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Evaluation of the Kenya long line pelagic fishery: Temporal variation in fishing effort and catch rates

Mary Binsari Ontomwa[a,b,*], Edward Ndirui Kimani[a], Bernerd Mulwa Fulanda[b], Chrisphine Sangara Nyamweya[c]

[a] Kenya Marine and Fisheries Research Institute, P.O. Box 81651 80100, Mombasa, Kenya
[b] Pwani University, P.O. Box 195 80108, Kilifi, Kenya
[c] Kenya Marine and Fisheries Research Institute, Kisumu Research Centre, P.O. Box 1881 40100 Kisumu, Kenya

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ABSTRACT

Pelagic fishes support a vital part of the local and export production and trade at global, regional, and local levels. In the Western Indian Ocean, pelagic fishes are mainly exploited by purse-seiners and long-line fishing vessels operating in national exclusive economic zones and international waters. Catch data from these vessels is often not adequately evaluated to determine the variation of catches and the state of the exploited stocks. This study evaluates the Kenya long line fishery between 2016 and 2020 to determine catch rates, temporal variation over time, and the key species' maximum sustainable yield (MSY). The catches were dominated by *Xiphias gladius* (44.7%), *Thunnus albacares* (24.4%), *Thunnus obesus* (10.9%), and *Prionace glauca* (7.7%). Catch rates were significantly different among years, months, vessels, and depths for all species except for *X. gladius* and *P. glauca*, whose catch rates did not significantly differ at different depths. The catch rates for *X. gladius*, *T. obesus*, and *T. albacares* were higher during the northeast monsoon season, while *P. glauca* had higher catch rates during the southeast monsoon season. The maximum sustainable yield (MSY) was higher than the annual catches for the four species. We recommend catch rates be monitored over a more extended period for trend comparison and future work to consider discards encountered during fishing. We recommend seasonal closures for management, especially for the vessels targeting tunas and swordfish to conduct fishing during the NEM season when the catch rates are higher. There is a need for future work to focus on hook selectivity for the long-line fisheries along the Kenya EEZ.

1. Introduction

Pelagic fishes are important contributing 20%–25% of the total annual global fisheries catch contributing about 16% of the global fish trade value (ICES, 2015; FAO, 2020). The Indian Ocean contributes 12.3 million tons representing 14.5% of the 84.4 million tons global marine catches. Pelagic fishes are the major contributors to the Indian Ocean marine catches (FAO, 2020). The Kenya offshore fisheries are composed of high-value fish species with great potential to support the coastal region's food security, employment, and economic activities. Historical data indicate that Kenya produces about 977–2096 metric tons of pelagic fish worth KSh 99 billion (the U.S. $903 million) annually, and this forms 18% of Kenyan marine fish landings (Obura, 2001; Wakwabi et al., 2003). However, there is more potential than this, and more economic opportunities that can be obtained from the Kenya offshore fisheries.

The large pelagic fish in Kenya are exploited by industrial, commercial fishers and accounts for 37% of the traded fish in Kenya (Kelleher et al., 2012). The industrial fishers are the distant water fishing nations (DWFNs), mainly from the European Union (EU) and the Far East (Kimani et al., 2018). Small and medium pelagic fish are exploited by small-scale fishers using non-mechanized vessels within the territorial waters and are essential for local food security (FAO, 2016; Kelleher et al., 2012). Occasionally, recreational fishers exploit medium and large pelagic fishes within 20 km of the outer reef along the coastline (Kimani et al. 2).

Kenya is planning to use the marine fisheries resources better to support economic activities in the coastal region (USAID, 2015). However, there is little information on the fisheries resources, especially for the offshore marine stocks, due to a lack of time-series data spanning a long period and catch data from DWFNs for the Western Indian Ocean (WIO) countries is often not reported by

* Corresponding author at: Kenya Marine and Fisheries Research Institute, P.O. Box 81651 80100, Mombasa, Kenya.
E-mail addresses: maryontomwa2013@yahoo.com (M.B. Ontomwa), edwardndirui@yahoo.com (E.N. Kimani), b.fulanda@pu.ac.ke (B.M. Fulanda), sanychris@yahoo.com (C.S. Nyamweya).

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the nations whose exclusive economic zones (EEZ) are fished by the flag states (Aloo et al., 2014). Yet, an important consideration for planning investment in the fishery and sharing regional fish stocks in the Indian Ocean depends on historical catch records. Many studies have been conducted to cover most aspects of the Kenya marine fisheries (McClanahan, 1988; Okemwa et al., 2009; Fulanda et al., 2011; Ontomwa et al., 2019), but information concerning the status of the Kenyan EEZ fisheries is limited (Kamau and Muthiga, 2009).

To develop the national fishing fleet, Kenya has registered four local long-line vessels since 2016. However, DWFN vessels continue to obtain fishing licenses to exploit the Kenya EEZ fisheries resources by paying an access fee. The locally registered vessels provide reliable catch data that can be analyzed to characterize the Kenya offshore fishery and provide baseline information useful for the regulation, management, and sustainable exploitation of pelagic fishes. This article provides information on the variation of catch, one of the key indicators of the health of the stocks, using standardized catch per unit effort (CPUE) data.

Different fishing designs used in long-line fishing result in large variations in catch rates. Changes in the design and structure of the gear, fishing operations, and target strategies affect the catch composition (Menezes de Lima et al., 2000). Using pooled long line data for stock assessment analysis limits the opportunity to realize or compensate for the changes caused by the different fishing designs (Hoyle, 2010). These variations lead to changes in catchability, which lead to erroneous abundance estimate indices (Gulland, 1983; Fréon and Misund, 1999; Maunder et al., 2006). The CPUE is usually standardized using appropriate generalized linear models to counter these effects. According to Maunder and Punt (2012), standardized CPUE indices are important for stock assessments that use integrated methods for catch data analysis. This approach has been used to evaluate catch data for most pelagic fish in other regions (Hazin et al., 2007; Carvalho et al., 2009, 2010; Ortiz, 2005).

Fisheries resources are among the many natural resources that have challenges in their assessment and management due to their vast spatial distribution, with species showing wide temporal variations in abundance and invisibility (Vivekanandan et al., 2005). For appropriate exploitation, management, and conservation of fisheries resources, it is essential to have accurate information on the stocks. The regional fisheries management organization (RFMO) conventions, recommends maximum sustainable yield (MSY) as the reference point (RP) for assessing the stock status of fish for management purposes. Most tropical fisheries are not overexploited but are being overfished in which the fishing mortality tends to be higher than the MSY levels. Precisely, the fishing mortality is gauged whether it is higher or lower than the maximum sustainable yield (Miyake et al., 2010). The objectives of this paper were to evaluate variation in catch rates and estimate maximum sustainable yields for swordfish (*Xiphias gladius*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus),* and blue shark (*Prionace glauca*) using fisheries dependent logbook data collected along the Kenya EEZ during the 2016–2020 fishing period.

2. Materials and methods

2.1. Study area

The Kenya marine waters extend from the Somalia border (1°30′ S) to Tanzania (5°25′ S) (Fig. 1) and the exclusive economic zone (EEZ) covers 200 nautical miles with an area of 230,000 km^2(Fulanda et al., 2011; Munga et al., 2013). The marine environment is characterized by warm tropical conditions, with temperatures ranging between 25 °C and 31 °C (Obura, 2001). The marine environmental conditions are influenced by the Inter-Tropical Convergence Zone (ITCZ) movement that drives ocean currents, winds, and other climatic factors. The ITCZ creates two seasons: the northeast monsoon (NEM), which lasts from October to March, and the southeast monsoon (SEM), which prevails from April to September (UNEP, 1998). During the NEM season, the northern part of the coast is washed by the Somali Current (SC) system that produces cold upwelling waters. The Kenya marine fisheries have a maximum sustainable yield of 150,000 mt (Ruwa et al., 2003) and the Kenya EEZ has a rich fisheries biomass potential of about 321 262 tons (KMFRI, 2018) The marine production is low, 24, 709 metric tons worth Kshs. 4254 billion. However, there is a substantial potential to produce about 150,000–300,000 mt per annum valued at 21–42 billion shillings (Government of Kenya, 2016).

2.2. Catch data from long-line fishery

Historical and existing fishery-dependent catch data for the period 2016 to 2020 obtained from catch records at Kenya Fisheries Service (KeFS) in Mombasa were used for this study. The catch data included the vessel name, geo-location of starting and finishing line deployment, start and finishing location of long line recovery, the number of hooks deployed, and the total weight of fish caught. The catch data records were from four Kenya and five Seychelles flagged and licensed commercial fishing vessels (FV). Kenya flagged fishing vessels include FV Seamar II (50 m length overall, LOA; 580 t gross tonnage, GRT), FV Shang Jyi (0 m LOA; 194 t GRT), FV Newfoundland alert (38 m LOA; 544 t GRT), and FV Ra-horakhty (56.7 m LOA; 411 t GRT). On the other hand, Seychelles flagged fishing vessels were FV NF Dafa No. 168 (39 m LOA; 296 t GRT), FV NF Alpha gold No. 6 (40.6 m LOA; 320 t GRT), FV Ashuneyu (51.5 m LOA; 575 t GRT), FV Chun Ying No. 212 (49 m LOA; 598 t GRT) and FV NF Woenfull No. 168 (50 m LOA; 296 t GRT) (vesseltraker.com, 2021). All the fishing vessels fished at a depth range of 37 m to 250 m. The depth range was grouped into different 50-m classes. All the Seychelles flagged fishing vessels fished at a depth range class of 50 m, FV Seamar II and FV Newfoundland alert fished at depth range classes of 50 m and 100 m, FV Ra-horakhty fished at depth range classes of 200 m and 250 m while FV Shang Jyi fished at depth range classes of 50 m to 250 m. A total of 1 343 long line sets were made during the 2016–2020 fishing period from which the catch data was recorded.

2.3. Data analysis

Species composition was determined using descriptive analysis in Microsoft® Excel, 2007. Then non-metric multidimensional scaling (n-MDS) was done in PRIMER version 6.1.1 software package (Clarke and Gorley, 2006) to explore the similarity in the abundance of the species caught. The abundance data were square-root transformed and standardized by total abundance before executing the 2D multidimensional scaling at minimum stress of 0.1 using Euclidean distance as the (dis)similarity index (Queen et al., 2002). Student's t-test in PAST (Hammer et al., 2001) was used to establish differences in the fishing effort and catches over time. The nominal catch rates were expressed as catch per unit effort (CPUE), i.e.

$$\mathrm{CPUE} = \frac{\text{Total catch weight (kg)}}{\text{Number of hooks}} \times \text{Average number of hooks} \quad (1)$$

For this study, 2000 hooks were the calculated overall average number of hooks deployed during the fishing period. Catch rates for different fishing vessels were standardized before comparing their variations because vessel power, speed, area and period of fishing, and length of the fishing vessels, including those of the fishing gear, are different (Everett et al., 2015).

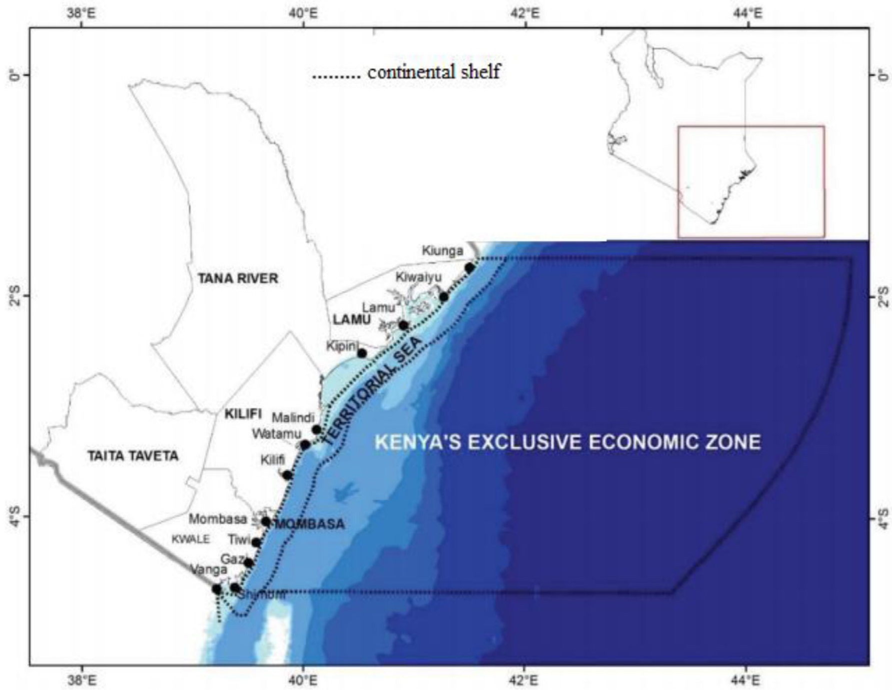

Fig. 1. Map of Kenya's Exclusive Economic Zone (EEZ) and the coastal counties.

Variation in catch rates was evaluated for four main species (*Thunnus obesus*, *Thunnus albacares*, *Xiphias gladius*, and *Prionace glauca),* which dominated the catches. The selected species' standardized CPUE was estimated using generalized linear models (GLM) in the statistical software package R, version 4.0.2 (R. Development Core team, 2020). Year, month, vessel, and depth were chosen as the model predictors because fish abundance varies by year, amount of CPUE varies with season, the type of vessel and crew influence the efficiency of capture, and fish abundance is not uniformly distributed by depth according to Siddeek and Zheng, unpublished report.

The catch data had many zero catches; therefore, the delta method (Lo et al., 1992; Maunder and Punt, 2004) was used to model CPUE variations for the dominant species. The delta method involves fitting the data into binomial and log-gamma sub-models was used as it allows both zero and positive catches to be analyzed (Vignaux, 1994; Starr, 2012). In the binomial sub-model, the probability of the positive catch is modeled based on the presence and absence of information, assuming a binomial error distribution. In the second sub-model, the non-zero catch is modeled assuming a log-normal gamma error distribution.

The delta model combines the binomial and log-normal gamma error estimates (Vignaux, 1994) to give the standardized catch rates as follows (Starr, 2012);

$$Y_y^{comb} = \frac{Y_y^{Ln}}{[1 - p_0[\ 1 - \frac{1}{Y_y^{Binom}}} \tag{2}$$

Where

Y_y^{comb} = combined CPUE index for year y;

Y_y^{Ln} = lognormal CPUE index for year y;

Y_y^{Binom} = binomial CPUE index for year *y* and

P_0 = proportion of zeros for base year 0

The CPUE indices were then computed as the product of the probability of the positive catch (binomial model) and the non-zero yield (gamma model) obtained from the coefficients of the two models. Data for the year (2020), the month of August, the FV Seamar II, and fishing depth levels of 51–100 m were used as reference points during standardization. The standardized (predicted) catch rates and nominal (observed) catch rates were presented in line graphs for comparison. Pearson's Chi-squared test was used to determine the influence of year, month, vessel, and depth on the catch rates. All statistical analyses were done at a 95% confidence interval $\alpha = 0.05$.

The stock status of the dominant species was assessed by estimating maximum sustainable yield (MSY) using catch effort data analysis (CEDA, (Kirkwood et al., 2001)) version 3.0 computer software. From CEDA the Schaefer (1954), Pella and Tom-linson (1969), and Fox (1970) non-equilibrium surplus production models (SPMs) were used to estimates the MSY. The SPMs combine recruitment, growth, and mortality factors into a single production function. The analysis was modeled with normal, log-normal, and gamma distribution errors. However, the Gamma distribution error results in minimization failure. The intrinsic population growth rate **r,** carrying capacity *K*, catchability coefficient *q*, replacement yield R_{yield} and final biomass were concurrently estimated.

The Schaefer production model is based on Graham's logistic population growth model

$$dB/dt = rB(B_\infty - B) \tag{3}$$

While the Fox model is based on the Gompertz growth equation

$$dB/dt = rB(lnB_\infty - lnB) \tag{4}$$

and the Pella–Tomlinson model is based on a generalized production curve;

$$dB/dt = rB(B_\infty^{(n-1)} - B^{(n-1)}) \tag{5}$$

Where *B* is fish stock biomass, *t* is time in months, B_∞ is the carrying capacity, r is the intrinsic rate of population increase, and *n* is the shape of the parameter.

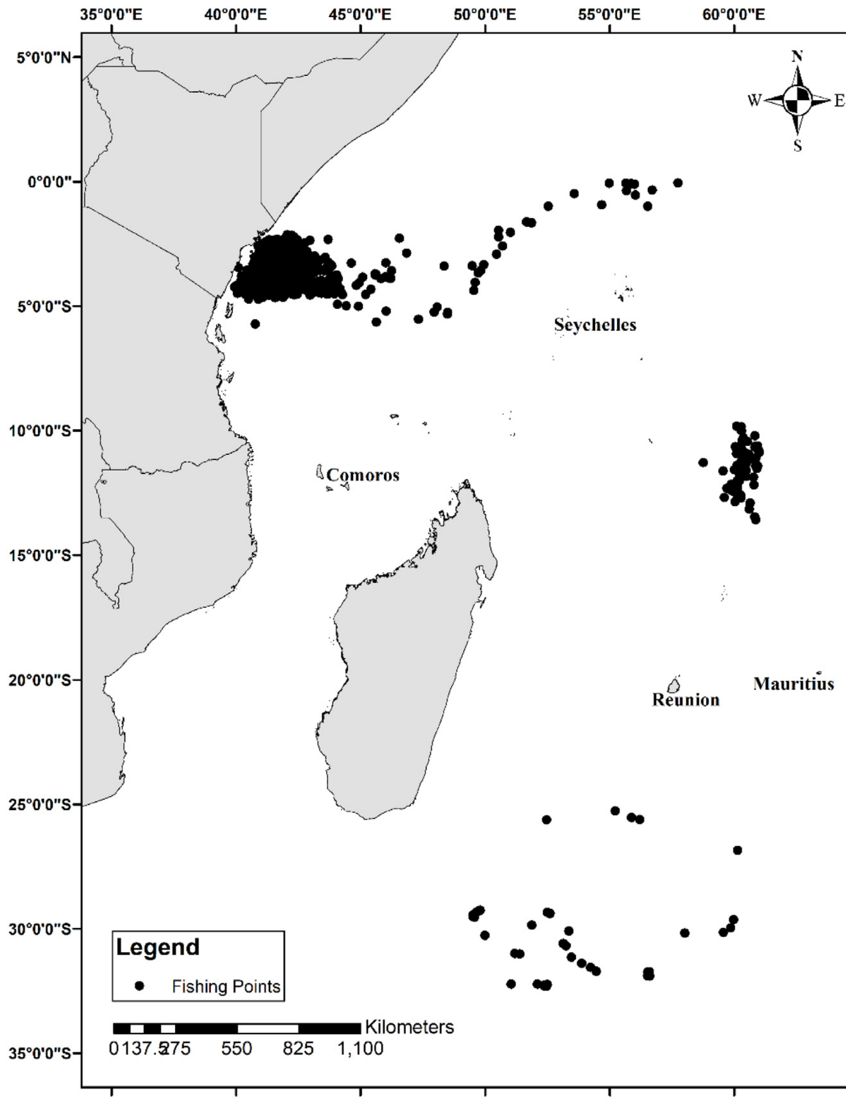

Fig. 2. The distribution of fishing effort for the period 2016–2020.

3. Results

3.1. Distribution of fishing effort in the Western Indian region's waters

The distribution of fishing effort for all the vessels during the period projected on a map (Fig. 2) shows that most of the fishing effort was deployed in the Kenya EEZ (2 692 964 hooks). This represents 85.92% of the total effort, followed by the international sea (370 538 hooks), the Mauritius EEZ (5 810 hooks), and least in the Tanzania EEZ (2 664 hooks). Some of the efforts in international waters were concentrated in the northern part of the Indian Ocean, concentrated in a small area to the west of Madagascar, and spread out in a part of the Southern Indian Ocean. The Kenya EEZ long line fisheries cover an area ranging from 2° 00″ to 5° 00″ S of latitude and from 39° 57′00″ to 44° 29′14″ E of longitude.

3.2. Catch composition

From the catch data records, a total of 90 510 fish specimens belonging to 20 species and ten families were recorded during the 2016–2020 fishing period. Of the 90 510 individuals, *X. gladius* (swordfish), *T. albacares* (yellowfin tuna), *P. glauca* (Blue shark), and *T. obesus* (Bigeye tuna) were the most dominant species representing 48.4%, 21.3%, 6.2%, and 6.1% of the total number, respectively. The total catch weight obtained during the fishing period was 2 328.7 metric tons. The catches were dominated by the large pelagic fish species (*X. gladius* - 44.7%, *T. albacares* - 24.4%, *T. obesus* - 10.9%, and *P. glauca* - 7.7%). The least dominant species were of the medium pelagic category composed of *Sphyraena barracuda* (Barracuda) and *Coryphaena hippurus* (Common Dolphinfish), each representing 0.2% of total relative abundance. Assorted fish formed 10.6% of the total abundance while other sharks and other tunas had a total relative abundance of 0.2% each (Table 1). The abundances of fish species caught during 2016–2020 period were similar for all the species except for *X. gladius*, *T. albacares*, and assorted fish (Fig. 3).

3.3. FisherIes effort and catch rates

The annual fishing effort (number of hooks) and the total catch recorded between 2016 and 2020 are shown in Fig. 4. Generally, a total fishing effort of 2 692 964 hooks was deployed between 2016 and 2020, with a total catch of about 2 328.7 metric tons. Fishing effort increased steadily throughout the period, increasing by almost 3 times between 2016 and 2019 (Fig. 4). The lowest catch was recorded in 2017 (106.1 metric tons) and the highest catch in 2019 (892.5 metric tons); fishing effort and catches declined significantly in 2020.

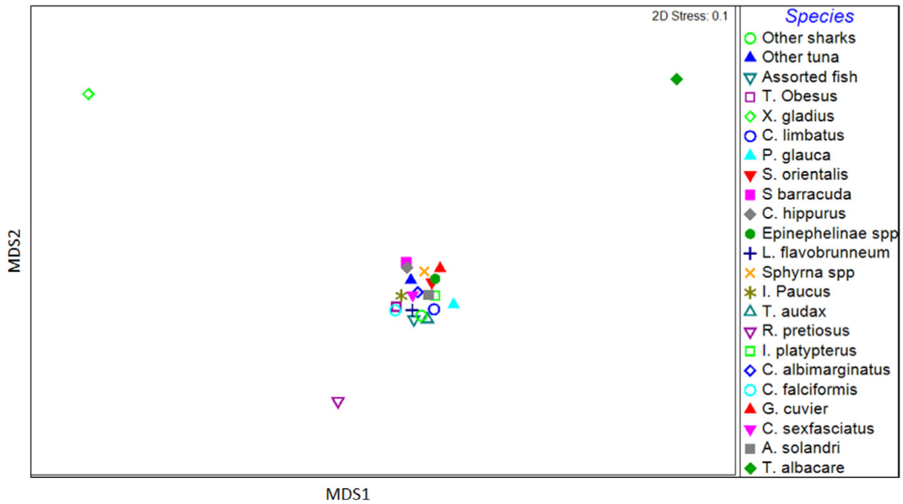

Fig. 3. 2D-Multidimensional scaling for the species caught between 2016 and 2020 period.

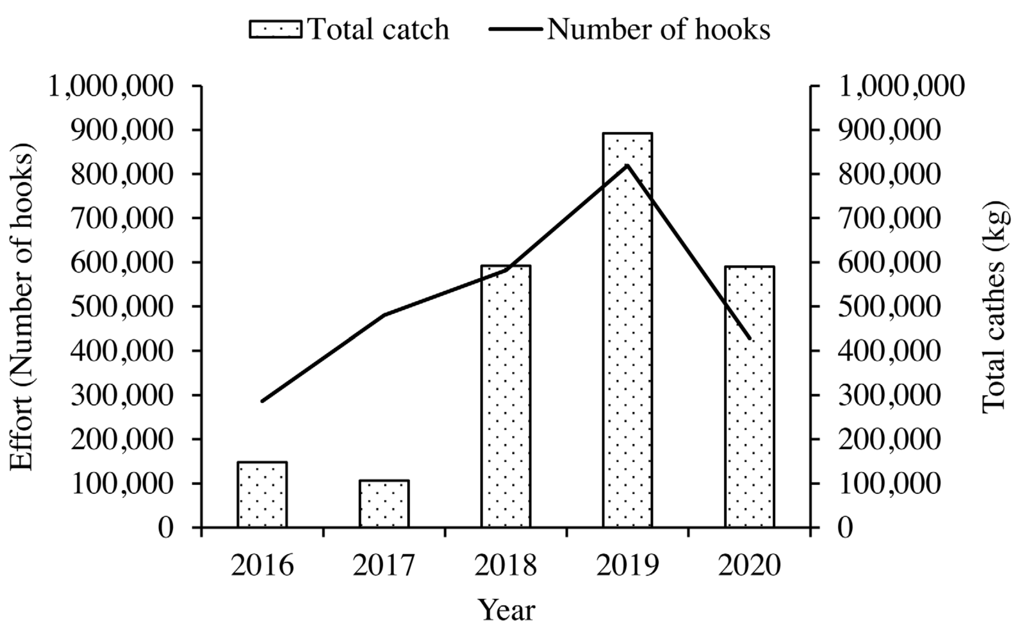

Fig. 4. Trends in the fishing effort (number of hooks) and catches for the five year fishing period.

The variations in monthly catches closely followed those of fishing effort (Fig. 5). The trend in monthly fishing effort kept fluctuating over time, with the highest fishing effort being deployed in October 2017 (168,480 hooks) and the lowest in June 2018 (2072 hooks). In 2016, the lowest fishing effort was applied in April (12 000 hooks), and the highest fishing effort was applied in November (48 530 hooks). The monthly catches for 2016 ranged between 9 730 kg in August and 36 937 kg in May. In 2017, the lowest fishing effort was deployed in July and the highest fishing effort was deployed in October. The lowest catch record of 1 133 kg and the highest catch record of 36 502 kg were recorded during the same months, respectively. For 2018, the lowest fishing effort of 2 072 hooks was deployed in June, giving the lowest catch record of 3 656 kg, and the highest fishing effort of 93 701 hooks was deployed in December, giving the highest catch record of 134 083 kg. In 2019, the lowest fishing effort of 27 051 hooks and catches of 25 060 kg were recorded in March, while the highest fishing effort of 160 630 hooks and catches of 104 932 kg were recorded in July, respectively. For 2020, the lowest fishing effort (16 510 hooks) was deployed in November, while the highest fishing effort (95 108 hooks) was deployed in March. In 2020, the lowest catch of 7 312 kg was recorded during November and the highest catch (125 495 kg) was recorded in January. However, fishing was done for only 9 and 8 months in 2016 and 2017, respectively (Fig. 5).

3.3.1. Effect of year, vessel, month, and depth of fishing on catch rates

The influence of year, vessel, month, and depth on the catch rates were done using Pearson's χ^2 test for *T. obesus*, *T. albacares*, *X. gladius*, and *P. glauca*, and the results are presented in Table 2. The catch rates were significantly different among years, months, fishing vessels, and at different depths for all species ($p = 0.0$) except for *X. gladius* and *P. glauca*, whose catch rates did not significantly differ at different depth levels ($p = 1.0$ and 0.1) respectively.

There was a high level of zero catches, representing 32.4% of the total catches, while the non-zero catch level was 67.6%. The binomial (logit) and gamma (log), standard error (S.E.), explained deviance, Akaike's information criterion (AIC), and degree

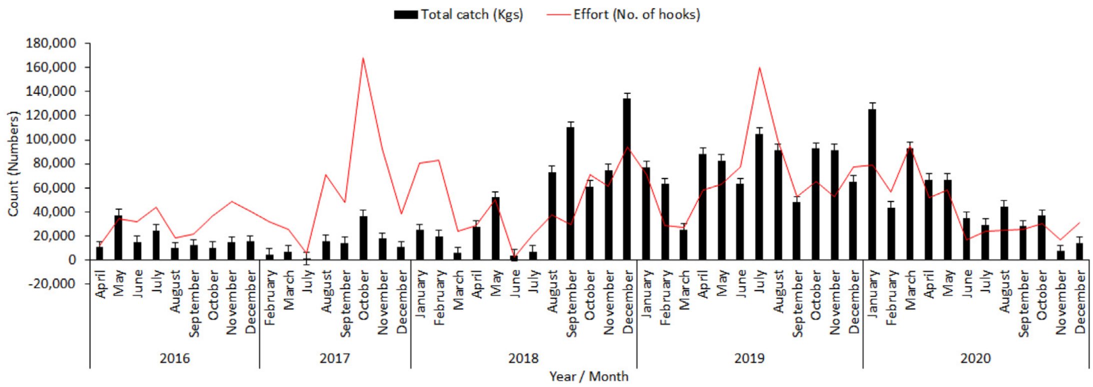

Fig. 5. Trend in the monthly catches and fishing effort (number of hooks) deployed during the 2016–2020 period (Error bar represent standard error of the average catch).

Table 1
Species, common name, relative abundance (%), and weight proportion (%) of the catches recorded between 2016 and 2020.

Species	Common name	Relative abundance (%)	Weight (%)
Xiphias gladius	Swordfish	48.439	44.700
Thunnus albacares	Yellowfin tuna	21.309	24.428
Prionace glauca	Blue shark	6.200	7.699
Thunnus obesus	Bigeye tuna	6.091	10.922
Tetrapturus audax	Marlin	1.867	2.967
Carcharhinus falciformis	Silky shark	1.300	1.001
Istiophorus platypterus	Sailfish	0.894	0.650
Carcharhinus albimarginatus	Shortfin mako	0.529	1.419
Lepidocybium flavobrunneum	Escolar	0.501	0.121
Sphyrna spp	Hammerhead Shark	0.419	0.521
Carcharhinus limbatus	Oilfish	0.313	0.070
Sphyraena barracuda	Barracuda	0.249	0.065
Carcharhinus limbatus	Blacktip shark	0.239	0.251
Coryphaena hippurus	Common Dolphinfish	0.225	0.056
Isurus paucus	Longfin mako	0.203	0.559
Galeocerdo cuvier	Tiger shark	0.134	0.229
Caranx sexfasciatus	Trevally	0.034	0.013
Epinephelinae spp	Grouper	0.022	0.014
Acanthocybium solandri	Wahoo	0.003	0.002
Sarda orientalis	Bonito	0.001	0.001
	Assorted Fish	10.649	3.700
	Other sharks	0.213	0.332
	Other Tunas	0.166	0.280

of freedom (d.f.) indices for the four dominant species (*Thunnus obesus*, *Thunnus albacares*, *Xiphias gladius*, and *Prionace glauca*) are indicated in Table 3

3.4. Annual variation in major species catch rates

The standardized and nominal annual catch rates for *T. obesus*, *T. albacares*, *X. gladius*, and *P. glauca* are shown in Fig. 6. The nominal and standardized catch rates exhibited a similar trend except for *T. obesus* which had lower standardized catch rates than the nominal catch rates. The nominal annual catch rates for *T. obesus* ranged between 107.5 kg/2000 hooks in 2017 and 316.6 kg in 2019, while the yearly nominal catch rates for *T. albacares* ranged from 190.8 kg to 668.5 kg in 2018. For *X. gladius*, a meager catch rate of 26.9 kg was recorded in 2016 and high catch rate (1 870.4 kg/2000 hooks) was recorded in 2020. For *P. glauca*, there were no catches recorded in 2016 and the highest nominal catch rate of 412.3 kg/2000 hooks was recorded in 2020. There was a continuous increase in the annual catch rates from

Table 2
Degree of freedom (d.f.), linear regression (LR), and Pearson's coefficients and significance codes (*** = 0, * = 0.1 and blank = 1) for *Thunnus obesus*, *Thunnus albacares*, *Xiphias gladius*, and *Prionace glauca*.

Species		LR Chisq	d.f	Pr (>Chisq)	Significance code
Thunnus obesus	Year	61.956	4	4.79E−12	***
	Month	92.242	11	6.05E−15	***
	Vessel	127.638	8	<2.2e−16	***
	Depth (m)	59.179	4	4.32E−12	***
Thunnus albacares	Year	116.402	4	<2.2e−16	***
	Month	71.878	11	5.36E−11	***
	Vessel	58.472	8	9.29E−10	***
	Depth (m)	186.161	4	<2.2e−16	***
Xiphias gladius	Year	115.832	4	<2.2e−16	***
	Month	37.036	11	0.0001136	***
	Vessel	42.719	8	9.92E−07	***
	Depth (m)	5.337	4	0.2544516	
Prionace glauca	Year	313.48	5	<2e−16	***
	Month	100.62	11	<2e−16	***
	Vessel	451.13	8	<2e−16	***
	Depth (m)	9.83	4	0.04335	*

2016–2020 for *X. gladius* and *P. glauca*, except in 2019 when the catch rates of the latter decreased. On the other hand, the annual nominal catch rates for *T. obesus* and *T. albacares* increased throughout the fishing period except in 2020 when there was a decline.

3.5. Seasonal variation in major species catch rates

Fig. 7 illustrates the monthly variation of the standardized and nominal catch rates for *T. obesus*, *T. albacares*, *X. gladius*, and *P. glauca*. Cumulatively, the nominal catch rates for the species were higher during the NEM season than during the SEM season, except *P. glauca* whose nominal catch rates were higher during the SEM season. For *T. obesus*, the nominal catch rates ranged from 118.3 kg/2000 hooks to 419.8 kg, while for *T. albacares*, the nominal catch rates ranged between 229.3 kg and 880.0 kg. The nominal catch rates for *X. gladius* ranged from 662.7 kg to 1 926.2 kg and those of *P. glauca* ranged from 118.4 kg to 364.4 kg. The seasonal nominal catch rates for *T. obesus* and *T. albacares* were significantly different ($p = 0.02$) except for those of *X. gladius* and *P. glauca*, which were not significantly different ($p = 1.0$).

3.6. Changes in catch rates with depth

The nominal catch rates for the four dominant species (Fig. 8) were highest at a depth range of 101–150 m, except for *P. glauca*, which had a high nominal catch rate at a depth of 51–100 m. The

Table 3
Species, generalized linear model (GLM) errors (Binomial and Gamma) estimates, coefficients (±SE) of the model parameters, link-functions, explained deviance, Akaike's information criterion (AIC), and degree of freedom (d.f.).

Species	***Thunnus obesus***				***Thunnus albacares***				***Xiphias gladius***				***Prionace glauca***			
Error	**Binomial**		**Gamma**		**Binomial**		**Gamma**		**Binomial**		**Gamma**		**Binomial**		**Gamma**	
Link	Logit		Log		Logit		Log		Logit		Log		Logit		Log	
AIC	1485.7		11001		1250.2		13746		912.4		17450		847.5		10022	
Explained deviance	432.1		631272		667.6		1308852		1005.4		3348719		1070.3		632607	
d.f.	28		28		28		28		28		28		28		22	
Year	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
2016	1.12	0.73	5.40	0.49	3.23	0.81	4.78	0.53	0.45	1.24	5.50	0.31	−38.11	3199.20	0.00	
2017	1.86	0.74	4.25	0.48	3.73	0.81	4.28	0.54	−0.96	1.25	4.71	0.31	−19.14	3095.08	4.29	0.26
2018	0.40	0.66	4.00	0.45	2.10	0.69	4.70	0.49	2.12	1.14	6.42	0.28	−17.66	3095.08	5.94	0.17
2019	0.74	0.70	4.38	0.47	1.53	0.75	4.80	0.52	2.25	1.24	7.15	0.29	−16.61	3095.08	5.79	0.15
2020	−0.38	0.70	4.03	0.47	0.63	0.74	4.49	0.51	1.54	1.18	6.84	0.29	−16.83	3095.08	5.86	0.14
Vessels																
Alpha gold	0.00	0.00	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Ashuneyu	0.77	0.92	1.80	0.48	1.59	1.26	1.88	0.54	0.58	1.24	−0.97	0.33	−1.31	3395.45	0.00	
Chunying	−1.01	0.74	1.57	0.46	−1.83	0.80	1.45	0.52	1.11	1.25	−0.88	0.31	−0.47	3337.46	0.00	
Newfoundland	0.04	0.66	2.59	0.45	−0.62	0.70	2.54	0.50	2.47	1.27	0.81	0.28	19.97	3095.08	0.00	
NF Dafa	1.37	0.82	2.25	0.45	0.36	0.80	1.31	0.50	−0.84	1.15	−2.13	0.29	−1.34	3378.23	0.00	
NF Woenfull	1.97	0.82	1.56	0.45	−0.27	0.75	2.47	0.52	−0.30	1.21	−0.94	0.29	−0.81	3407.23	0.00	
Seamar II	−0.29	0.64	2.65	0.43	−1.27	0.67	2.48	0.47	0.53	1.12	1.60	0.27	20.82	3095.08	0.52	0.12
Shang Jyi	−1.38	0.65	0.75	0.44	−0.90	0.69	1.45	0.48	0.29	1.14	−0.33	0.28	19.42	3095.08	−0.78	0.11
Ra-horakhty	−1.86	0.95	1.37	0.62	−17.85	448.60	0.51	0.71	−1.31	1.36	−2.11	0.44	16.86	3095.08	−1.27	0.46
Months																
April	0.00	0.00	0.00		0.00		0.00		0.00		0.00		0.00		0.00	
August	0.02	0.31	−0.43	0.20	−1.27	0.34	−0.69	0.22	0.40	0.49	0.17	0.13	−1.78	0.55	−0.26	0.17
December	0.39	0.32	−0.46	0.20	−1.04	0.35	0.09	0.22	−0.10	0.48	−0.07	0.13	−0.09	0.62	−0.08	0.17
February	0.30	0.34	−0.73	0.21	−0.02	0.37	−0.58	0.22	−0.97	0.48	−0.79	0.14	−2.41	0.53	0.04	0.19
January	2.39	0.44	−0.18	0.20	1.26	0.47	0.16	0.22	1.09	0.68	−0.56	0.13	−1.58	0.56	−0.41	0.19
July	−0.70	0.34	−0.39	0.24	−1.51	0.35	−0.80	0.25	0.20	0.50	−0.11	0.13	−1.99	0.56	−0.02	0.20
June	−0.30	0.35	−0.62	0.24	−0.23	0.39	−0.91	0.24	−0.35	0.51	0.17	0.14	−1.83	0.59	0.06	0.20
March	0.99	0.39	0.16	0.24	0.03	0.42	0.25	0.26	1.00	0.66	−0.22	0.15	0.44	0.87	0.15	0.20
May	0.31	0.32	−0.60	0.21	−0.23	0.36	0.33	0.21	0.67	0.53	0.22	0.13	−0.34	0.59	0.11	0.16
November	1.13	0.34	−0.53	0.20	−0.46	0.37	−0.39	0.22	0.79	0.50	−0.12	0.13	0.23	0.63	0.34	0.17
October	0.63	0.31	−0.73	0.19	−1.01	0.34	−0.71	0.22	0.87	0.50	0.24	0.13	−0.66	0.60	0.13	0.17
September	0.03	0.31	−0.34	0.21	−0.57	0.34	−0.06	0.23	0.51	0.52	0.13	0.13	−2.10	0.54	−0.04	0.17
Depth																
50 m	0.00	0.00	0.00		0.00		0.00		0.00		0.00	0.00	0.00		0.00	
100 m	0.02	0.16	0.02	0.09	1.07	0.18	−0.04	0.10	−0.29	0.20	−0.19	0.06	−0.62	0.22	0.53	0.10
150 m	16.15	482.42	0.61	0.24	18.04	1386.72	0.71	0.30	13.71	505.69	−0.11	0.20	−1.16	0.65	−0.32	0.30
200 m	1.37	0.40	0.40	0.16	18.14	448.60	0.54	0.18	−0.40	0.48	−0.11	0.13	−0.26	0.47	0.19	0.19
250 m	1.52	0.28	0.26	0.11	18.37	448.60	0.43	0.13	0.05	0.35	−0.26	0.09	−0.10	0.37	0.26	0.13

Table 4
Species, Standardized, Std catch rates (CPUE), nominal, Nom catch rates (CPUE) by species for the vessels used during the 2016–2020 fishing period.

#	Vessel	*Thunnus obesus*		*Thunnus albacares*		*Xiphias gladius*		*Prionace glauca*	
		Std CPUE	Nom CPUE	Std CPUE	Nom CPUE	Std CPUE	Nom CPUE	Std CPUE	Nom CPUE
1.	FV NF Alpha gold No. 6	2.2	18.0	25.9	35.1	777.2	569.7	2E-06	0.0
2.	FV Ashuneyu	16.6	280.0	247.3	476.4	316.7	73.6	6E-07	0.0
3.	FV Chun Ying No. 212	6.2	180.9	36.2	296.8	362.2	54.7	1E-06	0.0
4.	FV Newfoundland alert	29.3	458.4	245.5	698.3	2050.1	2022.4	311.5	345.2
5.	FV NF Dafa No. 168	29.1	329.8	109.4	400.3	75.8	55.3	5E-07	0.0
6.	FV NF Woenfull No. 168	15.5	260.4	272.4	580.4	288.6	439.4	9E-07	0.0
7.	FV Seamar II	27.0	370.7	155.0	738.3	4139.3	3060.2	639.0	665.1
8.	FV Shang Jyi	2.1	81.1	70.5	322.4	580.9	465.2	115.5	76.0
9.	FV Ra-horakhty	2.7	91.0	2E-06	111.5	65.4	48.2	11.1	55.9

catch rates for *T. obesus* and *T. albacares* followed a similar trend, with the maximum nominal catch rates recorded at a depth of 101–150 m, followed by a sharp decline at a depth of 151–200 m, and flattening off at a depth of 151–250 m. The nominal catch rates for *X. gladius* and *P. glauca* did not fluctuate greatly with depth, and the standardized catch rates followed a similar trend. The nominal catch rates recorded at depths of 0–50 m and 51–100 m significantly differed from those recorded at a depth of 101–150 m ($p = 0.03$ and 0.02) respectively. The nominal catch rates recorded at depths of 151–200 m and 201–250 m were not significantly different from the nominal catch rates recorded at all depths ($p > 0.05$) at 5% level of significance.

3.7. Catch rate variations by vessel

Nine different vessels were used during the fishing period, their standardized catch rates together with the nominal catch rates are shown in Table 4. The FV NF Alpha gold No. 6 recorded the lowest nominal catch rates for *T. obesus* (18.0 kg) and *T. albacares* (35.1 kg) respectively, while the FV Newfoundland alert recorded the highest nominal catch rate of 458.4 kg for *T. obesus*. The FV Seamar II vessel recorded the highest nominal catch rates (738.3 kg, 3 060.2 kg, and 665.1 kg) for *T. albacares*, *X. gladius*, and *P. glauca*, respectively. However, only FV Newfoundland alert, FV Seamar II, and FV Ra-horakhty had nominal catch records for

Table 5
Estimated parameters (K = carrying capacity, q = catchability coefficient, r = intrinsic population growth rate, MSY = maximum sustainable yield (kg), R_{yield} = replacement yield (kg) R^2 = goodness of fit and biomass) for *Xiphias gladius, Prionace glauca, Thunnus albacare* and *Thunnus obesus* fisheries.

Species	Model	*K*	*q*	*r*	*MSY* (kg)	R_{yield} (kg)	R^2	Biomass (kg)
Xiphius gladius	Fox normal	2.44E+07	1.15E−08	0.68	6.07E+06	4.79E+05	0.91	2.37E+07
	Fox (Log-normal)	4.76E+08	1.29E−09	0.14	2.46E+07	2.46E+07	0.76	2.12E+08
	Fox Gamma	1.18E+11	4.63E−12	0.19	8.43E+09	7.62E+09	0.85	6.40E+10
	Schaefer/Pella–Tom (normal)	2.85E+06	9.53E−08	1.27	9.05E+05	1.17E+05	0.92	2.76E+06
	Schaefer/Pella–Tom (Log-normal)	2.35E+08	2.62E−09	0.26	1.50E+07	1.49E+07	0.77	1.07E+08
Prionace glauce	Fox (normal)	2.13E+06	3.42E−08	3.58	2.80E+06	2.16E+06	0.59	3.16E+05
	Fox (Log-normal)	4.31E+08	6.92E−11	2.49	3.96E+08	−3.29E+05	0.12	4.33E+08
	Fox Gamma	3.95E+06	1.66E−08	4.06	5.90E+06	−2.25E+06	0.40	4471939
	Schaefer/Pella–Tom (normal)	4.96E+06	1.46E−08	3.98	4.94E+06	1.53E+06	0.60	418684.5
	Schaefer/Pella–Tom (Log-normal)	2.05E+08	1.46E−10	2.13	1.09E+08	−2.33E+05	0.12	2.05E+08
Thunnus albacare	Fox (normal)	1.29E+06	9.81E−07	1.46	6.92E+05	5.08E+05	0.49	8.61E+06
	Fox (Log-normal)	3.36E+07	5.62E−08	0.00	5.26E+04	5.17E+04	0.60	1.47E+07
	Fox Gamma	1.14E+06	1.14E−06	1.68	7.02E+05	4.98E+05	0.48	7.77E+05
	Schaefer/Pella–Tom (normal)	1.11E+06	1.09E−06	2.28	6.33E+05	5.06E+05	0.50	8.03E+05
	Schaefer/Pella–Tom (Log-normal)	4.36E+07	4.29E−08	0.00	1.32E+04	1.30E+04	0.60	1.95E+07
Thunnus obesus	Fox (normal)	1.48E+06	1.01E−07	0.44	2.40E+05	1.17E+05	0.92	1.18E+06
	Fox (Log-normal)	9.94E+07	2.21E−09	0.12	4.46E+05	4.12E+06	0.82	5.15E+07
	Schaefer/Pella–Tom (normal)	9.63E+05	1.30E−07	0.97	2.34E+05	6.42E+04	0.92	8.92E+05
	Schaefer/Pella–Tom (Log-normal)	4.20E+07	5.25E−09	0.20	2.05E+06	2.05E+06	0.82	2.19E+07

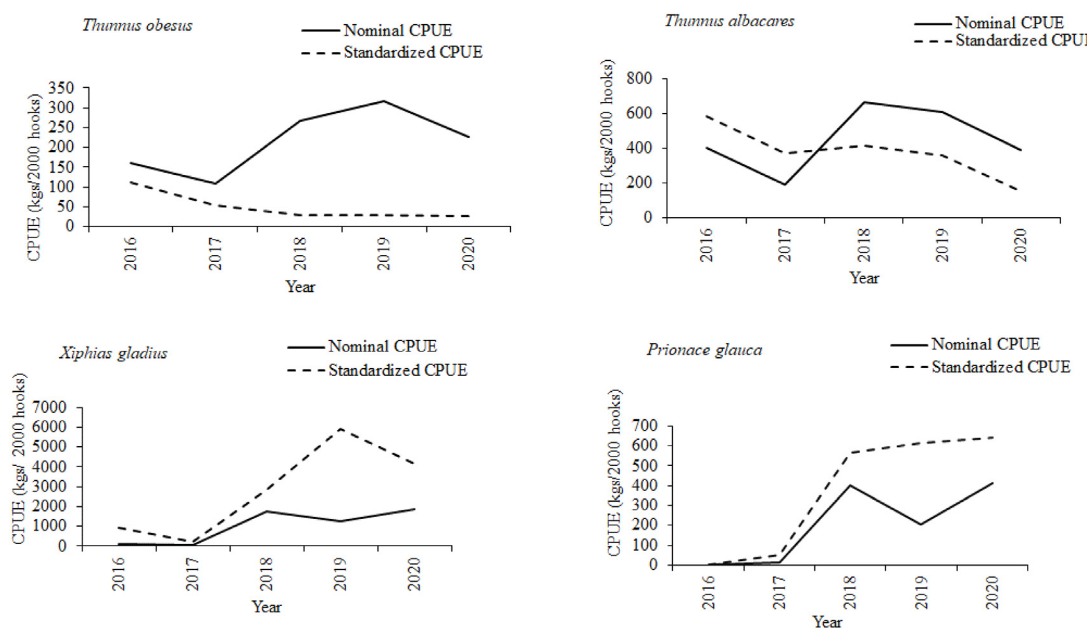

Fig. 6. Standardized and nominal annual catch rates (CPUE, kg/2000 hooks) for *Thunnus obesus, Thunnus albacares, Xiphias gladius*, and *Prionace glauca*.

P. glauca. There were significant variations in the observed catch rates for the four species among the various fishing vessels ($p < 0.05$).

3.8. Population parameter estimates

Generally, for the four dominant species, the highest annual catches were recorded in 2019 and the lowest annual catches were recorded in 2016 for *P. glauca* and *T. obesus*, while the lowest catches for *X. gladius* and *T. albacare* were recorded in 2017, respectively. The carrying capacity $\boldsymbol{K}$, catchability coefficient $\boldsymbol{q}$, intrinsic population growth rate $\boldsymbol{r}$, maximum sustainable yield ***MSY***, replacement yield $\boldsymbol{R_{yield}}$ and final biomass for *X. gladius*, *P. glauca*, *T. obesus*, and *T. albacare* using the Fox, Schaefer, and Pella–Tom surplus production models are shown in Table 5. Schaefer and Pella–Tom's production models produced similar results. The gamma error assumption produced minimization failure for the Schaefer and Pella–Tom production models.

The estimated *MSY* from Fox, Schaefer, and Pella–Tom with the normal and log-normal distribution errors were about 9.05E+5 - 8.43E+09 kg and R^2 were about 0.76 - 0.92 for *X. gladius* while the estimated *MSY* for *P. glauca* were 2.08E+06 - 3.96E+08 kg and R^2 were about 0.12–0.60. The estimated *MSY* for *T. albacares* were about 1.32E+04 – 7.02E+05 kg and R^2 were about 0.48 – 0.60 and the estimated *MSY* for *T. obesus* were about 2.34E+05 – 2.05E+06 kg and R^2 were about 0.82 – 0.92. The *MSY* estimates for *X. gladius*, *P. glauca*, *T. albacore*, and *T. obesus* were higher than their annual catches (Table 5). The estimated catches were found to be close to the observed catches for the four species investigated (Appendices A–D)

4. Discussion

4.1. Annual variation in major species catch rates

Long-line fishery catch and effort data are crucial for providing information on the of the fishery's performance both globally and at different geographic locations. Management and regulation of these fisheries depend on the information derived from the collected catch and effort data. Different factors, such as the

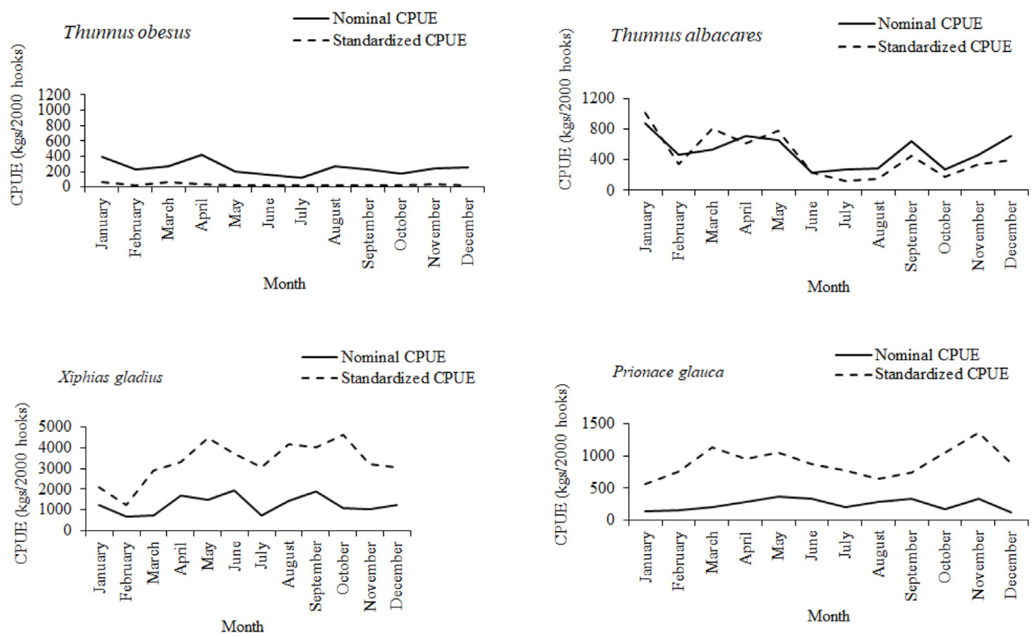

Fig. 7. Monthly standardized and nominal catch rates (CPUE, kg/2000 hooks) for *Thunnus obesus, Thunnus albacares, Xiphias gladius*, and *Prionace glauca*.

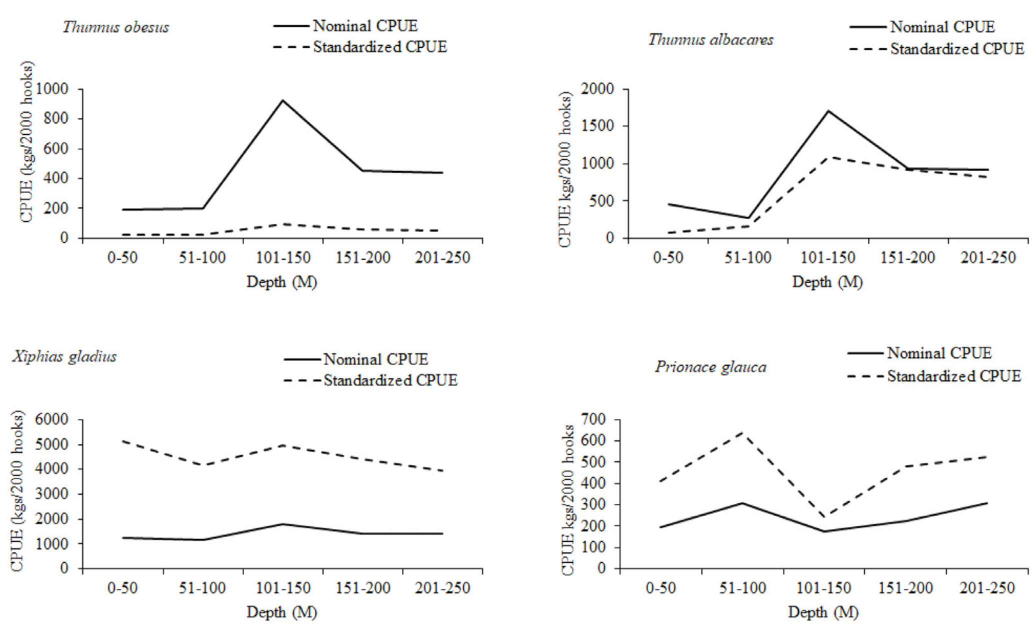

Fig. 8. Standardized and nominal catch rates (CPUE, kg/2000 hooks) for *Thunnus obesus, Thunnus albacares, Xiphias gladius*, and *Prionace glauca* by depth (m).

gear design and structure, season and depth of fishing, targeting design, and target species, influence the catch rates of any fishery. To account for the effect of different fishing designs and temporal changes in the catchability of species-specific fisheries, various approaches such as the generalized linear model (GLM) are employed to standardize the data (Hoyle, 2009). The model used relates to the factors that affect the distribution of fishing effort and target species such as seasonality, type of fishing gear, and fishing area (Hoyle et al., 2007; Chang et al., 2008). This study was designed to determine the variation of catch rates for four key species: *T. obesus*, *T. albacares*, *X. gladius*, and *P. glauca*, caught by long line fishing vessels during the period 2016 to 2020. The influence of the fishing year, vessel, month, and depth on catch rates were evaluated. Generally, an overlap between the small and medium pelagic fish with large pelagic fish was observed. This indicates that the pelagic fish categories get similar services from the pelagic ecosystem.

The high number of species recorded for the long line fishery shows a rich species diversity in the Kenya EEZ marine waters and the relative selectivity of the gear (Hammer et al., 2012). The higher disparity in the proportion of the large pelagic fish catches and that of the small and medium pelagic fish indicates an imbalanced distribution and environmental conditions that could not be suitable for the small and medium pelagic fish (FAO, 2020). The occurrence of the large pelagic fish together with the small and medium pelagic fish in the catch records indicates an overlap in the distribution of the species (Ward and Myers, 2005; Hurley et al., 2019). Low catches were recorded during 2016 and 2017 and this could be associated with the low fishing effort applied during the two years. This could be related to the fact that the crew were still new to the Kenya marine waters and were operating in areas of less abundance (Hazin et al., 2008), and were still exploring suitable locations for fishing.

On the contrary, high catches recorded in 2019 could be linked to the high fishing effort applied and the immigration of the fish species into the fishing grounds. The catches declined in 2020 due to a decrease in fishing effort. This decline in fishing effort could be linked to the COVID-19 pandemic, which disturbed most economic activities, including fishing. Due to the movement restrictions, there was less demand for fish worldwide, especially in Europe, which is the main market for Kenya's long-line catches. These results show that the number of catches increased with an increase in fishing effort for the long line fishery. The annual catch rates increased gradually up to 2019. There was a decline in 2020 for the tuna species (*T. obesus* and *T. albacares*) as the annual catch rates for *X. gladius* and *P. glauca* steadily increased over the years. Possibly, vessels targeting the tuna species fished less or altered their targets to target *X. gladius* and *P. glauca*. It could also result from the high occurrence of *X. gladius* and *P. glauca* in 2020.

4.2. Seasonal variation in catch rates of major species

Higher catch rates for *T. obesus*, *T. albacares,* and *X. gladius* were recorded during the NEM than during the SEM season. This indicates the abundance of the species could be higher during the NEM season than during the SEM season. This could be attributed to low effort deployed due to rough sea conditions, fish migration to deeper waters, and decreased fish density during the SEM season due to deeper thermocline and cooler waters (McClanahan, 1988). However, some studies have shown a high abundance of tuna species during the SEM season (Ruwa, 2006). On the other hand, higher catch rates were recorded for *P. glauca* during the SEM season than during the NEM season, indicating the abundance of this species is higher during the SEM season than during the NEM season. The result show that catch rates for the long line fishery are influenced by season. The lack of significant differences in the seasonal catch rates for *X. gladius* and *P. glauca* indicates that seasonality does not affect the catchability and abundance of the two species. Whereas the occurrence of differences in the *T. albacares* and *T. obesus* catch rates indicates seasonality influences their catchability and abundance, including the fishing effort deployed.

4.3. Changes in catch rates with depth

The catch rates varied at different depths for the four species. The highest catch rates for *T. obesus* and *T. albacares* were recorded at a depth of 101–150 m and decreased at depths beyond 150 m. This shows that the distribution of the two tuna species is high at a depth level of 101–150 m and decreases at a depth level beyond 150 m. These findings are similar to those of Nishida et al. (2012), in which high catch rates for *T. albacares* were found at a depth range of 120–150 m. High catch rates for *T. albacares* have been recorded at depths of 300 m and deeper (Saito and Sasaki, 1974). The catch rates for *X. gladius* and *P. glauca* did not fluctuate greatly with depth, indicating the species were uniformly distributed at the different depth levels. In their study, Nakano et al. (1997) recorded a lack of variation in *X. gladius* catch rates. The vessels recorded significantly different catch rates, which could be attributed to the different fishing strategies employed by the various vessels during the fishing period. However, the effects of extraneous factors such as vessel speed and currents that could affect the depth of the set line were not taken into account. The increase in catch rates from 2018 to 2020 could result from the fishing vessels' venturing into areas of high abundance and increased demand for the species, but could also be a result of the crew's gaining experience over time improving fishing strategy.

4.4. Population parameter estimates

For the surplus production models used in this study, it is assumed that there is no interaction among species and r is not dependent on the age structure of the fish species. There is no environmental influence on the population structure and fishing and natural mortality co-occur. Therefore the surplus models have been used for risk assessment to achieve management targets (Haddon, 2011).

The estimated MSY for *X. gladius*, *P. glauca*, *T. obesus*, and *T. albacare* were higher than their total annual catches during the 2016–2020 fishing period. This indicates that the population of the four species is sustainable and not at risk. However, the obtained MSY estimates, may not be the actual estimates as the catch data used was only for the industrial fleets not considering the artisanal fleet data and the unreported data. Also, the species are highly migratory and could not be restricted to the Kenya EEZ fishing grounds only. The higher MSY than the total annual catches for *T. obesus* and results conforms to the observations made by Miyake et al. (2010) for which the fishing mortalities were lower than the MSY for the Indian Ocean fishery. However, the fishing mortalities were higher than the MSY for *T. albacare* for the Indian Ocean fishery (Miyake et al., 2010). The MSY estimates obtained for this study may not be the actual as the data did not contain any information on discards which could be a source of error to the findings.

5. Conclusion and recommendations

This work provides findings on the variation of long line catch rates for *T. obesus*, *T. albacares*, *X. gladius,* and *P. glauca* caught by nine different fishing vessels. This work indicates an overlap between the small and medium pelagic fish and the large pelagic fish in the Kenya EEZ marine waters. The overall increase in fishing effort proportionately leads to increased catch rates. High catch rates were realized during the NEM season for *T. obesus*, *T. albacares*, and *X. gladius* and during the SEM season for *P. glauca*. Also, more catches were recorded at a depth of 101 – 150 m for *T. obesus* while for *T. albacares*, *X. gladius*, and *P. glauca* the catch rates were not greatly influenced by depth. It is worthy to note that the number of vessels that provided data has increased over the years.

There is a need for fisheries managers to monitor discard levels and composition for conservation purposes. We recommend seasonal closures for management, especially for the vessels targeting tunas and swordfish to conduct fishing during the NEM season when the catch rates are higher. The fishing effort applied at Kenya EEZ was high but the annual and monthly nominal catch rates for *X. gladius* and *P. glauca* were lower. However, the results presented here are for a five-year short-term period. Therefore, we recommend that the catch rates be monitored over a longer period to establish the impact of increased effort on the stocks. The CPUE used in this study was determined based on the average number of hooks used during fishing. It is recommendable that other methods for determining CPUE such as soak time be applied as the soak time influences the fishing effort and CPUE of the target species (Carruthers et al., 2011; Aneesh Kumar et al., 2016). We also recommend research be conducted on the overlap extent of the pelagic fish. We recommend studies on stock status and selectivity of the long line hooks for the dominant species to gather more information essential for the regulation and management of the Kenya EEZ fishery. We also recommend future work to consider the discarded fish during the fishing operations. Commercial valuation of the fishery is important to establish the benefits of these pelagic fisheries to the economy.

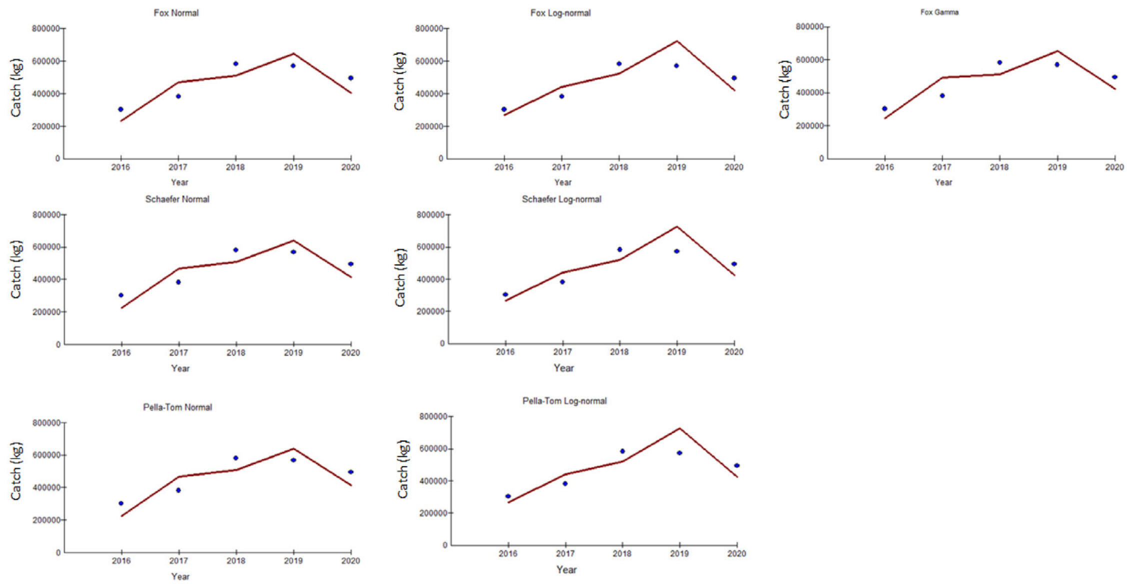

Fig. A.1. Annual observed (dots) and expected catch (kg) of Xiphias gladius for the Fox, Schaefer and Pella–Tom surplus production models.

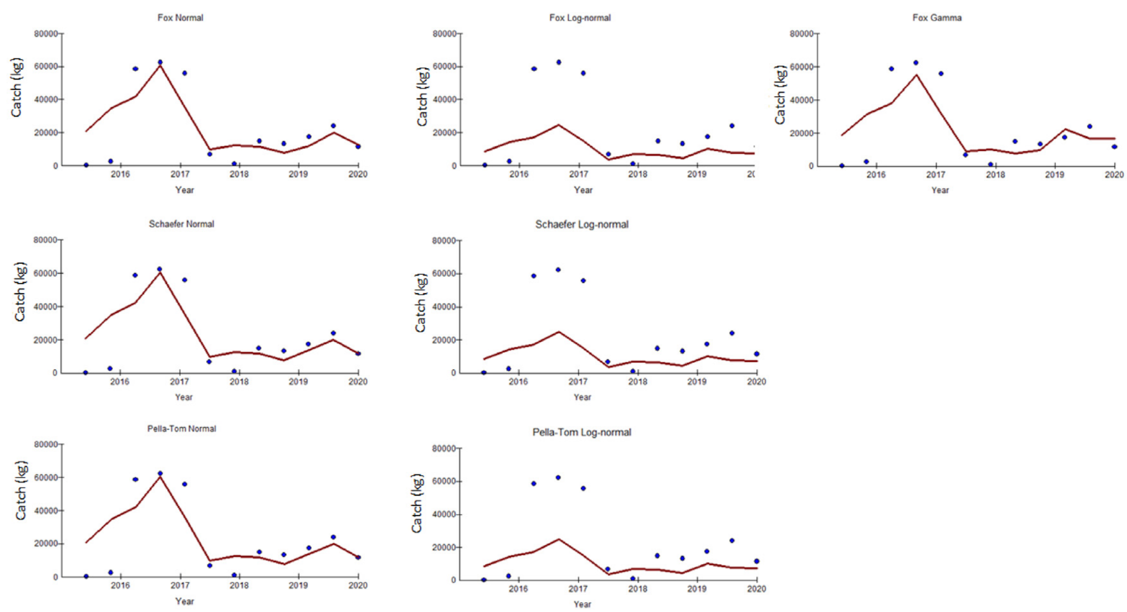

Fig. B.1. Annual observed (dots) and expected catch (kg) of Prionace glauca for the Fox, Schaefer and Pella–Tom surplus production models.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Annual observed (dots) and expected catch (kg) of *Xiphias gladius* for the Fox, Schaefer and Pella-Tom surplus production models

See Fig. A.1.

Appendix B. Annual observed (dots) and expected catch (kg) of *Prionace glauca* for the Fox, Schaefer and Pella-Tom surplus production models

See Fig. B.1.

Appendix C. Annual observed (dots) and expected catch (kg) of thunnus obesus for the fox, schaefer and pella–tom surplus production models

See Fig. C.1.

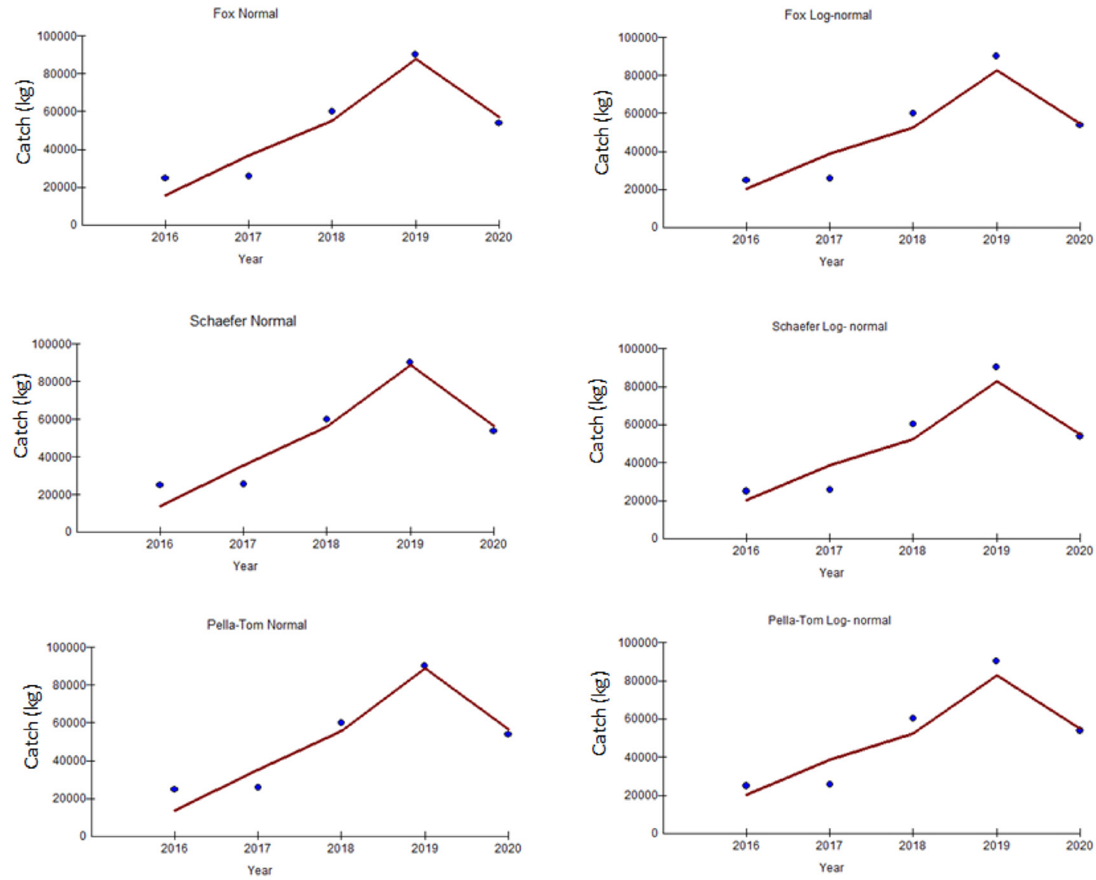

Fig. C.1. Annual observed (dots) and expected catch (kg) of Thunnus obesus for the Fox, Schaefer and Pella–Tom surplus production models.

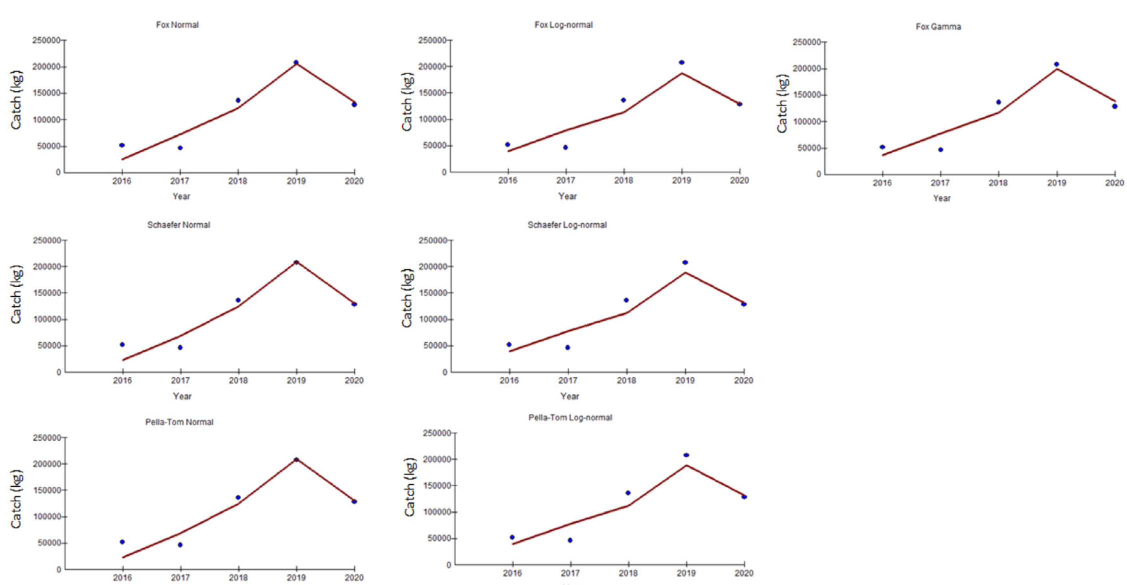

Fig. D.1. Annual observed (dots) and expected catch (kg) of Thunnus albacare for the Fox, Schaefer and Pella-Tom surplus production models.

Appendix D. Annual observed (dots) and expected catch (kg) of thunnus albacore for the fox, schaefer and pella–tom surplus production models

See Fig. D.1.

References

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Further reading

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