YELLOWFIN TUNA

SUPPORTING INFORMATION

(Information collated from reports of the Working Party on Tropical Tunas and other sources as cited)

Conservation and management measures

Yellowfin tuna (*Thunnus albacares*) in the Indian Ocean is currently subject to a number of Conservation and Management Measures adopted by the Commission:

- Resolution 19/01 and 18/01 *On an Interim Plan for Rebuilding the Indian Ocean Yellowfin Tuna Stock in the IOTC Area of Competence* set out measures including gear and CPC specific catch reductions required to rebuild the yellowfin tuna Indian Ocean stock
- Resolution 19/05 *On a ban on discards of bigeye tuna, skipjack tuna, yellowfin tuna and non-targeted species caught by purse seine vessels in the IOTC Area of Competence* set out the requirement for purse seiners to retain all catches of bigeye, skipjack and yellowfin tuna except those considered unfit for human consumption and ensure the safe release of any alive non-targeted species or the retention of all dead non-targeted species
- Resolution 15/01 *On the recording of catch and effort data by fishing vessels in the IOTC area of competence* sets out the minimum logbook requirements for purse seine, longline, gillnet, pole and line, handline and trolling fishing vessels over 24 metres length overall and those under 24 metres if they fish outside the EEZs of their flag States within the IOTC area of competence.
- Resolution 15/02 *Mandatory statistical reporting requirements for IOTC Contracting Parties and Cooperating Non-Contracting Parties (CPCs)* indicated that the provisions are applicable to tuna and tuna-like species
- Resolution 15/10 *On target and limit reference points and a decision framework* sets out procedures for the SC to follow when setting interim target and limit reference points when assessing stock status and providing recommendations to the Commission including the target and limit reference points for yellowfin tuna of $B_{TARGET} = B_{MSY}$ and $B_{LIM} = 0.40\ B_{MSY}$ respectively
- Resolution 14/02 *For the conservation and management of tropical tunas stocks in the IOTC area of competence* states that CPCs shall implement an action plan consisting of the establishment of an allocation system for the main targeted IOTC species and advising on appropriate reporting requirements and data collection systems for artisanal tuna fisheries.
- Resolution 11/04 *On a Regional Observer Scheme* which details the observer programme which should be implemented by CPCs to improve the collection of verified catch data and other scientific data related to fisheries for tuna and tuna-like species in the IOTC Area of Competence

Fisheries Indicators

Yellowfin tuna: General

Yellowfin tuna is a cosmopolitan species distributed mainly in the tropical and subtropical oceanic waters of the three major oceans, where it forms large schools, often associated with floating objects (Chassot et al. 2015). **Table 1** outlines some of the key life history traits of yellowfin tuna relevant for management.

Table 1: Yellowfin tuna: Summary of key biological traits of Indian Ocean yellowfin tuna (*Thunnus albacares*).

Parameter	Description
Range and stock structure	Longline catch data indicates that yellowfin tuna is distributed throughout the entire tropical Indian Ocean. The tag recoveries of the RTTP-IO provide evidence of large movements of yellowfin tuna, thus supporting the assumption of a single stock for the Indian Ocean. The average distance travelled by yellowfin tuna between being tagging and recovered is 710 nautical miles, and showing increasing distances as a function of time at sea. Tagging studies have also shown evidence of deep

	diving behaviours (over 1000 m depth). There is currently assumed to be a single stock in the India Ocean. Recent studies have indicated that the Indian Ocean stock is genetically differentiated from the Atlantic and Pacific Oceans and that there may be separate populations to the north and south of the equator. Genetic differentiations have also been found between sites in the north-western Indian Ocean suggesting the presence of sub-populations in this region.
Longevity	The longevity of yellowfin tuna in the Indian Ocean has been estimated at between 6-10 years (Kar et al. 2012, Rohit et al. 2012, Kaymaram et al. 2014, Nurdin et al. 2016)
Maturity (50%)	Age: females and males 3–5 years (Zudaire et al. 2013, 2016, Grande et al. 2014) Size: females and males 75-114 cm FL (Zhu et al. 2008, Froese & Pauly 2009, Zudaire et al. 2013)
Spawning season	Spawning occurs mainly from December to March in the equatorial area (0-10°S), with the main spawning grounds west of 75°E. Secondary spawning grounds exist off Sri Lanka and the Mozambique Channel and in the eastern Indian Ocean off Australia (Schaefer 2001, Nootmorn et al. 2005, Zhu et al. 2008)
Size (length and weight)	Maximum length: 240 cm FL; Maximum weight: 200 kg.(Anonymous 1994, IGFA 2001) Newly recruited fish are primarily caught by the purse seine fishery on floating objects. Males are predominant in the catches of larger fish at sizes than 140 cm (this is also the case in other oceans). The sizes exploited in the Indian Ocean range from 30 cm to 180 cm fork length. Smaller fish (juveniles) form mixed schools with skipjack tuna and juvenile bigeye tuna and are mainly limited to surface tropical waters, while larger fish are found in surface and sub-surface waters. Intermediate age yellowfin tuna are seldom taken in the industrial fisheries, but are abundant in some artisanal fisheries, mainly in the Arabian Sea (Pecoraro et al. 2017).

Further details on these and other biological characteristics can be found in the *Biology* Section later in this paper.

Fisheries and main catch trends

Yellowfin tuna have been exploited in the Indian Ocean for more than 700 years (Adam 2004). The industrial fishery dates back to 1952 when longliners started operating in the eastern region followed by the western region in 1954 and by 1960s most areas of the Indian Ocean were being exploited (Pecoraro et al. 2017). Taiwanese and South Korean longliners led this initial gradual expansion (Pecoraro et al. 2017).

Catches of yellowfin tuna remained stable between the mid-1950s and the early-1980s, ranging between 30,000 t and 70,000 t, with longliners and gillnetters as the main gear types being used. The purse seine fishery started in the early 1980s following exploratory cruises by Japanese, Mauritian and French purse seiners in the 1970s and then later, large numbers of European purse seine vessels moved to the Indian Ocean from the Atlantic Ocean (Pecoraro et al. 2017). The expansion of this fleet was supported by the development of modern equipment, the increasing use of support vessels and FADs which improved the efficiency of the fishery (Miyake et al. 2010, Pecoraro et al. 2017). Catches increased rapidly in the early-1980s with the arrival of the purse seiners and increased activity of longliners and other fleets, reaching over 400,000 t by 1993.

Landings of yellowfin tuna increased throughout the 1990s, fluctuating around 400,000 t until 2002 after which landings increased further up to a peak of 525,000 t in 2004. In the following years, overall landings decreased significantly due to displacement of effort in the western Indian Ocean as a result of the threat of piracy in this region until the introduction of armed personnel onboard purse seine vessels since 2009 at which point the decline in landings was less pronounced (Chassot et al. 2010). In recent years the effort of all fleets has increased significantly leading to higher landings up to a peak of around 448,000 t in 2019 (**Table 2**, IOTC 2021).

Main fishing gears (2015-19)

In recent years catches have been evenly split between industrial and artisanal fisheries. Purse seiners (free and associated schools) and longline fisheries still account for around 40% of total catches, while catches from artisanal gears – namely handline, gillnet, and pole-and-line – have steadily increased since the 1980s (Error! Reference source not found.; **Fig. 1**).

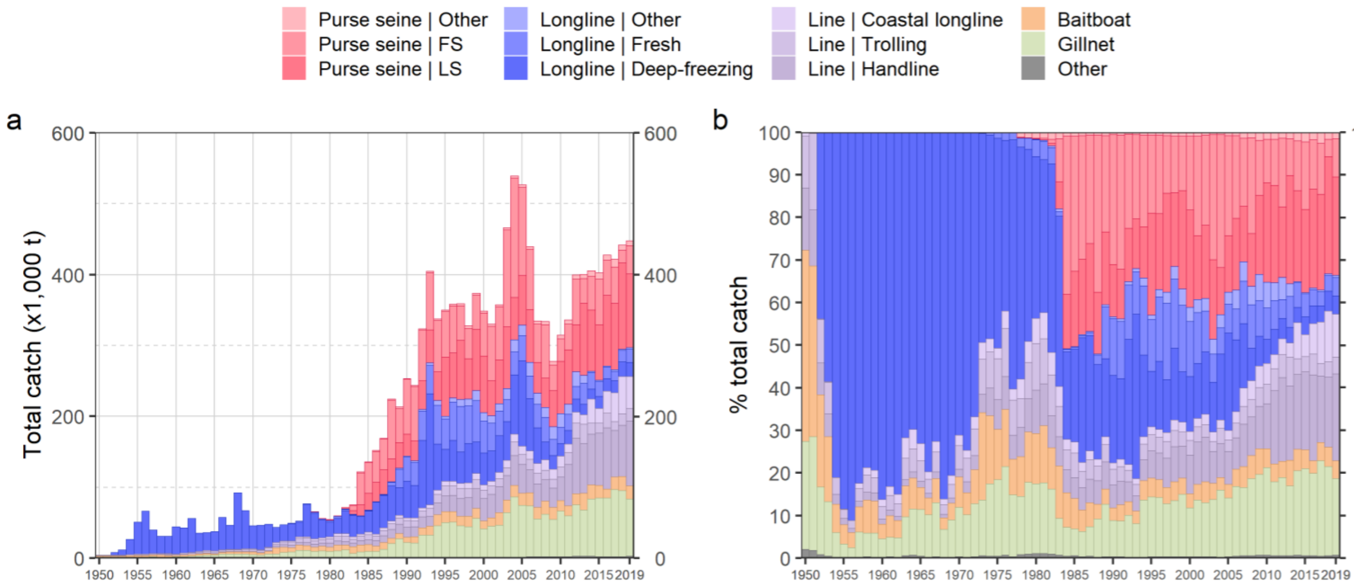

Fig. 1. Annual time series of cumulative nominal absolute (a) and relative (b) catches of yellowfin tuna in metric tons (t) by fishery for the period 1950-2019. LS = schools associated with floating objects; FS = free swimming schools. Source: IOTC 2021

Contrary to other oceans, the artisanal fishery component of yellowfin tuna catches in the Indian Ocean is substantial, accounting for catches of around 200,000 t per annum since 2012. The proportion of yellowfin tuna catches from artisanal fisheries has increased from around 30% in 2000 to nearly 50% in recent years (**Fig. 2**).

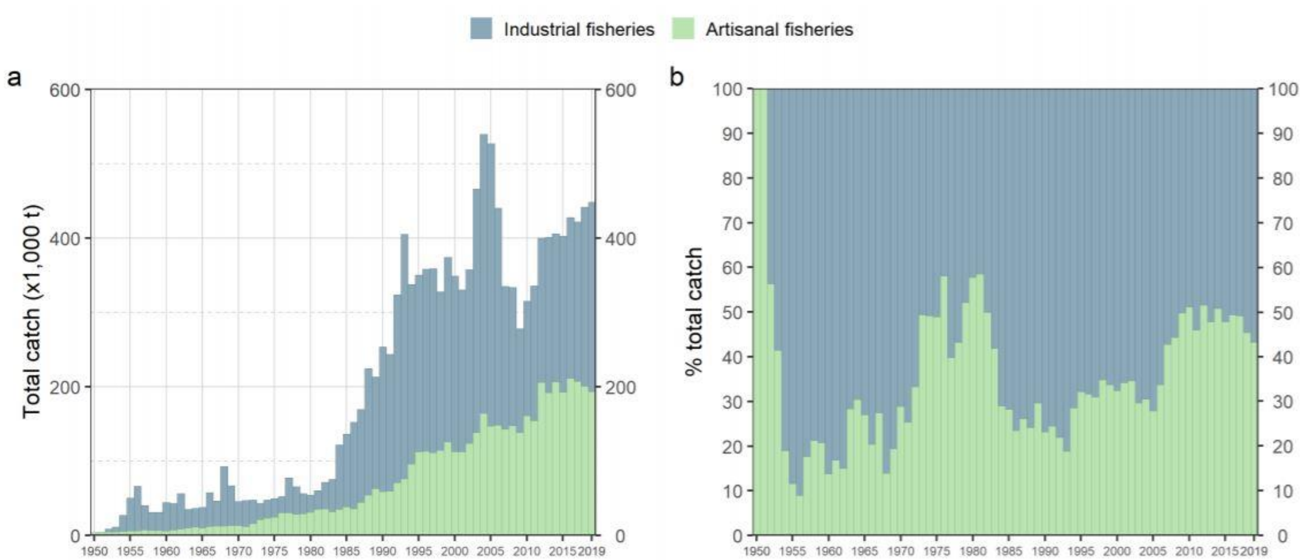

Fig. 2. Annual time series of cumulative nominal absolute (a) and relative (b) catches of yellowfin tuna by type of fishery in metric tons (t) for the period 1950-2019. Source: IOTC 2021

Purse seine fishery

Although some Japanese purse seiners have fished in the Indian Ocean since 1977, the purse seine fishery developed rapidly with the arrival of European vessels between 1982 and 1984. Since then, there has been an increasing number of yellowfin tuna caught, with a larger proportion of the catches consisting of adult fish, as opposed to catches of bigeye tuna, which are mostly composed of juvenile fish.

Purse seiners (free and associated schools) and longline fisheries still account for around 36% of total catches, while catches from artisanal gears – namely handline, gillnet, and pole-and-line – have steadily increased since the 1980s (**Fig. 1**) (Pecoraro et al. 2017, IOTC 2021).

The purse seine fishery is characterized by the use of two different fishing modes: the fishery on floating objects (FADs) catches large numbers of small yellowfin tuna in association with skipjack tuna and juvenile bigeye tuna, compared to the fishery on free swimming schools, which catches larger yellowfin tuna on multi-specific or mono-specific sets.

As for other tropical tuna species (bigeye tuna in particular), industrial purse seine catches of yellowfin tuna on free-school have shown a steady decline in recent years, reaching an all-time low of around 15,000 t in 2018 as opposed to an average of 45,000 t recorded for the previous ten years. Catches of tuna associated with floating objects represented more than 80% of the total purse seine catch in the Indian Ocean between 2007-2016 (Chassot et al. 2019).

Longline fishery

The longline fishery started in the early 1950s and expanded rapidly throughout the Indian Ocean. The longline fishery targets several tuna species in different parts of the Indian Ocean, with yellowfin tuna and bigeye tuna being the main target species in tropical waters. The longline fishery can be subdivided into a deep-freezing longline component (i.e., large scale deep-freezing longliners operating on the high seas from Japan, Korea and Taiwan,China) and a fresh-tuna longline component (i.e., small to medium scale fresh tuna longliners from Indonesia and Taiwan,China).

Main fleets (and primary gear associated with catches)

Percentage of total catches (2015–19): the five main fleets catching yellowfin tuna are I.R. Iran (gillnet): 12%; Maldives (handline, pole-and-line): 12%; EU,Spain (purse seine): 11%; Seychelles (purse seine): 10%; Sri Lanka (gillnet, coastal longliners): 9% (**Fig. 3**).

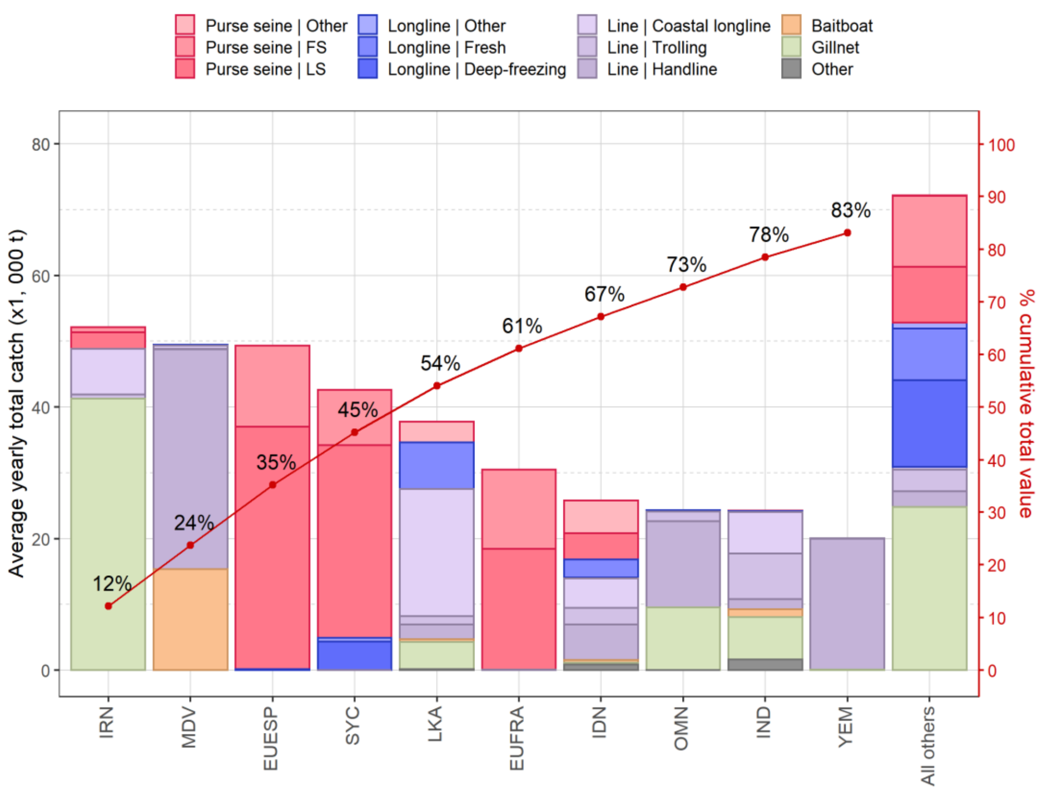

Fig. 3. Yellowfin tuna: average catches in the Indian Ocean over the period 2015 – 19, by country. Countries are ordered from left to right, according to the importance of catches of yellowfin reported. The red line indicates the (cumulative) proportion of catches of yellowfin for the countries concerned, over the total combined catches of this species reported from all countries and fisheries. LS = schools associated with floating objects; FS = free-swimming schools. Data as of May 2021. Source: IOTC 2021

Table 2: Yellowfin tuna: Best scientific estimates of the catches of yellowfin tuna (*Thunnus albacares*) by gear and main fleets (or type of fishery) by decade (1950–2019) and year (2010–2019), in tons. Catches by decade represent the average annual catch, noting that some gears were not used since the beginning of the fishery. Data as of July 2021.

	By decade (average)							By year (last ten years)									
FISHERY	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
PS | Other	-	4	143	1,170	2,185	3,590	7,222	5,317	5,516	5,479	6,235	8,323	9,102	7,390	10,855	7,145	6,856
PS| FS	-	-	18	31,552	64,938	89,204	43,728	32,135	36,453	64,593	34,459	47,426	63,963	49,460	50,700	17,944	40,147
PS | LS	-	-	17	17,597	56,278	61,890	90,214	73,383	76,659	66,166	101,898	86,417	78,395	99,268	94,479	121,699	103,774
LL | Other	-	-	-	354	5,706	14,488	7,432	19,221	13,899	20,626	11,699	1,081	1,204	1,544	1,593	1,464	1,990
LL | Fresh	-	-	615	4,286	47,612	34,150	20,482	23,240	22,709	17,808	28,981	23,763	21,987	16,749	13,915	16,506	19,159
LL | Deep-freezing	21,990	41,352	29,589	33,824	66,077	56,671	17,702	17,863	19,814	18,849	15,028	14,523	16,608	17,740	16,482	20,687	19,430
LN| Coastal longline	168	1,262	1,771	3,489	6,161	11,107	27,874	15,470	11,255	15,167	13,245	34,072	20,866	30,484	40,560	52,555	45,072
LN | Trolling	1,005	1,822	4,194	6,850	11,485	13,429	17,679	14,115	17,359	21,379	27,320	15,096	14,150	21,135	12,728	15,767	17,742
LN | Handline	619	638	2,948	7,861	19,803	34,368	70,155	33,397	58,071	78,565	70,016	71,484	73,901	86,023	65,557	72,959	91,576
BB	2,111	2,318	5,810	8,295	12,803	16,072	17,528	14,105	14,009	15,512	24,055	20,542	17,642	12,391	18,370	20,030	18,625
GN	1,574	4,117	7,928	12,034	39,199	58,819	77,361	64,529	57,848	72,749	65,191	80,416	82,572	82,881	94,515	92,437	80,469
OT	80	189	310	674	1,133	1,746	2,566	2,355	2,318	2,744	2,748	2,839	2,397	2,484	1,994	2,626	3,161
Total	27,546	51,702	53,344	127,986	333,379	395,533	399,943	315,129	335,910	399,636	400,873	405,982	402,786	427,551	421,748	441,818	448,000

Table 3: Yellowfin tuna: Best scientific estimates of the catches of yellowfin tuna (*Thunnus albacares*) by area by decade (1950–2019) and year (2010–2019), in tons. Catches by decade represent the average annual catch. The areas are presented in Error! Reference source not found.**(a). Data as of July 2021.**

	By decade (average)							By year (last ten years)									
AREA	1950s	1960s	1970s	1980s	1990s	2000s	2010s	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
IRYFT02	845	7,535	5,876	9,615	23,997	25,074	20,091	19,775	21,103	18,339	22,503	10,626	16,683	24,247	24,906	18,041	24,685
IRYFT03	909	1,766	1,406	1,268	8,446	8,417	4,089	4,780	5,978	4,513	6,706	3,090	5,053	3,058	1,993	3,252	2,465
IRYFT04	12,346	14,983	18,426	29,297	91,009	89,102	81,887	93,820	81,545	89,989	84,486	85,417	68,874	68,269	69,908	84,446	92,112
IRYFT1A	1,956	4,239	6,331	16,049	70,298	86,815	102,647	70,152	72,629	100,045	98,055	104,101	97,009	108,513	118,935	130,340	126,691
IRYFT1B	11,485	23,146	21,287	71,720	139,583	186,102	191,218	126,589	154,640	186,749	189,119	202,746	215,156	223,446	205,997	205,738	202,002
Total	27,541	51,669	53,326	127,948	333,333	395,510	399,931	315,115	335,895	399,634	400,870	405,980	402,775	427,533	421,739	441,817	447,955

Areas: Arabian Sea (**R1A/IRYFT1A**); Off Somalia (**R1B/IRYFT1B**); Mozambique Channel including southern (**R2/IRYFT2**); South Indian Ocean including southern (**R3/IRYFT3**); East Indian Ocean including Bay of Bengal (**R4/IRYFT4**). Background colour intensity is proportional to the catches by area and category (i.e. decade, year)

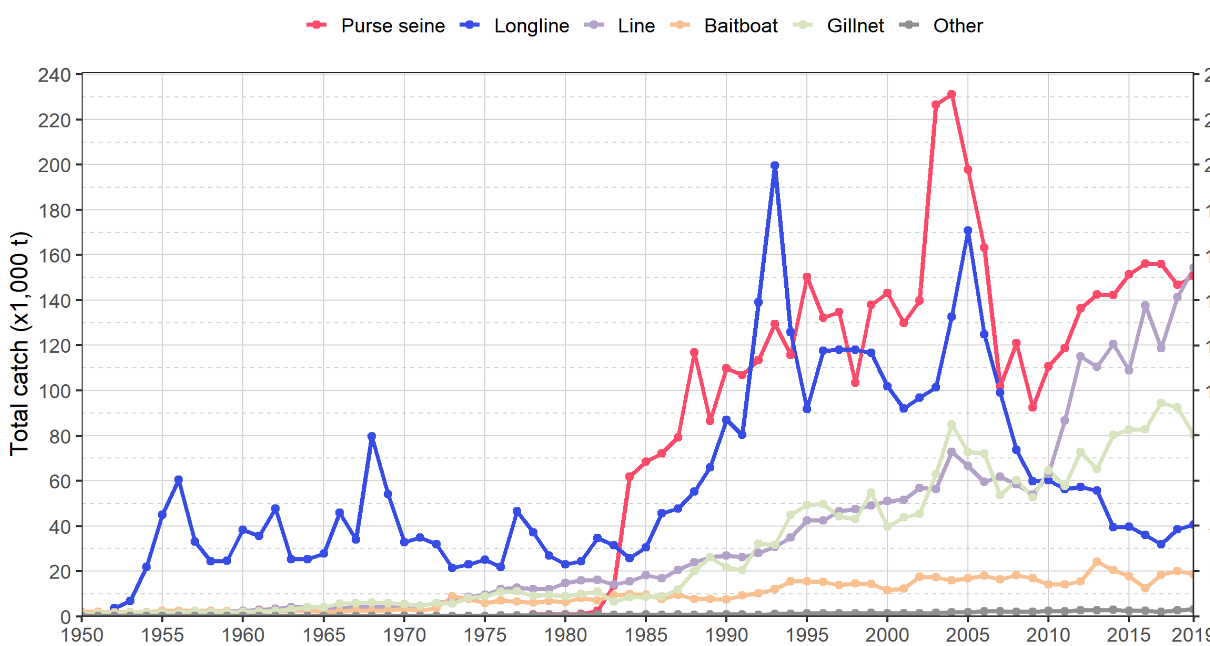

Fig. 4. Annual time series of nominal catches of yellowfin tuna by fishery group in metric tons (t) between 1950 and 2019. Data source: latest best scientific estimate of nominal catches

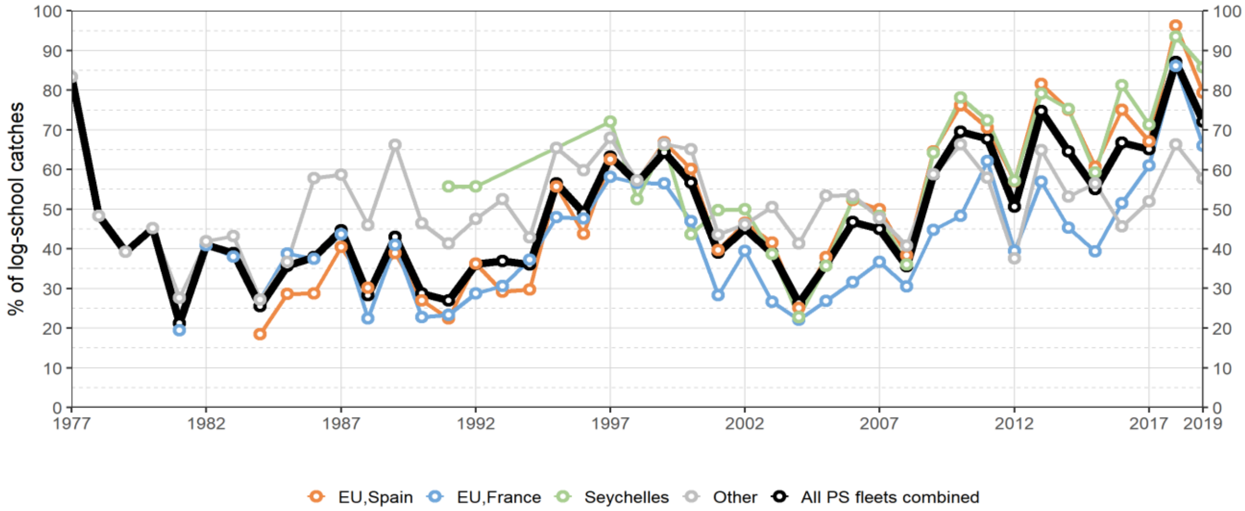

Fig. 5. Annual percentages of purse seine log-associated catches of yellowfin tuna by fleet between 1977 and 2019. *Other* includes purse seine fleets such as ex-Soviet Union, I.R. Iran, France (Mayotte), Mauritius, Japan, Korea, Indonesia, Thailand, EU,Italy, Belize and others. Data source: [latest time-area catch dataset for purse-seine fisheries]() (Res. 15/02)

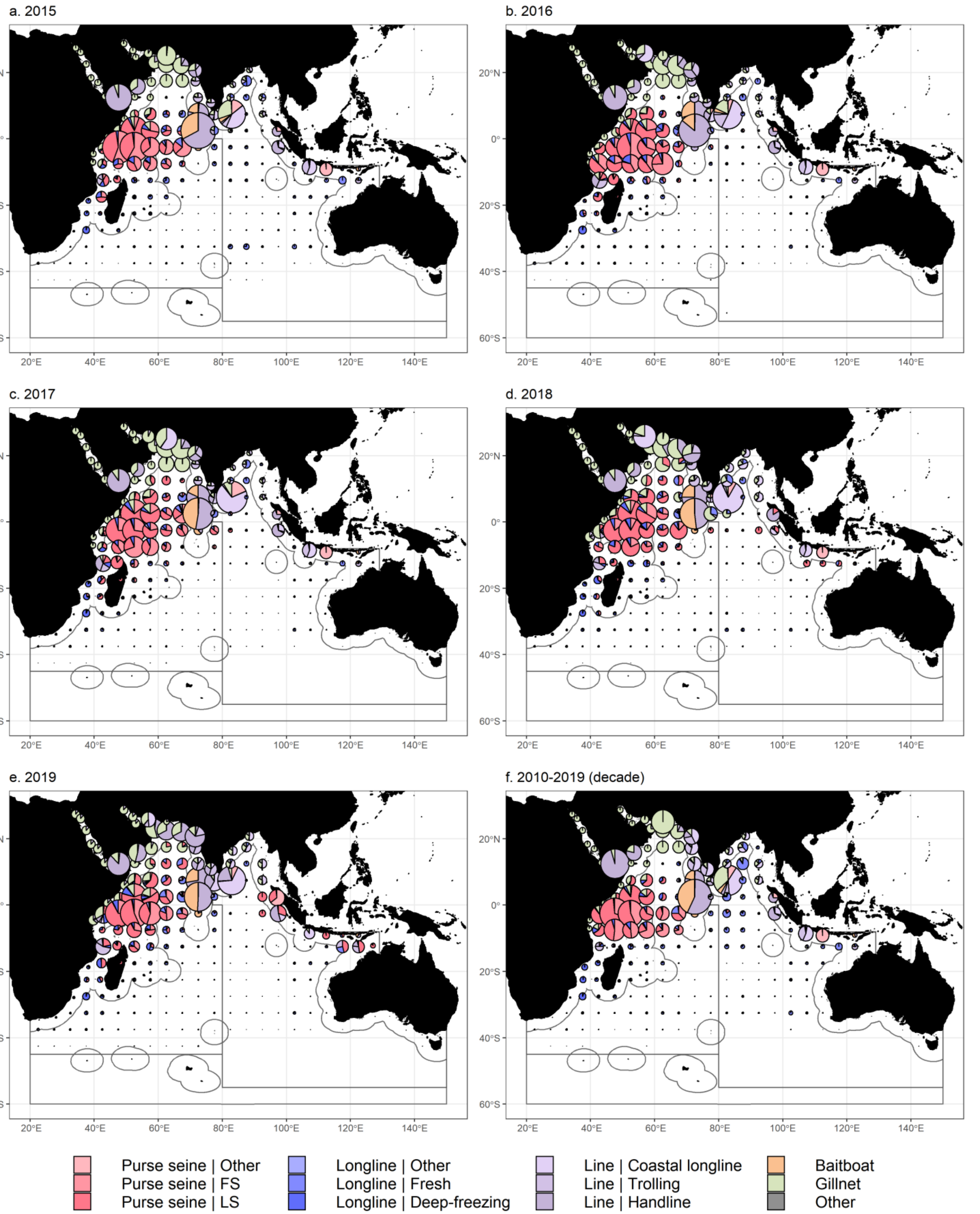

Fig. 6. Estimated average annual time-area catches of yellowfin tuna in metric tons (t) / year, by year / decade, 5x5 grid and fishery. Data source: yellowfin tuna raised time-area catches

Main fishing areas

Primary: Western Indian Ocean, around Seychelles and waters off Somalia (Area R1B), and Mozambique Channel (Area R2) (**Fig. 7**).

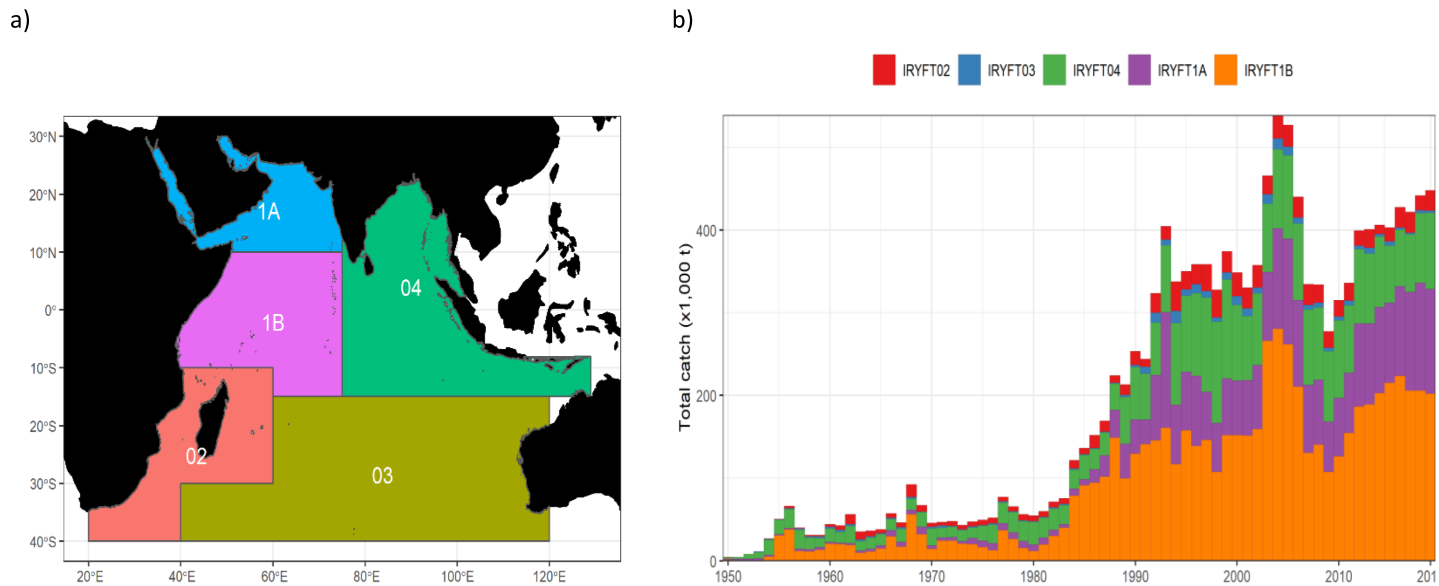

Fig. 7. Yellowfin tuna: Catches of yellowfin tuna by area by year estimated for the WPTT (1950–2019). Data as of July 2021.
Areas: Arabian Sea (R1A/IRYFT1A); Off Somalia (R1B/IRYFT1B); Mozambique Channel, including southern (R2/IRYFT2); South Indian Ocean including southern (R3/IRYFT3); East Indian Ocean, including Bay of Bengal (R4/IRYFT4).

Discard levels

Discard levels are thought to be low, although estimates of discards are unknown for most industrial fisheries (despite the obligation to report these data as per IOTC Res. 15/02).

Size distribution and estimated weights

Temporal trends in estimated average weights

Trends in average weights of yellowfin tuna can be derived from the raised time-area catches in weight and numbers. While they can be estimated for the entire time series and for each fishery, due to the lack of original samples for several strata (especially in the early periods of the fisheries) they are considered accurate only for those periods for which actual samples are available and cover strata that correspond to at least 50 t of retained catches per year.

Considering the limitations in the original data and in the process that produces this estimation, it shall be noted that the average weights estimated for the longline fisheries of Japan and Taiwan,China are considered to be fairly stable at around 40-50 kg / fish. On the contrary, average weights estimated for the log-associated school component of the purse seine fisheries show a declining trends from the mid-1990s onward, and the resulting estimated average weight of yellowfin tuna caught by this fishery is now as low as 5 kg / fish.

Trends in average weight for all other fisheries (baitboat, gillnet and all other gears) are more difficult to assess due to the inherently artisanal nature of several of them, which in turn implies a lower number of available samples which are often of lower quality compared to those provided by industrial fleets (recorded through logbooks or collected by scientific observers, in several cases).

Estimated average weights by last decade (2010-2019) and years (2015-2019)

Overall, the trend in average weights that results from combining data for all fisheries together shows a clear and steady decrease in the size of fish caught since the beginning of the 1990s, which can be explained by the generalized decline in deployed efforts by several industrial longline fleets combined with the rapid increase in catches from log-associated schools in the purse seine fishery (**Fig. 8**).

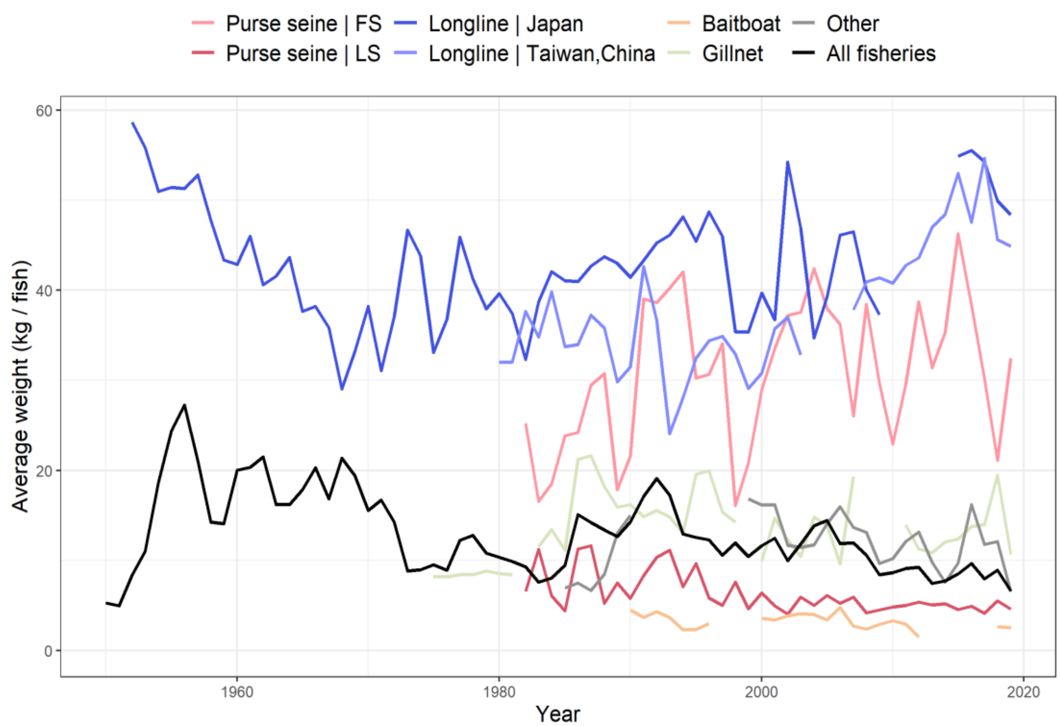

Fig. 8. Combined estimated yellowfin tuna average weight (kg/fish) by fishery and year. Data are only shown for those years for which the original size samples cover strata with reported catches (by year and fishery) higher than 50 t. LS = schools associated with floating objects; FS = free-swimming schools. Longline | Japan = includes data from longlines flagged by Japan, Rep. of Korea and Thailand; Longline | Taiwan,China = includes data from longlines flagged by Taiwan,China and all other flags not otherwise mentioned. Data source: yellowfin tuna raised time-area catches

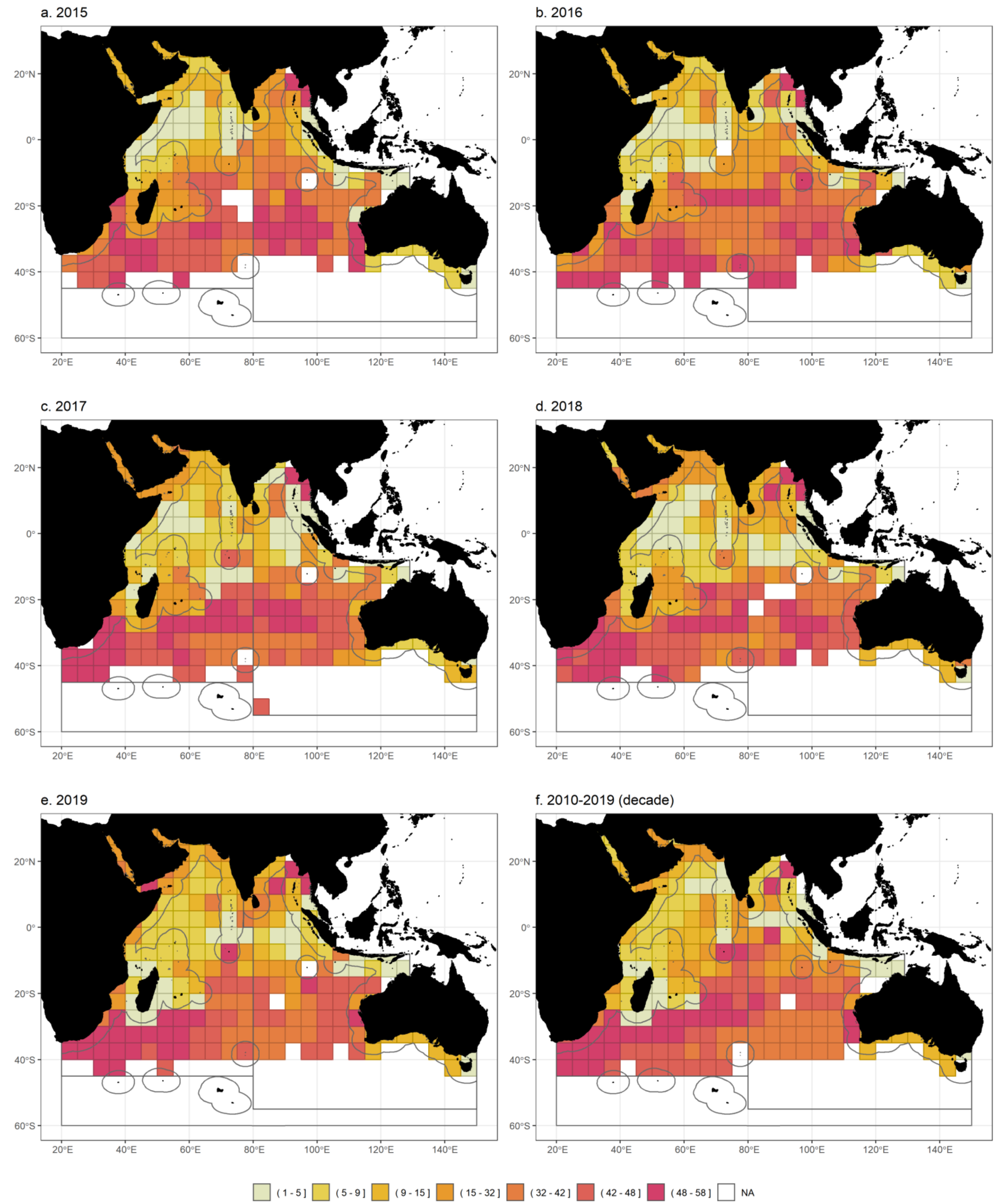

Fig. 9. Estimated average weight (kg / fish) by year and 5x5 grid, all fisheries combined. Data source: yellowfin tuna raised time-area catches

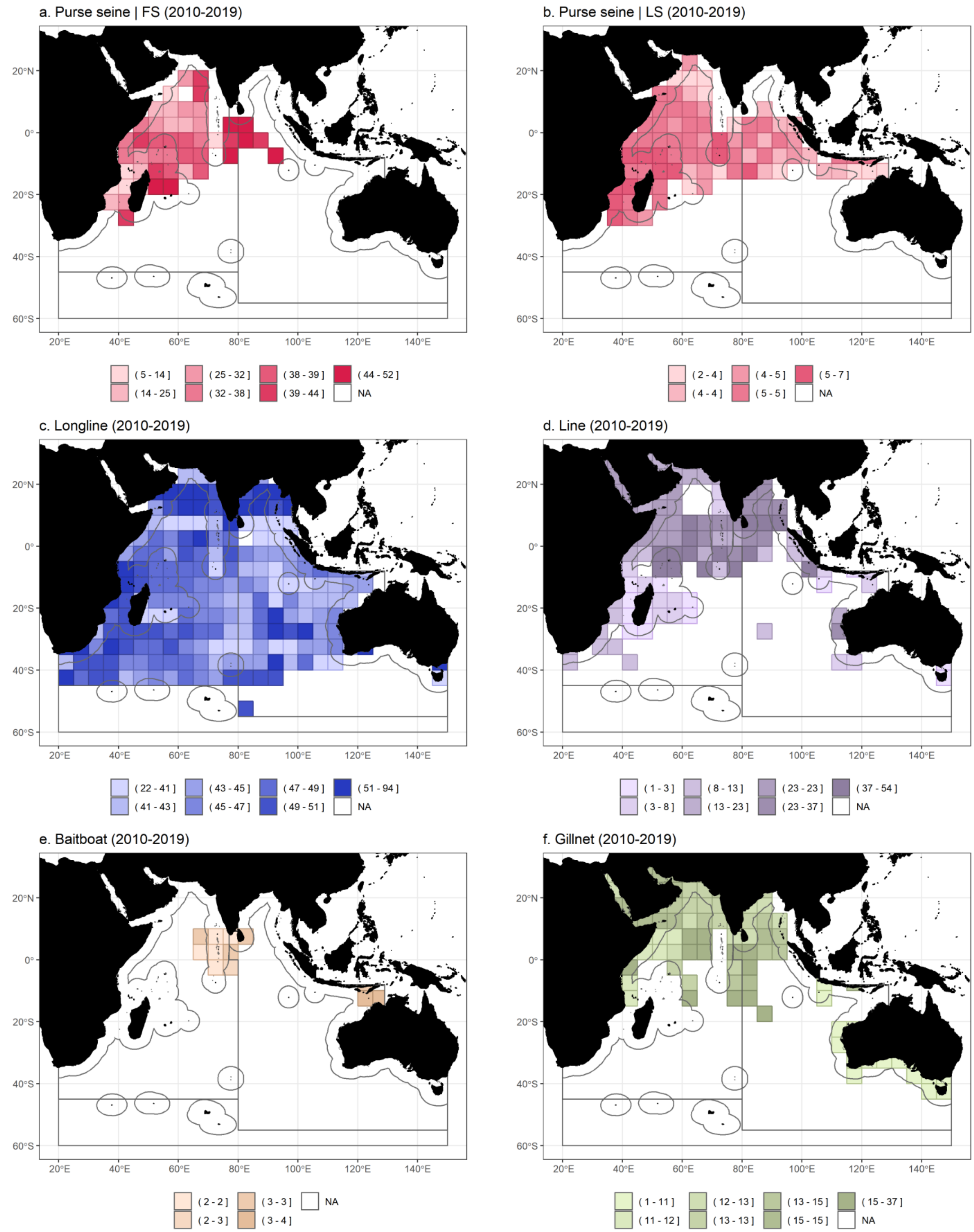

Fig. 10. Estimated average weight (kg / fish) by 5x5 grid and fishery group in the period between 2010 and 2019. LS = schools associated with floating objects; FS = free-swimming schools. Data source: yellowfin tuna raised time-area catches

Temporal patterns and trends in size distribution

Industrial purse seine fisheries

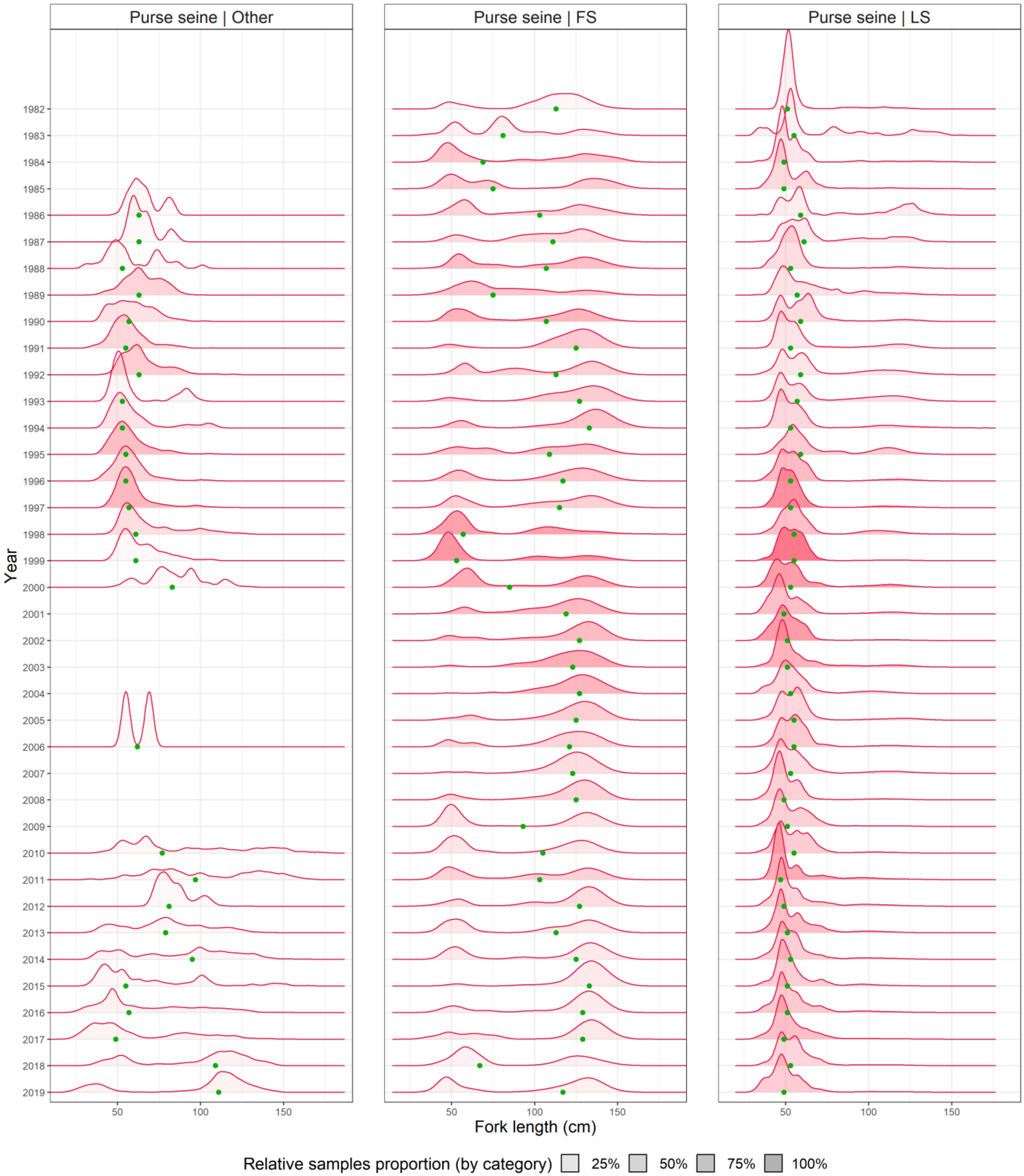

Fig. 11. Relative size distribution (fork length in 2 cm size bins) of yellowfin tuna caught by all purse seine fleets between 1982 and 2019. Other = no information provided on the school association; LS = schools associated with floating objects; FS = free-swimming schools. Fill intensity is proportional to the number of samples recorded for the year, while the green dot corresponds to the median value. Data source: [latest yellowfin tuna standardized size-frequency dataset] (Res. 15/02)

Industrial longline fisheries

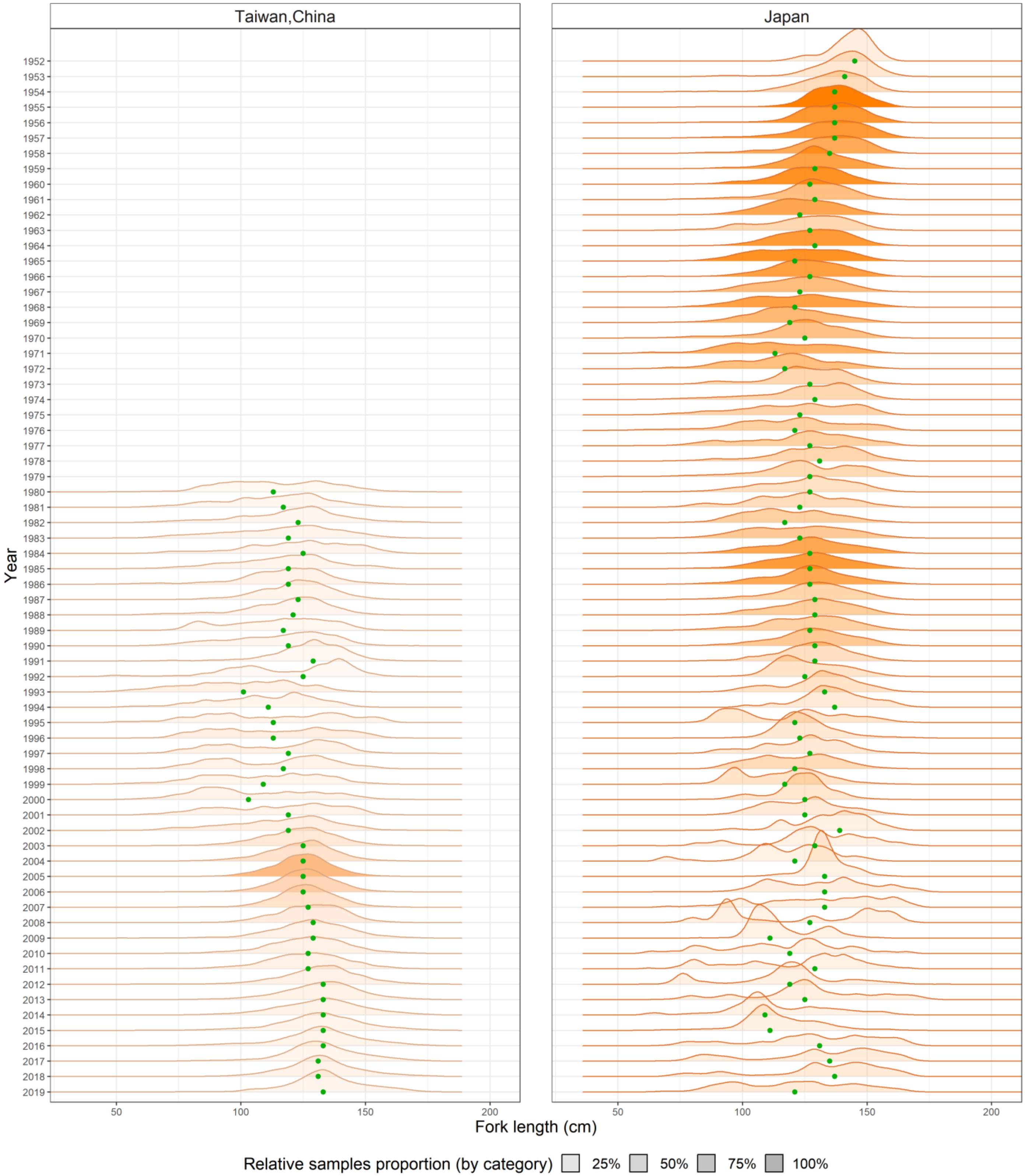

Fig. 12. Relative size distribution (fork length in 2 cm size bins) of yellowfin tuna caught by the main deep-freezing longline fleets during 1952-2019. Fill intensity is proportional to the number of samples recorded for the year, while the green dot corresponds to the median value. Data source: [latest yellowfin tuna standardized size-frequency dataset] (Res. 15/02)

Other longline fisheries

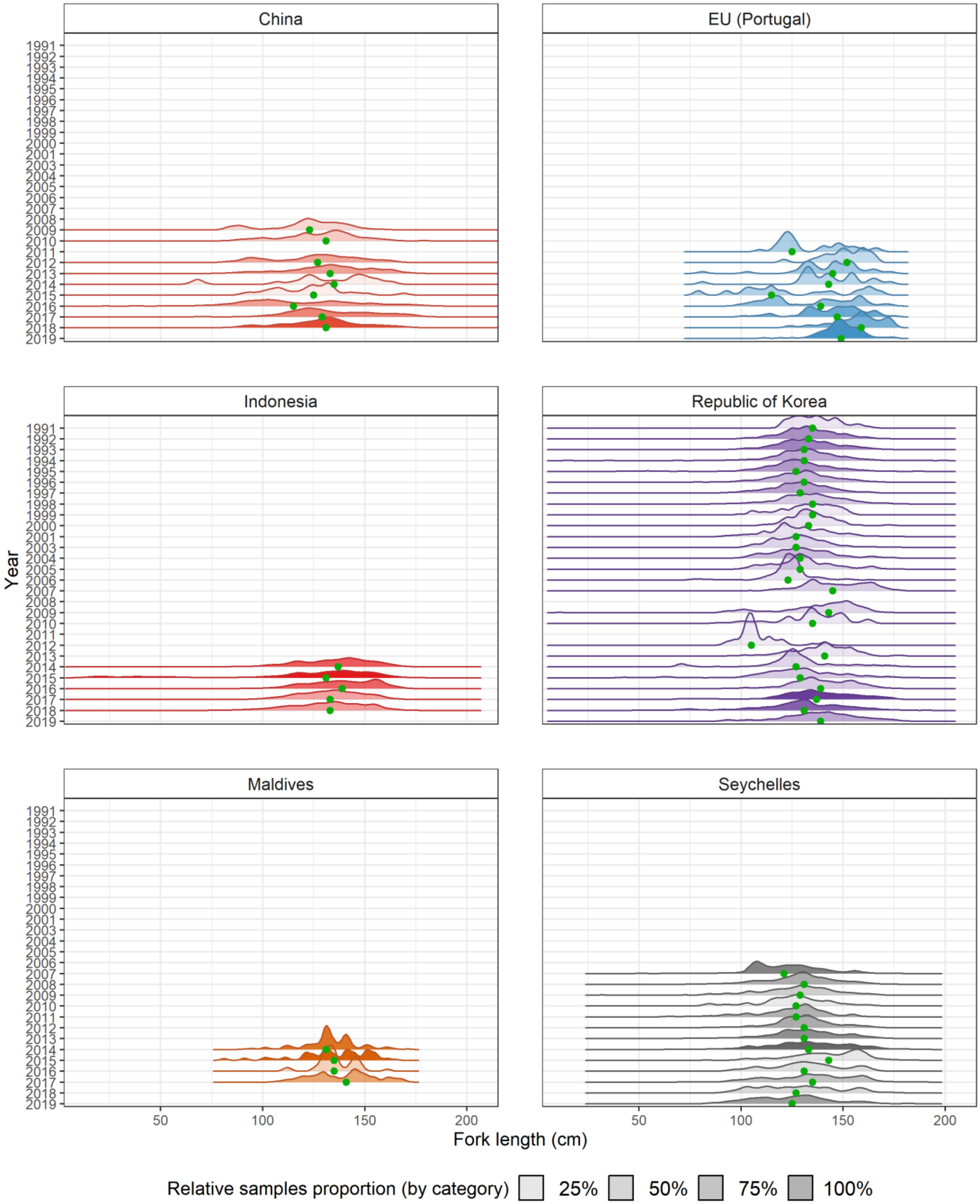

Fig. 13. Relative size distribution (fork length in 2 cm size bins) of yellowfin tuna caught by the all other longline fleets (excluding Japan and Taiwan,China), by origin and fleet (2000-2019). Data source: [latest yellowfin tuna standardized size-frequency dataset] (Res. 15/02)

Fishing effort trends

Total effort from longline vessels flagged to Japan, Taiwan,China and EU,Spain by five degree square grid in recent years are provided in **Fig. 14** , and total effort from purse seine vessels flagged to the EU and Seychelles (operating under flags of EU countries, Seychelles and other flags), and other purse seine fleets, by five degree square grid are provided in **Fig. 15**.

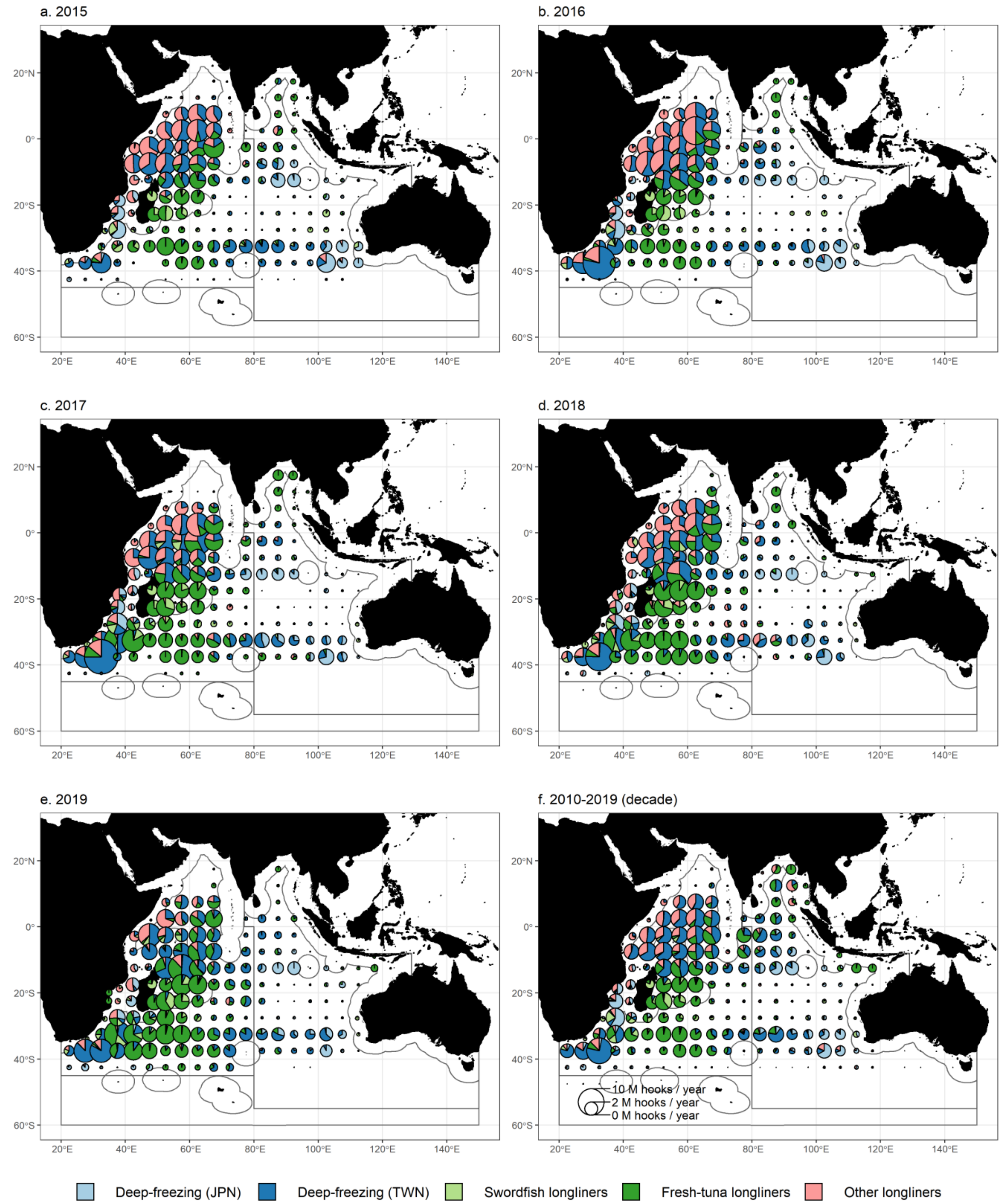

Fig. 14. Average annual effort exerted by industrial longline fleets in millions of hooks set / year, by year / last decade, 5x5 grid and fleet. Data source: latest time-area effort dataset for longline fisheries (Res. 15/02)

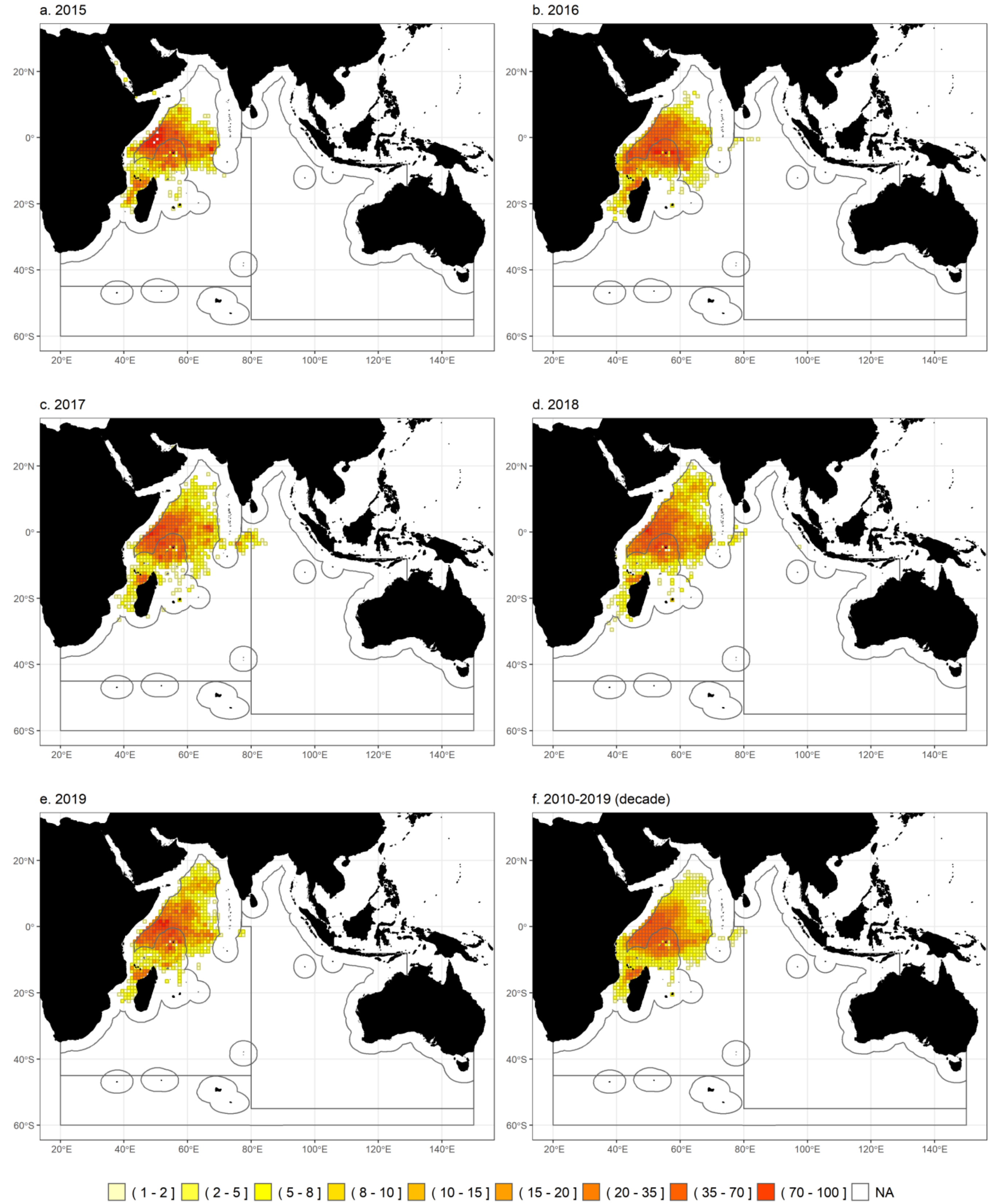

Fig. 15. Average annual effort exerted by the industrial purse seine fleets of the European Union and assimilated flags (EU) in fishing days / year, by year / decade and 1x1 grid. Data source: [latest time-area effort dataset for purse-seine fisheries](#) (Res. 15/02)

Yellowfin tuna: tagging data

- A total of 66,543 yellowfin tuna (representing 30% of the total number of fish tagged) were tagged during the Indian Ocean Tuna Tagging Programme (IOTTP). Most of the tagged specimens (82%) were released during the main Regional Tuna Tagging Project-Indian Ocean (RTTP-IO) and were released around Seychelles, in the Mozambique Channel, along the coast of Oman and off the coast of Tanzania, between May 2005 and September 2007 (**Fig. 16**). The remaining specimen were tagged during small-scale tagging projects, and by other institutions with the support of IOTC Secretariat, in Maldives, India, and in the south west and the eastern Indian Ocean.
- To date, around 10,842 specimens (16% of releases for this species), have been recovered and reported to the IOTC Secretariat. More than 86% of these recoveries we made by the purse seine fleets operating in the Indian Ocean, while around 9% were made by pole-and-line and less than 1% by longline vessels. The addition of the data from the past projects in the Maldives (in 1990s) added 3,211 tagged yellowfin tuna to the databases, or which 151 were recovered, mainly from the Maldives.

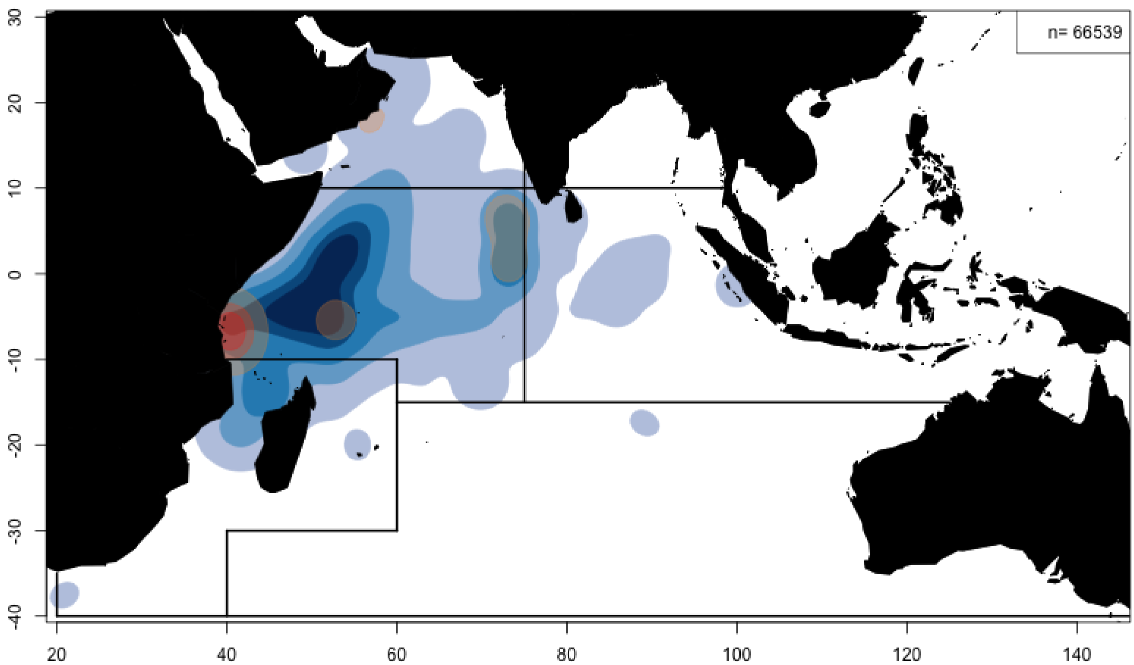

Fig. 16. Yellowfin tuna: Densities of releases (in red) and recoveries (in blue). The black line represents the stock assessment areas. Includes specimens tagged during the IOTTP and also Indian Ocean (Maldivian) tagging programmes during the 1990s

Yellowfin tuna: data availability and related data quality issues

Retained catches

- Data for retained catches are considered to be generally well known for the major industrial fisheries, with the proportion of catches estimated, or adjusted, by the IOTC Secretariat relatively low (**Fig. 17**). Catches are less certain for the following fisheries/fleets:
  - many coastal fisheries, notably those from Indonesia, Sri Lanka (other than gillnet/longline), Yemen, and Madagascar;
  - the drifting gillnet fishery of Pakistan;
  - the gillnet fishery of Tanzania;
  - longline fishery of Indonesia;

- the purse seine fishery of EU,Spain changes introduced in the methodology used to estimate the species composition of the catch for 2018 resulted in figures largely contrasting with other segments of the same fleet for which no official revision for the catches has been received (IOTC 2019);
- Non-reporting industrial purse seiners and longliners (NEI), and longliners of India.

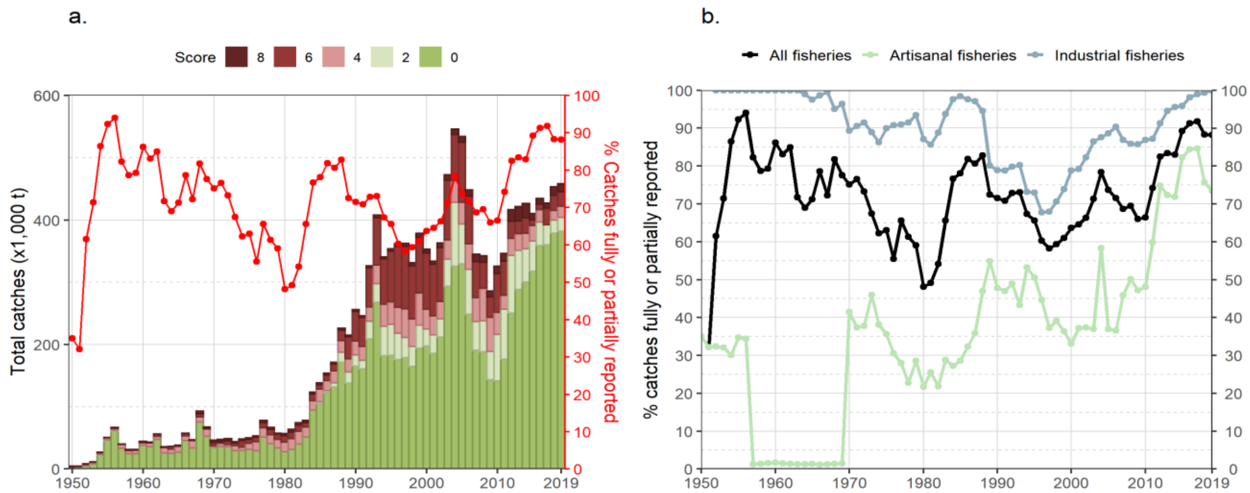

Fig. 17. Annual nominal catches of yellowfin tuna in metric tons (t) estimated by quality score (barplot) and percentage of nominal catch fully/partially reported to the IOTC Secretariat (lines with dots) for all fisheries (a) and by type of fishery (b), in the period 1950–2019

	0
	2
	4
	6
	8

Each IOTC dataset (nominal catch, catch-and-effort, and size data) are assessed against IOTC reporting standards, where:

- **Score: 0** indicates the amount of nominal catch associated with each dataset fully reported according to IOTC standards.
- **Score: 2 – 6** indicates the amount of nominal catches associated with each dataset partially reported by gear and/or species (i.e., adjusted by gear and species by the IOTC Secretariat or for any of the other reasons provided in the document).

Score: 8 indicates the amount of nominal catches associated that is fully estimated by the IOTC Secretariat (i.e., nominal catches) or data that are not available (i.e., catch-and-effort or size data).

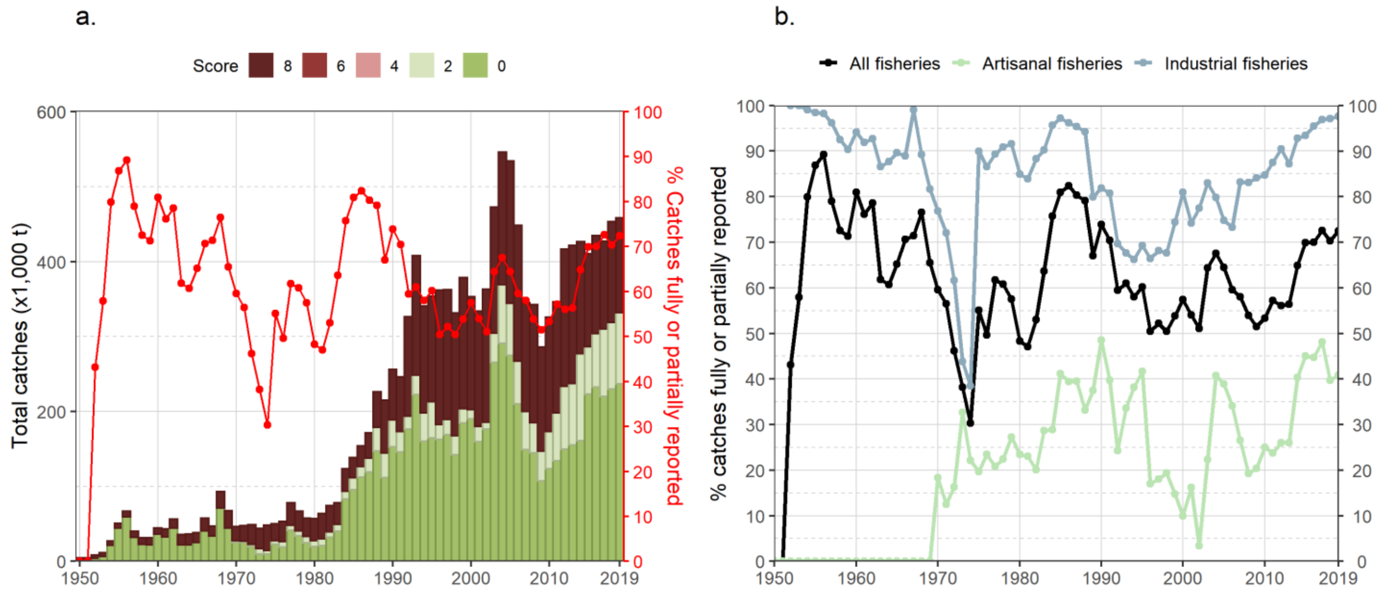

Fig. 18. Annual nominal catches (t) of yellowfin tuna estimated by quality score (barplot) and percentage of geo-referenced catches reported to the IOTC Secretariat in agreement with the requirements of Res. 15/02 (lines with dots) for all fisheries (a) and by type of fishery (b), in the period 1950–2019

Catch-per-unit-effort (CPUE) trends

- Availability: Catch-and-effort series are available for the major industrial and artisanal fisheries (e.g., Japan longline, Taiwan,China) (**Fig. 19**).

  However, for other important fisheries catch-and-effort are either not available, or are considered to be of poor quality for the following reasons:

  - data for the fresh-tuna longline fishery of Taiwan,China are only available since 2006 and partial data for the fresh-tuna longline fishery of Indonesia is available only for 2018 onwards;
  - insufficient data for the gillnet fisheries of I.R., Iran (before 2007) and Pakistan;
  - poor quality effort data for the significant gillnet-longline fishery of Sri Lanka (until 2014);
  - no data are available from important coastal fisheries using hand and/or troll lines, in particular Oman, Yemen, India, Madagascar and Indonesia (until 2018).

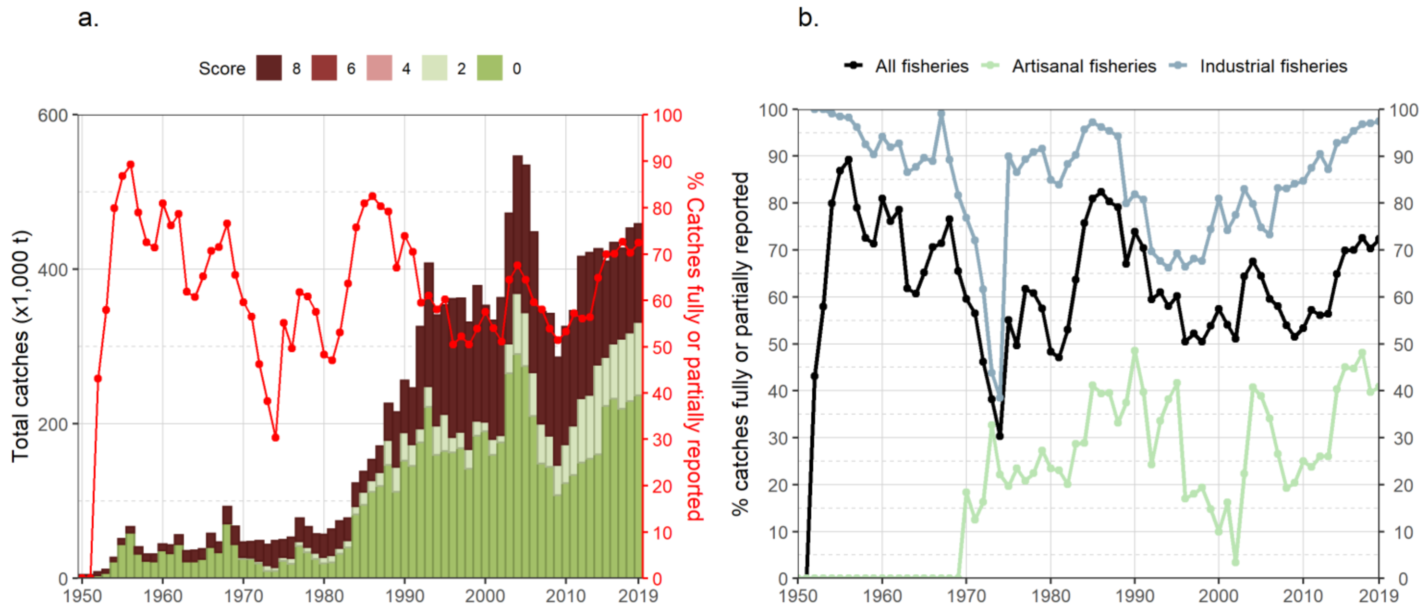

Fig. 19. Annual catch-effort data for yellowfin tuna estimated by quality score (barplot) and percentage of geo-referenced catches reported to the IOTC Secretariat in agreement with the requirements of Res. 15/02 (lines with dots) for all fisheries (a) and by type of fishery (b), in the period 1950–2019

Fish size or age trends (e.g., by length, weight, sex and/or maturity)

- Average fish weight: trends in average weight can be assessed for several industrial fisheries but they are very incomplete or of poor quality for some fisheries, namely hand lines (Yemen, Comoros, Madagascar), troll lines (Indonesia) and many gillnet fisheries.
  - ➢ Purse seine vessels typically take fish ranging from 40 to 140 cm fork length (FL), while smaller fish are more common in catches taken north of the equator.
  - ➢ Longline gear mainly catches large fish, from 80 to 160 cm FL, although smaller fish in the size range 60 cm – 100 cm (FL) have been taken by longliners from Taiwan,China since 1989 in the Arabian Sea.

- Size frequency data: data are available (**Fig. 20**), although the estimates are more uncertain in some years and some fisheries. Almost no size data are available prior to the 1980s and the general quality has varied around 50% (range 36-63%) since 1984. Following an increase in quality from about 40% in 2006-2007 to more than 60% in 2017, the quality substantially decreased to 52% in 2018 and 40% in 2019. Issues with data are due to:
  - ➢ size data not being available from important fisheries, notably Yemen, Pakistan, Sri Lanka and Indonesia (lines and gillnets) and Comoros and Madagascar (lines). Data from the artisanal fisheries of Oman (mainly handlines) is known to be available for some years (until 2016) but has not been officially submitted to the IOTC Secretariat.
  - ➢ the paucity of size data available from industrial longliners from the late-1960s up to the mid-1980s, and in recent years (Japan and Taiwan,China)
  - ➢ the paucity of catch by area data available for some industrial fleets (NEI fleets, I.R. Iran, India, Indonesia, Malaysia).

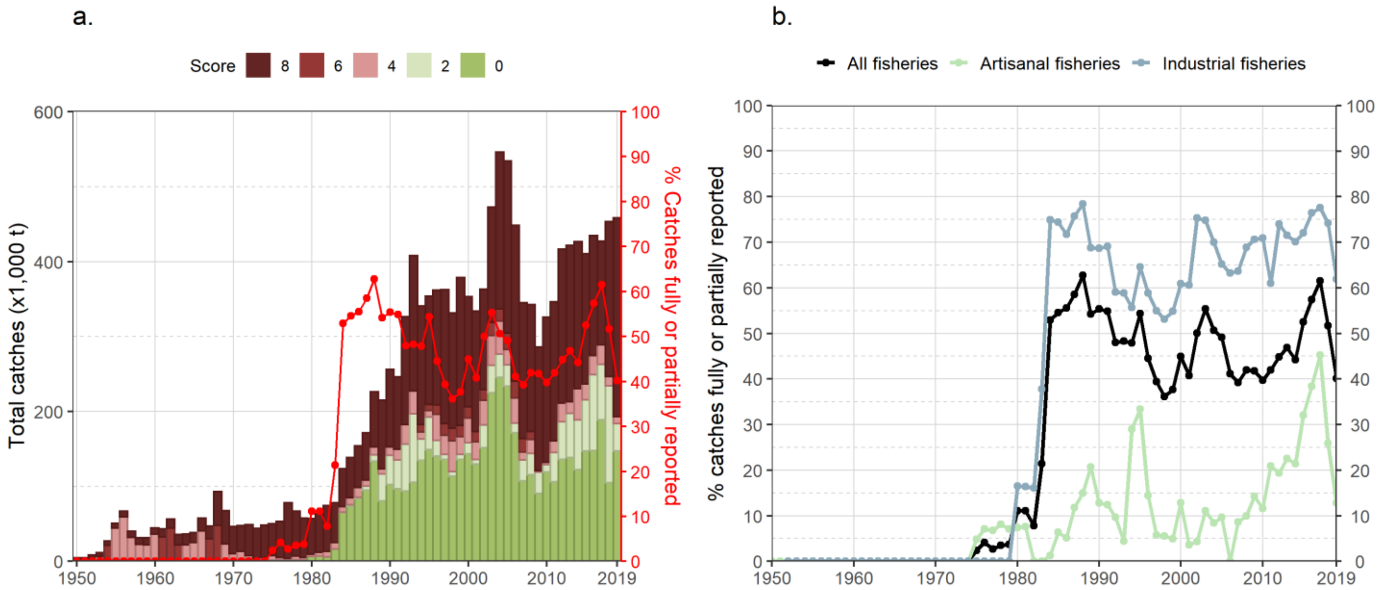

Fig. 20: Annual nominal catches (t) of yellowfin tuna estimated by quality score (barplot) and percentage of geo-referenced size-frequency data reported to the IOTC Secretariat in agreement with the requirements of Res. 15/02 (lines with dots) for all fisheries (a) and by type of fishery (b), in the period 1950–2019

Yellowfin tuna – Standardised catch–per–unit–effort (CPUE) trends

The CPUE series presented at the WPTT20 meeting in 2018 are listed below. The joint longline CPUE by region (1979–2015) was utilised for the final stock assessment model runs and in the development of management advice, noting that the Japanese and Taiwanese longline series from the tropical areas and the Indian Ocean as a whole, showed very similar trends (**Fig. 22** and **Fig**. 23).

- Joint longline CPUE (1979-2015): Series (regions 1 to 4) from document IOTC-2016-WPTT18-14.
- EU (France and Spain) PS CPUE from document IOTC–2016–WPTT18–24.
- Japan data (1960–2015): Series (whole Indian Ocean, tropical area, temperate area) from document IOTC–2016–WPTT18–25.

Note that since 2018, the region codes have been redefined. The following plots refer to the previously used region definitions as shown in **Fig. 21** whereas previous references to regions used region definitions as shown in **Fig. 7a**.

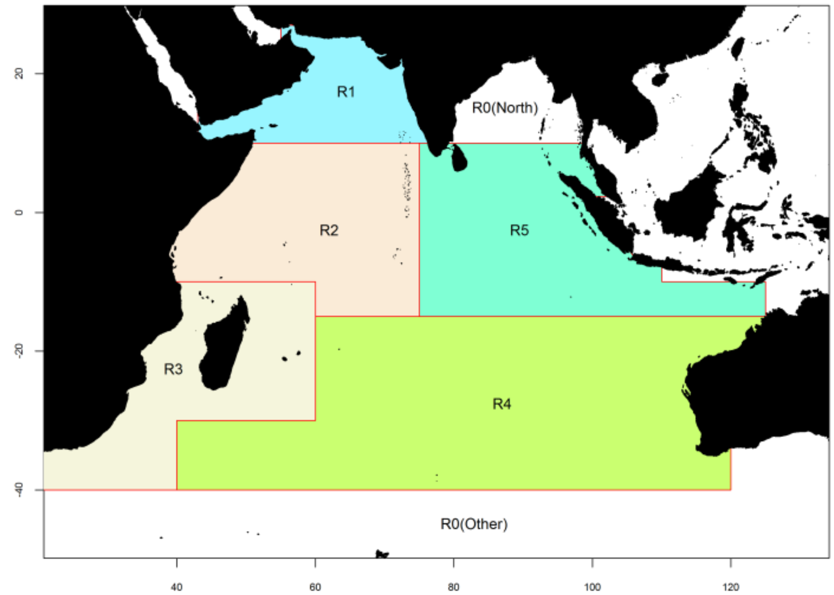

Fig. 21: Map showing regional codes used up to and including 2018

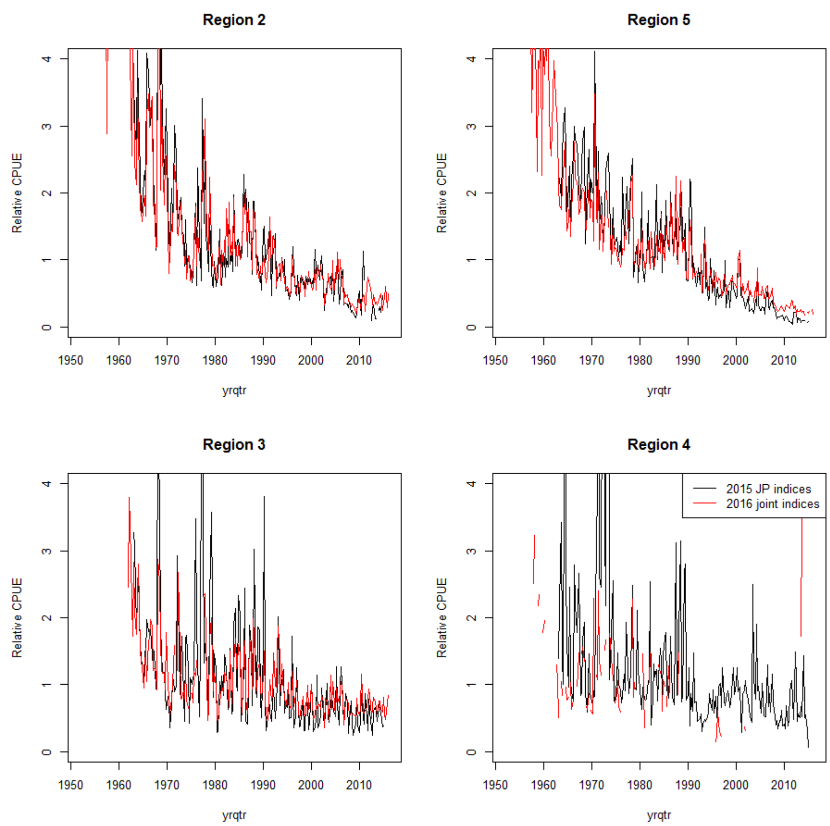

Fig. 22: Comparison of the 2016 joint indices described in this paper (red) with the Japanese indices developed in 2015 and used in the 2015 yellowfin stock assessment (black)

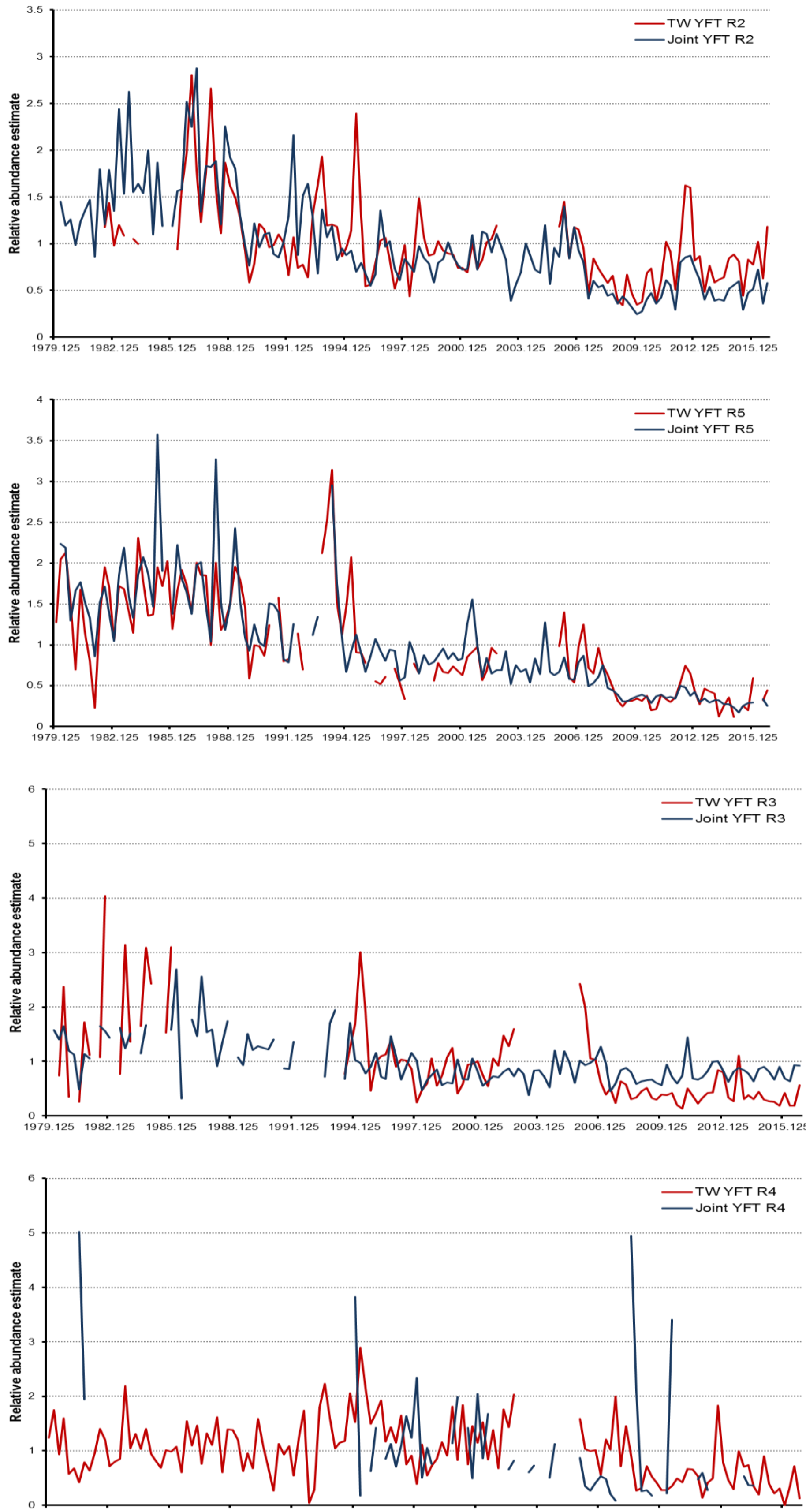

Fig. 23. Comparisons of Taiwan,China yellowfin tuna CPUE time series (red) with those estimated during the 2016 collaborative project (blue) by region

The following points in relation to the longline CPUE discussions in 2016 should be noted:

- The WPTT reiterated that the multi-nation CPUE standardisation collaboration continue their efforts to improve the understanding of commercial CPUE as relative abundance indices, and expand future work to include other fleets.

Stock Assessment

The following should be noted with respect to the SS3 modelling approach used for determining stock status (**Table 4**) at the WPTT18 meeting:

- The SS3 modelling approach (updated from 2015 stock assessment specifications) included the following additional data sets:
  - i. Fishery catches from 2015
  - ii. Revised purse seine catches from 2014
  - iii. Composite LL CPUE indices for Regions 1-4 (Hoyle, et al 2016)
  - iv. CPUE indices for free school (1984-2015) and FAD (2004-2014) from Katara et al (2016).
- CPUE indices for the PS fishery were available and were included in a number of model trials. However, the WPTT did not consider these indices to represent stock abundance and consequently did not include these indices in the final model options.
- The impact of each one of the changes made to the 2015 stock assessment model specification was assessed. The most influential factor was the use of the joint LL CPUE indices, which led to a stock status estimation of overexploited and undergoing overexploitation – but at relatively lower levels in *F* than estimated for 2014 (-17%), and with higher biomass levels of +35%.
- A series of sensitivity runs were made to the updated base case:
  - i. CPUE indices for free school (1984-2015) and FAD (2004-2014), from Katara et al (2016).
  - ii. Down weighting of tagging information.
  - iii. Increasing the tagging mixing period to 8 quarters.
- Based on the discussions on the tagging mixing period during previous WPTT meetings, related to the assessment of yellowfin and other tropical tuna stocks, the WPTT recommended that additional work be conducted to elucidate the most appropriate approach to tag modelling in IOTC stock assessments.
- The model scenario with an extended mixing period for the tag recoveries results in a stock at very similar levels relative to B_{MSY} of the base case scenario, but a fishing mortality for 2015 below the estimated F_{MSY}.
- The projections reflect low recruitment estimated for the recent past, which results in a decline in spawning biomass in the short term, regardless of the catch level projected. In the longer term, the assumption of deterministic recruitment results in increased spawning biomass when these cohorts enter the spawning population.

Table 4. **Yellowfin tuna: Key management quantities from the SS3 assessment conducted in 2016, for the Indian Ocean*. Values represent the Maximum Posterior Density from the base case and the confidence interval empirically derived from the covariance matrix.**

Management Quantity	Indian Ocean
Most recent catch estimate (t) (2015)	407,574
Mean catch over last 5 years (t) (2011–2015)	390,188
h (steepness)	0.8
MSY (1,000 t) (80% CI)	422 (406-444)
Data period (catch)	1950–2015
CPUE series/period	1972–2015
F_{MSY} (80% CI)	0.15 (0.15-0.15)
SB_{MSY} or *B_{MSY} (1,000 t) (80% CI)	947 (900-983)
F_{2015}/F_{MSY} (80% CI)	1.11 (0.86-1.36)

B_{2015}/B_{MSY} (80% CI)	n.a.
SB_{2015}/SB_{MSY} (80% CI)	0.89 (0.79-0.99)
B_{2015}/B_{1950} (80% CI)	n.a.
SB_{2015}/SB_{1950} (80% CI)	0.289 (n.a.-n.a.)
$SB_{2015}/SB_{current,\ F=0}$ (80% CI)	n.a.

** The management quantities refer to the data used in the last assessment, conducted in 2016.*

Biology

Taxonomy

Yellowfin tuna (*Thunnus albacares*) is a species in the Kingdom Animalia. Yellowfin tuna was named *Thunnus albacares* in 1788 by Pierre Bonnaterre and is one of eight species of the genus *Thunnus* which itself is one of five genera which form the tribe Thunnini (collectively known as the tunas).

Table 5. Taxonomic hierarchy and nomenclature (source: ITIS)

Kingdom	Animalia
Subkingdom	Bilateria
Infrakingdom	Deuterostomia
Phylum	Chordata
Subphylum	Vertebreta
Infraphylum	Gnathostomata
Superclass	Actinopterygii- ray-finned fishes
Class	Teleostei
Subclass	Acanthopterygii
Superorder	Perciformes - perch-like fishes
Order	Scombroidei - tunas, mackerels, bonitos, albacores, ribbonfishes
Family	Scombridae
Genus	Thunnus
Species	Thunnus albacares

Common names: Yellowfin tuna [English]; albacore [French]; atún de aleta amarilla [Spanish]

Synonyms: There are over forty synonyms for the species (source: WoRMS)

Distribution & habitat

Geographic range

Yellowfin tuna is distributed mainly in the tropical and subtropical oceanic waters of the three major oceans (**Fig. 24),** where it forms large schools, often associated with floating objects (Chassot et al. 2015). Longline catch data indicates that yellowfin tuna is distributed throughout the entire tropical Indian Ocean.

Archival tagging of yellowfin tuna has shown that this species can dive very deep (over 1000 m) probably to feed on meso-pelagic prey but spends most of the time at the top of the thermocline where phytoplankton production is higher and so epipelagic prey species are more concentrated (Sund et al. 1981, Block et al. 1997, Brill et al. 1999, Schaefer et al. 2009, 2011, Reygondeau et al. 2012).

Sea temperature is thought to be a very important factor limiting the spatial distribution and vertical movements of yellowfin tuna as below 15°C they are unable to control their heart rates resulting in a reduction in cardiac output which explains why they dive daily rather than spending large periods of time at depth (Brill et al. 1998, Brill & Lutcavage 2001, Brill & Bushnell 2001, Galli et al. 2009).

The local environmental and oceanographic conditions are thought to influence the distribution and survivorship of yellowfin tuna in their early life stages more than adults due to the endothermic capabilities which are acquired during these stages for which certain conditions are required meaning their range of habitats are much more confined (Reglero et al. 2014).

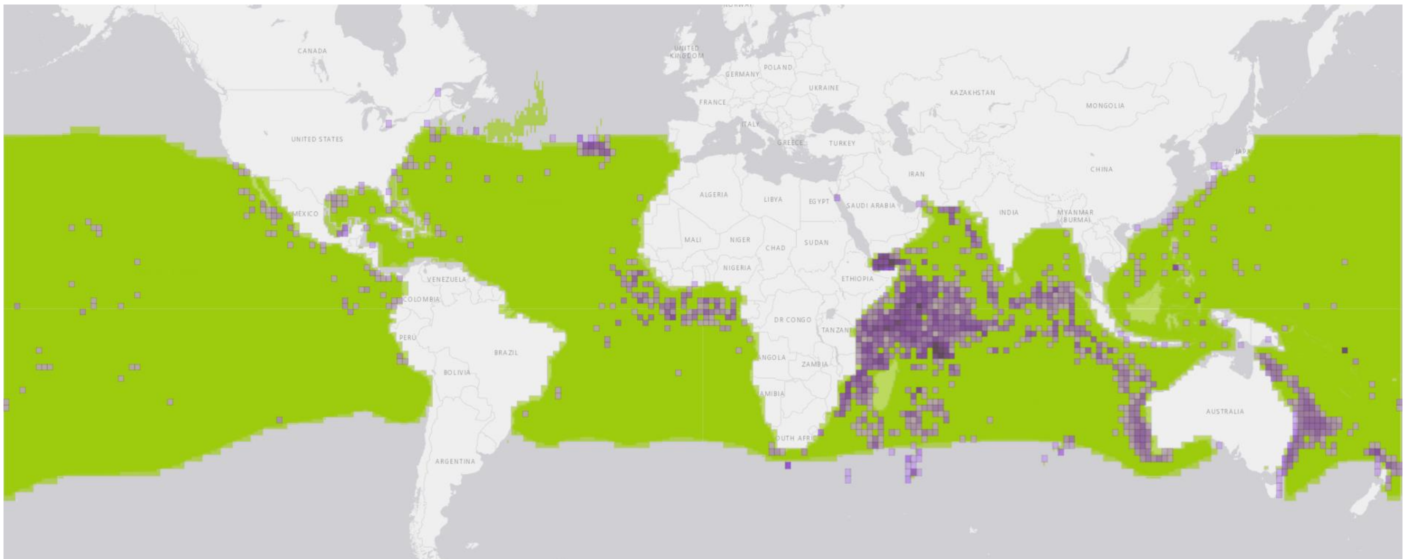

Fig. 24. Global distribution of yellowfin tuna according to IUCN expert range maps (green envelope) and observations (purple points) recorded in the Global Biodiversity Information Facility (purple squares). Source: www.mol.org

Movements & migrations

Yellowfin tuna are a highly migratory species, making extensive migrations across entire oceans, occupying vast pelagic habitats (Schaefer et al. 2011, 2015).

The tag recoveries of the RTTP-IO provided evidence of these large movements of yellowfin tuna, thus supporting the assumption of a single stock for the Indian Ocean. The average distance travelled by yellowfin between being tagged and recovered was 710 nautical miles and showed increasing distances as a function of time at sea. However, as the majority of tags were released close to the coasts of Tanzania and Mozambique and were mostly recovered in the western Indian Ocean by purse seiners operating in this region, there is a lack of data from the eastern Indian Ocean. It is unclear if this reflects the low rates of movement between the east and west of the Indian Ocean or if it is due to low reporting rates from fisheries operating in the eastern Indian Ocean (Langley & Million 2012).

Population structure

Numerous studies have been conducted to attempt to determine the population structure of yellowfin tuna both within the Indian Ocean and compared to other oceans. Results from the tagging study supported the hypothesis that there is one single well-mixed yellowfin tuna population in the Indian Ocean (Pecoraro et al. 2017).

However, genetic differentiations have been found between sites in the north-western Indian Ocean in studies using a variety of techniques (Dammannagoda et al. 2008, Kunal et al. 2013). The conclusion resulting from these studies is that there may be different sub-populations present in the northern Indian Ocean. Kunal et al. (2013) analysed the sequence of mtDNA D-loops and found at least three different genetic populations in Indian Ocean waters. These sub-populations could help to explain the fidelity to different spawning areas seen in the Indian Ocean (Pecoraro et al. 2017).

Results from a recent genetic study looking to determine the population structure of yellowfin tuna indicated that there are likely to be at least two genetic groupings in the Indian Ocean with genetic differentiation being most pronounced between groups sampled to the north and south of the equator. There was also some evidence to suggest the presence of two distinct genetic groups in the northern part of the Indian Ocean (Grewe et al. 2020). The study indicated that the Indian Ocean is genetically isolated from both the Atlantic and Pacific Oceans and suggested that this is likely to be the result of environmentally induced physiological barriers to migration (Grewe et al. 2020). The authors stated that analysis of further samples with a wider spatial distribution would be helpful to gain more confidence in these results.

Growth & morphometrics

The maximum recorded size of yellowfin tuna is 240 cm FL and the maximum recorded weight was 200 kg (Anonymous 1994, IGFA 2001).

Estimating yellowfin tuna age and growth parameters is challenging due of a number of issues: otoliths and other hard pieces used for fish aging are less marked in tropical environments compared with temperate waters; reproduction occurs year round making interpretation of otolith readings difficult; and there are several known biases and uncertainties which affect age estimates derived from reading micro-increments in otoliths (Sardenne et al. 2015). A number of different aging procedures have been used to determine yellowfin tuna growth. Most recently, the development of integrated modelling approaches which combine different data sources within a unifying statistical framework have been used to estimate growth in the Indian Ocean (Dortel et al. 2015, Eveson et al. 2015).

The von Bertalanffy model was first used to model yellowfin tuna growth, however, growth studies from the last few decades have provided support for the use of a two-stanza growth model with significant changes in the growth rates between juvenile and adult tunas (Fonteneau & Chassot 2012). In the Indian Ocean, it has been found that an initial slow growth phase with a rate of around 2 cm per month occurs in young yellowfin tuna until they reach the size 56-70 cm FL (Dortel et al. 2015, Eveson et al. 2015). When they reach the size of 145cm FL a second fast growth phase occurs (around 4 cm per month) followed by a progressive decrease of the growth rate at larger sizes (**Fig. 25**).

There are thought to be differences in growth between male and female yellowfin tuna in all oceans with an increasing proportion of males making up the larger size classes (Capisano 1991, Schaefer 1998). In the Indian Ocean, males have been found to become dominant in the 145-154 cm FL size class while females dominate the 115-130 cm FL size class (Nootmorn et al. 2005, Zhu et al. 2008, Zudaire et al. 2013).

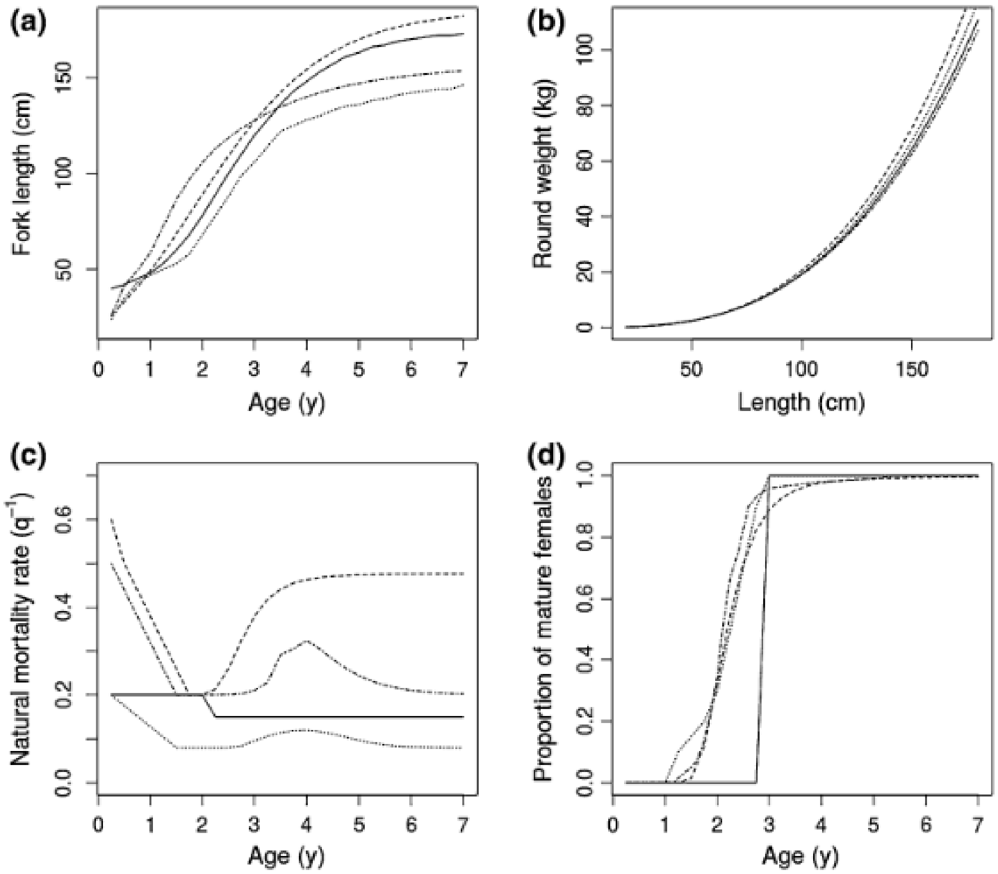

Fig. 25. Biological parameters currently used in stock assessments models of yellowfin (a) growth rate, (b) length-weight relationship, (c) natural mortality rates, (d) proportion of mature females. Different line types represent each Ocean: Atlantic Ocean (solid), Indian Ocean (dotted), Eastern Pacific Ocean (dashed), Western Pacific Ocean (dot-dash). Source: (Pecoraro et al. 2017)

Yellowfin tuna have several morphological characteristics which enable their enhanced swimming performance (Magnuson 1979, Brill 1996, Brill & Bushnell 2001). The fusiform and elongated body shape improves movement through the water and minimises hydrodynamic lift. The caudal peduncle includes three sets of bony keels that reduce drag and the anterior localisation of the muscle mass and insertion of myotomes over a greater number of vertebrae all contribute to yellowfin tuna's great ability to swim at high speeds for sustained periods of time (Westneat & Wainwright 2001).

Reproduction

Yellowfin tuna is an iteroparous, gonochoristic and oviparous species (Pecoraro et al. 2017). The size at which 50% of the yellowfin tuna population reaches maturity (L_{50}) varies between oceans and is thought to relate to relevant environmental cues (Pecoraro et al. 2017). In the western Indian Ocean L_{50} for females has been estimated at between 75-114 cm FL with the estimates varying due to different thresholds being taken to determine whether an individual has reached maturity (e.g., when displaying advanced vitellogenic oocytes or cortical alveolar stage oocytes) (Zhu et al. 2008, Zudaire et al. 2013). The age that 50% of females have reached maturity is estimated at 2.3 years of age (Zudaire et al. 2013, 2016, Grande et al. 2014).

While there is some seasonality in spawning, reproduction of yellowfin tuna occurs year round (Pecoraro et al. 2017). Spawning is thought to occur mainly between November and February in areas where surface temperature exceeds 24°C (Schaefer 2001, Stéquert et al. 2001, Zudaire et al. 2013). Spawning occurs mainly from December to March in the equatorial area (0-10°S), with the main spawning grounds west of 75°E (Schaefer 2001, Nootmorn et al. 2005, Zhu et al. 2008). Secondary spawning grounds exist off Sri Lanka and the Mozambique Channel and in the eastern Indian Ocean off

Australia (Chassot et al. 2019). The relative importance of different spawning areas on total catches as well as the degree of connectivity and mixing rates of yellowfin tuna are still unknown for the Indian Ocean.

Fecundity is thought to relate only to the mass-at-age of the sexually mature portion of the stock, regardless of the demographic composition of adults and so is not accounted for when estimating reproductive potential in stock assessments (Kell et al. 2016). Fecundity of yellowfin tuna has been estimated at around 76 eggs/g (±40) but the number of eggs released may depend not only on body size, but also on recent energy intake by individuals (Zudaire et al. 2013, 2016, Grande et al. 2014). Spawning frequency is not known for tunas in the Indian Ocean but data from the Pacific Ocean indicate a close to daily frequency (every 1.1-2 days for yellowfin tuna) (Hunter et al. 1986, McPherson 1991, Schaefer 1996, Itano 2000, Sun et al. 2013).

Tropical tunas are thought to mostly be recruited into the purse seine fishery at sizes around 30 cm FL before they reach the first stages of maturity and recruitment to the fishery is thought to be influenced by a number of environmental and oceanographic factors (Chassot et al. 2019). Lan et al. (2020) investigated the relationship between catch rates by longline fleets in the Indian Ocean and climatic variability and found that sea surface temperature was the most influential environmental variable for recruitment, but that Chl-a is not a significant factor. The same study found that there was a greater variance in the influence of Indian Ocean Dipoles than that of ENSO events with the influence of ENSO events only being evident near the Arabian Sea. Positive Indian Ocean Dipole and El Niño events were found to result in lower catch rates in the northwestern Indian Ocean (Lan et al. 2020).

Natural Mortality

The relationship between body size/age and natural mortality in tunas is generally assumed to decrease or follow a U-shaped relationship but there is thought to be a high level of variability between stocks of yellowfin tuna based on recent stock assessments (Hampton 2000). Mark-recapture experiments have been used to derive estimates of natural mortality but it is difficult to determine the contribution of natural mortality to total mortality affecting tuna stocks when selectivity patterns are considered (Pecoraro et al. 2017). Other issues resulting from these studies include the fact that low recovery rates of tagged individuals can cause biases with these data (Carruthers et al. 2014) and the time required for complete mixing of tagged individuals into the Indian Ocean population makes estimating natural mortality of juvenile yellowfin tuna very challenging (Kolody et al. 2016).

High natural mortality values (up to 0.33 per day) have been found for tuna in the early larval stages due to starvation and predation (Lang et al. 1994, Hampton 2000). Natural mortality during these early stages is thought to relate mostly to the size or age rather than the species of tuna (Hampton 2000, Fonteneau & Pallares 2005).

The longevity of yellowfin tuna in the Indian Ocean has been estimated at between 6-10 years (Kar et al. 2012, Rohit et al. 2012, Kaymaram et al. 2014, Nurdin et al. 2016).

Trophic ecology

Tunas are opportunistic predators which sit at the top of short food chains (Roger 1994). Yellowfin tuna are considered to be ‘energy speculators’ due to their high rates of energy turnover in nutrient poor environments including the open ocean (Korsmeyer et al. 1997). They have a varied diet which includes crustaceans, fish, cephalopods and gelatinous organisms (Potier et al. 2004). Preferred prey in the Indian Ocean are thought to include the nomeid *Cubiceps pauciradiatus* as well as the swimming crab *Charybdis smithii* (Potier et al. 2004, Zudaire et al. 2015). Habitat utilisation is thought to be strongly influenced by the presence of high prey densities with high prey densities being thought to be responsible for high levels of abundance and a degree of residency of yellowfin tuna (Itano & Holland 2000, Sibert & Hampton 2003, Schaefer & Fuller 2005).

Diet composition of yellowfin tuna is thought to be dependent on the size of the individuals with smaller fish (<40cm FL) feeding mainly on euphasiids and planktonic prey while larger fish (>50 cm FL) feed mainly on fishes, crustaceans and cephalopods (Ménard et al. 2007, Zudaire et al. 2015). These differences are thought to be a result of size associated increases in endothermic capability which allow larger individuals to dive to deeper depths which gives them access to a wider range of prey (Graham et al. 2007, Sardenne et al. 2016).

Yellowfin are thought to feed mostly during the day (displaying higher activity levels between sunrise and sunset) but have also been reported to feed at night (Reintjes & King 1953, Olson & Boggs 1986, Vaske-Júnior et al. 2003).

Analyses from a stable-isotope study conducted on yellowfin tuna in the Indian and Pacific Oceans estimated the average absolute trophic position of yellowfin tuna in the Indian Ocean to be around 2.7 compared with 2.6 for the Pacific Ocean (Lorrain et al. 2015). However, the same study also showed spatial variability in the absolute trophic position found within the Indian Ocean ranging from 2.6-3.0 (Lorrain et al. 2015). These estimates put the species in the tertiary consumer trophic level.

Markets

There are two main tuna product types for catches of industrial fisheries: high value products such as loins and steaks, mostly fish caught by longline fleets; and smaller, lower-quality fish mostly caught by purse seiners and other gears which are sent to canneries.

Fish caught by longline fleets are generally frozen onboard the vessels at -40°C or lower and are exported to Asia, in particular Japan for the high-value sashimi market (Miyake et al. 2010). Chassot et al. (2019) estimated the annual average value of bigeye and yellowfin imports into Japan at more than US$ 54 million globally. Chassot et al. (2019) estimated the annual value of purse seine catches taken just from within the Northern Mozambique Channel region to be around US$ 40 million using Bangkok import prices as a proxy during the period 2009-2019.

The increased demand for canned tuna in the 1950s drove major changes in tuna fisheries globally moving to much more industrial fleets which allowed the species to be exploited more fully over its entire range (Fonteneau 1997, 2010). While there are canneries located in several countries around the Indian Ocean, Seychelles acts as a regional hub for industrial tuna fisheries in the region and so a large proportion of purse seine catches are landed there (Robinson et al. 2006).

Canned tuna is exported around the world to the European Union, United States and Japan among others (Miyake et al. 2010). In these countries, supermarkets comprise a very large proportion of the sales of canned tuna and increasingly, canneries produce products under direct contract with the retailers (Miyake et al. 2010).

There is not thought to be a clear uniformity of prices in the world market for canned yellowfin and bigeye tuna in comparison to skipjack tuna (Bose & McIlgorm 1996, Squires et al. 2006). For the period 1992-2007, the price per kg of large yellowfin tuna in the Indian Ocean represented around 1.54±-0.16 times the price of mixed tuna, while mixed tuna represented 1.52±-0.20 times the price of small skipjack. This price distinction made free-school catches of large yellowfin tuna more valuable than FAD associated mixed fish or small skipjack (Miyake et al. 2010). However, many purse seiners have chosen to focus more on efficiency (the catch quantity per unit of fuel is highest for FAD fishing) and now the majority (80% of purse seine catches) are taken on FADs (Miyake et al. 2010, Chassot et al. 2019).

Literature Cited

Adam SM (2004) Country review–Maldives. Review of the State World Marine Capture Fisheries Management: Indian Ocean. In: *FAO fisheries technical paper 488*.

Anonymous (1994) Atlas pesquero de México. Inst Nac Pesca:234.

Block BA, Keen JE, Castillo B, Dewar H, Freund EV, Marcinek DJ, Brill RW, Farwell C (1997) Environmental preferences of yellowfin tuna (*Thunnus albacares*) at the northern extent of its range. Mar Biol 130:119–132.

Bose S, McIlgorm A (1996) Substitutability Among Species in the Japanese Tuna Market: A Cointegration Analysis. Mar Resour Econ 11:143–155.

Brill R, Lowe T, Cousins K (1998) How water temperature really limits the vertical movements of tunas and billfishes-it's the heart stupid. Int Congr Biol Fish American Fisheries Society:57–62.

Brill RW (1996) Selective advantages conferred by the high performance physiology of tunas, billfishes, and dolphin fish. Comp Biochem Physiol A Physiol 113:3–15.

Brill RW, Block BA, Boggs CH, Bigelow KA, Freund EV, Marcinek DJ (1999) Horizontal movements and depth distribution of large adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes. Mar Biol 133:395–408.

Brill RW, Bushnell PG (2001) The cardiovascular system of tunas. In: *Fish Physiology*. Academic Press, p 79–120

Brill RW, Lutcavage ME (2001) Understanding environmental influences on movements and depth distributions of tunas and billfishes can significantly improve population assessments. In. In: *Islands in the Stream: Oceanography and Fisheries of the Charleston Bump. Am Fish Soc Symp, Bethesda, MD 25*.

Capisano C (1991) Analysis of length frequencies, sex ratio and reproduction zones of the yellowfin Thunnus albacares in the Atlantic. ICCAT Coll Vol Sci Pap 36:214–279. p 214–279

Carruthers TR, Punt AE, Walters CJ, MacCall A, McAllister MK, Dick EJ, Cope J (2014) Evaluating methods for setting catch limits in data-limited fisheries. Fish Res 153:48–68.

Chassot E, Assan C, Soto M (2015) Statistics of the European Union and associated flags purse seine fishing fleet targeting tropical tunas in the Indian Ocean. 1981–2014. In: *IOTC proceedings. IOTC, Victoria*. p 32

Chassot E, Bodin N, Sardenne F, Obura D (2019) The key role of the Northern Mozambique Channel for Indian Ocean tropical tuna fisheries. Rev Fish Biol Fish 29:613–638.

Chassot E, Dewals P, Floch L, Lucas V, Morales-Vargas M, Kaplan DM (2010) Analysis of the effects of Somali piracy on the European tuna purse seine fisheries of the Indian Ocean. IOTC Sci. Comm. Rep. Indian. Indian Ocean Tuna Commission, Victoria, Seychelles

Dammannagoda ST, Hurwood DA, Mather PB (2008) Evidence for fine geographical scale heterogeneity in gene frequencies in yellowfin tuna (*Thunnus albacares*) from the north Indian Ocean around Sri Lanka. Fish Res 90:147–157.

Dortel E, Sardenne F, Bousquet N, Rivot E, Million J, Le Croizier G, Chassot E (2015) An integrated Bayesian modeling approach for the growth of Indian Ocean yellowfin tuna. Fish Res 163:69–84.

Eveson JP, Million J, Sardenne F, Le Croizier G (2015) Estimating growth of tropical tunas in the Indian Ocean using tag-recapture data and otolith-based age estimates. Fish Res 163:58–68.

Fonteneau A (2010) Atlas of Indian Ocean tuna fisheries.

Fonteneau A (1997) Atlas of tropical tuna fisheries. World catches and environment. ORSTOM Ed Paris Cedex:192.

Fonteneau A, Chassot E (2012) An overview of yellowfin tuna growth in the Atlantic Ocean: Von Bertalanffy or multistanza growth? In: *Tropical tunas = Thonidés tropicaux = Tunidos tropicales*. ICCAT, Madrid, Spain, p 2059–2075

Fonteneau A, Pallares P (2005) Tuna natural mortality as a function of their age: the bigeye tuna (Thunnus obesus) case. p 127–141

Froese R, Pauly DE (2009) Fishbase: Yellowfin tuna. https://www.fishbase.se/summary/Thunnus-albacares.html

Galli GLJ, Shiels HA, Brill RW (2009) Temperature sensitivity of cardiac function in pelagic fishes with different vertical mobilities: yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), mahimahi (*Coryphaena hippurus*), and swordfish (*Xiphias gladius*). Physiol Biochem Zool 82:280–290.

Graham B, Grubbs D, Holland K, Popp B (2007) A rapid ontogenetic shift in the diet of juvenile yellowfin tuna from Hawaii. Mar Biol 150:647–658.

Grande M, Murua H, Zudaire I, Goñi N, Bodin N (2014) Reproductive timing and reproductive capacity of the skipjack tuna (*Katsuwonus pelamis*) in the western Indian Ocean. Fish Res 156:14–22.

Grewe P, Feutry P, Foster S, Aulich J (2020) Genetic population connectivity of yellowfin tuna in the Indian Ocean from the PSTBS-IO Project. In: *IOTC Working Party on Tropical Tunas WPTT22*.

Hampton J (2000) Natural mortality rates in tropical tunas: size really does matter. Can J Fish Aquat Sci 57:1002–1010.

Hunter JR, Macewicz BJ, Sibert JR (1986) The spawning frequency of skipjack tuna, *Katsuwonus pelamis*, from the South Pacific. Fish Bull 84:895–903.

IGFA (2001) Database of IGFA angling records until 2001. http://www.igfa.org/

IOTC (2019) Alternative approaches to the revision of official species composition for the Spanish log-associated catch-and-effort data for tropical tuna species in 2018. Karachi, Pakistan, 27-30 November 2019, p 27

IOTC (2021) Review of the statistical data available for yellowfin tuna. In: *IOTC WPTT*.

Itano DG (2000) The Reproductive Biology of Yellowfin Tuna (*Thunnus albacares*) in Hawaiian Waters and the Western Tropical Pacific Ocean: project summary.

Itano DG, Holland KN (2000) Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in relation to FADs and natural aggregation points. Aquat Living Resour 13:213–223.

Kar AB, Ramalingam L, Govindaraj K, Prasad GV (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. In: *IOTC WPTT*.

Kaymaram F, Hosseini SA, Darvishi M, Parafkandeh F (2014) Estimates of length-based population parameters of yellowfin tuna (*Thunnus albacares*) in the Oman Sea. Turk J Fish Aquat Sci 14.

Kell LT, Nash RDM, Dickey-Collas M, Mosqueira I, Szuwalski C (2016) Is spawning stock biomass a robust proxy for reproductive potential? Fish Fish 17:596–616.

Kolody DS, Eveson JP, Hillary RM (2016) Modelling growth in tuna RFMO stock assessments: Current approaches and challenges. Growth Theory Estim Appl Fish Stock Assess Models 180:177–193.

Korsmeyer KE, Lai NC, Shadwick RE, Graham JB (1997) Heart rate and stroke volume contribution to cardiac output in swimming yellowfin tuna: response to exercise and temperature. |. J Exp Biol Co Biol 200.

Kunal SP, Kumar G, Menezes MR, Meena RM (2013) Mitochondrial DNA analysis reveals three stocks of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) in Indian waters. Conserv Genet 14:205–213.

Lan K-W, Chang Y-J, Wu Y-L (2020) Influence of oceanographic and climatic variability on the catch rate of yellowfin tuna (*Thunnus albacares*) cohorts in the Indian Ocean. Deep Sea Res Part II Top Stud Oceanogr 175:104681.

Lang KL, Grimes CB, Shaw RF (1994) Variations in the age and growth of yellowfin tuna larvae, *Thunnus albacares*, collected about the Mississippi River plume. Environ Biol Fishes 39:259–270.

Langley A, Million J (2012) Determining an appropriate tag mixing period for the Indian Ocean yellowfin tuna stock assessment.

Lorrain A, Graham BS, Popp BN, Allain V, Olson RJ, Hunt BPV, Potier M, Fry B, Galván-Magaña F, Menkes CER, Kaehler S, Ménard F (2015) Nitrogen isotopic baselines and implications for estimating foraging habitat and trophic position of yellowfin tuna in the Indian and Pacific Oceans. Deep Sea Res Part II Top Stud Oceanogr 113:188–198.

Magnuson JJ (1979) Locomotion by Scombrid fisheres: hydromechanics, morphology and behavior. In: *Fish Physiology*. p 239–313

McPherson G (1991) Reproductive biology of yellowfin tuna in the eastern Australian Fishing Zone, with special reference to the north-western Coral Sea. Mar Freshw Res 42:465–477.

Ménard F, Lorrain A, Potier M, Marsac F (2007) Isotopic evidence of distinct feeding ecologies and movement patterns in two migratory predators (yellowfin tuna and swordfish) of the western Indian Ocean. Mar Biol 153:141–152.

Miyake M, Guillotreau P, Sun C-H, Ishimura G (2010) Recent developments in the tuna industry: stocks, fisheries, management, processing, trade and markets. FAO

Nootmorn P, Yakoh A, Kawises K (2005) Reproductive biology of yellowfin tuna in the Eastern Indian Ocean. p 379–385

Nurdin E, Sondita MFA, Yusfiandayani R, Baskoro MS (2016) Growth and mortality parameters of yellowfin tuna (*Thunnus albacares*) in Palabuhanratu waters, west Java (eastern Indian Ocean). Aquac Aquar Conserv Legis 9:741–747.

Olson RJ, Boggs CH (1986) Apex predation by yellowfin tuna (*Thunnus albacares*): independent estimates from gastric evacuation and stomach contents, bioenergetics, and cesium concentrations. Can J Fish Aquat Sci 43:1760–1775.

Pecoraro C, Zudaire I, Bodin N, Murua H, Taconet P, Díaz-Jaimes P, Cariani A, Tinti F, Chassot E (2017) Putting all the pieces together: integrating current knowledge of the biology, ecology, fisheries status, stock structure and management of yellowfin tuna (*Thunnus albacares*). Rev Fish Biol Fish 27:811–841.

Potier M, Marsac F, Lucas V, Sabatié R, Hallier J-P, Ménard F (2004) Feeding partitioning among tuna taken in surface and mid-water layers: the case of yellowfin (<i>Thunnus albacares<i>) and bigeye (*T. obesus*) in the western tropical Indian Ocean. West Indian Ocean J Mar Sci 3:51–62.

Reglero P, Tittensor DP, Álvarez-Berastegui D, Aparicio-González A, Worm B (2014) Worldwide distributions of tuna larvae: revisiting hypotheses on environmental requirements for spawning habitats. Mar Ecol Prog Ser 501:207–224.

Reintjes JW, King JE (1953) Food of yellowfin tuna in the central Pacific. Fish Bull Fish Wildl Serv 138 81.

Reygondeau G, Maury O, Beaugrand G, Fromentin JM, Fonteneau A, Cury P (2012) Biogeography of tuna and billfish communities. J Biogeogr 39:114–129.

Robinson J, Aumeeruddy R, Isidore M, Payet R, Marguerite M, Laval M, Domingue G, Lucas V (2006) Country Review: Seychelles. In: *Review of the state of world marine capture fisheries management: Indian Ocean*. FAO FISHERIES TECHNICAL PAPER 488,

Roger C (1994) Relationships among yellowfin and skipjack tuna, their prey-fish and plankton in the tropical western Indian Ocean. Fish Oceanogr 3:133–141.

Rohit P, Rao GS, 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 J Fish 59:1–6.

Sardenne F, Bodin N, Chassot E, Amiel A, Fouché E, Degroote M, Hollanda S, Pethybridge H, Lebreton B, Guillou G, Ménard F (2016) Trophic niches of sympatric tropical tuna in the Western Indian Ocean inferred by stable isotopes and neutral fatty acids. Prog Oceanogr 146:75–88.

Sardenne F, Dortel E, Le Croizier G, Million J, Labonne M, Leroy B, Bodin N, Chassot E (2015) Determining the age of tropical tunas in the Indian Ocean from otolith microstructures. Fish Res 163:44–57.

Schaefer K, Fuller D (2005) Behavior of bigeye (*Thunnus obesus*) and skipjack (*Katsuwonus pelamis*) tunas within aggregations associated with floating objects in the equatorial eastern Pacific. Mar Biol 146:781–792.

Schaefer K, Fuller D, Hampton J, Caillot S, Leroy B, Itano D (2015) Movements, dispersion, and mixing of bigeye tuna (*Thunnus obesus*) tagged and released in the equatorial Central Pacific Ocean, with conventional and archival tags. Fish Res 161:336–355.

Schaefer KM (2001) Reproductive biology of tunas. In: *Fish Physiology*. Tuna: Physiology, Ecology, and Evolution, Academic Press, p 225–270

Schaefer KM (1998) Reproductive biology of yellowfin tuna *Thunnus albacares* in the eastern Pacific Ocean. Inter-Amer Trop Tuna Comm Bull 21:201–272.

Schaefer KM (1996) Spawning time, frequency, and batch fecundity of yellowfin tuna, *Thunnus albacares* near Clipperton Atoll in the eastern Pacific Ocean. Fish Bull 94:98–112.

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

Schaefer KM, Fuller DW, Block BA (2009) Vertical movements and habitat utilization of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tunas in the equatorial Eastern Pacific Ocean, ascertained through archival tag data. In: *Tagging and Tracking of Marine Animals with Electronic Devices*. Reviews: Methods and Technologies in Fish Biology and Fisheries, Nielsen JL, Arrizabalaga H, Fragoso N, Hobday A, Lutcavage M, Sibert J (eds) Springer Netherlands, Dordrecht, p 121–144

Sibert J, Hampton J (2003) Mobility of tropical tunas and the implications for fisheries management. Mar Policy 27:87–95.

Squires D, Kim T, Jeon Y, Clarke R (2006) Price linkages in Pacific tuna markets: implications for the South Pacific Tuna Treaty and the Western and Central Pacific region. Environ Dev Econ 11:747–767.

Stéquert B, Rodriguez JN, Cuisset B, Le Menn F (2001) Gonadosomatic index and seasonal variations of plasma sex steroids in skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) from the western Indian ocean. Aquat Living Resour 14:313–318.

Sun CL, Yeh SZ, Chang YJ, Chang HY, Chu SL (2013) Reproductive biology of female bigeye tuna *Thunnus obesus* in the western Pacific Ocean. J Fish Biol 83:250–271.

Sund PN, Blackburn M, Williams F (1981) Tunas and their environment in the Pacific Ocean: a review. Ocean Mar Biol Annu Rev:443–512.

Vaske-Júnior T, Vooren CM, Lessa RP (2003) Feeding strategy of yellowfin tuna (*Thunnus albacares*) and wahoo (*Acanthocybium solandri*) in the Saint Peter and Saint Paul Archipelago, Brazil. Bull Inst Fish 29:173–181.

Westneat MW, Wainwright SA (2001) 7. Mechanical design for swimming: muscle, tendon, and bone. In: *Fish Physiology*. Academic Press, p 271–311

Zhu G, Xu L, Zhou Y, Song L (2008) Reproductive biology of yellowfin tuna T. albacares in the west-central Indian Ocean. J Ocean Univ China 7:327–332.

Zudaire I, Chassot E, Murua H, Dhurmeea Z, Cedras M, Bodin N, Working Party on Tropical Tunas, 18., Victoria (SEY), 2016/11/05-10, Working Party on Tropical Tunas, 18., Victoria (SEY), 2016/11/05-10 (2016) Sex-ratio, size at maturity, spawning period and fecundity of bigeye tuna (*Thunnus obesus*) in the western Indian Ocean. CTOI, Victoria Mahé

Zudaire I, Murua H, Grande M, Goñi N, Potier M, Ménard F, Chassot E, Bodin N (2015) Variations in the diet and stable isotope ratios during the ovarian development of female yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. Mar Biol 162:2363–2377.

Zudaire I, Murua H, Grande M, Korta M, Arrizabalaga H, Areso JJ, Delgado-Molina A (2013) Fecundity regulation strategy of the yellowfin tuna (*Thunnus albacares*) in the Western Indian Ocean. Fish Res 138:80–88.