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Indicators of stock status for large-pelagic fish based on length composition from driftnet fisheries in Zanzibar

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Abstract

Small-scale fisheries (SSF) contribute to approximately half of the total landings of tuna and tuna-like species in the Indian Ocean and are an important form of employment and source of protein. Research into the properties and dynamics of SSF in East Africa are important for the assessment and sustainable management of fish stocks, however, detailed fisheries data are often inadequate or absent. Fisheries-dependent data on driftnet fisheries in Zanzibar, Tanzania, was collected during the northeast monsoon seasons in 2014 and 2015. The data describes the properties of the driftnet fisheries and allows for comparisons of the length composition of the landings of the SSF with large-scale industrial fisheries (IF) fishing in Tanzania's Exclusive Economic Zone (EEZ). This data also facilitates the calculation of stock indicators for the five most abundant tuna and tuna-like species landed in Zanzibar. Results show that the two fisheries (SSF and IF) exploit the same stocks, and landings are representative of a similar length composition, while operating in different parts of Tanzania's EEZ. High exploitation rates, above reference levels for all species were calculated, in agreement with official assessments by the IOTC, and suggest that calls for the expansion of the SSF should be reconsidered. The assessment and management of straddling stocks are discussed, as well as solutions to challenges faced by local observer programmes.

Keywords: Artisanal fisheries, billfish, IOTC, length-frequency data, tuna, Western Indian Ocean

Introduction

Although SSF contribute approximately half of global fish landings (FAO, 2015), few studies have directly compared SSF to IF (Chuenpagdee *et al.* 2006; Zeller *et al.* 2007). SSF are defined as "fishing households, using relatively small amounts of capital and energy, relatively small fishing vessels (if any), and making short fishing trips, close to shore" (Garcia, 2009). These fisheries can be commercial or subsistence, but provide fish mainly for local consumption (Garcia, 2009). In comparison to IF, SSF have access to far less technological equipment, storage capacity, and engine power, but involve a higher number of people and usually generate more yield per unit of fuel

(Kolding *et al.*, 2014). Compared to other coastal fisheries, large-pelagic fish are harvested in almost equal quantities by IF and SSF in the Indian Ocean (Anonymous, 2009), and therefore approaches which consider the two in unison are required. Large-pelagic fish are highly migratory with populations spanning over large areas (Kaplan *et al.*, 2014; Ward *et al.*, 1997). Accordingly, the fisheries which target large-pelagics are under jurisdiction of regional fisheries management organisations (RFMOs), such as the Indian Ocean Tuna Commission (IOTC) for the Indian Ocean. While these organisations utilise fisheries data for the management of the IF, such as CPUE, and additional data such as from large tagging programs

(Fonteneau and Hallier, 2015), catch information from SSF is often lacking and not incorporated in stock assessments. For this reason, management advice may not always be adequate for the stock under consideration (Costello *et al.*, 2012; Cullis-Suzuki and Pauly, 2010). The monitoring of SSF is complex due to the high number of small vessels involved, the usage of a variety of gears catching a large variety of species, and lastly, due to the decentralised landing sites along long coastal stretches (Anonymous, 2009; Salas *et al.*, 2007). Thus, fishery-dependent data for SSF such as catch and effort is either scarce or of low quality, for example, aggregated at a family level (Igulu and El Kharousy, 2013; Kolding *et al.*, 2014; Salas *et al.*, 2007). The use of length-frequency distributions (LFDs) in SSF are well established (Petersen, 1981), and provide a valuable and low-cost data source suitable for assessment. They allow for the estimation of population parameters, such as growth and mortality rates, and reference levels for the state of the fishery (Beverton and Holt, 1957; Mildenerberger *et al.*, 2017a). Moreover, they allow for the inference of selectivity properties of the gear and fleet, such as selected length and age classes represented in the landings.

Tanzania is the largest country in East Africa with a coastline 850 km in length and an Exclusive Economic Zone (EEZ) of over 240,000 km² within the Western Indian Ocean (Fig. 1; Jiddawi and Ohman, 2002). Tanzania's fishing fleet is dominated by SSF, apart from three flagged long line vessels (Igulu and El Kharousy, 2015). In 2012, the SSF in Tanzania was comprised of 4259 dugout canoes, 6815 outrigger canoes, 3842 boats powered by outboard engines, and 313 boats powered by inboard engine (Igulu and El Kharousy, 2013). Tanzania's SSF is concentrated mainly on reef areas within 6 nm from shore, while some boats exploit large-pelagic fish, like tuna, billfish and sharks using surface driftnets and handlines (Igulu and El Kharousy, 2013). In 2014, landings for tuna and tuna-like species comprised around 3468 tonnes (Igulu and El Kharousy, 2015). With regards to the IF, Tanzania sells licenses to foreign vessels for access to fish resources within its EEZ. The number of foreign vessels has increased in recent years, with licences increasing from 12 in the year 2002 (Jiddawi and Ohman, 2002) to 77 in the years 2013/2014 (Liganga, 2014). No information is available about sport fishermen and recreational fishing in Tanzania (Igulu and El Kharousy, 2015). Zanzibar, consisting of the two islands of Pemba and Unguja (Fig. 1), contributes around 30% of Tanzania's marine fish landings

(FAO, 2016). While around two thirds of Zanzibar's landings consist of near-shore resources, one third consists of large-pelagic fish caught by driftnet fisheries (FAO, 2016). Driftnets are passive nets deployed at the water surface or in the water column and used for targeting pelagic species (European Commission, 1992; Caddell, 2010). While near-shore resources are thought to be overexploited (Jiddawi and Öhman, 2002; Mkenda and Folmer, 2001; Jacquet *et al.*, 2010; Colbert-Sangree, 2012), several authors have claimed that the offshore resources provide investment potential for fisheries expansion (Jiddawi and Öhman, 2002; Feidi, 2005; FAO, 2007), resulting in research programmes to assess the potential establishment of a national IF to release pressure on near-shore resources (Igulu and El Kharousy, 2015). Aside from official assessments for large-pelagic fish for the whole of the Indian Ocean, locally and regionally explicit studies investigating the exploitation status of stocks are rare or absent. However, such studies should be of particular importance when considering potential fleet expansions, and in national fisheries management.

This study describes the small scale driftnet fisheries in Zanzibar, as well as the length-composition of the five most abundant species, in terms of landings: Indo-Pacific sailfish (IPS - *Istiophorus platypterus*, Shaw and Nodder, 1792; Swahili: Mbasi), Yellowfin tuna (YFT - *Thunnus albacares*, Bonnaterre, 1788; Swahili: Jodari), Common dolphinfish (CPH - *Coryphaena hippurus*, Linnaeus, 1758; Swahili: Panje), Skipjack tuna (SKJ - *Katsuwonis pelamis*, Linnaeus, 1758; Swahili: Jodari), and Kawakawa (KAW - *Euthynnus affinis*, Cantor, 1849; Swahili: Jodari). The LFDs of these species are analysed in regards to differences between SSF and IF, and stock status indicators estimated. Results are discussed in the light of the application of this type of information and its implications for the management of driftnet fisheries in Zanzibar. All collected data are also provided as open source.

Methods

Sampling area and routine

Fisheries-dependent data for small-scale driftnet fisheries in Zanzibar were collected at the landing sites of Nungwi, Mkokotoni, and Fukuchani in the northern district of Unguja, Zanzibar (Fig. 1). These data were collected over seven to fourteen days each month, between October 2014 and March 2015, corresponding to the northeast monsoon season in the Western Indian Ocean. Unguja is the most important island for driftnet fisheries in Zanzibar during the northeast monsoon

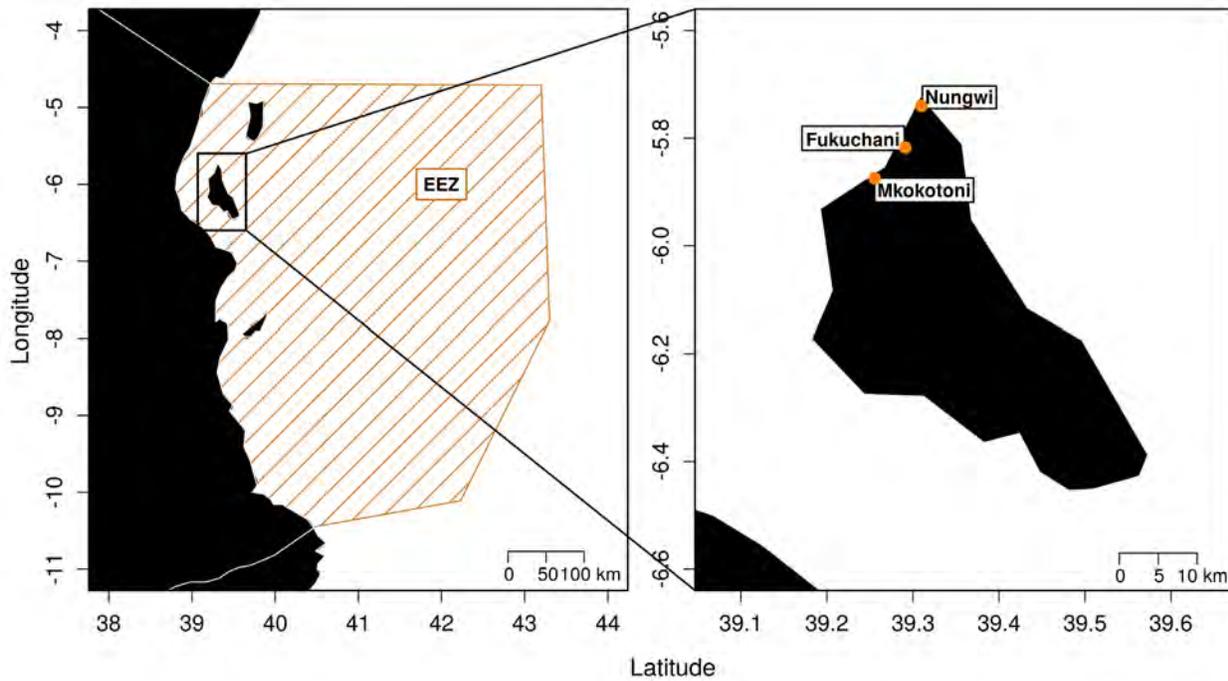


Figure 1. Map of the coastline and Exclusive Economic Zone (EEZ; hatched orange polygon) of Tanzania and close up of Unguja, the southern island of Zanzibar with the main sampling sites: Nungwi, Fukuchani, and Mkokotoni.

season, during which large-pelagic fish landings are highest (based on preliminary samplings and interviews with fishermen). Sampling effort was adjusted to the moon-dependent dynamics of fishing activities (no fishing effort for one week around full moon).

During sampling, fork length (FL: fish length from the front to the fork in the centre of the tail) of all fish landed by the driftnet fishermen was measured with a flexible tape, to the nearest 0.5 cm. In the case of sailfish, in addition to FL, the lower jaw fork length (LJFL) and the length from behind the eye to the fork (EFL)

were measured (Cerdaneres-Ladrón De Guevara *et al.*, 2011), allowing the inference of LJFL for individuals where the rostrum and the lower jaw was broken, damaged or missing ($FL = -2.07 + 0.75 EFL$ and $LJFL = -2.39 + 0.88 EFL$). Between 14 and 940 fish lengths of the SSF were measured each month (Table 1). FL, LJFL, and EFL are available on GitHub (see supporting online information). Maturity states and gender were not determined due to time limitations at auctions.

Length measurements from the IF were available for YFT and SKJ for the Tanzanian EEZ for the

Table 1. Number of fish measured for the small-scale fisheries (SSF) and industrial fisheries (IF) by month.

Species	Fisheries	Oct 2014	Nov 2014	Dec 2014	Jan 2015	Feb 2015	March 2015	Total
YFT	SSF	118	437	940	413	324	126	2358
	IF	132	204	2065	699	56	69205	72361
SKJ	SSF	151	354	523	110	135	82	1355
	IF						329686	329686
IPS	SSF	14	127	244	109	182	129	805
KAW	SSF	42	369	347	284	276	165	1483
CPH	SSF	20	151	467	121	365	433	1557

period from April 2014 to September 2015, and were retrieved from the corresponding IOTC working parties (Table 1; see supporting online information). IOTC compiles length-composition data of the catches collected by observers on board the fishing vessels, where length measurements are collected following two sampling strategies; stratified sampling or proportional sampling for multispecies fisheries, (IOTC, 2010). In both cases, 50 to 200 fish per haul are measured but the total number of measured fish is dependent on the size of fish, if catch consisted of one or multiple schools, and if a mode appears in the length frequency data. Observers record the FL for tuna and the LJFL for billfish to the nearest 1 cm using either large callipers (1.5 m), a measuring board, and/or flexible tape (IOTC, 2010). The IF length data covers the same period as the SSF data, but also provides data for the southeast monsoon season, and is therefore representative of a full meteorological year. The two main gears of the IF in Tanzania's EEZ are long lines (under Tawianese and Japanese flags) and purse seines (under French and Spanish flags) (Deep-sea Fishing Authority, pers. comm.). For IPS, KAW, and CPH, no length measurements from the IF were available, and our analysis was therefore focused on the SSF data only.

Data analysis

Length measurements were pooled over all gears into 2 to 4 cm length classes and compiled into LFDs for each species. The LFDs were compared between species and fisheries and used to construct length-converted catch curves, for the purpose of estimating the instantaneous total mortality rate (Z) from the slope of the regression of the descending part of the curve (Edeser, 1908; Pauly, 1983). The construction of the catch curves based on LFDs requires information about growth parameters to estimate the relative age of the individuals. Here, growth parameters (L_{∞} and K) of the von Bertalanffy growth equation (VBGE) (von Bertalanffy, 1934; 1938) were gathered from other studies for the catch curves estimates (Table 3).

The same growth parameters were used for data from the different fisheries. Growth parameters from nearby regions and the Indian Ocean were preferred, as well as parameters estimated with a single-stanza VBGE and age-based methods representative for both sexes. However, for SKJ and CPH, parameters derived by length-based methods were used (Pó *et al.*, 1992; CMFRI, 2016) and for IPS values representative of the sex-specific growth curves for the male fish were used (Hoolihan, 2006). Since all species

are highly migratory (Kaplan *et al.*, 2014; Ward *et al.*, 1997), the parameters from chosen studies and regions were deemed to be representative.

Based on the growth parameters, the instantaneous natural mortality rate (M) can be approximated by means of the empirical formula of Then *et al.* (2015):

$$M = 4.118K^{0.73} L_{\infty}^{-0.33}$$

where K and L_{∞} are the growth parameters of the VBGE. By subtraction of M from Z , an estimate of the instantaneous fishing mortality rate (F) can be approximated and an indicator of the exploitation rate be estimated ($E = F / Z$).

All analyses were done in R (R Core Team, 2018) using the TropFishR package (Mildenerger *et al.*, 2017b) and the following additional packages, gdata (Warnes *et al.*, 2017), SDMTTools (VanDerWal *et al.*, 2014), reshape2 (Wickham, 2007), sp (Pebesma and Bivand, 2005; Bivand *et al.*, 2013), adehabitatHR (Calenge, 2006), maps (Brownrigg, 2018), and rgdal (Bivand *et al.*, 2018).

Results

The main fishing grounds of the driftnet fisheries in Zanzibar are located between the northern island of Pemba and the southern island of Unguja, as well as in the Zanzibar channel (between Unguja and Pemba and the mainland; Fig. 1). The maximum distance to the mainland shore and the islands was estimated by means of GPS trackers to be ~37 km. More than 28 different species were caught by the driftnet fishermen during the study period; however, the five selected species (YFT, SKJ, IPS, KAW, CPH) comprise 88.6% of the catch of the driftnet fisheries in Zanzibar (Table 2).

Seven to 14 pieces of black, blue, or grey gillnet (100 m x 15 m), either hand-made or industrially fabricated, are used in the driftnet fisheries. These are bound together, reaching a total length of around 1 km. Mesh sizes range from 3 to 6 inch (7.6 cm to 15.2 cm), and nets are often combined indiscriminately. The gillnets are deployed at the surface reaching depths of up to 15 m. Some fishermen also used handlines on the way to or from the fishing grounds, which influences the species- and length-composition of the landings. The fisheries are carried out exclusively at night, and results from interviews indicate that nets are deployed for around 7.7 ± 2 h per fishing trip. For about a week around full moon, no fishing takes

Table 2. Catch composition, total landings (kg) and percentage contribution to landings (%) for North A district over whole study period. The table excludes other species with a percentage contribution less than 0.04% (e.g. *Carangidae spp* and sharks). The shaded rows represent the five most abundant species in the landings of the small-scale driftnet fisheries, which were selected for further length-based analyses in the present study.

Species	Landings	Percentage
Indo-Pacific sailfish (<i>Istiophorus platypterus</i>)	57207	36.8
Yellowfin Tuna (<i>Thunnus albacares</i>)	34663	22.3
Common Dolphinfish (<i>Coryphaena hippurus</i>)	22427	14.4
Skipjack Tuna (<i>Katsuwonus pelamis</i>)	13124	8.4
Kawakawa (<i>Euthynnus affinis</i>)	10411	6.7
Black marlin (<i>Istiompax indica</i>)	7937	5.1
Cobia (<i>Rachycentron canadum</i>)	1745	1.1
Longtail tuna (<i>Thunnus tonggol</i>)	1544	1
Wahoo (<i>Acanthocybium solandri</i>)	1340	0.9
Narrow-barred spanish mackerel (<i>Scomberomorus commerson</i>)	1326	0.9
Striped marlin (<i>Kajikia audax</i>)	1026	0.7
Blue marlin (<i>Makaira nigricans</i>)	791	0.5
Swordfish (<i>Xiphias gladius</i>)	673	0.4
Kingfish (<i>Scomberomorus plurilineatus</i>)	538	0.3
Frigate tuna (<i>Auxis thazard</i>)	535	0.3
Striped bonito (<i>Sarda orientalis</i>)	46	<0.05

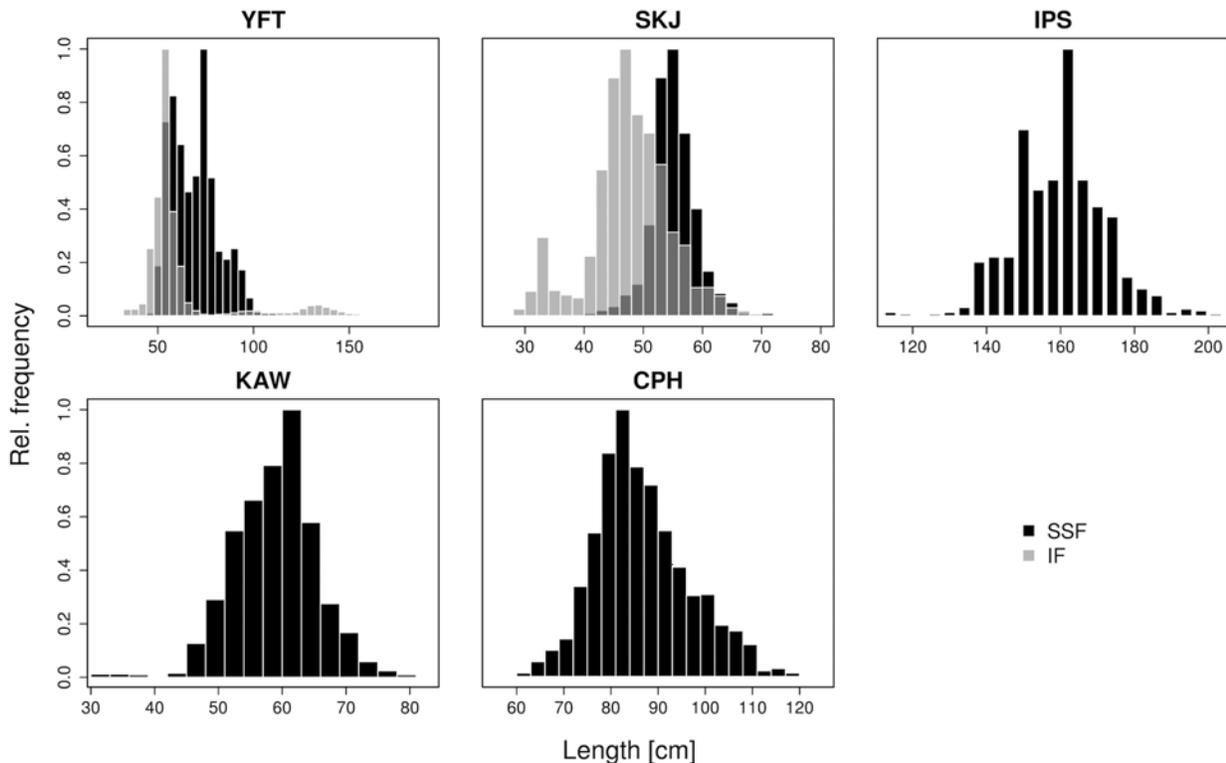


Figure 2. Length-frequency distributions (LFDs) of SSF landings for all species (black bars): Yellowfin tuna (YFT), Skipjack tuna (SKJ), Indo-Pacific sailfish (IPS), Kawakawa (KAW), and Common dolphinfish (CPH). Grey bars represent the LFDs of the IF landings for YFT and SKJ.

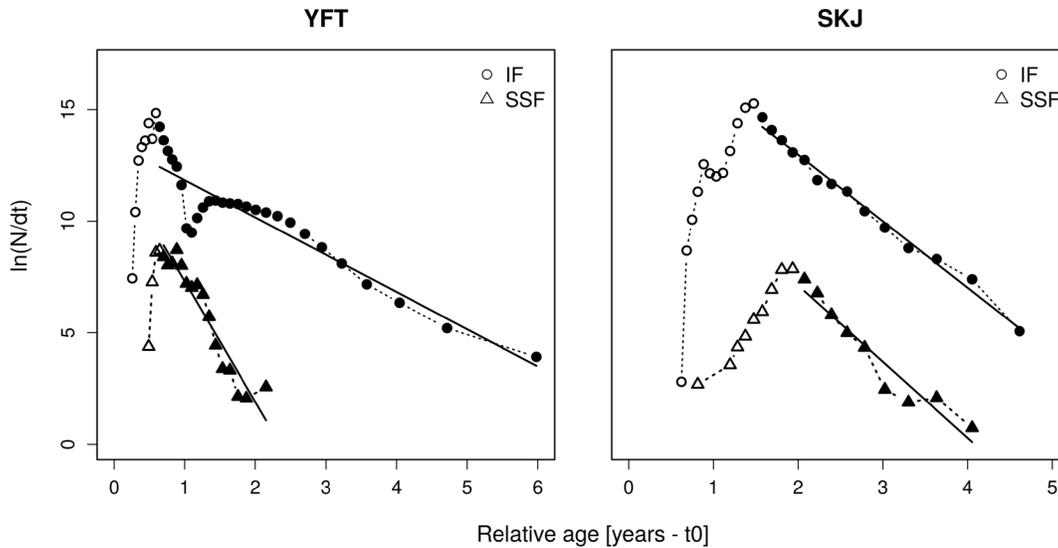


Figure 3. Length-converted catch curves for Yellowfin tuna (YFT) and Skipjack tuna (SKJ) based on data from the SSF (triangles) and from the IF (circles). Filled triangles and circles represent the data used for the regression line for both fisheries, respectively.

place, and shortly before and after full moon fishermen deploy the net for a shorter time (1.5 to 3 h).

While the length range of IF landings of YFT range from 25 to 199 cm, the SFF landed individuals between 45 and 143 cm during the study period. The length range differences between both fisheries for SKJ were less, with a range from 21 to 77 cm for IF and 32 to 79 cm for SFF. The length range for IPS, KAW, and CPH was from 118 to 200 cm, 34 to 80 cm, and 58 to 122 cm, respectively. The length composition of the landings for all species is displayed in Fig. 2.

While for SKJ, IPS, KAW, and CPH the LFDs of SFF shows a unimodal distribution with peaks around

56, 160, 60, and 84 cm, respectively, the distribution for YFT indicates three peaks at 55, 78, and 92 cm. The monthly LFDs indicate potential cohorts more clearly for YFT (Fig. 5a), while for the remaining species no multiple peaks and potential cohorts are visible (Fig. 5a and 5b). Comparing SSF and IF landings of YFT reveals that IF catch mainly smaller individuals of ~50 cm, and large individuals ~130 cm. IF landings for SKJ exhibit two peaks at 32 and 46 cm, below that of the SSF.

Overall, the catch curves show a clear pattern with a good representation of the descending part of the catch curves by the regression lines (Fig. 3 and 4). The high adjusted R^2 values (Table 3) reveal a good fit of the regression lines to the data. Estimates of the total

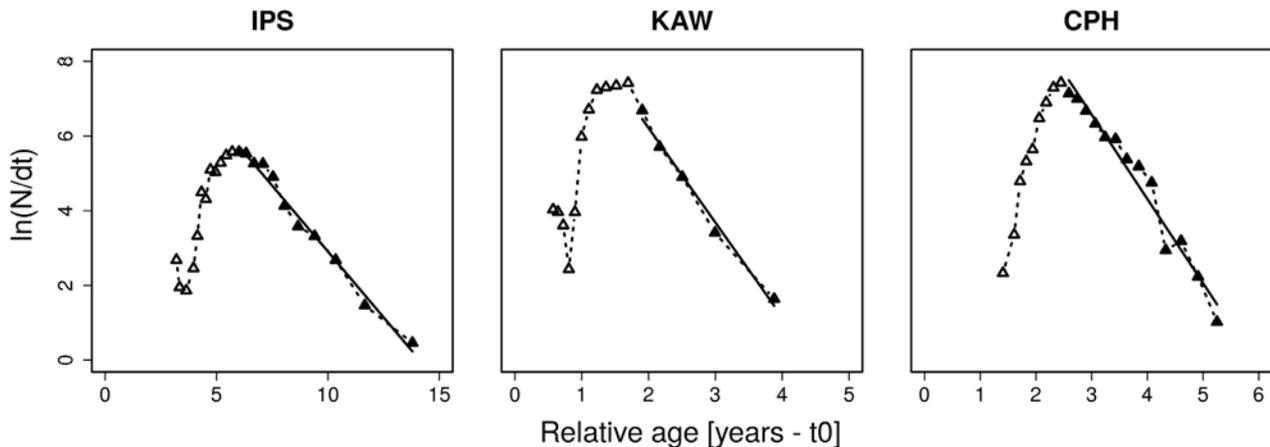


Figure 4. Length-converted catch curves for Indo-Pacific sailfish (IPS), Kawakawa (KAW), and Common dolphinfish (CPH) based on data from the SSF. Filled triangles represent the data used for the regression line for SSF.

mortality (slope of the regression line) have a wide range from 0.71 to 5.41, and differ between the five species sampled from the SSF. IPS demonstrated the lowest values, and SKJ the highest (Table 3).

Catch curves of KAW and CPH span a similar length range and show a similar slope of the regression lines of 2.53 and 2.26, respectively. A very different and much lower slope of 0.71 was found for IPS (Fig. 4 and Table 3). Overall, the descending part of the catch curves are well represented by the regression line with high adjusted R^2 values of 0.96 to 0.99 for those three species (Table 3).

Natural mortality estimates range from 0.3 and 0.36 for IPS and CPH, to 0.89 for KAW (Table 3). Fishing mortality is highest for YFT and lowest for IPS. For all species, the E values are above the reference level of 0.5, indicating overfishing (Gulland, 1983). While for IPS, E is only slightly larger than the reference level ($E=0.58$) for SKJ and CPH, E is with -0.8 much higher than the reference level.

The Z estimates from the SSF were significantly higher than for the IF, with values of 5.41 and 3.42 vs 1.67 and 2.98 for YFT and SKJ, respectively. While the regression line of the catch curve for YFT starts at a similar relative age in both fisheries, the curve for IF is above the curve of SSF due to the higher number of samples. Furthermore, the slope is far steeper for the SSF than for the IF, but the exploited age range much shorter. As demonstrated in Fig. 3, a single regression line is a poor representation of the landings for the IF over the whole size range. Between relative ages of 0.6 to 1.3 the decline is very high, followed by an increase and second lower decline from ages 1.7 to 6. This is also reflected by a lower overall R^2 value of the

regression line of 0.86. For SKJ, the catch curves of IF and SSF show a similar pattern (slope of decline and length range of declining part of the curve), however, there are more samples from the IF and the resulting curve is shifted vertically (Fig. 3). Similar to the Z estimates, the F estimates of the SSF are larger than for the IF. E values for SKJ are 0.8 and 0.78, almost identical between SSF and IF, respectively. However, for YFT, E is much higher for SSF than for IF (Table 3).

Discussion

This study describes SSF data from driftnet fisheries in Zanzibar, which target tuna and tuna-like species. Length-composition data were collected from SSF, and acquired for IF, for vessels operating in Tanzania's EEZ. These data were used to: (i) make a qualitative and quantitative comparison of the length composition of landings from both fisheries for the most abundant large-pelagic species; and (ii) for the estimation of stock indicators.

The length ranges of the landings highlight the selective nature of the gillnets used by the SSF, capturing only one cohort for all species. The exception to this was for YFT, where the monthly LFDs indicate three potential YFT cohorts, an observation which could not be determined from the yearly LFDs. SSF and IF operate in different parts of Tanzania's EEZ, due to the capacity of the vessels and jurisdictional/political boundaries (no distant water fleets are allowed in territorial waters). However, this study demonstrated that the two fisheries exploit the same resources of tuna and tuna-like species and the age ranges of these species overlap in the landings. Overall, IF catch a wider length range of fish, which can be attributed to the difference in gear type and fishery-dependent factors, as well as access of the IF to offshore fishing

Table 3. Literature parameters of the von Bertalanffy growth equation used for the estimation of the catch curve. Z represents the slope of the catch curve, however this might also include migration and is thus not referring to total mortality only (see discussion). The adjusted R^2 value is a goodness of fit statistic for the regression line of the catch curve analysis. The two values for Z, R^2 , M, F, and E represent the estimates based on the data from the SSF and IF, respectively. *The set of growth parameters for the male individuals of common dolphinfish of the sex-specific growth analysis were used (Hoolihan, 2016).

Species	L_{∞}	K	t_0	Reference	Location	Z	R^2	M	F	E
YFT	165	0.878	-0.49	Nurdin <i>et al.</i> (2016)	Indian Ocean	5.41/1.67	0.9/0.86	0.57	4.84/1.1	0.89/0.66
SKJ	80	0.601	-	Pó <i>et al.</i> (1992)	Mozambique	3.42/2.98	0.92/0.99	0.67	2.75/2.31	0.8/0.78
IPS*	191	0.29	-4.31	Hoolihan (2006)	Arabic gulf	0.71	0.99	0.3	0.41	0.58
KAW	79	0.89	-0.08	CMFRI (2012)	India	2.53	0.98	0.89	1.64	0.65
CPH	146	0.34	-	CMFRI (2016)	India	2.26	0.96	0.36	1.9	0.84

grounds. Although the youngest YFT cohort might be the same in SSF and IF landings, the IF landings were observed to contain a much higher number of smaller individuals. For SKJ, IF landings demonstrated a second, younger cohort, which was not represented in SSF landings. Although the (length-converted) catch curve analysis is an often used assessment tool to derive estimates of the instantaneous total mortality rate and exploitation rates in data-limited environments, the findings in this study suggest that the slope of the regression line of the catch curve analysis does not just reflect the sum of natural and fishing mortality rates. This rate might also be influenced by migration processes (emigration and immigration to fishing grounds), as well as gear and fishery-dependent aspects, such as gear selectivity. This method can thus not be used to directly infer information about the instantaneous total, or fishing mortality rates, of the stocks directly, but it allows for the comparison of the slopes between different fisheries/fleets, and the estimation of exploitation rates. As the nominator F and denominator Z are affected by migration processes to the same extent, this bias cancels out when calculating their ratio (E). Furthermore, under the assumption that natural mortality and migration do not differ spatially within the EEZ of Tanzania, the only other factor affecting the slope of the regression line is fishing mortality, apart from gear selectivity effects. Based on this reasoning, it may be assumed that the fishing mortality for skipjack tuna is comparable between the two fisheries, while it differs greatly between fisheries for yellowfin tuna. From the deviations in the descending part of the catch curve for YFT and IF (filled circles in Fig. 3) it may be inferred that F is relatively high for individuals younger than a relative age of 1.3, and much lower for individuals older than a relative age of 1.7. This trend in the catch curve can either be related to the different fleets (and thus gears) in the IF data (purse seiners vs. long-liners), or due to different mortality and migration regimes for juveniles and sub-adults. Tuna and tuna-like species have been shown to form size-dependent (mixed) schools (Broadhead and Orange, 1960), which display specific migratory behaviour (Hu *et al.*, 2018). The catchability of SSF is much lower than of IF, as it uses a passive, highly selective gear, only accessing the upper 15 m of the water column (size dependent schooling in different depths), while the IF uses active gears (purse seines) and passive gears (long lines), bird radar, helicopters and Fish Aggregation Devices (FADs; Majkowski, 2007; Tidd *et al.*, 2017). This allows IF to sustain relatively high landings even when stock

numbers are declining (Gulland, 1956; Tidd *et al.*, 2016). The SSF are limited in geographic range due to the size of their vessels, with many vessels operating without an engine and dependent on the wind.

The results show a high exploitation rate above reference levels, indicating overfishing in terms of fishing mortality for all species. No conclusion can be drawn regarding the stock status in terms of biomass. However, the estimated overfishing status corroborates official IOTC assessment results for YFT and IPS. IOTC classifies these species as overfished regarding fishing mortality (IPS), and fishing mortality and biomass (YFT; IOTC, 2017). The higher exploitation rate for YFT might reflect the fact that YFT is overfished in terms of F and biomass, while IPS only in terms of F , according to the IOTC. The smaller tuna species, SKJ and KAW are not classified as overfished according to the IOTC, but show high exploitation rates in this study. It is suggested that this may be due to the sub-population structures (Fonteneau, 2014) and local depletion of these stocks. While the official IOTC assessments consider data from the whole Indian Ocean for these species, only data from Tanzania's EEZ were considered in this study, and both data sources (SSF and IF) indicate high exploitation rates of 0.78 and 0.8, respectively. There are no official stock status estimates for CPH in the Indian Ocean or the region (Maguire *et al.*, 2006; IOTC, 2017). Although Benjamin and Kurup (2012) estimated a low exploitation rate for CPH between 2008-2009 in India, the findings from this study indicate that the exploitation rate of CPH in Tanzania might exceed biologically safe limits. The contrasting results between studies are likely explained by temporal or spatial differences in study period and location. Length-at-first-maturity (L_{50}) values of the studied species, SKJ: 41-43 cm, YFT: 100 cm, KAW: 38-50 cm, (IOTC, 2017), IPS: 157 cm EFL (Hernandez and Ramirez, 1998), and CPH: 47-49 cm (Rajesh *et al.*, 2016), show that 99% of the SSF length samples are smaller than L_{50} for YFT and 37% smaller for IPS, while the percentage for remaining species is close to 0%. This indicates that a large proportion of the tuna catches in Tanzania are juveniles (with 90% for IF YFT landings), which might reflect overfishing (Froese *et al.*, 2008; Myers and Mertz, 1998), the spatio-temporal occurrence of different length classes in the region, the gear selectivity, and a combination of these factors. Tanzania's EEZ forms an important section of the migration route of tuna (Hallier and Fonteneau, 2015), but is also part of the highly productive western Indian Ocean region (Bakun *et al.*, 1998;

Qasim, 1977) and therefore represents suitable habitat for the residence of juvenile tuna (Hu *et al.*, 2018).

Although the growth parameters used for the catch curve analysis were taken from regional studies, they allow for the comparison of the two fisheries (SSF and IF) as the same parameters were used. However, it should be noted that the growth of YFT could differ significantly between sexes (Shih *et al.*, 2014) and be better described by a gender-based two-stanza von Bertalanffy growth function (Dortel *et al.*, 2013). Furthermore, the results for SSF are based on data from one season only, and the variation in length-composition of the landings between seasons cannot determine. As with all fishery-dependent length-frequency data, results may be subject to biases due to recruitment variability, gear selectivity, and un-representative length measurements for the whole population (Punt *et al.*, 2001; Cope and Punt, 2009).

The management of straddling stocks has often been described as unsuccessful (Cullis-Suzuki and Pauly, 2010), although positive examples have also been acknowledged (Pons *et al.*, 2017). While spatial measures are prone to fail for highly-migratory species (Kaplan, 2013), input and output control measures might be more suitable. In any case, this study has demonstrated that IFs and SSFs targeting tuna and tuna-like species are interrelated, and must be managed in unison, a conclusion that was also shared by Leroy *et al.* (2016). Another challenge for management is the fact that two of the most abundant species in the SSF landings (KAW and CPH) are by-catch species in the IF (purse seiners (Ardill *et al.*, 2011), long liners (Huang and Liu, 2010), and any fishery associated with FADs (Dagorn *et al.*, 2013) and have an important market in Zanzibar, being sold to hotels and restaurants (Thyresson *et al.*, 2013). Accordingly, these species are important for the driftnet fisheries in Zanzibar, and are caught as by-catch by industrial. By-catch ratios greatly vary between areas and type of fisheries, but discard ratios for those fisheries can be as high as 60% (Dagorn *et al.*, 2013). The impact of sports and recreational fishermen should also be considered in the management of straddling stocks, particularly in light of growing tourism in Tanzania (MNRT, 2012).

Lastly, another crucial aspect of sustainable management concerns the monitoring of fishing activities and data collection, as this information is required for stock assessments and thus the definition of harvest control rules. The data collection on SSF must

be improved and included in the official assessments by RFMOs. With regard to the monitoring strategies and procedures in Zanzibar, the following suggestions might improve the quality and value of fisheries-dependent data: (i) catch data should be collected at species level, as the stock status of different species can be contrasting (e.g. YFT and SKJ; IOTC, 2017). Experience and interviews with local observers show that the problem is not the lack of knowledge of species identification of the observers, but the fact that this type of information is not required by the official agencies, or is lost in the administrative process. The quality of catch data can also be improved by monitoring the work of beach recorders; (ii) Effort data should be collected by beach recorders more frequently than the national survey (e.g. at a monthly level); (iii) Data representing the catch and effort of recreational fishing are needed and should be implemented by an obligatory observer monitoring procedure for companies renting boats and organising trips for recreational fishing; (iv) The collection of a subsample of length composition data should be considered. This type of data allows the inference of information about gear selectivity and exploited size ranges of SSF, and might be used directly in length-based stock assessment models such as SS3 (Methot and Wetzel, 2013), and used for official assessments such as for YFT and SKJ (IOTC, 2017). In particular, for by-catch species of the IF (KAW and CPH), LFDs from SSF are valuable and even allow inferences to be made regarding stock status, where no data from IF are available. For example, newly developed methods (e.g. Schwamborn *et al.*, 2018) are being used to derive reference levels to quantify uncertainty in catch data (Herrón *et al.*, 2018), and could be applied to species such as CPH. As this study shows, length measurements are easy and cost-efficient to collect, even without the necessity of owning or damaging sampled fish; and (v) lastly, the use of a mobile application, such as ABALOBI (<http://abalobi.info>) poses great potential for simplifying and standardising data collection.

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References

- Anonymous (2009) Report of the IOTC Performance Review Panel: January 2009. Indian Ocean Tuna Commission. 56 pp
- Ardill D, Itano D, Gillett R (2011) A review of bycatch and discard issues in Indian Ocean tuna fisheries. Indian Ocean Commission and SmartFish. pp 1-44
- Bakun A, Roy C, Lluch-Cota S (1998) Coastal upwelling and other processes regulating ecosystem productivity and fish production in the western Indian Ocean. In: Large Marine Eco- systems of the Indian Ocean Assessment, Sustainability, and Management (eds Okemwa, E., Ntiba, M. & Sherman, K.). Blackwell Science, Malden, MA, pp. 103-141.
- Benjamin D, Kurup BM (2012) Stock assessment of dolphinfish, *Coryphaena hippurus* (Linnaeus, 1758) off the southwest coast of India. Journal of the Marine Biological Association of India 54 (1): 1-96
- Beverton RJ, Holt SJ (1957) On the dynamics of exploited fish populations (Vol. 11). Springer Science and Business Media
- Bivand RS, Keitt T, Rowlingson B (2018) rgdal: Bindings for the 'Geospatial' Data Abstraction Library. R package version 1.3-6 [https://CRAN.R-project.org/package=rgdal]
- Bivand RS, Pebesma E, Gomez-Rubio V (2013) Applied spatial data analysis with R, Second edition. Springer, NY [http://www.asdar-book.org/]
- Broadhead GC, Orange CJ (1960) Species and size relationships within schools of yellowfin and skipjack tuna as indicated by catches in the Eastern Tropical Pacific Ocean. Inter-American Tropical Tuna Commission Bulletin 4 (7): 447-492
- Brownrigg R (2018) maps: Draw Geographical Maps. R package version 3.3.0. [https://CRAN.R-project.org/package=maps]
- Caddell R (2010) Caught in the net: Driftnet Fishing Restrictions and the European Court of Justice. Journal of Environmental Law 22 (2): 301-314
- Calenge C (2006) The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197: 516-519
- Cerdenares-Ladrón De Guevara G, Morales-Bojórquez E, Rodríguez-Sánchez R (2011) Age and growth of the sailfish *Istiophorus platypterus* (Istiophoridae) in the Gulf of Tehuantepec, Mexico. Marine Biology Research 7 (5): 488-499 [doi: 10.1080/17451000.2010.528201]
- Chuenpagdee R, Liguori L, Palomares MLD, Pauly D (2006) Bottom-up, global estimates of small-scale fisheries catches. Fisheries Centre Research Report 14 (8): 1-110
- CMFRI (2012) Annual report 2011-2012. Central Marine Fisheries Research Institute, Cochin. 274 pp
- CMFRI (2016) Annual report 2016-17. Central Marine Fisheries Research Institute, Kochi. 345 pp
- Colbert-Sangree N (2012) The state of artisanal fisheries in southern Unguja: Governance, Conservation and Community. Independent Study Project (ISP) Collection. [online] URL: http://digitalcollections.sit.edu/isp_collection/1279
- Cope JM, Punt AE (2009) Length-based reference points for data-limited situations: applications and restrictions. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science: 169-186
- Costello C, Ovando D, Hilborn R, Gaines SD, Deschenes O, Lester SE (2012) Status and solutions for the world's unassessed fisheries. Science 338 (6106): 517-520
- Cullis-Suzuki S, Pauly D (2010) Failing the high seas: a global evaluation of regional fisheries management organizations. Marine Policy 34 (5): 1036-1042
- Dagorn L, Holland KN, Restrepo V, Moreno G (2013) Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish and Fisheries 14 (3): 391-415
- Dortel E, Massiot-Granier F, Rivot E, Million J, Hallier JP, Morize E, Munaron JM, Bousquet N, Chassot E (2013) Accounting for age uncertainty in growth modelling, the case study of yellowfin tuna (*Thunnus albacares*) of the Indian Ocean. PloS One 8 (4): e60886
- Edser T (1908) Note on the number of plaice at each length, in certain samples from the southern part of the North Sea, 1906. Journal of the Royal Statistical Society 71 (4): 686-690
- European Commission (1992) Multilingual dictionary of fishing gear. Fishing News Book, second ed. Office for Official Publications of the European Communities. 360 pp [ISBN-1 3: 92-826-4380-0]
- FAO (2007) FAO Country Profiles: Tanzania. Food and Agriculture Organization of the United Nations, 2018 [http://www.fao.org/countryprofiles/index/en/]

- FAO (2015) Voluntary guidelines for securing sustainable small - scale fisheries in the context of food security and poverty eradication. Food and Agriculture Organization of the United Nations, Rome. 34 pp
- FAO (2016) The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Food and Agriculture Organization of the United Nations, Rome. 200 pp
- Feidi IH (2005) The fisheries of Zanzibar: potential for new investments. NAGA, WorldFish Center Quarterly 28 (3): 37-40
- Fonteneau A (2014) On the movements and stock structure of skipjack (*Katsuwonus pelamis*) in the Indian Ocean. IOTC TTWG Document
- Fonteneau A, Hallier JP (2015) Fifty years of dart tag recoveries for tropical tuna: a global comparison of results for the western Pacific, eastern Pacific, Atlantic, and Indian Oceans. Fisheries Research 163: 7-22
- Froese R, Stern-Pirlot A, Winker H, Gascuel D (2008) Size matters: how single-species management can contribute to ecosystem-based fisheries management. Fisheries Research 92: 231-241
- Garcia SM (2009) Glossary. In: Cochrane K, Garcia SM (eds) A fishery managers' handbook. FAO and Wiley-Blackwell. pp 473-505
- Gulland JA (1956) On the fishing effort in English demersal fisheries. Fishery Investigations Series II, No. 20. 41 pp
- Gulland JA (1983) Stock Assessment: Why? Food and Agriculture Organization of the United Nations, Rome. pp 18
- Hallier JP, Fonteneau A (2015) Tuna aggregation and movement from tagging data: A tuna "hub" in the Indian Ocean. Fisheries Research 163: 34-43
- Hernandez A, Ramirez N (1998) Spawning seasonality and length at maturity of sailfish (*Istiophorus platypterus*) off the Pacific coast of Mexico. Bulletin of Marine Science 63 (3): 459-468
- Herrón P, Mildenberger TK, Díaz JM, Wolff M (2018) Assessment of the stock status of small-scale and multi-gear fisheries resources in the tropical Eastern Pacific region. Regional Studies in Marine Science 24: 311-323
- Hoolihan JP (2006) Age and growth of Indo-Pacific sailfish, *Istiophorus platypterus*, from the Arabian Gulf. Fisheries Research 78 (2-3): 218-226
- Hu C, Harrison DP, Hinton MG, Siegrist ZC, Kiefer DA (2018) Habitat analysis of the commercial tuna of the Eastern Tropical Pacific Ocean. Fisheries Oceanography 27: 417-434
- Huang HW, Liu KM (2010) Bycatch and discards by Taiwanese large-scale tuna longline fleets in the Indian Ocean. Fisheries Research 106 (3): 261-270
- Igulu M, El Kharousy ZM (2013) Tanzania National Report to the Scientific Committee of the Indian Ocean Tuna Commission. Indian Ocean Tuna Commission: 1-8
- Igulu M, El Kharousy ZM (2015) Tanzania National Report to the Scientific Committee of the Indian Ocean Tuna Commission. Indian Ocean Tuna Commission: 1-8
- IOTC (2010) Indian Ocean Tuna Commission. Regional observer scheme. Observer manual. Version November 2010. Indian Ocean Tuna Commission: 44-47
- IOTC (2017) Indian Ocean Tuna Commission [http://www.iotc.org/science/status-summary-species-tuna-and-tuna-species-under-iotc-mandate-well-other-species-impacted-iotc]
- Jacquet J, Fox H, Motta H, Ngusuru A, Zeller D (2010) Few data but many fish: marine small-scale fisheries catches for Mozambique and Tanzania. African Journal of Marine Science, 32 (2): 197-206
- Jiddawi NS, Öhman MC (2002) Marine fisheries in Tanzania. Ambio: a journal of the Human Environment 31 (7): 518-527
- Kaplan DM, Bach P, Bonhommeau S, Chassot E, Chavance P, Dagorn L, Fromentin JM (2013) The true challenge of giant marine reserves. Science 340 (6134): 810-811
- Kaplan DM, Chassot E, Amandé 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: 10.1093/icesjms/fst233]
- Kolding J, Béné C, Bavinck M (2014) Small-scale fisheries-importance, vulnerability, and deficient knowledge. In: Garcia JR, Charles A (eds) Governance of marine fisheries and biodiversity conservation. pp 317-331
- Leroy B, Peatman T, Usu T, Caillot S, Moore B, Williams A, Nicol S (2016) Interactions between artisanal and industrial tuna fisheries: Insights from a decade of tagging experiments. Marine Policy 65: 11-19
- Liganga L (2014) Tanzania profits little from tuna production. The Citizen, Tanzania, 14 October 2014 [http://www.thecitizen.co.tz/magazine/INSIGHT--Revealed--Tanzania-profits-little-from-tuna-production/1840564-2474994-o9h2fi/index.html]
- Maguire JJ, Sissenwine M, Csirke J, Garcia S (2006) The state of world highly migratory, straddling and other

- high seas fishery resources and associated species. Food and Agriculture Organization of the United Nations, Rome, No. 495
- Majkowski J (2007) Global fishery resources of tuna and tuna-like species. Food and Agriculture Organization of the United Nations, Rome, No. 483
- Methot Jr RD, Wetzel CR (2013) Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* 142: 86-99
- Mildenberger TK, Taylor MH, Wolff M (2017a) TropFishR: an R package for fisheries analysis with length-frequency data. *Methods in Ecology and Evolution* 8: 1520–1527 [doi:10.1111/2041-210X.12791]
- Mildenberger TK, Taylor MH, Wolff M (2017b) TropFishR: tropical fisheries analysis with R (version 1.1.3) [https://github.com/tokami/TropFishR]
- Mkenda AF, Folmer H (2001) The maximum sustainable yield of artisanal fishery in Zanzibar: A cointegration approach. *Environmental and Resource Economics* 19 (4): 311-328
- MNRT (2012) Tourism Statistical Bulletin 1995–2010. Ministry of Natural Resources and Tourism, Tourism Division: 1-22
- Myers RA, Mertz G (1998) The limits of exploitation: a precautionary approach. *Ecological Applications* 8: 165-169
- Nurdin E, Sondita MFA, Yusfiandayani R, Baskoro MS (2016) Growth and mortality parameters of yellowfin tuna (*Thunnus albacares*) in Palabuhanratu waters, west Java (eastern Indian Ocean). *AAFL Bioflux* 9 (3): 741-747
- Pauly D (1983) Length-converted catch curves: a powerful tool for fisheries research in the tropics (part 1). *Fishbyte* 1.2: 9-13
- Pebesma EJ, Bivand RS (2005) Classes and methods for spatial data in R. *R News* 5 (2) [https://cran.r-project.org/doc/Rnews/]
- Petersen CGJ (1891) Eine Methode zur Bestimmung des Alters unter Wushses der Fische. *Mitteilungen der Deutch Seefischerei* 11: 226-235
- Pó LA, Dionísio C, De Paula e Silva R (1992) Growth of skipjack *Katsuwonus pelamis* from Mozambique. *Revista de Investigação Pesqueira* (Maputo) 21: 98-105
- Pons M, Branch TA, Melnychuk MC, Jensen OP, Brodziak J, Fromentin JM, Parma AM (2017) Effects of biological, economic and management factors on tuna and billfish stock status. *Fish and Fisheries* 18 (1): 1-21
- Punt AE, Campbell RA, Smith AD (2001) Evaluating empirical indicators and reference points for fisheries management: application to the broadbill swordfish fishery off eastern Australia. *Marine and Freshwater Research* 52 (6): 819-832
- Qasim SZ (1977) Biological productivity of the Indian Ocean. *Indian Journal of Marine Sciences* 6: 122-137
- Rajesh KM, Rohit P, Abdussamad EM (2016) Fishery, diet composition and reproductive biology of the dolphinfish *Coryphaena hippurus* (Linnaeus, 1758) off Karnataka, south-west coast of India. *Indian Journal of Fisheries* 63 (4): 35-40
- R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria [https://www.R-project.org/]
- Salas S, Chuenpagdee R, Seijo JC, Charles A, (2007) Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean, *Fisheries Research* 87 (1): 5-16 [ISSN 0165-7836]
- Schwamborn R, Mildenberger TK, Taylor MH (2018) Assessing source of uncertainty in length-based estimates of body growth in populations of fishes and macroinvertebrates with bootstrapped ELEFAN [https://arxiv.org/abs/1808.07154]
- Shih CL, Hsu CC, Chen CY (2014) First attempt to age yellowfin tuna, *Thunnus albacares*, in the Indian Ocean, based on sectioned otoliths. *Fisheries Research* 149: 19-23
- Then AY, Hoenig JM, Hall NG, Hewitt DA (2015) Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science* 72 (1): 82-92
- Thyresson M, Crona B, Nyström M, de la Torre-Castro M, Jiddawi N (2013) Tracing value chains to understand effects of trade on coral reef fish in Zanzibar, Tanzania. *Marine Policy* 38: 246-256
- Tidd AN, Reid C, Pilling GM, Harley SJ (2016) Estimating productivity, technical and efficiency changes in the Western Pacific purse-seine fleets. *ICES Journal of Marine Science* 73: 1226-1234
- VanDerWal J, Falconi L, Januchowski S, Shoo L, Storlie C (2014) SDMTTools: Species Distribution Modelling Tools: Tools for processing data associated with species distribution modelling exercises. R package version 1.1-221 [https://CRAN.R-project.org/package=SDMTTools]
- von Bertalanffy L (1934) Untersuchungen über die Gesetzmäßigkeit des Wachstums I Teil: Allgemeine Grundlagen der Theorie; Mathematische und Physiologische Gesetzmäßigkeiten des Wachstums bei Wassertieren. *Development Genes and Evolution* 131: 613-651
- von Bertalanffy L (1938) A quantitative theory of organic growth (inquiries on growth laws II). *Human Biology* 10: 181-213

- Ward RO, Elliott NG, Innes BH (1997) Global population structure of yellowfin tuna, *Thunnus albacares*, inferred from allozyme and mitochondrial DNA variation. *Oceanographic Literature Review* 12 (44): pp 1553
- Warnes GR, Bolker B, Gorjanc G, Grothendieck G, Korosec A, Lumley T, MacQueen D, Magnusson A, Rogers J and others (2017) gdata: Various R Programming Tools for Data Manipulation. R package version 2.18.0. [<https://CRAN.R-project.org/package=gdata>]
- Wickham H (2007) Reshaping Data with the reshape Package. *Journal of Statistical Software* 21 (12): 1-20. [<http://www.jstatsoft.org/v21/i12/>]
- Young JW, Lamb TD, Le D, Bradford RW, Whitelaw AW (1997) Feeding ecology and interannual variations in diet of southern bluefin tuna, *Thunnus maccoyii*, in relation to coastal and oceanic waters off eastern Tasmania, Australia. *Environmental Biology of Fishes* 50 (3): 275
- Zeller D, Booth S, Pauly D (2007) Fisheries contribution to GDP: underestimating small-scale fisheries in the Pacific. *Marine Resource Economics* 21: 355-374

Appendix

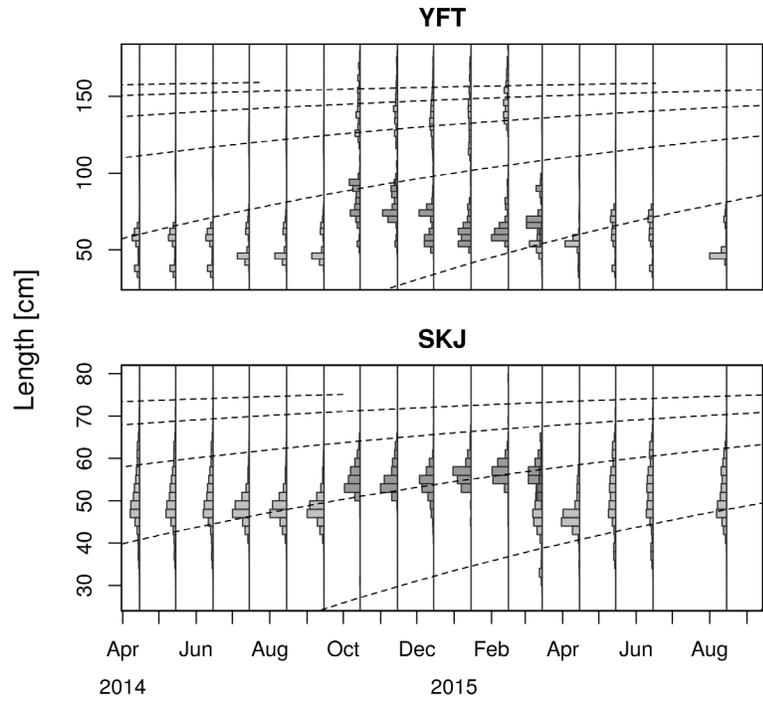


Figure 5a. Monthly length-frequency distributions (LFDs) of SSF and IF landings combined for Yellowfin tuna (YFT) and Skipjack tuna (SKJ) with von Bertalanffy growth curves. Dark grey bars represent the LFDs of the SSF while light grey bars represent the IF landings.

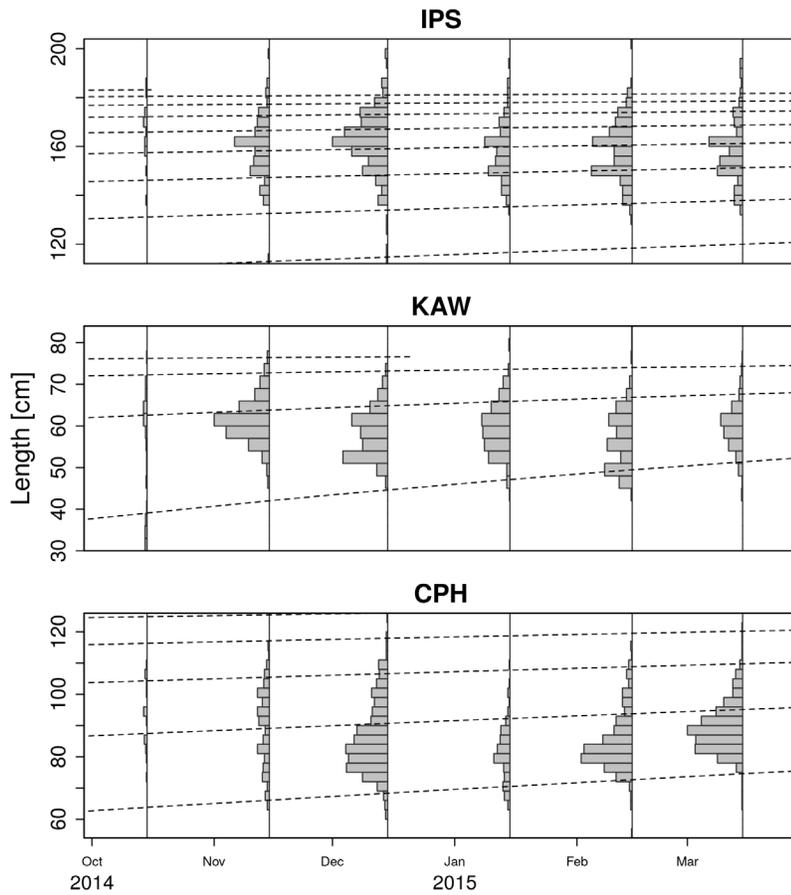


Figure 5b. Monthly length-frequency distributions (LFDs) of SSF landings for Indo-Pacific sailfish (IPS), Kawakawa (KAW), and Common dolphinfish (CPH) with von Bertalanffy growth curves.

Online supporting material

The length-composition data from IF was retrieved from the respective IOTC working groups (i) Neritic tunas (<http://www.iotc.org/meetings/7th-working-party-neritic-tunas-wpnt07>, accessed: 21/10/2017 1:30pm), (ii) Tropical tunas (<http://www.iotc.org/meetings/19th-working-party-tropical-tunas-wptt19>, accessed 21/10/2017 1:30pm), and (iii) Billfish (<http://www.iotc.org/meetings/15th-working-party-bill-fish-wpb15>, accessed: 21/10/2017 1:30pm). All collected length measurements for the five species: Yellowfin tuna, Skipjack tuna, Indo-Pacific sailfish, Kawakawa, and Common dolphinfish are available on GitHub at <https://github.com/tokami/Jodari>.