Western Indian Ocean JOURNAL OF Marine Science

Volume 20 | Issue 1 | Jan – Jun 2021 | ISSN: 0856-860X

Western Indian Ocean JOURNAL OF Marine Science

Published biannually

Aims and scope: The *Western Indian Ocean Journal of Marine Science* provides an avenue for the wide dissemination of high quality research generated in the Western Indian Ocean (WIO) region, in particular on the sustainable use of coastal and marine resources. This is central to the goal of supporting and promoting sustainable coastal development in the region, as well as contributing to the global base of marine science. The journal publishes original research articles dealing with all aspects of marine science and coastal management. Topics include, but are not limited to: theoretical studies, oceanography, marine biology and ecology, fisheries, recovery and restoration processes, legal and institutional frameworks, and interactions/relationships between humans and the coastal and marine environment. In addition, *Western Indian Ocean Journal of Marine Science* features state-of-the-art review articles and short communications. The journal will, from time to time, consist of special issues on major events or important thematic issues. Submitted articles are subjected to standard peer-review prior to publication.

Manuscript submissions should be preferably made via the African Journals Online (AJOL) submission platform (http://www.ajol.info/index.php/wiojms/about/submissions). Any queries and further editorial correspondence should be sent by e-mail to the Chief Editor, wiojms@fc.ul.pt. Details concerning the preparation and submission of articles can be found in each issue and at http://www.wiomsa.org/wio-journal-of-marine-science/ and AJOL site.

ISSN 0856-860X

Cover image: The mudskipper *Periophthalmus argentilineatus* on the mangrove of Ulo Beach, Cabo Delgado, North Mozambique. © José Paula, 2006

Population characteristics and exploitation of yellowfin tuna (*Thunnus albacares* Bonnaterre, 1788) in the coastal waters of Kenya

Edward Kimakwa[1]*, Micheni Ntiba[2], Agnes Muthumbi[2]

[1] World Wide Fund for Nature (WWF), PO Box 51089-00100, Nairobi, Kenya

[2] School of Biological Sciences, University of Nairobi, PO Box 30197-00100, Kenya

*Corresponding Author: kimakwa2001@gmail.com

Yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) is a highly migratory and important commercial fishery species. Data on length-frequency, growth parameters and mortality rates of yellowfin tuna in the coastal waters of Kenya is limited. We assessed Catch Per Unit Effort (CPUE), size distribution, growth parameters and mortality rates based on length-frequency and catch data collected from August 2015 to December 2016 at five fish landing sites along the Kenyan coast. The sample comprised of 1281 individuals of yellowfin tuna weighing 12,671 kg. Highest CPUE was recorded in October 2015 (10.8 kg·Fisher^{-1}Trip^{-1}) and lowest CPUE, 2.6 kg·Fisher^{-1}Trip^{-1} in December 2016. Yellowfin tuna was more abundant in the South-East Monsoon (SEM), from May to October, with an average CPUE of 7.3 kg Fisher^{-1}Trip^{-1} compared to North East Monsoon (NEM), from November to April, with a CPUE of 7.0 kg Fisher^{-1}Trip^{-1}. Spatial variation of CPUE was evident. Old Town recorded the highest CPUE of 54.2 kgTrip^{-1}, while Mnarani the lowest of 19.4 kgTrip^{-1}. At least 91 % of the fish sampled were < 100 cm FL and hence not yet mature. The asymptotic Length ($L\infty$) was found to be 195 cm FL, the Von Bertalanffy growth constant (K) 0.43 year^{-1}, t_0 - 0.82 and the Growth Performance Index (ϕ) 4.21. The total mortality coefficient (Z) was 2.59 year^{-1}, Natural Mortality (M) 0.59 year^{-1}, Fishing Mortality (F) 2.00 year^{-1} and Exploitation Rate (E) 0.77 year^{-1}. Results show that mortality and exploitation rates were above the optimal, indicating high fishing pressure on coastal yellowfin tuna. The information generated by this study provides some further insights on the scientific knowledge of the coastal yellowfin tuna to inform policy for sustainable management and development of this fishery in Kenya and the entire South West Indian Ocean (SWIO) region.

Keywords: yellowfin tuna, length-frequency, mortality, growth parameters

Introduction

Tunas are highly migratory species that are distributed globally, occurring mainly in tropical and sub-tropical waters in the Indian, Pacific and Atlantic Oceans (ISSF, 2020; Chassot *et al.*, 2019; Prathibha *et al.*, 2012). Yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) is a fast growing tropical species which belongs to the Scombridae family. Yellowfin tuna is one of the principal tropical tunas that contributes significantly to commercial harvests of many countries in the world including Kenya (Chassot *et al.*, 2019; Pillai and Palanisamy, 2012). The management of tunas in the Indian Ocean falls under the responsibility of the Indian Ocean Tuna Commission (IOTC) (Kaplan *et al.*, 2014; Pillai and Palanisamy, 2012). The Kenya Fisheries Service (KeFS) is responsible for the management of fisheries including yellowfin tuna in Kenyan waters (Kimani *et al.*, 2018).

An estimated catch of 427,240 metric tons (Mt) was landed in the Indian Ocean in 2019 (IOTC, 2020). The average catch for yellowfin tuna in the IOTC area of competence for the period 2015 – 2019 was estimated at 424,103 Mt compared to the Maximum Sustainable Yield (MSY) of 403, 000 Mt (IOTC, 2020). The European Union, mostly Spain and France, accounted for 21 % of the yellowfin tuna catches from 2014 – 2018, closely followed by Maldives, Iran, Seychelles and Sri Lanka with 13 %, 12 %, 10 % and 9 %, respectively (IOTC, 2019). Other countries contributed to the remaining 35

http://dx.doi.org/10.4314/wiojms.v20i1.9

% of the catch to a lesser extent, with Kenya only contributing some 108 Mt of the industrial yellowfin tuna to the total catch reported in 2018 (IOTC, 2018).

In Kenya, marine fisheries are one of the most important resources that contribute to the national economy, food security and livelihoods, though its potential is not fully maximized (Mueni *et al*., 2019; Ministry of Agriculture, Livestock, Fisheries and Irrigation, 2019; Kimani *et al.,* 2018). Kenya has an Exclusive Economic Zone (EEZ) of 200 nautical miles and 12 nautical miles of territorial waters (Republic of Kenya, 1989) which is not fully exploited (Ministry of Agriculture, Livestock and Fisheries, 2016). The country's coast is also located within the rich tuna migratory route in the SWIO (Campling, 2012). Yellow fin tuna (*Thunnus albacares*) is one of the most important commercial tuna species occurring in Kenya's coastal and EEZ waters.

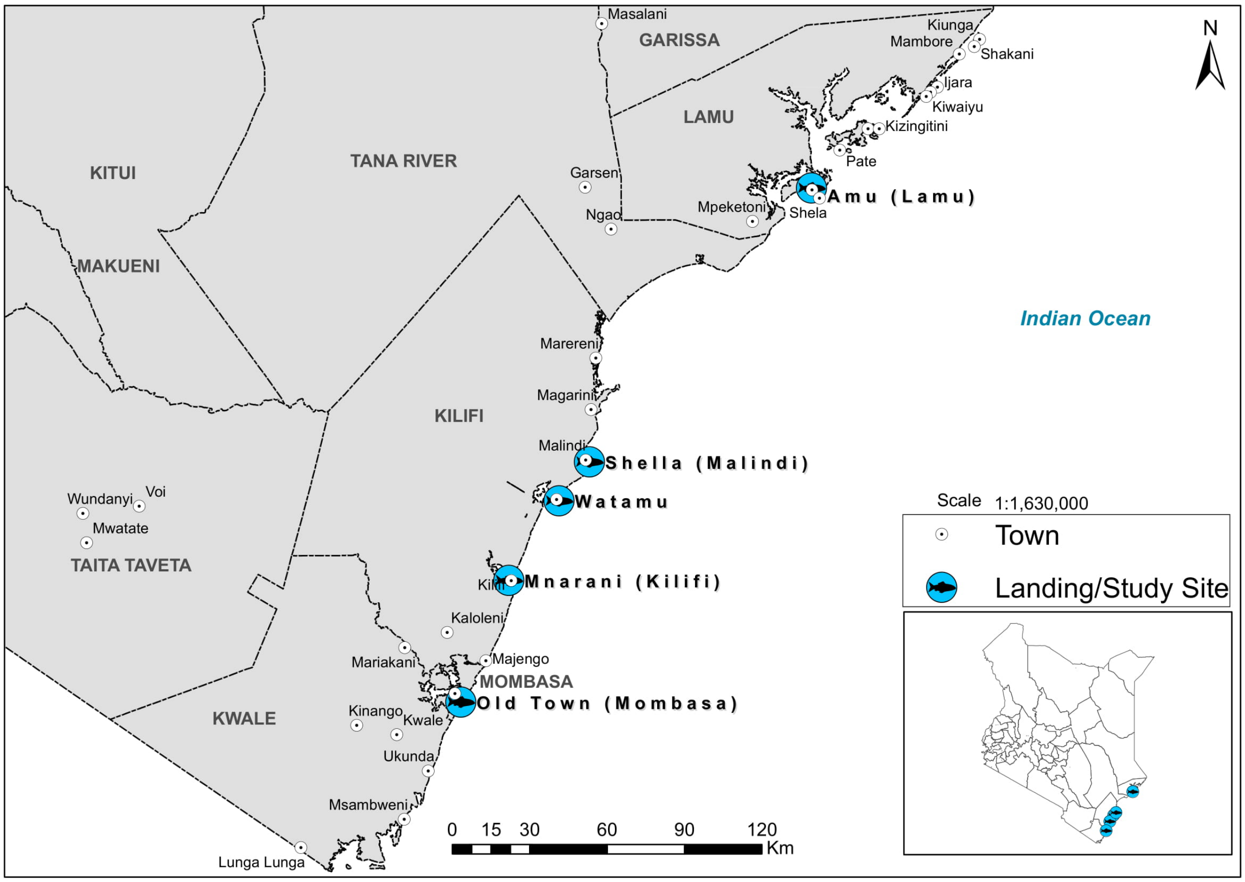

Figure 1. Artisanal yellowfin tuna fishery landing and study sites along the Kenyan Coast.

The species is highly migratory and forms free or associated schools with other tunas (Fishbase, 2018, Majkowski, 2007). Yellowfin is usually caught using various gears including handline, purse seine, gillnet, longline, ringnet, and pole and line (Kaplan *et al.,* 2014; Chassot *et al.,* 2019). Yellowfin tuna is caught in the nearshore waters primarily by artisanal fishers. At least 8,265 Mt, 3,431 Mt and 1, 931 Mt of fishes belonging to the scombrid family were landed by artisanal fishers in Kenyan coastal waters in 2015, 2016 and 2017, respectively (IOTC, 2017; IOTC, 2018). It is estimated that 414 – 800 artisanal fishing vessels target tuna and tuna-like species within 3-5 nautical miles of the coast in Kenyan waters (Ministry of Agriculture, Livestock and Fisheries, 2016; Hoof and Steins, 2017; IOTC, 2018). The fishers employ different gear types to catch yellowfin tuna including longlines, handlines, trolling lines and gillnets (Tuda *et al.,* 2016; Ministry of Agriculture, Livestock and Fisheries, 2016; IOTC, 2017; Alicli *et al.,* 2012; Tuda *et al*., 2016).Generally artisanal fishers lack suitable fishing vessels to venture far offshore (Wakwabi *et al.,* 2003). Fondo (2004) studied catch distribution for different gears in Lamu and Vanga landing sites, although this was for non-tuna species. There is limited information and studies on the biological aspects of tuna and tuna-like species in the coastal waters of Kenya (Fondo, 2004; KMFRI, 2018). Some efforts have been made to collect catch data on the artisanal tuna fishery but this is not disaggregated to species level and is confined only to the quantity of fish catch landed (Ministry of Agriculture, Livestock and Fisheries, 2016; IOTC, 2017). However, some data and information on biological and environmental parameters have been collected though this has not been continuous, consistent and is limited to a few fish landing sites (Wekesa, 2013; Ndegwa and Okemwa, 2017; Fulanda and Wamukota., 2015; KMFRI, 2018). Most studies on yellowfin tuna have been undertaken elsewhere, especially in the Western and Central Pacific Ocean and the East Indian Ocean regions (Mitsunga *et al*., 2013; Abdel-Barr, 2012; Viera, 2005; Kar *et al*., 2012).

In this paper, results are presented on catch rates, growth parameters, mortality rates, gear selectivity and Virtual Population Analysis - VPA (Catch, natural losses, survivors and fishing morality) of yellowfin tuna in Kenyan coastal waters, based on data collected from five fish landing sites along the Kenyan coast over a period of 16 months from August 2015 to December 2016. Sound knowledge and scientific information about the yellowfin tuna fishery in Kenyan waters is necessary to inform policy for effective fisheries management. The findings of this study will contribute to improved scientific knowledge of the yellowfin tuna in Kenyan coastal waters and the entire Indian Ocean region.

Materials and methods

Study sites

The study site was the Kenyan coast and climatic conditions are primarily determined by the reversing Monsoon winds; the dry NEM season occurs between November and March, and the wet SEM season between April and October (McClanahan, 1988; Government of Kenya, 2017; Schott and Mc Creary, 2001). Fish samples were collected from five fish landing sites, namely Lamu (Amu), Mombasa (Old Town), Kilifi (Mnarani), Malindi (Shella) and Watamu (Watamu) (Fig. 1).

Sampling and data collection

Fish samples were collected from the catches of artisanal fishers on a monthly basis over a period of 16 months from August 2015 to December 2016. The Primary Sampling Unit (PSU) was the vessel and the Secondary Sampling Unit (SSU) was the fishing trip while the catch was the tertiary sampling Unit. The fish landing site was the stratification.

Fish samples were identified to the lowest taxon possible using various identification guides/keys (Regional Tuna Tagging Project in the Indian Ocean [RTTP-IO], 2004; Itano, 2005; Anam *et al*., 2012; IOTC, 2013). Each individual yellowfin tuna caught was weighed whole to the nearest kilogram (kg) using an electronic balance. Fork length (FL) of each yellowfin tuna was measured to the nearest centimeter (cm) using a flexible measuring tape. The type of fishing gear, vessel type, the number of fishing crew per boat, date and time of departure and arrival for each fishing trip, name of the landing site and the price per kg of fish were recorded on biological sampling forms for all tuna and tuna-like species, adapted from the IOTC data collection template.

Data analyses

Catch Per Unit Effort (CPUE)

Nominal CPUE was computed by dividing the weight of fish caught (kg) with the number of fishing crew for every fishing trip. This relationship was summarized in the equation below:

$$CPUE = C_t/E_t \qquad \text{Eqn 1}$$

Where C_t is catch at time *t*, and E is the fishing effort deployed at time *t*.

The CPUE was expressed as kg $trip^{-1}$ and $kg{\cdot}Fisher^{-1}Trip^{-1}$.

Length-Frequency distribution

The length-frequency data was grouped by month and binned into 10 cm intervals. The Length-Frequency measurements were used to prepare length-frequency distribution graphs and curves. The length and weight measurements were used to determine the length-weight relationship according to the formula:

$$W = aL^b \text{ (Cren, 1951)} \qquad \text{Eqn 2}$$

Where W is total body weight (kg), L is Fork Length (cm), a is a growth coefficient or condition factor (a constant), and b is the relative growth rate (exponent).

The length-weight relationship was calculated by drawing a scatter plot of the data and applying a power regression to determine the *a* and *b* parameters. The degree of association between the length and weight was computed by the determination coefficient R^2.

Estimation of growth parameters

The von Bertalanffy growth function (VBGF) including asymptotic length (L_∞) and the growth coefficient (K) were estimated using the ELEFAN 1 (Pauly, 1987) routine in FISAT II (Gayanilo *et al.,* 1994). The mean annual water surface temperature of 26 °C (for species in the tropics) was used in the model.

The response surface analysis routine with fixed starting points in ELEFAN1 was used to estimate the best fit growth curves to our data (Gayanilo and Pauly, 1997) given a range of the values of L_∞ and K and a fixed starting point (SS), and the starting Length. The following length based VBGF formula (Sparre and Venema, 1998) was fitted to the data:

$$L_t = L_\infty(1-\exp(-K(t-t_0))) \qquad \text{Eqn 3}$$

Where L_∞ is the asymptotic length, K is the von Bertalanffy growth coefficient, t_0 is the theoretical age at length zero, and L_t is the length at age t.

The index of growth performance (ϕ,) (Pauly and Munro, 1984) was estimated using the equation:

$$\phi = \log(K) + 2\log(L_\infty) \qquad \text{Eqn 4}$$

Estimation of mortality rates

The instantaneous rate of total mortality (Z) was calculated using a linearized length converted catch curve (Pauly 1983, 1984) on pooled data used with the estimated growth parameters, Asymptotic Length (L_∞) and the Von Bertalanffy growth constant (K). The following equation was used:

$$\mathrm{Ln}(N_i / Dt_i) = a + b^* t_i \qquad \text{Eqn 5}$$

Where N is the number of fish in length class i, Δt is the time required for the fish to grow through length class i, t is the age corresponding to the mid-length of class i, and b is an estimate of the total mortality coefficient (Z).

The natural mortality rate (M) was estimated using indirect methods following the Pauly (1980) empirical relationship expression:

$$\mathrm{Log}\,M = -0.0066 - 0.279\log L_\infty + 0.6543\log K + 0.4634\log T \qquad \text{Eqn 6}$$

Where M is the instantaneous natural mortality rate, L_∞ is the asymptotic length, T is the mean surface temperature at 26 °C and K refers to the growth rate coefficient of theVBGF.

Fishing mortality (F) was calculated using the relationship (Gulland, 1971):

$$F = Z - M \qquad \text{Eqn 7}$$

Where Z is the instantaneous total mortality rate and M is the instantaneous natural mortality rate.

The exploitation rate (E) was calculated as a ratio of the fishing mortality to the total mortality:

$$E = F/Z \qquad \text{Eqn 8}$$

Fishing gear catch selectivity

To estimate the selection parameters at 25 %, 50 % and 75 % of L_{max} (Lc_{25}, Lc_{50}, Lc_{75}), the analysis was based on the logistic curve assuming that selection to be symmetrical, or nearly so, based on the following logistic curve equation:

$$\mathrm{Ln}((1/P_L)-1) = S_1 - S_2 \cdot L \qquad \text{Eqn 9}$$

Where P_L is the probability of capture for length L, and

$L_{25} = (\mathrm{Ln}(3)-S_1)/S_2$

$L_{50} = S_1/S_2 L_{75} = (\mathrm{Ln}(3)+S_1)/S_2$

according to methods described by Pauly (1984a, 1984b, 1990).

Virtual Population Analysis (VPA)

A length based Virtual Population Analysis (VPA) on yellowfin tuna in Kenya coastal waters was conducted in FISAT II (Gayanilo *et al.,* 1994) using methods described by Jones and van Zalinge (1981) adapted for length frequency data to show survivors and losses due to natural and fishing mortalities. VPA required the following inputs that were estimated in this study: the coefficient of growth rate (K); asymptotic length (; natural mortality (M); fishing mortality (F); and the length weight relationship constant (*a*) and exponent (*b*). In this study, the *(a)* and *(b)* values were estimated at 0.0002 and 2.5, respectively. These values were slightly lower than what is reported in Fishbase. This indicated that the growth was negatively allometric since the (*b)* value was less than 3. For the purpose of the VPA, the values a = 0.0224, and b = 2.94 were accessed from Fishbase in October 2018 and used in the analysis.

Results

Yellowfin tuna fish catch rates

A total of 1281 individual yellowfin tuna weighing 12,671 kg were sampled. The minimum and maximum weight of the fish sampled was 1 kg and 97 kg, respectively with a mean weight of 9.9 kg. The size ranged from 11 cm to 205 cm FL, with a mean size of 77.7 cm FL.

Watamu and Shella each accounted for 27 % of the total catch sampled. This was followed closely by Old Town accounting for 21 % of the sampled catch. Amu and Mnarani recorded 15 % and 10 %, respectively. Crew sizes ranged from 3 – 5 fishers per boat with an average of 4 fishers per vessel. A total of 1,808 fisher days were recorded over the sampling period with an average CPUE of 7.2 kg·Fisher^{-1}Trip^{-1}. The highest fishing effort was concentrated at Watamu accounting for 33 % of the fisher days. This was followed closely by Shella with 32 % of the fisher days. Old Town, Mnarani and Amu accounted for 16 %, 13 % and 6 % fisher days, respectively. It is evident that total fish catches correlated with the fishing effort.

Main fishing gears deployed by artisanal fishers targeting yellowfin tuna were handlines, longlines, trolling line and gillnets (Table 1). Trolling accounted for 46 % of the total catch sampled. Handlines, longlines and gillnets accounted for 32 %, 21 % and 1 % of the total catch sampled, respectively. Trolling accounted for 54 % of the fisher days. This was followed closely with handlines which accounted 27 % of the fisher days recorded. Longlines and gillnets accounted for 16 % and 3 % of the fisher days, respectively. The average size of fish harvested using longlines was above 100 cm FL (133.78 cm FL) while from handlines this was 77.2 cm FL. Gillnets recorded the smallest average size of the fish catch sampled. Almost 100 % of the yellowfin tuna in the sample harvested using gillnets were below the size at first maturity (< 100 cm FL), with sizes ranging from 52 cm – 82 cm FL. Trolling, handlines and longlines recorded 99.6 %, 93.7 % and 31.3 % of the catch less than 100 cm FL, repectively.

Temporal variations in yellowfin tuna catches

Monthly variation in yellowfin tuna catch rates was evident (Fig. 2). Highest CPUE was recorded in the month of October 2015 (10.8 kg·Fisher^{-1}Trip^{-1}), with a corresponding catch of 1,430 kg. This was closely followed by November 2015 with a CPUE of 10.7 kg Fisher^{-1}Trip$^{-1.}$ In 2016, high catch rates of 8.6 kg Fisher^{-1}Trip^{-1} and 8.5 kg Fisher^{-1}Trip^{-1} were recorded in February and June, respectively. The lowest CPUE of 3.6 kg·Fisher^{-1}Trip^{-1} was recorded in December 2016. The results indicate monthly variations with better catches reported in the months of May to October (SEM), with an average CPUE of 7.3 kg Fisher^{-1}Trip^{-1} (Table 2). Low catches were reported in the months of November to April (NEM) with an average CPUE of 7.0 kg·Fisher^{-1}Trip^{-1}. High fishing effort occurred during the SEM months, accounting for 62 % of the fisher days compared to 38 % in the NEM season. Nevertheless the Kruskal-Wallis test did not indicate any significant difference between the SEM and NEM catches.

Spatial variations in yellowfin tuna catches

There were variations in fish catch rates between the five fish landing sites (Fig. 3). The results showed that Old Town recorded the highest catch rates with a mean weight of 54.2 kgTrip^{-1} and a mean CPUE of 9.2 Kg·Fisher^{-1}Trip^{-1}. This was closely followed by

Table 1. Comparison of catch rates and under sized individuals (< 100 cm FL) of yellowfin tuna among the main fishing gears in the artisanal fishery in the coastal waters of Kenya.

Gear	Fisher Days	Total catch in the sample (Kg)	Mean Catch/ Day (Kg)	Catch/ Day N	Catch/ Day Std.Err	KgFisher-1Trip^{-1}	Mean Fork Length (cm)	% proportion of under size fish in the sample (Less than 100 cm FL)
Gillnet	60	131	10.08	13	1.99	2.2	65.4	100
Handline	481.75	4038	33.58	119	2.87	9.29	77.2	93.7
Longline	289.00	2717	53.27	51	6.97	9.09	113.78	31.3
Trolling line	977.32	5785	23.61	245	0.96	6.06	73.0	99.6
All Grps	1808.07	12671	29.50	428	1.36	7.21	78.83	

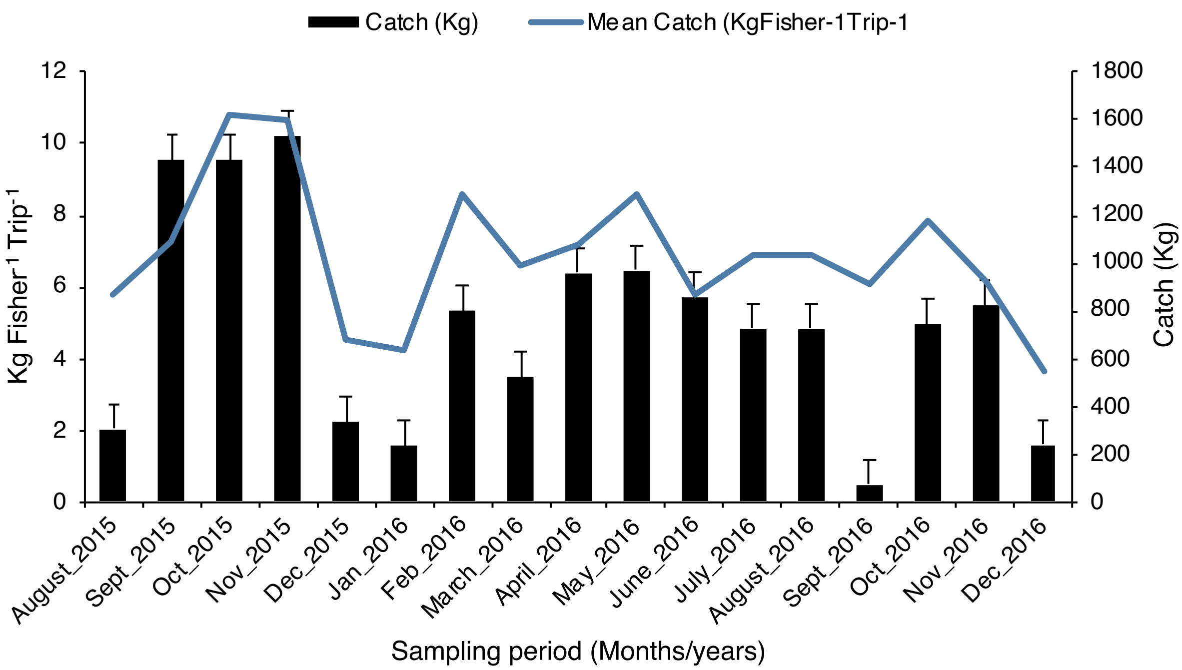

Figure 2. Monthly variation in CPUE of yellowfin tuna (Kg) and KgFisher^{-1}Trip^{-1} from the coastal waters of Kenya for the period August 2015 – December 2016.

Amu with a mean weight of 49.4 kg^{-1}Trip^{-1}and CPUE of 16.7 kg·Fisher^{-1}Trip^{-1}, which was the highest. Shella and Watamu each recorded 24.6 kgTrip^{-1}, with a mean CPUE of 5.8 kg·Fisher^{-1}Trip^{-1} and 5.9 Kg·Fisher^{-1}Trip^{-1}, respectively. Mnarani recorded the lowest mean catch of 19.35 kgTrip^{-1} and CPUE of 5.9 kg·Fisher^{-1}Trip^{-1}. Results of the Kruskal – Wallis test showed a significant difference in yellowfin catches betwee Old Town and other fish landing sitess ($P < 0.05$). The difference in fish catch rates at Mnarani and that of Shella, Watamu and Amu was significant ($P < 0.05$). There was no significant difference in yellowfin tuna catch rates between Watamu and Amu as well as Shella and Amu.

Length-frequency distribution

The length of the 1281 fish measured ranged from 11 cm to 205 cm FL (Fig. 4). Most of the individuals (36 %) were in the length class of 66 cm -76 cm FL. At least 91 % of the individuals sampled were less than 100 cm FL, which is the length at maturity for yellowfin tuna (Viera, 2005; Stequert *et al*., 1996; Kaplan *et al*., 2014; Itano, 2000). Three length classes dominated the size structure namely 55-65, 66-76 and 77-87 cm FL. Different gear types were highly selective for size. Mean sizes for yellowfin tuna caught by longline, handline, trolling and gillnet were 113 cm, 77.2 cm, 73.0 cm and 65.4 cm, respectively (Table 1). The results suggest that all (100 %) of the yellowfin tuna harvested by gillnet were undersize (< 100 cm FL). Trolling and handline resulted in 99.6 % and 93.7 % of their catch in the sample being undersize. Longline resulted in some 31.3 % of the undersize catch in the sample. The results indicate that the majority yellowfin tuna caught by the artisanal fishers are juveniles and are more vulnerable to gillnet, handline and trolling gears. However, this study did not look into the specific sizes of the different fishing gears that were deployed by the artisanal fishers at the respective landing sites. It is highly likely that the fishers are using mesh sizes and hooks that are of small sizes. The use these fishing gears (small

Table 2. Comparison of yellowfin tuna catch rates during the SEM and NEM seasons.

Season	KgFisher^{-1}Trip^{-1} Mean	KgFisher^{-1} Trip^{-1} N	KgFisher^{-1} Trip^{-1} Std. Dev	KgFisher^{-1} Trip^{-1} Std. Err
NEM	7.008050	156	8.202849	0.656754
SEM	7.373973	272	6.261162	0.379639
All Grps	7.240599	428	7.023964	0.339516

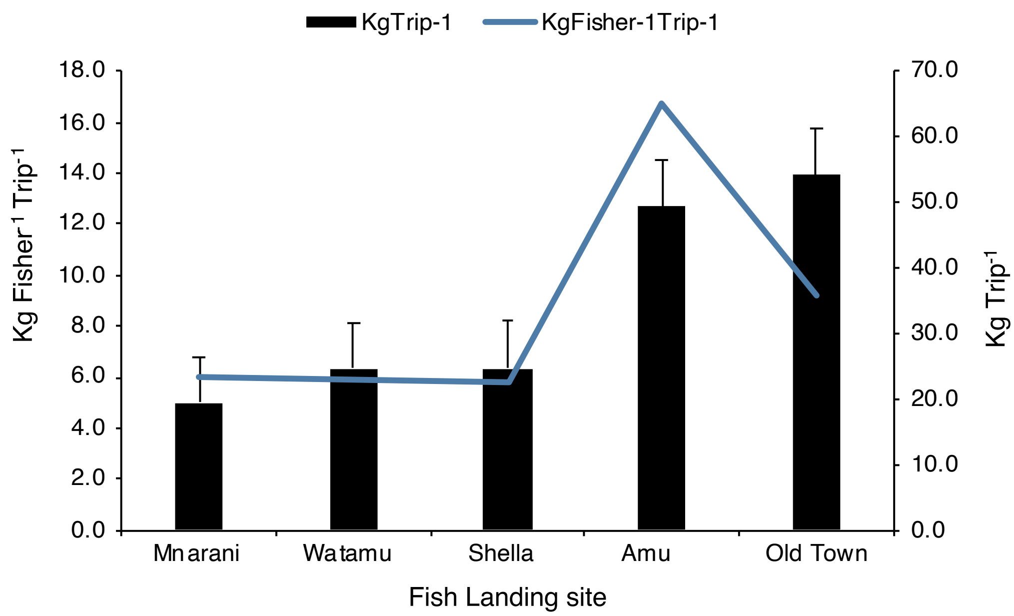

Figure 3. Spatial variation of yellowfin tuna Catch Per Unit Effort (CPUE) from the coastal waters of Kenya for the period August 2015 – December 2016.

mesh sizes and hooks) require close monitoring by the relevant national institutions including KeFS and KMFRI to ensure that the recommended sizes of nets and gears are used by the fishers.

Growth parameters

Life history parameters for yellowfin tuna based on the pooled data set were estimated as follows: Asymptotic Length (L_∞) = 195 cm FL; Von Bertalanffy growth constant (K) = 0.43 year^{-1}; t_0 = 0.82; and the Growth Performance Index (ϕ) = 4.21.

Mortality rates

Total mortality coefficient (Z) was 2.59 year^{-1}. Natural Mortality (M) with a mean annual water surface temperature of 26 °C was estimated at 0.59 year^{-1}. Fishing Mortality (F) was 2.00 year^{-1} and Exploitation Rate (E) 0.77 year^{-1} (Fig. 5).

Fishing gear catch selectivity

Fishing selectivity for yellowfin tuna varied with gear type used (Table 3). The mean length at first capture (L_{50}) for all the gear types combined was 65.4 cm FL.

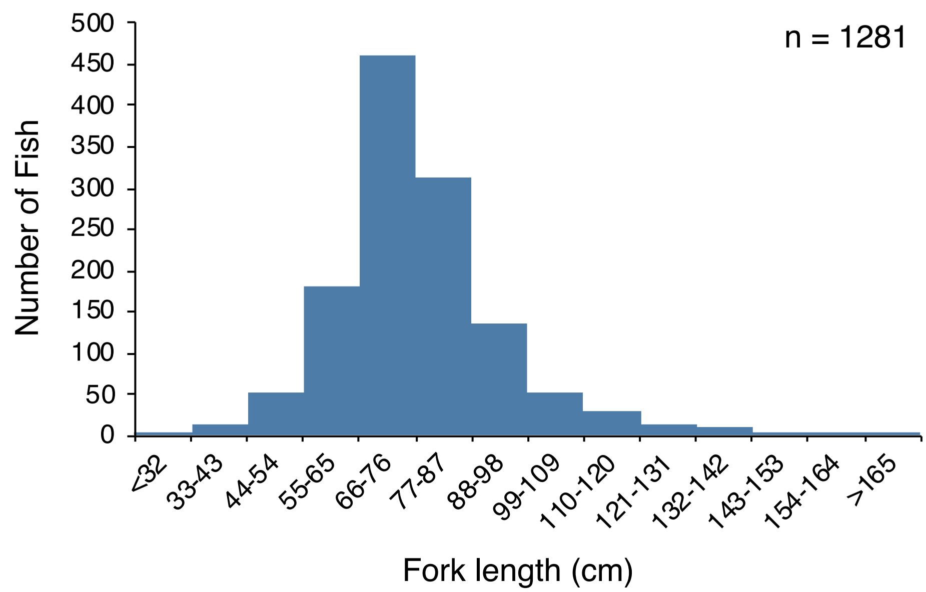

Figure 4. Length frequency distribution of *Thunnus albacares* in the coastal waters of Kenya for the period August 2015 to December 2016.

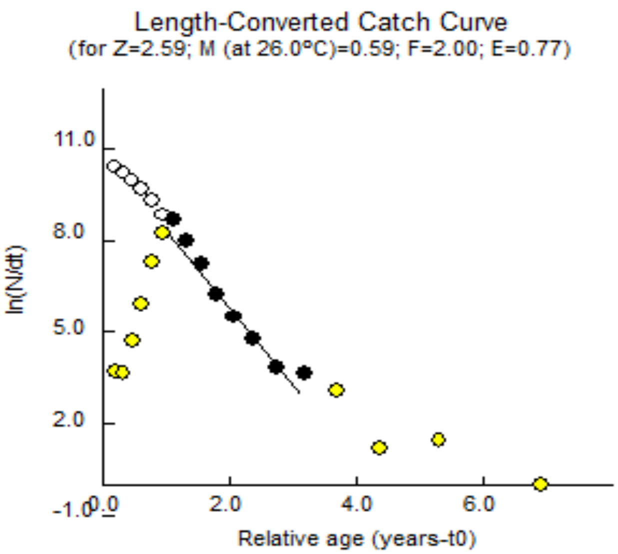

Figure 5. Length-Converted Catch Curve for yellowfin tuna caught in the artisanal fishery in Kenyan waters between August 2015 to December 2016.

However, (L_{50}) in the main gear types used i.e. longline, handline and trolling was 93.3 cm, 75.6 cm and 68.9 cm, respectively. The mean length at which 95 % of the individuals were retained in the fishing gear was 80.66 cm for combined gears, 115.9 cm for longline, 91.4 cm for handline and 83.7 cm for trolling line. These results indicated that specific gears targeted different sizes of yellowfin tuna. Larger individuals were captured by longline as opposed to the other gear types.

Virtual Population Analysis (VPA)

The VPA for yellowfin tuna indicated that individuals were vulnerable to capture from >45 cm FL midlength, with highest catches occurring between 65-85 cm FL midlength (Fig 6). As expected, natural mortality gradually decreased with increasing length (and age). Fishing mortality was highest between the lengths of 65-105 cm FL midlength with a peak at 75 cm FL midlength.

Discussion

There was clear evidence of temporal variation and the results indicated that tuna catches peaked in May-June and October -November during the study period. These findings are comparable to the results of other studies (Kimani and Okemwa, 2019; Kaplan *et al*., 2014). The temporal variation of yellowfin tuna catch rates observed in this study could be attributed to a number of factors, including ocean dynamics, the quality of the habitat, food availability, type and selectivity of fishing gears, sex and size of individuals, spawning and the migratory nature of the tunas (Tuda *et al.,* 2016; Potier *et al*., 2007; Abdel-Barr *et al*., 2012; Kar *et al.,* 2012; Kaplan *et al.,* 2014). The coastal waters of the Somali basin are highly productive in the months of July to October (Kaplan *et al.;* 2014; Chassot *et al*., 2019) with some upwellings (Chassot *et al*., 2019; Schott *et al*., 2009) leading to increased food abundance for tunas, and this would explain why there was an increased abundance of yellowfin tuna during this period.

Yellowfin tuna are highly migratory species and respond to changes in seasons (Boggs, 1994). The monsoon climatic season and weather patterns experienced along the coastline in the Western Indian Ocean region have some influence on the distribution and abundance of marine fishes including the tunas (Koido and Suzuki, 1989; Yamanaka, 1990; Nzioka, 1990; Zudaire *et al.,* 2013). The relatively low catches of yellowfin tuna recorded between December and April (NEM months) demonstrate that some of the individuals could have moved out of the study area for spawning purposes or other natural reasons (Campling,

Table 3. Selectivity parameters of yellowfin tuna from length converted catch curve and the probabilities of capture (Fork Lengths in cm).

Parameter	All gears	Longline	Trolling line	Handline
Total Mortality (Z)	2.59	1.11	3.9	3.9
Fishing Mortality (F)	2.0	0.52	3.3	3.4
Exploitation rate (E)	0.77	0.47	0.85	0.85
Length at capture (Lc 25)	58.9			
Length at capture (Lc 50)	65.4	93.3	68.9	75.6
Length at capture (Lc 75)	71.9	102.4	74.7	81.8
Length at capture (Lc 95)	80.66	115.9	83.7	91.4

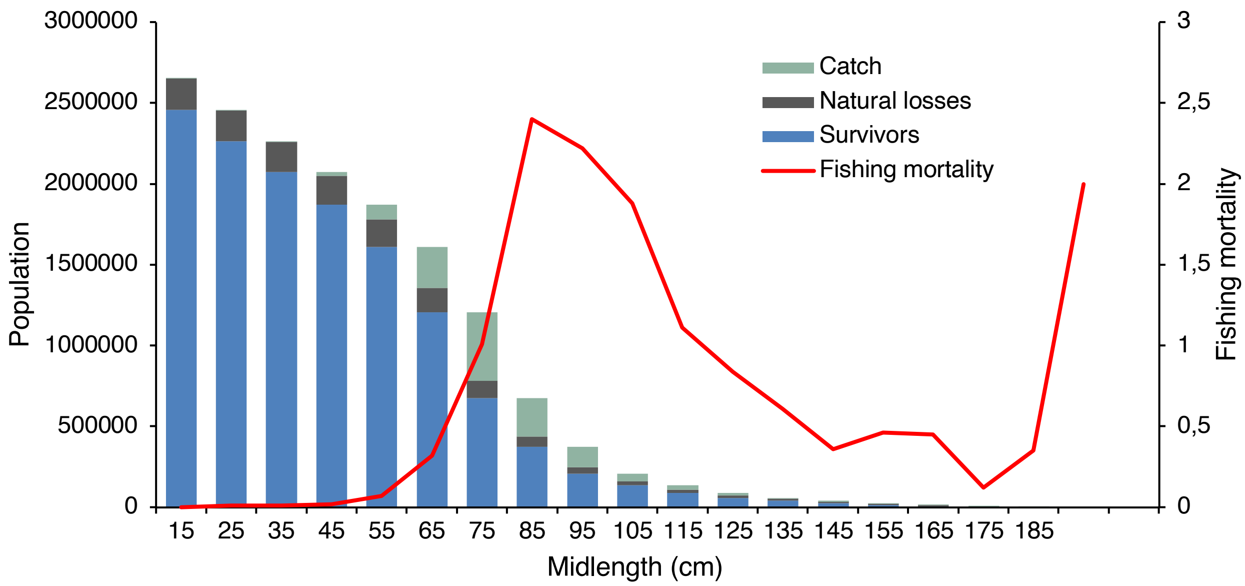

Figure 6. Output of the Virtual Population Analysis showing total population, catches, fishing mortality, natural mortality and survivors (biomass) per length group of yellowfin tuna caught by the artisanal fishers off the coast of Kenya.

2012; Ministry of Agriculture, Livestock and Fisheries, 2013). Peak spawning activity for yellowfin tuna in the Indian Ocean occurs during summer between October and May in the southern hemisphere (Stequert *et al.*,1996; IOTC, 2003; Gouping *et al.*, 2008). Yellowfin tuna catches were recorded throughout the sampling period at all the sites, although with varying high and low peaks in abundance. This suggests that some individuals, particularly juvenile fish, were more resident in the coastal waters of Kenya, however this will require validation using evidence from tagging studies . Similar observations have been reported by other studies which suggest regional residency and limited movements for yellowfin tuna, especially in inshore coastal waters (Chassot *et al.*, 2019; Schaefer *et al.*, 2007; Schaefer *et al.*, 2011; Kaplan *et al.*, 2014).

Analysis of the yellowfin tuna catch sampled revealed variation in fish catch rates across the sites with Shella and Watamu reporting high catches. This observation is partly attributed to the level of fishing effort, the type and size of fishing gears deployed by the fishers as well as the size of fish targeted. The correlation between fishing effort and fish catches had an implication on the CPUE across the fish landing sites. Highest fishing effort was concentrated in Watamu and Shella accounting for at least 33 % and 32 % of the fisher days whereas Amu had the lowest fishing effort (6 %).

Mombasa reported the highest mean catch rate compared to the other fish landing sites. Watamu reported the highest quantities of the total catch sampled (27 %), however , the site also reported the highest fishing effort which resulted to low CPUE for the fisher. The correlation between fishing effort and catches had implication on the CPUE across the fish landing sites. The type of fishing gear also contributed to the difference observed in fish catch rates across the sites. Fishers deployed different gears and gear combinations to maximize the harvest and size of targeted fish. Results show that the highest quantities of fish sampled at Watamu were harvested using trolling lines. On the other hand, longline catches dominated the landings at Old Town. The longline gear on average harvested fairly large sized individuals of yellowfin tuna, ranging from 59 cm FL – 205 cm FL with an average of 113.78 cm FL. Trolling line on the other hand captured individuals within the size range 11 cm FL – 120 cm FL with an average size of 73.0 cm FL. However this study did not investigate the different size ranges of gears including gillnets and hooks deployed by fishers. Further research is required to investigate selectivity of the different sizes of gears on yellowfin tuna fishery in Kenyan coastal waters.

The length -frequency distribution of yellowfin tuna caught suggest that the catch was dominated by juveniles peaking at the 66-76 cm FL size class. Size at first maturity for yellowfin tuna has been estimated at approximately 100 cm FL (Viera, 2005; Stequert *et al.*, 1996; Kaplan *et al.*, 2014; Itano, 2000). The results of this study compare well with the work reported by other authors. For example, the IOTC (2016) reported that most of the yellowfin tuna landed by artisanal fishers in Kenya ranged in size from 70 – 85 cm FL. Further afield, Kaymaram *et al.* (2014) reported a size range of 37 – 172 cm FL from the gillnet fishery in the Oman Sea. Prathibha (2013) estimated a size range of 20 – 185 cm FL for the yellowfin tuna on the east coast of India. Mildenberger *et al*. (2018) reported a size range of 25cm – 199 cm FL for yellowfin tuna in the driftnet fishery in Zanzibar waters.

The growth parameters from this study compare closely with those of Kayamaram *et al*. (2014) who estimated L_∞ = 183.3 cm, K = 0.45 and ϕ = 4.21 for yellowfin tuna in the Oman Sea. Studies conducted by other authors show a range of estimated growth parameters for yellowfin tuna in different parts of the Indian Ocean (Prathibha *et al.,* 2012; Chantawong, 1998; Maldeniya and Joseph 1986; Prathibha, 2013; Nurdin *et al.,* 2016) (Table 4). The growth coefficient (K) in this study was estimated at 0.43 year^{-1} which was found to be higher than 0.30 year^{-1} found in waters on the east coast of India (Prathibha *et al*., 2012; Prathibha, 2013; Nurdin *et al.,* 2016). However, the growth coefficient was lower than that found in a number of other studies from the Indian Ocean (Chantawong, 1998; Maldeniya and Joseph 1986; Nurdin *et al.,* 2016; Kayamaram *et al*., 2014) . This result suggests that yellowfin tuna encountered in the coastal waters of Kenya do not grow at a faster rate than elsewhere. Froese *et al*. (2011) reported that a high proportion of juveniles or adults in the sample may limit the size ranges of the fish, consequently leading to under-estimating or over-estimating the growth parameters. In this study, over 90 % of the fish sampled were below the estimated length at first maturity (100 cm FL). This probably explains why the growth coefficient was lower compared to other studies.

Yellowfin tuna mortality rates estimated in this study were compared with other studies in the Indian Ocean. Kaymaram *et al.* (2014) estimated an exploitation rate (E) of 0.76 year^{-1} and a total mortality rate (Z) of 2.04 year^{-1} which compares favourably to the results of this study (E = 0.77 year^{-1} and Z = 2.59 year^{-1}, respectively). Natural mortality rate (M) estimated in the present study (M = 0.59 year^{-1}) was very similar to a number of other estimates from the same region of between 0.52 year^{-1} and 0.67 year^{-1} (Pillai *et al.,*1993; John, 1995; Kaymaram *et al.,* 2000).

This study revealed that the estimated fishing mortality rate (F = 2.0 year^{-1}) was substantially higher than the natural mortality rate (M) suggesting that fishing pressure is too high and not sustainable. Moreover, the exploitation rate (E) of 0.77 year^{-1} is higher than the recommended optimal rate of 0.5 year^{-1} further emphasizing the high fishing pressure on yellowfin tuna in Kenya's coastal waters. Since most of the individuals being harvested were juvenile fish less than 100 cm FL, this implies that growth overfishing is occurring in this fishery.

The artisanal fishery in Kenya targets multiple species and fishers deploy different gears (Tuda *et.al*., 2016). Major fishing gears deployed by artisanal fishers to catch yellowfin tuna in Kenyan coastal waters are longlines, hand lines and trolling lines. This study reveals that trolling line was the most used gear targeting tuna and tuna-like species accounting for 54 % fisher days. Handline accounted for 27 % of the fisher days. Longline and gillnet accounted for 16 % and 3 %

Table 4. Comparison of growth parameters for yellowfin tuna in the Indian Ocean from different authors.

Study area/region	L_∞	K (Year^{-1})	t_0	Author
Kenya coastal waters	195.0	0.43	- 0.83	This study
India (East Coast)	197.4	0.3	- 0.116	Prathibha *et al*. (2012)
Eastern Indian Ocean	194.0	0.66	- 0.27	Chantawong (1998)
Sea of Oman	183.2	0.45	- 0.184	Kaymaram *et al.* (2014)
Sirilanka (West and South)	178.0	0.47	- 0.28	Maldeniya and Joseph (1986)
East Coast India (Andhra and Pradesh)	197	0.3	- 0. 115	Prathibha (2013)
Eastern Indian Ocean	178	0.47	-0.213	Nurdin *et al*. (2016)
Zanzibar (Tanzania)	165	0.878	-0. 49	Mildenberger *et al.* (2018)

of the fisher days, respectively. The size at first capture (L_{c50}) for yellowfin tuna varied with the different gears used. Longline was highly selective to large sized individuals with length at first capture of 93.3 cm FL and an average size of 113.8 cm FL. There was no significant difference in the average size of yellowfin tuna captured using handlines and trolling line, although the length at first capture (L_{c50}) was slightly different (75.6 cm FL and 68.9 cm FL, respectively.) Similarly, the size of yellowfin tuna captured by different gear combinations varied spatially with landing sites. Old Town recorded the largest mean size of fish landed there (115.04 cm FL) whereas Mnarani reported the lowest mean size (69.82 cm FL). This can be partly attributed to the fact that relatively larger fishing vessels using longlines were predominantly used to catch yellowfin tuna landed at Old Town. These vessels could venture further offshore and remain at sea for longer periods despite the sea conditions being rough. At the other landing sites smaller fishing boats employing handlines and trolling lines were predominantly used by artisanal fishers to target yellowfin tuna. Approximately 78 % of the total fish catch sampled was captured using trolling (46 %) and handlines (32 %).

The results suggest that the selectivity of the gears depends on the size and population dynamics of the fish targeted (Maunder *et. al.,* 2006), the type and size of fishing gear used, and the fishing ground (Tuda *et. al,* 2016). It is evident from this study that fishers employing gillnets, handlines and trolling lines generally target smaller sized yellowfin tuna. Noting that most of the individuals of yellowfin tuna sampled in this study were juveniles and sub-adults, efforts should be directed towards close monitoring of the catch to ensure young fish that are necessary for recruitment are not caught. Development of technical measures and appropriate regulations defining the type of fishing gear, seasons, and fishing grounds to catch larger sizes of tuna is desirable. This would enhance stock sustainability of the target species and minimize the capture of juvenile fish and non-target species in the nearshore waters.

The results of this study showed that the highest fishing mortality (F) of yellowfin tuna was experienced between 65 cm – 105 cm mid-length . These results suggest that the fishing mortality rate was highest at this specific size range due to the selectivity of the fishing gear used (Amponsah *et al*., 2017; Kar *et al*., 2012). Furthermore, the high fishing mortality rate over this size range (i.e. mostly juvenile or sub-adult fish) is likely to have a substantial impact on survivorship and the number of yellowfin tuna that reach adulthood and are subsequently able to spawn (i.e. growth overfishing).

Conclusion

Findings from this study show that yellowfin tuna are present in Kenyan coastal waters throughout the year although most of them are small juvenile fish. This indicates the importance of nearshore/coastal waters as a nursery habitat and foraging grounds for juvenile yellowfin tuna; hence the need to put in place appropriate fisheries conservation and management measures to protect these critical ecosystems and fish stocks.

Over 91 % of the yellowfin tuna caught by artisanal fishers in Kenyan coastal waters are juveniles (less than 100 cm FL). Fishing mortality rate (F = 2.0 for combined gears) is substantially higher than the natural mortality rate (M = 0.59). The estimated exploitation rate (E) of 0.77/year is higher than the recommended optimal of 0.5/year. These are clear indications that growth overfishing is occurring in this fishery. These results reinforce the concerns raised by the IOTC that yellowfin tuna stocks within Kenya's inshore waters are being overfished. Unless efforts are made to address this situation, the fishery is most likely to decline. Enforceable measures to reduce fishing effort on yellowfin tuna and putting in place stock recovery plans should be a priority for the relevant national and regional fisheries management authorities including the Kenya Fisheries Service and the IOTC. The IOTC has recommended stock rebuilding for the Indian Ocean yellowfin tuna stocks.

To achieve this the following recommendations are proposed for Kenya's artisanal tuna fishery:

1. A comprehensive study on the biology of yellowfin tuna in the Indian Ocean is necessary to address the complexity of yellowfin tuna growth rates.
2. The artisanal and industrial fishers target the same yellowfin tuna stock. A study on yellowfin tuna resource overlaps and interactions between the artisanal and industrial fishers is recommended. This would yield useful data and information that would assist Kenya and the IOTC to develop effective measures to reduce overall fishing effort on the yellowfin tuna stocks in the Indian Ocean region.
3. It is evident from this study that fishing mortality for yellowfin tuna in the coastal waters of Kenya is

above the optimal levels indicating that the fishery is being overfished. The fishery should be closely monitored with a view to controlling fishing effort, restrictions on gear size and minimum landing size, closed areas and seasons for coastal fisheries.

4. The South West Indian Ocean Fisheries Commission (SWIOFC) should work closely with member states in collaboration with WIOMSA to undertake a regional assessment of yellowfin tuna in coastal waters in the SWIO region. This would inform the development of a regional management strategy for yellowfin tuna that would help drive this fishery to sustainability in order to derive more sustainable socio-economic benefits to the local fishing communities and the national economies of the respective SWIO range states.

Acknowledgements

The authors are grateful to the small scale fishers in the study sites who allowed us to use their catch in the sampling. We acknowledge the contribution of Kenya Fisheries Service (KeFS) and their field staff who were very helpful in facilitating the work on the ground. We are grateful to the University of Nairobi and WWF for their support which made this study possible. Thanks to the Editorial Committee of the Western Indian Ocean Marine Science Association (WIOMSA) for accepting this paper for publication in the Western Indian Ocean Journal of Marine Science.

References

Abdel-Barr M, El-Sayedi A, Al-Oraimi A (2012) Length-frequency, yield and biomass per recruit analysis for yellowfin tuna, *Thunnus albacares* (Bonnaterre 1788) in the Arabian Sea off Oman. Asian Fisheries Science 25: 290-302

Alicli TZ, Oray IK, Karakulak FS, Kahraman AE (2012) Age, sex ratio, length - weight relationships and reproductive biology of Mediterranean swordfish (*Xiphias gladius* L., 1758) in the Eastern Mediterranean. African Journal of Biotechnology 11 (15): 3673-3680

Amponsah SKK, Abdulhakim A, Ofori-Danson PK, Anyan KF (2017) Population dynamics if Bigeye Grunt, *Brachydeuterus auritus* (Valenciennes, 1831) in Ghana and management implications. Fisheries and Aquaculture Journal 8: 233 [doi:10.4172/2150-3508.1000233]

Anam R, Mostarda E (2012) Field identification guide to the living marine resources of Kenya. FAO species identification guide for fishery purposes. FAO, Rome. 357 pp

Boggs CH (1994) Methods for analyzing interactions of limited-range fisheries: Hawaii's pelagic fisheries. In: Shomura RS, Majkowski J, Langi S (eds) Interactions of Pacific tuna fisheries. Proceedings of the first FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, 3-11 December 1991. Noumea, New Caledonia. FAO Fisheries Technical Paper. No. 433 Volume 1. Rome, FAO. pp 74-91

Campling L (2012) The tuna "commodity frontier": Business strategic and environment in the industrial tuna fisheries of the Western Indian Ocean. Journal of Agrarian Change Volume 12 (2 & 3): 252-278

Chantawong P, Harnphachonkit S, Singtongyam W (1998) Tuna fisheries in the Eastern Indian Ocean. Paper presented at the Marine Fisheries Seminar, 5-7 August 1998, Eastern Marine Fisheries Development Center, Rayong Province, Thailand. 35 pp

Chassot E, Bodin N, Sardenne F, Obura D (2019) The key role of the Northern Mozambique Channel for Indian Ocean tropical tuna fisheries. Reviews in Fish Biology and Fisheries 29: 613-638 [https://doi.org/10.1007/s11160-019-09569-9]

Cren, CD (1951) The Length-Weight relationship and seasonal cycle in gonad weight and condition in Perch, *Perca fluviatilis*. Journal of Animal Ecology 20: 201-219

Fishbase (2018) Length weight parameters for *Thunnus albacares* (geometric means for (*a*) and (*b*)).

Fondo EN (2004) Assessment of the Kenya marine fisheries from selected fishing gears. Students Project. The United Nations University, Iceland. 55 pp

Froese R, Tsikliras AC, Stergiou KI (2011) Editorial note on weight–length relations of fishes. Acta Ichthyologica et Piscatoria 41 (4): 261-263

Fulanda BM, Wamukota A (2015) Socio-economic valuation of the artisanal tuna fishery in Kenya: The Lamu Seascape case study. WWF Tanzania Consultancy Report. Dar es Salaam, Tanzania. 59 pp

Gayanilo FC, Sparre P, Pauly D (1994) FAO-ICLARM Stock Assessment Tools (FISAT) user's guide. FAO Computerized information series (Fisheries) Vol. 1048

Gayanilo FC, Pauly D (1997) FAO-ICLARM Stock Assessment Tools (FISAT) Reference Manuals. FAO Computerized information series (Fisheries), No.8. FAO, Rome. 262 pp

Gouping Z, Liuxiong XU, Yingqil Z, Liming S (2008) Reproductive biology of yellowfin tuna *T. albacares* in the West-Central Indian Ocean. Journal of Ocean University of China (Oceanic and Coastal Sea Research) 7 (3): 327-332

Government of Kenya (2017) State of the coast report II: Enhancing integrated management of coastal and marine resources in Kenya. National Environment Management Authority (NEMA), Nairobi. 100 pp

Gulland J (1971) The fish resources of the oceans. FAO/ Fishing News Books, Surrey, England. 255 pp

Hoof LV, Steins N (2017) Mission report Kenya; Scoping mission marine fisheries Kenya. Wageningen Marine Research (University & Research Centre), Wageningen Marine Research Report C038.17. 136 pp.

IOTC (2013) Identification of tuna and tuna-like species in the Indian Ocean fisheries. IOTC, Seychelles. 26 pp

IOTC-SC20 (2017) Report of the 20th Session of the IOTC Scientific Committee, Seychelles. 30th November – 4th December 2017. IOTC-2017-SC20-R(E). Indian Ocean Tuna Commission (IOTC). 232 pp

IOTC (2003) Report of the sixth session of the Scientific Committee (IOTC-SC-06-03 R(E). Victoria, Seychelles. 83 pp

IOTC (2018) Kenya National Report to the Scientific Committee of the Indian Ocean Tuna Commission (IOTC). Victoria, Seychelles. 10 pp

IOTC (2018) Online Data Querrying Services (OQS) report for Kenya industrial yellowfin tuna [https://iotc.org/oqs]

IOTC (2019) Status of the Indian Ocean yellowfin tuna (YFT: *Thunnus albacares*) resource. IOTC-2019-SC 22-ES04. Indian Ocean Tuna Commission (IOTC). Victoria, Seychelles. 4 pp

IOTC (2020) Executive summary: yellowfin tuna. Indian Ocean Tuna Commission, Victoria, Seychelles. 6 pp

ISSF (2020) Status of the world fisheries for tuna. March 2020. ISSF Technical Report 2020. International Seafood Sustainability Foundation (ISSF), Washington DC, USA. 109 pp

Itano DG (2000) The reproductive biology of yellowfin tuna (*Thunnus albacares*) in Hawaiian waters and the western tropical Pacific Ocean: Project summary. Joint Institute for Marine and Atmospheric Research, University of Hawaii. 69 pp

Itano DG (2005) A handbook for the identification of yellowfin and bigeye tunas in fresh condition (v2). Pelagic Fisheries Research Programme, University of Hawai, USA. 57 pp

John ME (1995) Studies on yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) in the Indian Seas. PhD Thesis, University of Mumbai. 258 pp

Jones R, Van Zalinge NP (1981) Estimates of mortality rate and population size for shrimp in Kuwait waters. Kuwait Bulletin of Marine Science 2: 273-288

Kaplan DM, Chassot E, Amande JM, Dueri S, Demarcq H, Dagorn L, Fonteneau A (2014) Spatial management of Indian Ocean tropical tuna fisheries: potential and perspectives. ICES Journal of Marine Science 71 (7): 1728-1749 [doi.org/10.1093/icesjms/fst233]

Kar AB, Ramalingam L, Govindaraj K, Prasad GVA (2012) Study of the growth and population parameters of yellowfin tuna (*Thunnus albacares*) in the Adaman and Nicobar waters based on the length frequency data. IOTC-2012-WPTT14-30 Rev_1. Fishery Survey of India, Port Blair, A&N Islands, India. 17 pp

Kaymaram F, Emadi H, Kiabi B (2000) Population parameters and feeding habits of yellowfin tuna (*Thunnus albacares*) in the Oman Sea. India Ocean Tuna Commission (IOTC) Proceedings 3: 283-285

Kaymaram F, Seyed AH, Mohamed D (2014) Estimates of length-based population parameters of yellowfin tuna (*Thunnus albacares*) in the Oman Sea. Turkish Journal of Fisheries and Aquatic Sciences 14: 101-111

Kimani EN, Aura MC, Okemwa GM (eds) (2018) The status of Kenya fisheries: Towards the sustainable exploitation of fisheries resources for food security and economic development. Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa. 135 pp

Kimani E, Okemwa G (2019) An overview of the industrial tuna fishery in Kenya. KMFRI, Mombasa. 9 pp

KMFRI (2018) In: Njiru JM, Ruwa RK, Kimani EN, Ong'anda HO, Okemwa GM, Osore MK (eds) The RV Mtafiti: Marine research towards food security and economic development for Kenya. Kenya Marine and Fisheries Research Institute, Mombasa, Kenya. 102 pp

Koido T, Suzuki Z (1989) Main spawning season of yellowfin tuna, *Thunnus albacares*, in the western tropical Pacific Ocean based on gonad index. Bulletin - Far Seas Fisheries Research Laboratory (Japan) 26: 153-64

Majkowski J (2017) Global fishery resources of tuna and tuna-like species. FAO Fisheries Technical Paper No. 483. FAO, Rome. 54 pp

Maldeniya R, Joseph L (1986) On the distribution and biology of yellowfin tuna (*Thunnus albacares*) in the Western and Southern Coastal waters of Sri Lanka. National Aquatic Resources Agency. Colombo. Sri Lanka. 14 pp

Maunder MN, Sibert JR, Fonteneau A, Hampton J, Kleiber P, Harley SJ (2006) Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science 63: 1373e1385

McClanahan TR (1988) Seasonality in East Africa's coastal waters. Marine Ecology Progress Series 44: 191-199

Mildenberger TK, Omar OH, McLaverty C, Jiddawi N, Wolf M (2018) Indicators of stock status for large-pelagic fish based on length composition from driftnet fisheries in Zanzibar: Western Indian Ocean Journal of Marine Science 17 (2): 51-65

Ministry of Agriculture, Livestock and Fisheries (2013) Kenya tuna fisheries development and management strategy 2013 – 2018. Ministry of Agriculture, Livestock and Fisheries. Nairobi, Kenya. 45 pp

Ministry of Agriculture, Livestock and Fisheries (2016) Marine artisanal fisheries frame survey report. State Department of Fisheries. Nairobi, Kenya. 97 pp

Ministry of Agriculture, Livestock, Fisheries and Irrigation (2019) Agricultural sector transformation and growth strategy: Towards sustainable agricultural transformation and food security in Kenya (2019-2029). Nairobi, Kenya. 216 pp

Mitsunga Y, Endo C, Ricardo P, Babaran RP (2013) Schooling behaviour of juvenile yellowfin tuna *Thunnus albacares* around a Fish Aggregating Device (FAD) in the Philippines. Aquatic Living Resources 26: 79-84 [doi.org/10.1051/alr/2012031]

Mueni E, Ndegwa S, Wambiji N, Okemwa G, Kadagi N (2019) Kenya National Report to the Scientific Committee of the Indian Ocean Tuna Commission, 2019. IOTC-2019-SC22-NR_Rev1. 26 pp

Ndegwa S, Okemwa G (2017) Kenya National Report to the Scientific Committee of the Indian Ocean Tuna Commission (IOTC), 2016. IOTC-2016-SC19 –NR13. IOTC, Victoria, Seychelles. 7 pp

Nurdin E, Sondita M F A, Yusfiandayani R, Baskoro MS (2016) Growth and mortality parameters of yellowfin tuna (*Thunnus albacares*) in Palabuhanratu waters, west Java (eastern Indian Ocean). AACL Bioflux 9 (3): 741-747

Nzioka RM (1990) Fish yield of Kilifi coral reefs in Kenya. Hydrobiologia 208 (1): 81-84

Pauly D (1980) A selection of simple methods for the assessment of tropical fish populations. FAO Fisheries Circular 729. FAO, Rome. 54 pp

Pauly D (1983) Some simple methods for the assessment of tropical fish stocks. FAO Fisheries Technical Paper No. 234. 52 pp

Pauly D (1984) Length-converted catch curves: a powerful tool for fisheries research in the tropics (III: Conclusion). Fishbyte.

Pauly D, Munro JL (1984) Once more on the comparison of growth in fish and invertebrates. Fishbyte 2: 1-21

Pauly D (1984a) Fish population dynamics in tropical waters: a manual for use with programmable calcultors. ICLARM Studies and Reviews 8. Manila. 325 pp

Pauly D (1984b) Length converted catch curves : A powerful tool for fisheries research in the tropics (Part II). Fishbyte 2 (1): 17-19

Pauly D (1987) A review of the ELEFAN System for analysis of length-frequency data in fish and aquatic invertebrates. International Centre for Living Aquatic Resources Management. Manila, Philippines. 34 pp

Pauly D (1990) Length-converted catch curves and the seasonal growth of fishes. Fishbyte: The World Fish Centre Vol 8 (3): 33-38

PiIlai PP, Said KP, PiIlai NGK, Jayaprakash AA (1993). Fishery and biology of yellowfin tuna occurring in coastal fishery in Indian Seas. In: Sudarsan D, John ME (eds) Tuna research in India. pp 23-38

Pillai NGK, Palanisamy SK (2012) Biology, fishery, conservation and management of Indian Ocean tuna fisheries. Ocean Science Journal 47 (4): 411-433

Potier M, Marsac F, Cherel Y, Lucas V, Sabatie R, Maury O, Menard F (2007) Forage fauna in the diet of three large pelagic fishes (lancetfish, swordfish and yellowfin tuna) in the Western Equatorial Indian Ocean. Fisheries Research 83: 60-72

Prathibha R, Rao GS, Rammohan K (2012) Age, growth and population structure of the yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) exploited along the East Coast of India. Indian Journal of Fisheries 59 (1): 1-6

Prathibha R (2013) Traditional small scale fishing for yellowfin tuna *Thunnus albacares* in Andhra Pradesh along east coast of India. Central Marine Fisheries Research Institute. India. 6 pp

Regional tuna tagging project in the Indian Ocean (RTTP-IO) (2004) Tag recovery manual. Indian Ocean Tuna Commission (IOTC). Victoria, Seychelles. 23 pp

Schaefer KM, Fuller DW, Block BA (2007) Movements, behaviour and habitat utilization of yellowfin tuna (*Thunnus albacares*) in the Northern Pacific Ocean, ascertained through archival tag data. Marine Biology 152: 503-525

Schaefer KM, Fuller DW, Block BA (2011) Movements, behaviour and habitat utilization of yellowfin tuna (*Thunnus albacares*) in the Pacific Ocean off Baja California, Mexico, determined from archivial tag data analyses, including unscented Kalman filtering. Fisheries Research 112: 22-37

Schott F, McCreary J (2001) The monsoon circulation of the Indian Ocean. Progress in Oceanography 51: 1-123

Schott FA, Xie Shang-Ping, McCreary JP (2009) Indian Ocean circulation and climate variability. Reviews of Geophysics: 1-46

Sparre P, Venema SC (1998) Introduction to tropical fish stock assessment. Part 1-manual. FAO Fisheries Technical Paper (306.1) Rev. 2. 407 pp

Stequert B, Panfili J, Dean JM (1996) Age and growth of yellowfin tuna, *Thunnus albacares,* from the western Indian Ocean, based on otolith microstructure. Fishery Bulletin 94: 124-134

Tuda PM, Wolf M, Breck W (2016) Size structure and gear selectivity of target species in the multi-species and multi-gear fishery of Kenyan south coast. Ocean & Coastal Management 130: 95-106

Viera A (2005) Study of the growth of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on the length frequency data from 2000 to 2004. IOTC-2005-WPTT-32. IOTC, Victoria, Seychelles. 17 pp

Wekesa PN (2013) Kenya national report to the scientific committee of the Indian Ocean Tuna Commission. State Department of Fisheries. Nairobi, Kenya. 9 pp

Yamanaka KL (1990) Age, growth and spawning of yellowfin tuna in the southern Philippines. Working paper – Indo-Pacific Tuna Development and Management Programme. Colombo, Sri Lanka. 87 pp

Zudaire I, Murua H, Grande M, Bodin N (2013) Reproductive potential of yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. Fishery Bulletin 111 (3): 252-264