GLOBAL TUNA ALLIANCE

THIS REPORT HAS BEEN PREPARED BY NAUNET FISHERIES CONSULTANTS FOR THE GLOBAL TUNA ALLIANCE (GTA)

Sustainability of yellowfin tuna *(Thunnus albacares)* fisheries in the Indian Ocean, with a special focus on juvenile catches

MARCH 2021

Table of contents

List of acronyms and abbreviations

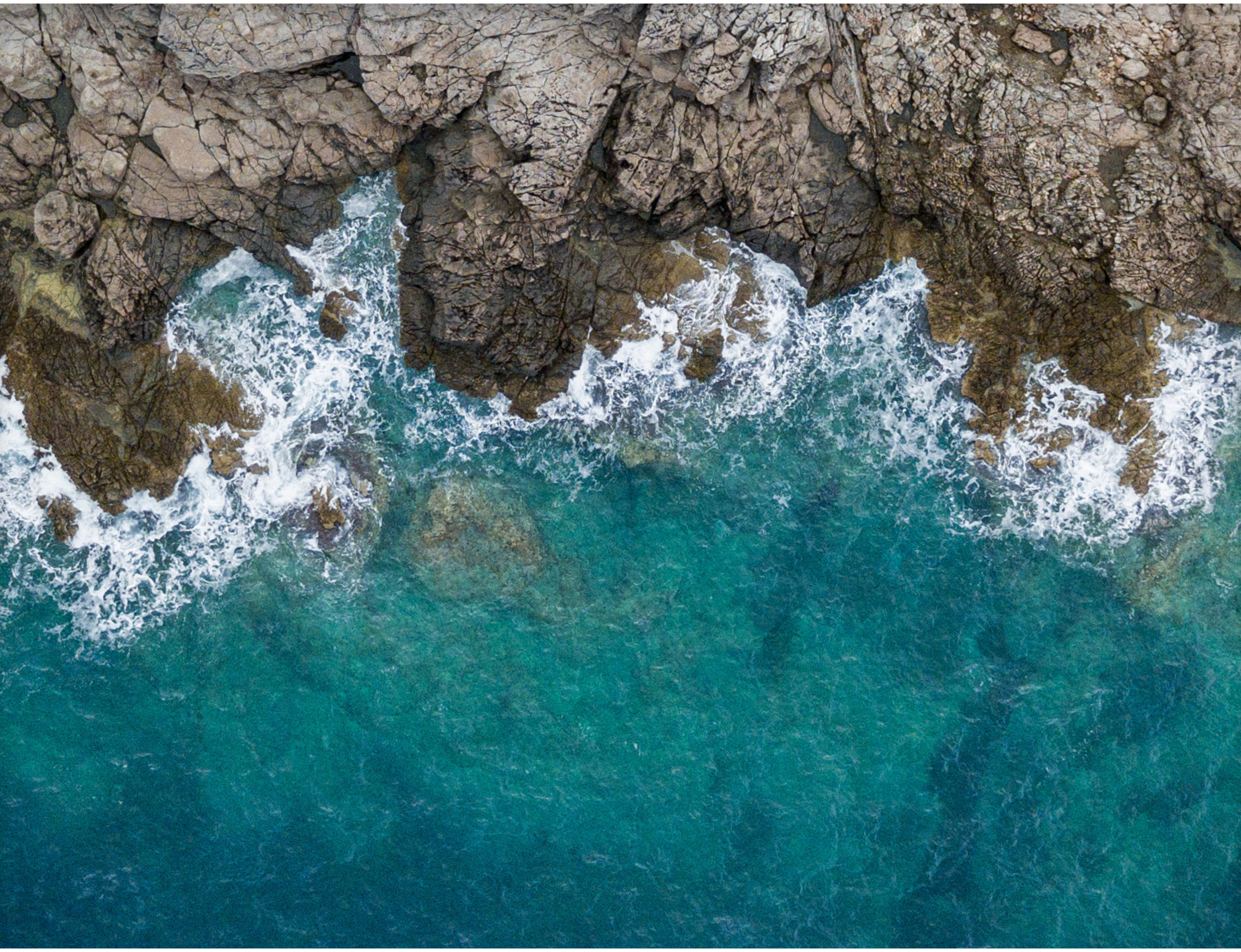
B	stock biomass (total)
B_{MSY}	biomass which produces MSY
CPCs	Contracting Parties and cooperating non-Contracting Parties
CPUE	catch per unit effort
EEZ	exclusive economic zone
EU	European Union
F	fishing mortality
FAD	fish aggregation device (Anchored FAD: aFAD; drifting FAD: dFAD)
FAO	Food and Agriculture Organization of the United Nations
FL	fork length
F_{MSY}	fishing mortality at MSY
FS	free swimming (tuna) school
GT	gross tonnage
GTA	Global Tuna Alliance
IATTC	Inter-American Tropical Tuna Commission
IO	Indian Ocean
IOTC	Indian Ocean Tuna Commission
IPNLF	International Pole and Line Foundation
ISSF	International Seafood Sustainability Foundation
IUU	Illegal, Unregulated and Unreported Fishing
K	growth rate parameter measuring the rate at which the asymptote is approached
K2SM	Kobe II Strategy Matrix
LB-SPR	Length-based spawning potential ratio
LL	Longline
L_m	Length at first maturity
L_{m50}	Length at first maturity (50% of the population is mature)
L_{m95}	Length at first maturity (95% of the population is mature)
LOA	Length overall (of a vessel)
L_{opt}	Optimal length
LS	Log-associated set
M	natural mortality
MSY	maximum sustainable yield
PS	Purse seine
PSFS	Purse seine fisheries on free schools
PSLS	Purse seine fisheries on log (FADs)-associated schools
RFMO	Regional Fisheries Management Organisation
SB	Spawning biomass
SC	Scientific Committee of the IOTC
SIDS	Small Island Developing States
SSB	spawning stock biomass
SSB_{MSY}	spawning stock biomass which produces MSY
UNCLOS	United Nations Convention on the Law of the Sea
UNGA	United Nations General Assembly
WP	Working Party of the IOTC
WPTT	Working Party on Tropical Tunas of the IOTC
WWF	World Wildlife Fund
YFT	Yellowfin tuna

Glossary of terms *(page 1)*

TERM	DEFINITION
CPUE	Catch per unit of fishing effort. Used as an index of stock abundance, where some relationship is assumed between that index and the stock size.
FAD	Fish Aggregating Device (FAD) means a permanent, semi-permanent or temporary object, structure or device of any material, man-made or natural, which is deployed and/or tracked, for the purpose of aggregating target tuna species for consequent capture. -Anchored FAD: A FAD tethered to the bottom of the ocean. It usually consists of a very large buoy and anchored to the bottom of the ocean with a chain. -Deployed FAD: FAD that is physically placed or deposited in the water by a vessel engaged in or supporting the activities of fishing. -Drifting FAD: A FAD not tethered to the bottom of the ocean. A DFAD typically has a floating structure (such as a bamboo or metal raft with buoyancy provided by buoys, corks, etc.) and a submerged structure (made of old netting, canvass, ropes, natural material such as bamboo, etc.).
FAD Set	Setting a fishing gear around a tuna school associated with a FAD.
Fishing effort	Fishing effort is the amount of fishing gear of a specific type used on the fishing grounds over a given unit of time, e.g. hours trawled per day, number of hooks set per day or number of hauls of a beach seine per day.
F_{MSY}	The fishing mortality rate that produces MSY.
Free School Set	A fishing operation where the net is set around a free-swimming school of tuna, i.e. a school that is not associated with any floating object or cetaceans.
Kobe II Strategy Matrix (K2SM)	Scientific stock assessment advice given by the IOTC Scientific Committee is presented in the form of a Kobe II Strategy Matrix (K2SM). Traditionally, the K2SM shows the probabilities by year for different catches of achieving the management objective of ensuring that the stock biomass is greater than B_{MSY} and fishing mortality less than F_{MSY}.
Kobe plot	A plot that shows the current stock status, or a trajectory over time for a fished population, with abundance on the horizontal axis and fishing mortality on the vertical axis. These are often shown relative to B_{MSY} and F_{MSY}, respectively. A Kobe plot is often divided into four quadrants by a vertical line at $B=B_{MSY}$ and a horizontal line at $F=F_{MSY}$.
Length at first maturity (L_m)	Mean length at first maturity, i.e., the mean length at which juvenile fish become sexually mature for the first time.
Maximum Sustainable Yield	The largest (typically annual) yield that can be taken continuously from a stock sustainably (i.e. without reducing its size). In real, and consequently stochastic situations, this is usually estimated as the largest average long-term yield that can be obtained by applying a constant fishing mortality F, where that F is denoted as F_{MSY}. The highest theoretical equilibrium yield that can be continuously taken on average from a stock under existing environmental conditions without affecting significantly the reproduction process.
Nominal catches	Total annual retained catches (in live weight and number), estimated per fleet, IOTC area, gear and year.
Optimum length (L_{opt})	The length where the number of fish in a given unfished year class multiplied with their mean individual weight is maximum and where thus the maximum yield and revenue can be obtained (Froese, 2004).

Glossary of terms *(page 2)*

Spawning potential ratio (SPR)	The spawning potential ratio of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure (Goodyear, 1993; Walters and Martell, 2004) and is commonly used to set target and limit reference points for fisheries. By definition, the SPR equals 100% in an unexploited stock, and zero in a stock with no spawning (e.g. all mature fish have been removed, or all female fish have been caught).
SSB_{MSY}	The equilibrium spawning biomass that results from fishing at F_{MSY} in the presence of recruitment variability. Fishing a stock at F_{MSY} will result in a biomass that fluctuates above and below SSB_{MSY}.
Subsistence fishery	A subsistence fishery is a fishery where the fish caught are consumed directly by the families of the fishers rather than being bought by middle-(wo)men and sold at the next larger market (FAO).
Support Vessel	A vessel that operates in support of purse seine vessels fishing on FADs, and whose role is to deploy, repair, retrieve or maintain FADs at sea.
Total Allowable Catch (TAC)	The catch quota set for a stock (it could be fishery-specific or the aggregate across fisheries, depending on context).



I.

Executive Summary

The most recent full stock assessment (2018) of the yellowfin tuna *(Thunnus albacares)* stock in the Indian Ocean concluded that the stock was overfished and subject to overfishing. Recent updates of the assessment have reached the same conclusion. The IOTC acknowledged that a reduction in total catches was necessary to avoid continuing overfishing the stock and to allow it to recover to sustainable levels. However, several resolutions (16/01 and its amendments) recently adopted by the Commission to reduce the YFT catch and thus allow its rebuilding have not been adequately implemented and have fallen short in their objectives, resulting in increased catches in recent years, which puts the stock at risk of collapse.

Naunet Fisheries Consultants was commissioned in 2020 by the Global Tuna Alliance (GTA) to develop management advice for Indian Ocean yellowfin tuna that would rebuild the stock in two generations time in order to meet GTA's sustainability standards. This previous report focused on the impact of the Indian Ocean fisheries on the YFT stock. It recommended a 25 per cent catch reduction in reference to the 2017 catch levels, put forward three proposals on how catch reductions could be achieved, taking into consideration different factors, and recommended a series of supporting measures. The report was presented at the 22th Regular Session of the IOTC WPTT conducted in October 2020.

The GTA is now aiming to undertake a short analysis of the impact of the Indian Ocean yellowfin tuna fisheries on the juvenile fraction of the stock, explaining recent increases in juvenile yellowfin catch, their causes and possible impacts on the stock status; and recommending specific management measures needed to address the catch of the juvenile fraction of the stock.

This report presents the results of the desk-based study undertaken to fulfil the assignment. Length-frequency distributions for all main Indian Ocean tuna fleets have been downloaded from the IOTC database and analysed. Relevant reports have been consulted and a series of consultations with stock assessment experts and fisheries managers have been held. As in the previous study, major concerns for our analysis are the uncertainties in the quality of data provided by several countries to the IOTC (nominal catch data, size-frequency data, tagging data, incomplete or fragmented historical datasets, etc.), which jeopardise not only the results of this study but also the stock assessment results for the IO yellowfin tuna. Despite the shortcomings, the main findings of this study are:

1. Handline (119.1 cm) and Longline (125.7 cm) fisheries present the highest average length in the catch whereas the FAD-associated purse seine (54.9 cm) and the pole and line (51.0 cm) fisheries have the lowest. The pole and line, FAD-associated purse seine and gillnet fisheries catches have the highest percentage of juveniles: 98.8%, 77.8% and 64.7% respectively *(Table 1)*.

Table 1 Average length of the catch and percentage of immature and mature yellowfin tuna caught per gear between 2000 and 2019. Source: own, based on IOTC data.*

Gear		PL	LS	FS	GILL	LL	HL	TROL
Average length		51.0 cm	54.9 cm	106,9 cm	78,0 cm	125.7 cm	119. 1 cm	96,9 cm
Catch per gear (in weight)	**Immature**	98.8%	77.8%	3.6%	64.7%	2.1%	6.6%	3.3%
	Mature	1.2%	22.2%	96.4%	35.3%	97.9%	93.4%	96.7%

**No data was available for GILL in 2010 and for HL in 2000, 2001, 2002 and 2004. For TROL, data were available only in 2015, 2016, 2017 and 2019.*

2) The main fisheries catching juvenile yellowfin tuna in the Indian Ocean are: FAD-associated purse seine (47.6% of the juvenile catch), gillnets (35.1%) and to lesser extent pole and line (10.8%). Handline and longline fisheries present a catch size distribution that is closer to the optimal size as defined by Froese (2004) and by Prince and Hordyk (2019).

3) From 2015 to 2019, 37% and 53.7% of the catch (in weight) of yellowfin in the Indian Ocean (all gears included) was composed of juveniles (below 76 cm) or by individuals below the optimum length (125 cm), respectively *(Table 2)*.

4) The implementation of Resolution 16/01 (and subsequent resolutions) resulted in an increase of juvenile yellowfin catch in the purse seine fishery (in weight; both set types combined) from 45.3% in 2015 to 67.2% in 2018, presumably because the purse seine fleets shifted their effort towards targeting skipjack in FAD sets (where it forms mixed schools with juvenile yellowfin), instead of targeting yellowfin in sets to free swimming schools. However, it decreased to 53.2% in 2019.

5) The combined impact of all fisheries on the juvenile fraction of the stock is causing growth overfishing.

Based on the findings above, a series of recommendations are given:

1) **In order to reduce the impact on both the juvenile and adult tuna age components of the yellowfin stock, and** thus **allow for recovering the stock,** it is crucial **to implement an overall catch reduction set to 20% relative to 2014 catch levels[1]. Only subsistence fisheries should be exempt from catch reductions.**

   However, as this catch reduction has not been implemented yet, the implementation of complementing measures to reduce the impact on juvenile yellowfin tuna is necessary.

2) The **number of FADs and instrumented buoys** used by the purse seine fishery needs to be **reduced to decrease the impact of this fishing modality on juvenile tuna.** This reduction should be large enough to move from the current passive use of the FADs (where they are deployed by the vessels, and left insufficiently managed until they spent their lifetime) to an active management, in which each vessel would have a proper control of the FADs used.

3) **Time/area fishery closures** might be implemented in **juvenile hotspot areas** where immature yellowfin is more abundant in the catch. Alternatively, an ocean-wide **seasonal closure** should be contemplated. This closure should be implemented for a sufficient period of time in order to be effective.

4) For the remainder of 2021, the **prohibition of the use of large-scale gillnets** in offshore waters and in semi-enclosed seas such as the Persian Gulf should be immediately enforced. Once large-scale gillnets become prohibited (as of 1 January 2022) from the entire IOTC area under Res 17/07, the prohibition should be **strictly enforced.**

5) Implement **multi-specific TACs for all three tropical tunas,** where the impact of a fishery does not decrease co-dependent stocks to below MSY.

6) **Improving data reporting by all CPCs** and for all gears, both for total catch data, catch and effort data and size data. **Non-compliance** with reporting responsibilities should be **sanctioned.**

Table 2 percentage of the total catch of immature and mature yellowfin tuna per gear (average 2015-2019).

Gear		BB	LS	FS	GILL	LL	HL	TROL	All
Percentage of the total catch	**Immature**	10.8%	47.6%	1.0%	35.1%	1.0%	3.2%	0.6%	37.3%
	Mature	0.1%	8.2%	16.1%	11.5%	27.1%	27.4%	10.1%	62.7%
Average catch (2015-2019)		17,397	97,590	44,131	86,567	73,240	77,621	27,557	424,103

[1] Based on data provided in the IOTC Scientific Committee, a catch reduction of 25% relative to the catch in the year 2017 was calculated to be necessary for recovering the stock in two generations in our previous report (GTA 2020). However, the K2SM model used to generate this figure has now been withdrawn by the SC. Anyway, a 20% catch reduction of 2014 levels (323,004 t) is similar to a 25% catch reduction relative to the catch in the year 2017 (313,919 t).

II. Introduction

Yellowfin tuna fisheries in the Indian Ocean

Yellowfin tuna (Thunnus albacares; YFT) is one of three tropical tuna species targeted in the Indian Ocean; the other species are skipjack tuna (Katsuwonus pelamis) and bigeye tuna (Thunnus obesus). They are targeted by a number of fleets using a wide array of fishing gears, such as longline, purse seine (in two different modalities), handline, gillnets, pole and line, and others. A fourth species, albacore tuna (Thunnus alalunga), straddles between tropical and temperate waters of the IO and is targeted mostly by the longline fleet (ISSF 2020).

The Indian Ocean has a key role in the global tuna supply. Combined ex-vessel values of species under the mandate of the IOTC were estimated at US$ 4.76 billion in 2017 (Macfadyen and Defaux 2019). In 2016, 84% of IOTC tuna was caught by fleets belonging to coastal States, with the remainder caught by distant waters fleets (basically EU purse seiners and East Asian longliners) (IOTC 2018a). Tuna fisheries are thus a key component of the fisheries sector and the overall economy of many of these coastal States, especially Small Island Developing States (SIDS) (Lecomte *et al*., 2017, Andriamahefazafy and Kull 2019). For instance, in 2017, in the Seychelles the tuna fishery sector was valued at US$ 38.8 million (equivalent to 2.6% of the GDP); in Mauritius the tuna fishery represented around 1.4% of GDP; and in the Maldives the contribution of the fisheries sector (almost entirely tuna-based) to GDP was estimated at 4.7% (Macfadyen and Defaux 2019).

Tuna fisheries in the IO have been growing for the last four decades. Initially, their expansion was fueled by the longline fishery; but since the 1980s the longline catch was surpassed in importance by that of the purse seine and, increasingly, the gillnet fleets (IOTC 2020a). Indian Ocean's YFT catch reached its maximum historic peak in 2004 with a total of 530,000 t, of which 230,000 t were caught by purse seine (IOTC 2020a). After a brief hiatus (2007-2011) when piracy activities off Somalia's coast reduced the fishing effort of some fleets, thus lowering the total YFT catch, fishing pressure on the YFT stock kept growing. IO YFT catch in 2019 was 454,138 t (IOTC 2021). The main fleets, per gear and country, as defined by IOTC based on the average catch for 2015-19 are the following: I.R. Iran (gillnet): 12%; Maldives (handline, pole and line): 12%; EU-Spain (purse seine): 12%; Seychelles (purse seine): 8%; Sri Lanka (gillnet, coastal longliners): 8% (IOTC 2020a). The increase in YFT catch in the IO is linked to the expansion of the purse seine fleet (Zudaire et al., 2013) and more recently with that of the gillnet and miscellaneous gear fleets (which despite their growing importance, remain poorly estimated) (ISSF 2020).

Stock assessment of yellowfin tuna in the Indian Ocean

The stock of yellowfin tuna in the Indian Ocean is overfished, with its spawning biomass below the SSB_{MSY} level. Overfishing is also occurring, with current fishing mortality above the F_{MSY} level (IOTC 2020a). This situation is not new, given that the stock was first acknowledged by IOTC to be "very close to an overfished state, or already overfished" already in 2008 (Rattle 2020).

The IOTC Scientific Committee (SC) indicated that uncertainties in data inputs (reported nominal catch data, CPUE indices, size-frequency data, tagging data, etc.) and stock assessment model assumptions (stock distribution, growth, natural mortality, maturity at size/age, steepness of the stock-recruitment relationship) resulted in a poor predictive capacity of the stock assessment model used and, although a K2SM was provided, no explicit recommendations on catch limits were given (IOTC 2018a, IOTC 2019a). As a precautionary measure, the SC recommended that the Commission should ensure that catches are reduced to end overfishing and allow the SSB to recover to

SSB_{MSY} levels, but no specific advice was given.

Moreover, in 2020 the IOTC WPTT noted that the model analysts encountered a potential problem with the projections that were run in 2018 to build the K2SM. They indicated that the way in which total recruitment is allocated between some of the model areas might be causing the models to crash and therefore potentially producing bias in the probabilities estimated for the K2SM (IOTC 2020b). Again, no clear management advice was given other than catches should be reduced to a level at least below the C_{MSY} estimate (403,000 MT).

Therefore, the complexity, uncertainty and data deficiency inherent to IO YFT fisheries means that the impact of fishing on the stock is difficult to assess using conventional stock assessment methods and mathematical models. These methods require good quality fisheries related data, including catch and effort data, size-frequency distribution data, and other data which are particularly difficult to obtain for the IO YFT fishery due the large number and variety of fleets targeting the stock.

Moreover, recent resolutions implemented by the IOTC aimed to reduce the yellowfin catch (Resolution 16/01, superseded by 17/01, 18/01 and 19/01) have resulted in changes in fishing patterns which appear to have caused a net increase in the catches of yellowfin tuna juveniles. This report analyses the current catches of juvenile yellowfin tuna in the Indian Ocean for the main fisheries and countries and their impact on the status of the stock.

III. Methodology

Froese (2004) defined three simple and easily understood indicators that allow an effective assessment of stock status and trends in most fisheries:

i. Percentage of mature fish in catch. The target for sustainable fisheries would be to let all fish spawn at least once before they are caught, in order to rebuild and maintain healthy spawning stocks.

ii. Percentage of specimens with optimum length in the catch. Optimum length is defined as the length where the number of fish in a given unfished year class multiplied with their mean individual weight is maximum and where thus the maximum yield and revenue can be obtained. Fisheries managers should strive to adjust the mean length in their catch towards the L_{opt}. Froese (2004) considers that the target would be to catch all fish (100%) within, for example, ±10% of optimum length.

iii. Percentage of 'mega-spawners' in the catch. Mega-spawners are defined as old, large fish in the catch, i.e. fish of a larger size above the optimal length, measured as optimum length plus 10%. According to Froese (2004), the target depends on the management regime: the aim is to implement a fishing strategy that results in no (0%) mega-spawners being caught. If no such strategy is in place and thus the catch reflects the age and size structure of the stock, values of 30–40% mega-spawners[2] represent a healthy age structure and are desirable, whereas less than 20% will be a matter of concern.

To use these indicators, it is necessary first to identify and define some life history parameters (LHP) for Indian Ocean yellowfin, in order to define "juvenile yellowfin", including:

i. Length at first maturity (L_m): This is the mean length at which fish of a given population mature for the first time (Fishbase 2020);

ii. Length on 50% maturity (L_{m50}): This is the length at which 50% of the population has reached the maturity (Fishbase 2020);

and

iii. Length at maximum yield (L_{opt}): as indicated above, this is the length class with the highest biomass in an unfished population, where the number of survivors multiplied by their average weight reaches a maximum (Beverton 1992). A fishery would obtain the maximum possible yield if it were to catch only fish of this size. L_{opt} is estimated from the parameters of the Von Bertalanffy growth function and the natural mortality, as follows:

$$L_{opt} = L_\infty \left(\frac{3}{3+M/K} \right) \quad \text{(Beverton 1992)}$$

Where L_∞ is the length that the fish of a population would reach if they were to grow indefinitely (also known as asymptotic length), M is the instantaneous rate of natural mortality (M; 1/year) and K is the growth coefficient, expressing the rate (1/year) at which the asymptotic length (L_∞) is approached.

$$L_t = L_\infty \left(1-e^{-k(t-t0)} \right) \quad \text{(Von Bertalanffy 1938)}$$

L_m, L_{m50} and L_{opt} can be used to evaluate length-frequency diagrams for signs of growth overfishing (catching fish before they have realized their growth potential) and recruitment overfishing (reducing the number of parents to a level that is insufficient to maintain the stock and hence the fishery). In this report, juvenile YFT is defined as all the individuals caught below L_m, sub-adult YFT as those between L_m and L_{m50}, and adult YFT are all individuals over L_{m50}.

In order to define these values, published reports presenting biological parameters of yellowfin tuna in the Indian Ocean were consulted and average values of L_∞ (21 studies), M (8 studies) and K (15 studies) extracted from them. However, due to the low number of references found for L_m (3 studies) and L_{m50} (6 studies), these last values were obtained directly from IOTC reports (Fu et al., 2018, IOTC 2017a). Finally, L_{opt} was calculated using the formula (1) shown above.

[2] This attention to large specimens draws on the increasing evidence that older, larger fish play several important roles in the long-term survival of a population: (i) older, larger females are much more fecund than younger, recently matured females. Older females produce more eggs, but also, these eggs are richer in lipids and other nutrients, so that the larvae have a higher probability of survival; (ii) mega-spawners are reservoirs and distributors of desirable genes; and (iii) extending longevity and prolonging the reproductive phase can be viewed as a natural safeguard against subsequent recruitment failure (Froese 2004, Hixon et al. 2014). For yellowfin tuna in the Indian Ocean mega-spawners would correspond to individuals larger than 138 cm *(Table 3)*.

IOTC Resolution 15/02 on "Mandatory statistical requirements for IOTC Members and Cooperating Non-Contracting Parties (CPCs)" states that size data shall be submitted to the Secretariat for all species under the IOTC mandate as well as for the most commonly caught elasmobranch species, in accordance with IOTC reporting guidelines and, possibly, through Form 4SF in agreement with the IOTC reporting guidelines. The resolution also states that the size sampling shall be representative of all periods and areas fished, and that it shall cover at least one fish by ton caught, by species and type of fishery.

This report has used the last dataset available of size frequency data in standard measurement, Fork length (FL), released on 19th September 2020 in the 22nd Working Party on Tropical Tunas (WPTT) meeting. It was downloaded from the IOTC database on 21st January 2021 (https://www.iotc.org/WPTT/22AS/Data/11-SFYFT). It is important to recall that the Secretariat has detected anomalies in size data submitted by some countries and fleets (IOTC-2020c).

In section V (analysis of juvenile yellowfin tuna catch by fleet), we present data extracted for the last 20 years (between 2000 and 2019). Six main fisheries/gears were selected using the following IOTC codes:

1. **Handline fisheries -** IOTC codes HAND (handline), HLOF (handline offshore) and HOOK (hook and line) (sample size: 71,208).
2. **Pole and line fisheries -** IOTC codes BB (bait boat) and BBOF (bait boat offshore) (sample size: 622,064).
3. **Longline fisheries -** IOTC codes FLL (fresh longline), LL (longline), LLCO (longline coastal), LLEX (longline exploratory) and LLOB (longline observer onboard) (sample size: 6,664,821).
4. **Gillnet fisheries -** IOTC codes GILL (gillnet) and GIOFF (gillnet offshore) (sample size: 1,392,129).
5. **Purse seine fisheries -** IOTC codes PS (purse seine), PSOB (purse seine observer onboard) and PSS (purse seine small). In this case, free school (PSFS) sets and log (FAD) associated (PSLS) sets were separated (sample size: 443,543,693).
6. **Trolling fisheries -** IOTC codes TROL (Trolling) (sample size: 57,743).

In section VI (analysis of juvenile yellowfin tuna by country), at least the top three countries for each of the previously selected fisheries/gears were selected, in order to make an analysis of the catch of juveniles at the country level. However, due to the poor data quality for some combinations of country/gear, the final number of countries and years selected is variable. This particular is explained in the correspondent sections.

Average length (av. FL); the percentage of mature fish in the catch (% > L_{m50}); the percentage of fish caught at optimum length (% L_{opt} +/- 10%), and the percentage of mega-spawners (M-S) in the catch (% > L_{opt} + 10%) were calculated using Microsoft Excel.

Finally, another analysis has been undertaken. The spawning potential ratio (SPR) is the ratio of the fished to the unfished reproductive potential and is a measure of the impact of fishing on the potential productivity of a stock (Goodyear, 1993). The Length-based spawning potential ratio (LB-SPR) uses the length composition of the catch and key life history parameters of the target species to calculate the residual spawning potential (SP) of the exploited stock for a single fishery (Hordyk et al. 2015a, 2015b and 2016). In this case, the target for sustainable fishing is a spawning potential of 30% to 40% (Mace and Sissenwine, 1993). For undertaking this analysis, a length on 95% maturity (L_{m95}) is also required. The LB-SPR of YFT aggregations targeted by each fishery during the period 2015-2019 was calculated using an application developed by Hordyk et al. (2021) (http://barefootecologist.com.au/lbspr).

The above mentioned indicators are presented in Table 3 (pg 12).

Table 3 Assessment indicators used in this study.

Limits	Fork length (FL)	References
L_m	76 cm	Fu et al., 2018
L_{m50}	100 cm	IOTC 2017a
L_{opt}	125 cm	Obtained based on Beverton (1992)
L_{m95}	110 cm	Obtained based on Creech & Gunasekera (2020)
M	0.53	Calculated based on Kumar et al., (2020), Kaymaram et al. (2000), Kaymaram et al. (2014), Creech & Gunasekera (2020), Hashemi et al. (2020) , IOTC 2017a, Kar et al. (2012), Prathibha et al. (2012), Rohit et al. (2012), Nurdin et al., 2016, Mallawa & Zainuddin 2018.
K	0.41	Calculated based on Hashemi et al. (2020), IOTC 2017a, Ramalingam et al. (2012), Prathibha et al. (2012), Rohit et al. (2012), Kaymaram et al. (2000), Kaymaram et al. (2014), Nurdin et al., 2016, Haruna et al., 2018, Shono et al. (2007), Damora & Baihaqi (2013), Kantun & Amir (2013), Dortel et al (2013), Kumar et al., (2020), Tantivala (2000), Somvanshi et al. (2003) and Creech & Gunasekera (2020).
Juvenile (L_m)	< 76 cm	-
Sub-adult (L_{m50})	76 -100 cm	-
Adult	≥ 100 cm	-
Optimal range	112 - 138 cm	Based on Froese 2004
Mega-spawners	≥ 138 cm	Based on Froese 2004

IV.

Analysis of juvenile yellowfin tuna catch by fleet: current catches and trends

4.1. Historical changes in average length

Purse seine fisheries on free schools: The net trend of the trajectory of average length of YFT caught by PSFS fisheries between 2000 and 2019 was slightly positive, increasing from 96.5 cm in 2000 to 97.4 cm in 2019. It declined from 2005 to 2013, reaching the minimum of the time series in 2010 (90.5 cm).

The general trajectory of average length is above the length at first maturity (L_{m50} and L_m), although some years (2009-13) and since 2018 it has been below the length at first maturity (L_{m50}) (Fig. 1, pg.14).

Purse seine fisheries on log associated schools (FADs): The average length of YFT harvested by PSLS fisheries was relatively constant between 2000 and 2019, although the net trend of the trajectory of average length of YFT was negative, decreasing from 57.7 cm in 2000 to 50.9 cm (the minimum of the time series) in 2019. The general trajectory of average length is well below the length at first maturity (L_{m50} and L_m) (Fig. 1).

Pole and line fisheries: The net trend of the trajectory of average length of YFT caught by pole and line between 2000 and 2019 was slightly negative, decreasing from 51.0 cm in 2000 to 48.2 cm in 2019. Fluctuations occurred throughout this time series with the average length increasing and decreasing, reaching its minimum in 2008 (46.3 cm) and its maximum in 2012 (64.2 cm). The general trajectory of average length is below the length at first maturity (L_{m50} and L_m) (Fig. 1).

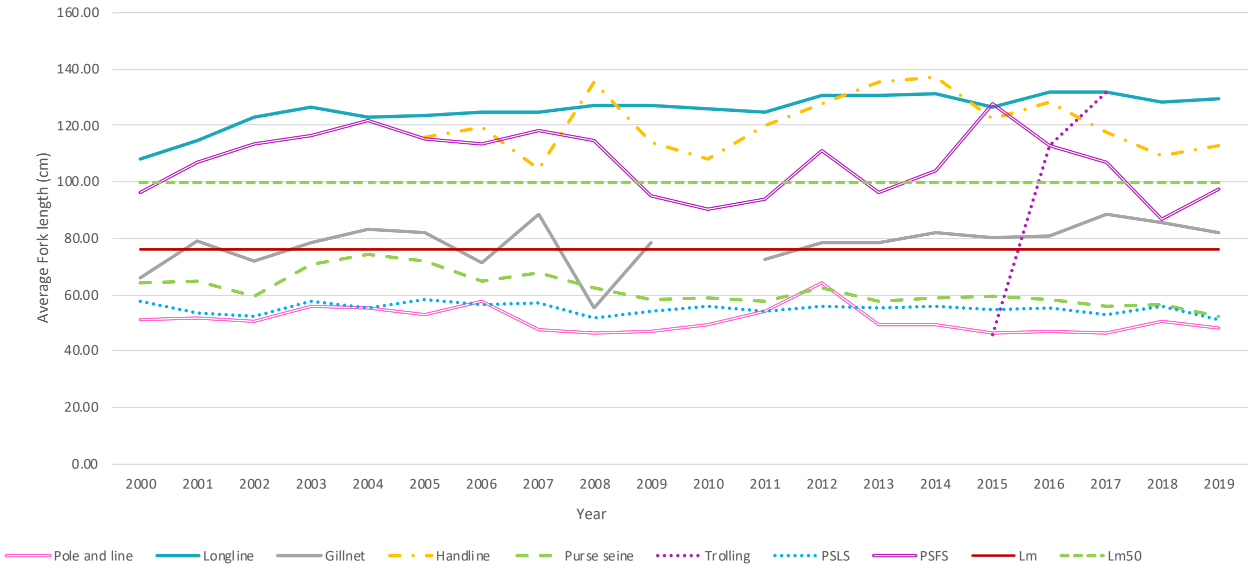
Longline fisheries: The net trend of the trajectory of average length of YFT caught by longline between 2000 and 2019 was positive, increasing from 108.3 cm in 2000 to 129.4 cm in 2019. Although there were small fluctuations throughout this time series, the net trend in the trajectory of average length was increasing. The general trajectory of average length is above the length at first maturity (L_{m50} and L_m) (Fig. 1).

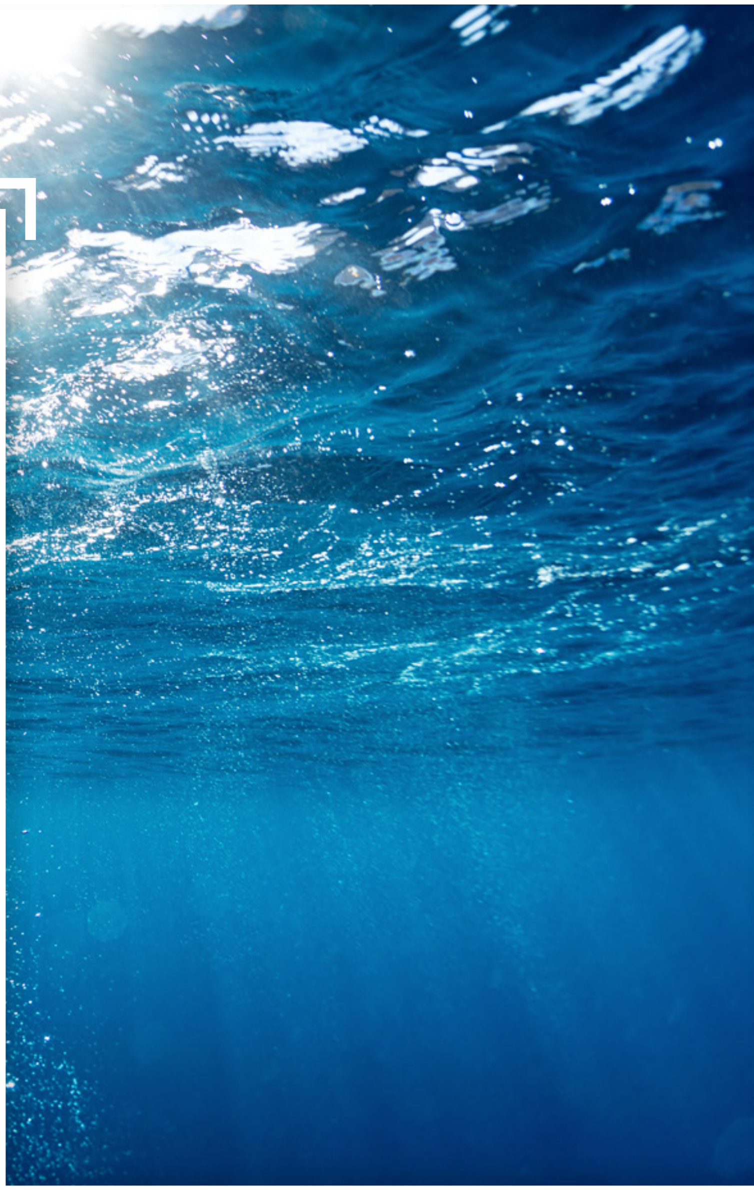
Gillnet fisheries: The net trend of the trajectory of average length of YFT caught by gillnet between 2000 and 2019 was positive, increasing from 65.9 cm in 2000 to 81.9 cm in 2019 (though no data were available in 2010). Fluctuations occurred throughout this time series with the average length increasing and decreasing, reaching its minimum in 2008 (55.0 cm) and its maximum in 2017 (88.8 cm). The general trajectory of average length is below the length at first maturity (L_{m50}) and it is hovering at about L_m (Fig. 1).

Handline fisheries: The net trend of the trajectory of average length of YFT caught by handline between 2003 and 2019 was positive, increasing from 97.3 cm in 2003 to 112.7 cm in 2019. Fluctuations occurred throughout this time series with the average length increasing and decreasing, reaching its minimum in 2003 and its maximum in 2014 (137.1 cm). The general trajectory of average length is below the length at first maturity (L_m) (Fig. 1).

Trolling fisheries: Data are only available for the years 2015, 2016, 2017 and 2019. The net trend of the trajectory of average length of YFT caught by trollling was negative, increasing between 2015 and 2017 and decreasing in 2019 (Fig. 1).

Figure 1 Average fork length (cm) of YFT caught by seven fisheries between 2000 and 2019, where L_m = 76 cm (red solid line) and L_{m50}=100 cm (green dotted line). Source: own, based on IOTC data.





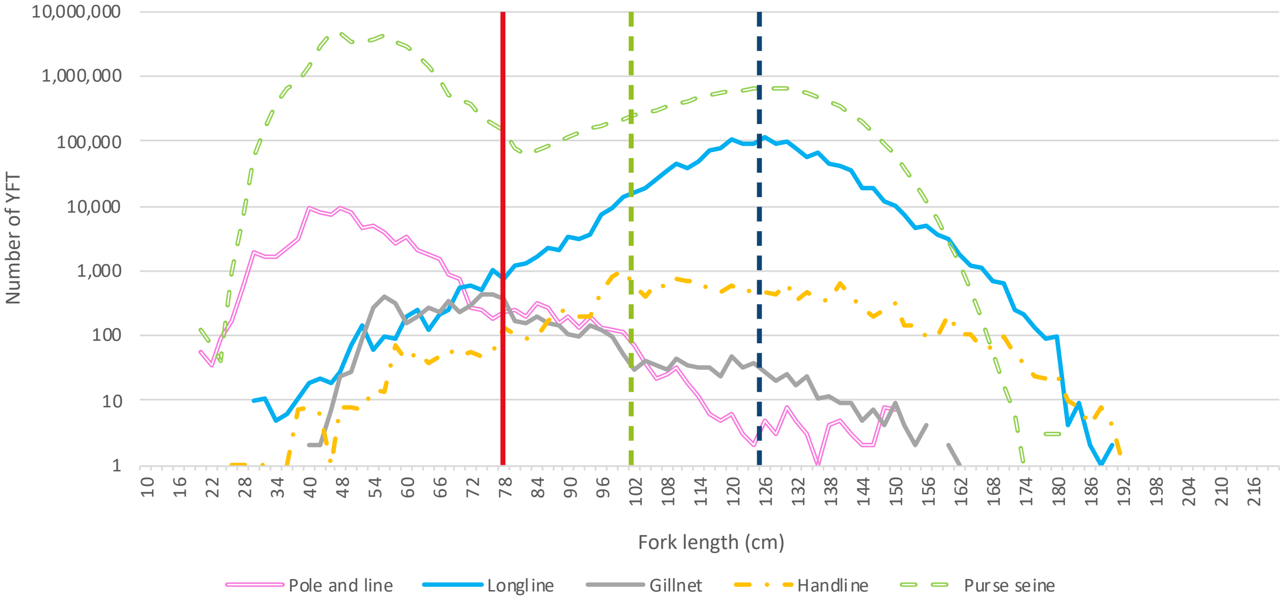
4.2. Length frequency distributions

Main gears: The comparison of length frequency distributions (by 2 cm length class) of yellowfin tuna of all the six main gears for 2005 to 2019 and PSFS and PSLS for 2000 to 2019 in period of 5 years, is shown at Fig. 2[3], pg 15. No significant differences are observed in the length frequency distribution throughout the periods analysed. It is noted that the purse seine, the pole and line, and the gillnet fisheries, present the catch size distribution that is most distant to the optimal size. In contrast, the longline, followed by the handline fisheries, present the catch size distribution that is closer to the optimum size.

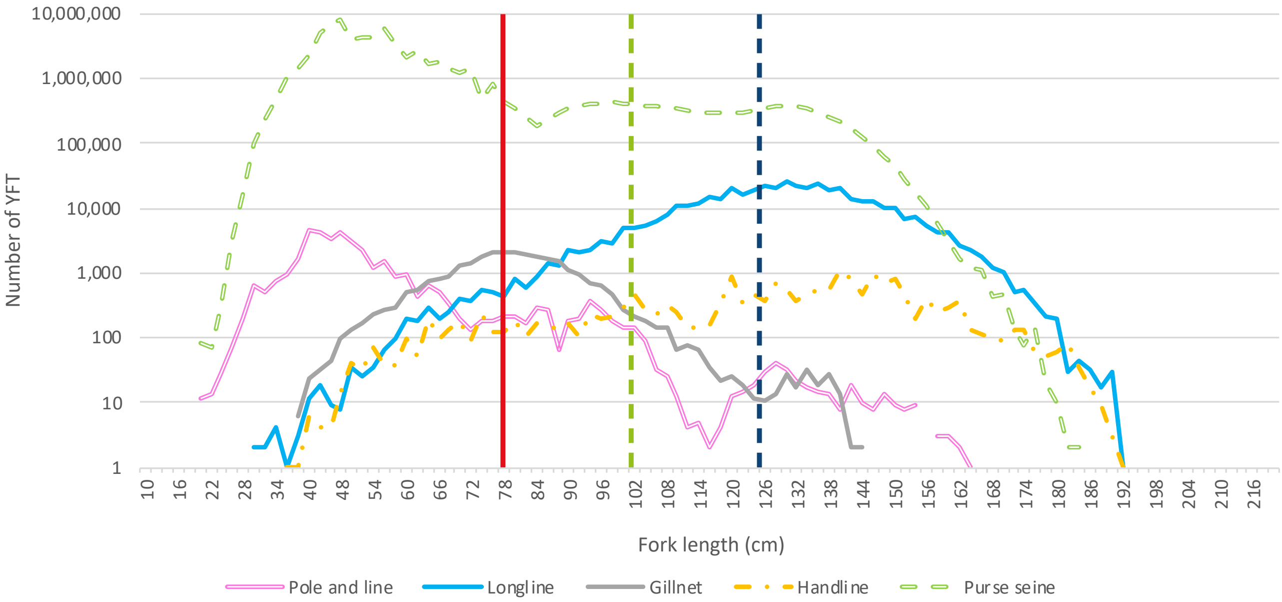
The trolling fleet (only data available in 2016, 2017 and 2019) has two size catch ranges: one extremely small, basically catching juveniles of yellowfin and the other catching much larger individuals. The purse seine fleet also presents two size ranges of catches, one of greater catches below L_m and others around the optimum size. This will be explained when FAD-based (PSLS) and free school purse seine (PSFS) sets are analysed separately (Fig. 3, pg 16).

[3] In this general section, the PS fishery is treated as a single unit as some PS fisheries does not separate FS and LS catches in the IOTC database. At the end of the section, separated data on FS and LS is used to explore the differences in catch length between these two catching methods.

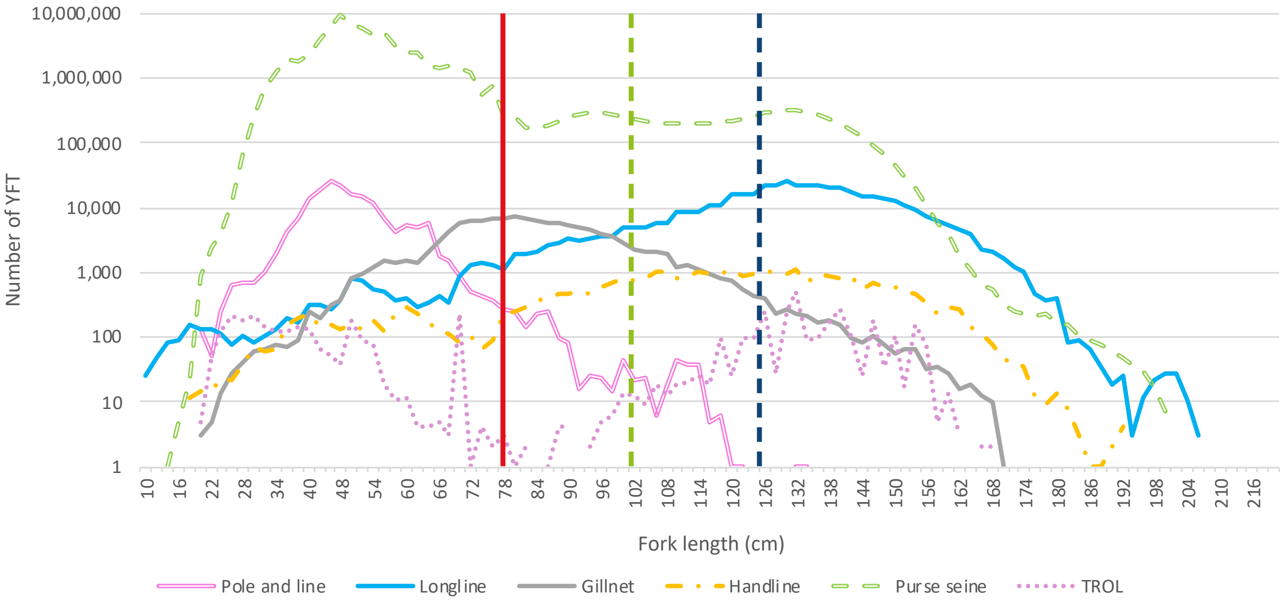
Figure 2 Length frequency distributions (by 2 cm length class) of yellowfin tuna caught using six fisheries in 2005-2009 (a), 2010-2014 (b) and 2015-2019 (c). L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Note: Please note that Y axis uses the log base 10 scale, which may distort the initial perception of the relative importance of each fishery. Source: own, based on IOTC data



2005 - 2009 N= 57,499,006

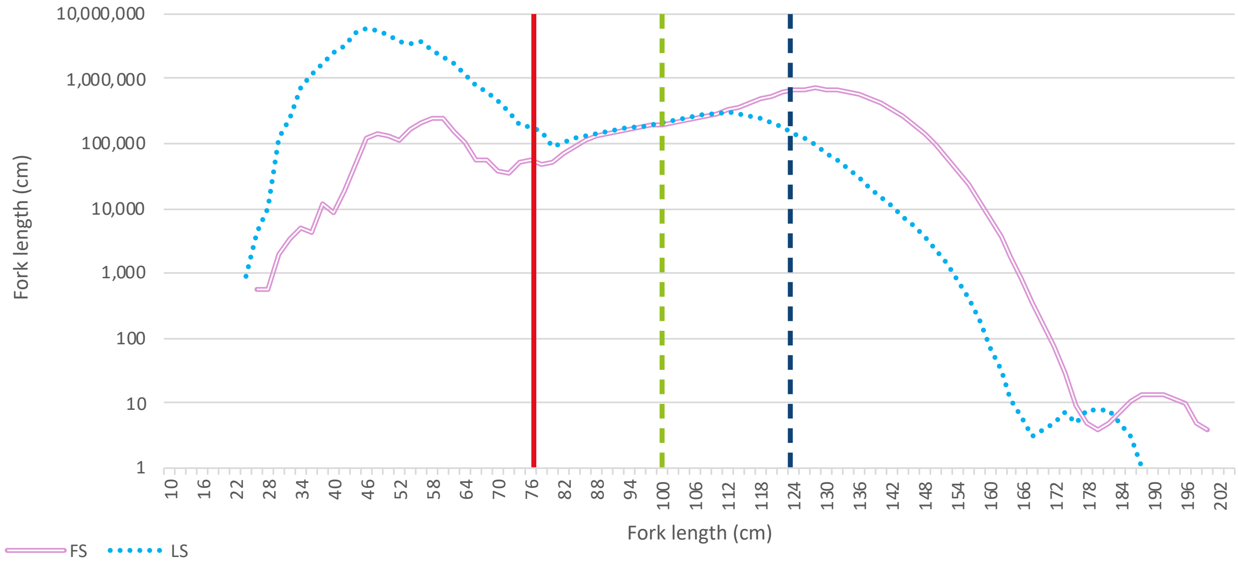


2010 - 2014 N= 74,219,724

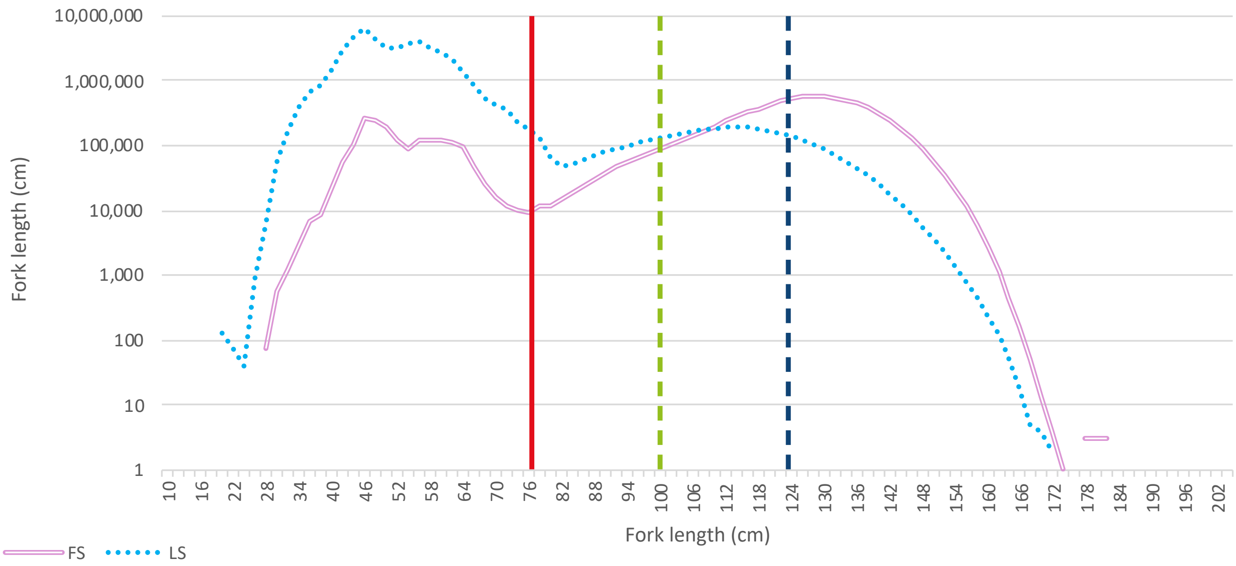


2015 - 2019 N= 77,582,053

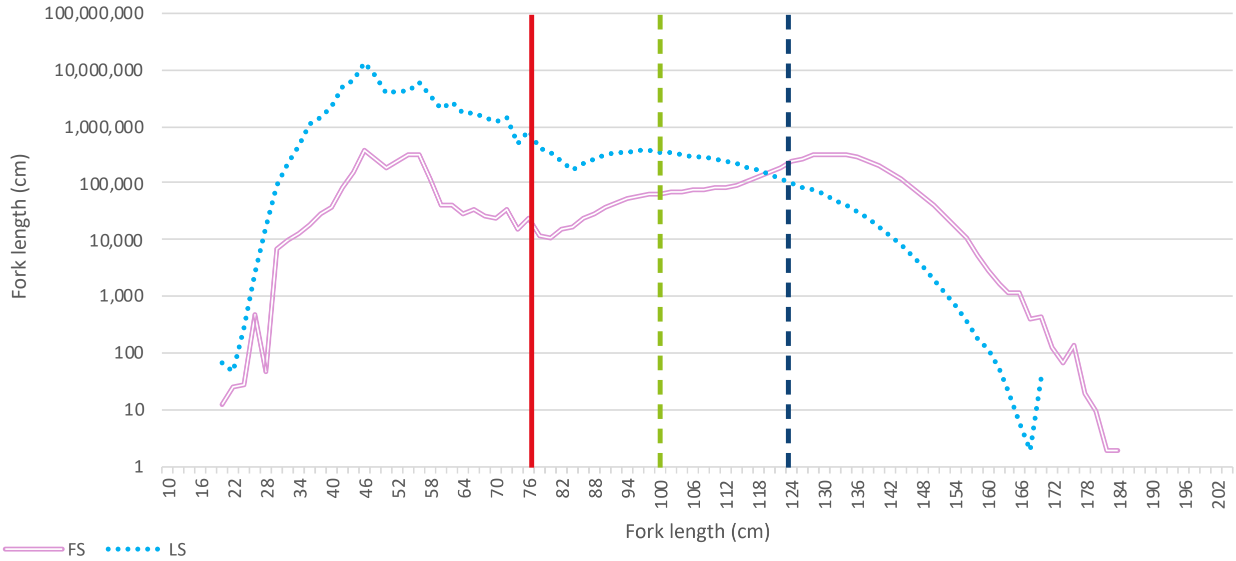
Figure 3 Length frequency distributions (by 2 cm length class) of yellowfin tuna caught using Purse seine fisheries on free schools (PSFS) and on log (FADs) -associated schools (PSLS) in 2000-2004 (a), 2005-2009 (b), 2010-2014 (c) and 2015-2019 (d). L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Note: Please note that Y axis uses the log base 10 scale, which may distort the initial perception of the relative importance of each fishery. Source: own, based on IOTC data.



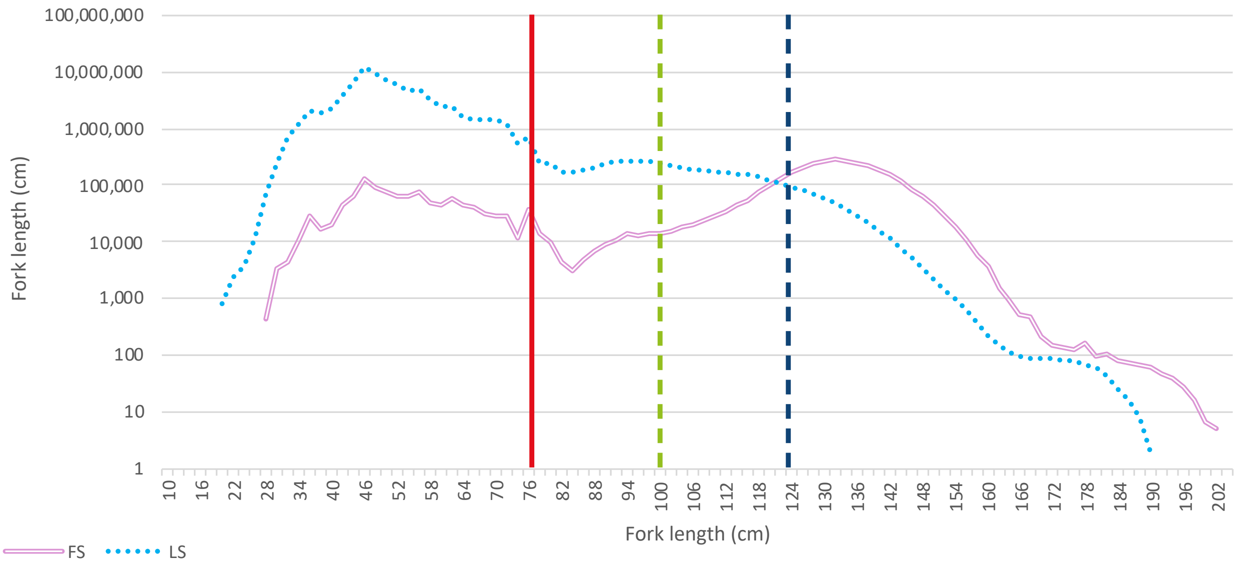
2000 - 2004 N= 71,811,634



2000 - 2004 N= 71,811,634



2005 - 2009 N= 62,428,669



2005 - 2009 N= 62,428,669

Looking at each gear individually during the last two years, 2018 and 2019[4] (Figs. 4, pg 18 and 5, pg 19), it is noted that:

Purse seine fisheries on free schools (PSFS): The size range caught in this modality goes from 30 to 192 cm in 2019 and from 30 to 190 cm in 2018. The catch encompasses two differentiated size modes, one below all indicators (L_m, L_{m50} and L_{opt}), concentrated between 42 and 52 cm; and another around the L_{opt}, concentrated between 118 and 138 cm. (Fig. 4a).

Purse seine fisheries on log (FADs) -associated schools (PSLS): The size range caught in this modality goes from 20 to 172 cm in 2019 and from 24 to 190 cm in 2018. The yellowfin tuna is concentrated below all indicators (L_m, L_{m50} and L_{opt}). The catch is majoritarily composed of juveniles between 40 and 56 cm (Fig. 4b).

Pole and line: The size range goes from 20 to 116 cm in 2019 and from 20 to 118 cm in 2018. Most YFT caught are concentrated below all indicators (L_m, L_{m50} and L_{opt}). The catch was constituted mainly by juveniles between 28 and 66 cm (Fig. 5a).

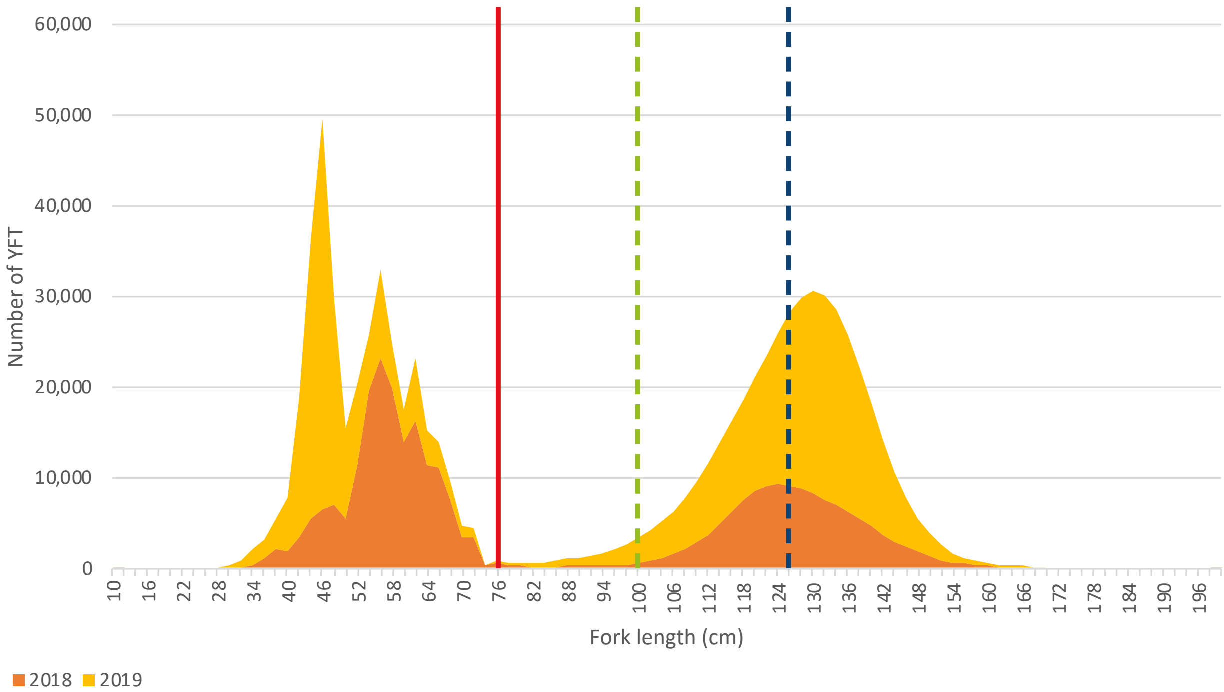
Longline: The size range goes from 34 to 206 cm in 2019 and from 36 to 198 cm in 2018. Most YFT caught are concentrated above all indicators (L_m, L_{m50} and L_{opt}), with a significant fraction of the catch above L_{opt}. The catch was mainly composed of mature between 108 and 154 cm (Fig. 5b).

Gillnet: The size range goes from 48 to 150 cm in 2019 and from 20 to 180 cm in 2018. However, more than half are caught below the L_{m50}, and almost all are harvested below L_{opt}. Therefore, the predominant age classes are juveniles and subadults, taking L_{m50} as the indicator, between the 70 and 88 cm (Fig. 5c).

Handline: The size range goes from 18 to 192 cm in both years. Most YFT caught are concentrated above all indicators (L_{m50} and L_{opt}) and presented a catch mainly of mature individuals between the sizes of 96 and 142 cm (Fig. 5d).

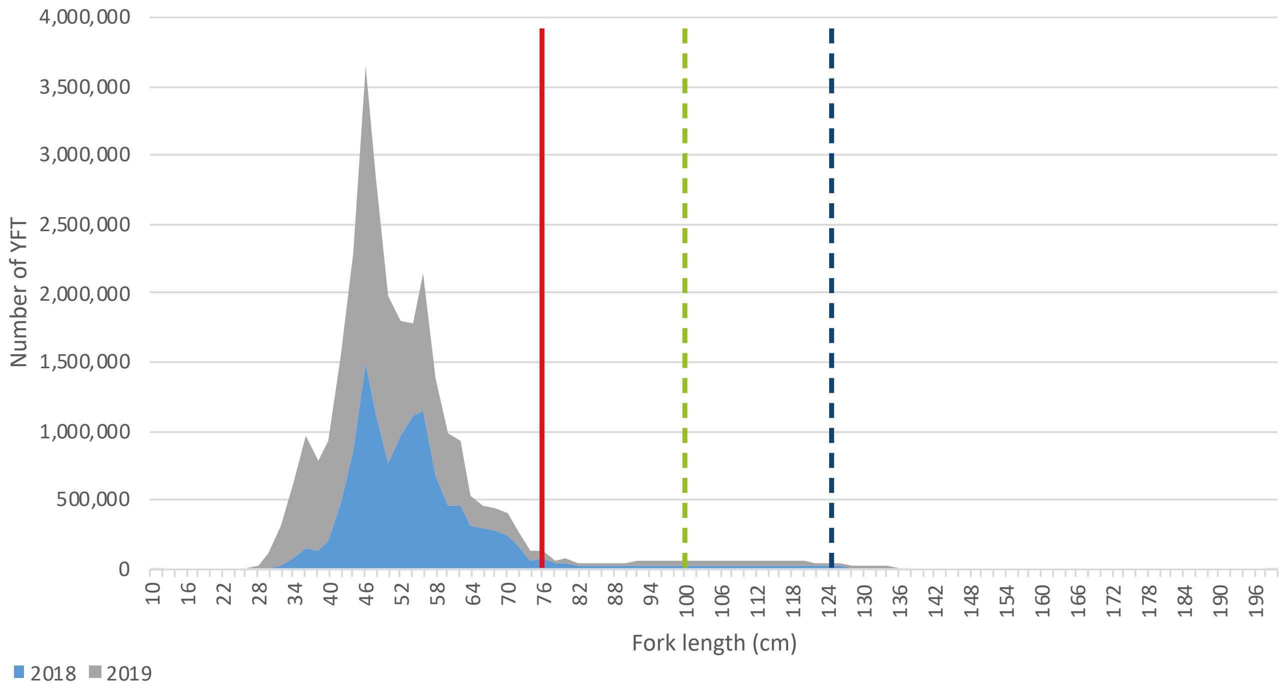
Trolling: The size range goes from 20 to 170 cm in both, 2019 and 2018. YFT are caught below all indicators (L_m, L_{m50} and L_{opt}). The catch was mainly of juveniles between 24 and 32 cm (Fig. 5e).

Figure 4 Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with PSFS (a) and PSLS (b). Period 2018-2019. L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.



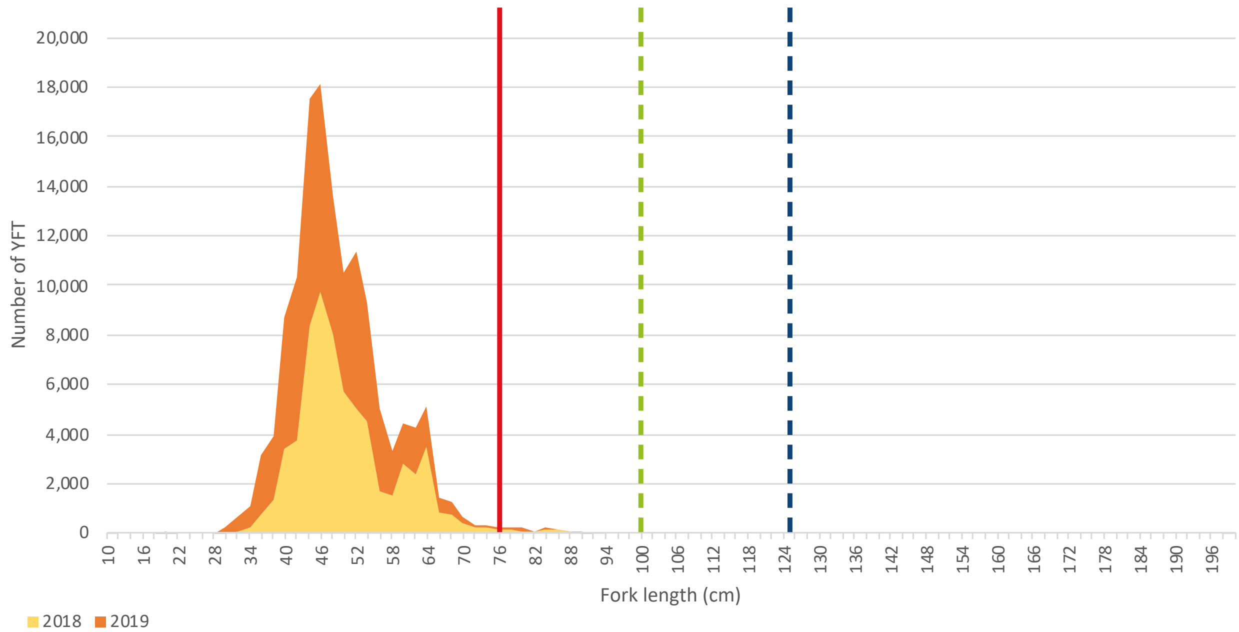
PSFS

[4] Except for gillnet, where 2017 and 2019 are compared due to lack of data in 2018.

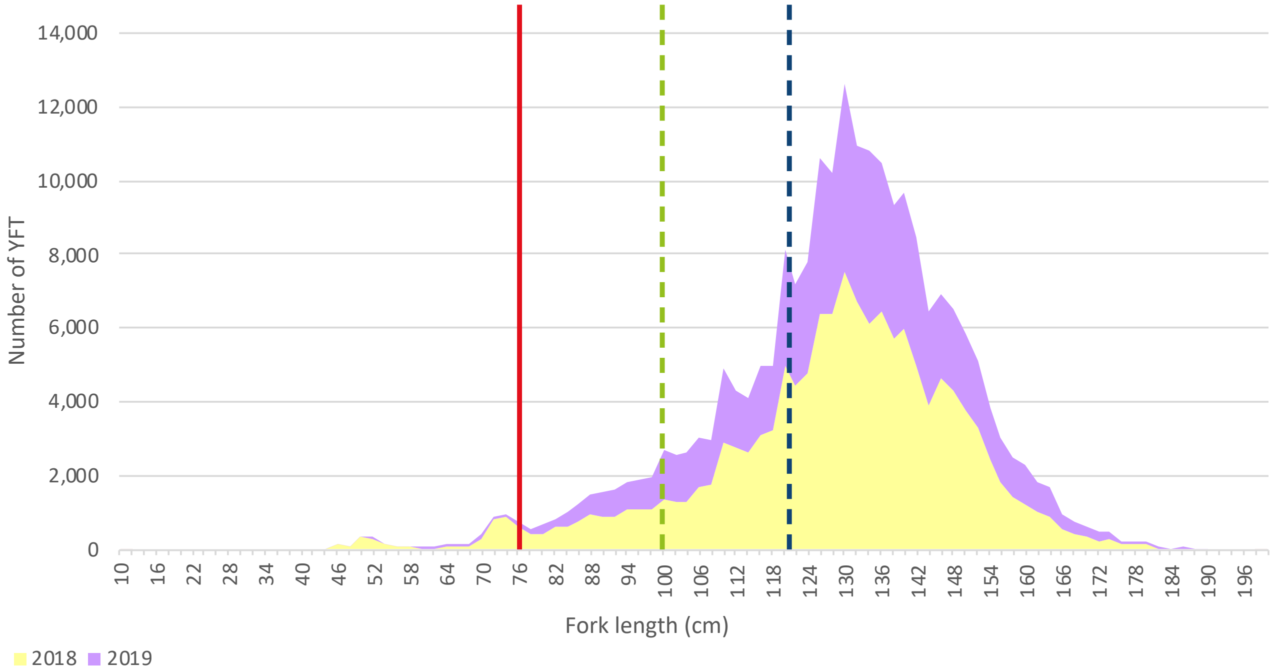


PSLS

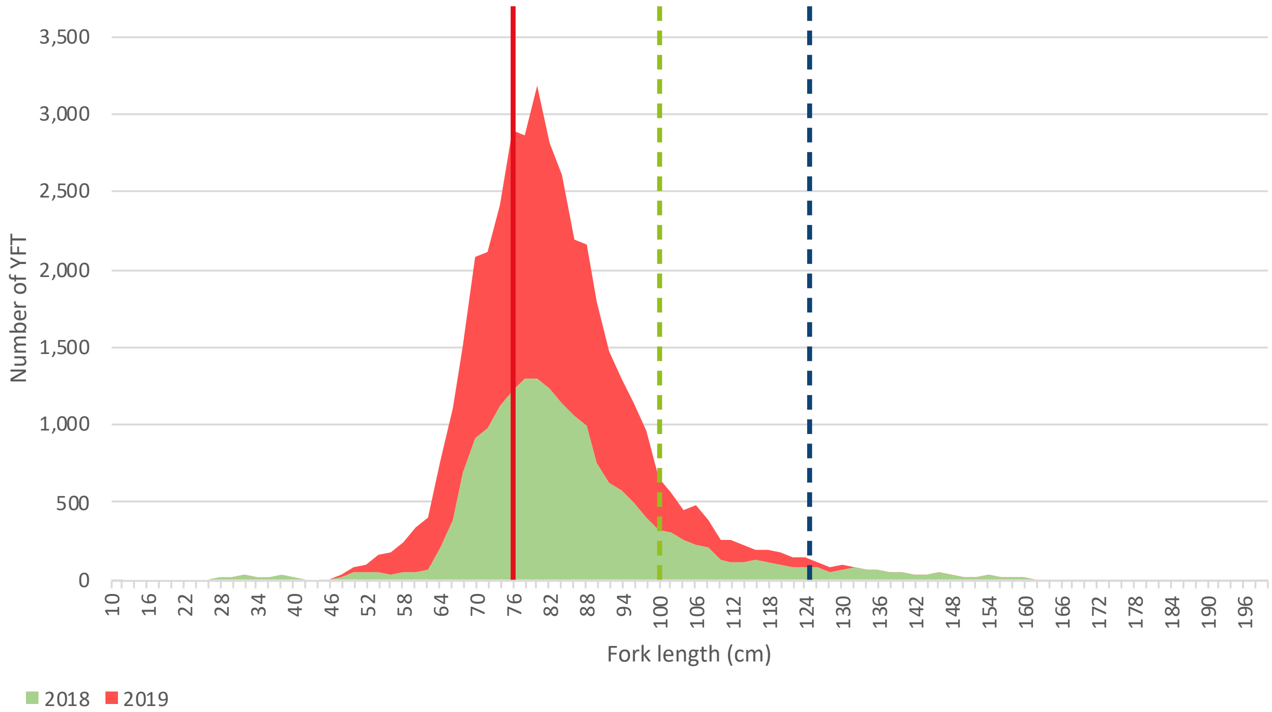
Figure 5 Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with a) Pole and line, b) Longline, c) Gillnet, d) Handline, and e) Trolling, where L_m = 76 cm (red solid line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Period 2018-2019 (except for gillnet, which used 2017 and 2019). Source: own, based on IOTC data.



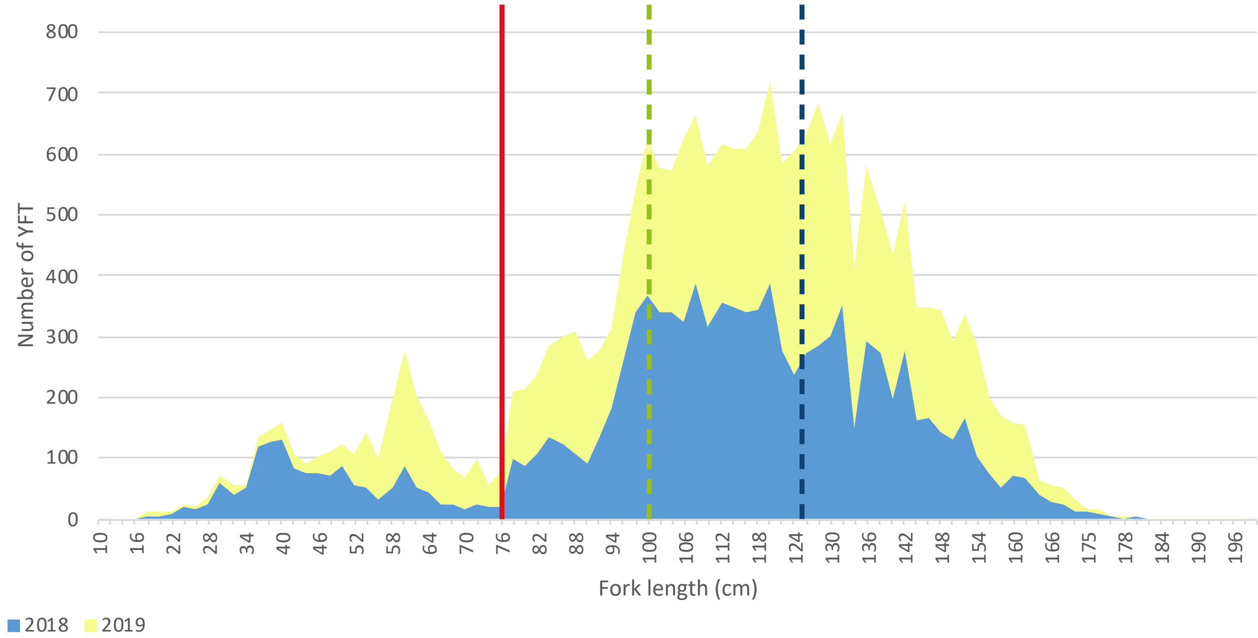
a) Pole and Line



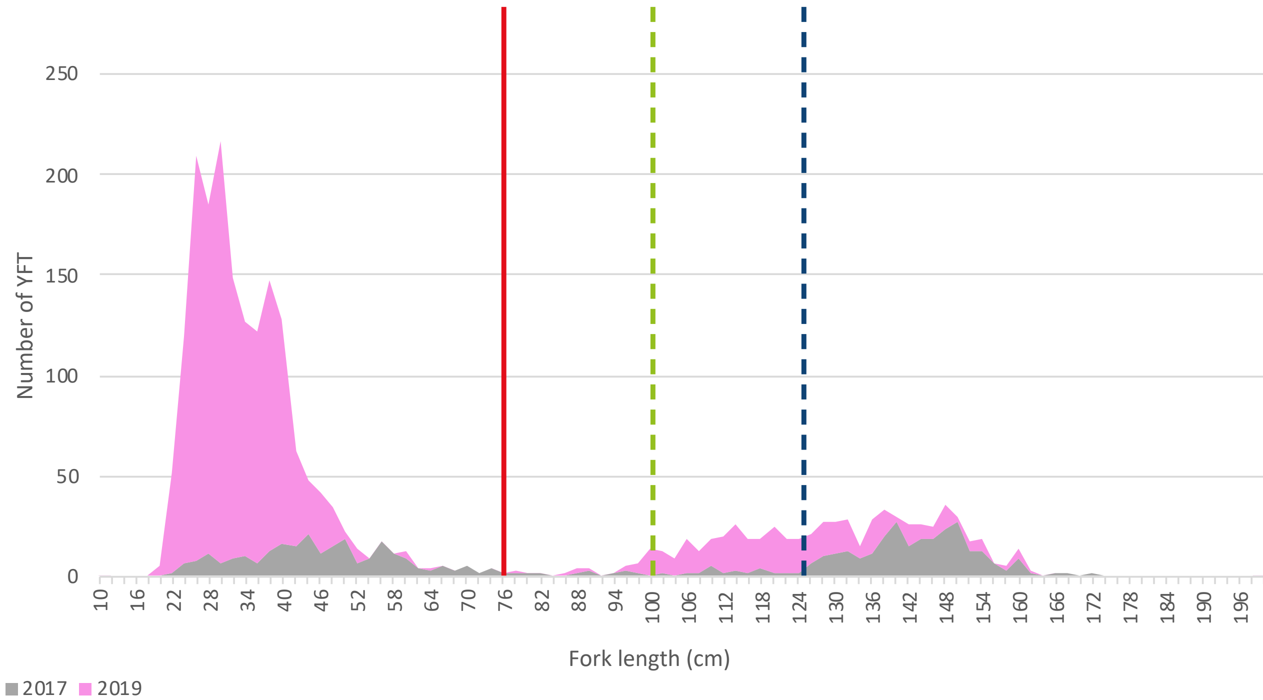
b) Longline



c) Gillnet



d) Handline



e) Trolling

4.3. Percentage of mature fish, fish at optimun length and mega-spawners

Purse seine fisheries on free schools (PSFS): In 2003 the percentage of mature fish on free schools catch was of 51%, increasing to 80.6% in 2008, decreasing afterwards and increasing again to a peak of 92.5% in 2015. Since 2016 it has decreased steadily, reaching a minimum of 42.4% in 2018. A similar pattern was found for catches at the optimum length (maximum in 2004 (60.5%) and 2015 (58.5%), minimum in 2018 (31.1%)). However, the percentage of mega-spawners fluctuated annually, reaching the peak of the historical series in 2015 (30.9%) and the minimum in 2010 (7.23%) (Table 1 in Annex 1).

Purse seine fisheries on log (FAD-) associated schools (PSLS): In 2003 the percentage of mature fish reached the peak of the historical series (9.4%), then declined irregularly to its lowest value of 2.1% in 2017. The percentage of fish harvested at optimum length fluctuated between 5.3% and 1.6% from 2000 to 2007. Since 2008 catches of fish harvested at optimum length remained below 2%. Mega-spawners were rarely caught in purse seine on log associated schools between 2000 and 2019 (maximum 0.4 %) (Table 1 in Annex 1).

Pole and line fisheries: The catch of mature fish in pole and line fisheries has been low during the time series, ranging from 0.01% to a maximum of 7.5% in 2012. Similarly, yellowfin harvested at optimum length has been low, with a maximum of 4.5% again in 2012. No catches at optimum length with pole and line were observed in 2008, 2010, 2013 and 2017. Mega-spawners were rarely observed in the pole and line catch between 2000 and 2019 (with the exception of 2012 when 3% were caught) (Table 2 in Annex 1).

Longline fisheries: The percentage of mature fish in the longline catch remained above 93% from 2000 to 2019. The percentage of fish harvested at optimum length ranged between 37% and 49% from 2000 to 2004, increasing afterwards (50%-74% from 2005 to 2013) and decreasing again to below 50% since 2014. The catch of mega-spawners ranged from 11% to 31% between 2000 and 2011. Since 2012, it has remained at around 35% (Table 2 in Annex 1).

Gillnet fisheries: The percentage of mature fish caught in gillnet fisheries peaked at 47% in 2007; the rest of years it ranged between 2.5% and 29% except in 2008 when no adult yellowfin were recorded. The highest percentage of fish harvested at optimum length using gillnet was 28% in 2007, declining to 1% by 2011, keeping at very low levels since then. Mega-spawners were rarely harvested using gillnet (maximum 4.3% in 2007). Less than 0.8% of the fish caught by gillnet fisheries were mega-spawners in 2019 (Table 2 in Annex 1).

Handline fisheries: In 2003 the percentage of mature fish in the handline line catch was of 23% increasing to a maximum of 96.6% in 2015 and decreasing again to around 75% between 2016 and 2019. Similarly, the percentage of fish caught at optimum length was minimum in 2003 at 3.9%. It increased since 2004 reaching a maximum of 52% in 2015 and decreasing to around 36% afterwards. However, the percentage of mega-spawners in the catch was minimum in 2006, with 2.9%, reaching a peak in 2012 with 58%. Since 2016, it ranged from 18% to 28% (Table 2 in Annex 1).

Trolling fisheries: No mature fish, no YFT caught at optimum length and no mega-spawners were observed in the trolling catch in 2015. In 2016 the percentage of mature fish, catches at optimum length and mega-spawners harvested by trolling fisheries was 72.2%, 42.6% and 29.5% (respectively), decreasing in 2017 and 2019.
In general, catch records for trolling fisheries throughout the time series are too fragmented to allow for any conclusions.

4.4 Proportion of juvenile and adult yellowfin tuna – PSFS and PSLS

Figures 6 and 7 (pg 24) compare the proportion of juvenile to adult yellowfin caught on free schools (PSFS) and log-associated schools (PSLS) sets in the Indian Ocean by the purse seine fleet between 2000 and 2019. Two categories have been used: percentage of mature tuna (individuals caught with a fork length equal to or greater than 100 cm (> L_{m50})), and juveniles (individuals caught with a fork length below 100 cm (< L_{m50})).

In the case of purse seine fisheries on free schools (PSFS) (Fig. 6), although mature tuna have predominated in the catches over the 2000-2019 period, there is a trend towards a decrease in the number of adult individuals caught.

In contrast, in the case of purse seine fisheries on log-associated schools (PSLS) (Fig. 7), there is an extremely high proportion of juvenile tunas in the catch. This proportion has been very high throughout all the historic period studied, with a net increase from 93% in 2000-2004 to 97% in 2015-19.

Figure 6 Proportion of juvenile and mature of yellowfin tuna caught on Purse seine fisheries on free schools (PSFS) in the Indian Ocean purse seine fleet between 2000 and 2019. Source: own, based on IOTC data.

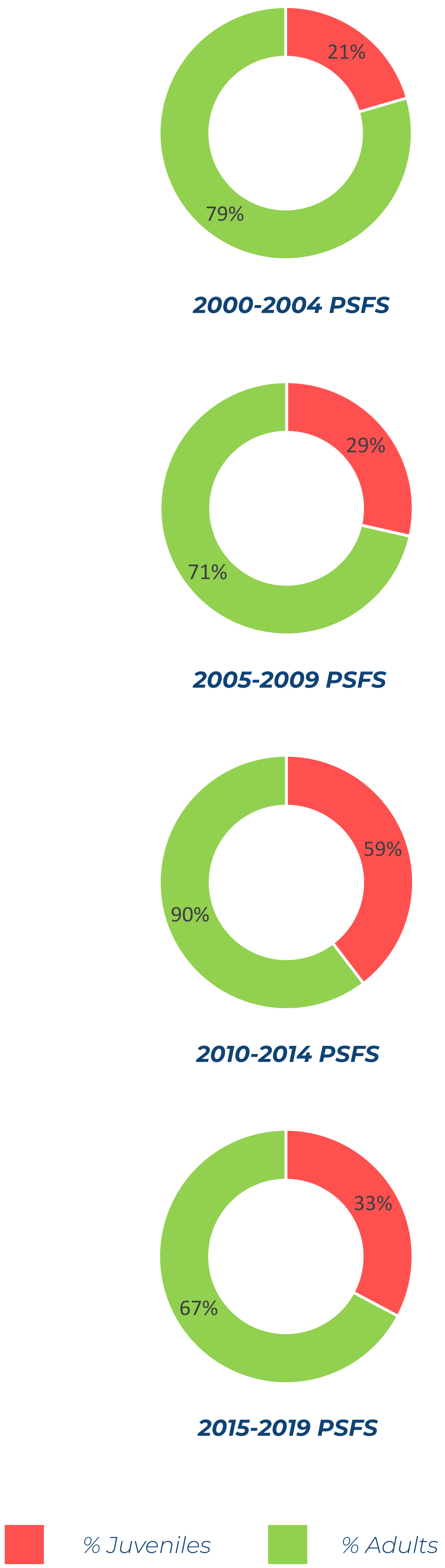


Figure 7 Proportion of juvenile and mature of yellowfin tuna caught on log (FAD-) associated schools (PSLS) in the Indian Ocean purse seine fleet between 2000 and 2019. Source: own, based on IOTC data.

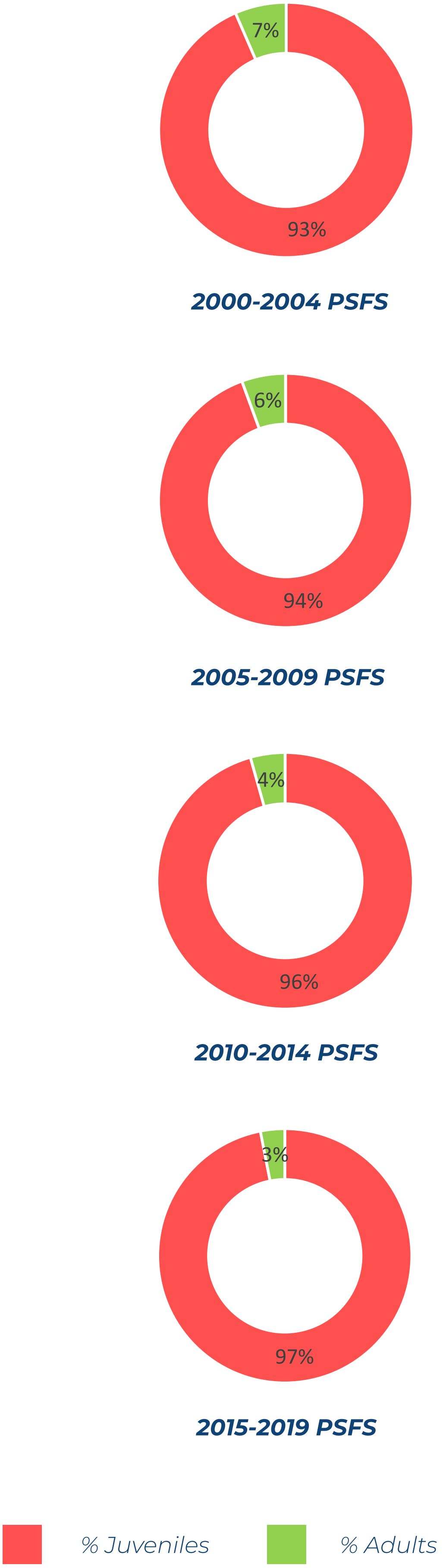


Figure 8 Proportion of juvenile and mature of yellowfin tuna caught Purse seine fisheries on free schools (PSFS) (up) and on log (FAD-) associated schools (PSLS) (down) in the Indian Ocean purse seine fleet from 2015 to 2019. Source: own, based on IOTC data.

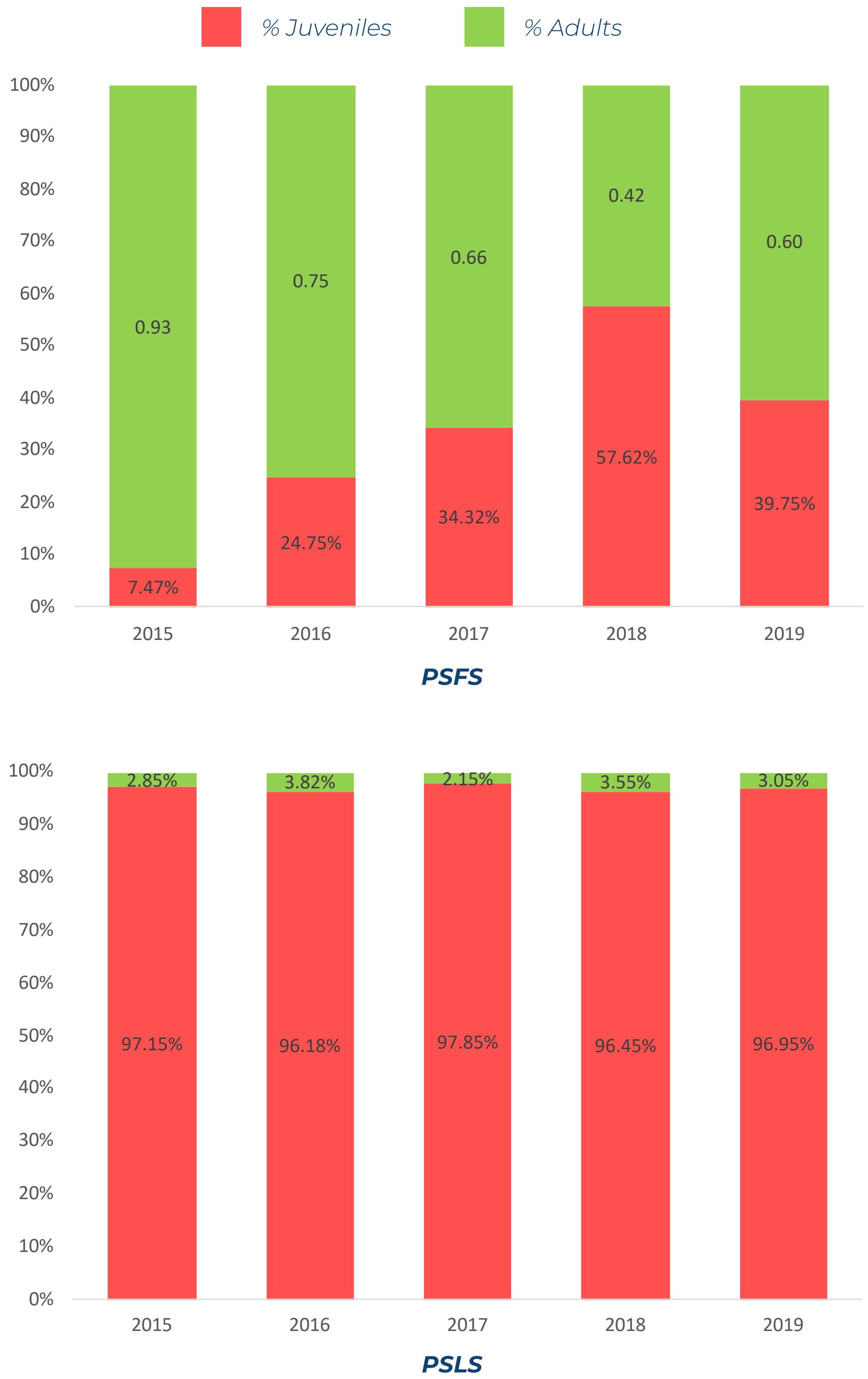


Fig. 8 (above) analyses in detail the catches of juvenile yellowfin tuna from 2015 to 2019, noting that 2017 was the first year of implementation of Resolution 16/01. It is noted that while the percentage of juveniles caught in the PSLS remained constant at around 97% through the period. However, the percentage of juveniles caught in the PSFS increased nearly eight-fold from 2015 to 2018 and decreased again in 2019, but it is still over the average of the period. Due to the short period of application of the resolutions it is not possible to establish a conclusive connection between both circumstances.

4.5 Spawning potential ration analysis

Finally, as indicated in the methodology section, an analysis of the spawning potential ratio was undertaken for each of the selected fisheries. The spawning potential ratio is the ratio of the fished to the unfished reproductive potential and is a measure of the impact of fishing on the potential productivity of a stock (Goodyear, 1993). The Length-based spawning potential ratio (LB-SPR) uses the length composition of the catch and key life history parameters of the target species to calculate the residual spawning potential (SP) of the exploited stock (Hordyk et al. 2015a, 2015b and 2016). The target for sustainable fishing is a spawning potential of 30% to 40% (Mace and Sissenwine, 1993). The results for this analysis are shown in Annex 2. Three fisheries have a SPR within or over the target: the LL fishery (40%), the PSFS fishery (35% from 2015 to 2018) and the HL fishery (31%). The PSLS, gillnet, pole and line and troll fisheries get a SPR between 0% and 4%. This analysis gives us an idea about the impact of each fishery on the potential productivity of the stock although these results needs to be considered carefully as it assesses each fishery as a single unit without taking into consideration the combined impact on the stock.

V.

Analysis of juvenile yellowfin tuna catch per country: current catches and trends

5.1. Introduction

This section presents an analysis of length frequency of YFT caught per gear for the main countries catching YFT. When combining all fleets, the top ten countries catching YFT in the Indian Ocean between 2015 and 2019 were: Iran (average catch 52,105 t), Maldives (49,487 t), EU-Spain (49,366 t), Seychelles (42,867 t), Sri Lanka (37,791 t), EU-France (30,469 t), Oman (24,307 t), India (24,273 t), Indonesia (39,752 t) and Yemen (20,004 t) (see Fig. 9 below).

Figure 9 Catches of yellowfin tuna per country> Period 2015-2019. Source: own, based on IOTC data.

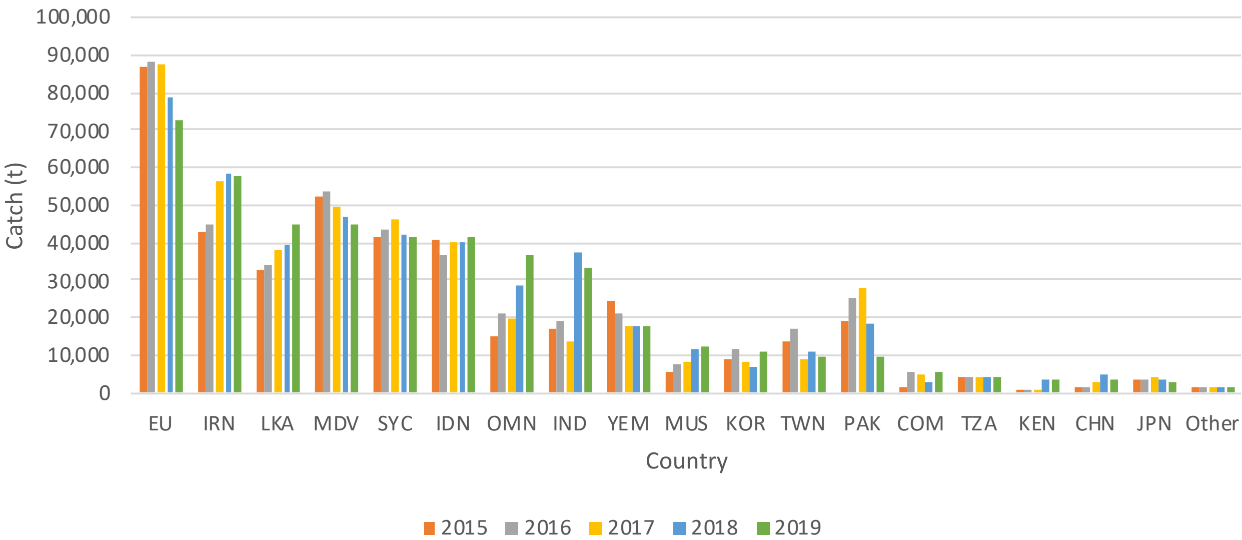


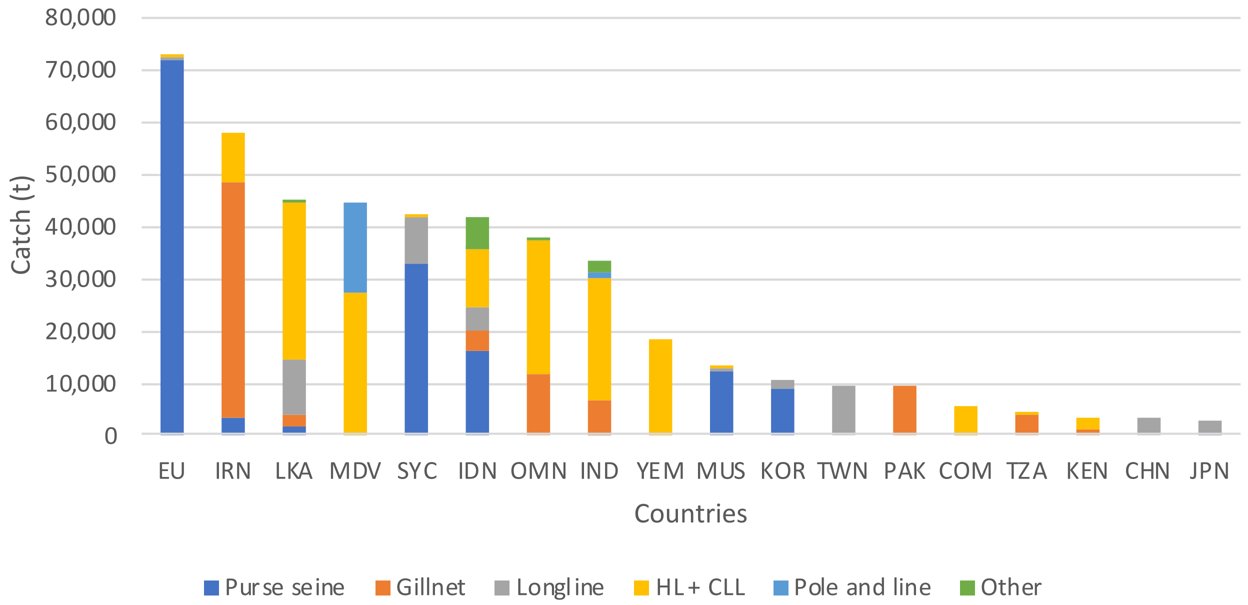
Table 4 Catches of yellowfin tuna per fishery. Period 2015-2019. Source: own, based on IOTC data.

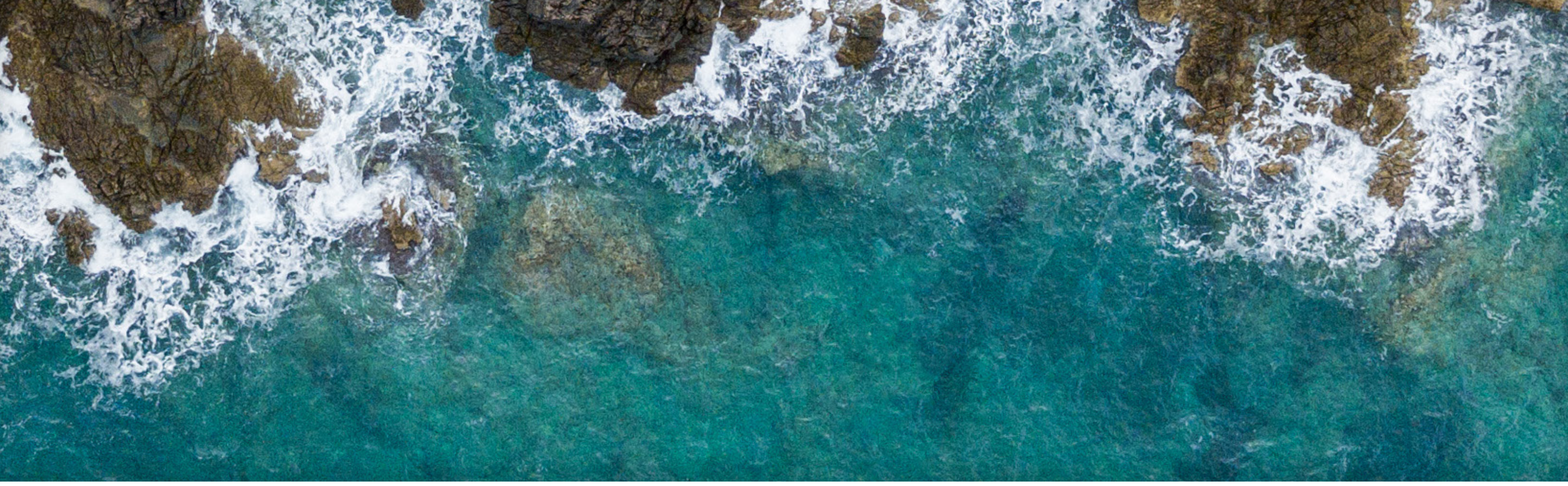
Fishery	2015	2016	2017	2018	2019	Average
Purse seine - LS	78,395	99,268	94,479	121,699	94,111	97,590
Gillnet	82,650	82,967	94,515	92,437	80,268	86,567
Handline	73,907	86,025	65,557	72,959	89,656	77,621
Longline	59,454	64,964	70,951	88,427	82,403	73,240
Purse seine - FS	63,963	49,460	50,700	17,944	38,588	44,131
Pole and line	17,642	12,391	18,370	20,030	18,551	17,397
Other gears	26,902	32,631	27,253	27,338	23,662	27,557
Total	**402,913**	**427,706**	**421,825**	**440,834**	**427,239**	**424,103**

Catches of YFT per gear between 2015 and 2019 are also shown in Table 4. The main fishing gears catching YFT in the Indian Ocean are purse seine-LS, with an average catch of 97,590 t; gillnets, with an average catch of 86,567 t and in the third place handlines and longlines, with an average catch of 77,620 t and 73,240 t respectively.

Catches per country and gear for the most recent year (2019) are shown in Fig. 10 below.

Figure 10. Catches per gear and country in 2019. Source: own, based on IOTC data.



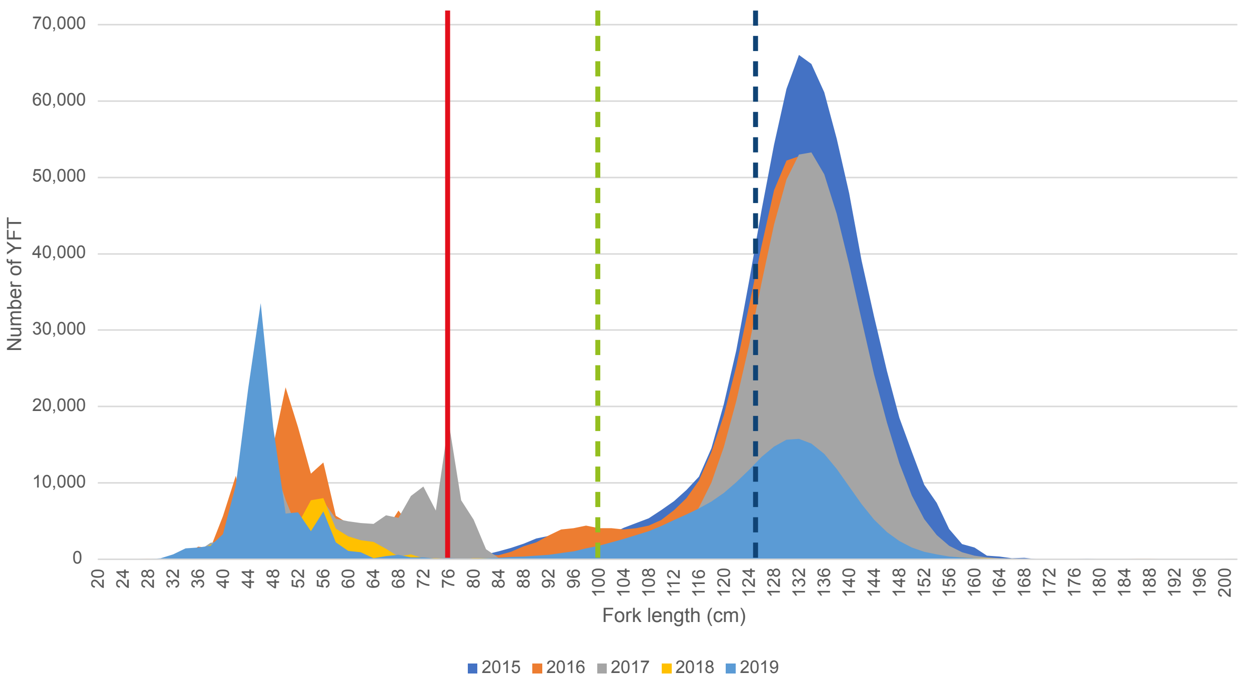


5.2. Purse seine fishery

The purse seine fishery in the Indian Ocean developed rapidly with the arrival of European vessels between 1982 and 1984 (IOTC 2020a). Since then, the volume of yellowfin tuna caught by this fleet has kept at a high level. The purse seine fishery is characterized by the use of two different fishing modes: the fishery on floating objects (FADs) and the fishery on free swimming schools. The main countries using purse seine for catching YFT in the Indian Ocean are the EU (Spain (42,273 t in 2019)/France (27,206 t)), Seychelles (33,006 t) and Mauritius (12,290 t), where important Spanish- and French-owned fleets are respectively based; and to a lesser extent, Indonesia (9,775 t), Republic of Korea (8,730 t) and I.R. Iran (3,361 t). Length-frequency distributions of YFT caught by these countries are shown in Figs. 11 (below) through 13 (pg 30).

Fig. 11 shows the aggregated length frequency distributions in the catch of the EU purse seine fleets (Spain and France)[5] setting on free schools (PSFS). As seen in the previous section, two modes are identified in this data: the first is less clear and variable across years, at around 46 cm, both below L_m and L_{m50}; and the second one at around 134 cm, within the range of optimal length (112 – 138 cm).

Figure 11. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with PSFS by the EU fleet (Spain and France). Period 2015-2019. where L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.



In the case of the EU log-associated purse seine fishery (PSLS, Fig. 12), only one mode is found at around 46 cm, well below the L_m and L_{m50}.

[5] Data from Seychelles and Mauritius have not been included in this analysis as they are basically the same fleet that the EU Spain/France purse seine fleet and no differences were appreciated.

Figure 12. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with PSLS by the EU fleet (Spain and France). Period 2015-2019. where L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.

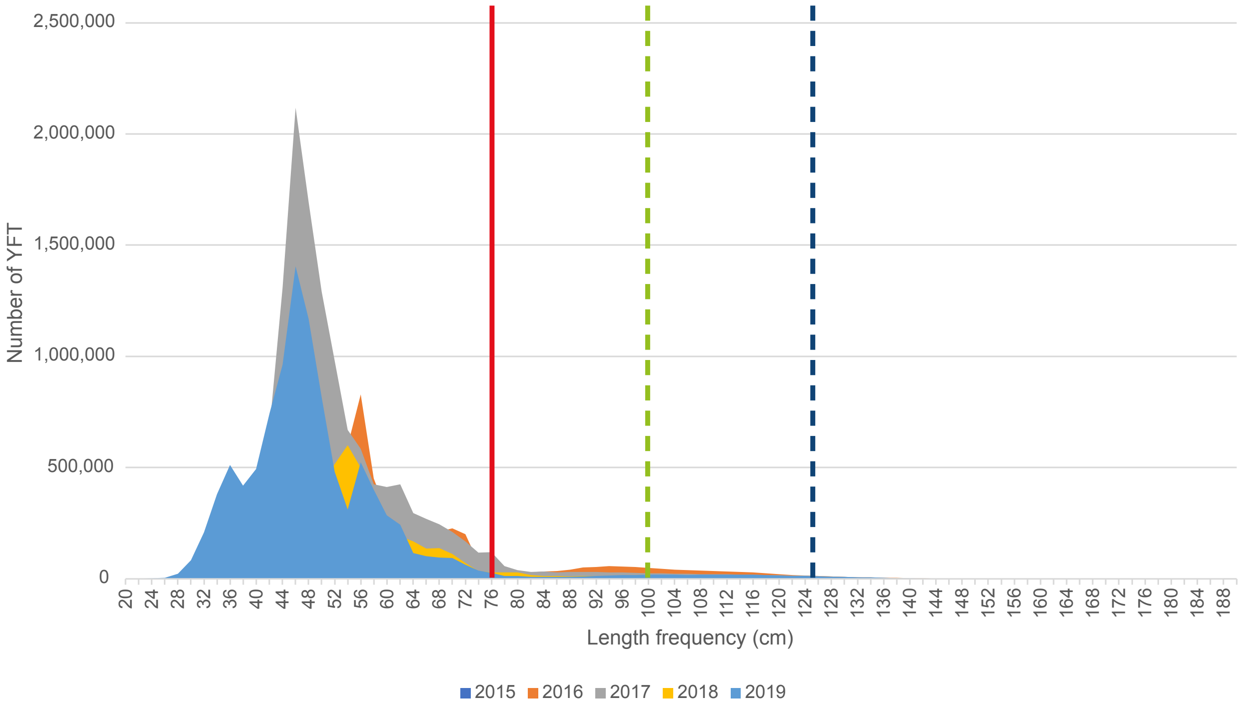
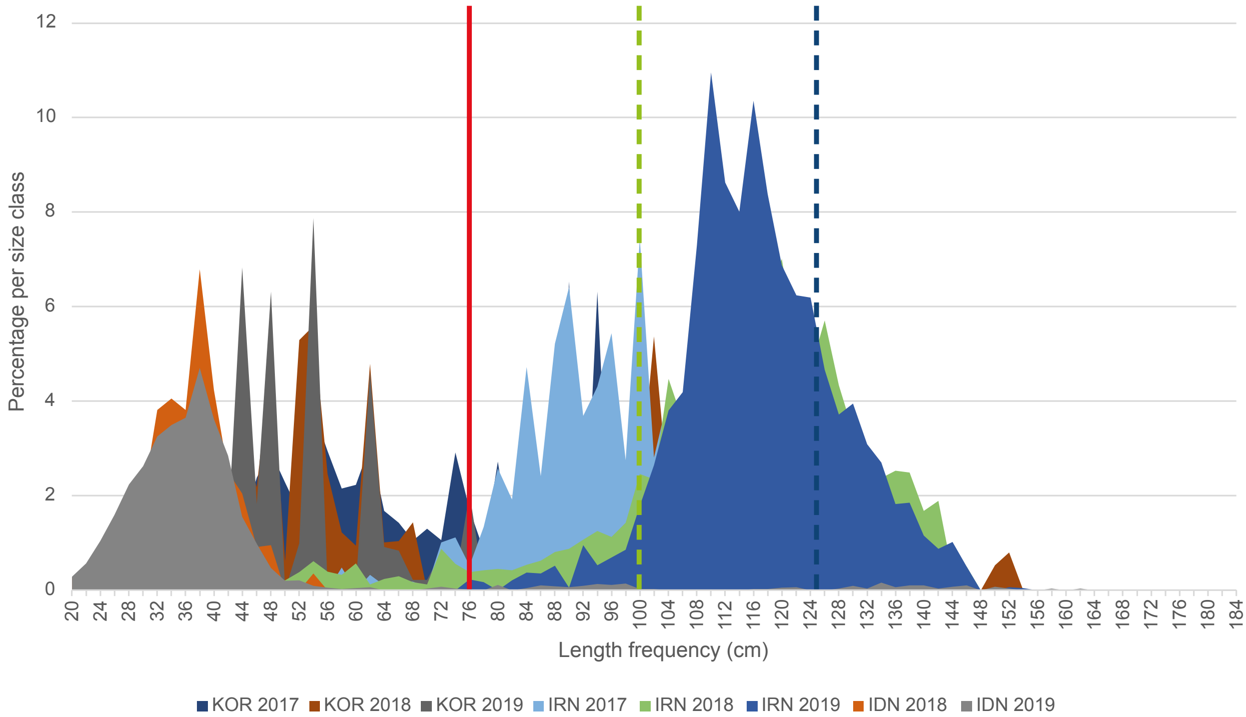


Figure 13. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with PS by other countries (School type UNCL). Period 2017-2019. where L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.



Length-frequency data for purse seine catch by the rest of the countries is found in Fig. 13. In this case, the set type is not specified (UNCL) in the database. However, based on the graphic representation, it can be guessed that the Irani purse seine fishery mainly targets free schools, whereas the Korean and Indonesian fisheries seem to be log (FAD)-associated.

It is important to highlight, however, two points: one, the average size of the Iranian purse seine YFT catch (average size 107.6 cm although it was lower in 2017) seems smaller than the average size in the EU fishery, and below the L_{opt}; and two, the average size of the YFT catch by the Indonesian fishery is much smaller (35.6 cm) than in the Korean (67.3 cm) and the EU PSLS (55.5 cm) fisheries.

5.2.1 Impact of Resolution 16/01 in the catch of juvenile yellowfin tuna in the purse seine fishery

PSFS and PSLS catches of yellowfin for the main countries are shown in Table 5. As seen in the Table, catches in these set types decreased in recent years, reaching an all-time low of around 16,000 MT in 2018. In 2019, the catches of large yellowfin tuna on free schools re-increased to almost 40,000 MT. In 2017, 2018 and 2019, catches on FADs were 91,909 t, 111,189 t and 85,595 t respectively. This increase in the use of FADs in the PS fishery is thought to have occurred due to the implementation of Resolution 16/01 which set catch cuts for yellowfin tuna. Presumably, purse seiners tried to avoid reaching their quota of yellowfin tuna, by switching effort towards setting mainly on FADs, so as to catch skipjack and avoid free swimming tuna schools which are mainly composed of adult yellowfin tuna (Merino et al., 2018). This circumstance increased the volume of juveniles caught in the fishery during these years.

Table 5. Catches of yellowfin tuna per country in the PSFS fishery. Period 2015-2019 (IOTC data)

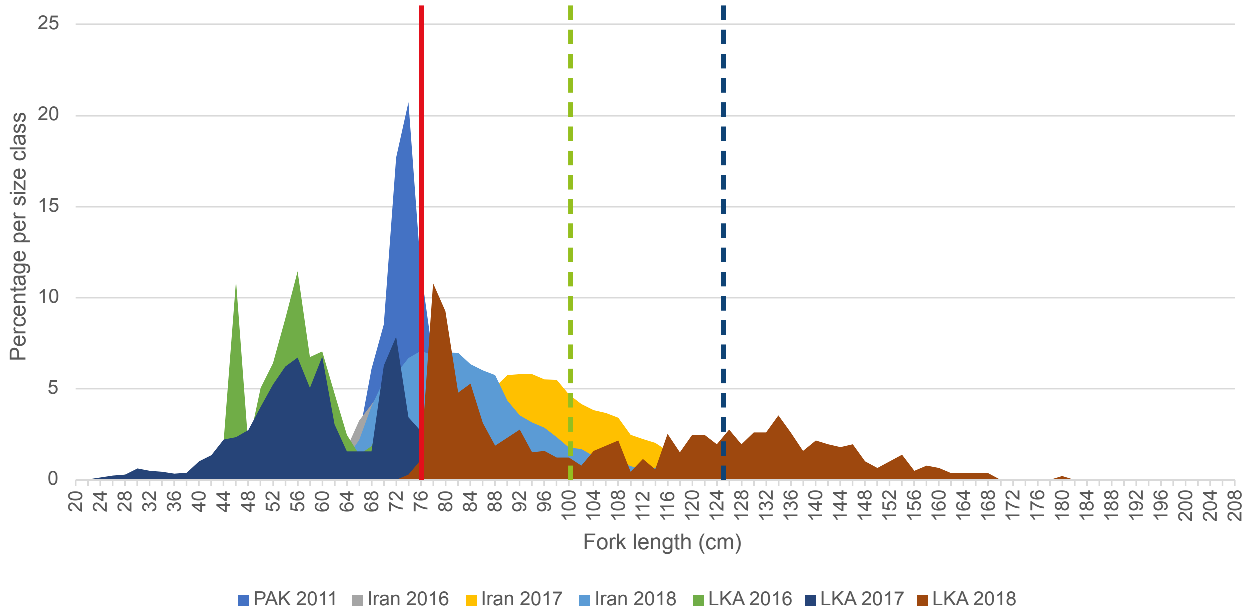
	Country	2015	2016	2017	2018	2019
PSFS	EUESP	20,682	12,827	17,929	1,665	8,697
	EUFRA	18,831	16,359	11,681	4,164	9,258
	EUITA	1,666	0	0	0	0
	KOR	1,969	5,422	3,452	2,587	6,849
	MUS	3,300	5,214	3,279	5,235	8,410
	SYC	15,902	7,512	11,953	2,275	4,677
	Total	**62,350**	**47,334**	**48,293**	**15,926**	**37,891**
PSLS	EUESP	31,948	38,662	36,583	43,644	33,569
	EUFRA	12,216	17,360	18,280	25,888	17,945
	EUITA	806	0	0	0	0
	KOR	5,538	4,925	2,910	2,828	1,881
	MUS	2,117	2,189	4,401	6,085	3,876
	SYC	23,112	32,496	29,735	32,743	28,324
	Total	**75,737**	**95,632**	**91,909**	**111,189**	**85,595**
	Grand total	**138,087**	**142,966**	**140,202**	**127,114**	**123,486**

As indicated in section IV above, the increase in the catch of juveniles in the PSFS fishery from 2015 to 2018, together with the increase in catches in the PSLS fishery from 2015 to 2018, resulted in an increase in the total catch of juveniles in these two fisheries combined from 45.3% in 2015 to 67.2% in 2018. However, this percentage decreased again to 53.2% in 2019.

5.3. Gillnet fishery

Gillnets are used to caught YFT in the Indian Ocean by: Iran (45,298 t in 2019, 10% of the total catch of YFT in the Indian Ocean), Pakistan (11,516 t), Oman (9,359 t), India (6,801 t), Sri Lanka (2,025 t) and Tanzania (3,814 t). Length-frequency distributions in the YFT catch of these countries are shown in Fig. 14. No length-frequency data is available for India, Oman and Tanzania during the last decade. Only data for 2011 is available for Pakistan. As seen in Fig. 14, the average length of YFT caught by gillnets for these countries is variable.

Figure 14. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with gillnets for the main country ("PAK, Pakistan; "LKA", Sri Lanka). Period variable due to the lack of specific data for some countries. L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.



Gillnet is the most common fishing gear used in Iran, where approximately more than 93% of the fish are caught using this gear (Eighani et al., 2020), including YFT (80% in 2019). Gillnet selectivity is presumed to be dome-shaped, as it generally includes fish <100cm. The average length for Iran-caught YFT in 2016 and 2018 was around 86.7 cm, which is similar to the average size indicated by Kaymaram et al., 2014, 86.1 cm) and slightly over the average size indicated by Eighani et al. 2020 (84.4 cm). Kaymaram et al., 2014 also found a seasonal pattern in the catch. The modal size of yellowfin tuna gradually increased from 61 cm at the beginning of the fishing season (October-December) to 93 cm in the fourth quarter of the season (July-September) during the monsoon period.

In the case of Sri Lanka, the average size shown in Fig. 14 for the period 2016-2018 is 81.2 cm. However, it varies between 63 cm in 2016 to 108.6 cm in 2018. Herath (2012) describes that in Sri Lanka some gillnetters attach longlines at the end of the net, thus combining two modalities of fishing in the same fishing trip. It might be possible that in 2018 catches from the gillnet and the longline fishery (which catches larger fish) were mixed, as at least two modes are identified in the figure: one around 78 cm and another at around 134 cm. However, it is unclear why the average size of the catch was so low in 2016.
In the case of the Pakistani gillnet fishery, only length data for 2011 is available with an average size for YFT of 76.5 cm, below the average sizes of both Iran and Sri Lanka. According to Shaid (2015), Pakistani gillnets have stretched mesh sizes between 13 and 17 cm, larger than the Irani nets which have a stretched mesh size between 10 cm to 12 cm. Therefore, this difference in size composition does not seem to be explained by the mesh size used in that fishery.

5.3. Longline fishery

YFT is caught in the Indian Ocean by Sri Lanka (32,735 t of YFT caught in 2019), Taiwan (9,427 t), India (8,943 t), Iran (8,441 t), Seychelles (6,417 t) and Indonesia (6,111 t) and to lesser extent, China (3,212 t), Japan (2,560 t) and Korea (2,060 t).

Length-frequency data for the longline fisheries is available since 1952. Length-frequency for the three main countries (LKA, TWN and SYC, no data is available for IND) using this gear is shown in Fig. 15. As indicated in the previous section, average sizes for YFT caught in the LL fishery are much larger than for the other fisheries analyzed. YFT catches in the LKA LL fishery seem to be larger (mode 142 cm) than in the Taiwanese and Seychelles fisheries (130 cm).

Figure 15. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with gillnets for the main country. Period variable due to the lack of specific data for some countries. L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.

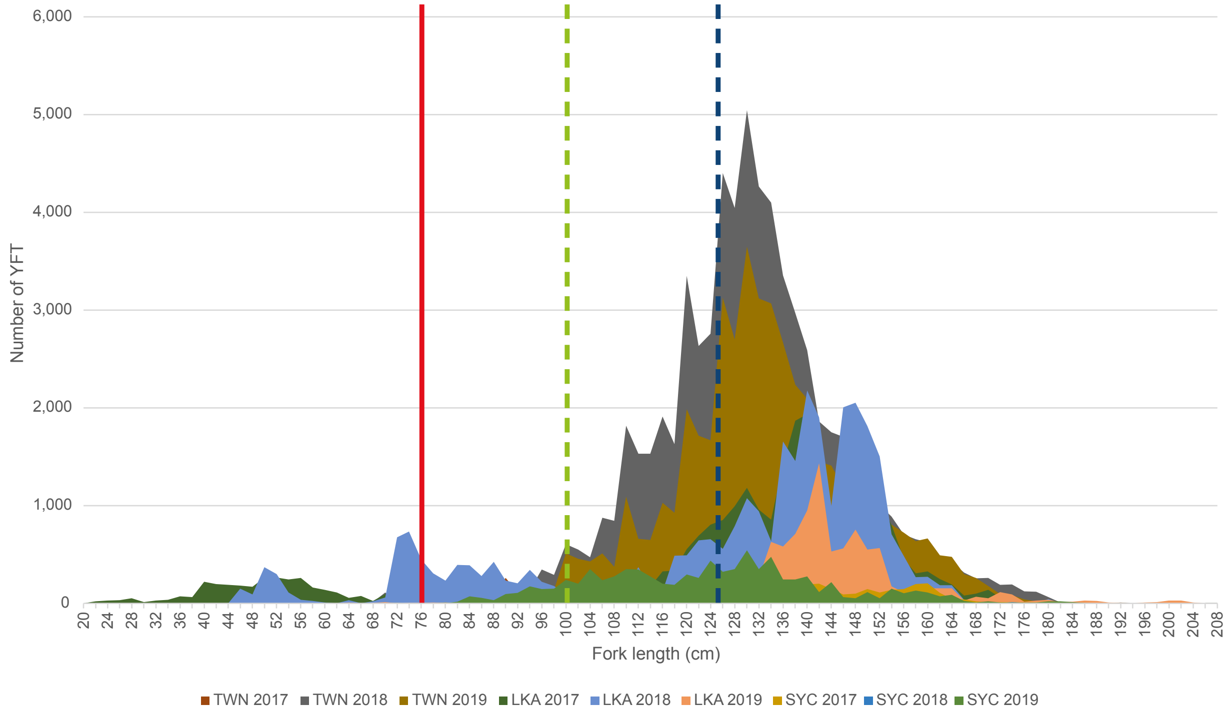
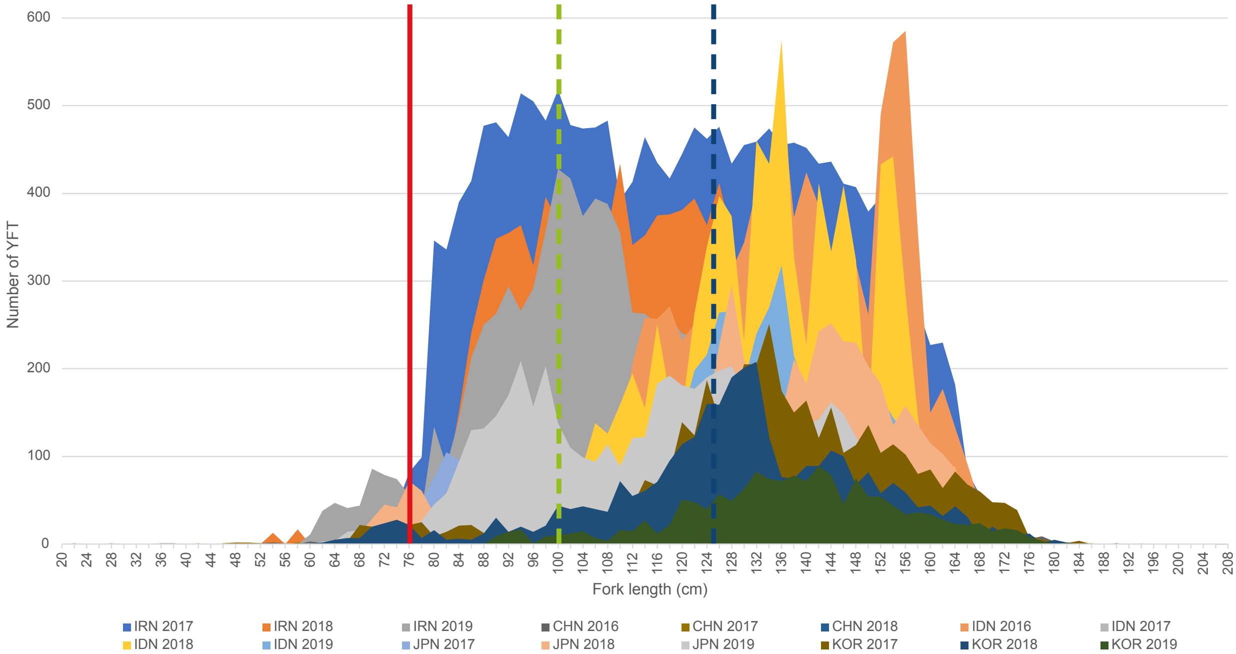


Figure 16. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with LL for the other countries using this gear. Period 2016-2019 where L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.

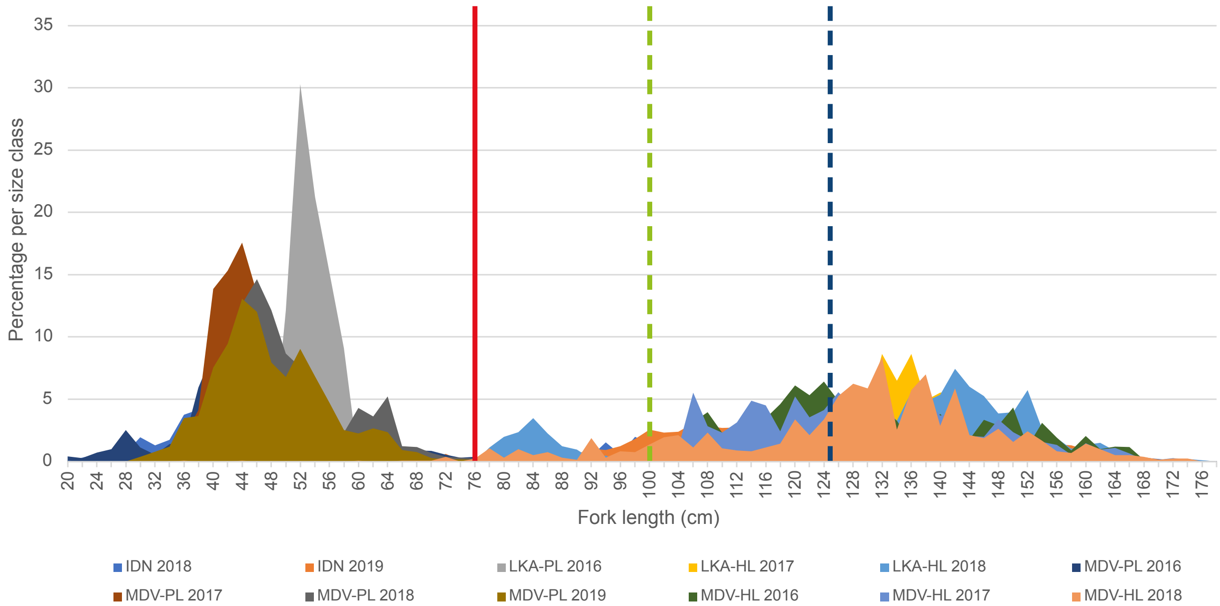


Length-frequency data for the rest of the countries is shown in Fig. 16. In this case, average size of YFT caught in the Chinese and Japanese LL fisheries (125 and 126 cm respectively) seem to be lower than in the Korean and Indonesian LL fisheries (134 cm and 133 cm). The lowest average size is found for the Iranian LL fishery at around 111 cm, in line with the values found by Eighani et al. 2020 for this fishery. This, together with the results found in the PS fishery seem to indicate that the area were the Irani fisheries operate (Gulf of Oman and Arabian Sea) could concentrate a larger number of sub-adult yellowfin tuna. It is also important to indicate that some of the longline data provided by these countries include a mix of true longline and coastal longline (more similar to handlines) fisheries.

5.5. Handline and pole and line fisheries.

Handlines are mainly used by Maldives (26,933 t in 2019), Oman (25,201 t), Yemen (18,063 t), Sri Lanka (7,943 t), India (5,705 t) and Indonesia (4,343 t). Pole and line (baitboats) is mainly used by Maldives (17,241 t). No length frequency data is available for Oman, Yemen and India. The average size for the pole and line fishery is 48 cm, well below L_m and L_{m50}, whereas for the handline fishery is 128 cm within the optimum length. No differences are found between countries, except for the HL fishery in Indonesia which in 2018 reported an average size of 97 cm below the sizes reported by Sri Lanka and Maldives (Fig. 17).

Figure 17. Length frequency distributions (by 2 cm length class) of yellowfin tuna caught with HL and PL for the main countries using these gears.. Period 2016-2019 where L_m = 76 cm (red solid Line), L_{m50}=100 cm (green dotted line) and L_{opt}=125 cm (black dotted line). Source: own, based on IOTC data.

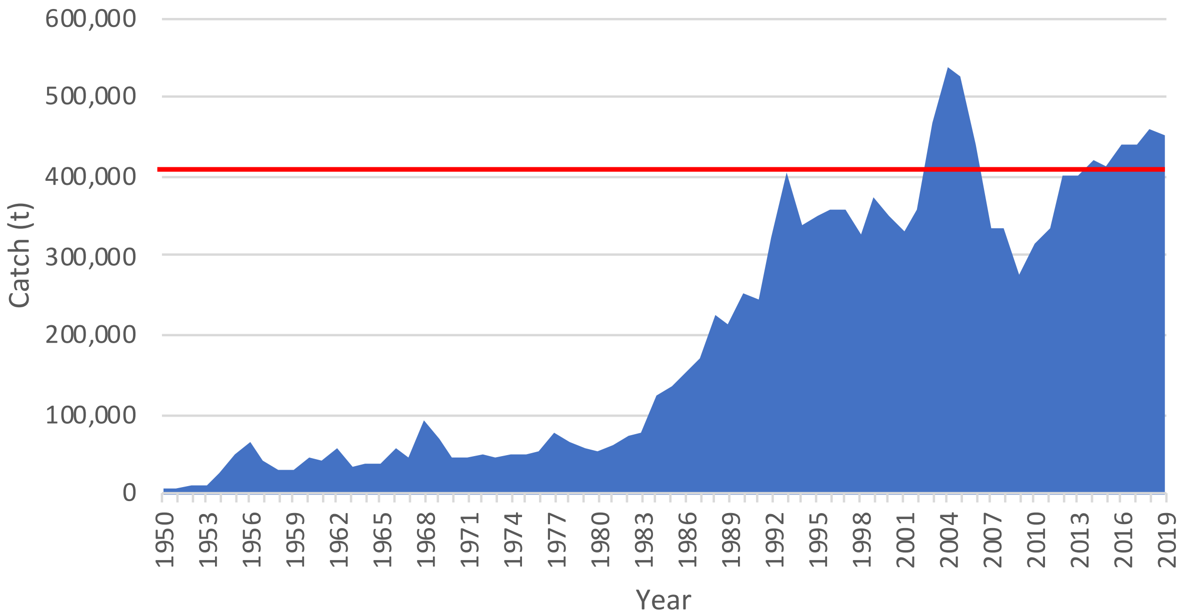


VI. Discussion

6.1 Relative impact of each fishery

The Maximum Sustainable Yield (MSY) estimate for the Indian Ocean yellowfin stock is 403,000 MT with a range between 339,000-436,000 t (IOTC 2020a). The 2015-2019 average catches (424,100 t) were above the estimated MSY level. Last year's catch (2019) has been substantially higher than the median MSY (Fig. 18).

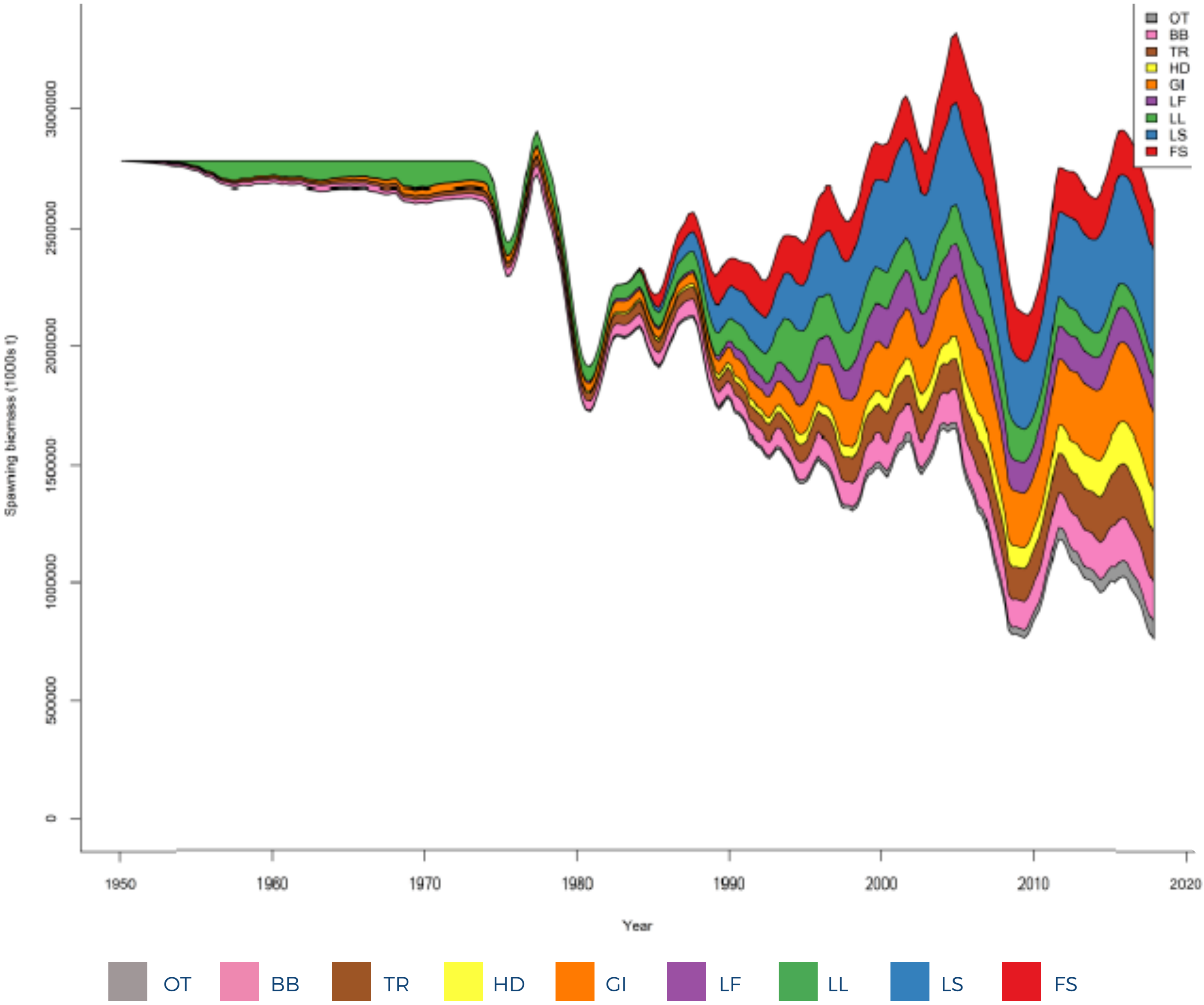
Figure 18 Total catches of YFT between 1950 and 2019. The red line indicates the MSY (403,000 t). Source: own, based on IOTC data.

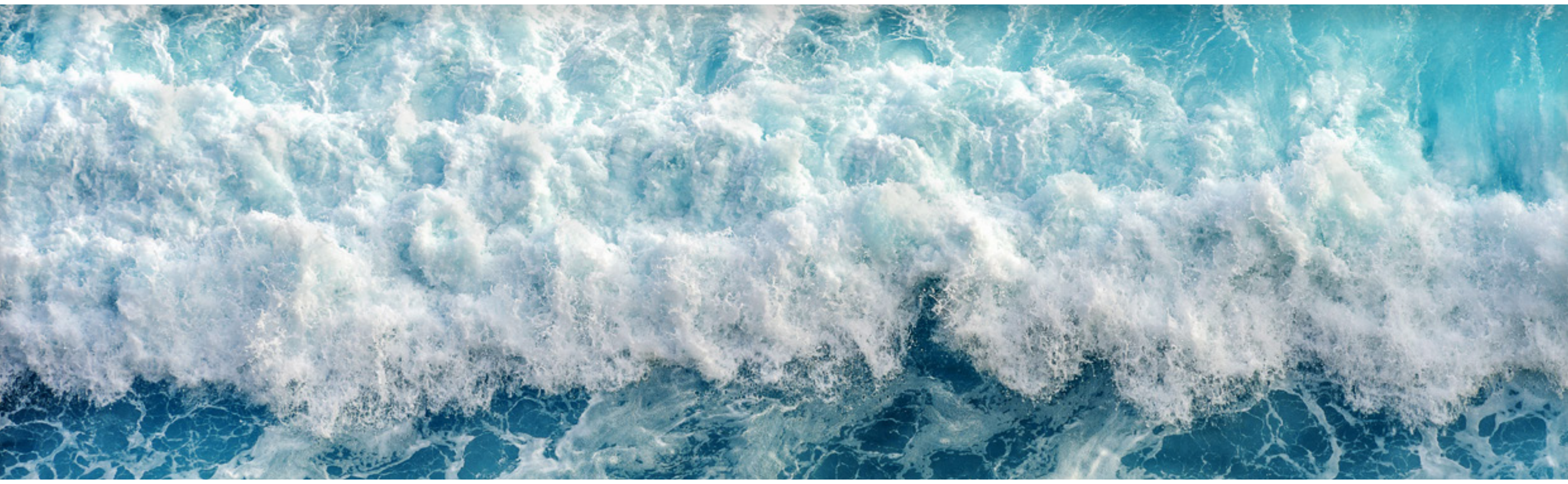


A full analysis of the impact of the catch of these fisheries on the stock status of the yellowfin tuna is out of the scope of this short report. However, some indications of the impact can be given with base on available information. Fig. 19 shows a fishery impact analysis conducted by the IOTC WPTT in the 2018 yellowfin preliminary stock assessment using a similar approach commonly applied in the Eastern Pacific Ocean (IATTC area) (Minte-Vera et al. 2016). This was essentially done by plotting the trajectory of spawning biomass over time that would have occurred in the absence of historical fishing. Estimates of reduction in spawning biomass induced by fishing can be further attributed to specific fishery components (grouped by gear type across regions), so that the impact of different types of fishing activity on SSB can be compared. The fishery impact of a fishing activity is related to both the historical level of catch (e.g. purse seine and gillnet fisheries), as well as the selectivity pattern. The latter can be seen from the figure which suggested that both troll and pole and line fisheries appeared to have a higher impact than the handline fishery despite their relatively smaller overall catches due to the fact that the first two fisheries were predominantly targeting smaller and younger fish than handline.

This impact is more marked in those fisheries that combine having high catches and are catching smaller fish (see for example the relatively higher impact of the PSLS fishery versus the PSFS and the GILL fisheries in years in which total catches between these fisheries have not been very different (2012 and 2015 for the PSLS vs PSFS, and the period 2015-2017 for the PSLS vs GILL)). Overall impacts are distributed amongst the main fisheries, although highest impacts were attributable to the purse seine and gillnet fisheries.

Figure 19 Estimates of reduction in spawning biomass due to fishing over all regions attributed to various fishery groups for the base model. The shaded areas between the lines show the portions of the impact attributed to each fishing method (Source: IOTC–2018–WPTT20–33).





6.2 IO YFT catch and the expansion of FAD-associated purse seine fisheries

Purse seine fisheries have been growing globally since the 1980-1990s (Hall and Roman 2013, Coulter et al., 2020). This boom is explained by the adoption of floating aggregating devices (FADs) as a means to increase the efficiency of the purse seine fleet. Modern fish aggregating devices (FADs) are artificial floating objects specifically constructed to attract tuna and other fish (Gershman et al., 2015). They usually consist of a floating raft with attached synthetic ropes and/or netting which can reach up to 80 m deep, and often also a satellite buoy that facilitates the location of the FAD by the fishing vessels (Gershman et al., 2015). The use of FADs takes advantage of a natural behaviour of tuna and other pelagic schooling species, which tend to aggregate under natural floating objects such as flotsam, living megafauna (e.g. whales, whale sharks) or their carcasses (Hall and Roman 2013). Anchored FADs (aFADs) have been used since historical times by artisanal fisheries in the Mediterranean targeting dolphinfish *(Coryphaena hippurus)* (Morales-Nin et al., 2000; Blasi et al., 2016), and they are also widely used in other regions such as the Caribbean, the Philippines and Indonesia (Macusi et al., 2017; Sadusky et al., 2018).

However, the recent expansion in FAD-associated purse seine has been triggered by the use of a different type of artificial FADs: drifting FADs (dFADs). These are individually deployed by the purse seiners or their supply vessels (Fonteneau et al., 2015). Often, satellite-linked echosounder fish finders are also attached to the dFADs, so that the vessels not only can know the position of each FAD at any given time (via the satellite buoy): they also can receive the information of which FADs have aggregated fish schools beneath them (Dagorn et al., 2013). FADs further facilitate the catch by stabilizing tuna schools and reducing their swimming speed, making them easier to catch than free swimming schools (Dagorn et al., 2013). The global expansion of purse seine associated to dFADs is due to two main factors: a) a high percentage of success, with only 8.5% of failed sets compared to 46% on free swimming school sets; and b) a higher average catch per set: in the French IO purse seine fleet, catch per unit of effort (CPUE) in dFAD sets can be 60% higher than that of school sets (Hall and Roman 2013). The intense development of dFADs use has improved the efficiency of purse seine fleets so that they currently represent about half of global tuna catch (Davies et al., 2014), and in fact has changed the purse seine operation to a harvesting activity rather than a search and catch operation (IOTC 2018c).

At the same time, purse seine fleets have also experienced an increase in their overall capacity. Spanish and French purse seining companies in the IO have developed ever larger vessels, “super-seiners” (>2,000 gross tonnage; GT) and even “super super-seiners” (> 3,500 GT), which allow the fleets to perform longer fishing trips and increase the vessels’ fish hold volume (MRAG 2017). In turn, this “supersizing” of the fleets has brought increased operating costs (e.g. higher sensitivity to fuel price) (MRAG 2017). Hence, the fleets must now offset these higher operational costs by increasing the number of FAD sets, and also the number of dFADs deployed, as a strategy to reduce the fuel costs, which can be as high as 50% of operating costs (Bailey et al., 2013). Gershman et al. (2015) estimated that the total number of drifting FADs deployed globally by the purse seine fleets in 2013 ranged from 81,000 to 121,000. Of these, between 10,500 and 14,500 dFADs were deployed in the Indian Ocean by EU (Spanish and French) purse seine fleets.

Estimating the real amount of dFADs currently deployed in the IO is very difficult: In the one hand, the estimates presented above did not include non-EU purse seine fleets, which also use dFADs (Gershman et al. 2015); on the other hand, successive IOTC resolutions (to be discussed later) have decreased the maximum amounts of FADs allowed per vessel, from no limits to 500 and currently, 300 dFADs per vessel. Still, the actual level of compliance with these resolutions by all the purse seine fleets operating in the IO is unclear. As a result, there is a high uncertainty around the number of dFADs currently deployed in the IO.

A key factor that has fuelled the expansion of FAD-based purse seine is the use of supply vessels. Supply (also called auxiliary or support) vessels greatly contribute to increase the efficiency of the purse seine fishery, by contributing to the construction, deployment, maintenance and monitoring of the FAD network. They also visit and check the FAD locations and, if they detect the presence of fishable schools, they inform the associated purse seiners so that they can catch these schools. Finally, they also transport crew, materials, etc. (López and Scott, 2014; Assan et al., 2015; Chassot et al., 2019). In consequence, supply vessels have been identified as the main source for increases of purse seine efficiency (Merino et al. 2018). They have been banned in the IATTC (López and Scott, 2014).

Efficient as they are in concentrating and facilitating the capture of tuna schools, dFADs have a number of negative ecological effects, such as: they are sources of ghost fishing, marine pollution and impacts on coral reefs and other marine habitats once they are lost or abandoned[6]; they increase bycatch of non-tuna species (including vulnerable taxa, such as pelagic sharks etc.); and they may act as "ecological traps" (although there is ongoing debate around this latter theory; see next page). Fortunately, the IOTC has started taking action to address these issues: on its 23rd Annual Meeting, the IOTC agreed to the mandatory use of non-entangling FADs from 1 January 2020 and to promote the use of biodegradable FADs from 1 January 2022 (IOTC 2019c). During this meeting a number of improvements were also made related to how FAD data are gathered and reported. It is to be hoped that these decisions will be matched by resolute action from the pertinent CPCs to implement the new measures while ensuring a high level of compliance by their fleets. If this high compliance was achieved, an expected result might be that several issues related to the ecological impact of dFADs would start to be progressively ameliorated. But this will have to be assessed in the near future. At the time being, the above mentioned issues continue to be relevant to the use of dFADs in the IO.

Lastly, the use of dFADs leads to larger amounts of juvenile bigeye and yellowfin tuna (Fontaneau et al. 2013, Hall and Roman 2013). The following discussion will focus on this last issue.

[6] Several PS fleets using dFADs in the IO have committed to follow ISSF's recommended best practices for better FAD management. These best practices specifically address the problems of bycatch entanglement, ghost fishing, and others (Restrepo et al. 2019). This is a very welcome and necessary initiative. However, high transparency, better data sharing and evidence of compliance with the best practices are needed. Furthermore, it being a voluntary initiative, there are still several PS fleets that have not committed to adopt these best practices. Thus, overall, the above mentioned issues continue to be relevant to the use of dFADs in the IO.

The ecological trap hypothesis

Many pelagic species, including tropical tuna and billfish but also other taxa, are attracted by floating objects. In the case of tuna, they form large mixed-species aggregations around the floating objects, composed of similarly sized adult skipjack and juvenile yellowfin and bigeye. The reasons why tuna displays this attraction to floating objects are still not well understood, but there are two main hypotheses: the "meeting point" and the "indicator-log" (Leroy et al., 2013; Pérez et al., 2020). The "meeting point" hypothesis suggests that floating objects can function as aggregation points for tunas, facilitating the formation of larger schools. The "indicator-log" hypothesis suggests that natural floating objects (such as floating tree branches or vegetation mats) aggregate at productive frontal zones and eddies, and could thus act as indicators of nutrient-rich environments (Leroy et al., 2013). The tuna fishing industry has exploited this natural behaviour of tuna species to the point that nowadays, about 40% of the world's tropical tuna catch consists of fish associated with floating objects (Pérez et al. 2020). The networks of thousands of artificial drifting and anchored FADs may act as 'ecological traps' of pelagic species by altering their natural spatial and temporal distributions, habitat associations, migration patterns, and residence times (Marsac et al. 2000, Bromhead et al. 2003, Hallier & Gartner 2008, Leroy et al. 2013). FADs may retain tuna in areas that they erroneously associate with high levels of prey biomass; drifting FADs may transport tunas away from their natural forage areas to areas of low productivity, thus resulting in reduced growth and condition, lower fitness, and increased natural mortality (Leroy et al. 2013, Tolotti et al. 2020).

There is some evidence that FADs do affect the diet, nutritional status and hunting strategies of tuna associated to them (Leroy et al. 2013). For instance, Hallier and Gaertner (2008) compared the proportions of empty stomachs between FAD- and free swimming school-caught skipjack and yellowfin tuna, in the Indian and Atlantic Oceans. These authors found that the rate of empty stomachs was very high for tunas caught under drifting FADs when compared to tunas caught in free swimming schools: 74% vs. 13% for skipjack, and 49% vs. 7% for yellowfin (Similar results were also found for bigeye tuna, but they were not presented due to the small sample size) (Hallier and Gaertner 2008). Also, Jaquemet et al. (2011) compared dietary composition in skipjack and yellowfin tuna caught in anchored and drifting FADs. They found significant differences in the diet of both tuna groups, with tuna caught around anchored FADs preying on a richer assemblage of prey (coastal fish and crustacean larvae and juveniles) than tuna associated with drifting FADs (whose diet was dominated by a few species of epipelagic prey). Also, the frequency of empty stomachs was significantly higher and the stomach content mass significantly lower among skipjack and small yellowfin tunas caught around drifting FADs. This difference was magnified in low productivity areas, where the FADs often drifted, suggesting that these FADs could negatively impact the growth of skipjack and small yellowfin tuna (Jaquemet et al. 2011).

However, the ecological trap hypothesis is still somewhat controversial because it is difficult to evaluate the impacts of FADs on the ecology of tunas, largely due to the uncertainty in how tunas interact with floating objects (e.g. the duration of the "residence" time near FADs, the reasons for the tuna schools associating to or leaving an object, etc.). In consequence, the hypothesis remains open to discussion (Dagorn et al. 2013, Leroy et al. 2013, Davies et al. 2014). However, a recent study by Pérez et al. (2020) presented evidence of tuna showing associative behavior changes depending on the density of FADs: when the FAD density increases, the connectivity between FADs also increases (more FADs are visited), tuna spend shorter times unassociated to FADs, and exhibit longer residence times.

In another recent study Tolotti et al. (2020) used tagging to assess the duration of residence time near FADs for the three tropical tuna species (and also other fish species) in the eastern Atlantic Ocean. The longest total association periods were recorded for bigeye and yellowfin tuna at 55 days, corresponding to the total duration of the experiment (which ended prematurely due to equipment failure; thus, the figure of 55 days is very likely an underestimation). During this length of time the yellowfin and bigeye tuna followed the FAD for at least 607 km. In contrast, skipjack exhibited a much shorter residence time, with a maximum of 15 days and 107 km travelled (Tolotti et al. 2020). For both yellowfin and bigeye tuna, the long residence times and the length of distance travelled whilst in association with the FADs seem to add credibility to the ecological trap hypothesis (Tolotti et al. 2020). These results add up to the evidence presented by the other mentioned studies (i.e. Hallier and Gaertner 2008, Jaquemet et al. 2011, Pérez et al. 2020), making the ecological trap hypothesis to appear increasingly more likely.

Ultimately, one thing is certain: the fact that a large share of the world's tropical tuna catch is made in FADs shows the need to ascertain the true extent of FADs' impacts on the ecology of tunas, in order to allow for a truly sustainable management of tuna fisheries.

6.3 Juvenile catch in the main IOTC gears

6.3.1 Juvenile tuna catch in purse seine sets

Although skipjack is the main target for purse seine fleets using dFADs, juvenile yellowfin and bigeye tuna are also caught because they form mixed schools with similarly sized (but more mature) skipjack. These mixed schools are attracted by dFADs and are thus caught by the purse seiners (Gillman 2011, Hall and Roman 2013). According to the IOTC data, FAD catches in the Indian Ocean during the period 2010-2018 were composed by 57% skipjack, 35.3% yellowfin and 7.6% bigeye (IOTC–2020–WPTT22(DP)–08).

Fig. 1 (pg 14) shows the average length of Indian Ocean yellowfin tuna caught in the seven fishing methods (six main gear groups, with purse seine split in its two main modalities) assessed in this study for the period 2000-2019. Whilst purse seine sets to free swimming schools show a higher interannual variability, their average catch size remained above L_m throughout the period. The opposite is true in the case of purse seine in FADS ("logs", in IOTC's terminology): for the entire study period, their average catch size remained well below L_m.

Fig. 4 (pg 18) shows the length frequency distributions of yellowfin caught by free school sets (Fig. 4a) and FAD-associated sets (Fig. 4b) in 2018 and 2019. Free schools sets show a bimodal length distribution, with the first mode at around 42 and 52 cm FL, and the second mode partly around L_{opt}, between 118 and 138 cm FL.

In contrast, FAD-associated sets have a unimodal distribution with most catch concentrated between 40 and 56 cm, i.e. juveniles. This is in line with the results of Delgado de Molina, Areso and Ariz (2010), cited by Hall and Roman (2013), who found that the average weight of yellowfin caught in FADs by the Indian Ocean Spanish purse seine fleet was 4 kg, compared with more than 30 kg in free school sets. In another study Báez et al. (2018) found that the principal modal size of yellowfin tuna caught in FAD-associated sets by the Spanish purse seine fleet was around 50 cm (in contrast to 130 cm in sets to free swimming free schools). These authors provide mean weight data for yellowfin caught in both types of sets between 1990 and 2016. In this 27-year long data series, the average weight of yellowfin caught in FAD sets was 5.7 ± 1.8 kg, with the lowest average recorded in 2008 at 3.8 kg. In contrast, the average weight of yellowfin caught in free swimming schools sets was 31.9 ± 7.1 kg, with the lowest average recorded in 1998 at 14.5 kg.

In terms of total catch volume (not just juvenile, but all yellowfin catch), purse seine sets to free schools (PSFS) caught **37,891 t** in 2019, i.e. a **8% of the total YFT catch (454,138 t)**. On the other hand, FAD-associated purse seine (PSLS) caught **85,595 t** in 2019, **19% of the IO yellowfin total** (IOTC 2020b).

That said, FAD-associated purse seine is not the only Indian Ocean fishery that catches juvenile yellowfin tuna. As shown in Fig. 1, for the twenty-year period (2000 to 2019) there were at least three other fisheries whose average catch size indicates mostly immature tuna: the pole and line fishery, some trolling line fisheries, and the gillnet fishery. This is also highlighted in Fig. 5 (pg 19), which shows the length frequency distribution in the yellowfin catch of these fisheries during recent years.

6.3.2 Pole and line

The Indian Ocean pole and line yellowfin catch is almost exclusively based in the Maldives, where there are two main tuna fisheries: the pole and line fishery that targets skipjack, but also catches juvenile YFT (and smaller amounts of bigeye); and a handline fishery that targets sub-adult and adult yellowfin tuna (Adam et al. 2015, Ahusan et al. 2017). The 2018 and 2019 Maldivian pole and line catch of yellowfin was concentrated at between 36 and 64 cm FL (Fig. 5a pg 19). Thus, most yellowfin caught by pole and line in the Maldives are juveniles. The total catch of YFT reported by the Maldivian pole and line fleet in 2019 was **18,551 t**, which is **4.3% of the total IO yellowfin catch** (IOTC 2020b). **This catch represents one-fifth of the FAD-based purse seine catch.** Therefore, although both fisheries have a similar catch size distribution, their respective impact on overfishing of juvenile yellowfin in the Indian Ocean is not at the same scale. **With a catch volume five times larger, the impact of FAD-based purse seine is far greater than that of pole and line.** This is further shown by **Fig. 19** (pg 36), which indicates the portions of the impact attributed to each fishing method.

6.3.3 Gillnets

During the last decades Indian Ocean tuna gillnet fisheries have experienced a swift growth, comparable to that of FAD-based purse seine fisheries (IOTC 2020a). Several coastal Indian Ocean countries harbour gillnet fleets: Iran, Pakistan, India and Sri Lanka, among others (Aranda 2017, IOTC 2018b, Sivadas et al., 2019). Iran has the highest gillnet catch on a per country basis (IOTC 2020b). Importantly, the gear that the IOTC classifies as “gillnets”, in reality is, often, large-scale (>2.5 km) driftnets. The United Nations General Assembly (UNGA) resolution 46/215 (UNGA 1991) declared a moratorium on the use of large-scale driftnets within the High Seas due to their high ecosystem impacts.

Nevertheless, in the IOTC area they are still allowed within EEZ waters (although they will be completely banned as of January 1st 2022; this will be discussed later).

As shown by Fig. 5c (pg19), the size distribution of IO gillnet fisheries has a mode at between 70 to 88 cm FL. Hence it is majoritarily catching juvenile and sub-adult tuna. YFT catch by gillnets in the Indian ocean reached **80,268 t** in 2019 **(18.8% of the total)** (IOTC 2020b), thus representing a catch volume **comparable to that of FAD-based purse seine.** Its **overall contribution to yellowfin tuna overfishing in the Indian Ocean is therefore the second largest** of all the assessed gears, as shown in Fig. 19 (pg 36).

A study by Eighani et al. (2020) found that “the gillnet fishery represents about 90% of the total YFT catch for all fishing gears over the past decade” in Iran. Thus, for the past decade, 90% of YFT catch by Iran stemmed from fisheries catching mostly juveniles. Worryingly, Iran’s YFT catch almost tripled from 19,482 t in 2008 to 56,121 t in 2017, fostered by the increasing demand in the domestic market (Eighani et al. 2020). At a lesser scale, gillnet fleets from other countries such as Oman and India are also showing an increasing trend (Table 6 pg 46).

6.3.4 Trolling

The analysis of this particular gear is hampered by the fact that data are only available for 2015, 2016, 2017 and 2019. Trolling is a subset of fisheries where two distinct catch length modes are found: one group of trolling fisheries is catching very small yellowfin (mode between 22 and 42 cm), whilst another group catches much larger individuals, mostly mature, above L_{m50} (100 cm FL) (Fig. 5e pg 21).

A possible explanation for this discrepancy is that these might be two rather distinct fisheries: the first fishery might be targeting the smaller tuna classes (skipjack, and juvenile yellowfin and bigeye, as well as other scombrids) in anchored FADs located close to coastal areas, whilst the second might be targeting free swimming schools further offshore. Or it might also be that they show a spatial overlap, but present fine-scale differences in their choice of hook sizes, depths, lures used, etc. which result in catching very different yellowfin age groups. Simultaneously, it is also possible that some CPCs might be reporting their catch under the “trolling” gear codes as an umbrella term encompassing several miscellanea small-scale gears. For instance, small-scale tuna fishers in Indonesia use a wide array of “fishing line” gears such, for instance: “taber”, “kite”, “tomba”, “batuan” and “coping” fishing lines, among others (Damora et al., 2020).

However, regardless of the reason(s) behind the striking bimodal catch size distribution, the combined YFT catch by all gears reported by the CPCs to the IOTC as “OTHER” was **23,662t** in 2019 (IOTC–2020b). Of this total, not all would have been caught by trolling fisheries. The “OTHER” catch represented **5.5% of the total IO yellowfin catch in 2019** (IOTC 2020b), and about **one fourth of the FAD-based purse seine catch.**

Fig. 19 (pg 36) shows that its contribution to the overall overfishing of the yellowfin stock is low.

Lastly, **the two other gears** (or rather, gear groups) included in the study **(handlines and longline)** are **majoritly catching sub-adult and adult tuna**, as shown by both their 20-year average catch size (Fig. 1 pg 14) and their length frequency distribution (Fig. 5b pg 19 and d pg 21, respectively). Fig. 19 pg 36 further shows that **the contribution by these gears to the overall overfishing of the Io yellowfin tuna stock is low** (in fact extremely low, in the case of longline).

6.4. Are current juvenile yellowfin catch levels sustainable?

As mentioned earlier, the Indian Ocean yellowfin stock is overfished and suffering overfishing (IOTC 2020a). If the Indian Ocean yellowfin tuna was sustainably fished, and if most of the catch was concentrated on a restricted range of age groups, catching juveniles might not be so deleterious to the stock status. But in reality, the IO YFT stock is overfished and suffering overfishing. And also, given the vast array of fishing gears that exploit the stock, there is virtually no age group free from a high fishing mortality pressure. A fishery catching juveniles is, obviously, catching the tuna before they can spawn. As noted by Bailey et al. (2013), "catching of juvenile fish of a target species can lead to both growth and recruitment overfishing, and can thus lead to a decline in the resource of interest".

Recruitment overfishing is defined as "diminishing the ability of fish to reproduce" (Froese 2004). Or, in other words, is what happens "when the abundance of mature fish is reduced by fishing to the point where recruitment of young fish is reduced" (Sun et al., 2019). **Growth overfishing** happens when "fish are caught before they can fully realize their growth potential" (Froese 2004).

Growth overfishing prevents the natural trajectory of a cohort of fish, which if let unfished would steadily increase its total biomass as the fish are growing. This is so because total weight gains offset and exceed the loss due to natural mortality through predation or other causes (Sun et al., 2019). Once the fish cohort reaches a specific age, total biomass gains by individual growth become equal with total biomass losses by natural mortality. This point is defined as the "critical size" (Sun et al., 2019). Thus, by removing vast numbers of individual yellowfin juveniles annually, FAD-associated purse seine and gillnet fisheries are causing growth overfishing to the yellowfin stock (Fig. 19 pg 36, Tables 1 pg 6 and 2 pg 7).

In contrast, "targeting sizes around or larger than size at maturity may result in the largest long-term yields in the future" (Prince and Hordyk, 2019, cited in Eighani et al., 2020). Prince and Hordyk (2019) study the concept of **optimal size or catch (L_{opt})**, i.e. the size or age "at which growth and natural mortality reach a balance and cohort biomass is maximized, before growth slows and mortality begins reducing cohort biomass (Beverton and Holt, 1957)." These authors state that "Optimal size roughly coincides with maturation, because energy used for growth in juveniles in increasingly directed towards reproduction", and revisit the classical three basic principles defined by Froese (2004) that allow sustainable fisheries: "(a) letting fish spawn at least once before they are caught, (b) managing fishing pressure to allow fish to grow to L_{opt}", and "(c) allowing large mature fish (mega-spawners) to keep spawning" (Prince and Hordyk, 2019).

Building up on Froese's three principles, Prince and Hordyk's results show that "when the size of first capture is sufficiently greater than the size of maturity (L50), both yield and spawning biomass can be maintained at high levels, despite high levels of fishing pressure. Conversely, when the size of first capture is at or below the size of maturity, populations are prone to extinction under higher fishing pressure". The authors further expose that "The great weakness of reference points denoted purely in terms of F or F/M is that they only provide meaningful reference points within the context of specific selectivity parameters and thus cannot be as universally applicable as implied." They insist that spawning potential ratio (SPR) is "indisputably the superior metric for generic indices of fishing pressure, because it directly tracks the object of management interest, the reproductive potential of the stock".

As mentioned before, FAD-based purse seine (PSLS) extracts a greater number of yellowfin (and of younger cohorts) than purse seine targeting free-swimming schools of tunas (PSFS), although the latter also catches juveniles (Griffiths et al., 2019). Gillnet fisheries are catching a high number of juveniles as well, as has been discussed. Juvenile yellowfin cohorts are being caught by these fisheries (PSLS and gillnets) before they can reach their optimal size and before they can reproduce. Thus, these two fisheries are arguably responsible for a non-trivial share of the growth and recruitment overfishing that is currently impacting the IO YFT stock, since they are thwarting two of Froese's principles: "letting fish spawn at least once before they are caught” and “managing fishing pressure to allow fish to grow to L_{opt}”. In fact, the sum of FAD-based purse seine and gillnet fisheries is responsible for 83% of the catch of yellowfin juveniles in the IO (Table 1 pg 6). Pole and line and handline follow with 10.8% and 3.2%, respectively. Whilst purse seine sets to free swimming schools, longline and troll lines have a minimum impact (Table 1, Fig. 19).

In contrast, the average size of yellowfin caught by IO handline and longline fisheries shows a good fit with the optimal catch. They catch a significant proportion of large, old individuals, i.e. megaspawners (fully mature, more fecund yellowfin) and can thus be checked against Froese’s third and last principle for sustainable fishing: “allowing large mature fish (mega-spawners) to keep spawning”.

Thus, in a first analysis based only on the average sizes caught by each main fishery, the sustainability ranking among the main Indian Ocean fleets would appear thus, in decreasing order:

- Both handline and longline fisheries present a catch size distribution that is closer to the optimal size as defined by Froese (2004) and by Prince and Hordyk (2019) (But see the last point below, about the overall sustainability of longline fisheries). Therefore, the two fisheries would be very small contributors to the overall juvenile yellowfin overfishing in the Indian Ocean.

- After them, purse seine sets to free swimming schools (PSFS) show a catch size distribution which is not too far from the optimal range, albeit with an increasing percentage of juveniles due to the bimodal size distribution. It would be a moderate contributor to overall overfishing.

- Three fisheries would score poorly: FAD-associated purse seine (PSLS), gillnets, and pole and line. “Trolling” fisheries cannot be assessed adequately because their catch records are fragmentary and, besides, it seems that they could be a kind of mixed-bag category. The crucial point here is that in 2019 PSLS and gillnets combined represented a large catch volume (174,379 t, 40.8% of total IO catch; IOTC 2020a), while in contrast, pole and line combined with trolling represented a much smaller catch (42,213 t, 9,9% of the total IO catch; IOTC 2020a). Hence, when the respective catch volumes of each fishery are considered, pole and line and trolling fisheries would be small to moderate contributors to overall overfishing, whereas gillnet and FAD-associated purse seine would both be major contributors to overall overfishing.

Lastly, longline fisheries would not represent a sustainability issue within the framework of this study, which is restricted to analyze the catch of juvenile yellowfin tuna. But longline fisheries certainly have heavy ecosystem impacts, especially through their high bycatch rates of biologically vulnerable species (e.g. pelagic sharks, seabirds and sea turtles, among others (Ardill et al. 2011, Hall and Roman 2013, Clarke et al., 2014)). In terms of social sustainability, also, some distant-water longline fisheries have been associated to instances of human rights abuses and/or poor working conditions, as well as IUU fishing (Greenpeace 2019, McDonald et al. 2021). Therefore, it is by no means the intention of this report to advocate in favour of the overall sustainability of longline fisheries.

6.5 Ways to address unsustainable juvenile bycatch

This subsection focuses on the two gears/fishing methods identified as having the highest impact on juvenile yellowfin catch, i.e. FAD-associated purse seine and gillnets.

6.5.1. Limiting use of FADs

Anchored FADs (aFADs) are not differentiated from dFADs in IOTC data and thus it is difficult to gauge their relative importance. From the literature it is apparent that aFADs are used in at least some coastal CPCs. In general, aFADs are located close to the coast and are thus accessible to a large variety of small-scale gears, including subsistence fisheries. However, local purse seine fleets also can use aFADs, and at least in one CPC, Indonesia, this seems to be developing into a growing resources access conflict between the local purse seine fleets and the artisanal/small-scale fleets, as shown by Hargiyatno et al. (2018). These authors propose that the Indonesian government must prevent the local purse seine fleets to access the aFADs, reserving them exclusively for the use of artisanal/small scale gears.

However, in terms of catch volume, the main issue is the massive use of drifting FADs (dFADs) by the large-scale purse seine fleets operating in open oceanic waters, whose impact has been shown to be critical. IOTC initially issued Res 15/08, which was subsequently superseded by Res 17/08, 18/08 and 19/02. The superseded Res 17/08 partially addressed the FAD issue through a set of provisions that included a limitation on the number of FADs, more detailed specifications of catch reporting from FAD sets, and the development of improved FAD designs to reduce the incidence of entanglement of non-target species (IOTC 2018c).

In particular, under Res 17/08 the maximum number of active instrumented buoys allowed to be used (i.e. followed) by a purse seiner at any one time was 350 (down from 550 under Res 15/08) and the maximum number of instrumented buoys that could be acquired by any purse seiner annually was set at 700 (IOTC 2018c). Also, under 17/08 a flag State could adopt a lower FAD number limit for its vessels, and a coastal State may also adopt a lower limit for the number of FADs deployed in its EEZ. This was however left to the will to the States, and in likewise manner it left the control of the number of 'instrumented buoys' deployed and used by purse seine fleets under responsibility of each flag State (IOTC 2018c). It soon became apparent that the provisions in 17/08 were insufficient to harness the increasing efficiency of the FAD-based purse seine fleet. Resolutions 18/08 and then 19/02, which is the one currently in force, were issued.

Res 19/02 (IOTC 2019b) contemplates among others the following points:

- The maximum number of operational buoys followed by any purse seine vessel is set at 300 (down from 350) at any one time.
- The number of instrumented buoys that may be acquired annually for each purse seine vessel is set at no more than 500. No purse seine vessel shall have more than 500 instrumented buoys (buoys in stock and operational buoy) at any time.
- An instrumented buoy shall be made operational only when physically present on board the purse-seine vessel to which it belongs or its associated supply or support vessel, and the event shall be recorded in the appropriate logbook, specifying the instrumented buoy unique identification number and the date, time and geographical coordinates of its deployment.
- All purse seine vessel, supply or support vessel shall declare to its respective CPC, the number of instrumented buoys onboard, including each unique identifier of the instrumented buoy before and after each fishing trip.

At least three IOTC CPCs have submitted their proposals aiming to strengthen Res 19/02: Kenya and Sri Lanka (IOTC 2021a), Maldives (IOTC 2021b), and the EU (IOTC 2021c). Besides, several stakeholders such as WWF (WWF 2021), Blue (Blue Marine Foundation) and the International Pole and Line Foundation (IPNLF), have also presented their position statements (in the case of Blue and IPNLF through a joint position statement (IOTC 2021d)). Other stakeholders (e.g. Pew, ISSF) did also present their own position statements, but given to time limitation we have focused on those that have been mentioned. Thus, in their joint proposal Kenya and Sri Lanka address (among many others) the following points:

- Setting the maximum number of operational buoys followed by any purse seine vessel at 150 (instead of 300, as is currently set under Res 19/02);

- The number of instrumented buoys that may be acquired annually for each purse seine vessel is set at no more than 300 (now it is 500 under Res 19/02);

- No PS vessel shall have more than 300 instrumented buoys (buoy in stock and operational buoy) at any time (it is 500, currently);

- Purse seiners shall be prohibited to fish on dFADs or deploy dFADs during a three-month period between 00:00hrs of 1 July and 00:00hrs 30th September each year.

- During the dFAD closure period specified above, no purse seine vessel or supply or support vessel shall conduct any part of a set within five nautical miles of a dFAD. That is, at no time may the vessel or any of its fishing gear or tenders be located within five nautical miles of a dFAD while a set is being conducted.

- Consistent with Resolution 19/01, CPCs shall gradually reduce supply or support vessels by 31 December 2022. After 31 December 2022, no supply or support vessels shall support purse seine vessels in the IOTC area of competence. (IOTC 2021a).

Besides, the proposal includes other provisions aimed at decrease the bycatch caused by FADs (FADs must be made of non-entangling and non-meshed structures, and compulsorily built of biodegradable materials). Other points aim to achieve greater transparency in how FADs are deployed, tracked and retrieved (IOTC 2021d). In the other hand, the proposal sent by Maldives (IOTC 2021b) although less focused in FAD management, includes the following points:

- A gradual phasing out of supply or support vessels, until 1 Jan 2025 when they will be no longer allowed.

- Supply vessels can no longer be registered by CPCs.

In turn, Blue and IPNLF's joint statement (IOTC 2021d) is rather brief. It asks for a 15% reduction in catch from 2015 levels, and states their full support to the submissions by Maldives and by Kenya and Sri Lanka. It emphasizes the support to the submission by Kenya and Sri Lanka when it calls for reducing the number of dFADs per vessel from 300 to 150, calls for greater transparency in how these FADs are deployed, tracked and retrieved, and further calls for a three-month ban on fishing around drifting FADS and a phasing out of supply vessels (IOTC 2021d).

On the other hand, the submission by WWF (WWF 2021) is quite similar to the above mentioned, in that it also calls for an overall catch reduction of 15-20% from 2015, coincides in asking for a reduction of dFADs per vessel to 150, and calls for the implementation of a four-month seasonal closure on FAD fishing.

It also asks for the responsibility of the CPCs to ensure full transparency of any dFADs operations by their flag fleets, including submission of all data transmitted by operational buoys to an independent third party in near real-time. WWF (2021) also asks that dFADs should be fully biodegradable by the end of 2021, and should not include any netting; also, it calls for the purse seine fleets to ensure that 100% of all deployed FADs are retrieved. Importantly, WWF's submission remarks that tuna fisheries in the Indian Ocean are multispecies by nature (even more so in the case of FAD-based purse seine), which brings the necessity to implement multi-species management reference points, where the impact of a fishery does not decrease co-dependent stocks to below MSY.

6.5.2. Making all fleets (except subsistence fisheries) subject to catch reductions

The EU also sent its own submission (IOTC 2021c). Perhaps not surprisingly, it focuses on asking for a fairer distribution of the yellowfin catch reduction scheme, so as to include all main fleets, several of which are currently exempt.

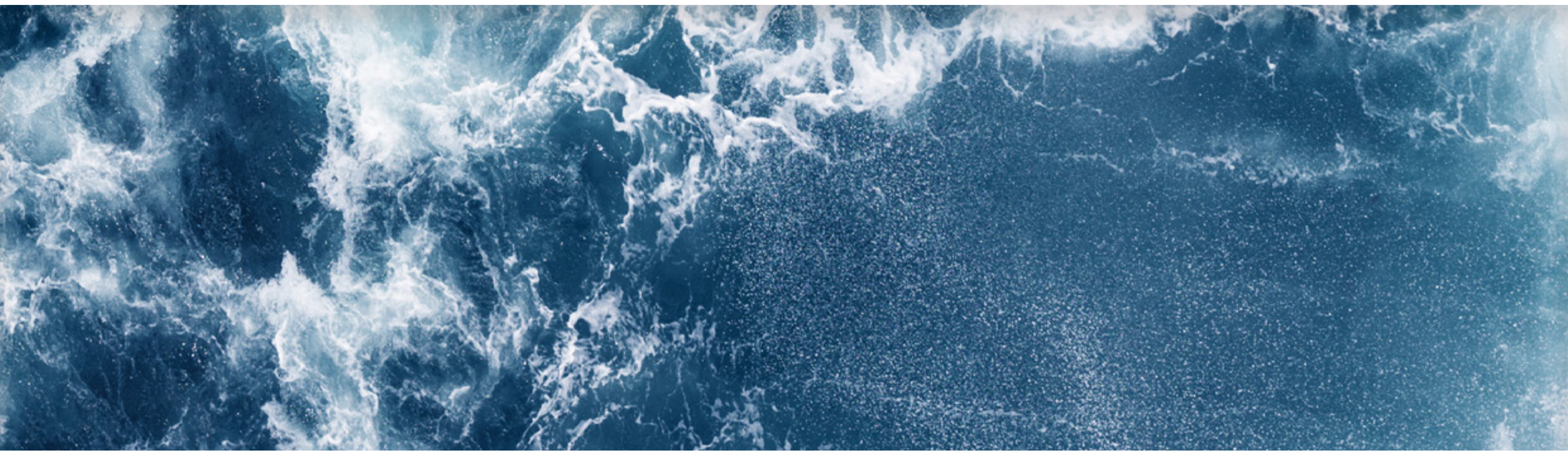
There is little reference in the EU submission to the need to reduce the use of FADs; hence it is understood that it does not ask for further reductions in the number of dFADs used and acquired by the purse seine fleets, and there is also no mention to the possibility of implementing seasonal closures of the FAD-based fishery. Nevertheless, EU's submission rightly highlights that practically half of IO yellowfin tuna catch stems from fleets and/or CPCs not subject to Resolution 19/01, which obviously jeopardises the likeliness of success of the catch reduction scheme. This became evident in 2019, when a number of fleets exempt from catch reduction have substantially increased their catch, in some cases showing an explosive growth compared to 2014 levels (IOTC 2021e) table 6.

Table 6 YFT catch in 2014 and 2019 by fleets exempt from catch reduction under Res 19/01. Source: IOTC 2021e (GTA Position Statement).

Country/Fleet	2014 YFT catch (t)	2019 YFT catch (t)	% Increase
Mauritian purse seine fleet*	4,844	12,290	154%
Indonesian purse seine fleet	5,598	9,775	75%
Seychelles longline fleet	1,616	6,984	192%
Indian gillnet fleet	5,153	6,801	32%
Omani gillnet fleet	2,268	11,516	408%
Iranian "other gears" fleets	57	9,385	16,263%
Sri Lankan "other gears" fleets	15,280	30,076	97%
Omani "other gears" fleets	4,912	25,219	413%

** Mauritius is subject to 7.5% reduction on 2018 levels within 19/01 (clause 10 in R19/01)*

Therefore, the request by the EU's submission that all these fleets -and essentially, all fleets, other than subsistence fleets- should be encompassed by the catch reduction scheme, seems justified.



6.5.3. *Use of a joint/ combined TAC for all three tropical tuna species*

During 2020 a number of experts on Indian Ocean tuna fisheries were interviewed by the consultants in order to gather their input about how to achieve the rebuilding of the IO YFT stock within two generations time (GTA 2020). Several interviewed experts suggested that, due to the multi-species nature of tropical tuna surface fisheries, the introduction of a joint TAC for all tropical tunas (skipjack, yellowfin and bigeye), might have a positive impact on the status of all three stocks. A joint TAC would prevent the problem of exhausting a TAC for a specific species too early in the year. In this case, the joint TAC should be set taking into consideration the expected reduction in catches and the percentage of each species in the sets.

A consequence of the catch reduction scheme implemented under Res 19/01 within the current mono-specific management approach in the IOTC is that yellowfin is acting as a choke species in the skipjack purse seine fishery (Merino et al. 2018). The purse seine fleet has reacted to this situation by shifting part of its effort from free swimming schools sets (PS FS) to FAD sets (PS LS). Free swimming yellowfin schools tend to be monospecific. This contrasts with PS LS sets in FADs, where skipjack forms mixed schools with juvenile yellowfin and bigeye tuna (Merino et al. 2018). Basically, PS FS is rather selective and catches mostly subadult and adult yellowfin. In contrast, PS LS sets have skipjack as its target species, but also do have a significant catch of juvenile yellowfin and bigeye. PS FS sets, when successful, may result in large volumes of yellowfin catch. These large catches cause the fleets to reach their yellowfin catch limit early within the fishing season, and thus bring in a premature (from the industry's perspective) cessation of the fishery, also stopping the skipjack fishery.

However, the claim by the purse seine fleets that yellowfin is choking the purse seine skipjack fishery is difficult to reconcile with the fact that the skipjack TAC has been largely overshot during recent years: the IO skipjack stock was subject to an overall TAC of 470,029 t for the period 2018 -2020, but this TAC was vastly surpassed in 2018 (609,179 t) and again in 2019 (547,249 t) (Table A3 in IOTC 2020a). In both years purse seine FAD fisheries (PS LS) represented about half of the total skipjack catch: 301,570 t in 2018 and 247,687 t in 2019 (Table A3 in IOTC 2020a). Thus, with FAD-based purse seine being the single main contributor to total skipjack catch, and the overshoot of the skipjack TAC, the argument that free swimming yellowfin schools sets are choking the purse seine skipjack fishery by causing a premature end of the fishing season would seem debatable.

Under these conditions, targeting free swimming yellowfin schools might be detrimental to the purse seine fleets because it could prevent them from maximizing their skipjack catch. Hence, IO purse seine fleets are concentrating their fishing effort on FAD sets, as a way to maximize their skipjack catch, and unavoidably catch juvenile yellowfin (and bigeye) in the process (Merino et al. 2018). In this way, the application of the catch reduction scheme in the absence of any other complementary measures has brought an increase of juvenile catch. One way of strengthening the catch reduction scheme, and to decrease the catch of juvenile tuna, might be the implementation of complementary measures, such as the said multispecific TAC. But also the implementation of fishing effort limits such as spatial and temporal closures might be contemplated. This will be assessed in the following subsection.

6.5.4. *Time/area closures*

As noted by Merino et al. (2018), there is only one instance of other tuna Regional Fishery Management Organisations (tRFMO) that has already implemented TACs or overall catch limits for the fleets targeting tropical tuna stocks: the ICCAT, where both yellowfin and bigeye catch are subject to TACs. However, these TACs implemented by ICCAT for both stocks have been repeatedly overshot during recent years (Merino et al. 2018, Sharma and Herrera 2020). The analysis of the level of compliance with the catch reduction scheme currently in place in the IO yields similar conclusions: the 2019 YFT catch actually increased by 4% regarding 2017 levels (IOTC 2021e).

Given this situation, additional measures would need to be explored. One of the main complementary measures to address IO YFT overfishing is to apply effort reduction strategies, as highlighted by Sharma & Herrera (2019) and also by Merino et al. (2018). A way to apply effort reduction measures is through the implementation of seasonal and spatial closures.

Seasonal and spatial closures might have a positive impact on the stock status of all three tropical tuna stocks being fished in the IO, because they have the potential to limit FAD-based purse seine catches (as well as catches by other fleets that also have an impact on juvenile yellowfin). FAD-associated purse seine fisheries are either the main fishery (as is the case for skipjack), or one of the main fisheries (in yellowfin and bigeye) contributing to the total catch of all three tropical tuna species in the IO. It has been already presented that the TAC set for skipjack during the period 2018-20 was largely exceeded in 2018 and 2019. It has also been presented how the objective set for the yellowfin catch reduction scheme is not being achieved. FAD-based purse seine is (together with gillnets) a major contributor of juvenile yellowfin catch. As for the third tropical tuna species, bigeye tuna, the IO bigeye stock is experiencing overfishing, although it is not overfished (ISSF 2020). It is caught majoritarily with longlines, but FAD-based purse seine also catches bigeye (which are juveniles) in a significant proportion: it caught 21.4%, 45.6% and 25.9% of the total bigeye catch in 2017, 2018 and 2019, respectively (Table A2 in IOTC 2020a). There is no TAC currently in place for IO bigeye tuna. Hence, purse seine effort control measures that would go beyond the ones currently implemented (Res 19/02, basically addressing the amount of allowed FADs, and their design) could benefit all three stocks.

Sharma and Herrera (2019) explored the application of full seasonal closures to the multi-species tuna purse seine fishery in the IO in order to achieve the levels of catch reduction required under IOTC Res 17/01 (later superseded by 19/01). They aimed to define a Control Rule which yielded a range of possible time-area closure periods, highlighting the effect that each of these periods would have in terms of reduced catch of immature or mature YFT, BET and SKJ. They obtained a range of closure periods, with varying levels of efficacy in terms of reducing fishing pressure in each of the three tuna stocks studied. Thus it would be a matter of refining this study in order to identify which closure period would yield the maximum reduction of juvenile yellowfin catch whilst at the same time also benefiting the bigeye and skipjack stocks. A more detailed analysis of Sharma and Herrera's (2019) results was provided in GTA (2020). Kaplan et al. (2014) identified a large time-area closure east of Somalia which, if it remained closed for a significant fraction of the year, could greatly reduce purse-seine juvenile tuna catch in FAD-associated sets. As it was, the area functioned as a one-month IOTC-implemented closure during November for purse seine fisheries and during February for longline fisheries (none of which corresponded to the peaks of the respective fishing seasons for each fishery). This seasonal closure was designated in 2010 and discontinued shortly after in 2012. The area overlapped partly with Somalia's EEZ and extended eastwards to 60˚ E. This area was found by Kaplan et al. (2014) to be central to ecosystem dynamics and tuna fisheries in the IO. Kaplan et al. (2014) also noted the high catch rates of juvenile yellowfin within the area (Fig. 20). Furthermore, Kaplan et al. (2014) presented mark-recapture data from tagged juvenile tuna which shown that the closure area corresponded to a hotspot where juveniles were found for long periods of time, possibly indicating also that small tuna may be resident in the northwest IO (Fig. 21 pg 49).

Figure 20. Spatial distribution of juvenile yellowfin tuna from European purse-seine catch on floating-objects (a) for the period 1993–2004. Darker shades of grey indicate increasing catch with the maximum value indicated (176t/year/104 km2). Source: Adapted from Kaplan et al. (2014).

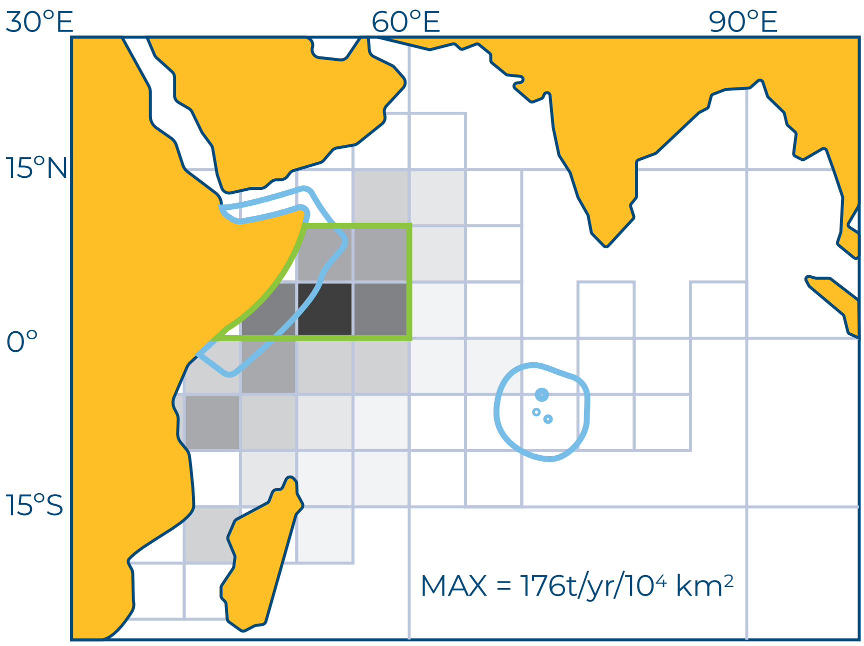
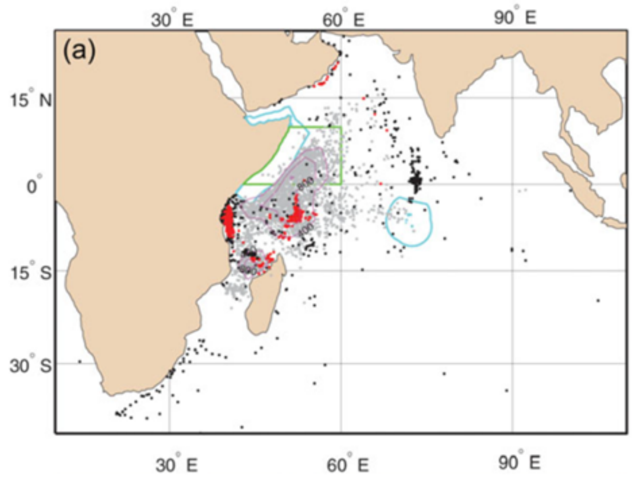
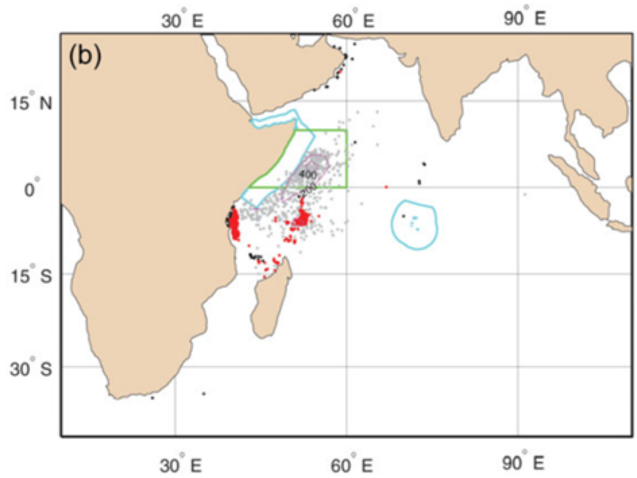


Figure 21. Maps of results from IO juvenile tropical tuna mark–recapture program. In (a) all recaptures are shown, whereas in (b) recaptures are limited to those for which the time between mark and recapture was larger than 3 months. Red dots indicate locations where fish were marked, grey dots indicate purse-seine recapture locations (25,100 in total) and black dots indicate recaptures by gears other than purse-seine (1,510 total; mostly pole-and-line, longline and gillnet). Magenta contours indicate density of purse-seine recaptures after placing recapture locations on a 2.5° × 2.5° grid. Source: Kaplan et al. (2014).



A.



B.

Kaplan et al. (2014) highlighted that the closure area represented (during the years covered by the study) 21% of all annual commercial fishing in the IO and 47% of purse-seine juvenile catch. However, these authors also pointed out that its duration (one month) was likely insufficient to ensure an effective protection for juvenile yellowfin, and also that the two fleets affected by the closure found ways to keep their fishing effort relatively unaltered despite the closure, through effort reallocation (Kaplan et al. 2014).

Another study by Davies et al. 2017 re-assessed the case of the short-lived Somalian sea closure. These authors undertook a retrospective analysis of the response of the purse seine fishing fleet to the closed area. They used model-based predictions to study whether the closure caused the fleet to reallocate fishing effort; and they found that it did, although in varying degrees depending on the specific fleet component: apparently, the Spanish fleet showed the most marked change in behaviour, while the French fleet tended to stay closer to its traditional fishing grounds outside the closed area (Davies et al. 2017).

Therefore, it seems that the seasonal closure implemented by the IOTC in 2010-12 might have had more success if it would have been set for a longer period (instead of only one month), and if this period would have overlapped with the peak months of the purse seine fishing season. This is supported by the results of Escalle et al. (2017), which found that a more extensive six-month restriction on FAD-associated fishing within the designated closure area would achieve a significant reduction of the catch of small tuna (skipjack and juveniles of yellowfin and bigeye). Nevertheless, such a closure would also have important economic consequences for the fisheries affected.

To conclude, it is important to note that if the true aim of IOTC is to keep (or rebuild) the tuna stocks under its jurisdiction within a healthy level, the approach taken to realize this objective should be as holistic as possible. There is an important difference between IO tuna fisheries and tuna fisheries in the other RFMOs: whilst in ICATT, WCPFC and IATTC it is the industrial tuna fisheries (purse seine and in lesser measure, longline fisheries) that take the largest share of the tuna catch, in the IO the yellowfin catch is split in practically even parts between industrial fisheries in one side, and artisanal and semi-industrial fisheries in the other side. This split adds a further layer of complexity to the task of managing IO yellowfin tuna (as well as the other tropical tuna species), and makes it further unlikely that a single-measure approach (such as the current yellowfin catch reduction scheme) will fully achieve its objectives. This does not mean, at all, that the catch reduction scheme should be abandoned; to the contrary, it should be reinforced and complemented with fishing effort control measures, such as sufficiently long seasonal closure in the Somalian sea.

In short, it seems crucially important to realize that the problem of IO tuna management should not be conceptually reduced to a mutually exclusive choice between TAC-based (or reduction-based) management versus a management based on fishing effort controls:

both types of management approaches seem necessary in order to increase the likeability of success. This is especially relevant given the dire situation of the IO yellowfin stock, which requires urgent and effective action to avoid its collapse.

6.5.5. Limiting gillnet fisheries

As discussed earlier, the gear which IOTC terms as gillnets in reality is in most cases large-scale (> 2.5 km) driftnets. The use of large-scale driftnets within the High Seas has been under global moratorium since 1991, as per the United Nations General Assembly Resolution 46/215 (UNGA 1991). However, the ban does not encompass EEZs, and the IOTC allows the use of driftnets within the EEZs of its coastal CPCs. There seems to be very little leverage for implementing changes in the main Indian Ocean "gillnet" fleets aimed at reducing the catch of juvenile yellowfin, given the very weak monitoring, control and surveillance (MCS) capacities by the main CPCs hosting these fleets (García and Herrera, 2018; Sivadas et al., 2019; Eighani et al., 2020). Also, in this sense, the prospects for compliance of any possible measures that might be taken (e.g., a larger mesh size, reduction in the length of the nets, implementation of area and spatial closures) appear weak.

It is noteworthy, though, that UNGA Res 46/215 specifically includes "enclosed and semi-enclosed seas" as areas where the moratorium applies, together with the High Seas (UNGA 1991). In turn, UNCLOS Article 122 provides the definition of these seas (UNCLOS 1982). The Persian Gulf fulfills entirely the description of a semi-enclosed sea. It is unclear whether any driftnet fleets currently operate within the Persian Gulf. But if they do, they might be considered in breach of UNCLOS and thus, for practical effects, might be deemed IUU fisheries. They might have been operating as such for decades.

However, as of January 1st 2022, all large-scale driftnets will be prohibited in the entire IOTC area, according to IOTC Resolution 17/07 (IOTC 2017b). This would be a very positive perspective from the point of view of safeguarding the Indian Ocean yellowfin stock and the wider marine ecosystem, except because the IOTC acknowledges that the details of implementation of Res 17/07 are left to the discretion of individual CPCs: *"While there are no explicit technical requirements for coastal State CPCs under this resolution,* ***it would appear obvious that coastal States are expected to incorporate the expanded prohibition for driftnet fishing within the EEZ into their national legal framework –*** *and this is supported by the tenets of paragraph 8.* ***However, the resolution does not address this particular matter, and rules from an exclusive flag State perspective.****"* (IOTC 2018c; own highlighting).

It is the responsibility of IOTC to ensure that this incoming total ban on large-scale driftnets is effectively and timely implemented. It seems necessary to define a sanction plan to ensure compliance by all CPC members. If not, it seems quite likely that most large-scale driftnet fleets might continue active well beyond January 2022, becoming, at all effects, IUU fisheries.

VII.

Conclusions and recommendations

Based on the findings presented above, a series of recommendations are given in order to reduce the catch of yellowfin tuna juveniles by the assessed fisheries:

1. **The overall catch reduction is crucial to reduce the impact on both juvenile and mature yellowfin tuna.** It should be set at **20% relative to 2014.** Setting the catch at or near the currently estimated MSY level (403,000 t, estimated in the 2018 stock assessment, IOTC 2019a) would not be precautionary, given the dire status of the stock and the high uncertainties in the stock assessment.

   The catch reduction scheme, if it was adequately implemented, might be expected to be sufficient to ensure the stock's recovery. However, the failure by IOTC in harnessing the overfishing of the YFT stock over recent years makes it necessary to suggest the following complementary measures, in order to increase the likeliness of putting an end to IO YFT overfishing. Some of these measures (e.g., seasonal/spatial closures, combined TACs for all tropical tunas, etc.) were already addressed in our previous report (GTA 2020). Nevertheless they have been also included here, with a focus on the reduction of the overfishing of juvenile yellowfin tuna.

   The measures suggested are as follow:

2. Notwithstanding the principles of fairness and equity, there must be an explicit end to the exemption from catch reduction for fleets below 24m LOA within EEZs. The exemption should only apply to fleets that are composed by vessels ≤12 m LOA; i.e. only subsistence fisheries would be exempt. The sole criterion to determine whether a fleet is subject to the catch reduction obligation should be whether it reaches the catch threshold (2,000 t) suggested in the catch reduction scheme.

3. The number of FADs (and instrumented buoys) used by the purse seine fishery needs to be reduced, and the tracking of these FADs improved, so as to allow for a real decrease of the fishing effort of the FAD-associated purse seine fishery, which is one of two fisheries identified as having the greatest impact on the overfishing of juvenile YFT.

4. The implementation of seasonal and spatial closures should be considered. One or several spatio-temporal fishery closures should be implemented in specific areas where the catch of immature yellowfin tuna is concentrated (GTA 2020, Kaplan et al. 2014.). A seasonal (three-month or four-month closure) in the FAD-based purse seine fishery has been proposed by some stakeholders (IOTC 2021a; WWF 2021); a similar proposal was also presented in our previous report (GTA 2020).

5. For the remainder of 2021, the prohibition of the use of large-scale gillnets (in reality, driftnets) in offshore waters should be immediately enacted. These large-scale gillnets should also be banned from operating in semi-enclosed seas (such as the Persian Gulf), in fulfilment with UNGA Resolution 46/215 (UNGA 1991), which bans them from enclosed and semi-enclosed seas. As of 1 January 2022, large-scale gillnets will be prohibited from the entire IOTC area under Res 17/07 (IOTC 2017b). The prohibition should be strictly enforced and severe sanctions should be imposed in case of infractions.

6. It is necessary to implement multi-specific TACs for all three tropical tunas, where the impact of a fishery does not decrease co-dependent stocks to below MSY. In other words, targeting skipjack should not result in overfishing juvenile yellowfin (and bigeye) tuna. Besides, the currently existing TAC for IO skipjack is not being complied with, as shown by the large overcatch in 2018 and 2019 (see Discussion).

7. Improving data reporting by all CPCs and for all gears, both for total catch data, catch and effort data, and size data. The IOTC

capacity building program needs to be reinforced to improve data collection, with incentives given to the countries which meet IOTC data requirements under Resolution 15/02. Without good basic data, it is not possible to undertake an appropriate stock assessment: Data collection and inputs to the model need to be improved in several areas, such as increasing observer coverage and in-port sampling, improving the tagging programmes, addressing the excessive reliance on longline data, etc. Compliance with adequate reporting must be controlled and enforced by an effective sanction mechanism; repeated non-compliance by CPCs should carry sanctions in the form of further catch reductions commensurated with the gravity of the non-compliance.

In summary, the implementation of an overall catch reduction at 20% relative to 2014 needs to be urgently enforced in order to halt the overfishing of the yellowfin stock and avoid its collapse. But, at the same time, recovering the Indian Ocean yellowfin tuna stock requires a holistic approach, especially in view of the difficulties by IOTC to adequately implement the said reduction. In the real world, tuna management is exceedingly complex, and even more so in the case of the IOTC. The implementation of the overall catch reduction is essential to reduce the fishing pressure on both the juvenile and adult fractions of the yellowfin stock, and it constitutes the core of the yellowfin stock rebuilding strategy. However, on the face of IOTC's multiple dysfunctionalities, the implementation of additional management measures such as stated above in points 2 through 7 might be necessary to reach the stated goal of avoiding the collapse of the Indian Ocean yellowfin stock.

VIII. References

Adam, M. S., Jauharee, A. R., & Miller, K. I. (2015). *Review of yellowfin tuna fisheries in the Maldives. Paper submitted to IOTC Working Party on Tropical Tunas.* IOTC-2015-WPTT-17-17. Retrieved February, 9, 2021. https://cpanel.iotclists.org/sites/default/files/documents/2015/10/IOTC-2015-WPTT17-17_-_Maldives_YFT_fishery.pdf

Ahusan, M., Adam, M. S., Ziyad, A., Ali, K., & Shifaz, A. (2017). *Maldives national report submitted to the Indian Ocean Tuna Commission Scientific Committee-2017.* IOTC-2017-SC20-NR16. Retrieved February, 9, 2021. http://202.1.196.69/jspui/handle/123456789/4632

Andriamahefazafy, M., & Kull, C. A. (2019). *Materializing the blue economy: tuna fisheries and the theory of access in the Western Indian Ocean.* Journal of Political Ecology, 26 (1), 403-424.

Aranda, M. (2017). *Description of tuna gillnet capacity and bycatch in the IOTC Convention Area.* Report no. IOTC-2017-WPEB13-18. Retrieved February, 16, 2021. https://iotc.org/sites/default/files/documents/2017/08/IOTC-2017-WPEB13-18.pdf

Assan, C., Lucas, J., Augustin, E., Delgado de Molina, A., Maufroy, A. and Chassot, E. (2015). *Seychelles auxiliary vessels in support of purse seine fishing in the Indian Ocean during 2005–2014: summary of a decade of monitoring.* IOTC–2015–WPTT17–41 Rev_1. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2015/10/IOTC-2015-WPTT17-41_Rev_1_-_Seychelles_support_vessels.pdf

Báez, J. C., Fernández, F., Pascual-Alayón, P. J., Ramos, M. L., Deniz, S., & Abascal, F. (2018). *Updating the statistics of the EU-Spain purse seine fleet in the Indian Ocean (1990-2017).* IOTC-2017-WPTT19-INFO5. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2017/10/IOTC-2017-WPTT19-INFO5_Spanish_PS.pdf

Bailey, M., Sumaila, U. R., & Martell, S. J. (2013). *Can cooperative management of tuna fisheries in the Western Pacific solve the growth overfishing problem?* Strategic Behavior and the Environment, 3(1-2), 31-66.

Bertalanffy, L. von. (1938). *A quantitative theory of organic growth (Inquiries on growth laws. II).* Human Biol. 10: 181-213.

Beverton, R. J. H. (1992). Patterns of reproductive strategy parameters in some marine teleost fishes. Journal of Fish Biology 41 (Suppl. B), 137–160

Blasi, M. F., Roscioni, F., & Mattei, D. (2016). *Interaction of loggerhead turtles (Caretta caretta) with traditional fish aggregating devices (FADs) in the Mediterranean Sea.* Herpetological Conservation and Biology, 11(3), 386-401.

Bromhead, D., J. Foster, R. Attard, J. Findlay, and J. Kalish. (2003). *A review of the impact of fish aggregating devices (FADs) on tuna fisheries.* Final Report to Fisheries Resources Research Fund, Australia Bureau of Rural Sciences.

Chassot, E., Lucas, V., Lucas, J., Assan, C. and Santiago, J. (2019). *Outburst of FAD fishing following quota implementation: The case of Indian Ocean yellowfin.* Retrieved January, 29, 2021. https://iattc.org/Meetings/Meetings2019/SAC-10/OTM-33/Docs/_Spanish/OTM-33-01a_Arrebato%20de%20pesca%20sobre%20plantados%20despues%20de%20implementar%20una%20cuota-ENO.pdf

Coulter, A., Cashion, T., Cisneros-Montemayor, A.M., Popov, S., Tsui, G., Le Manach, F., Schiller, L., Palomares, M.L.D., Zeller, D. and Pauly, D., (2020). *Using harmonized historical catch data to infer the expansion of global tuna fisheries.* Fisheries Research, 221, p. 105379.

Creech, S., & Gunasekera, E. (2020). *An application of length-based assessment methods to Indian Ocean fisheries for yellowfin tuna (Thunnus albacares) between 1955 and 2015: implications for sustainable fisheries management.* IOTC-2020-WPTT22(AS)-22_Rev1. Retrieved January, 29, 2021. https://iotc.org/sites/default/files/documents/2020/10/IOTC-2020-WPTT22AS-22_Rev1_0.pdf

Dagorn, L., Holland, K. N., 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.

Damora, A. and Bayhaqi, (2013). *Size distribution and population parameters of yellowfin tuna (Thunnus albacares) in Banda Sea.* Bawal 5(1):59-65.

Damora, A., Gigentika, S., Adityarini, S., Rahmah, A., Tamanyira, M. M., Nurdin, E., & Wiadnya, D. G. R. (2020). *Optimization of FADs-based tuna fishing in the Fishing Port of Pondokdadap, East Java, Indonesia.* In IOP Conference Series: Earth and Environmental Science. Vol. 420, No. 1, p. 012009.

Davies, T. K., Mees, C. C., & Milner-Gulland, E. J. (2014). *The past, present and future use of drifting fish aggregating devices (FADs) in the Indian Ocean.* Marine policy, 45, 163-170.

Davies, T. K., Mees, C. C., & Milner-Gulland, E. J. (2017). *Use of a counterfactual approach to evaluate the effect of area closures on fishing location in a tropical tuna fishery.* Plos one, 12(3), e0174758.

Delgado de Molina, A., Areso, J.J. & Ariz, J. (2010). *Statistics of the purse seine Spanish fleet in the Indian Ocean (1984-2009).* IOTC-2010-WPTT-19. Unpublished IOTC working document No. IOTC-2010-WPTT-19 21 (2010).

Dortel, E., Massiot-Granier, F., Rivot, E., Million, J., Hallier, J.P., Morize, E., Munaron, J.M., Bousquet, N. and Chassot, E. (2013). *Accounting for age uncertainty in growth modeling, the case study of yellowfin tuna (Thunnus albacares) of the Indian Ocean.* PloS one, 8(4), p.e60886

Eighani, M., Naderi, R. A., & Cope, J. (2020). *Understanding fishery interactions and stock trajectory of yellowfin tuna exploited by Iranian fisheries in the Sea of Oman.* OTC-2020-WPTT22(AS)-20. Retrieved January, 29, 2021. https://www.iotc.org/documents/interim-plan-rebuilding-indian-ocean-yellowfin-tuna-stock-iotc-area-competence-european

Escalle, L., Gaertner, D., Chavance, P., Delgado de Molina, A., Ariz, J. and Mérigot, B., (2017). *Forecasted consequences of simulated FAD moratoria in the Atlantic and Indian Oceans on catches and bycatches.* ICES Journal of Marine Science, 74(3), pp.780-792.

Ewell, C., Hocevar, J., Mitchell, E., Snowden, S., & Jacquet, J. (2020). *An evaluation of Regional Fisheries Management Organization at-sea compliance monitoring and observer programs.* Marine Policy, 115, 103842.

Fonteneau, A., Chassot, E., & Bodin, N. (2013). *Global spatio-temporal patterns in tropical tuna purse seine fisheries on drifting fish aggregating devices (DFADs):* Taking a historical perspective to inform current challenges. Aquatic Living Resources, 26(1), 37-48.

Fonteneau, A., Chassot, E., Gaertner, D., (2015). *Managing tropical tuna purse seine fisheries through limiting the number of drifting fish aggregating devices in the Atlantic: food for thought.* Collect. Vol. Sci. Pap. ICCAT 71, 460–475.

Froese, R. 2004. *Keep it simple: three indicators to deal with overfishing.* Fish and Fisheries, 5: 86–91.

Fu, D., Merino, G., Langley, A.D. and Urtizberea-Ijurco, A. (2018). *Indian Ocean yellowfin tuna SS3 model projections.* IOTC-SC21-16. Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/2018/11/IOTC-2018-SC21-16_0.pdf

Garcia, A., & Herrera, M. (2018). *Assessing the contribution of purse seine fisheries to overall levels of bycatch in the Indian Ocean.* OTC-2018-WPDCS14-26. Retrieved January, 29, 2021. https://webmail.iotclists.org/sites/default/files/documents/2018/11/IOTC-2018-WPDCS14-26_Rev1.pdf

Gershman, D., Nickson, A., & O'Toole, M. (2015). *Estimating the use of FADs around the world: an updated analysis of the number of fish aggregating devices deployed in the ocean.* Pew Environ. Gr, 1-24.

Gilman, E.L., (2011). *Bycatch governance and best practice mitigation technology in global tuna fisheries.* Marine Policy 35, 590–609.

Gilman, E., Castejón, V. D. R., Loganimoce, E., & Chaloupka, M. (2020). *Capability of a pilot fisheries electronic monitoring system to meet scientific and compliance monitoring objectives.* Marine Policy, 113, 103792.

Goodyear, C. P. (1993). *Spawning stock biomass per recruit in fisheries management: foundation and current use.* p. 67-81. In S. J. Smith, J. J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Greenpeace (2019). *Seabound: The journey to modern slavery on the High Seas.* Greenpeace, in collaboration with Serikat Buruh Migran Indonesia (SBMI). 52 pp.

Griffiths, S. P., Allain, V., Hoyle, S. D., Lawson, T. A., & Nicol, S. J. (2019). *Just a FAD? Ecosystem impacts of tuna purse-seine fishing associated with fish aggregating devices in the western Pacific Warm Pool Province.* Fisheries Oceanography, 28(1), 94-112.

GTA (2020). *Developing management advice to rebuild the Indian Ocean yellowfin tuna (Thunnus albacares) stock in two generations.* Naunet Fisheries Consultants. IOTC-2020-WPTT22AS-18.

Hallier, J.P. & Gaertner, D. (2008). *Drifting fish aggregation devices could act as an ecological trap for tropical tuna species.* Marine Ecology Progress Series. Vol. 353: 255–264.

Hampton, J., Leape, G., Nickson, A., Chassot, E., Gaertner, D., & Taquet, M. (2017). *What does well-managed FAD use look like within a tropical purse seine fishery?* Doc. No. j-FAD_35/2017.

Hargiyatno, I. T., Utomo, S. W., & Sue, R. A. (2018). *Tuna fisheries sustainable management: Assessing of Indonesia fish aggregating devices (FADs) fisheries.* In E3S Web of Conferences (Vol. 68, p. 04019). EDP Sciences.

Hashemi, S. A. R., Doustdar, M., Gholampour, A., & Khanehzaei, M. (2020). *Length-Based fishery status of Yellowfin tuna (Thunnus albacares Bonnaterre, 1788) in the northern waters of the Oman Sea.* Iranian Journal of Fisheries Sciences, 19(6), 2790-2803.

Herath, H.L. (2012). *Management of shark fishery in Sri Lanka.* IOTC–2012–WPEB08–10 Rev_1. Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/proceedings/2012/wpeb/IOTC-2012-WPEB08-10%20Rev_1.pdf

Hixon, M. A., Johnson, D. W., & Sogard, S. M. (2014). *BOFFFFs: on the importance of conserving old-growth age structure in fishery populations.* ICES Journal of Marine Science, 71(8), 2171-2185.

Hordyk, A., Ono, K., Sainsbury K., Loneragan, N., Prince, J.D., (2015a). *Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio.* ICES J. Mar. Sci. 72, 204-216. doi:10.1093/icesjms/fst235

Hordyk, A., Ono, K., Valencia, S.V., Loneragan, N., Prince, J.D., (2015b). *A novel length-based estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries.* ICES J. Mar. Sci 72, 217-231. doi:10.1093/icesjms/fsu004

Hordyk, A., Ono, K., Prince, J.D., Walters, C.J., (2016). *A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks.* Can. J. Fish. Aquat.Sci.73,1787-1799.doi:10.1139/cjfas-2015-0422.

IOTC (2017a). *Yellowfin tuna supporting information.* Updated: December 2017. Working Party on Tropical Tunas. Retrieved January, 29, 2021. http://www.iotc.org/sites/default/files/documents/science/species_summaries/english/Yellowfin_tuna_Supporting_information.pdf

IOTC (2017b). *Resolution 17/07 on the prohibition to use large-scale driftnets in the IOTC area.* Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/compliance/cmm/iotc_cmm_1707_0.pdf

IOTC (2018a). *Report of the 21st session of the IOTC Scientific Committee.* IOTC-2018-SC21-R[E]_Rev1. Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/2019/02/IOTC-2018-SC21-RE_FINAL_DO_NOT_MODIFY_Rev1.pdf

IOTC (2018b). *Implementation of IOTC Conservation and Management Measures – Part A: Understanding IOTC and the international fisheries management framework.* Seychelles, FAO. 80 pp. Retrieved January, 29, 2021. http://www.fao.org/3/i8310en/I8310EN.pdf

IOTC (2018c). *Implementation of IOTC Conservation and Management Measures Part B: Implementation of IOTC CMMs entailing reporting obligations.* Seychelles, FAO. 136 pp. Retrieved January, 29, 2021. http://www.fao.org/3/i8409en/I8409EN.pdf

IOTC (2019a). *Report of the 22nd session of the IOTC Scientific Committee.* IOTC–2019–S22 Bangkok, Thailand, 21–25 May 2018. Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/2020/02/IOTC-2019-SC22-RE.pdf

IOTC (2019b). *Resolution 19/02 procedures on a fish aggregating devices (FADS) management plan.* Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/compliance/cmm/iotc_cmm_1902.pdf

IOTC (2019c). *Report of the 23rd Session of the Indian Ocean Tuna Commission.* IOTC-2019-S23 Hyderabad, India, 17-21 June 2019. Retrieved January, 29, 2021. https://www.iotc.org/sites/default/files/documents/2019/10/IOTC-2019-S23-RE_Rev1_FINAL.pdf

IOTC (2020a). *IOTC–2020–WPTT22(AS)–R. Report of the 22nd Session of the IOTC Working Party on Tropical Tuna, Stock Assessment Meeting.* Online, 19 - 23 October 2020. IOTC–2020–WPTT22(AS)–R[E]_Rev1. 106 pp. Retrieved January, 29, 2021. https://www.iotc.org/documents/WPTT/2202/RE

IOTC (2020b). *Review of the statistical data and fishery trends for tropical tunas. 52 pp.* IOTC–2020–WPTT22(AS)–03_Rev4. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2020/12/IOTC-2020-WPTT22AS-03_Rev4_-_Data_and_statistics.pdf

IOTC (2020c). *IOTC-2020-WPDCS16-16. Review of detected anomalies in size frequency in Size frequency data Submitted to the Secretariat.* Retrieved January, 29, 2021. https://www.iotc.org/documents/WPDCS/16/16

IOTC (2021a). *IOTC-2021-SS4-PropD. On management of fish aggregating devices (FADs) in the IOTC Area of Competence.* Submitted by Kenya & Sri Lanka. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2021/02/IOTC-2021-SS4-PropD_-_On_management_of_fish_aggregating_devices_Kenya_Sri_Lanka.pdf

IOTC (2021b). *IOTC-2021-SS4-PropC. On an interim plan for rebuilding the Indian Ocean yellowfin tuna stock in the IOTC Area of Competence.* Submitted by Maldives. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2021/02/IOTC-2021-SS4-PropC_-_On_an_interim_plan_to_rebuild_the_yellowfin_tuna_stock_Maldives.pdf

IOTC (2021c). *IOTC-2021-SS4-PropB. On an interim plan for rebuilding the Indian Ocean yellowfin tuna stock in the IOTC Area of Competence.* Submitted by the European Union. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2021/02/IOTC-2021-SS4-PropBE_-_On_an_interim_plan_to_rebuild_the_yellowfin_tuna_stock_EU.pdf

IOTC (2021d). *IOTC-2021-SS4-INF05. Blue and IPNLF position statement in advance of the Special Session of the Indian Ocean Tuna Commission.* Submitted by Blue and IPNLF. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2021/02/IOTC-2021-SS4-INF05_-_BLUE-IPNLF_statement_Final.pdf

IOTC (2021e). *IOTC-2021-SS4-INF02. GTA Position Statement.* Submitted by GTA. Retrieved February, 16, 2021. https://www.iotc.org/sites/default/files/documents/2021/01/IOTC-2021-SS4-INF02_-_GTA_Position_Statement.pdf

ISSF (2020). *Status of the world fisheries for tuna. Nov. 2020.* ISSF Technical Report 2020-16. International Seafood Sustainability Foundation, Washington, D.C., USA.

Jaquemet, S., Potier, M., & Ménard, F. (2011). *Do drifting and anchored Fish Aggregating Devices (FADs) similarly influence tuna feeding habits? A case study from the western Indian Ocean.* Fisheries Research, 107(1-3), 283-290.

Kantun, W. and F. Amir, (2013). *Age structure, growth pattern and mortality of yellowfin tuna- Thunnus albacares (Bonnatere, 1788) in Macassar strait.* Jurnal Balik Diwa 4(1):8-14. [In Bahasa Indonesia].

Kaplan, D. M., Chassot, E., Amandé, J. M., 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.

Kar, A. B., Ramalingam, L., Govindaraj, K., Prasad, G. V. A., Blair, P., & Islands, A. N. (2012). *Study of the growth and population parameters of yellowfin tuna (Thunnus albacares) in the Andaman and Nicobar waters based on the length frequency data.* IOTC 14th Working party on tropical tuna, Mauritius, 24-29.

Kaymaram, F., Emadi, H. and Kiabi, B. (2000). 2nd IOTC proceedings, Victoria, 23-27 September, Seychelles, 283-285.

Kaymaram, F., Hosseini, S.A., Darvishi, M. (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.

Kumar, M. S., Ghosh, S., Sreeramulu, K., Manjulatha, C., Mahesh, V. U., & Rao, M. V. (2020). *Fishery and stock structure of Thunnus albacares (Bonnaterre, 1788) off Andhra waters along western Bay of Bengal.*

Lecomte, M., Rochette, J., Laurans, Y., & Lapeyre, R. (2017). *Indian Ocean tuna fisheries: between development opportunities and sustainability issues.* Paris: IDDRI. 85 pp.

Leroy, B., Phillips, J.S., Nicol, S., Pilling, G.M., Harley, S., Bromhead, D., Hoyle, S., Caillot, S., Allain, V. and Hampton, J. (2013). *A critique of the ecosystem impacts of drifting and anchored FADs use by purse-seine tuna fisheries in the Western and Central Pacific Ocean.* Aquatic Living Resources, 26(1), pp.49-61.

López, J. & Scott, G. (2014). *The use of FADs in tuna fisheries. European Parliament no.* IP/B/PECH/IC/2013-123 (January 2014), Policy Department B: Structural and Cohesion Policies: Fisheries. Brussels, 70 pp.

Lucas, J., Lucas, V., Krug, I., Tirant, A., Assan, C., Mein, M., ... & Chassot, E. (2017). *The Seychelles purse seine fishery observer program: Overview, challenges, and perspectives. In IOTC Proceedings.* IOTC, Victoria, Seychelles, 26-28 November 2017, 16p. Retrieved January, 29, 2021. https://3ww.iotc.org/sites/default/files/documents/2017/11/IOTC-2017-WPDCS13-23_-_OBS_PS_SYC.pdf

Mace, P. M., and Sissenwine, M. P. (1993). *How much spawning per recruit is enough? In Risk Evaluation and Biological Reference Points for Fisheries Management, pp. 101–118.* Ed. by S. J. Smith, J. J. Hunt and D. Rivard. Canadian Special Publication in Fisheries and Aquatic Sciences, 120.

Macfadyen, G. and Defaux, V. (2019). *Scoping Study of Socio-economic Data and Indicators of IOTC Fisheries.* Report produced by Poseidon Aquatic Resources Management Ltd for the IOTC/FAO.IOTC-2019-S23-13_Rev1.Retrieved January, 29, 2021. https://www.iotc.org/documents/scoping-study-socio-economic-data-and-indicators-iotc-fisheries

Mallawa, A., & Zainuddin, M. (2018). *Population dynamic indicator of the yellowfin tuna Thunnus albacares and its stock condition in the Banda Sea, Indonesia.* Aquaculture, Aquarium, Conservation & Legislation, 11(4), 1323-1333.

Marsac, F., Fonteneau, A., Ménard, F. (2000). *Drifting FADs used in tuna fisheries: an ecological trap?* In: Le Gall JY, Cayré P, Taquet M (eds). Pêche thonière et dispositifs de concentration de poisons. Actes Colloques-IFREMER 28:537–552.

Mueni, E. et al. (2019). *Species composition, abundance and preliminary spawning potential Ratio (SPR) assessment for tuna and tuna like species: Some results from application of mobile phone-Catch Assessment Survey, Kenya.* 15th Working Party on Data Collection and Statistics. IOTC-2019-WPDCS15-23. 15 pp.

McDonald, G.G., Costello, C., Bone, J., Cabral, R.B., Farabee, V., Hochberg, T., Kroodsma, D., Mangin, T., Meng, K.C. and Zahn, O., (2021). *Satellites can reveal global extent of forced labor in the world's fishing fleet.* Proceedings of the National Academy of Sciences, 118(3).

Macusi, E. D., Abreo, N. A. S., & Babaran, R. P. (2017). Local ecological knowledge (LEK) on fish behavior around anchored FADs: the case of tuna purse seine and ringnet fishers from Southern Philippines. Frontiers in Marine Science, 4, 188.

Merino, G., Urtizberea, A., Santiago, J., Prellezo, R. & Abascal, F. (2018). *Prospects for an effort-based management of Indian Ocean yellowfin stock.* IOTC-2018-WPTT20-43. 16 pp.

Minte-Vera, C.V., Aires-da-Silva, A., Maunder., M. N. (2016). *Status of yellowfin tuna in the eastern Pacific Ocean in 2016 and outlook for the future.* SAR-18-2-YFT-assessment-2016. IATTC.

Morgan, A.C. (2011). *Fish Aggregating Devices and Tuna: Impacts and Management Options.* Ocean Science Division, Pew Environment Group, Washington, DC. 20 pp.

MRAG (2017). *An analysis of the uses, impacts and benefits of fish aggregating devices (FADs) in the global tuna industry.* A report produced for WWF-UK by MRAG Ltd. London, UK. pp. 51.

Morales-Nin, B., Cannizzaro, L., Massuti, E., Potoschi, A., & Andaloro, F. (2000). *An overview of the FADs fishery in the Mediterranean Sea.* In Pêche thonière et dispositifs de concentration de poissons, Caribbean-Martinique, 15-19 Oct 1999.

Nootmorn, P., Yakoh, A., & Kawises, K. (2005). *Reproductive biology of yellowfin tuna in the Eastern Indian Ocean.* IOTC-WPTT, 14, 379-385.

Nurdin, E., Sondita, M. F., Yusfiandayani, R., & Baskoro, M. S. (2016). *Growth and mortality parameters of yellowfin tuna (Thunnus albacares) in Palabuhanratu waters, west Java (eastern Indian Ocean).* Aquaculture, Aquarium, Conservation & Legislation, 9(3), 741-747.

Pérez, G., Dagorn, L., Deneubourg, J.L., Forget, F., Filmalter, J.D., Holland, K., Itano, D., Adam, S., Jauharee, R., Beeharry, S.P. and Capello, M. (2020). *Effects of habitat modifications on the movement behavior of animals: the case study of Fish Aggregating Devices (FADs) and tropical tunas.* Movement ecology, 8(1), pp.1-10.

Prathibha, R., Syda Rao, G. and 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.

Prince, J., & Hordyk, A. (2019). *What to do when you have almost nothing: A simple quantitative prescription for managing extremely data-poor fisheries.* Fish and fisheries, 20(2), 224-238.

Ramalingam, A.B., Kar, L., Govindaraj, K. and Prasad, G.V.A. (2012). *Study of the growth and population parameters of yellowfin tuna (Thunnus albacares) in the Andaman and Nicobar waters based on the length frequency data.* Report of14th IOTC proceedings. 24– 29 October. Mauritius: 17 pp.

Rattle, J. (2020). *Failure to manage yellowfin tuna by the Indian Ocean Tuna Commission.* Blue Marine Foundation, London, 62 pp.

Restrepo, V., H. Koehler, G. Moreno and H. Murua (2019). *Recommended Best Practices for FAD management in Tropical Tuna Purse Seine Fisheries.* ISSF Technical Report 2019-11. International Seafood Sustainability Foundation, Washington, D.C., USA.

Rohit, P., Rao, G. S., & Ram Mohan, 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.

Sadusky H., Chaibongsai P., Die D.J., Agar J., Shivlani M. (2018). *Management of moored fish aggregation devices (FADs) in the Caribbean.* Coll. Vol. Sci. Papers. 74(5): 2230-2242.

Shahid, U., Moazzam Khan, M., Nawaz, R., Razzaq, S.A and Ayub, S. (2016). *Bycatch analysis of tuna gillnet fisheries of Pakistan: An analysis of bycatch data from 2013-2015.* IOTC-2016- WPEB12-INF11. Retrieved January, 29, 2021.

Sharma, R. & Herrera, M. (2019). *Using effort control measures to implement catch limits in IOTC purse seine fisheries.* IOTC-2019-WPTT21-23.

Sharma, R., & Herrera, M. (2020). *Using effort control measures to implement catch capacity limits in ICCAT PS fisheries: an update.* Collect. Vol. Sci. Pap. ICCAT, 76(6), 530-557.

Shono, H., Satoh, K., & Okamoto, H. (2007). *Preliminary stock assessment for yellowfin tuna in the Indian Ocean using stock synthesis II (SS2). IOTC-2007-WPTT-11.* Victoria, Mahe, Seychelles. 12pp.

Sinan, H., & Bailey, M. (2020). *Understanding barriers in Indian Ocean Tuna Commission allocation negotiations on fishing opportunities.* Sustainability, 12(16), 6665.

Sivadas, M., Abdussamad, E. M., Margaret Muthu Rathinam, A., Mohan, S., Vasu, P., & Laxmilatha, P. (2019). *Tuna drift gillnet fishery at Chennai, Tamil Nadu-an update.* Journal of the Marine Biological Association of India, 61(2), 41-46.

Somvanshi, V. S., Bhargava, A. K., Gulati, D. K., Varghese, S., & Sijo, P. V. (2003). *Growth parameters estimated for yellowfin tuna occurring in the Indian EEZ.* IOTC Proceedings, WPTT-03-21, 6, 191-193.

Sun, C. H., Maunder, M. N., Pan, M., Aires-da-Silva, A., Bayliff, W. H., & Compeán, G. A. (2019). *Increasing the economic value of the eastern Pacific Ocean tropical tuna fishery: Tradeoffs between longline and purse-seine fishing.* Deep-Sea Research Part II, 169(170), 104621.

Tantivala, C. (2000). *Some biological study of yellowfin tuna (Thunnus albacares) and bigeye tuna (Thunnus Obesus) in the eastern Indian Ocean.* 2nd IOTC proceedings. Victoria, 23-27 September, Seychelles, 436-440.

Tolotti, M.T., Forget, F., Capello, M., Filmalter, J.D., Hutchinson, M., Itano, D., Holland, K. and Dagorn, L. (2020). *Association dynamics of tuna and purse seine bycatch species with drifting fish aggregating devices (FADs) in the tropical eastern Atlantic Ocean.* Fisheries Research, 226, p.105521.

UNCLOS (1982). *United Nations Convention on the Law of the Sea (UNCLOS).* Retrieved January, 29, 2021. https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

UNGA (1991). *United Nations General Assembly Resolution 46/215: Large-Scale Pelagic Drift-Net Fishing and Its Impact on the Living Marine Resources of the World's Oceans and Seas.* Retrieved January, 29, 2021. https://undocs.org/en/A/RES/46/215

WWF (2021). *WWF Position for the Special Session of the Indian Ocean Tuna Commission 24th Session (SS4) Virtual Meeting 8-12 March 2021.* IOTC-2021-SS4-NGO. 5 pp. Retrieved February, 16, 2021.https://wwf.panda.org/wwf_news/?1444941/WWF-Position-for-the-Special-Session-of-the-Indian-Ocean-Tuna-Commission-24th-Session

IX.

Annex 1. Supporting figures and tables

Table 1 Percentage of mature fish, fish at optimum length and mega-spawners in yellowfin PSFS (free schools sets) and PSLS (FAD-associated sets) fisheries in the Indian Ocean. Source: own, from IOTC data.

GEAR	LIMITS	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
PSFS	>Lm	58.11%	82.18%	84.84%	95.20%	96.85%	84.31%	85.43%	94.17%	85.51%	57.11%	53.19%	62.12%	80.20%	59.72%	67.87%	95.14%	79.55%	69.60%	43.62%	62.33%
	>Lm50	51.44%	68.50%	75.80%	82.44%	89.81%	80.86%	81.51%	89.16%	80.58%	54.62%	51.41%	51.93%	73.13%	57.90%	62.19%	92.53%	75.25%	65.68%	42.38%	60.25%
	Lopt	36.21%	45.83%	51.44%	56.15%	60.46%	56.21%	56.65%	67.47%	58.66%	40.42%	39.00%	32.85%	49.20%	36.25%	39.70%	58.46%	52.89%	43.39%	31.11%	41.70%
	Lms	12.25%	10.02%	17.33%	13.05%	18.20%	16.37%	13.98%	10.75%	14.94%	13.00%	7.23%	10.27%	17.75%	13.91%	19.81%	30.89%	19.03%	21.52%	8.27%	13.13%
	% Juveniles	48.56%	31.50%	24.20%	17.56%	10.19%	19.14%	18.49%	10.84%	19.42%	45.38%	48.59%	48.07%	26.87%	42.10%	37.81%	7.47%	24.75%	34.32%	57.62%	39.75%
	% Adults	51.44%	68.50%	75.80%	82.44%	89.81%	80.86%	81.51%	89.16%	80.58%	54.62%	51.41%	51.93%	73.13%	57.90%	62.19%	92.53%	75.25%	65.68%	42.38%	60.25%
PSLS	>Lm	13.49%	8.37%	4.15%	13.17%	9.23%	9.61%	6.94%	10.38%	5.94%	5.74%	6.18%	10.83%	11.79%	9.66%	9.70%	8.25%	8.93%	5.60%	7.01%	4.84%
	>Lm50	9.41%	6.64%	2.92%	8.48%	5.17%	7.84%	5.12%	8.11%	4.13%	2.74%	3.23%	4.29%	5.37%	4.19%	4.76%	2.85%	3.82%	2.15%	3.55%	3.05%
	Lopt	5.31%	3.97%	1.59%	5.24%	2.09%	5.30%	2.96%	4.70%	2.34%	1.71%	1.46%	1.85%	2.39%	1.64%	2.31%	1.05%	1.71%	1.11%	2.08%	1.76%
	Lms	0.17%	0.10%	0.07%	0.19%	0.07%	0.40%	0.14%	0.38%	0.12%	0.12%	0.04%	0.13%	0.13%	0.06%	0.11%	0.04%	0.09%	0.08%	0.10%	0.12%
	% Juveniles	90.59%	93.36%	97.08%	91.52%	94.83%	92.16%	94.88%	91.89%	95.87%	97.26%	96.77%	95.71%	94.63%	95.81%	95.24%	97.15%	96.18%	97.85%	96.45%	96.95%
	% Adults	9.41%	6.64%	2.92%	8.48%	5.17%	7.84%	5.12%	8.11%	4.13%	2.74%	3.23%	4.29%	5.37%	4.19%	4.76%	2.85%	3.82%	2.15%	3.55%	3.05%

Table 2 Percentage of mature fish, fish at optimum length and mega-spawners in the main six fisheries catching yellowfin tuna in the Indian Ocean. Source: own, from IOTC data.

GEAR	LIMITS	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Pole and line	>Lm	4.32%	4.68%	4.75%	11.16%	6.33%	2.32%	13.67%	0.93%	1.63%	4.16%	5.93%	16.88%	20.89%	3.08%	7.05%	0.38%	2.13%	0.93%	1.13%	0.91%
	>Lm50	3.61%	2.93%	3.27%	2.16%	2.89%	0.28%	1.69%	0.29%	0.09%	0.68%	0.36%	3.76%	20.55%	0.02%	2.11%	0.15%	0.67%	0.14%	0.08%	0.01%
	<Lm	95.68%	95.32%	95.25%	88.84%	93.67%	97.68%	86.33%	99.07%	98.37%	95.84%	94.07%	83.12%	79.11%	96.92%	92.95%	99.62%	97.87%	99.07%	98.87%	99.09%
	<Lm50	96.39%	97.07%	96.73%	97.84%	97.11%	99.72%	98.31%	99.71%	99.91%	99.32%	99.64%	96.24%	79.45%	99.98%	97.89%	99.85%	99.33%	99.86%	99.92%	99.99%
	Lopt	1.98%	1.90%	2.29%	1.14%	1.60%	0.05%	0.16%	0.04%	0.00%	0.20%	0.00%	0.06%	12.24%	0.00%	0.79%	0.08%	0.30%	0.00%	0.01%	0.00%
	Lms	0.72%	0.38%	0.30%	0.14%	0.25%	0.01%	0.01%	0.07%	0.00%	0.03%	0.00%	0.00%	8.30%	0.00%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%
Longline	>Lm	93.03%	95.54%	97.91%	99.86%	99.77%	99.88%	99.70%	99.70%	99.78%	99.49%	99.56%	99.03%	99.17%	99.58%	99.53%	95.56%	98.61%	96.43%	97.52%	99.28%
	>Lm50	59.18%	72.80%	86.29%	93.99%	94.29%	97.11%	97.73%	97.49%	96.64%	95.77%	94.28%	93.31%	96.58%	95.94%	95.73%	91.39%	93.42%	88.31%	90.61%	92.54%
	<Lm	6.97%	4.46%	2.09%	0.14%	0.23%	0.12%	0.30%	0.30%	0.22%	0.51%	0.44%	0.97%	0.83%	0.42%	0.47%	4.44%	1.39%	3.57%	2.48%	0.72%
	<Lm50	40.82%	27.20%	13.71%	6.01%	5.71%	2.89%	2.27%	2.51%	3.36%	4.23%	5.72%	6.69%	3.42%	4.06%	4.27%	8.61%	6.58%	11.69%	9.39%	7.46%
	Lopt	37.26%	40.54%	46.63%	49.72%	67.98%	73.43%	73.90%	72.17%	62.05%	60.05%	58.77%	59.38%	55.71%	50.28%	46.76%	47.68%	46.29%	42.50%	46.07%	46.18%
	Lms	11.58%	18.26%	27.22%	31.16%	13.45%	11.71%	14.27%	15.21%	24.24%	25.48%	24.74%	22.53%	33.47%	36.29%	37.52%	33.93%	40.32%	37.78%	34.97%	34.72%
Gillnet	>Lm	19.11%	49.02%	25.66%	46.58%	63.41%	49.56%	38.53%	47.60%	0.00%	50.75%	34.37%	67.25%	62.53%	72.81%	61.10%	62.73%	77.93%	74.33%	70.38%	66.10%
	>Lm50	7.33%	14.50%	11.81%	13.67%	26.39%	18.46%	6.82%	45.67%	0.00%	8.90%	16.46%	2.56%	3.34%	6.56%	8.92%	13.79%	29.18%	16.02%	8.97%	14.37%
	<Lm	80.89%	50.98%	74.34%	53.42%	36.59%	50.44%	61.47%	52.40%	100.00%	49.25%	65.63%	32.75%	37.47%	27.19%	38.90%	37.27%	22.07%	25.67%	29.62%	33.90%
	<Lm50	92.67%	85.50%	88.19%	86.33%	73.61%	81.54%	93.18%	54.33%	100.00%	91.10%	83.54%	97.44%	96.66%	93.44%	91.08%	86.21%	70.82%	83.98%	91.03%	85.63%
	Lopt	2.01%	10.72%	8.35%	8.37%	8.20%	14.41%	2.57%	27.88%	0.00%	4.33%	11.17%	0.96%	0.45%	1.15%	2.88%	5.37%	9.86%	6.17%	3.10%	5.20%
	Lms	0.60%	2.02%	0.36%	1.81%	1.35%	2.91%	1.05%	4.33%	0.00%	0.52%	2.90%	0.00%	0.00%	0.07%	0.30%	0.39%	1.30%	2.22%	0.10%	0.77%

Table 2 Continued.

GEAR	LIMITS	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Handline	>Lm				84.00%	97.08%	99.88%	99.10%	98.30%	92.82%	80.35%	88.77%	94.41%	99.29%	98.41%	85.24%	97.15%	95.62%	86.80%	87.40%	92.25%
	>lm50				22.97%	89.69%	87.57%	66.16%	94.27%	76.03%	61.05%	74.38%	83.11%	94.57%	96.25%	77.76%	96.62%	78.72%	71.75%	71.44%	78.18%
	<Lm				16.00%	2.92%	0.12%	0.90%	1.70%	7.18%	19.65%	11.23%	5.59%	0.71%	1.59%	14.76%	2.85%	4.38%	13.20%	12.60%	7.75%
	<lm50				77.03%	10.31%	12.43%	33.84%	5.73%	23.97%	38.95%	25.62%	16.89%	5.43%	3.75%	22.24%	3.38%	21.28%	28.25%	28.56%	21.82%
	Lopt				3.87%	55.50%	44.84%	25.72%	39.04%	34.98%	26.81%	30.90%	26.64%	26.52%	31.79%	24.64%	52.02%	38.47%	35.21%	36.23%	34.55%
	Lms				18.58%	10.02%	18.11%	2.91%	50.06%	18.17%	20.03%	33.87%	47.00%	58.21%	57.09%	50.28%	32.98%	22.83%	18.00%	21.14%	28.06%
Purse seine	>Lm	20.78%	23.97%	13.89%	31.91%	34.08%	27.86%	18.13%	24.97%	19.71%	11.06%	10.00%	15.07%	20.39%	12.48%	13.79%	14.45%	12.79%	9.16%	7.95%	6.55%
	>lm50	16.27%	19.72%	11.72%	25.38%	29.18%	25.68%	16.01%	22.22%	17.37%	8.11%	7.15%	8.22%	13.89%	7.21%	8.79%	9.25%	7.72%	5.68%	4.54%	4.75%
	<Lm	79.22%	76.03%	86.11%	68.09%	65.92%	72.14%	81.87%	75.03%	80.29%	88.94%	90.00%	84.93%	79.61%	87.52%	86.21%	85.55%	87.21%	90.84%	92.05%	93.45%
	<lm50	83.73%	80.28%	88.28%	74.62%	70.82%	74.32%	83.99%	77.78%	82.63%	91.89%	92.85%	91.78%	86.11%	92.79%	91.21%	90.75%	92.28%	94.32%	95.46%	95.25%
	Lopt	10.36%	12.82%	7.61%	16.87%	18.64%	17.74%	10.61%	15.63%	12.09%	5.71%	4.51%	4.41%	8.27%	3.59%	4.93%	5.15%	4.50%	3.46%	2.82%	2.94%
	Lms	2.14%	2.20%	2.16%	3.13%	5.21%	4.30%	2.11%	2.19%	2.69%	1.45%	0.63%	0.97%	2.34%	0.84%	1.49%	2.24%	1.12%	1.27%	0.31%	0.50%
Trolling	>Lm																0.00%	72.16%		55.02%	20.34%
	>lm50																0.00%	72.16%		52.04%	19.60%
	<Lm																100.00%	27.84%		44.98%	79.66%
	<lm50																100.00%	27.84%		47.96%	80.40%
	Lopt																0.00%	42.61%		14.13%	11.40%
	Lms																0.00%	29.55%		36.43%	4.10%

X.

Annex 2. LB-SPR results

The results of the LF-SPR analysis are shown in this annex, for each main fishery. The first figure represents a fitted histogram of length data for the fishery. The second figure shows estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals). Finally, the estimated spawning potential and reference points are shown in a pie chart for the last year of the series (2019).

Pole and Line Fishery

Figure 1 Fitted histogram of length data for the pole and line fishery.

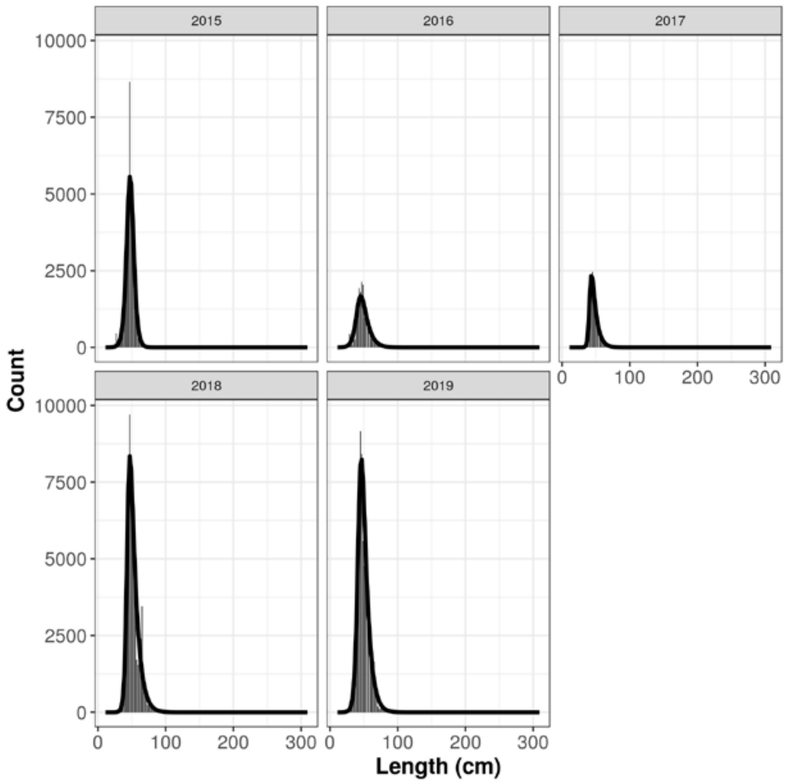


Figure 2 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the pole and line fishery.

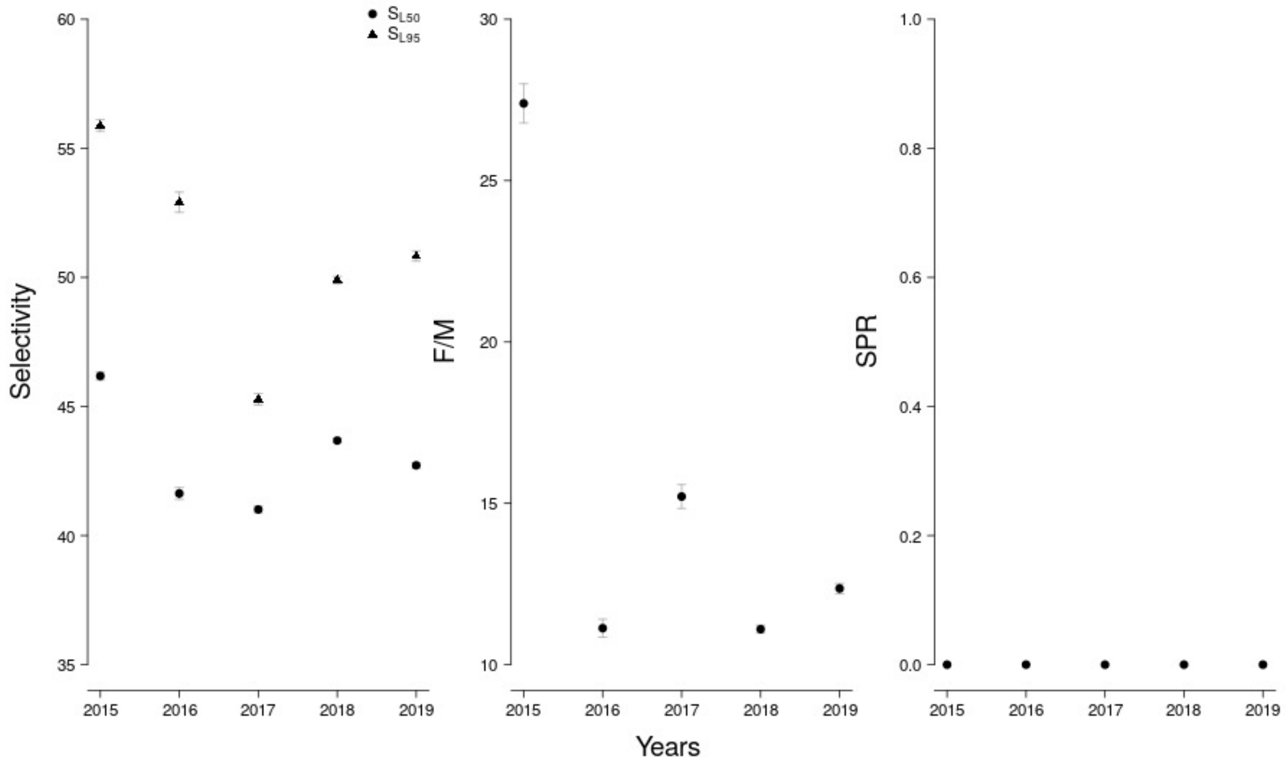
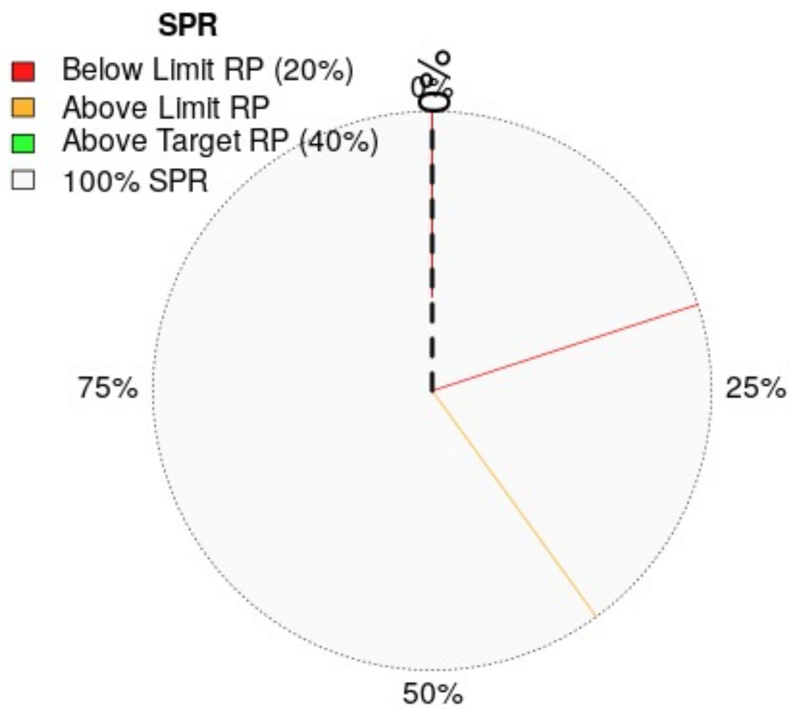


Figure 3 Spawning potential and reference points for the pole and line fishery.



Longline Fishery

Figure 1 Fitted histogram of length data for the pole and line fishery.

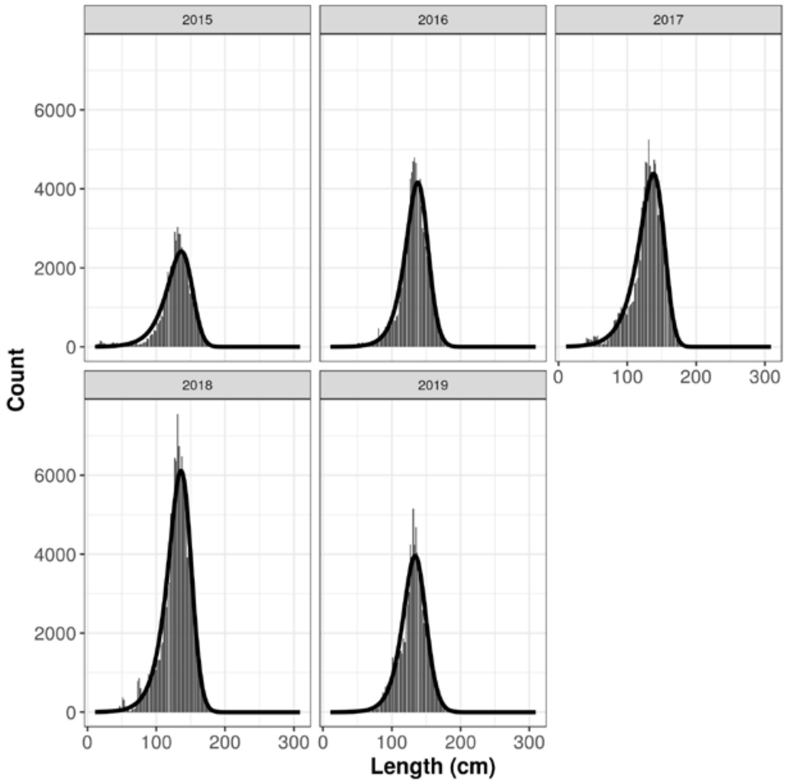


Figure 5 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the longline fishery.

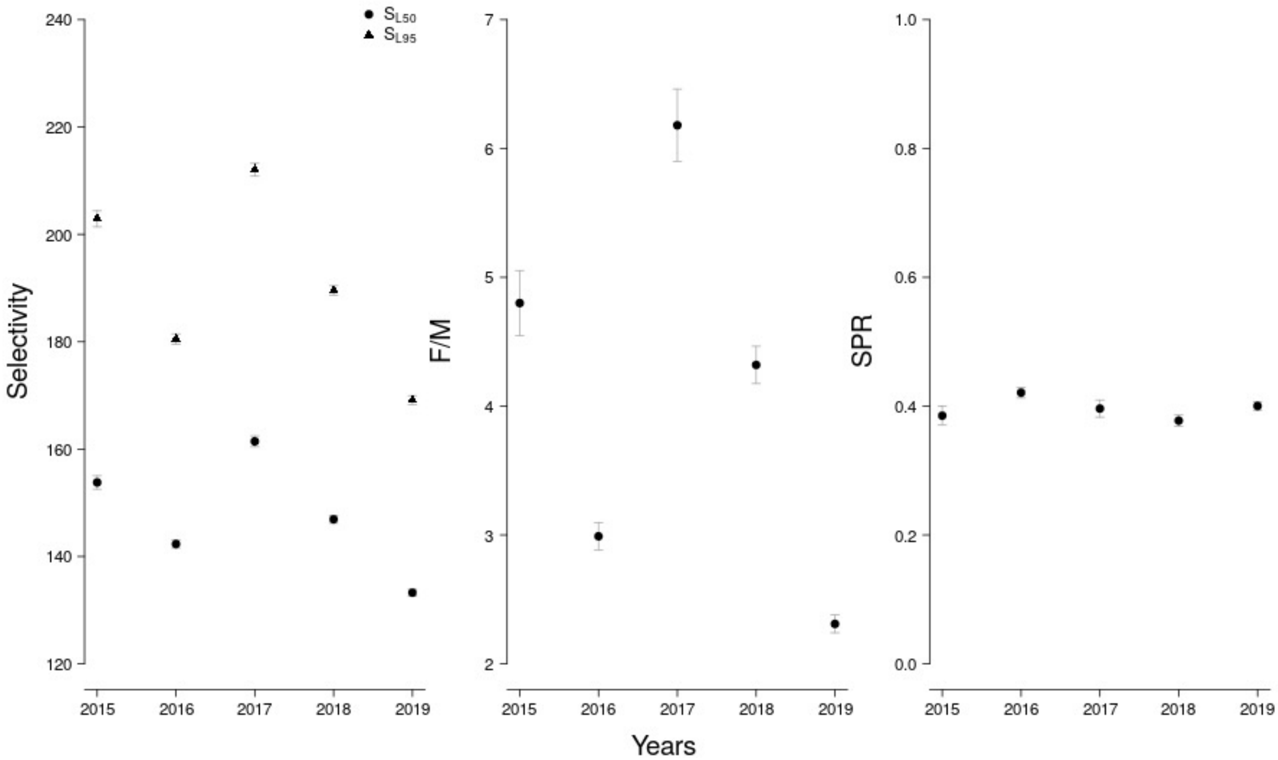
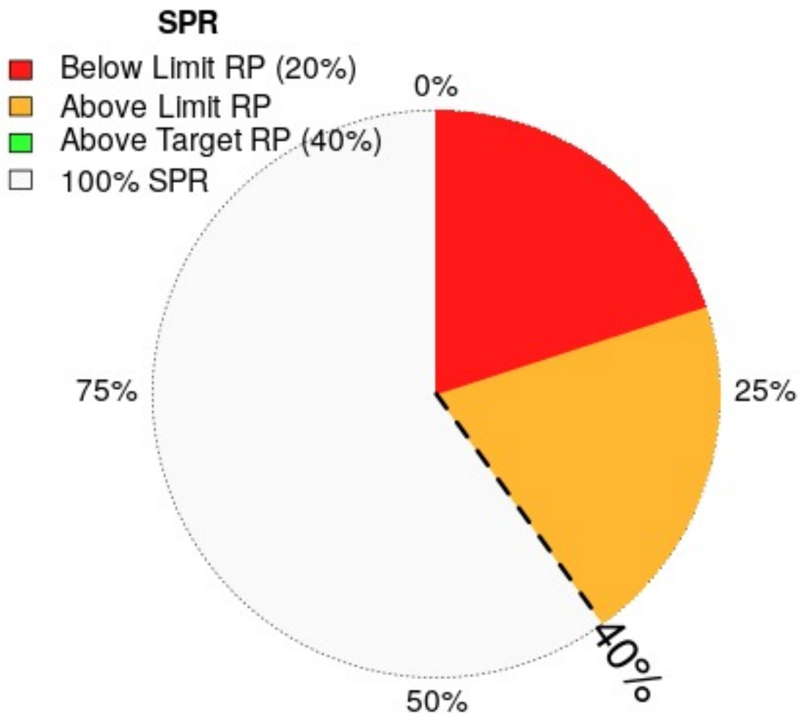


Figure 6 Spawning potential and reference points for the longline fishery.



Gillnet Fishery

Figure 5 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the longline fishery.

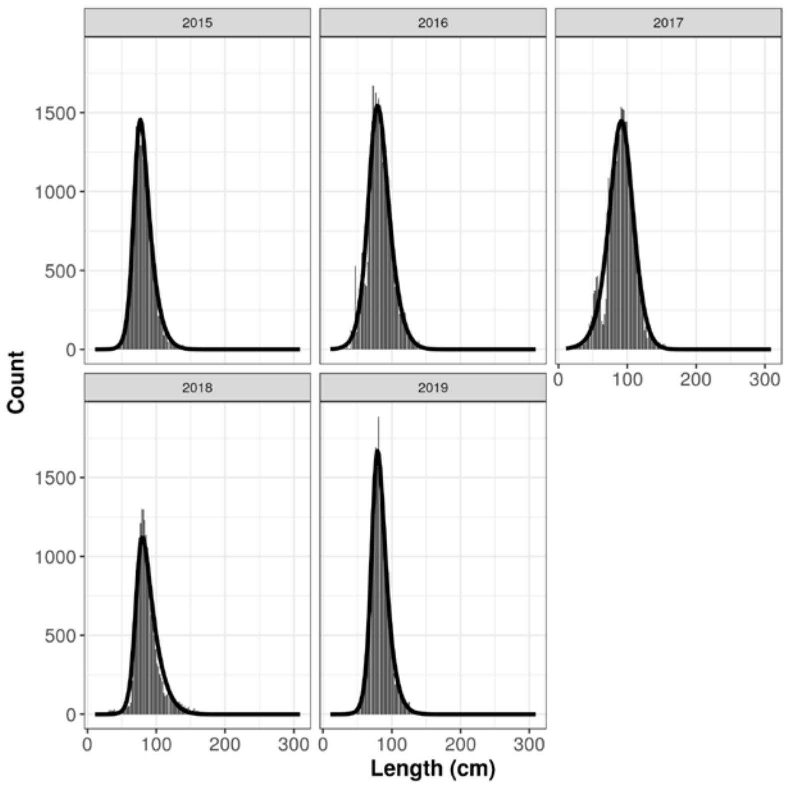


Figure 8 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the gillnet fishery.

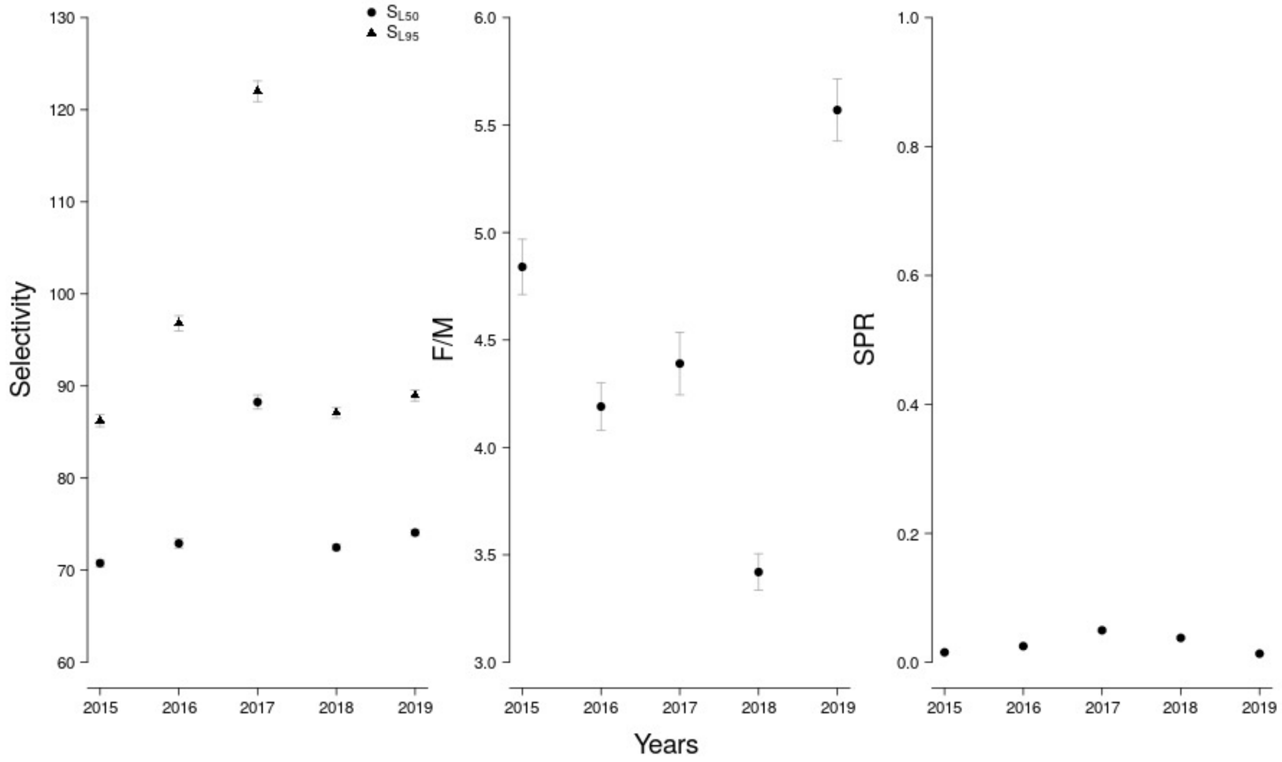
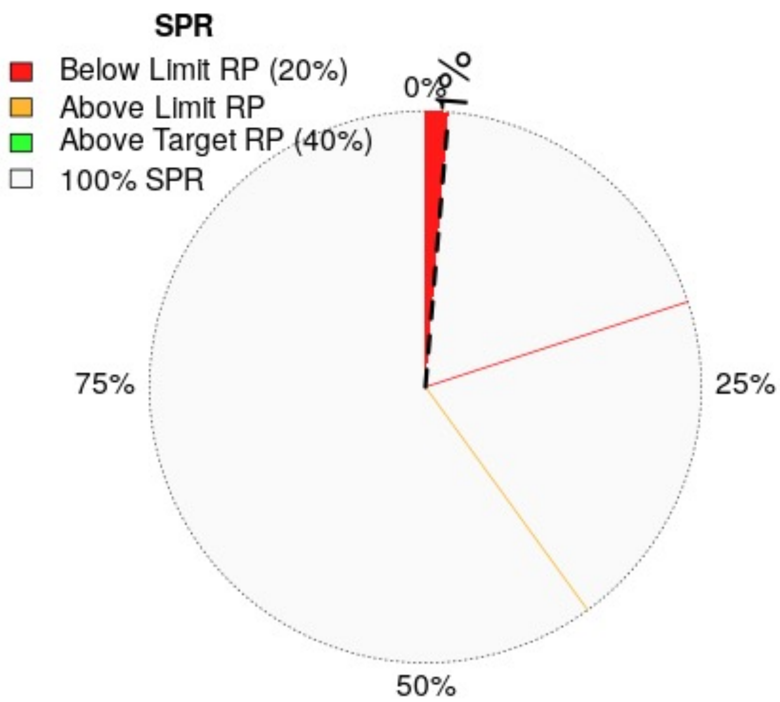


Figure 9 Spawning potential and reference points for the gillnet fishery.



Handline Fishery

Figure 10 Fitted histogram of length data for the handline fishery.

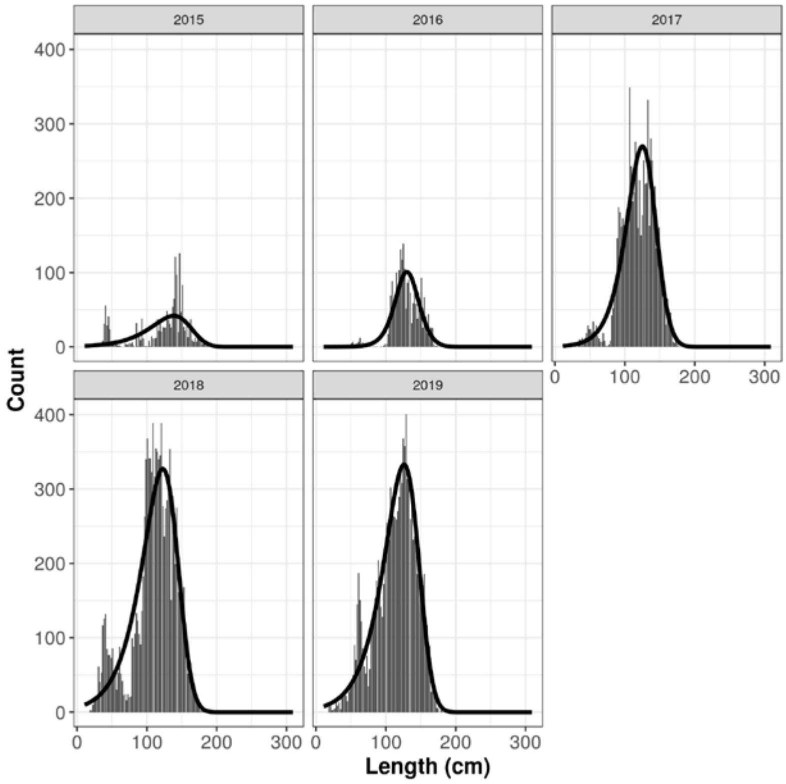


Figure 11 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the handline fishery.

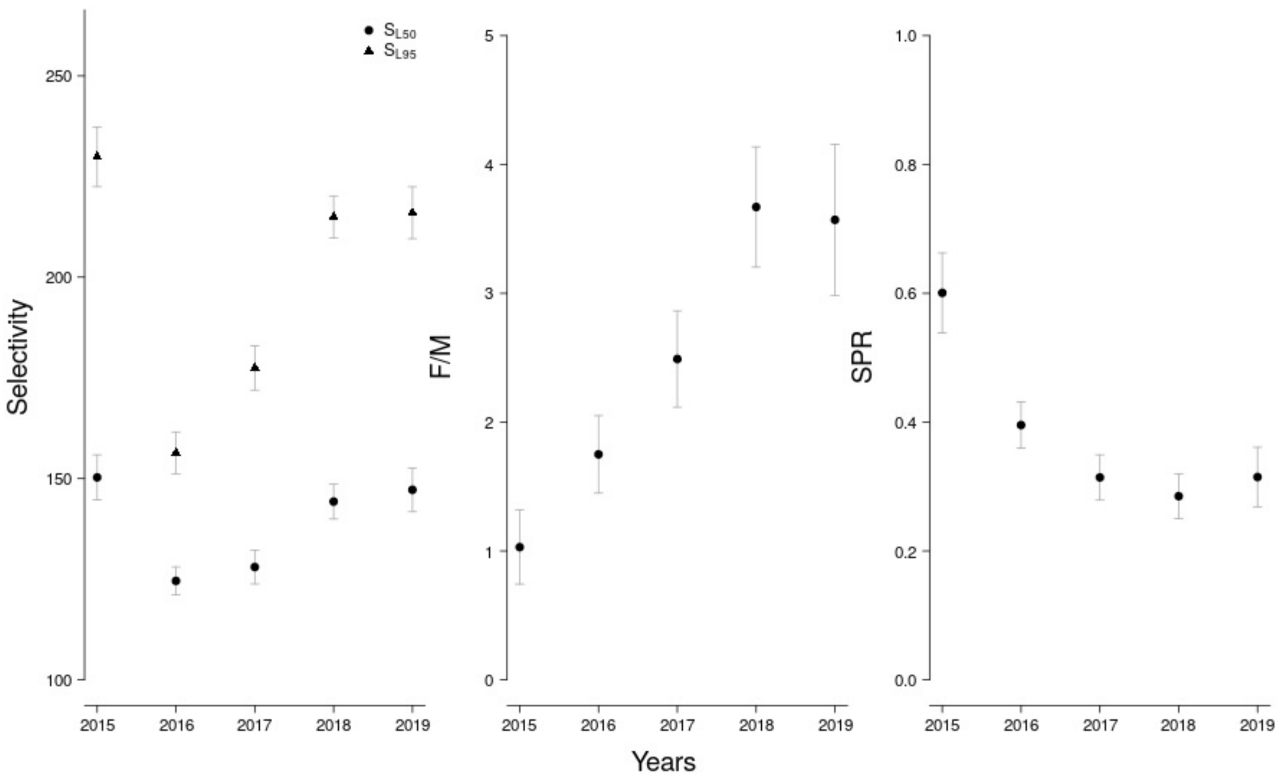
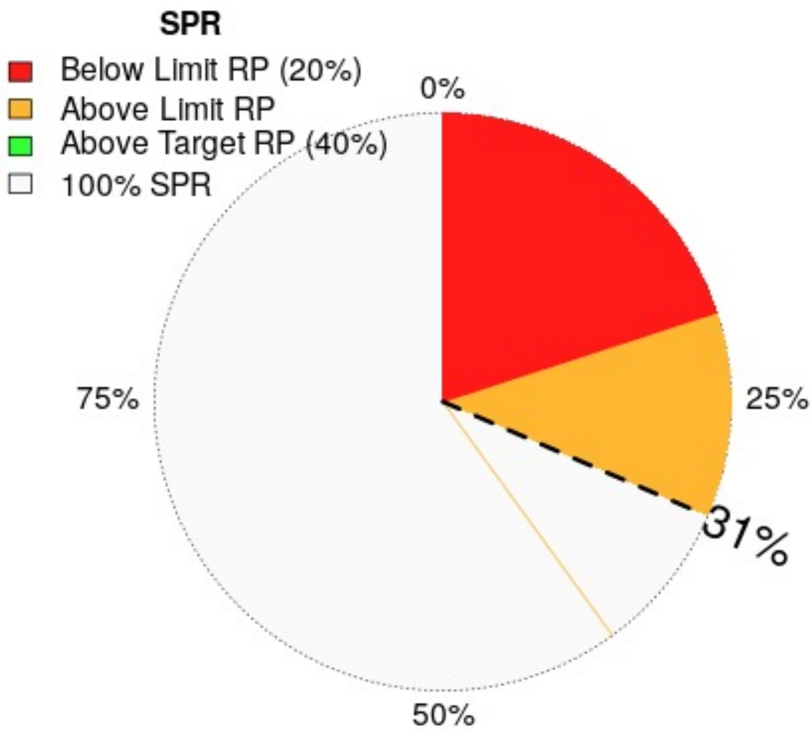


Figure 12 Spawning potential and reference points for the handline fishery.



Handline Fishery

Figure 13 Fitted histogram of length data for the trolling fishery.

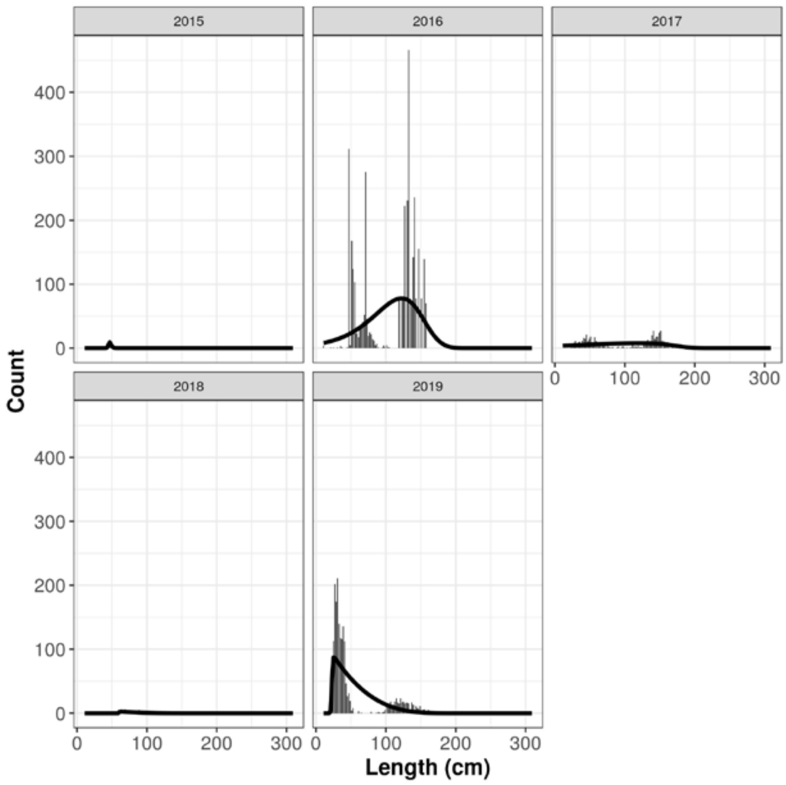


Figure 14 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the trolling fishery.

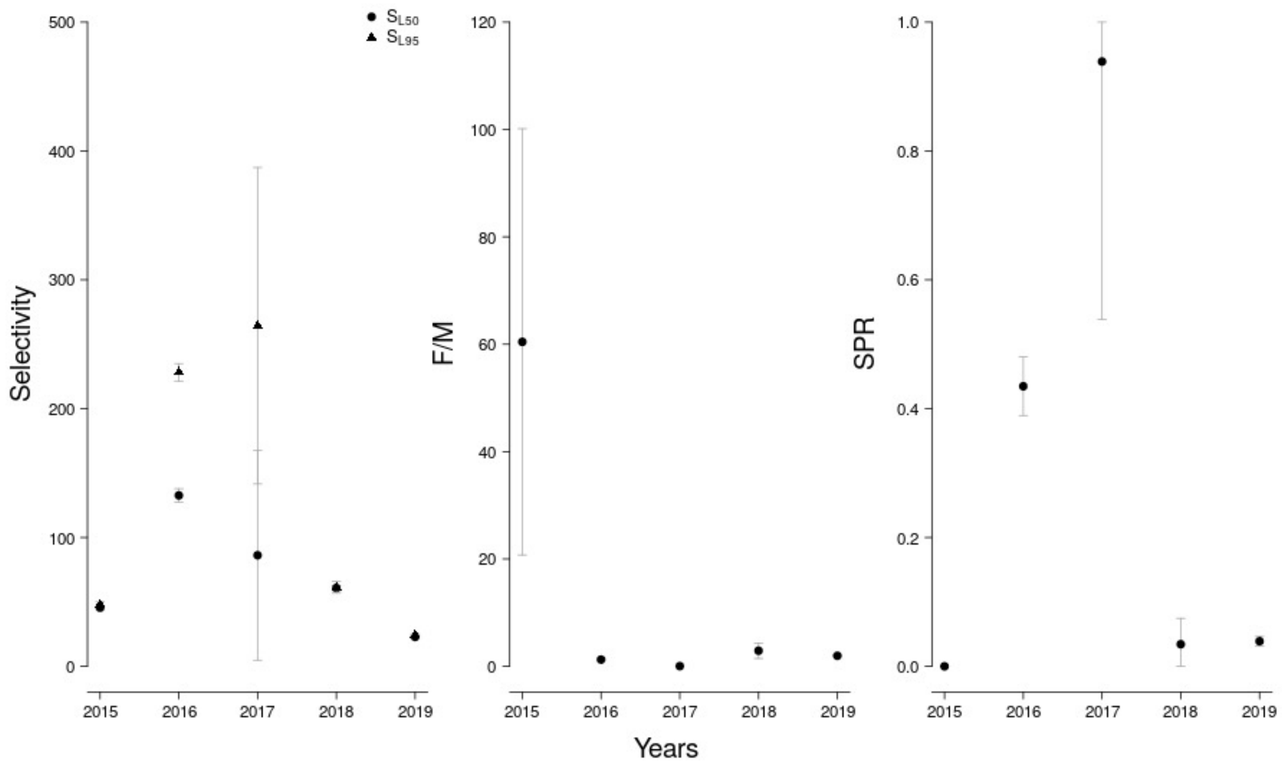
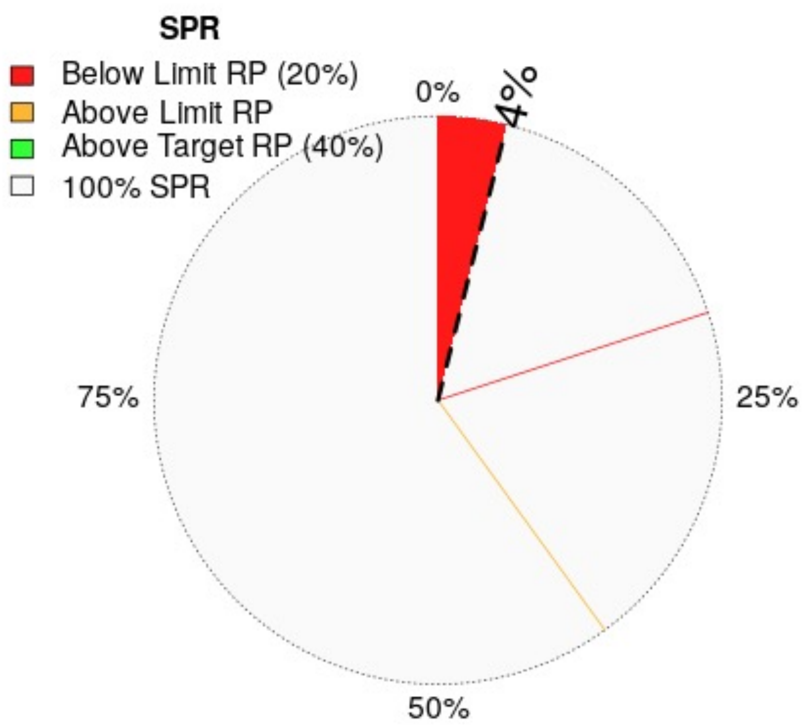


Figure 15 Spawning potential and reference points for the trolling fishery.



Free schools purse seine fishery

Figure 16 Fitted histogram of length data for the free school purse seine fishery.

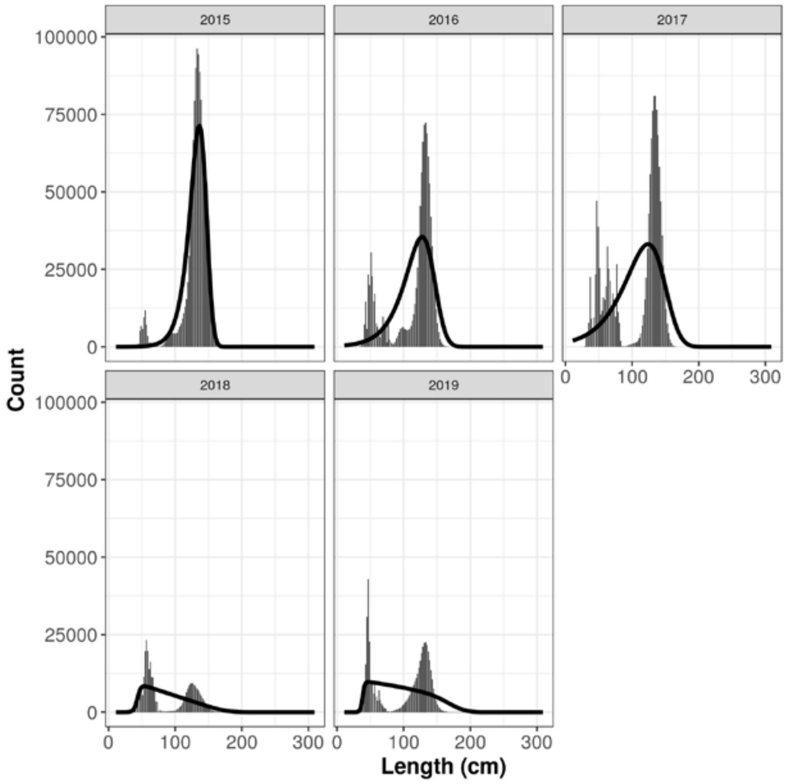


Figure 17 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the free school purse seine fishery.

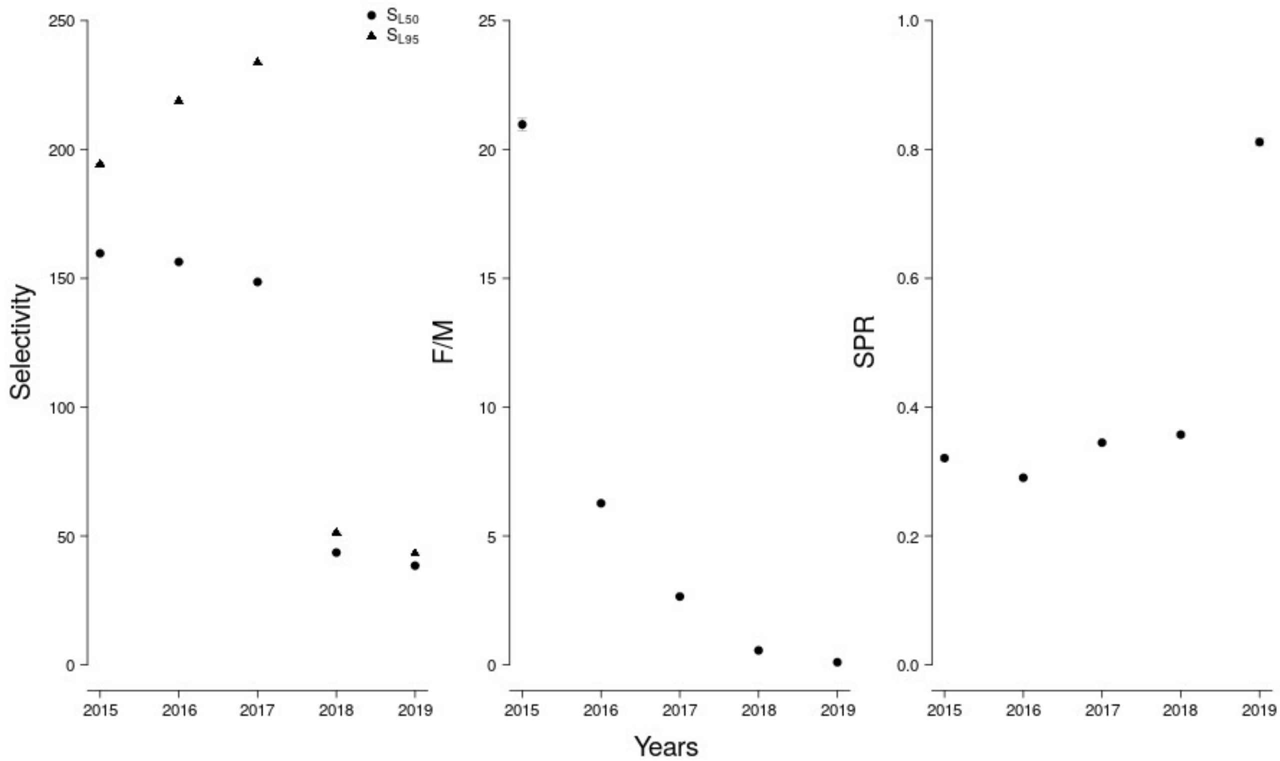
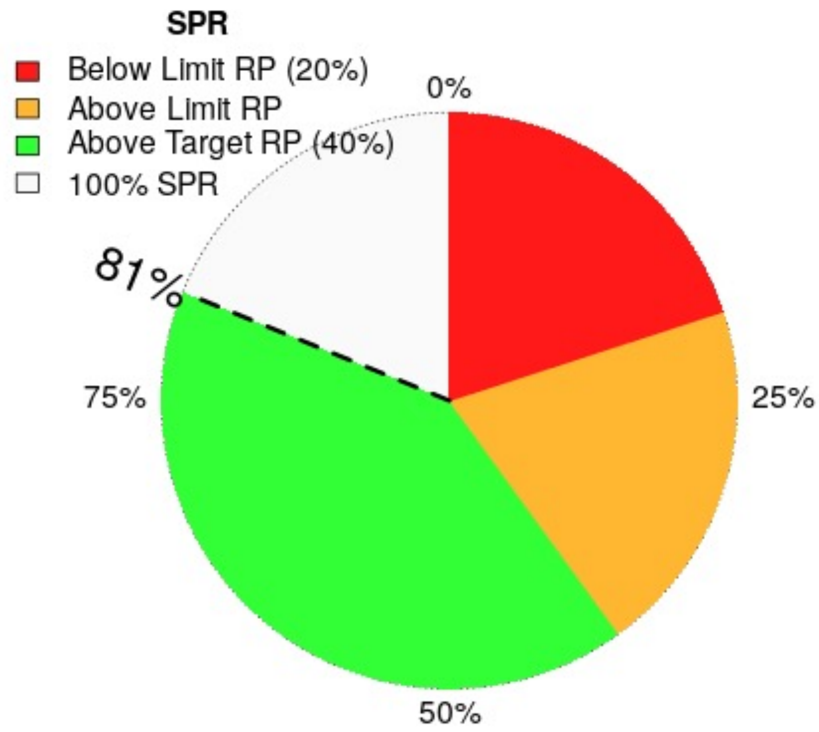
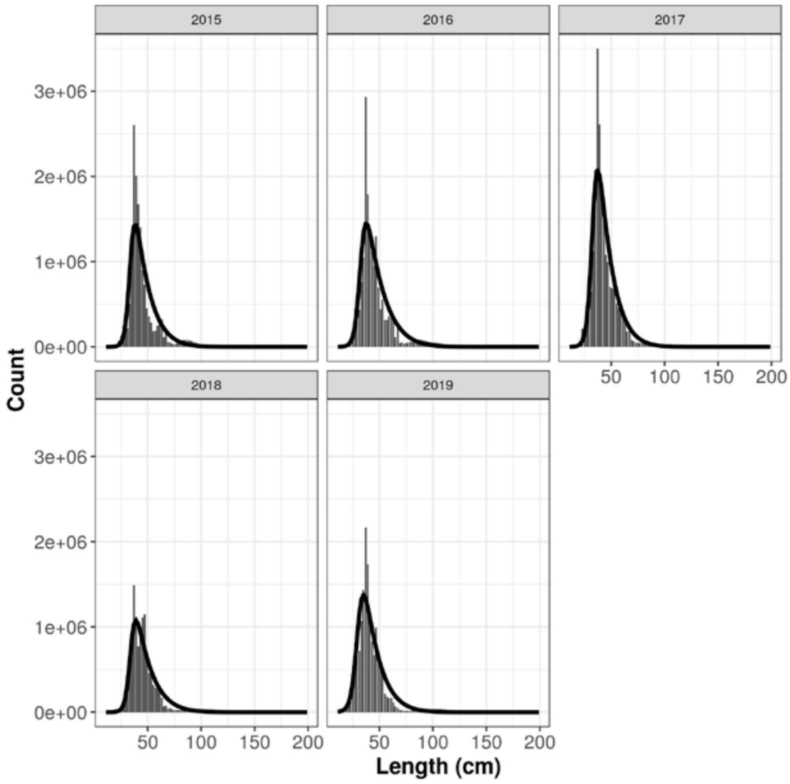


Figure 18 Spawning potential and reference points for the free school purse seine fishery.[7]



FAD-associated purse seine fishery

Figure 19 Fitted histogram of length data for the FAD-associated purse seine fishery.



[7] In this graph and the associated pie chart it should be noted that the SPR result for the PSFS fishery in 2019 is extremely high, which casts doubt on the validity of this value. An SPR of around 0.35 (35%) in line with the 2015-2018 values is considered to be more realistic.

Figure 20 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the FAD-associated purse seine fishery.

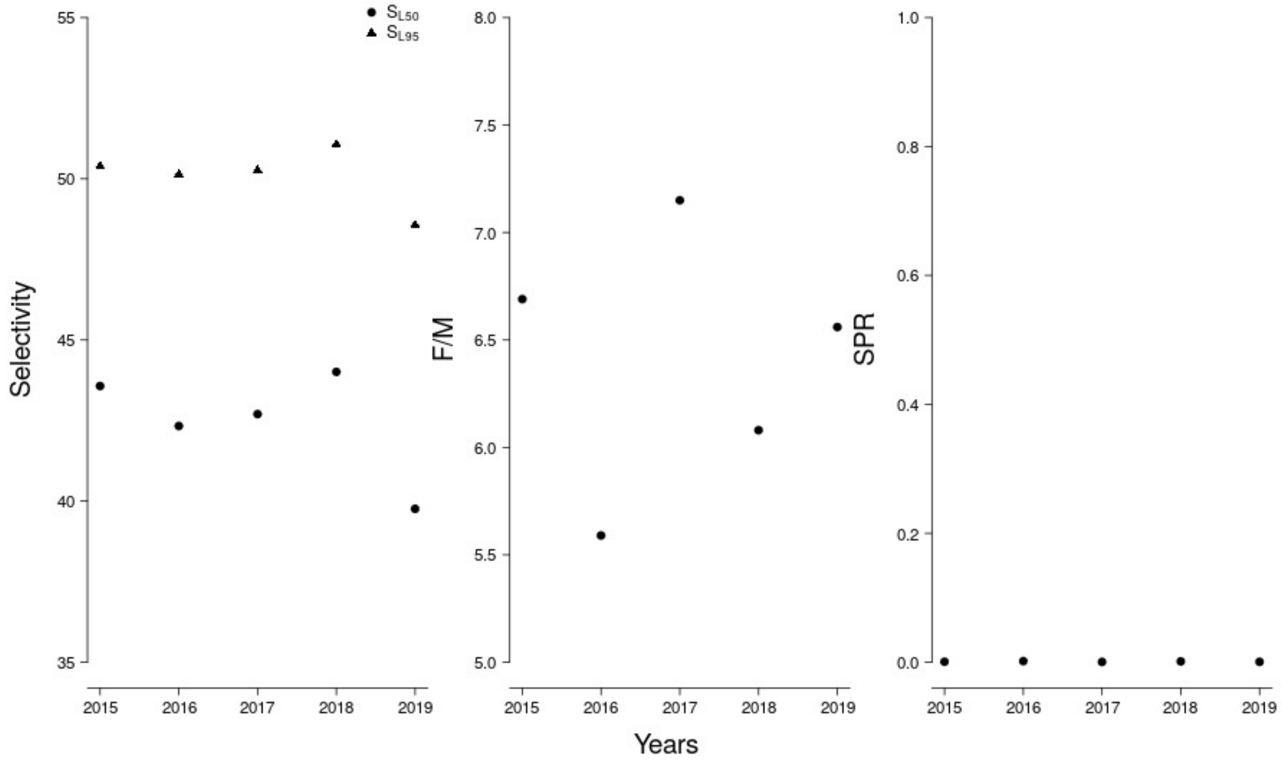


Figure 21 Spawning potential and reference points for the FAD-associated purse seine fishery.

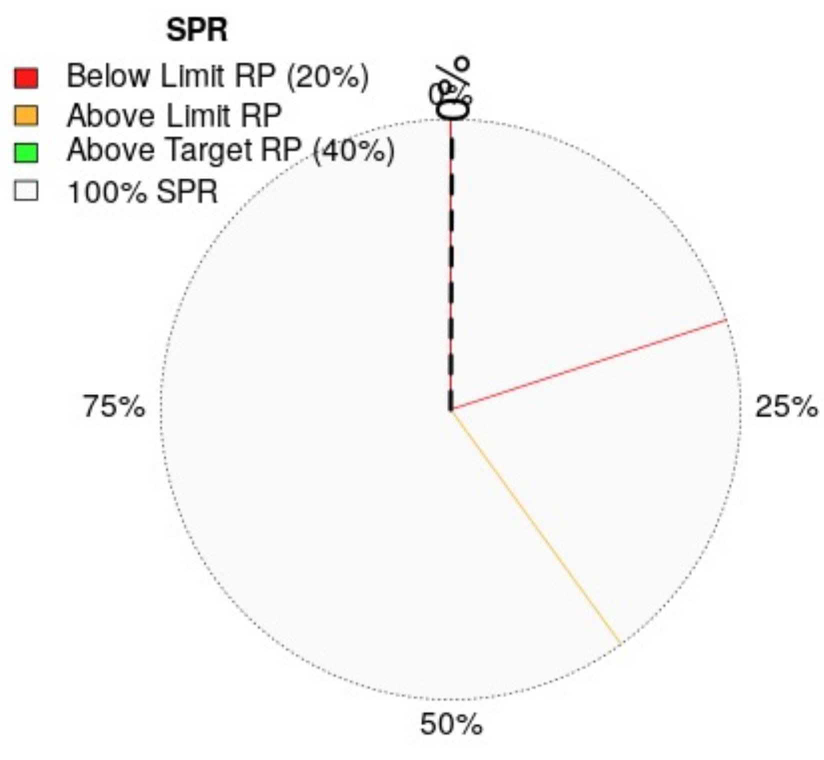


Figure 20 Estimates of selectivity, ratio F/M and SPR by year (with 95% confidence intervals) for the FAD-associated purse seine fishery.

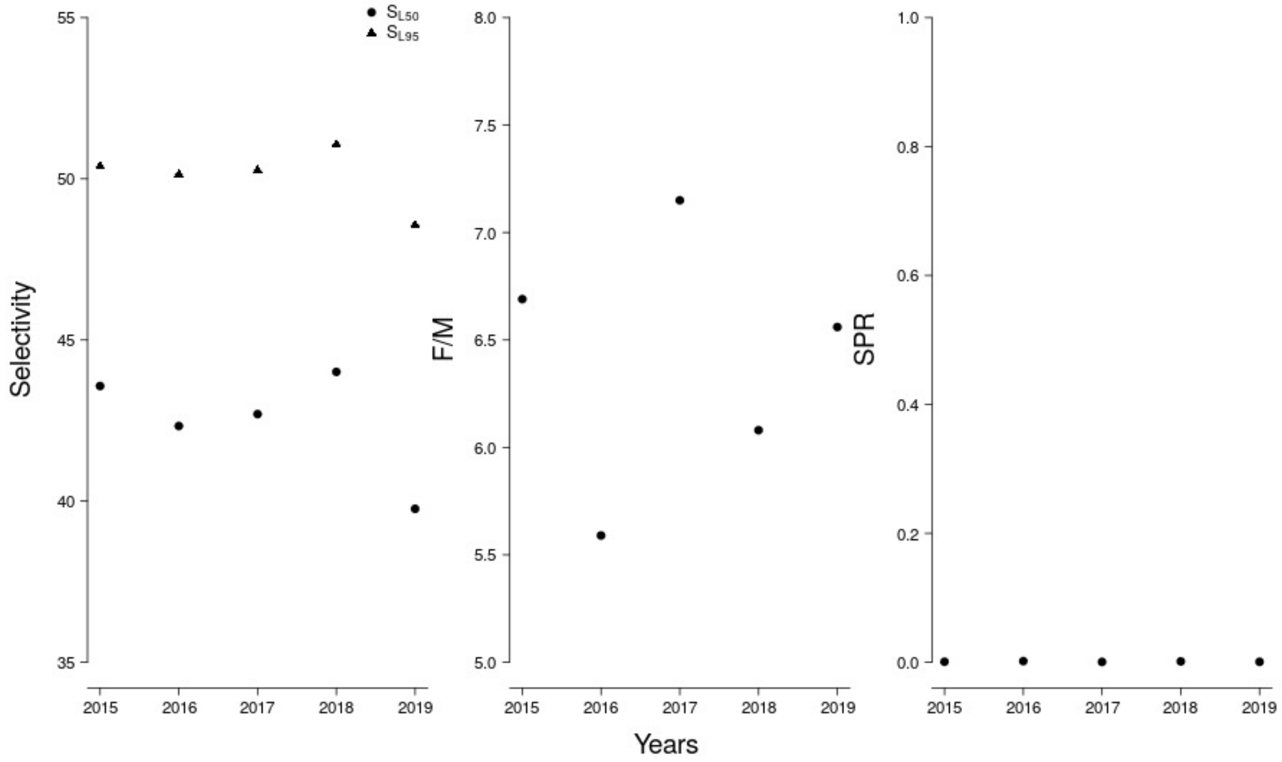
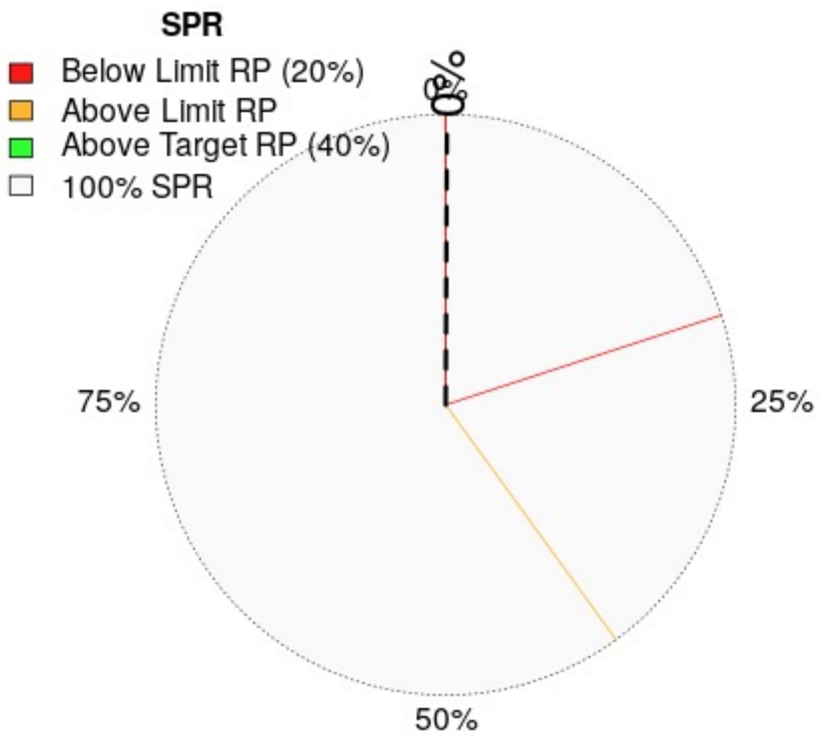


Figure 21 Spawning potential and reference points for the FAD-associated purse seine fishery.



XI.

Annex 3. IOTC tuna fishing country codes

CODE	FLEET	CODE	FLEET
AUS	AUSTRALIA	LKA	SRI LANKA
BLZ	BELIZA	MDG	MADAGASCAR
CHN	CHINA	MDV	MALDIVES
COM	COMOROS	MOZ	MOZAMBIQUE
EGY	EGYPT	MUS	MAURITIUS
EUSP	EU.SPAIN	MYS	MALAYSIA
EUGBR	EU.UK	NEICE	NEI.FRESH
EUITA	EU.ITALY	NEIFR	NEI.FROZEN
EUPRT	EU.PORTUGAL	OMN	OMAN
EUREU	EU.FRANCE.REUNION	PAK	PAKISTAN
GBRT	UK.TERRITORIES	PHL	PHILIPPINES
IDN	INDONESIA	SYC	SEYCHELLES
IND	INDIA	THA	THAILAND
IRN	IRAN ISLAMIC REP.	TMP	EAST TIMOR
JOR	JORDAN	TWN	TAIWAN,CHINA
JPN	JAPAN	TZA	TANZANIA
KEN	KENYA	YEM	YEMEN
KOR	KOREA REP.	ZAF	SOUTH AFRICA

XII.

Annex 4. IOTC tuna fishing gear codes

Large Group	Gear	Description	NCCode
Baitboat	BB	Baitboat	BB
Gillnet	G/L	Gillnet and Longline combination	GILL
Gillnet	GIHA	Gillnet and hand line	GILL
Gillnet	GILL	Gillnet	GILL
Gillnet	GIOF	Offshore gillnet	GILL
Line	HAND	Hand line	HAND
Line	HATR	Hand line and Troll line	LINE
Line	HOOK	Hook and line	LINE
Line	LLCO	Coastal longline	LL/HAND
Line	SPOR	Sport fishing	TROL
Line	TROL	Troll line	TROL
Longline	ELL	Longline targeting swordfish	LL
Longline	ELLOB	Longline targeting swordfish with observer	LL
Longline	FLL	Longline Fresh	LL
Longline	LL	Longline	LL
Longline	LLEX	Exploratory longline	LL
Longline	LLHA	Longline and Handline combination	LL
Longline	LLOB	Longline with observer	LL
Other	BS	Beach seine	OTHER
Other	HARP	Harpoon	OTHER
Other	TRAW	Trawl	OTHER
Other	UNCL	Unclassified	OTHER
Purse Seine	PS	Purse seine	PS
Purse Seine	PSOB	Purse with observer	PS
Purse Seine	PSS	Small purse seine	PSS
Purse Seine	RIN	Ring net	PSS
Purse Seine	RNOF	Ring net (offshore)	PSS


GLOBAL TUNA ALLIANCE
www.globaltunaalliance.com