium pelagic fish are usually found above the continental shelf [54], while the large pelagic fish species are highly migratory fish living outside the continental shelf [55]. Species assemblage was evaluated by zone (zone-I: nearshore zone, zone-II: the mid-EEZ zone and zone-III: offshore zone) and by the month of the year. The assemblages were determined using the frequency of occurrence and the raw catch per unit effort (CPUE) for each species by survey station. CPUE was defined as the number of individuals per 1000 hooks as guided by Tracey et al. [56] as follows:

$$CPUE = \frac{\text{Total catch(numbers)}}{\text{Number of hooks}} \text{X1000hooks} \tag{1}$$

The trend of catch rates was determined for the most abundant species, which were swordfish (*Xiphias gladius*), blue shark (*Prionace glauca*), oceanic whitetip shark (*Carcharhinus longimanus*), silky shark (*Carcharhinus falciformis*), bigeye tuna (*Thunnus obesus*), and yellowfin tuna (*T. albacares*).

Margalef's species richness index (d) [57], Pielou's evenness index (J') [58], Shannon-Wiener diversity index (H') [59], and Simpson's diversity index ($1\text{-}\lambda'$) index [60] were used to compare the diversity of EEZ pelagic fish species as follows:-

a) Shannon-Wiener diversity

$$H' = -\sum_{i=1}^{s} Pi \ln Pi \tag{2}$$

where $Pi = S/N$, S = number of individuals of one species, and N = total number of all individuals sampled.

The diversity index was further converted into the effective number of species (ENS) by getting the exponent of H' to give the real biodiversity of the pelagic fish species.

b) Pielou's species evenness index

This is a measure of how evenly individuals of different species are distributed. This index is sensitive to ecological properties [27,61] Evenness was calculated following Pielou's evenness equation as follows:

$$J' = \frac{H'}{\mathrm{Log}(S)} \tag{3}$$

where S is the number of species

c) Simpson's dominance index

This was used to quantify biodiversity, and takes into account the number of species and the abundance of each species, it was calculated as follows:

$$1 - \lambda' = 1 - \frac{\sum n(n-1)}{N(N-1)} \tag{4}$$

where n is the total number of individuals of a given species and N is the total number of individuals of all species.

d) Species richness was determined by adopting Margalef's index (d) formula as follows:

$$d = \frac{(S-1)}{Log(N)} \tag{5}$$

where S is the number of species in each sample with non-zero counts and N is the number of individuals in the sample.

All the analyses (diversity, richness, and evenness) were executed in PRIMER, version 6.1.1 [62] software.

Size at maturity, the length at which 50% of all fish were sexually mature (L_{50}), was estimated for the most abundant species. The L_{50} was estimated from the percentage of reproductive mature fish and unsexed fish using the logistic equation, which follows a cumulative curve where L_{50} corresponds to the average size when a species starts to reproduce for the first time. The normal curve was obtained by fitting Eq. 6 (below) in Delta graph Win (Version 5.6.2) software, followed by comparison of the length sizes of the most abundant fish species with length at maturity (L_{50}) estimates to determine the maturity of individuals caught as a proxy for overfishing.

$$M\ (TL) = 100/\ (1+e^{\ (\text{-}a(TL\text{-}b))}) \tag{6}$$

where M (TL) is the maturation length, 'a' and 'b' are constants.

Descriptive statistics in Microsoft® Excel [63] were used to determine the abundance distribution of catch rates. The spatial distribution of fish abundance was done for the most abundant species in Quantum Geographic Information system (QGIS) Development Team [64] version 3.18 software. Non-metric multidimensional scaling [65] was applied to evaluate the distribution of fish species in the EEZ zones. Abundance data was square-root transformed and standardized by totals before executing the 2D multidimensional scaling at a minimum stress of 0.1 using Euclidean distance as the (dis)similarity index according to Buja et al. [66]. Mann-Whitney's pairwise analysis was adopted to evaluate whether there were significant differences in CPUE and catches for the three zones and among sampling months in the Paleontological statistic software package for education and data analysis, PAST [67]. Factorial analysis of variance (ANOVA) was employed to determine the effect of month of fishing, depth, and fishing zone on fish abundance and biomass in STATISTICA version 7.0.6.1 [68]. All the analyses were done at a precision of alpha, $\alpha = 0.05$.

3. Results

3.1. Species composition and assemblages

A total of 110 longline sets were conducted during the survey with an estimated total effort of 36754 hooks applied during the sampling period. Analysis showed that the highest effort was deployed at the offshore-EEZ zone at 15411 hooks, followed by the shallow nearshore zone at 13365 hooks while the mid-EEZ zone had the lowest effort of 7978 hooks. Fishing effort showed little variation for all stations in the three zones except one station which had the lowest fishing effort of 234 hooks in the nearshore and mid-EEZ zones, while one station recorded a similarly low fishing effort of 280 hooks in the offshore-EEZ zone.

A total of 4217 individuals belonging to 50 species and 23 families were caught, with a total catch weight of 137.90 Mt (Table A1). The catches were predominantly composed of large pelagic fish species (96.2%), accounting for 136.80 Mt. The rest of the catch comprised medium pelagic fish species with a total catch weight of 1.10 Mt. A larger proportion of the catches (84.8%) was processed and retained, while about 15.1% of the catches were discarded as dead and 0.09% of the catches were returned back to the waters alive. Most of the discarded fish, representing 11.3% (430 individuals) of the total catches, were of no commercial value, while 3.1% were discarded because they were depredated with majority being mainly swordfishes including *X. gladius*, *T. obesus*, *P. glauca*, *Alepisaurus brevirostris*, *Alepisaurus ferox*, and *C. longimanus*. The other group of discards was composed of undersized fish, which accounted for 0.45% of the catches. Fish that had minor injuries were also discarded alive while nine other fish disentangled and escaped during hauling.

The most abundant fish species in the catch were *X. gladius* (70.2%), *P. glauca* (7.8%), and *T. obesus* (4.4% of the total catch) with *X. gladius* being the most abundant species in majority of the stations in the shallow nearshore zone, mid-EEZ zone, and offshore-EEZ zone, accounting for 73.5%, 72.7%, and 65.6% of the total catch, respectively. The second most abundant species in the three zones was *P. glauca*, with the highest dominance in the offshore-EEZ zone accounting for 12.6%, followed by the mid-EEZ zone (7.3%) and shallow nearshore zone (3.4% of the total catches), respectively.

Some of the captured fish forming about 5.5% of the total catches fall under the Endangered, Threatened and Protected, (ETP) species, such as scalloped hammerhead shark (*Sphyrna lewini*) and *C. longimanus*, pelagic thresher shark (*Alopias pelagicus*), shortfin mako (*Isuru oxyrinchus*), longfin mako (*I. paucus*), shortfin devil ray (*Mobula kuhlii*), spinetail devil ray (*Mobula mobular*), giant manta ray (*Mobula birostris*), *A. superciliosus* and great white shark (*Carcharodon carcharias*).

There was a marked variation in the occurrence of species among stations despite little variation in fishing effort, thus influencing assemblage structures within the three zones. The most frequently observed fish species were *X. gladius*, *P. glauca*, *C. longimanus*, *C. falciformis*, *T. obesus*, and *T. albacares* with *X. gladius* occurring in 98.1% of the stations, *P. glauca* occurred in 73.6% of the stations, *C. longimanus* occurred in 61.8% of the stations, *T. obesus* occurred in 62.6% of the stations, and *C. falciformis* occurred in 49.0% of the stations, respectively. On the other hand, the infrequently observed species were albacore (*Thunnus alalunga*), wahoo (*Acanthocybium solandri*), smooth hammerhead shark (*Sphyrna zygaena*), and *C. carcharias* (Table 1).

The dominant fish species in the shallow nearshore zone were *X. gladius*, *P. glauca*, *T. albacares*, *C. falciformis*, *T. obesus*, *C. longimanus*, shortfin mako (*Isurus oxyrinchus*), scalloped hammerhead shark (*Sphyraena lewini*), and tiger shark (*Galeocerdo cuvier*), while the dominant fish species in the mid-EEZ zone were *X. gladius*, *P. glauca*, *C. longimanus*, *T. obesus*, *C. falciformis*, and *T. albacares*. Lastly, the dominant fish species in the offshore-EEZ zone were *X. gladius*, *P. glauca*, *C. longimanus*, *T. obesus*, *C. falciformis*, *T. albacares*, oil fish (*Ruvettus pretiosus*), and short snouted lancetfish (*Alepisaurus brevirostris*) (Table A2). This assemblage pattern indicates more uncommon species were caught from the shallow nearshore zone.

Multidimensional scaling analysis indicate more of large head haitail (*Trichiurus lepturus*), opahs (*Lampris guttatus*), great trevally (*Caranx tille*), hump head snapper (*Lutjanus sanguinius*), Northern red snapper (*Lutjanus campechanus*), sandbar shark (*Carcharhinus plumbeus*),

Table 1

Family, Species name, common name, number (N), size range (cm), and observed frequency of the fish caught.

Family	Scientific name	Common name	Species code	Size (cm)		*N*	Observed frequency
				Mean	Range		
Alepisauridae	*Alepisaurus brevirostris*	Short snouted lancetfish	*ALO	119.4	84-174	25	19
	Alepisaurus ferox	Long snouted lancetfish	ALX	127.3	69-175	31	16
Alopiidae	*Alopias pelagicus*	Pelagic thresher shark	BTH	-	-	2	2
	Alopias superciliosus	Bigeye thresher	BTH	285.9	135-440	15	14
Bramidae	*Taractichthys steindachneri*	Sickle pomfret	*TST	68.0	47-88	14	8
Carangidae	*Caranx ignobilis*	Great trevally	NXI	84.5	73-96	2	2
	Caranx sexfasciatus	Bigeye trevally	CXS	73.3	62-82	4	4
	Caranx tille	Tille trevally	NXT	78.0	78-78	1	1
Carcharhinidae	*Carcharhinus albimarginatus*	Silvertip shark	ALS	197.0	194-200	2	2
	Carcharhinus falciformis	Silky shark	*FAL	142.2	70-250	136	54
	Carcharhinus longimanus	Oceanic whitetip Shark	*OCS	166.9	11-274	154	68
	Carcharhinus plumbeus	Sandbar shark	CCP	179.3	139-200	4	3
	Carcharodon carcharias	Great white shark	WSH	254.0	254-254	1	1
	Galeocerdo cuvier	Tiger shark	TIG	224.4	104-282	25	13
	Prionace glauca	Blue shark	*BSH	262.8	76-346	330	81
Coryphaenidae	*Coryphaena hippurus*	Common dolphinfish	*DOL	105.0	94-118	8	7
Dasyatidae	*Pteroplatytrygon violacea*	Pelagic stingray	PLS	44.5	30-122	19	16
Drepaneidae	*Drepane longimana*	Concertina fish	DRL	73.0	73-73	1	1
Gempylidae	*Gemphylus serpens*	Snake mackerel	*GES	124.4	87-182	12	9
	Lepidocybium flavobrunneum	Escolar	*LEC	99.4	72-142	18	14
	Ruvettus pretiosus	Oil fish	OIL	93.3	50-127	38	15
	Thyrsitoides marleyi	Black snoek	THM	-	-	2	1
Istiophoridae	*Istiophorus platypterus*	Indo-Pacific sailfish	SFA	186.3	181-190	4	3
	Makaira indica	Black marlin	BLM	238.0	238-238	1	1
	Makaira nigricans	blue marlin	#BUM	231.0	207-255	2	2
	Tetrapturus angustirostris	Short bill spearfish	#SSP	184.0	163-211	4	3
	Tetrapturus audax	Striped marlin	#MLS	190.3	162-249	12	8
Lamnidae	*Isurus oxyrinchus*	Shortfin Mako	*SMA	202.1	151-285	45	25
	Isurus paucus	Longfin mako	*LMA	225.5	218-233	2	2
	Lamna nasus	Porb eagle shark	POR	315.0	315-315	2	2
Lampridae	*Lampris guttatus*	opahs	*LAG	114.0	114-114	1	1
Lutjanidae	*Lutjanus campechanus*	Northern red snapper	SNR	-	-	1	1
	Lutjanus sanguineus	Hump head snapper	LZI	75.0	75-75	2	2
	Macolor niger	White snapper	MLN	67.2	57-75	5	1
Mobulidae	*Mobula birostris*	Giant manta ray	RMB	-	-	1	1
	Mobula mobular	Spinetail devil ray	RMM	176.0	176-176	1	1
	Mobula kuhlii	Shortfin devil ray	RMK	-	-	1	1
Molidae	*Mola mola*	Ocean sunfish	MOX	-	-	1	1
Scombridae	*Acanthocybium solandri*	Wahoo	*WAH	98.0	98-98	1	1
	Thunnus alalunga	Albacore	*ALB	107.0	107-107	1	1
	Thunnus albacares	Yellowfin Tuna	*YFT	129.6	90-189	88	32
	Thunnus obesus	Bigeye Tuna	*BET	143.2	82-199	184	62
Serranidae	*Epinephelus multinotatus*	White-blotched grouper	EWU	76.0	76-76	1	1
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	GBA	130.0	120-142	6	6
	Sphyraena qenie	Blackfin barracuda	BAB	76.9	62-94	11	5
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	SPL	192.8	142-251	25	8
	Sphyrna zygaena	Smooth hammerhead shark	SPZ	163.0	163-163	1	1
Tetraodontidae	*Arothron nigropunctatus*	Yellow puffer	OTK	-	-	1	1
Trichiuridae	*Trichiurus lepturus*	Large head hairtail	LHT	149.8	127-167	9	1
Xiphiidae	*Xiphias gladius*	Swordfish	#SWO	131.2	10.5-291	2960	108

Size measurement: * for fork length (FL), # for lower jaw fork length (LJFL), • for total length (TL), and ɵ for width disk (WD).

S. lewini, M. mobular, and *M. mola* are found in the nearshore-EEZ zone. While the concertina fish (*Drepane longimana*), *M. kuhlii*, *M. birostris*, blue marlin (*Makaira nigricans*), black marlin (*Makaira indica*), and black snoek (*Thysitoides marleyi*) assemble in the mid-EEZ zone. On the other hand, more of *X. gladius*, *P. glauca*, *T. obesus*, *T. albacares*, *C. longimanus*, *P. glauca*, bigeye thresher (*Alopias superciliosus*), *I. oxyrinchus*, pelagic stingray (*Pteroplatytrygon violacea*) and *G. cuvier* are found in the offshore-EEZ zone.

Other fish species including *T. alalunga* and *S. zygaena*; sickle pomfret (*Teractichthys steindachneri*) and short bill spearfish (*Tetrapturus angustirostris*) occur together while longfin mako (*Isurus paucus*), great barracuda (*Sphyraena barracuda*), *S. qenie*, *C. carcharias, R. pretiosus* and Indo-Pacific sailfish (*Istiophorus platypterus*) occur in isolation (Fig. 4).

3.2. Spatial and temporal variation of catch rates

The abundance of *X. gladius* was high in majority of the stations in zone one and zone three compared to zone two station which had low abundance. Conversely, the abundance of *P. glauca* and *C. longimanus* was high in majority of the stations in zone three. For the tuna species, the abundance of *T. albacares* was high in majority of the stations in zone one, while the abundance of *T. obesus* was high in majority of the stations in zone two and zone three (Fig. 5).

The overall average CPUE, accounting for 122.7 ± 8.5 (SE) and ranging between 44.6 and 256.0 individuals per 1000 hooks, was highest at shallow the nearshore zone. The catch rates markedly varied among the stations in the shallow nearshore zone, with about 44.6% of the stations having catch rates greater than 100 individuals per 1000 hooks. The average CPUE at the mid-EEZ zone was 118.1 ± 9.5 (SE), with a range of 3.0 to 202.3 individuals per 1000 hooks. There was no much variation in catch rates among stations in the mid-EEZ zone. In the mid-EEZ, 78.9% of the stations had catch rates greater than 100 individuals per 1000 hooks. The lowest average CPUE of 105.8 ± 8.2 (SE), with a range of 6.0 to 234.0 individuals per 1000 hooks was recorded at the offshore-EEZ zone. There was a great variation in the catch rates among the stations in the offshore-EEZ zone, with half of the stations having catch rates greater than 100 individuals per 1000 hooks.

Xiphias gladius recorded the highest average catch rate in all the three zones, with the catch rates decreasing from the shallow nearshore zone to the offshore-EEZ zone while *P. glauca*, *T. obesus*, *T. albacares*, *G. cuvier*, and *C. falciformis* recodred high average CPUE in the shallow nearshore zone. *Xiphias gladius* had the highest CPUE in all stations in the offshore-EEZ zone, except at three stations, *T. obesus*, *T. albacares, P. glauca*, and *C. falciformis* were having high average CPUE in the mid-EEZ zone, while *P. glauca*, *C. longimanus*, and *R. pretiosus* were having high average CPUE in the offshore-EEZ zone (Table A3). The average CPUE of *X. gladius*, *T. albacares*, and *C. falciformis* decreased gradually from the shallow nearshore zone to the offshore-EEZ zone. On the contrary, the average CPUE of *P. glauca* increased gradually from the shallow nearshore zone to the offshore-EEZ zone, while the average CPUE of *T. obesus* was highest in the mid-EEZ zone. The average CPUE for *I. oxyrinchus*, *G. cuvier*, and common dolphinfish (*Coryphaena hippurus*) was high in the nearshore zone, while that of *C. longimanus*, *R. pretiosus* and striped marlin (*Tetrapturus audax*) was high at the offshore zone (Table A3). The average catch rate in the offshore zone was significantly different from those of the nearshore and mid-EEZ zones.

Fig. 6 shows the mean monthly CPUE in the three zones. The abundance of fish ranged from 2.9 to 232.1 individuals per 1000 hooks while in the shallow nearshore zone, 2.9 to 167.2 in the mid-EEZ zone and 2.9 to 193.0 individuals per 1000 hooks in the offshore-EEZ zone. The average catch rate was high during July for the three zones with the shallow nearshore zone having 26.7 ± 9.1 individuals per 1000 hooks, the mid-EEZ zone recorded 24.5 ± 7.7 individuals per 1000 hooks and the offshore-EEZ zone recorded 22.5 ± 7.2 individuals per 1000 hooks. On the other hand, the average catch rate was low during September with shallow nearshore zone having 16.8 ± 8.4 individuals per 1000 hooks, the mid-EEZ zone had 13.7 ± 6.5 individuals per 1000 hooks, while the offshore-EEZ zone had an average of 12.7 ± 2.6 individuals per 1000 hooks. The monthly average catch rates varied significantly in the shallow nearshore zone ($p < 0.05$) while the monthly average catch rates for the mid-EEZ and offshore zones were not significantly different (Fig. 6).

Five species (*X. gladius*, *P. glauca*, *C. longimanus*, *T. obesus*, and *I. oxyrinchus*) were encountered during all the sampling months. *Xiphias gladius* had the highest average catch rates in all months with highest average catch rate recorded during May and the lowest average catch rate recorded during September. On the other hand, *P. glauca* had the highest average catch rate recorded during July and *C. longimanus* had the highest average catch rate recorded during June. Lowest average catch rates for the two shark species were recorded during October and September, respectively. Additionally, highest average catch rate for *T. obesus* and *I. oxyrinchus* were obtained during May, while the lowest average catch rate for *T. obesus* was recorded during July and the average catch rates for *I. oxyrinchus* were equal during June, July and September (Table A4). The average monthly catch rates for all species were significantly different ($P > 0.05$).

3.3. Species diversity

Margalef's species richness (*d*), Shannon-Weiner diversity index (*H*'), and Simpson's diversity index (1-*λ*') estimates are shown in Table 2. High species richness, Shannon-Weiner diversity, and

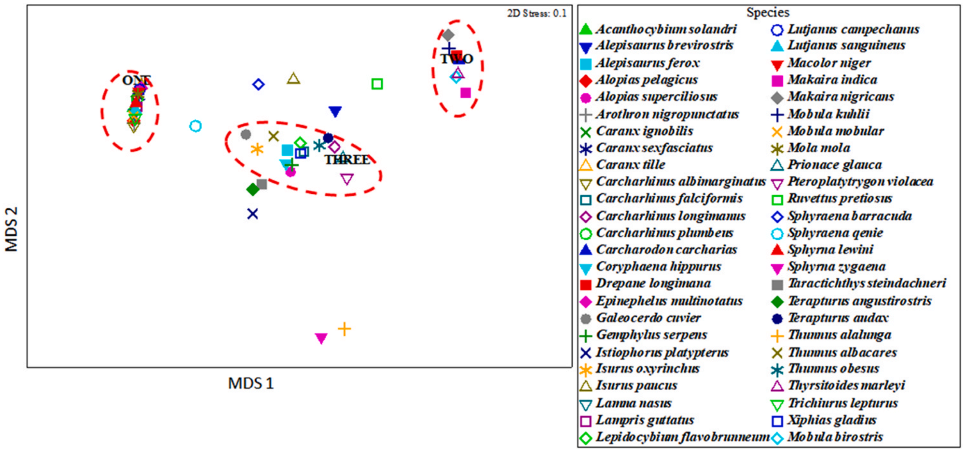

Fig. 4. Non-metric multidimensional scaling (nMDS) for the fish species caught at different zones of the Kenya EEZ during the survey period.

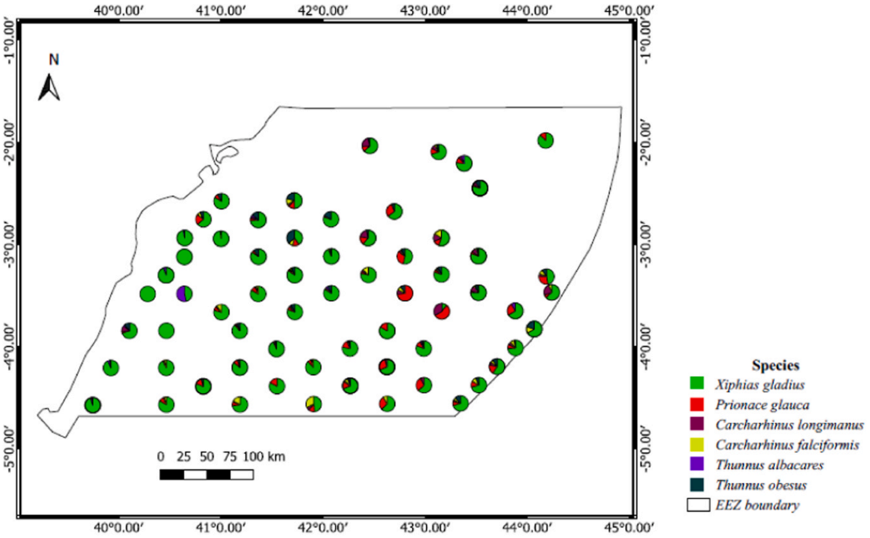

Fig. 5. Spatial distribution of the most abundant fish species caught during the survey period.

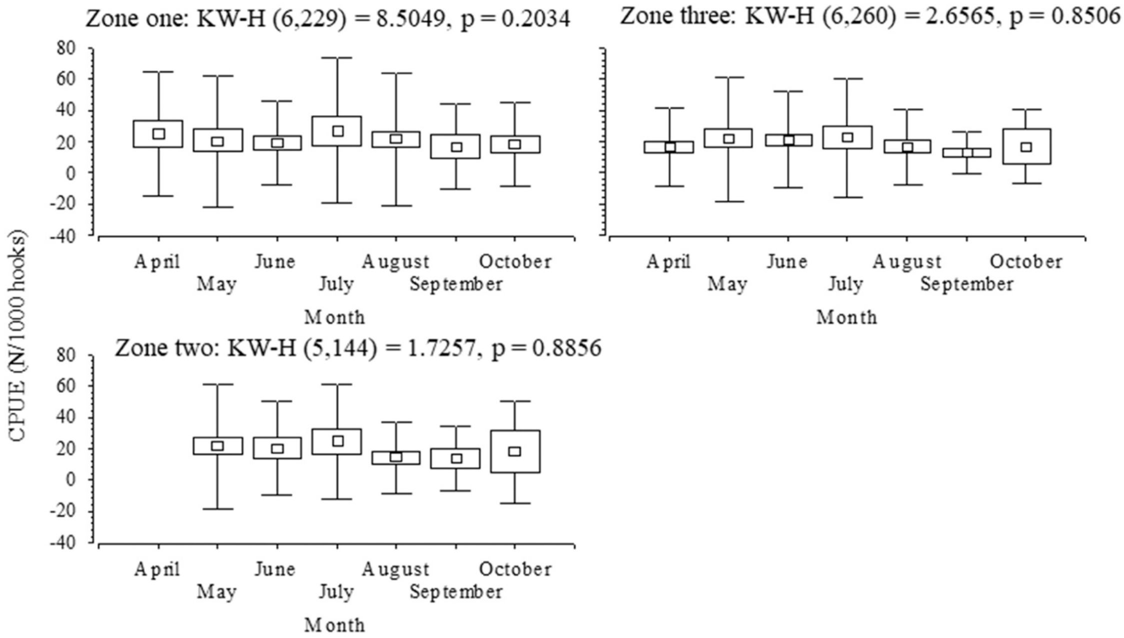

Fig. 6. Monthly mean catch per unit effort (CPUE) ± standard error (SE) and 95% confidence interval for the catches obtained in the three zones during the survey.

Table 2
Number of species (S), species richness (d), species evenness (J'), Shannon-Weiner diversity index (H'), Simpson's diversity index (1-λ'), and effective number of species (ENS) for the fish sampled during the survey period.

		S	d	J'	H' (loge)	1-λ'	ENS
Zone	One	41	8.093	0.8504	3.16	0.92	23.55
	Two	23	4.928	0.8341	2.62	0.88	13.67
	Three	27	5.44	0.8123	2.68	0.89	14.88
Month	April	20	4.569	0.8551	2.56	0.90	12.96
	May	28	5.914	0.8349	2.78	0.90	16.15
	June	21	4.538	0.8289	2.52	0.89	12.48
	July	16	3.664	0.7959	2.21	0.84	9.20
	August	29	6.201	0.8499	2.86	0.91	17.34
	September	12	3.095	0.8393	2.09	0.84	8.05
	October	14	3.695	0.844	2.23	0.85	9.27

Simpson's diversity were obtained for the shallow nearshore zone compared to the mid-EEZ and offshore-EEZ zones which had similar estimates. The estimated species evenness was equal for the three zones with the shallow nearshore zone having the highest converted effective number of species (23), while the offshore-EEZ zone had the lowest effective number of species (14).

Moreover, high estimates of species richness, Shannon-Weiner diversity, and Simpson's diversity were obtained during August while low estimates were obtained during September. Highest converted effective number of species estimate was recorded during May (16) and August (17), while the lowest converted effective number of species estimate was recorded during September and October. The findings indicate there are chances of getting 16 or 17 species occurring together during May and August, respectively (Table 2). The diversity indices were not statistically different among zones and months.

3.4. Interaction effect of zone, month, and depth on fish abundance, catch and catch rates

Analysis of variance (ANOVA) revealed that the abundance of fish, catch weight and CPUE were influenced by the month of sampling and zone of fishing while the depth of fishing only influenced the abundance of fish caught. The interaction of month of sampling and the zone of fishing had a significant effect on the abundance, catch weight, and CPUE of fish while the interaction of depth of fishing, month of sampling and the zone of fishing did not influence the abundance, catch weight and CPUE (Table 3). This denotes that changing the month of sampling and the zone of sampling can lead to changes in fish abundance, catch weight, as well as CPUE.

3.5. Size structure

Size structure and size at maturity (L_{50}) were evaluated for the most abundant four fish species, thus *X. gladius, P. glauca, T. obesus* and *T. albacares*. The sizes of *X. gladius* ranged from 53.0 to 244.0 cm, LJFL, with a mean length of 131.7 ± 36.9 (SD, cm) and estimated L_{50} of 127.7 cm, LJFL and $r^2 = 0.99$ (Fig. 7a). A high proportion of *X. gladius* individuals accounting for 57.7% of the catches had sizes less than L_{50} with almost half of the *X. gladius* individuals caught from each zone having sizes less than L_{50} (Fig. 7b and c). High proportions of mature *X. gladius* individuals was observed during June–August while majority of the immature *X. gladius* were observed during the remaining months (Fig. 7d). The immature *X. gladius* individuals were caught from all the three zones with majority spread to the nearshore and offshore-EEZ zones (Fig. 8).

The sizes of *P. glauca* ranged from 120.0 to 346.0 cm, FL, with a mean of 260.2 ± 41.8 (SD, cm) and estimated L_{50} of 271.9 cm, FL, and $r^2 = 1.0$ (Fig. 9a). About 45.5% of the *P. glauca* individuals caught were having sizes less than L_{50}, with almost equal proportions of immature individual, accounting for 44.0% caught from each zone (Fig. 9b and c). The proportions of mature *P. glauca* individuals was high during July and August and low for the remaining survey months (Fig. 9d). There was even distribution of individuals of immature *P. glauca* individuals at the mid-EEZ and offshore-EEZ zones with a few immature *P. gluaca* individuals in the shallow nearshore zone (Fig. 10).

On the other hand, the sizes of *T. obesus* individuals caught ranged from 82.0 to 198.0 cm, FL, with a mean of 153.0 ± 20.7 (SD, cm) and estimated L_{50} of 158.3 cm, FL, and $r^2 = 1.0$ (Fig. 11 a). About 45.3% of the *T. obesus* caught had sizes less than L_{50} with the proportion of mature *T. obesus* increasing from zone one through zone three (Fig. 11 b and c). The proportion of mature *T. obesus* individuals was high during April, May, and September (Fig. 11 d). Additionally, the sizes of *T. albacares* individuals ranged from 90.0 to 208.0 cm, FL, with a mean of 141.8 ± 28.9 (SD, cm) and estimated L_{50} of 146.4 cm, FL, and $r^2 = 0.98$ (Fig. 12 a). A high proportion, accounting for 54.5% of the *T. albacares* individuals caught had sizes less than L_{50} (Fig. 12 b). The proportion of mature *T. albacares* increased from zone one through zone three, with zone two having the highest proportion of mature *T. albacares* individuals (Fig. 12 c). High proportions of mature *T. albacares* individuals were observed during April, May, and July (Fig. 12 d). However, the abundance of *T. albacares* individuals was negligible during July and could not be representative enough.

Fig. 13 shows the spatial distribution of immature *T. obesus* and *T. albacares* caught during the survey period. Majority of immature *T. obesus* were from the shallow nearshore zone with scanty immature individuals in the mid-EEZ zone while majority of immature *T. albacares* individuals were from the mid-EEZ and the offshore-EEZ zones with few individuals at the nearshore zone (Fig. 13).

4. Discussion

4.1. Species composition and assemblages

Small-scale and industrial fishers use different exploitation technologies and target different fish species and this impose consequences on each sector which affect the composition, assemblages, and population structure of the marginal fish stocks left for future exploitation [69]. Assessment and monitoring the impact of anthropogenic and natural activities on the pelagic fisheries require reference indicators such as fish assemblage patterns and diversity indices [25].

Catches from the pelagic longline survey were composed of the medium and large pelagic groups, with *X. gladius*, and *P. glauca* being the most abundant large pelagic species. Similar findings were recorded by Kimani et al. [15], Santos et al. [70] and Ontomwa et al. [71], in which *X. gladius* and *P. glauca* were the dominant species in the longline catches. Additionally, *P. glauca* was found to be the second most abundant species in the recreational longline fishery [72]. A study conducted by Nakano and Seki [73] revealed that *P. glauca* was the most abundant species.

The abundance of tuna species, *T. obesus* and *T. albacares* was low compared to the other species encountered during the survey. This could be due to the diel migration pattern of the fish species, for instance,

Table 3
P–values for the Analysis of variance (ANOVA), the effects of month, zone, and depth on the abundance of fish captured.

	Effect	SS	DF	MS	F	p
Abundance	Month	103,727.0	6	17,287.8	6.5358	0.000
	Zone	11,194.3	2	5597.1	3.7877	0.034
	Depth	17,488.2	2	8744.1	3.3058	0.049
	Month *Zone	57,880.0	11	5261.8	3.5608	0.003
	Month*Depth	10,107.6	9	1123.1	0.4246	0.912
	Zone*Depth	5009.7	4	1252.4	0.284	0.887
	Month *Zone*Depth	13,398.1	16	837.4	0.876	0.827
Catch	Month	91,395	6	15,233	15.560	0.000
	Zone	21,092	2	10,546	10.772	0.000
	Depth	1844	2	922	0.942	0.390
	Month*Zone	22,195	11	2018	2.061	0.020
	Month*Depth	4644	9	516	0.527	0.856
	Zone*Depth	3240	4	810	0.827	0.508
	Month*Zone*Depth	11,842	16	740	0.756	0.737
CPUE	Month	61,422	6	10,237	10.225	0.000
	Zone	20,668	2	10,334	10.322	0.000
	Depth	1465	2	732	0.732	0.481
	Month*Zone	34,529	11	3139	3.135	0.000
	Month *Depth	7400	9	822	0.821	0.597
	Zone*Depth	2326	4	581	0.581	0.677
	Month *Zone*Depth	14,337	16	896	0.895	0.575

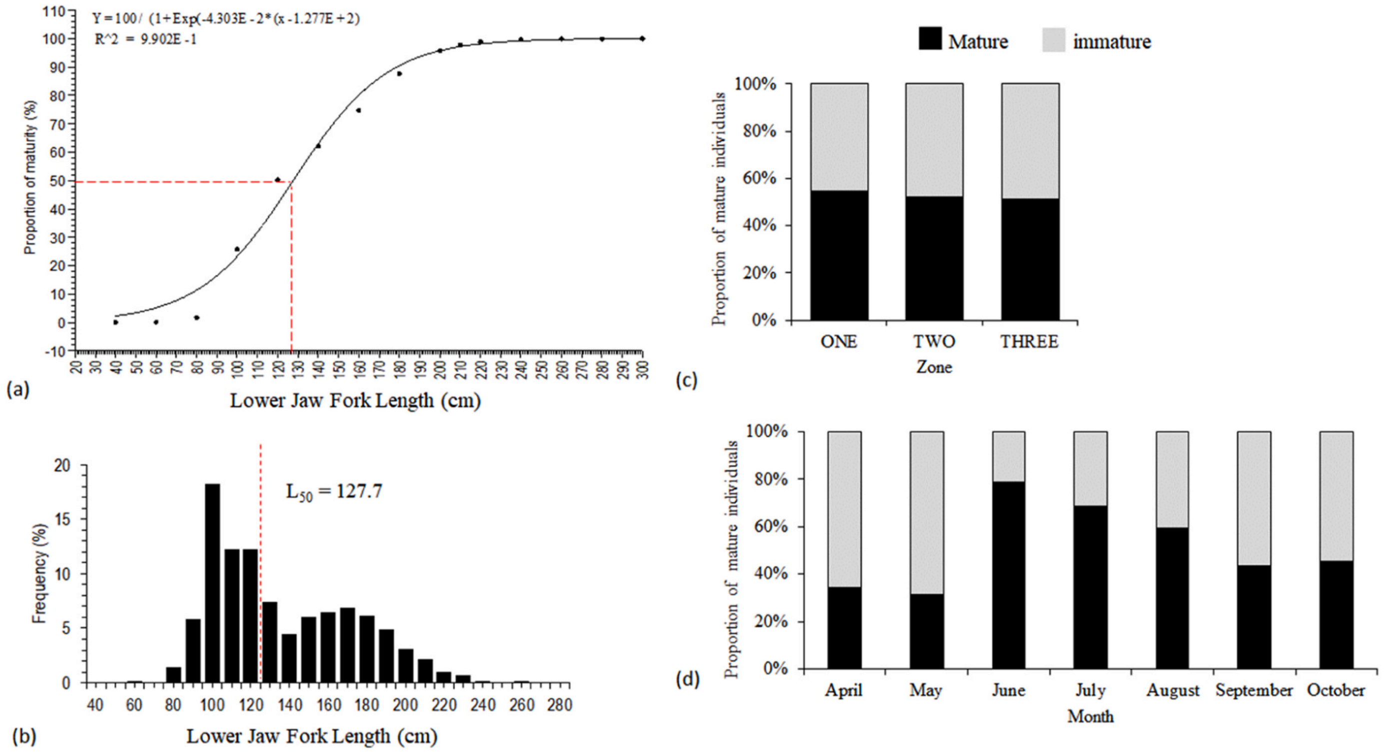

Fig. 7. Observed (dots) and estimated (line) proportion of sexually mature individuals with increasing size (LJFL), (a), size frequency distribution (b) maturity proportions by zone and month (c, d) for Xiphias gladius.

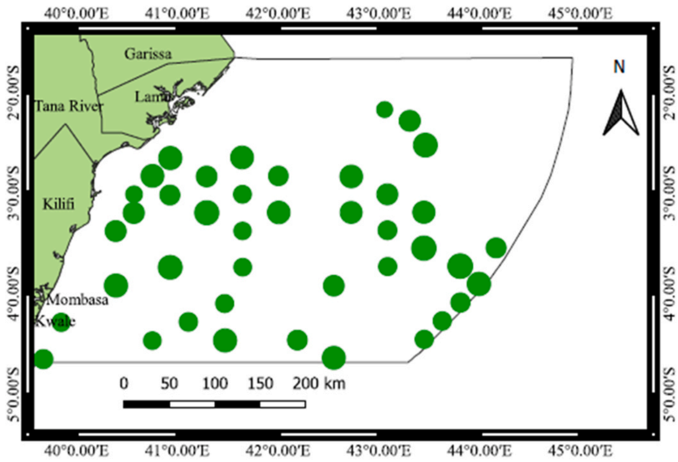

Fig. 8. Spatial distribution of immature Xiphias gladius caught during the survey period.

X. gladius occur at depths of up to 400 m during daytime and migrate to the surface shallower than 100 m for feeding and to recover from thermal and oxygen debt acquired during daytime, *T. obesus* occur in deep waters during daytime and shallow waters at nighttime while *T. albacares* occupy shallow water of about 71.3 m during daytime and 47.3 m at nighttime altering their availability time for the gear [74–76].

Additionally, differences in the vertical distribution of the fish species could be another reason for the abundance variations; *P. glauca* spend about 46.4% of their time in shallow waters of less than 50 m, while *T. obesus* can descend to depths beyond 450 m [77–79]. Also, differences could arise in the setting of the longline after sunset, which led to the capture of more *X. gladius* compared to the tuna species whose setting is usually done close to sunrise when the tunas are vulnerable to the fishing gear [80].

Lastly, fishing strategy including the number of hooks and depth of fishing could lead to fish abundance variations [81], for instance the longline fishing strategy for *X. gladius* is set at shallow depths of ≈ 30 – 90 m while that for the tuna species is set at moderate (≈ 100 – 250 m) or greater depths of ≈ 250 – 400 m [82,83]. During survey, the longline gear at a depth range of 50 – 150 m, a possible indication that the vertical ranges *T. obesus* species may not have been fully covered by the longline gear leading low abundance.

The abundance of fish was high in the shallow nearshore zone compared to the offshore-EEZ zone. Similar findings were recorded in a study conducted in the central-eastern Pacific Ocean, where fish abundance decreased from the nearshore to the offshore [84]. The abundance of *P. glauca* and *C. longimanus* increased from the shallow nearshore zone to the offshore-EEZ zone, while the abundance of *X. gladius* and *T. albacares* decreased from the shallow nearshore zone to the offshore-EEZ zone. This could be due to the solidary opportunistic feeding behavior of *X. gladius* that feed on fish and cephalopods most likely to be found in the shallow nearshore areas [85]. Also, *T. albacares* also feed on near-surface fishes, squids and crabs that are found at the shallow nearshore [86]. On the other hand, *T. obesus* spend most of their time feeding in deep waters [79]. This is an indication that the two latter species could be having more preference for the nearshore habitat than the offshore habitat and the former shark species have more preference for the offshore habitats. Further, Oostenbrugge et al. [87] in their study, inferred that distance from the shore influence the composition and abundance of catches. In conclusion, differences in abundance in Kenya's EEZ marine waters could be attributed to the inshore-offshore migrations controlled by temperature cycles, differences in oceanographic regimes, feeding and reproduction behavior and seasonality [81]. Endangered, Threatened and Protected, (ETP) species were encountered during the survey period, indicating the longline gear other non-target species of conservation concern [88].

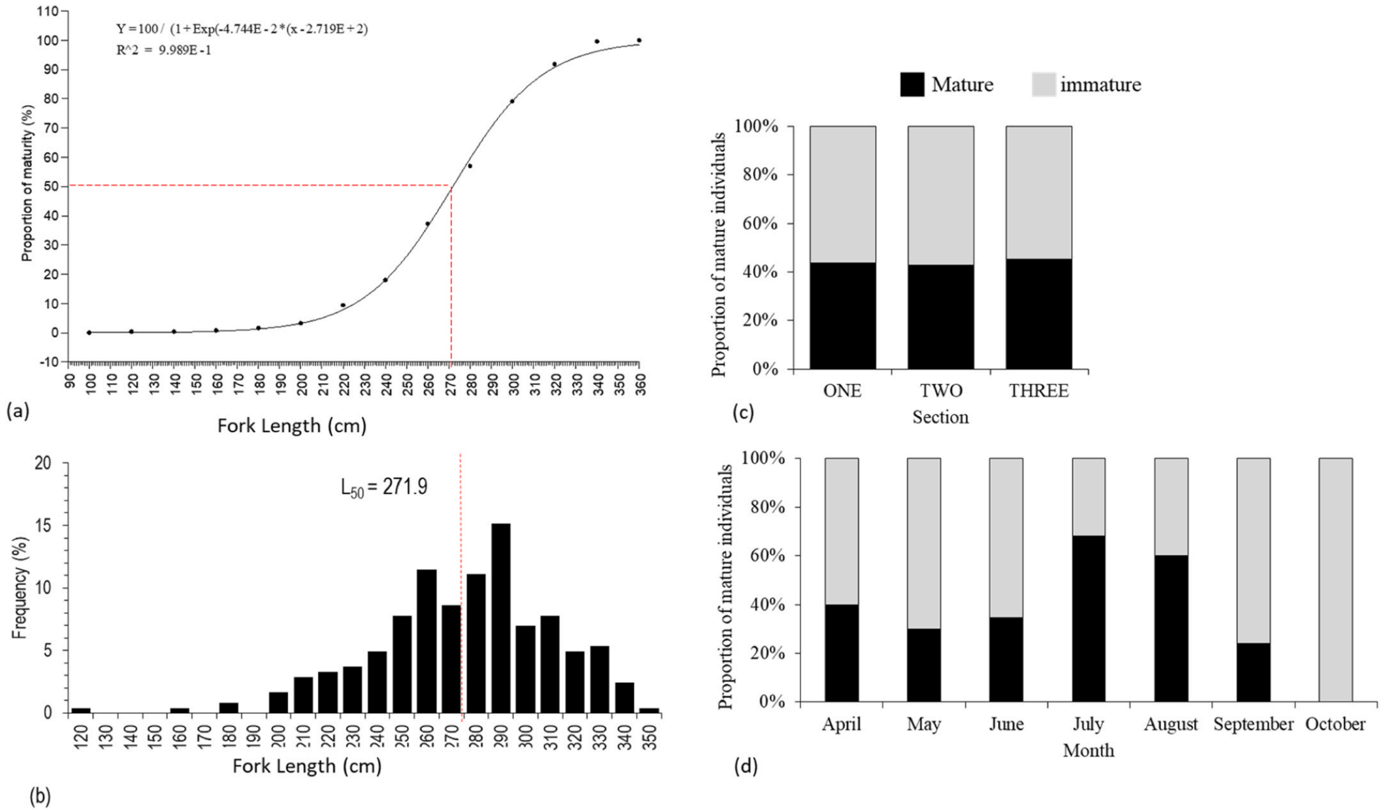

Fig. 9. Observed (dots) and estimated (line) proportion of sexually mature individuals with increasing size (FL), (a), size frequency distribution (b) maturity proportions by zone and month (c, d) for Prionace glauca.

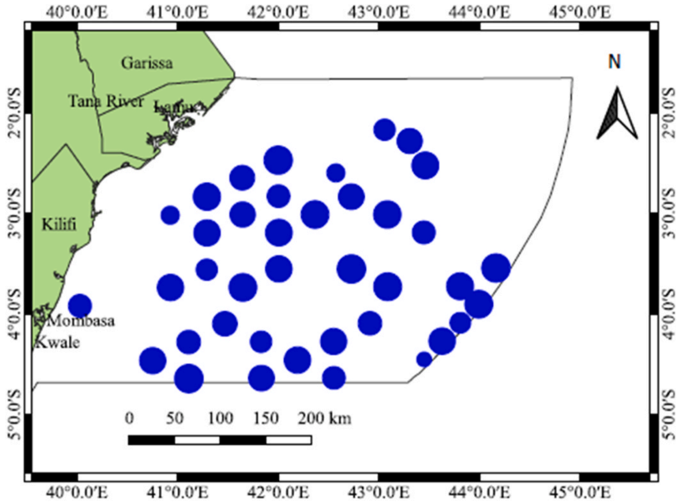

Fig. 10. spatial distribution of immature *Prionace glauca* caught during the survey period.

4.2. Spatial and temporal variation of catch rates

In the absence of fishery-independent data, catch rate information can be used as a measure of stock abundance which may vary due to the spatial distribution and fishing effort changes [30]. Fishers rely on relative catch rate information in choosing fishing areas [89]. However, other fishers rely on prior information based on their previous experience and that of other fishers [89,90].

Fish distribution information is important for understanding the impact of fishing on fish populations [91]. Changes in fish locations and their vertical distribution influence catch rates which can be improved by setting the fishing hooks at suitable depths [92,93]. Catch rate estimation was based on the assumption that catchability of the longline gear and availability of fish remained constant during the survey period. Catch rates varied markedly in the three zones for the most abundant species which could be due to the fluctuation of fish abundance at different zones and months, which is influenced by seasonal migrations related to the reproduction, feeding, or withering behavior of the fish [92]. Additionally, the selectivity of the longline gear for large individuals, the spatial distribution of fish species could lead to catch rate fluctuations [92,94]. Lastly, changes in catch rates during the sampling months could be due stock density changes of the specific species [30].

Assessment of fisheries discards is important for sound management and utilization of fisheries resources. Both live and dead discards allow for comprehensive assessment and estimation of total fishing mortality [8,95]. Accurate data produce reliable stock assessment and management advice [96,97]. Returned alive fish with high probability of survival, species targeted for release such as sharks, rays, swordfish and dolphins back to the waters is recommended. However, dead discards with potentially low commercial value are bad [98]. High levels of discards in any fishing activity waste marine resources which is contrary to the responsible stewardship and utilization of marine resources [98]. The recorded level of discards accounting for 15.1% of the total catches was within 10% for the Canada and 19% for Seychelles swordfish longline fisheries, respectively [99]. *Prionace glauca* was the most discarded species during the survey period, this conforms to the IOTC database report in which indicate *P. glauca* as the most commonly discarded species.

4.3. Species diversity

The interpretation of species diversity indicators and their application in predicting the effect of fishing is difficult [100]. Assessment of

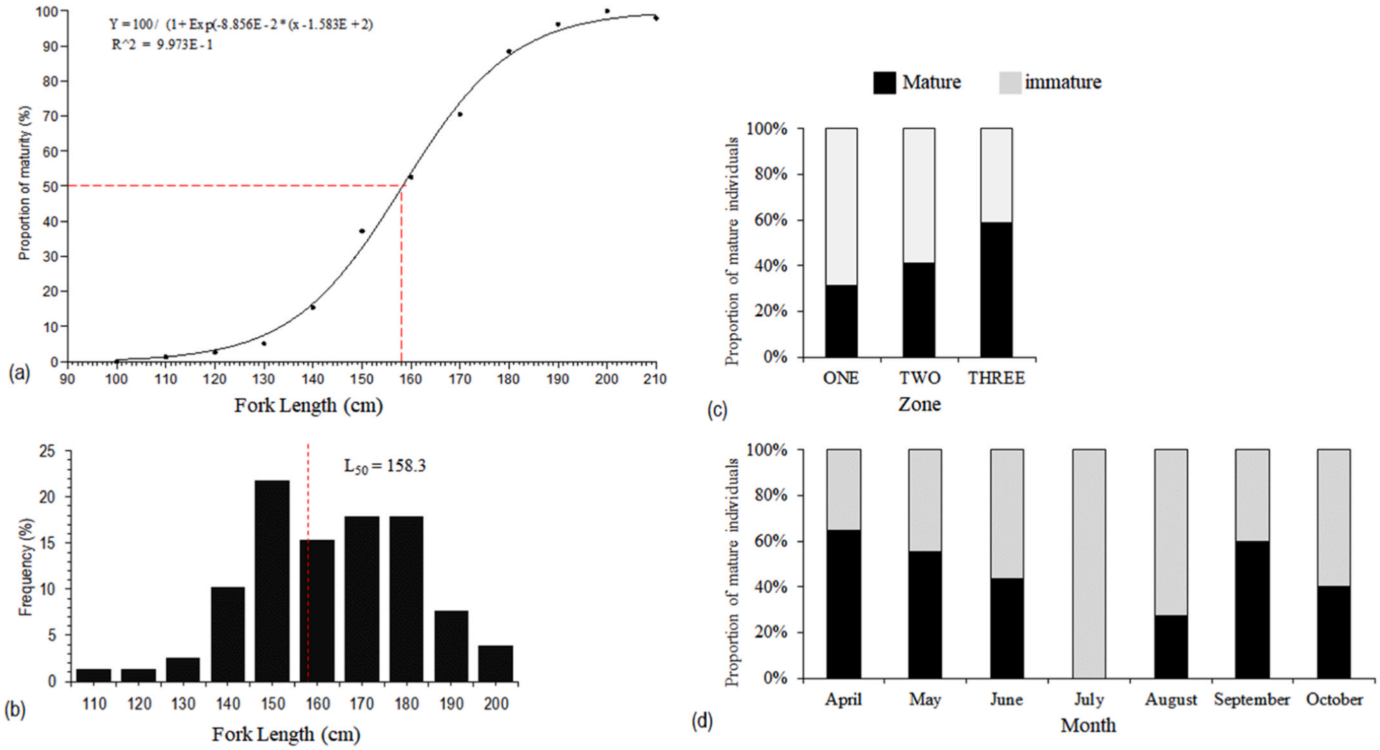

Fig. 11. Observed (dots) and estimated (line) proportion of sexually mature individuals with increasing size (FL), (a), size frequency distribution (b) maturity proportions by zone and month (c, d) for Thunnus obesus.

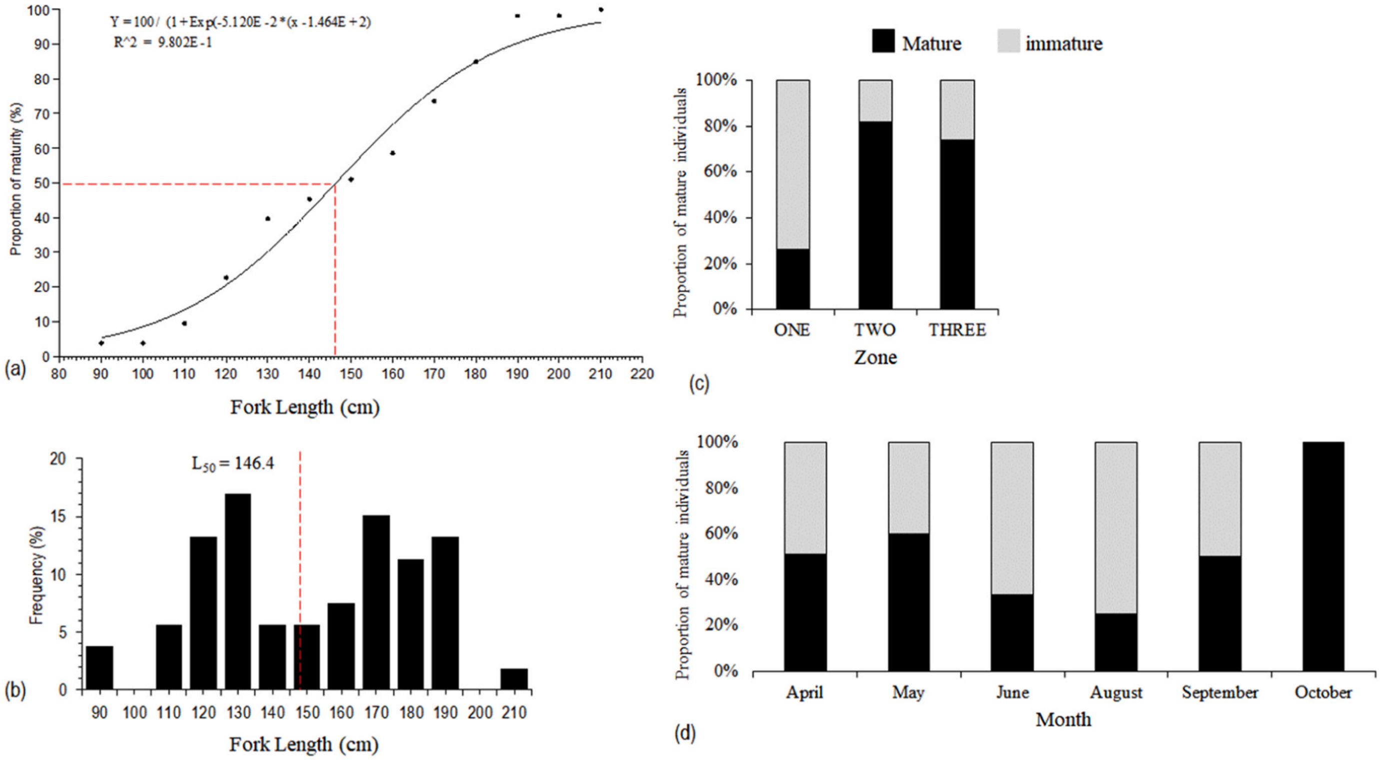

Fig. 12. Observed (dots) and estimated (line) proportion of sexually mature individuals with increasing size (FL), (a), size frequency distribution (b) maturity proportions by zone and month (c, d) for Thunnus albacares.

fish community changes using a single index is challenging [61]. According to the 1982 United Nations Convention on the Law of the Sea [101], the exclusive economic zone is the most extensive area that needs appropriate biodiversity conservation by coastal states. However, knowledge of deep-sea fisheries and information on the impact of fishing activities on biodiversity are limited. Species richness, diversity, and

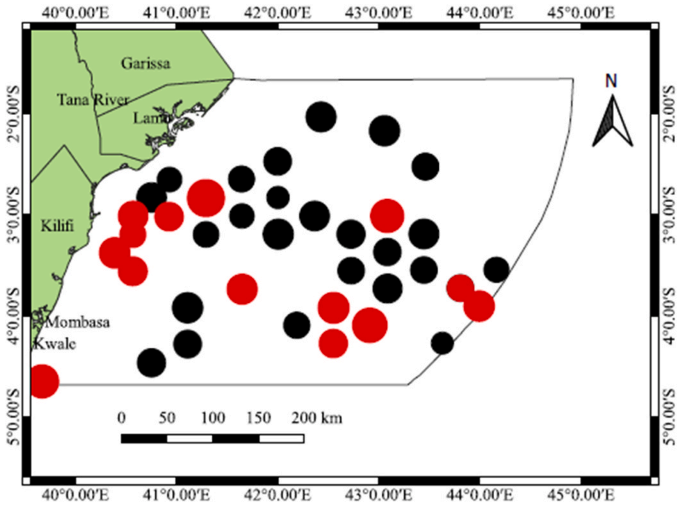

Fig. 13. spatial distribution of immature *Thunnus obesus* (red dots) and *Thunnus albacres* (black dots) caught during the survey period.

evenness were described by the actual number of individuals of the species encountered during the survey.

A high number of fish species was recorded during the pelagic longline survey period and this could be due to the nature of the fish which occupy broad geographic ranges that support different fisheries [81]. Species number was high in the shallow nearshore zone compared to the mid-EEZ and offshore-EEZ zones, indicating a high diversity of pelagic fish species assemble at the shallow nearshore area compared to the offshore area of Kenya's EEZ marine waters. High species diversity in the shallow nearshore zone than in the mid-EEZ and offshore-EEZ zones is in agreement with the findings of Anderson et al. [102], Schultz et al. [103] and Mellin et al. [104]. The assemblage pattern could be associated with the migration of pelagic species to the shallow nearshore waters to breed and feed [105]. Additionally, differences in species diversity between the three zones could be linked to differences in ocean currents, thermal fronts, upwelling regions, eddies, and mixing, which control the distribution, composition, and abundance of pelagic life that contribute to pelagic diversity [106]. Further, the fluctuation of ecosystem structure with the increase in the distance from the shoreline could contribute to variation of species diversity among the three zones [107].

More species were caught during August and May showing high species diversity recorded during August and May while the lowest number of species were caught during September and October which reflects low species diversity and assemblage during September and October. The occurrence of high species diversity during August could be an indicator of high primary and secondary productivity during August [7]. However, according to Gaertner et al. [25] there was no variation in species diversity among seasons. Results of the study revealed high effective number of species in the three zones, indicating that Kenya's EEZ marine waters has a high diversity of fish species and the longline gear captures a variety of fish species.

Species richness and evenness influence species diversity [61]. Species evenness was similar in the three zones and for the sampling months, meaning fish individuals were evenly distributed among the species encountered during the survey period.

The longline gear used during the survey could be species-selective, therefore, diversity estimates of all fish in Kenya's EEZ marine waters may not be fully described. The fishing strategy, including bait type, size and type of fishing hooks, crew, data enumerators, and taxonomists were similar throughout the survey period, indicating sampling in the three zones was not biased. Hence, species diversity for the three zones and months provided actual differences despite that the survey did not cover all months of the year which may limit the findings. Assemblage studies are usually affected by sampling technique, but similar results can be obtained even with different sampling techniques and there is no perfect sampling technique [25,108].

4.4. *Size structure*

Size structure is a useful indicator of fish population dynamics, especially for identifying areas and periods of slow growth or excess mortality [109], and size structure of a sample would be the similar as that of the underlying fish population. However, size structure of a sample can be influenced by seasonality, location and the type of sampling gear [53]. Murphy and Willis [53] recommend that the adult fish of greater lengths are fished for proper management of any fishery.

Size frequency for the key species was examined to determine the size structure of the underlying fish population in Kenya's marine waters.

Fishing activities when done for long can shift the sizes of fish caught towards smaller sizes leading to alterations in fish size composition in communities [110]. Environmental and density-depended factors related to growth and recruitment also influence fish size structure in a community [111]. Management regimes require that a sufficient number of juveniles reach maturity before they are exploited [112]. From this study, more than half of the *X. gladius* and *T. albacares* individuals sampled had sizes less than the length at which 50% of the species are sexually mature and 45% of the *P. glauca* and *T. obesus* individuals sampled were sexually immature. These results show that Kenya's EEZ marine fisheries are dominated with sexually immature *X. gladius*, *P. glauca*, *T. albacares*, and *T. obesus* individuals. This could be linked to continued use of the longline as the main gear which is highly size-selective leading to a decline of larger *X. gladius* and *T. obesus* individuals [113]. In addition, high levels immature fish in the sample could be due to high recruitment rates [94].

The L_{50} obtained for *X. gladius* ($L_{50} = 127.7$ cm, LJFL), is slightly lower than the L_{50} estimates of 146.5 cm, LJFL, 141.5 cm, TL and = 140–160 cm, LJFL obtained from other studies [114–116] respectively. The L_{50} value obtained is within the $L_{50} = 170$ and $L_{50} = 120$ cm range obtained for the male and female *X. gladius* individuals caught from the Indian ocean, respectively [117]. The L_{50} estimate obtained for *P. glauca* is higher than 202.9 cm, TL obtained for the male individuals and 214.7 cm, TL for the female individuals, respectively [118] with other studies, [119–121] reporting lower L_{50} estimates for *P. glauca*. The size L_{50} obtained for the tuna species were higher than values obtained from other studies [122,123]. The differences in L_{50} estimates could be associated to stock units [124] or the different methods used to determine L_{50}.

Generally, majority of the *X. gladius* and *P. glauca* captured in the three zones had sizes less than L_{50}. While most individuals of *T. obesus* and *T. albacares* captured in the mid-EEZ and the offshore-EEZ zones were having sizes less than L_{50}. This indicate majority of the *X. gladius* fish captured at Kenya's EEZ were sexually immature and the zone of fishing influenced the size of tuna fish caught.

About 56% of the *X. gladius* and 42% of the *P. glauca* mature individuals were caught in the three zones showing that there is an even distribution of mature *X. gladius* and *P. glauca* individuals in Kenya's EEZ marine waters. High proportion of mature *X. gladius* and *P. glauca* individuals were obtained at 100 m and 150 m indicating mature *X. gladius* and *P. glauca* assemble in deeper water compared to the shallower water.

The proportion of mature *X. gladius* individuals was highest during June – August. Similarly, high proportions of mature *P. glauca* were observed in July and August. The results indicate mature *X. gladius* and *P. glauca* assemblages can be found in the Kenya EEZ during June – August. There were few mature *X. gladius* individuals during the April, May, September and October. Generally, these findings clearly show that *X. gladius* and *P. glauca* species share common and similar assemblages in Kenya's EEZ marine waters.

The L_{50} of 158.3 cm FL obtained for *T. obesus* is higher than the values obtained from other studies [84,123] and the differences could be associated with environmental or genetic effects. High proportion of mature *T. obesus* at zone three indicate mature *T. obesus* assemble far from the nearshore while high proportions of mature *T. albacares* at zones two and three reveal high assemblages of mature *T. albacares* far from the nearshore. High proportions of mature *T. obesus* during April, May and September and a zero proportion during July show mature *T. obesus* assemblages together during April, May and September while there were no mature *T. obesus* assemblages during July. There was a high proportion of mature *T. albacares* individuals in May and October indicating high mature *T. albacares* assemblages during these months. These results indicate seasonality influence the size of fish capture at Kenya's EEZ marine waters.

5. Conclusion and recommendations

Gear configuration, size of bait, design of hooks, light sticks, soak time, and number of hooks per basket in the longline fishery influence the species composition and size structure of fish caught during fishing. Similarly, the composition of fish catch is usually camouflaged by location and time of fishing [125], therefore we recommend future research to consider standardizing the data to remove the influence of time and location on the results. In this study, the *T. symmetricus* bait used was not of a standard size, therefore we recommend future work to consider the impact of bait size, different bait types, longline configuration, and soak period on species diversity and catch rates.

In this study, we used longline sampling on the free-moving fish species within the pelagic zone. Some studies have indicated a positive influence of fish aggregating devices (FADs) on the diversity of pelagic fish in the Western Indian Ocean waters [126]. We recommended future research considers the effect of FADs on the diversity of fish in the Kenyan EEZ marine ecosystem.

A high proportion of fish with no commercial value were discarded dead during the pelagic longline survey, we recommend management to do continuous monitoring and control of the level of discards for the longline fishery, a major fishing gear in Kenya's EEZ fisheries. However, it is difficult to have a management regime which can completely avoid the capture of fish to be discarded because strategies meant to reduce discards of one species may increase discard levels of other species hence complicating the implementation of discard management regulations [127]. Additionally, it is important to initiate ways of retaining and utilizing dead discards in the fish feed industry. Further, we recommend for a detailed research on discards to provide information important for the regulation of Kenya's EEZ marine fisheries.

Pelagic longline gears usually capture tuna and *X. gladius* species, but during the survey, other species were captured along with these species including endangered, threatened and protected (ETPs) species some of which are migratory. We recommend management to monitor and control the capture of the ETPs and to come up with sustainable conservation measures for the ETPs species. Catches of *P. glauca* species, which is likely to be threatened in the near future (near-threatened), were high during the pelagic longline survey period, this calls for establishment of measures which can be used to regulate the capture of this species.

Environmental factors influence the distribution of pelagic fish resources and accurate stock assessment require the incorporation of environmental variables such as salinity, temperature, dissolved Oxygen (DO) into assessment models [78]. This study was conducted independent of environmental variables, we recommend future research to consider incorporating environmental variables to determine how they impact relative abundance, assemblage and diversity of fish in Kenya's EEZ marine waters.

The nearshore zone exhibited higher species assemblages and high species richness compared to other zones. This suggests the importance of prioritizing conservation efforts in the nearshore zone, as it serves as a critical habitat for diverse fish populations. Implementing protective measures, such as marine protected areas or fishing restrictions, can help preserve the biodiversity and sustainability of fish assemblages in this zone.

The assemblage results from this study were based on short term survey data not covering all months of the year, which may limit our findings. We therefore, recommend longer surveys for future research, which will allow for seasonal variation comparisons. Our study focused on the pelagic longline fishing gear. We recommend future research to consider using other gears such as purse-seines, to compare the findings.

Continued use of the longline gear in the Kenya EEZ, may lead to a decline of *P. glauca* stocks which is a near-threatened species with recorded high catch rates. There is a need for management to monitor the levels of *P. glauca* species capture for its long term sustainability.

Most individuals of *T. obesus* and *T. albacares* captured at the nearshore zone were having sizes less than their estimated L_{50}. We recommend management to initiate restrictions of tuna fishing at the nearshore zone to protect and conserve the immature tuna individuals. It is also important for management to enforce size limits for the *X. gladius* and *P. glauca* fishery which had high proportions of fish with sizes less than their L_{50} estimates to conserve immature individuals. Size structure analyses were based on absolute data and for the unsexed fish. We recommend future work to consider using sexed the fish for comparison to standardize sampling to overcome the influence of the gear and season on the size structure.

CRediT authorship contribution statement

Fulanda Bernerd Mulwa: Supervision, Validation, Writing – review & editing. **Nyamweya Chrisphine Sangara:** Data curation, Investigation, Validation. **Kimani Edward Ndirui:** Conceptualization, Validation, Visualization. **Ontomwa Mary Binsari:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

As the corresponding author I concur that this work "**Longline pelagic fishery assemblage in Kenya's exclusive economic zone marine waters"** was done following the research ethics in our country and no one of the co-authors has conflict of interest to this manuscript. Ethical procedures were followed in the production of this manuscript.

I therefore own this work and any queries can be directed to me to address if need arises.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix

Table A1
Family, species, common name, mean weight and weight range (kgs), number, and total weight (kgs) of fish caught during the survey period.

			Weight (kgs)			Total weight (kg)
Family	Species name	Common Names	Mean	Range	*N*	
Alepisauridae	*Alepisaurus brevirostris*	Shortsnouted lancetfish	12.2	0.9 – 107.5	25	244.0
	Alepisaurus ferox	Longsnouted lancetfish	3.69	1.0 – 8.0	31	95.9
Alopiidae	*Alopias pelagicus*	Pelagic threshershark –		–	2	–
	Alopias superciliosus	Bigeye thresher	75.44	2.1 – 158.0	15	980.7
Bramidae	*Taractichthys steindachneri*	Sickle pomfret	7.39	3.1 – 10.5	14	81.3
Carangidae	*Caranx ignobilis*	Great trevally	8.0	5.9 – 10.1	2	16.0
	Caranx sexfasciatus	Bigeye trevally	5.35	3.6 – 7.6	4	21.4
	Caranx tille	Tille trevally	3.2	–	1	3.2
Carcharhinidae	*Carcharhinus albimarginatus*	Silvertip shark	47.0	47.0 – 47.0	2	47.0
	Carcharhinus falciformis	Silky shark	24.90	0 – 121.2	136	2838.7
	Carcharhinus longimanus	Oceanic whitetip Shark	37.05	2.8 – 165.9	154	4853.9
	Carcharhinus plumbeus	Sandbar shark	55.3	48.2 – 62.4	4	110.6
	Carcharodon carcharias	Great white shark	80.0	–	1	80.0
	Galeocerdo cuvier	Tiger shark	71.87	5.8 – 200.0	25	790.6
	Prionace glauca	Blue shark	82.23	2.7 – 199.0	330	26644
Coryphaenidae	*Coryphaena hippurus*	Common dolphinfish	9.54	6.2 – 13.2	8	66.8
Dasyatidae	*Pteroplatytrygon violacea*	Pelagic stingray	6.54	1.0 – 70.3	19	111.2
Drepaneidae	*Drepane longimana*	Concertina fish	8.6	–	1	8.6
Gempylidae	*Gemphylus serpens*	Snake mackerel	2.63	0.7 – 6.7	12	31.6
	Lepidocybium flavobrunneum	Escolar	10.48	4.3 – 28.0	18	167.6
	Ruvettus pretiosus	Oil fish	11.59	2.2 – 29	38	440.6
	Thyrsitoides marleyi	Black snoek	1.6	1.5 – 1.7	2	3.2
Istiophoridae	*Istiophorus platypterus*	Indo-Pacific sailfish	26.05	18.3 – 36.8	4	104.2
	Makaira indica	Black marlin	43.0	–	1	43.0
	Makaira nigricans	blue marlin	57.0	43.0 – 71.0	2	114.0
	Tetrapturus angustirostris	Shortbill spearfish	29.675	26.5 – 34.6	4	118.7
	Tetrapturus audax	Striped marlin	51.61	22.7 – 123.0	12	619.3
Lamnidae	*Isurus oxyrinchus*	Shortfin Mako	71.99	31.1 – 208.8	45	3239.5
	Isurus paucus	Longfin mako	65.65	52.1 – 79.2	2	131.3
	Lamna nasus	Porbeagle shark	135.0	135 – 135	2	135.0
Lampridae	*Lampris guttatus*	opahs	53.7	53.7 – 53.7	1	53.7
Lutjanidae	*Lutjanus campechanus*	Northern red snapper	5.5	–	1	5.5
	Lutjanus sanguineus	Humphead snapper	7.45	7.2 –7.7	2	14.9
	Macolor niger	White snapper	6.06	3 – 9.1	5	30.3
Mobulidae	*Mobula birostris*	Giant manta ray –		–	1	
	Mobula mobular	Spinetail devil ray	–	–	1	
	Mobula kuhlii	Shortfin devil ray	16.3	16.3 –16.3	1	16.3
Molidae	*Mola mola*	Ocean sunfish	–	–	1	
Scombridae	*Acanthocybium solandri*	Wahoo	5.6	–	1	5.6
	Thunnus alalunga	Albacore	23.5	–	1	23.5
	Thunnus albacares	Yellowfin tuna	42.65	8.3 – 119.3	88	3710.3
	Thunnus obesus	Bigeye tuna	56.07	5.2 – 120	184	9587.7
Serranidae	*Epinephelus multinotatus*	White-blotched grouper	7.4	–	1	7.4
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	9.08	6.9 – 11.3	6	36.3
	Sphyraena qenie	Blackfin barracuda	2.34	1.0 – 6.2	11	25.7
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	50.10	15.0 – 105.9	25	1202.5
	Sphyrna zygaena	Smooth hammerhead shark	16.6	–	1	16.6
Tetraodontidae	*Arothron nigropunctatus*	Yellow puffer	0.7	–	1	0.7
Trichiuridae	*Trichiurus lepturus*	Largehead hairtail	1.72	1.0 – 2.5	9	8.6
Xiphiidae	*Xiphias gladius*	Swordfish	28.50	0.9 – 248.0	2960	81,072.9

Table A2
Zone, set number, effort (number of hooks), the position of the set, CPUE (Number of individuals/ 1000 hooks), and FAO code for the most abundant species caught per set during the survey.

	Set No.	No. of hooks	Position of set		CPUE (Number / 1000 hooks)	Most abundant species
			Latitude	Longitude		FAO Code
Zone one	1	340	-4.6476	39.670	123.5	SWO
	2	336	-4.2831	39.847	145.8	SWO
	3	336	-3.9192	40.029	172.6	SWO, OCS
	4	336	-3.5576	40.567	131.0	YFT,SWO
	23	346	-3.3759	40.388	251.4	SWO
	24	339	-3.0110	40.570	94.4	SWO
	25	339	-3.1953	40.567	188.8	SWO
	27	338	-3.1939	41.292	180.5	SWO
	37	328	-2.4706	42.000	67.1	SWO
	38	330	-2.6451	41.642	54.5	SWO

(*continued on next page*)

Table A2 (*continued*)

	Set No.	No. of hooks	Position of set		CPUE (Number / 1000 hooks)	Most abundant species
			Latitude	Longitude		FAO Code
	39	332	-2.8338	41.291	84.3	SWO
	40	334	-3.0181	40.926	182.6	SWO, YFT
	43	343	-3.7371	40.929	134.1	SWO
	47	336	-4.4522	42.913	89.3	SWO, BSH
	49	336	-4.4508	43.450	148.8	SWO, BSH
	62	336	-4.2759	41.829	131.0	SWO
	63	336	-4.6374	41.833	101.2	SWO, FAL
	66	336	-4.6432	40.390	211.3	SWO,BSH
	67	336	-4.2817	40.389	169.6	SWO
	68	336	-4.2817	40.389	116.1	SWO,BSH
	77	336	-2.4706	42.000	80.4	SWO,OCS
	78	336	-2.6451	41.642	80.4	SWO, BET
	79	336	-2.8338	41.291	83.3	SWO
	81	336	-3.1939	41.292	133.9	SWO
	82	336	-2.6508	40.930	44.6	SWO
	83	336	-2.8281	40.753	47.6	SWO
	84	336	-3.0181	40.926	214.3	SWO
	85	336	-3.0110	40.570	145.8	SWO,SPL
	86	336	-3.1953	40.567	172.6	SWO
	87	336	-3.3759	40.388	116.1	SWO,LHT,SMA,TIG
	88	336	-3.9192	40.391	256.0	SWO,SMA
	89	336	-3.3759	40.388	68.5	SWO
	90	252	-3.5590	40.208	111.1	SWO
	96	336	-2.5227	43.461	92.3	SWO
	97	336	-2.5227	43.461	92.3	SWO
	106	336	-4.4580	42.191	80.4	SWO
	107	336	-2.5227	43.461	92.3	SWO
	108	336	-4.4638	40.752	77.4	SWO
	109	336	-4.6476	39.670	89.3	SWO
	110	336	-4.2730	42.550	53.6	SWO
Zone two	16	336	-4.2788	41.109	148.8	SWO,BSH
	20	341	-3.9192	41.109	202.3	SWO
	35	336	-3.0110	42.365	199.4	SWO
	58	336	-3.0110	42.365	187.5	SWO,FAL,BSH
	19	336	-3.7357	41.648	169.6	SWO
	26	343	-3.3745	41.647	157.4	SWO
	65	336	-4.6418	41.111	148.8	SWO,FAL
	18	336	-3.5519	42.006	133.9	SWO
	61	336	-4.0973	41.469	133.9	SWO
	28	336	-3.0110	41.646	125.0	SWO
	21	336	-4.0973	41.469	119.0	SWO
	22	234	-4.4638	40.752	115.4	SWO
	73	336	-3.3745	41.647	110.1	SWO
	74	336	-3.1911	42.006	107.1	SWO
	75	336	-3.0110	42.365	107.1	SWO,OCS
	105	336	-2.0310	42.429	107.1	SWO
	42	330	-3.5590	41.289	103.0	SWO
	36	340	-2.8281	42.003	97.1	SWO
	64	336	-4.4623	41.474	92.3	SWO,BSH
	80	336	-3.0110	41.646	68.5	SWO,BET
	103	336	-2.1677	43.057	68.5	SWO
	99	336	-4.2788	41.109	65.5	SWO
	29	342	-3.1911	42.006	64.3	SWO
	102	336	-2.1677	43.057	3.0	OCS
Zone three	5	336	-4.6302	43.270	6.0	THM
	6	336	-4.2695	43.629	53.6	ALX,BSH,MLS
	7	336	-3.7290	43.087	116.1	SWO,OIL,BSH
	8	336	-3.9028	43.993	169.6	SWO,BET,BSH
	9	336	-3.7247	43.807	20.8	SWO
	10	336	-3.1888	43.446	145.8	SWO,BSH,OCS
	11	336	-3.5458	43.446	145.8	SWO,OIL
	12	336	-3.7290	43.087	29.8	BSH,OCS
	13	341	-3.9200	42.553	137.8	SWO,BSH
	14	338	-4.0929	42.911	221.9	SWO,BSH
	15	342	-4.2730	42.550	233.9	SWO,BET
	17	342	-4.4580	42.191	155.0	SWO,BSH
	30	334	-3.5429	44.164	59.9	SWO
	31	336	-3.3675	43.085	131.0	SWO
	32	338	-3.1888	43.446	109.5	SWO,BET
	33	334	-3.0110	43.084	98.8	SWO
	34	338	-2.8338	42.726	112.4	SWO,BET,BSH
	41	336	-3.0110	43.084	95.2	SWO
	44	328	-3.1888	43.446	210.4	SWO,BSH
	45	280	-3.5519	42.727	117.9	SWO,BSH

(*continued on next page*)

Table A2 (*continued*)

Set No.	No. of hooks	Position of set		CPUE (Number / 1000 hooks)	Most abundant species
		Latitude	Longitude		FAO Code
46	336	-4.6345	42.553	113.1	SWO,BSH
48	336	-4.6302	43.270	107.1	SWO
50	336	-4.2695	43.629	98.2	SWO,BSH
51	336	-4.0871	43.810	107.1	SWO
52	336	-3.9028	43.993	125.0	SWO,BSH
53	336	-3.5429	44.164	148.8	SWO,OCS
54	336	-3.7247	43.807	148.8	SWO,OCS
55	336	-3.5458	43.446	101.2	SWO
56	336	-3.0110	43.084	163.7	SWO
57	336	-3.9200	42.553	166.7	SWO,BSH
59	336	-4.2730	42.550	160.7	SWO,BSH
60	336	-4.0929	42.189	139.9	SWO,BSH
69	336	-3.1888	43.446	151.8	SWO
70	336	-3.0110	43.084	80.4	SWO
71	336	-3.1911	42.725	136.9	SWO,BSH
72	336	-3.3732	42.369	68.5	SWO
76	336	-2.8338	42.726	50.6	SWO
91	336	-3.7247	43.807	44.6	SWO
92	336	-3.3886	44.113	62.5	SWO,BSH
93	336	-3.9200	42.553	17.9	SWO
94	336	-2.2803	43.306	65.5	SWO
95	336	-2.0558	44.105	47.6	SWO
98	336	-3.9028	43.993	6.0	SWO
100	336	-3.9028	43.993	44.6	SWO
101	336	-2.2803	43.306	53.6	SWO
104	336	-1.5973	42.573	83.3	SWO

Table A3
Average catch per unit effort, CPUE ± SE (catch number per 1000 hooks) for the species caught from the three zones during the sampling period.

Species	Zone 1	Zone 2	Zone 3
Xiphias gladius	89.6 ± 7.8	89.6 ± 6.7	71.5 ± 6.3
Thunnus obesus	8.4 ± 1.3	9.3 ± 1.9	8.8 ± 1.5
Thunnus albacares	11.5 ± 4.9	8.1 ± 2.5	4.9 ± 0.7
Tetrapturus audax	4.6 ± 1.5	2.9 ± 0.0	5.2 ± 2.2
Ruvettus pretiosus	3.0 ± 0.0	3.0 ± 0.0	8.7 ± 1.7
Pteroplatytrygon violacea	3.0 ± 0.0	4.0 ± 0.6	3.4 ± 0.4
Prionace glauca	8.3 ± 1.4	10.4 ± 1.5	15.0 ± 1.5
Lepidocybium flavobrunneum	3.5 ± 0.5	5.4 ± 1.8	3.6 ± 0.6
Isurus oxyrinchus	7.4 ± 2.0	3.3 ± 0.4	3.6 ± 0.6
Gemphylus serpens	3.0 ± 0.0	5.9 ± 3.0	4.5 ± 1.5
Galeocerdo cuvier	8.0 ± 2.7	3.0 ± 0.0	3.0 ± 0.0
Coryphaena hippurus	3.9 ± 0.9	3.0 ± 0.0	3.0 ± 0.0
Carcharhinus longimanus	5.8 ± 1.3	5.5 ± 1.2	7.7 ± 1.2
Carcharhinus falciformis	8.7 ± 1.6	7.5 ± 2.6	6.5 ± 0.9
Alopias superciliosus	3.6 ± 0.6	3.0 ± 0.0	3.0 ± 0.0
Alepisaurus ferox	6.4 ± 1.0	5.2 ± 1.4	5.3 ± 1.7
Alepisaurus brevirostris	4.5 ± 0.9	3.0 ± 0.0	3.9 ± 0.4

Table A4
Average catch per unit effort (CPUE ± SE, number of catch/ 1000 hooks) for the species caught in all months of sampling.

Species /Month	April	May	June	July	August	September	October
Xiphias gladius	72.7 ± 13.0	107.6 ± 10.3	79.0 ± 5.5	107.4 ± 8.7	78.4 ± 11.7	40.4 ± 6.1	66.3 ± 6.6
Prionace glauca	13.0 ± 2.0	11.6 ± 1.8	13.1 ± 2.1	17.1 ± 3.1	10.9 ± 2.6	7.4 ± 1.3	6.0 ± 0.0
Carcharhinus longimanus	7.4 ± 2	4.4 ± 0.4	9.5 ± 2.6	5.4 ± 1.3	8.3 ± 2.1	3.4 ± 0.4	6.9 ± 1.0
Thunnus obesus	9.9 ± 2.5	11.4 ± 2	10.6 ± 2.3	5.0 ± 2.0	7.0 ± 1.7	6.0 ± 1.3	3.7 ± 0.7
Isurus oxyrinchus	3.7 ± 0.7	5.9 ± 1.6	3.0 ± 0.0	3.0 ± 0.0	10.7 ± 4.3	3.0 ± 0. 0	3.7 ± 0.7

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