REVIEW OF THE STATISTICAL DATA AND FISHERY TRENDS FOR INDIAN OCEAN TEMPERATE TUNA

Author: IOTC Secretariat

Abstract

This document provides an overview on the consolidated knowledge of fisheries catching albacore (*Thunnus alalunga*) in the Indian Ocean since the early 1950s, based on a range of data sets collected by the Contracting Parties and Cooperating Non-Contracting Parties (CPCs) of the IOTC and curated by the IOTC Secretariat. The available fisheries statistics indicate that over the last decade albacore has been essentially caught by large-scale longline fisheries, which are composed of a combination of deep-freezing longliners (also targeting bigeye tuna and yellowfin for the sashimi market) and "fresh" longliners (mostly targeting albacore for the canning market). Catches showed an increasing trend over time and reached about 40,000 t in recent years. Little information is available on discarding practices of albacore in industrial longline fisheries but the literature and few data sets collected through the IOTC Regional Observer Scheme suggest that discard levels are small regarding the high market value of the species. Furthermore, discarding is considered to be negligible in the coastal line fisheries interacting with the species. The information available on geo-referenced catch, effort, and size composition shows strong, consistent spatial patterns in the distribution of the fisheries across the Indian Ocean. During the last decade (2010-2019), hotspots appeared to have emerged in the fishing grounds east of Mozambique (including their adjacent high seas), in the southeastern waters of Indonesia, and in the high seas south of 25°S in the southwestern Indian Ocean. This latter area now represents the main fishing grounds of Indian Ocean albacore, with most of the catch coming from longline fisheries operating between 40-80°E and 10-40°S. Size data mainly collected onboard longliners flagged by Taiwan,China show that the larger individuals are mostly caught in tropical waters while their smaller counterparts mostly occur in the south of the Indian Ocean.

Keywords: albacore, canning, discard, Indian Ocean, longline fisheries

Introduction

The global catch levels of albacore (*Thunnus alalunga*; ALB) and southern bluefin tuna (*Thunnus maccoyii*; SBF) have been relatively stable over the last decade at around 246,000 and 13,000 metric tons (t), respectively (FAO 2021). In the Indian Ocean, these two temperate tuna species have represented a small component of the total tuna catch since the major development of the fisheries targeting tropical tuna in the 1980s.

In 2020, the total catch of Indian Ocean temperate tunas has been estimated at 51,547 t, representing 2.7% of catches of all species managed by the Indian Ocean Tuna Commission (IOTC). Although SBF falls under the Agreement for the Establishment of the IOTC, the species' range extends beyond the Indian Ocean and therefore SBF is now exclusively managed by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT).

The overarching objective of this paper is to provide participants at the data preparatory meeting of the 8th Session of the IOTC Working Party on Temperate Tunas (WPTmT08(DP)) with a review of the status of the information available on albacore. The document provides an overview of the data available for the species in all IOTC Secretariat databases as of March 2022 and focuses on the progress achieved in relation to the collection and verification of data, identifies problem areas, and proposes actions that could be undertaken to improve them.

Materials

Several fisheries data sets shall be reported to the Secretariat by IOTC Contracting Parties and Cooperating Non-Contracting Parties (CPCs) having vessels flying their flag that fish for species under the IOTC mandate within the IOTC area of competence as per the IOTC Conservation and Management Measures (CMMs). The IOTC data requirements concern the 16 IOTC species that are listed in Annex B of the IOTC Agreement as well as the most commonly caught elasmobranch species listed in Appendix I of IOTC Resolution 15/01. It is worth noting that the IOTC definition of bycatch differs from those used in other areas and fisheries as bycatch species correspond to all species other than the 16 IOTC species, whether caught or interacted with by fisheries for tuna and tuna-like species in the IOTC area of competence.

Data sets submitted to the Secretariat shall follow the standards and formats defined in the IOTC Reporting guidelines. Although not mandatory, the use of the IOTC forms is recommended to report the data to the Secretariat as these forms facilitate data curation and management.

Nominal catch data

Nominal catches correspond to the total retained catches (in live weight) estimated per year, Indian Ocean major area, fleet, and gear (IOTC Res. 15/02) and can be reported through IOTC form 1RC.

Geo-referenced catch and effort data

Catch and effort data refer to fine-scale data, usually from logbooks, reported in aggregated format and stratified per year, month, grid, fleet, gear, type of school, and species (IOTC Res. 15/02). The IOTC forms designed for reporting geo-referenced catch and effort data vary according to the nature of the fishing gear (i.e., surface, longline, and coastal gears). In addition, information on the use of fish aggregating devices (FADs) and activity of the support vessels that assist industrial purse seiners also has to be collected and reported to the Secretariat through IOTC forms 3FA and 3SU.

Discard data

The IOTC follows the definition of discards adopted by FAO in previous reports (Alverson et al. 1994; Kelleher 2005) which considers all non-retained catch, including individuals released alive or discarded dead. Estimates of total annual discard levels in live weight (or number) by Indian Ocean major area, species and type of fishery shall be reported to the Secretariat as per IOTC Res. 15/02. The IOTC form 1DI has been designed for the reporting of these data already extrapolated at the source to represent the total level of discards for the year, gear, fleet, Indian Ocean major area, and species concerned (including turtles, cetaceans, and seabirds).

Nevertheless, discard data reported to the Secretariat with IOTC Form 1DI are generally scarce, not raised, and not complying with IOTC reporting standards. For these reasons, the most accurate information available on discards comes from the IOTC Regional Observer Scheme (ROS) (IOTC Res. 11/04) that aims to collect detailed information (e.g., higher spatio-temporal resolution, fate, etc.) on discards of IOTC and bycatch species for industrial fisheries (see below).

Size frequency data

The size composition of catches may be derived from the data set of individual body lengths or weights collected at sea and during the unloading of fishing vessels. The IOTC Form 4SF provides all fields requested for a complete reporting of size frequency data to the stratified by fleet, year, gear, type of school, month, grid and species as required by IOTC Res. 15/02. While the great majority of size data reported through IOTC Form 4SF are for retained catches, CPCs can also use the same form to report size data of discarded individuals. Furthermore, additional size data (including those for individuals discarded at sea) may be collected through onboard observer programs and reported to the Secretariat as part of the ROS (see below).

Socio-economic data

The IOTC Form 7PR has been designed to voluntarily report prices of fish per type of product and market for the target species of Indian Ocean tuna and tuna-like species. To date, very little information is available at the Secretariat on the socio-economics of tuna and tuna-like fisheries (e.g., sale price, operating costs, jobs).

The Fisheries Development Division of the Pacific Islands Forum Fisheries Agency (FFA) has been collating monthly time series of tuna price data on key markets to use them as indicators of the trends in the price received by operators (IOTC 2021a). Time series of price include (i) import prices in Thailand for canning-grade frozen albacore (USD/t; 2000-2020) and (ii) import prices in the USA from Oceania for sashimi-grade fresh (chilled) albacore caught with longline (USD/kg; 2000-2020). Fish prices were adjusted for inflation using US Consumer Price Index data to obtain real prices (Ruaia et al. 2020). These time series are considered more representative of trends in tuna price than the prices received by operators (i.e., ex-vessel prices) which may strongly depend on the markets and transport costs (Ruaia et al. 2020).

In addition, the FFA collates information on fuel price, which is a major driver of costs in high seas fisheries and is considered a good proxy of fishing costs (Sala et al. 2018), assuming that real non-fuel fishing costs have remained constant over time (Ruaia et al. 2020). The crude oil spot price, computed as the arithmetic average of the spot prices of Brent, Dubai, and West Texas, provides a global index of the value of fuel for fishing vessels as crude oil forms the basis for most fuels used in most fishing vessels, e.g, marine diesel oil. Time series of import price for albacore and fuel price are given in Appendix V.

Observer data

Resolution 11/04 on the ROS makes provisions for the development and implementation of national observer schemes among the IOTC CPCs starting from July 2010 with the overarching objective of collecting *"verified catch data and other scientific data related to the fisheries for tuna and tuna-like species in the IOTC area of competence"*. The ROS aims to cover *"at least 5% of the number of operations/sets for each gear type by the fleet of each CPC while fishing in the IOTC Area of competence of 24 meters overall length and over, and under 24 meters if they fish outside their EEZs shall be covered by this observer scheme"*. Observer data collected as part of the ROS include: (i) fishing activities and vessel positions, (ii) catch estimates with a view to identifying catch composition and monitoring discards, bycatch, and size frequency, (iii) gear type, mesh size and attachments employed by the master, and (iv) information to enable the cross-checking of entries made to the logbooks (i.e., species composition and quantities, live and processed weight and location). In addition, the ROS database includes morphometric data (i.e., lengths and weights) collected at sea by fisheries observers which are of particular interest to derive morphometric relationships (see section Morphometric data). The document IOTC-2021-WPDCS17-INF10 provides a full description of the ROS data requirements for each fishing gear (IOTC 2021b).

The document IOTC-2021-WGEMS01-09 provides a comprehensive description of the status, coverage, and data collected as part of the ROS (IOTC 2021c). Although incomplete and characterized by a large variability in coverage between fisheries and over space and time, observer data include information on the fate of the catches (i.e. retained or discarded at sea) as well as on the condition of the discards. Observer data are also the main source of spatial information on interactions between IOTC fisheries and seabirds, marine turtles, cetaceans, as well as any other species encountered.

To date, the ROS regional database contains information for a total of 1,492 commercial fishing trips (845 from purse seine vessels and 647 from longline vessels of various types) made during the period 2005-2019 from 7 fleets: Japan, EU,France and Sri Lanka for longline fisheries and EU,Spain, EU,France, Japan, Korea, Mauritius, and Seychelles for purse seine fisheries. In addition, some observer reports have been submitted to the Secretariat by some CPCs (e.g., Taiwan,China) but data sets were not provided in electronic format at the operational level following the ROS standards, *de facto* preventing the entry of the data in the ROS regional database.

Morphometric data

Different length-length and length-weight relationships have been estimated for Indian Ocean albacore based on morphometric data collected through fisheries monitoring programs and research projects (**Table 1**). In addition, a mean conversion factor of 1.1 between gilled-gutted weight and round weight has been derived in the Indonesian longline fishery from samples collected in Indonesia within the framework of the IOTC/OFCF sampling program (IOTC 2005). It is important to note that the current official relationship between fork length (FL) and round weight (RD) has been derived for albacore caught in the southeast Atlantic Ocean (Penney 1994).

Table 1: Summary of morphometric relationships available for Indian Ocean albacore. FL = fork length (cm); RD = round weight (kg); PFL = pectoral fork length (cm); LD1 = pre-dorsal length (cm). N = number of samples; LL = longline; GN = gillnet; PL = pole and line; PS = purse seine

Equation	Period	Gears	N	MinFL	MaxFL	a	b	Reference
RD = a*FL^b	1987-1990	LL;GN	446	45.0	120	3.5050e-05	2.8570	Huang et al. (1991)
RD = a*FL^b	1990-1991	GN	2,499	46.2	112	5.6907e-05	2.7514	Hsu (1999)
RD = a*FL^b	2011	LL	497	83.0	106	8.0000e-05	2.7271	Setyadji et al. (2012)
RD = a*FL^b	2013-2015	LL;PL;PS	1,516	67.0	118	3.2537e-06	3.4240	Dhurmeea et al. (2016)
PFL=a*FL+b	2013-2015	LL;PL;PS	1,060	67.0	118	7.0160e-01	0.6174	Dhurmeea et al. (2016)
LD1=a*FL+b	2013-2015	LL;PL;PS	925	83.0	116	2.6780e-01	5.4938	Dhurmeea et al. (2016)

Although biological data are not part of IOTC data requirements and most historical data sets collected by the CPCs were not made available to the Secretariat (Geehan and Hoyle 2013), some morphometric data have been collated from different sources, including: (i) historical longline observer programs from Korea and the UK (IOTC 2005), (ii) research project conducted on albacore by the University of Mauritius and the French national Research Institute for Sustainable Development (Dhurmeea et al. 2016; Bodin et al. 2018), (iii) routine monitoring program on the biology of large pelagics conducted by Ifremer at a processing factory in Reunion Island (Bonhommeau et al. 2018, 2019), and (iv) national scientific observer programs conducted by the CPCs from which data have been submitted to the Secretariat as part of the ROS. Data available for assessing the relationship between fork length and round weight are given in Appendix VI.

Methods

Data processing

The release of the curated public-domain data sets for albacore is done following data quality control and processing steps that are briefly summarized here.

First, standard controls and checks are performed to ensure that the metadata and data submitted to the Secretariat are consistent and include all mandatory fields (e.g., dimensions of the strata). The controls depend on each type of data set and may require the submission of revised data from CPCs if the original one is found to be incomplete.

Second, a series of processing steps is applied to derive the best scientific estimates of nominal catches for the 16 IOTC species (see **Appendix V** of IOTC (2014)), by implementing the following rules:

a. When nominal catches are not reported by a CPC, catch data from the previous year may be repeated or catches may be derived from a range of sources, such as partial catch and effort data (raised to represent total catches), the FAO FishStat database, data on imports of tuna from processing factories collaborating with the International Seafood Sustainability Foundation, etc. The same approach generally applies to non-members of the IOTC who are not requested to report data to the Secretariat;

b. For some specific fisheries characterized by well-known, outstanding issues in terms of data quality and completeness, a process of re-estimation of species and/or gear composition may be performed based on data available from other years or areas, or by using proxy fleets, i.e., fleets occurring in the same strata which are assumed to have similar catch composition, e.g., Moreno et al. (2012);

c. Finally, a disaggregation process tailored to each fishing fleet is performed to break down the catches by species and gear when they are reported as aggregates (**Table 2**).

Table 2: List of species groups including albacore

Species code	Name	Scientific name
AG45	Albacore, yellowfin tuna and bigeye tuna	*Thunnus alalunga; Thunnus albacares; Thunnus obesus*
TUN	Tunas nei	*Thunnini*
TUS	True tunas nei	*Thunnus spp*
TUX	Tuna-like fishes nei	*Scombroidei*

Third, and applying only to the five major IOTC species (albacore, bigeye tuna, skipjack tuna, yellowfin tuna, and swordfish), geo-referenced catches are raised to the best scientific estimates of nominal catches using available information and by either leveraging data from proxy fleets or adopting substitution schemes when the spatio-temporal information is not available for a given stratum. For this reason, the raised data sets represent the best scientific estimates of the geo-referenced catches given the information available to the Secretariat and the issues with data availability and data quality affecting several fisheries. The raised data are comprised of catches in weight and number and stratified by year, month, fleet, gear, school type (when available) and 5x5 degrees grid, covering the entire time series for which nominal catches are available. The average weight of swordfish in the catch can be computed directly from the raised weights and numbers for each fishery, with the accuracy of the results being directly proportional to the availability and quality of geo-referenced catch and size-frequency data for the stratum.

Fourth, and applying to all 16 IOTC species plus the most common shark species defined in the appendices of IOTC Resolution 15/01, filtering and conversions are applied to the size-frequency data in order to harmonize their format and structure and remove data which are non-compliant with IOTC standards, e.g., because provided with size bins exceeding the maximum width considered meaningful for the species (IOTC 2020a). The standard length measurements considered at IOTC are the eye fork length (EFL; straight distance from the orbit of the eye to the fork of the tail) for black and blue marlins and the fork length (FL; straight distance from the tip of the lower jaw to the fork of the tail) for all other species subject to mandatory size measurements (IOTC 2020a). All size samples collected using other types of measurements are converted into FL and EFL by using the IOTC equations, considering size range and intervals that may vary with species. If no IOTC-endorsed equations exist to convert from a given length measurement for a species to the standard FL and EFL measurements, the original size data are not disseminated but kept within the IOTC databases for future reference.

Last, a specific process is applied to the tagging data collected for the three tropical tuna species, to specifically filter dubious records, correct for potential tag loss, and adjust for under-reporting of recaptures (IOTC 2020b).

Data quality

Different processes may affect the quality of the statistical data reported to the Secretariat, depending on the complexity of the fisheries and the adequacy of the systems put in place by each CPC for collecting, processing, and managing the data. Specifically, the accuracy and precision of the data may be affected by some key factors such as low coverage of fishing logbooks, limited catch sampling, poor data resolution (e.g., due to species misidentification or absence of accurate information on fishing grounds), and general misreporting. In the absence of ancillary sources of information for cross-check and validation, assessing the accuracy of the data is a difficult task and controls put in place at the Secretariat mainly rely on assessing the timeliness and quality of the data reported against IOTC standards and checking the consistency of time series of the data (i.e., catch level and fishing effort trends, as well as catch composition).

A scoring system has been designed to assess the reporting quality of the nominal catch, catch-effort, and size-frequency data available at the Secretariat for all IOTC species. The determination of the score varies according to each type of data set and aims to assess the reporting coverage and the level of compliance with IOTC reporting standards (**Table 3**). Overall, the lower the score, the better the quality, although it is important to note that the quality scoring does not account for sources of uncertainty affecting the nominal catches such as under-reporting and/or misreporting.

Table 3: Key to IOTC quality scoring system

Data set	Criterion	By species	By gear
Nominal catch	Fully available	0	0
	Partially available	2	2
	Fully estimated	4	4
Catch and effort	Available according to standards	0	0
	Not available according to standards	2	2
	Low coverage (<30% logbooks)	2	
	Not available	8	
Size frequency	Available according to standards	0	0
	Not available according to standards	2	2
	Low coverage (<1 fish per ton caught)	2	
	Not available	8	

Results

Nominal catches

Historical trends (1950-2020)

Nominal catches of albacore have increased from about 4,000 t in the early 1950s to about 37,000 t in the 2010s (**Fig. 1**). Industrial fisheries represent the bulk of the catch since the development of high-seas longline fisheries in the early to mid-1950s, although catches from artisanal fisheries have shown an increase in recent years, reaching a maximum contribution of about 20% to total catches of albacore in 2020.

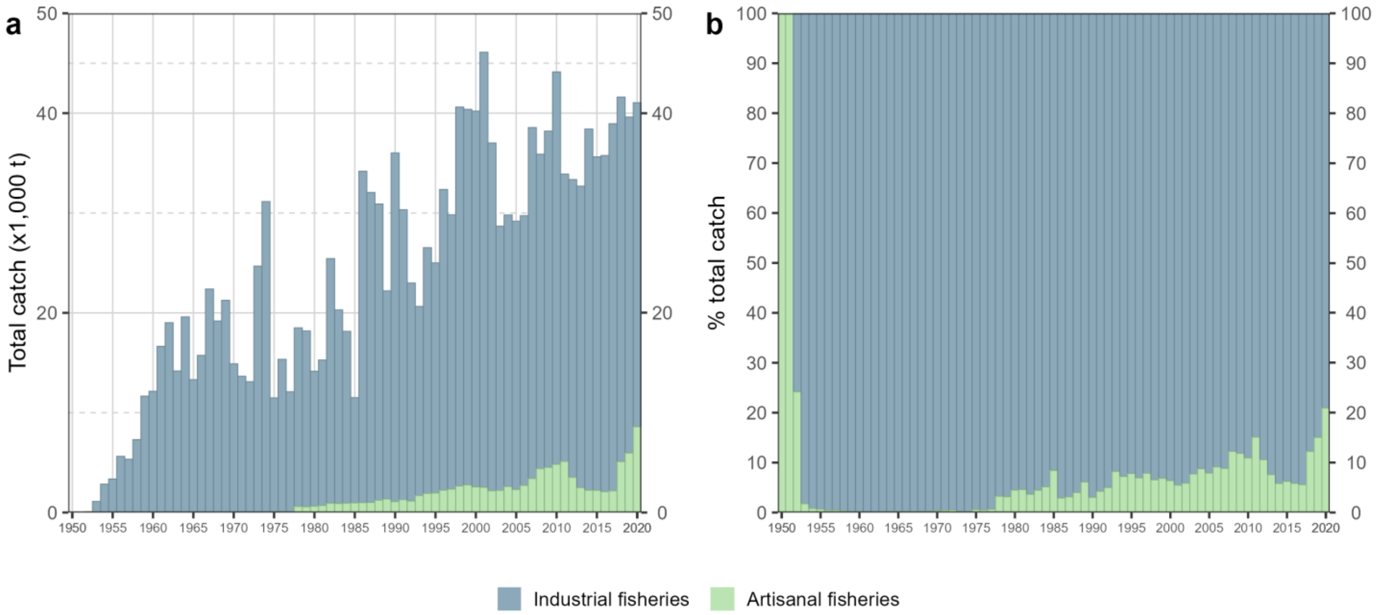

Figure 1: Annual time series of cumulative nominal absolute (a) and relative (b) catches (t) of albacore by type of fishery for the period 1950-2020

Over the last seven decades, albacore has been essentially caught by large-scale longline fisheries, except for the years between 1986 and 1991, when a large-mesh driftnet fishery (mostly operating in the high seas) was responsible for a substantial part of the total catches for the species (**Table 4** and **Fig. 2**). In December 1991, following the UN Resolution 44/225 that focused on the issue of bycatch mortality in large-scale high seas driftnet fisheries, the UN General Assembly passed Resolution 46/215 which called for a worldwide moratorium on high seas large scale driftnet fishing, de-facto causing the activities of this Indian Ocean fishery to end.

After a major increase in catches throughout the 1990s, which went from about 8,000 t in 1990 to 38,000 t in 2001, the deep-freezing longline fishery showed a substantial decline that brought down catches to about 9,000 t in 2007, with catch levels fluctuating around 11,000 t since then. Meanwhile, a fresh longline fishery quickly developed during the 2000s to reach annual catch levels of around 20,000 t over the last decade (**Table 4** and **Fig. 2**).

Table 4: Best scientific estimates of average annual nominal catches (t) of albacore by decade and fishery for the period 1950-2019. The background intensity color of each cell is directly proportional to the catch level

Fishery	1950s	1960s	1970s	1980s	1990s	2000s	2010s
Purse seine | Other			7	60	110	161	199
Purse seine | FS				187	1,578	858	409
Purse seine | LS				7	104	53	83
Longline | Other				18	219	1,060	560

Fishery	1950s	1960s	1970s	1980s	1990s	2000s	2010s
Longline | Fresh			80	314	1,309	11,702	21,327
Longline | Deep-freezing	3,715	17,313	17,061	14,966	21,609	18,720	11,430
Line | Coastal longline			75	618	1,163	1,571	1,886
Line | Trolling	15	25	58	207	449	807	997
Line | Handline	4	5	16	11	50	131	174
Baitboat				44	3		0
Gillnet	2	3	8	5,947	3,801	98	132
Other			5	37	75	179	208
Total	3,736	17,347	17,310	22,417	30,472	35,339	37,406

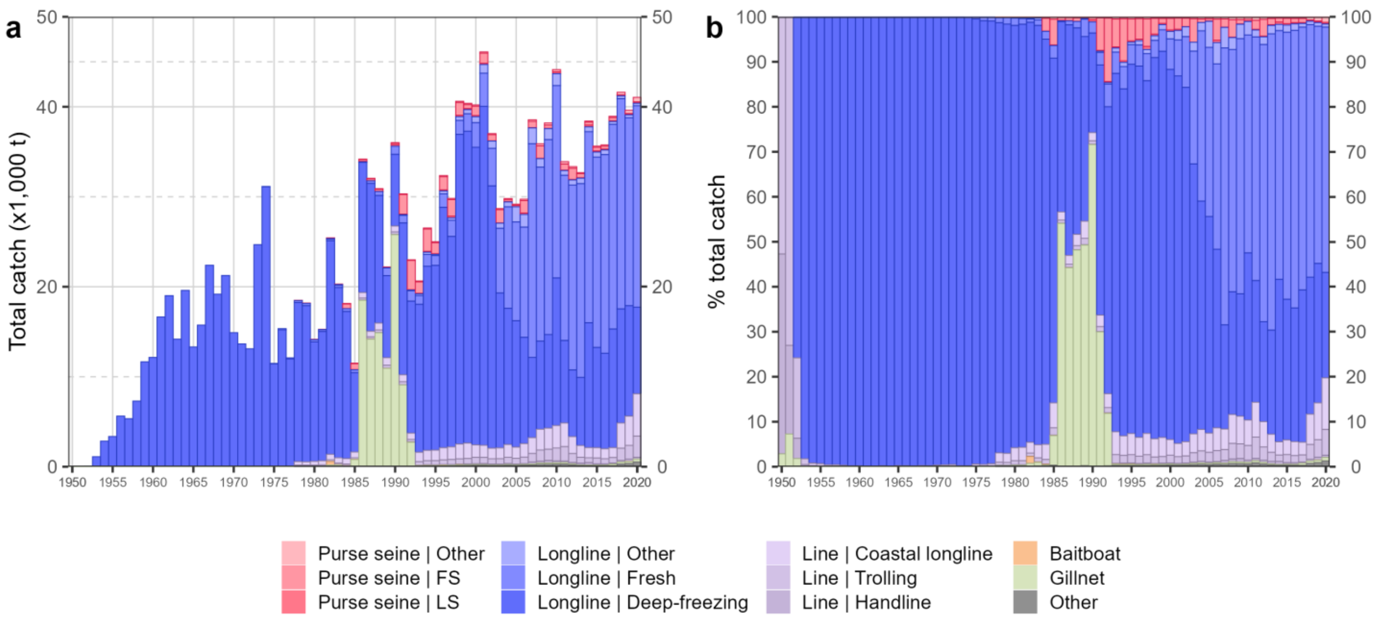

Figure 2: Annual time series of cumulative nominal absolute (a) and relative (b) catches (t) of albacore by fishery for the period 1950-2020. FS = free-swimming schools; LS = schools associated with floating objects

The available nominal catch data for albacore show the predominance of the fresh longline fishery during the last decade, with a contribution of almost 60% of the total catches of albacore on average each year (**Table 5**). The catches of this fishery have slightly increased during the last decade, from about 18,000 t in 2011 to about 22,000 t in 2020. Meanwhile, catches of the deep-freezing longline have varied between a minimum of 7,000 t in 2012 to a maximum of 14,000 t in 2014, with total landings of albacore for the deep-freezing longline fishery accounting for less than 10,000 t in 2020 (**Table 5**).

Table 5: Best scientific estimates of annual nominal catches (t) of albacore by fishery for the period 2011-2020. The background intensity color of each cell is directly proportional to the catch level

Fishery	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Purse seine | Other	267	189	124	113	122	128	138	294	367	511
Purse seine | FS	679	1,249	449	341	414	340	360	15	78	119
Purse seine | LS	46	48	52	193	120	93	79	98	64	28

Fishery	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Longline | Other	525	571	614	536	565	517	315	314	324	282
Longline | Fresh	18,361	20,547	21,528	21,234	21,147	22,069	22,750	23,361	20,890	22,382
Longline | Deep-freezing	9,167	7,410	7,564	13,873	11,142	10,619	13,181	12,674	12,276	9,626
Line | Coastal longline	2,626	1,877	1,316	1,130	1,156	1,109	1,103	2,802	3,243	4,709
Line | Trolling	1,612	986	654	545	644	569	612	1,364	1,537	2,348
Line | Handline	160	154	177	257	125	124	109	169	265	197
Baitboat									0	
Gillnet	163	115	75	69	69	75	179	213	211	318
Other	297	210	138	125	123	117	117	311	363	531
Total	33,902	33,355	32,691	38,414	35,628	35,761	38,943	41,615	39,616	41,051

Main fishery features (2016-2020)

Table 6: Mean annual catches (t) of albacore by fishery between 2016 and 2020. LS = schools associated with floating objects; FS = free-swimming schools

Fishery	Fishery code	Catch	Percentage
Longline | Fresh	LLF	22,290	56.6
Longline | Deep-freezing	LLD	11,675	29.6
Line | Coastal longline	LIC	2,593	6.6
Line | Trolling	LIT	1,286	3.3
Longline | Other	LLO	350	0.9
Purse seine | Other	PSOT	288	0.7
Other	OT	288	0.7
Gillnet	GN	199	0.5
Purse seine | FS	PSFS	182	0.5
Line | Handline	LIH	173	0.4
Purse seine | LS	PSLS	72	0.2
Baitboat	BB	0	0.0

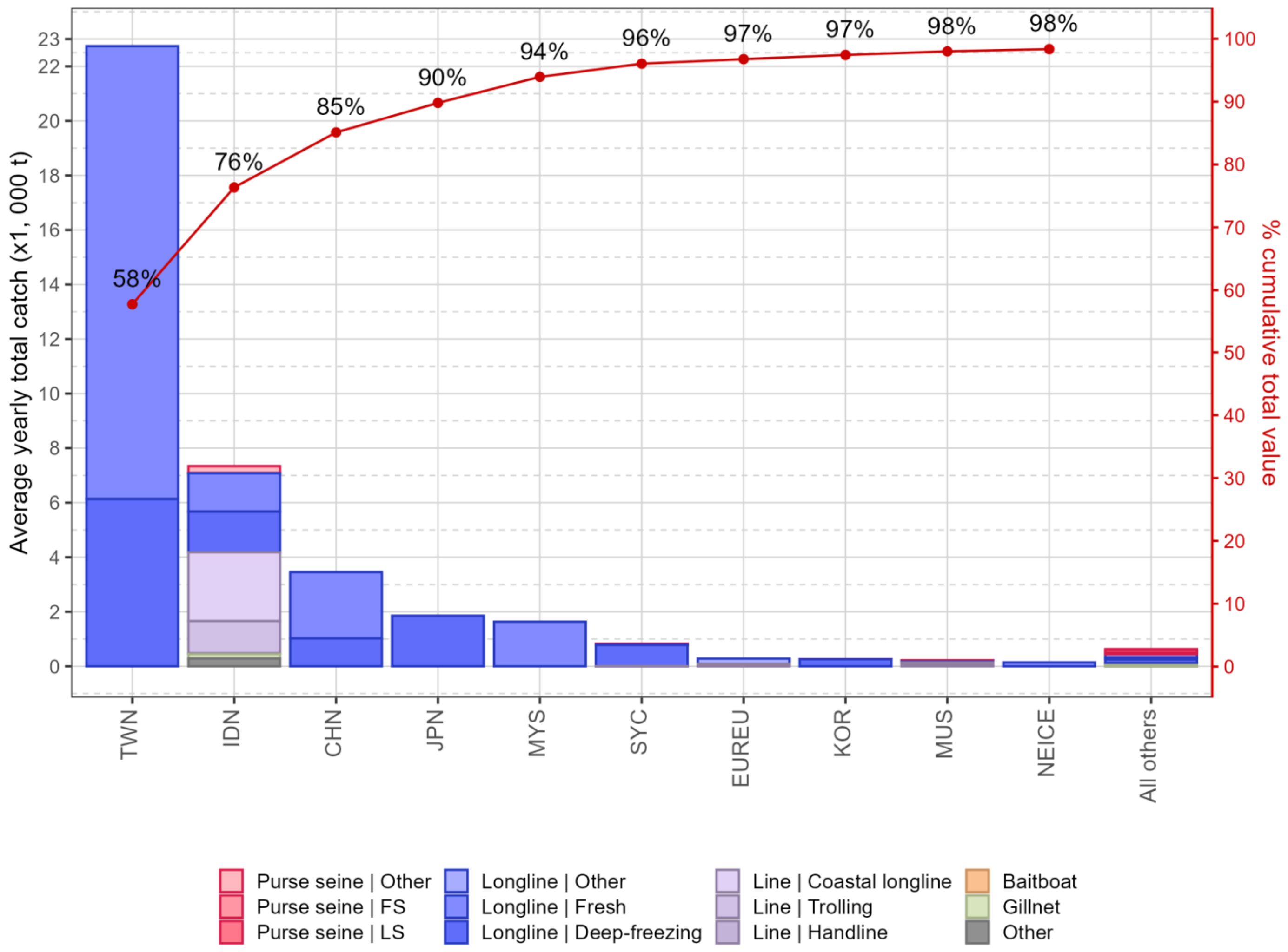

Figure 3: Mean annual catches (t) of albacore by fleet and fishery between 2016 and 2020, with indication of cumulative catches by fleet. FS = free-swimming schools; LS = schools associated with floating objects

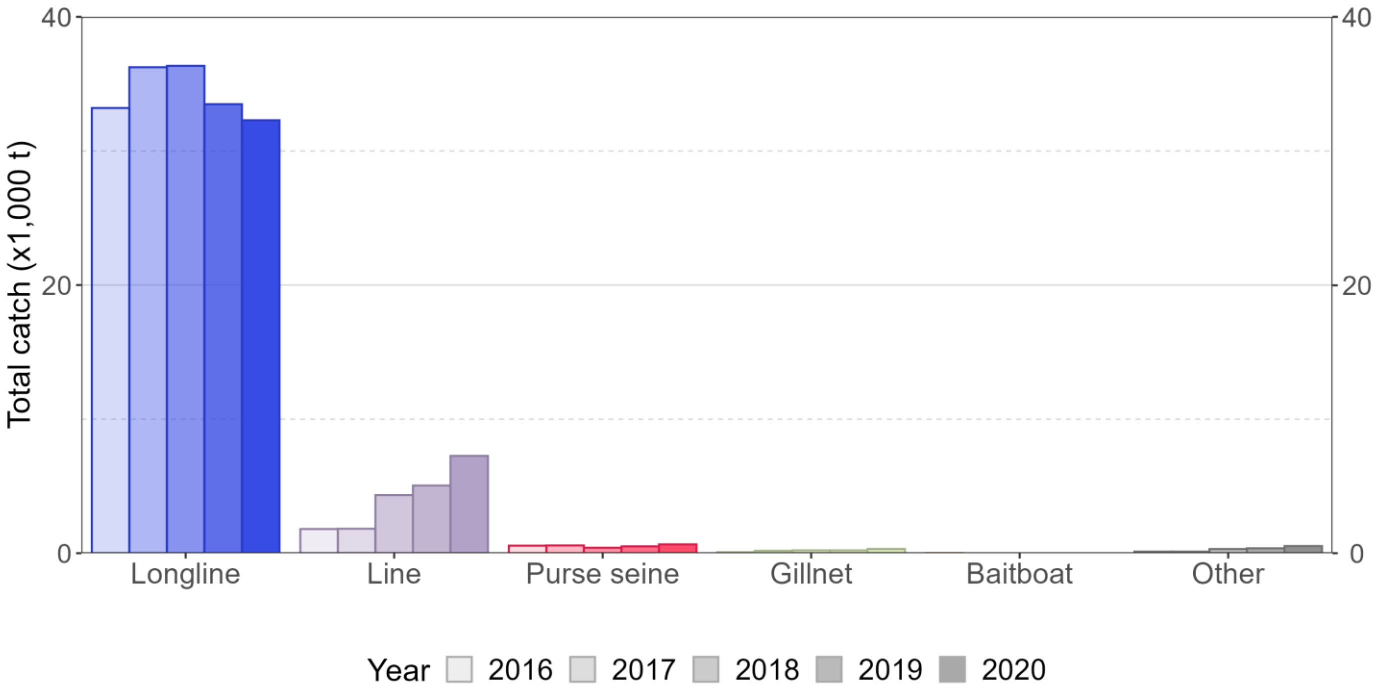

Figure 4: Annual catch (t) trends of albacore by fishery group between 2016 and 2020

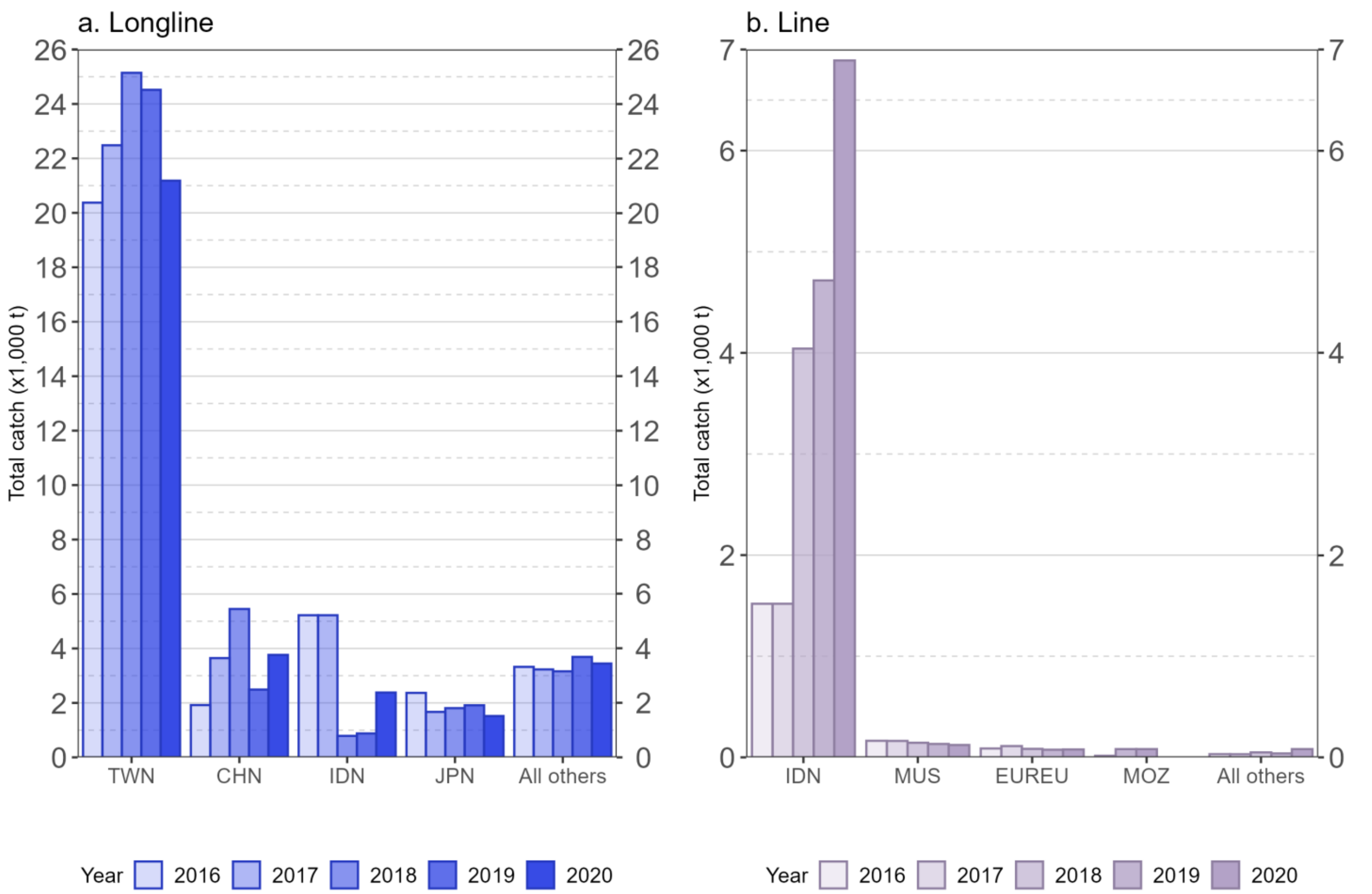

Figure 5: Annual catch (t) trends of albacore by main fishery group and fleet between 2016 and 2020

Uncertainties in nominal catch data

The overall reporting quality of nominal catches for albacore is considered to be good, on par with tropical species and generally better than what available for neritic species managed by the IOTC. Catches between the 1950s and early-1990s are considered to be fairly reliable with more than 80% of the total nominal catches of albacore being fully or partially reported to the Secretariat (quality scores 0-2; **Table 3**) (**Fig. 6**). The reporting quality shows a decreasing trend throughout the 1990s and 2000s, reaching a minimum score of around 55% during 2009-2011 due to poor catch reports from some industrial longline fleets operating under flags of non-reporting countries (e.g., Malaysia, foreign unloadings) which have been estimated by the Secretariat. Since then, the reporting quality increased to reach about 80% in recent years (**Fig. 6**).

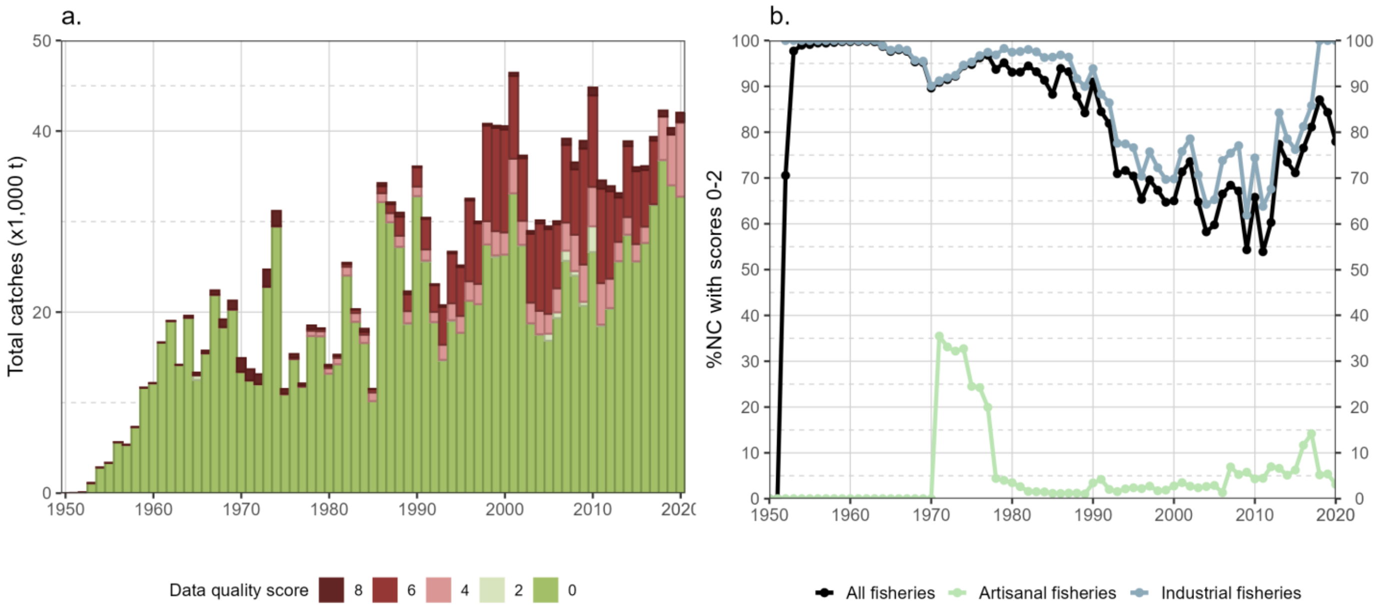

Figure 6: (a) Annual nominal catches (t) of albacore estimated by quality score and (b) percentage of nominal catches by type of fishery fully and partially reported to the Secretariat according to IOTC standards

In 2020, 78% of the nominal catches of albacore was fully reported to the Secretariat, while the rest had to be partially or fully estimated. Part of the nominal catches was derived from alternative data sources, and specifically the fraction attributed to CPCs and non-members of the IOTC that did not report data to the Secretariat (Appendix I). In addition, a re-estimation process was applied to catches of the artisanal fisheries of Indonesia which have been known to be affected by data quality issues for some time (Proctor et al. 2003, 2011; Moreno et al. 2012). It is good to note that Indonesia has been improving the system of collection and management of fisheries data since 2017 through the "One Data initiative" project and is actively engaged with the Secretariat and other international stakeholders in reviewing the estimation process currently used for their artisanal fisheries.

In addition to well-known issues in data reporting, several other key issues need to be noted when considering the historical time series of nominal catches of albacore:

- Catches of albacore from longliners operating under flags of non-reporting countries (e.g., Belize, Honduras, Indonesia, Malaysia) have been estimated by the Secretariat between 1985 and 2016 based on some strong assumptions on the numbers of vessels and their annual catch rates (Herrera 2002a, 2002b). While the estimates of non-reported catches were moderately high during the 1990s and early 2000s (up to almost 10,000 t in 1999), they have substantially decreased from the mid-2000s and have been considered nil in recent years in consequence of the reduced practice of reflagging, the implementation of port state measures, and the improved monitoring of vessels activities and data reporting by the concerned CPCs (such as Malaysia);

- In the past, catches of albacore from the longline fisheries of Philippines (1999-2010), India (2004-2011), and Oman (2017-2018) were re-estimated by the Secretariat as they appeared only partially reported based on i) the inconsistencies observed between the levels of bigeye tuna reported in the catches and monitored through the IOTC Statistical Document Programme in the case of Philippines, and ii) to the number of vessels available in the Record of Authorized vessels (RAV) and the Active List of Vessels (AVL) for India, and also because of the lack of detailed catch by species reported by Oman;

- Catches of albacore for both the artisanal and industrial fisheries of Indonesia have been estimated by the Secretariat in collaboration with Indonesia to overcome some major issues in data collection and reporting identified for the country (Herrera 2002a; Proctor et al. 2003; IOTC 2013; Yuniarta et al. 2017). The estimation methodology developed for Indonesian fresh longliners in the early 2010s and revised in 2018 is considered to have improved the nominal catch statistics between 2013 and 2018 while estimates prior to 2013 continue to remain highly uncertain (Moreno et al. 2012; Geehan 2018). It is useful to note that the estimation method has not been applied to the industrial longline and purse seine fisheries in recent years but is still in use for Indonesian artisanal fisheries (Appendix I);

- The catches of albacore estimated for the fresh-tuna longline fishery of Taiwan,China are only available from 2001 onward: prior to 2001, catches for the Taiwanese fleet remain relatively uncertain.

Discard levels

The total amount of albacore discarded at sea remains unknown for most fisheries and time periods despite the obligation to report these data as per IOTC Res. 15/02. Information from the literature indicates that discard levels of albacore are generally low in longline fisheries, mostly because of the high market value fetched by the species (Huang and Liu 2010; Wang et al. 2021). Discarding by longliners mainly happens when the fish is damaged or shows signs of depredation by whales and sharks (e.g., Munoz-Lechuga et al. 2016). Almost no information on discarding of albacore is available for coastal line fisheries, although the phenomenon is supposed to be negligible.

Information available in the ROS regional database for longline fisheries covers the period 2009-2019 and only a fraction of the Indian Ocean fishing grounds, as data are limited to vessels flagged by EU,France, Japan, and Sri Lanka. Levels of discarding appear to be low but this should be considered with caution due to the current low level of ROS data coverage. The size range of albacore discarded at sea in the longline fisheries of EU,France and Japan is similar to the size of the fish retained (see section Size distribution and estimated average weights) and does not show any individual smaller than <60 cm fork length (**Fig. 7**).

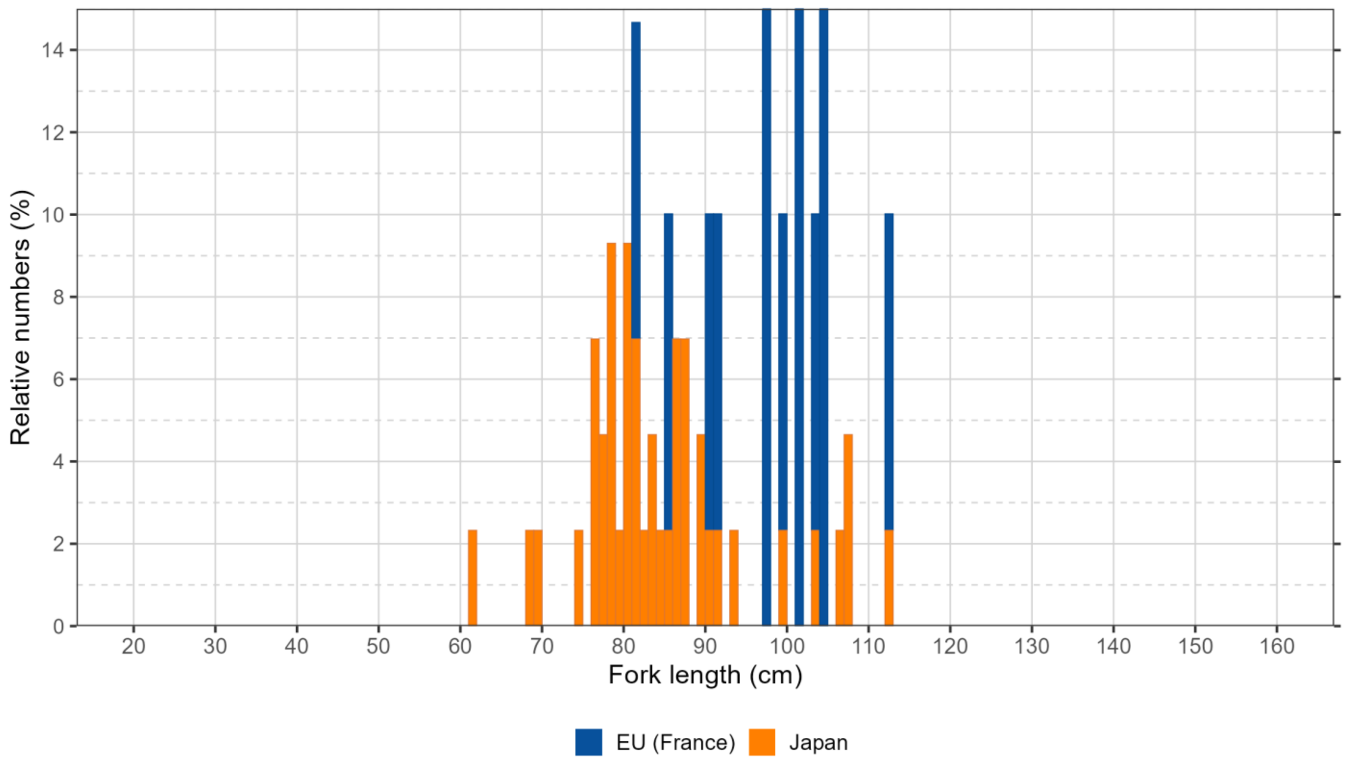

Figure 7: Distribution of fork lengths (cm) of albacore discarded at sea in the EU,France and Japan longline fisheries as available in the ROS regional database

Geo-referenced catches

Geo-referenced catch data for albacore have been reported to the Secretariat in numbers, weights, or both (depending on the fisheries and periods). Furthermore, the data provided by the CPCs have not been systematically raised to the total catches, although IOTC Res. 15/02 explicitly calls for data raising and documents describing extrapolation procedures.

In the case of albacore, as for the other four main IOTC species, georeferenced catches are raised by the Secretariat to total catches by year, fleet and gear, in order to provide a comprehensive estimation of their distribution, although several assumptions are required to produce this dataset (see section Methods).

The distribution of raised catches for albacore over seven decades shows the species as mostly occurring in the southern quadrants of the Indian Ocean, from 45°S to the equator, and predominantly in temperate waters south of 20°S (**Figs. 8-9**).

Although catches of albacore by deep-sea longline fisheries were most frequently reported in the eastern Indian Ocean during the 1950s, in the following decades these fisheries progressively expanded towards the southwestern Indian Ocean where the catch levels remained generally higher than in other areas (**Fig. 8**).

The species was also found to be frequently caught by industrial purse seiners operating in tropical waters in the northwest Indian Ocean immediately after the initial development of the fishery (1990-1999), as well as by a now disappeared driftnet fishery operated by Taiwanese-flagged vessels that operated in the southern-central part of the Indian Ocean during the 1980s and 1990s in the same fishing grounds as longliners (**Fig. 8d-e**). Catches from purse seines, however, always represented a small component of the total catch of albacore recorded for the whole Indian Ocean.

During the last decade (2010-2019), hotspots appeared to have emerged in the fishing grounds east of Mozambique (including their adjacent high seas), in the southeastern waters of Indonesia, and in the high seas south of 25°S in the southwestern Indian Ocean (**Fig. 9**). This latter area now represents the main fishing grounds of albacore in the Indian Ocean, with most of the catch in recent years coming from longline fisheries operating between 40-80°E and 10-40°S.

Although recent catches of albacore taken with coastal longlines and troll lines from Indonesia show a substantial increase, this trend should be considered with caution due to the uncertainties associated with the current catch re-estimation process applied to these fisheries (Appendix I).

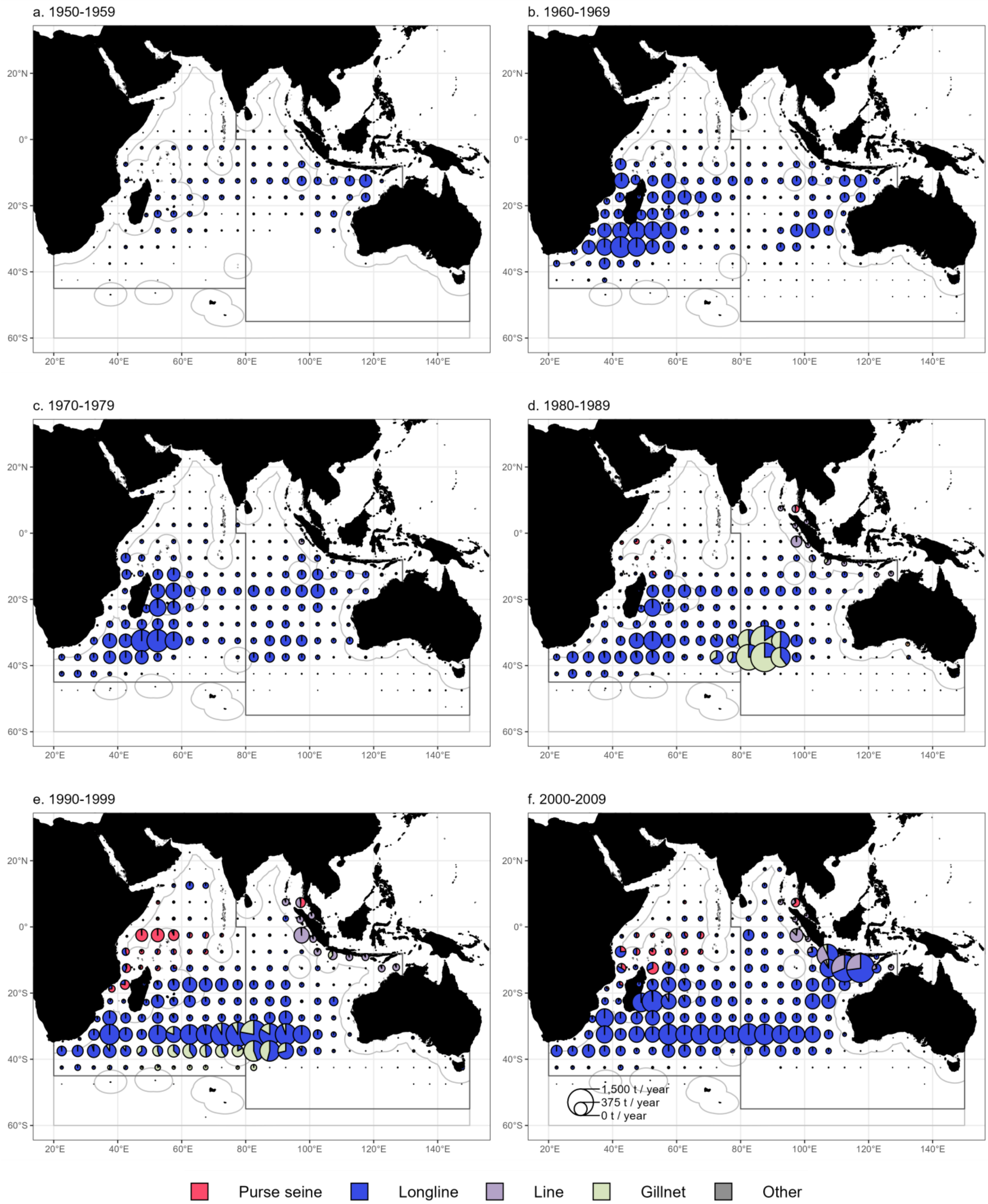

Figure 8: Mean annual time-area catches (in weight) of albacore raised to the nominal catches for the period 1950-2009, by decade and fishery. Source: raised time-area catches dataset (1950-2020)

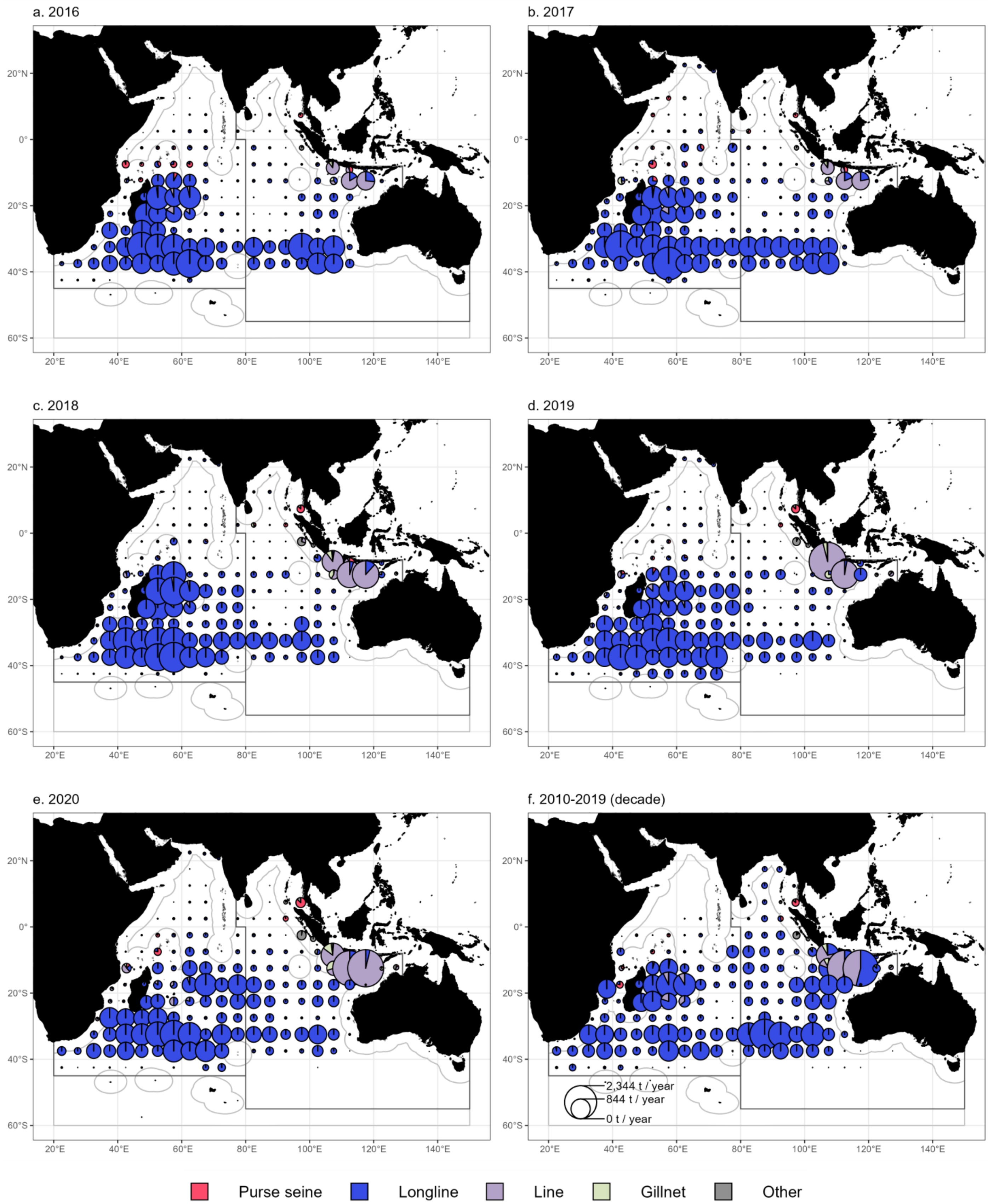

Figure 9: Mean annual time-area catches (in weight) of albacore raised to the nominal catches for the last decade (2010-2019) and for each year during the recent period (2016-2020). Source: raised time-area catches dataset (1950-2020)

Uncertainties in geo-referenced catch and effort data

From a general perspective, the reporting quality of the geo-referenced data on catch and effort for albacore is quite good compared to other IOTC species such as neritic tunas since most catches come from a few large-scale longline fisheries, some of which have been monitored with logbooks for decades (**Fig. 10**). The percentage of nominal catches of albacore for which geo-referenced catch data are available was close or above 90% in the 1960s and throughout the 1980s and showed a major decline during the 1990s and 2000s in relation with the non-reporting of data by several longline fishing nations (see below). The situation has substantially improved since the mid-2000s and the reporting quality was estimated to be good for more than 90% of the nominal catch in 2020 (**Fig. 10**).

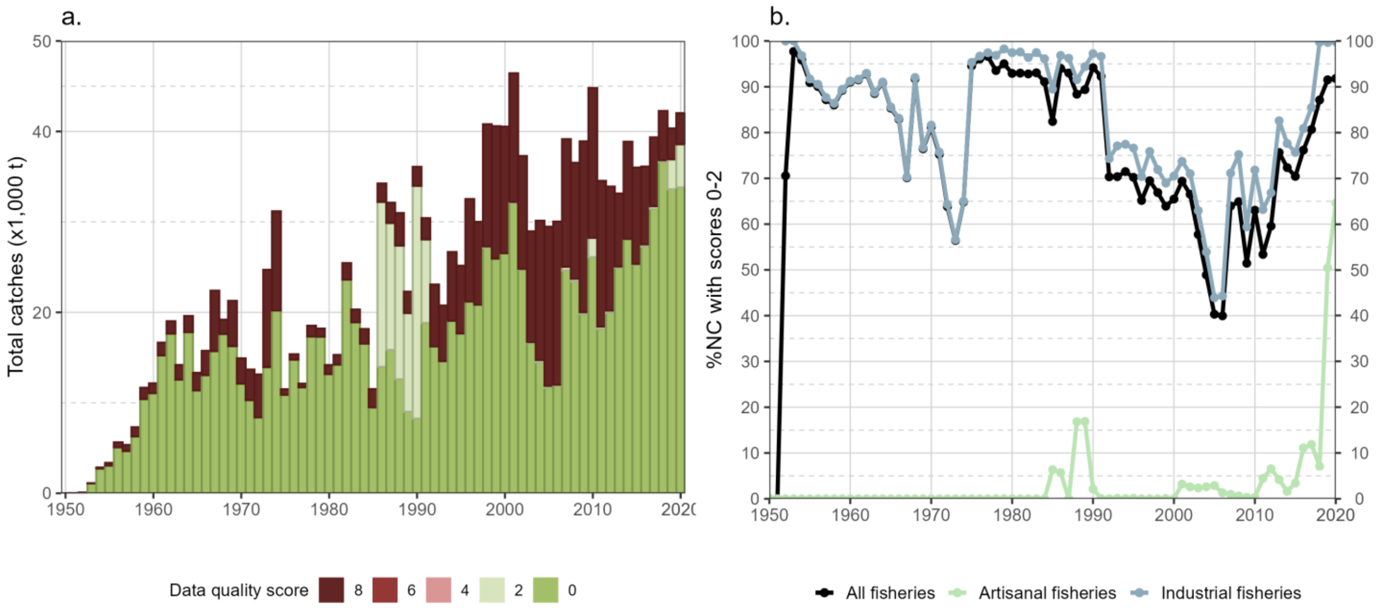

Figure 10: (a) Annual nominal catches (t) of albacore estimated by quality score and (b) percentage of nominal catches by type of fishery with good quality information (i.e., logbook coverage>30% and compliant with IOTC standards) for the corresponding geo-referenced catch and effort data reported to the IOTC Secretariat

The following uncertainties in catch and effort data for albacore should be noted:

- Very little information on catch and effort has been reported for the industrial longline fishery of Indonesia over the last decades. In 2015 an IOTC-OFCF mission was conducted to assist Indonesia with the reporting of catch-and-effort data, and some information has been received for the period 2018-2020 following the implementation of the One Data Initiative in 2017. The coverage remains however quite low with the geo-referenced catch representing about 17% of the nominal catch of albacore caught between 2018 and 2020 in the Indonesian longline fishery;
- Catch and effort data for the fresh-tuna longline fishery from Taiwan,China are only available since 2007, compared to nominal catches from 2001. Estimates of total catches, and time-area catches, prior to these periods therefore remain highly uncertain;
- Although some catch and effort data are available for the longline fisheries of India, Malaysia, Oman, and Philippines, they are usually incomplete and fall short of the IOTC data reporting standards of Resolution 15/02.

Size distribution and estimated average weights

Size data availability

The number of fish sampled for size is dominated by longline and purse seine fishing gears while almost no samples of albacore are available from gillnet and coastal line fisheries (**Fig. 11**). Data collected from purse seiners are available from the early 1990s with the number of samples steadily decreasing from about 160,000 in 1991 to an average of 18,365 between 2013 and 2017, and very few since then (**Fig. 11 - Top left panel**). Purse seine size data mostly come from non-reporting countries classified as NEI in the IOTC database. By contrast, the number of samples collected from longline fisheries shows an increasing trend with some variability over the last decade and an average of 1,176 samples in recent years (**Fig. 11 - Top right panel**). Most longline samples have been collected from the fresh and deep-freezing longliners of Taiwan,China.

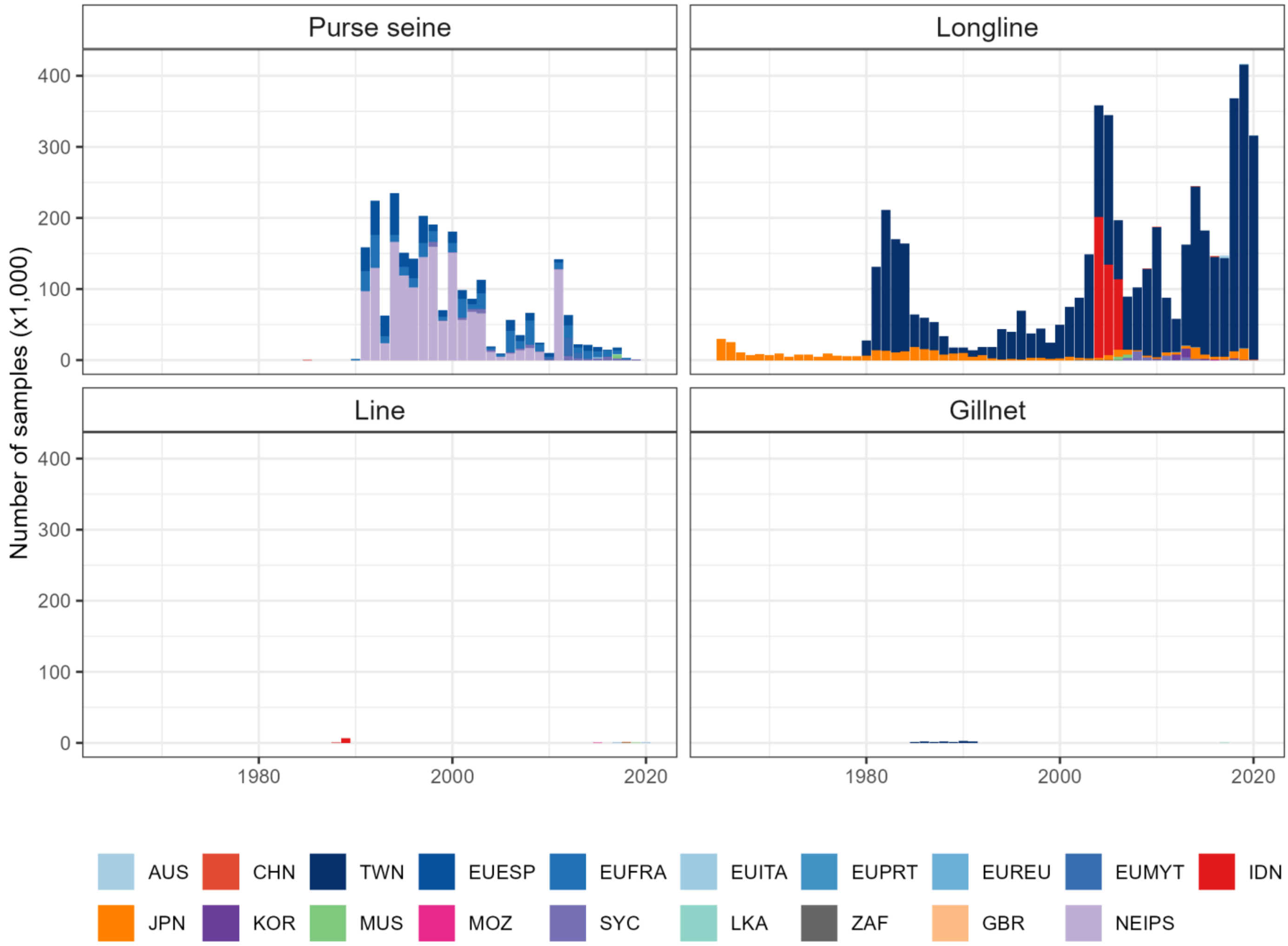

Figure 11: Annual number of fish sampled for size by fishery group and fleet

However, size samples collected by crews onboard Taiwanese longliners since 2001 have been shown to be of poor quality and size data collected by observers were recommended to be used instead (Hoyle et al. 2021). In the case of albacore, the comparison of the size distributions measured by the crews and the observers between 2002 and 2020 appear to be very similar, with an identical median fork length of 90 cm in both cases (**Fig. 12**).

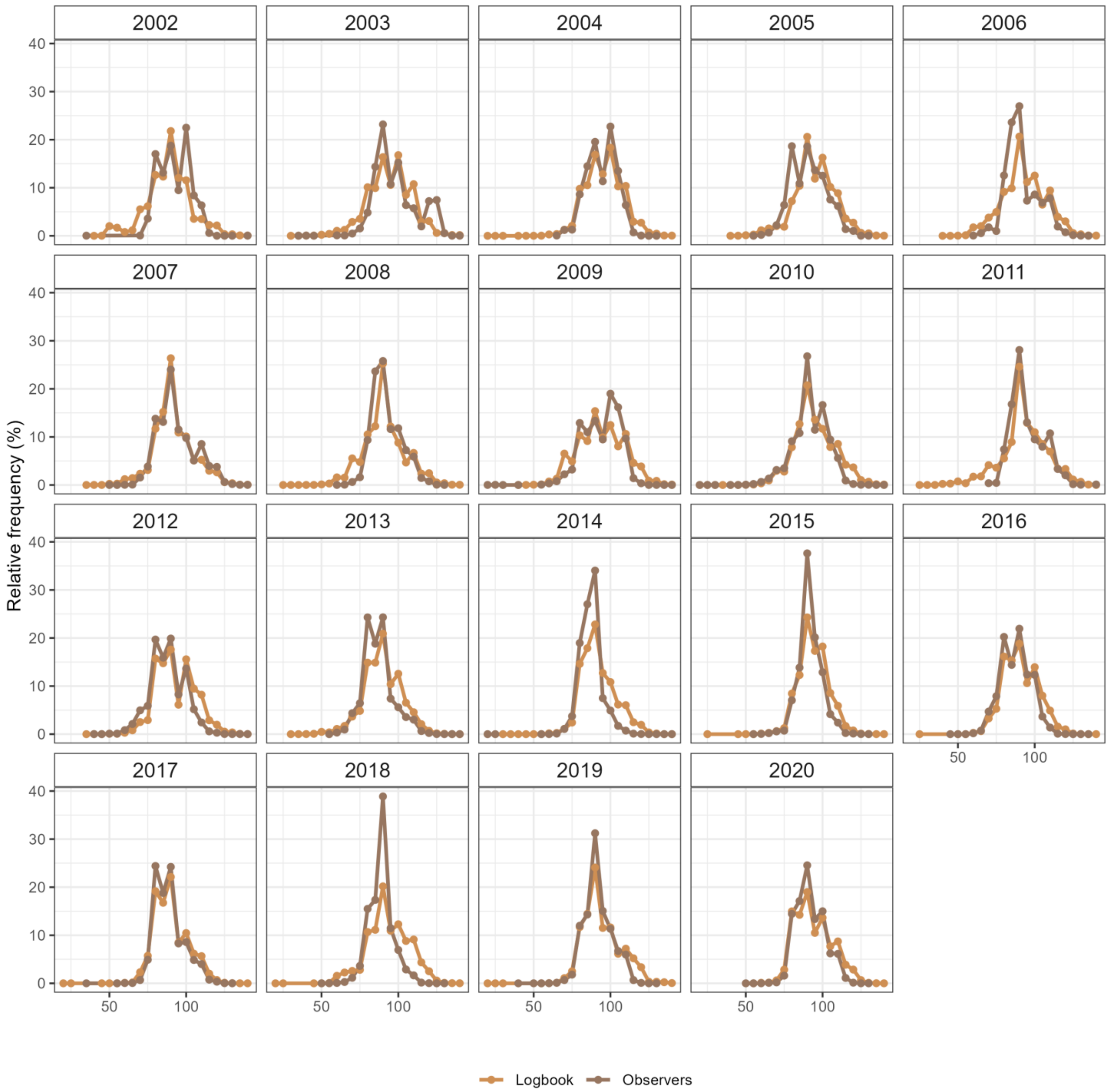

Figure 12: Annual fork length (cm) frequency distribution of albacore caught in the deep-freezing longline fishery of Taiwan,China derived from crews and observers

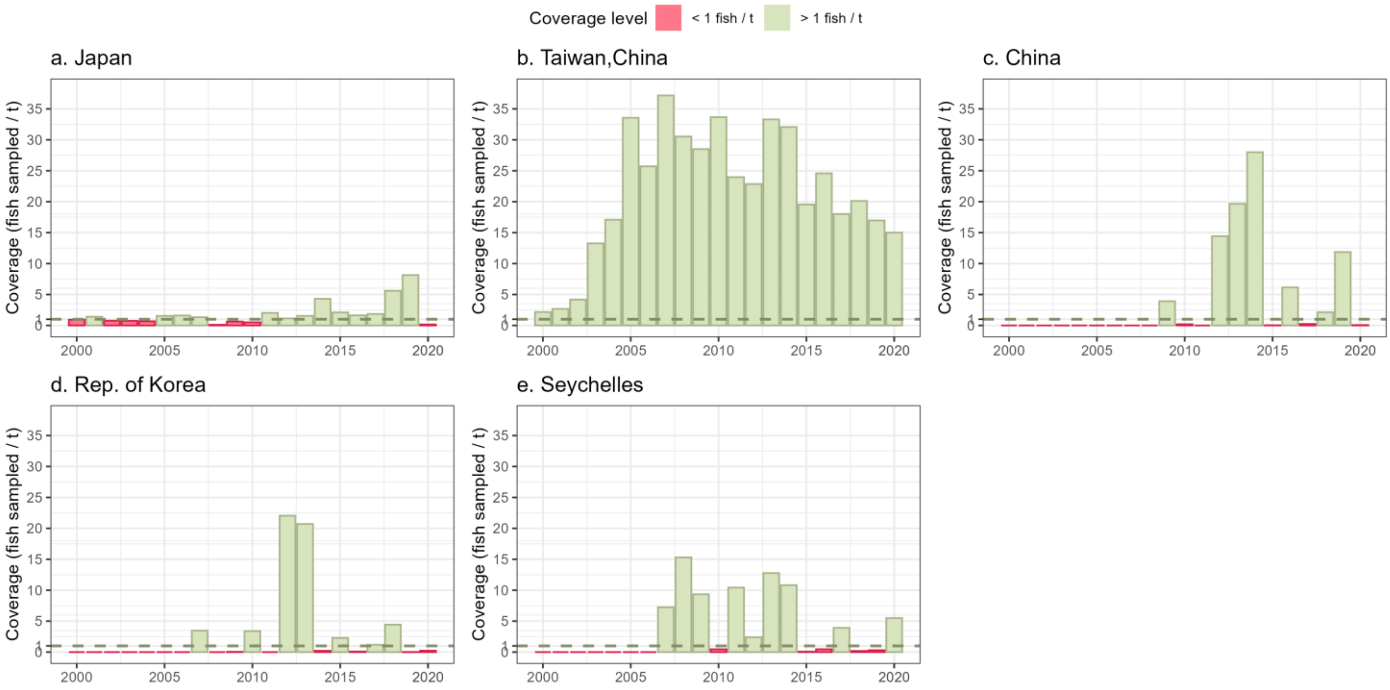

Figure 13: Coverage levels (average number of fish sampled per metric ton of catch) for the major deep-freezing longline fleets (2000-2020)

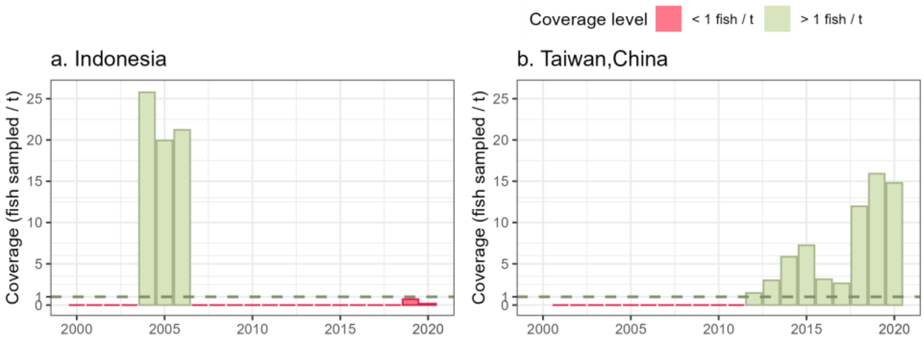

Figure 14: Coverage levels (average number of fish sampled per metric ton of catch) for the major “fresh” longline fleets (2000-2020)

IOTC Res. 15/02 explicitly calls CPCs to sample for length at least one fish per metric ton of catch (by gear and species). In the case of albacore longline fisheries, which are responsible for the majority of catches of the species, this requirement is not always met: while, Taiwanese deep-freezing and fresh tuna longliners are generally well sampled (the latter at least for years from 2012 onward), the same is not always true for all other fleets, with the exception of some time periods depending on the gear and flag considered (**Fig. 13** and **Fig. 14**).

Temporal patterns and trends in size distribution

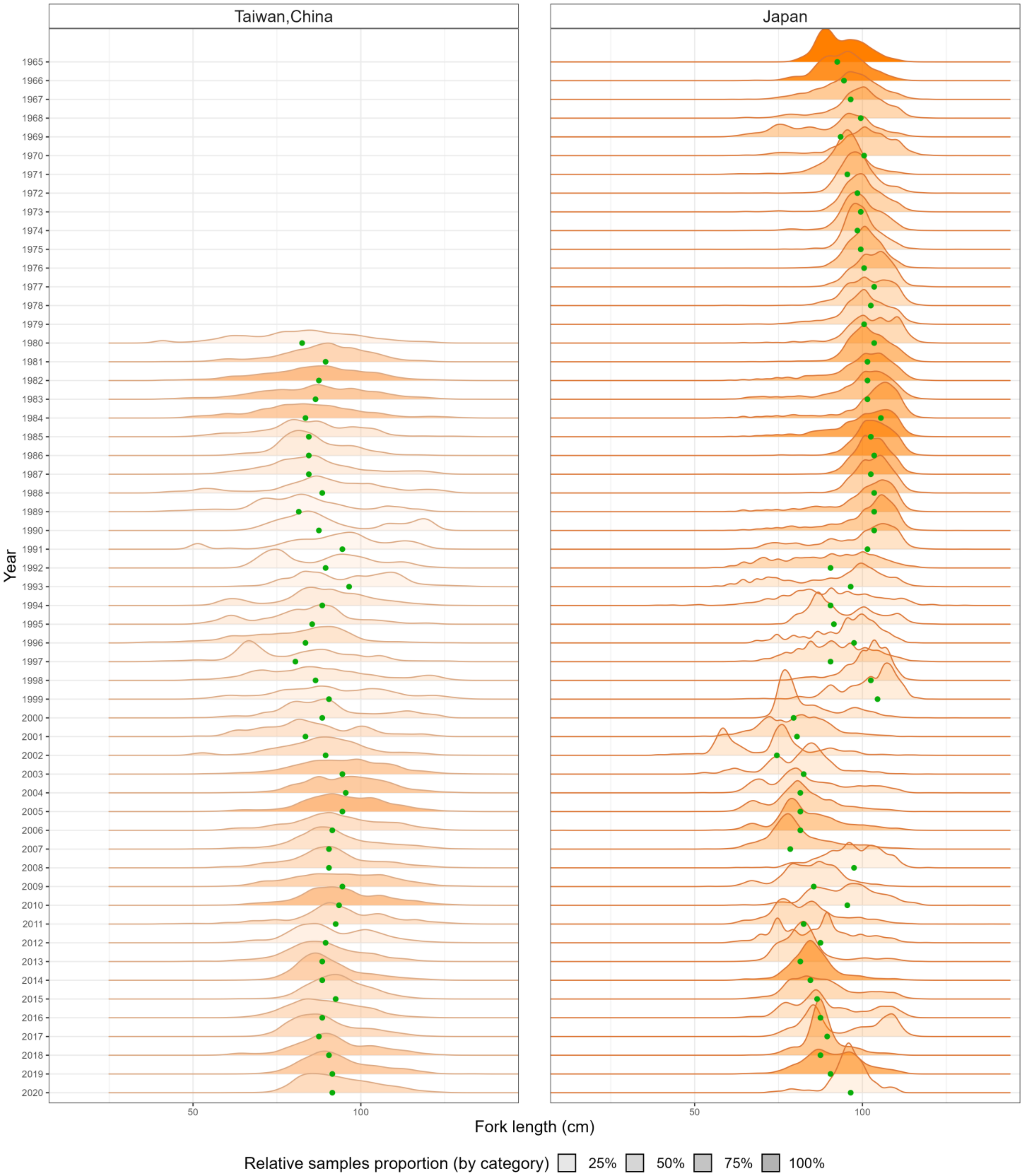

Figure 15: Annual fork length (cm) frequency distribution of albacore caught in the deep-freezing longline fisheries of Taiwan,China and Japan. Fill intensity is proportional to the number of samples recorded for the year, while the green dot corresponds to the median value

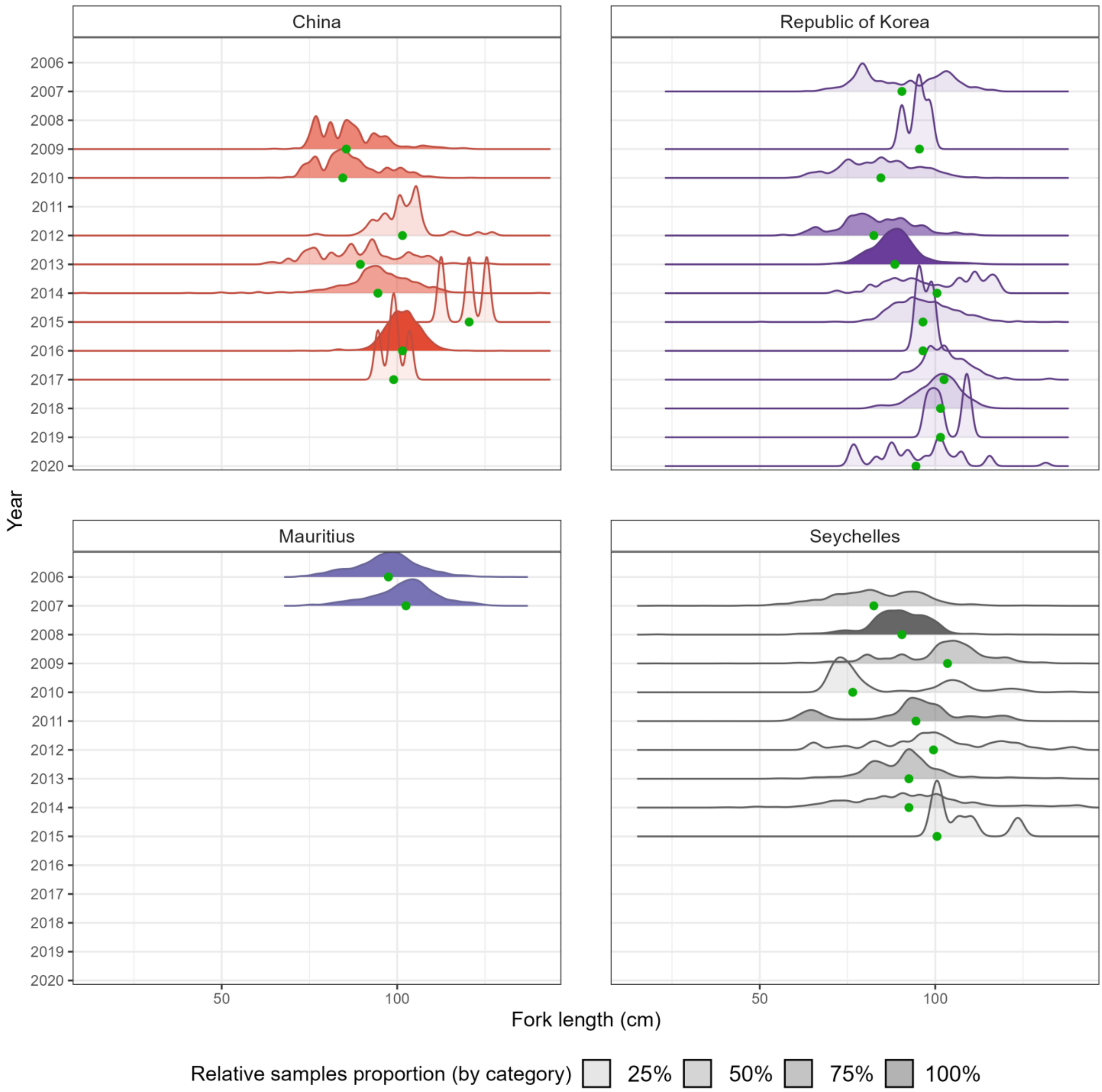

Figure 16: Annual fork length (cm) frequency distribution of albacore caught in the deep-freezing longline fisheries of China, Korea, Mauritius, and Seychelles. Fill intensity is proportional to the number of samples recorded for the year, while the green dot corresponds to the median value

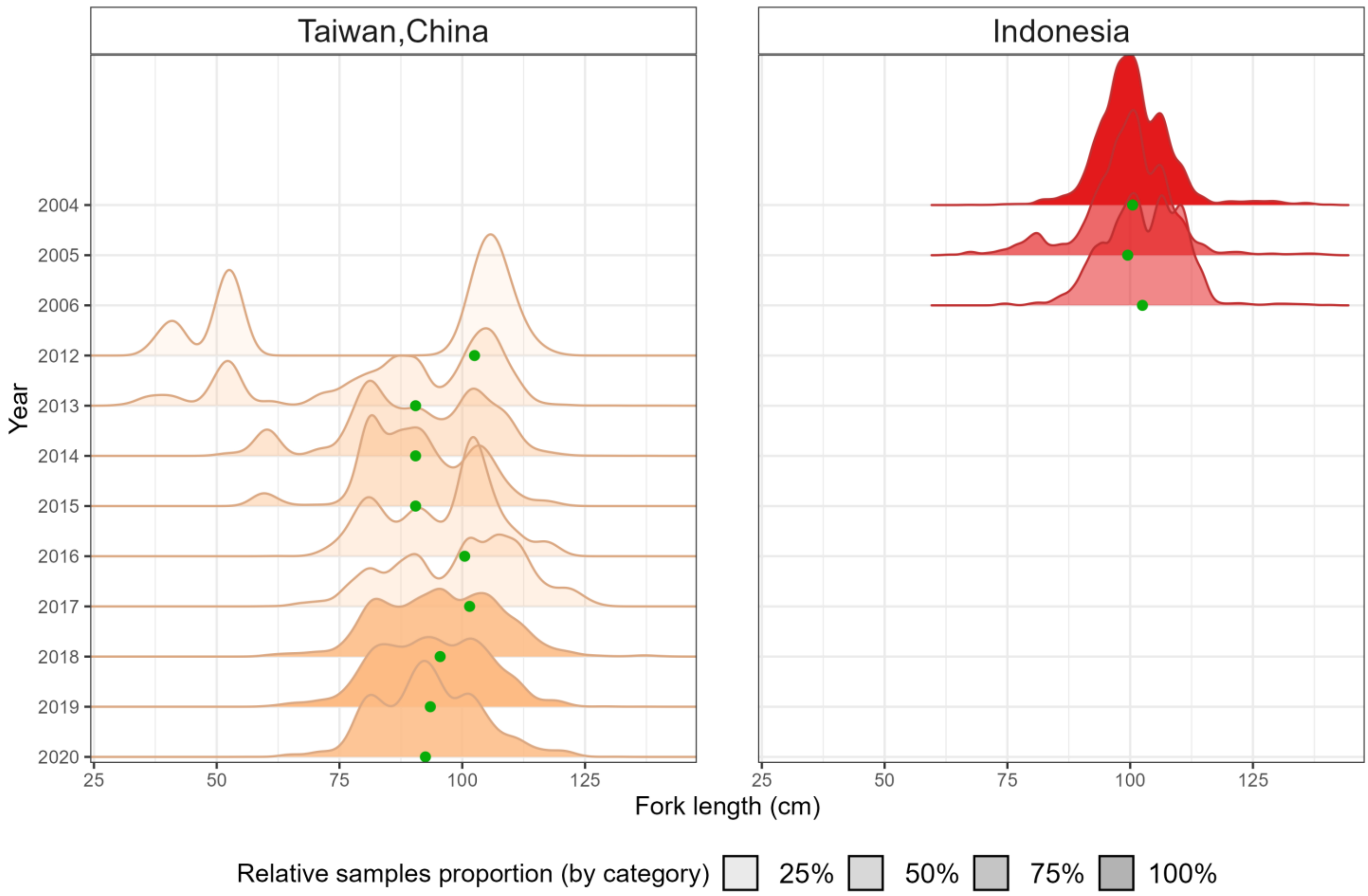

Figure 17: Annual fork length (cm) frequency distribution of albacore caught in the fresh tuna longline fisheries of Taiwan,China and Indonesia. Fill intensity is proportional to the number of samples recorded for the year while the green dot corresponds to the median value

Temporal patterns and trends in estimated average weights

Average weights of Indian Ocean albacore were derived from the geo-referenced catches by fleet, gear, fishing mode, year, month, and grid raised to the nominal catch (see section Methods). Considering the limitations in the original data sets and the assumptions required by the estimation process (e.g., use of proxy fleets), the estimated average weights should be considered with caution. This is particularly true for most coastal fisheries considering the paucity or absence of their original size data which cause the estimates of average weights to be based on strong assumptions (**Fig. 11**). As such, we only show here the time series of average weights for industrial longline and purse seine fisheries which represent between 80% and 100% of the annual total catch of albacore since the mid-1950s.

The average weight of fish caught by the deep-freezing longline fishery shows a steady decrease between the early 1950s and 1990s, from about 22.9 kg in 1952 to a minimum of 12.3 kg in 1996, oscillating around a mean value of 16.7 kg (without any clear trend) thereafter (**Fig. 18**). Although shorter, the time series of average weights of fish caught by fresh tuna longliners shows some synchronicity with the average weight estimated for the deep-freezing longline fishery until the early 2000s when it increased to an average of 22.1 kg and largely exceeded the sizes reported for the deep-freezing longline component of Taiwan,China (**Fig. 18**).

Albacore caught in purse seine fisheries are larger than in longline fisheries in the Indian Ocean, with average weights of fish caught by purse seine on free-swimming schools and by deep-freezing longline fisheries between 1984 and 2020 estimated at 26 and 16.1 kg, respectively. The average weights in the purse seine catches of free-swimming schools and schools associated with drifting floating objects showed a similar decreasing trend since the mid-1990s, from about 29.7 kg in 1989 to 25.3 kg in 2020 (**Fig. 18**).

Due to their contribution to the total catch, deep-freezing and fresh longline fisheries drive the temporal patterns of average weight in the catch of Indian Ocean albacore since the 1950s (**Fig. 18**). Overall, average weight of albacore in the catch of the main fisheries targeting albacore showed a decreasing trend between 1952 and 1997, before increasing to more than 20 kg in 2009 and showing a decreasing trend thereafter, reaching 18.6 kg in 2020.

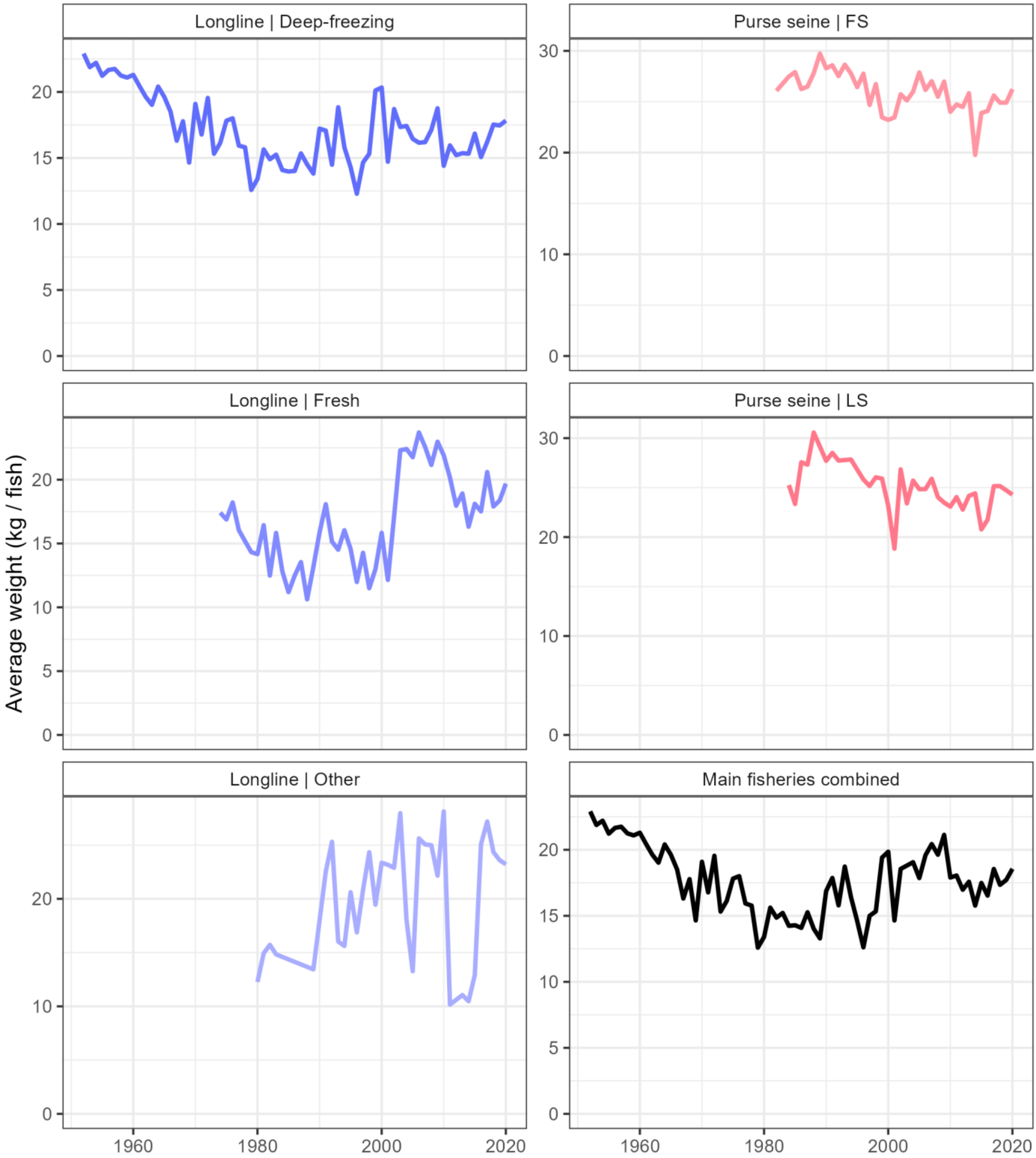

Figure 18: Annual time series of estimated average weight (kg/fish) of albacore for the fisheries described by a good coverage of size data. Longline | Other includes swordfish and shark-targeted longlines; FS = Free-swmming schools; LS = schools associated with floating objects

Spatial distribution of estimated average weights

The distribution of estimates weights of albacore over the last decades shows a strong spatial pattern in the sizes of fish caught in the Indian Ocean (**Fig. 19**). Larger albacores are found in tropical waters, while their smaller counterparts occur in temperate waters in the southern Indian Ocean. Although albacores are caught at different sizes according to the fishing gear (see section Temporal patterns and trends in size distribution), the distribution of the average weight of albacore caught with longlines confirms this pattern with a clear distinction between juveniles occurring south of 25°S (average weights of 10-15 kg) and adult albacore larger than 20-25 kg distributed along the equatorial area, this pattern being consistent across decades (Appendix X).

The recent annual distribution of average weights of albacore appears to be very consistent across the years, with fish less than 15 kg located in the southern Indian Ocean, along the coasts of Indonesia, and in the Bay of Bengal (**Fig. 20**). The larger individuals (>25 kg) are found in the catches located in the tropical area, in particular in the western Indian Ocean with a predominance in the Gulf of Oman and off the coasts of Somalia, except for 2019 (**Fig. 20**).

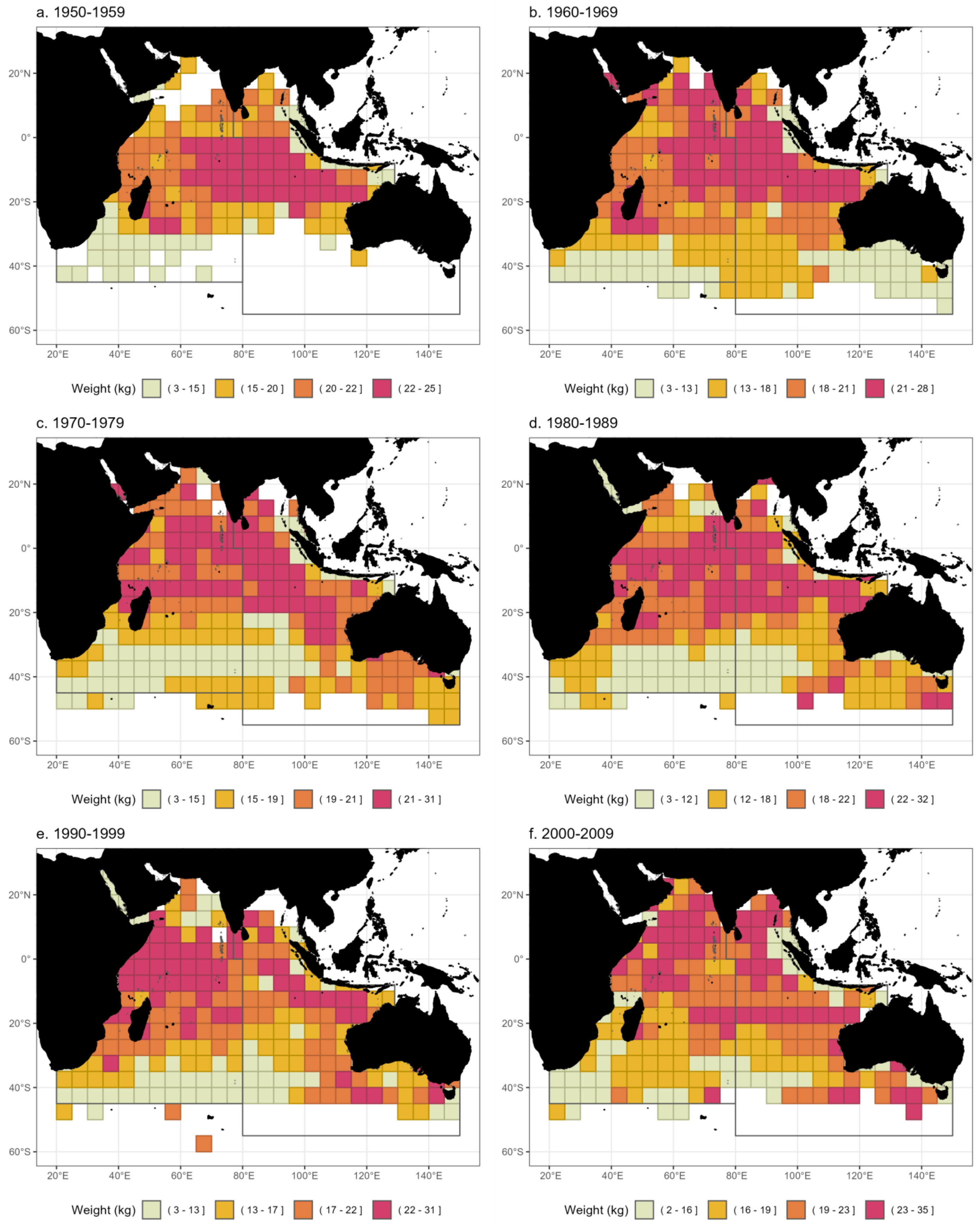

Figure 19: Estimated average weight (kg / fish) in the catch of Indian Ocean albacore by decade and 5x5 grid, all fisheries combined, 1950-2009

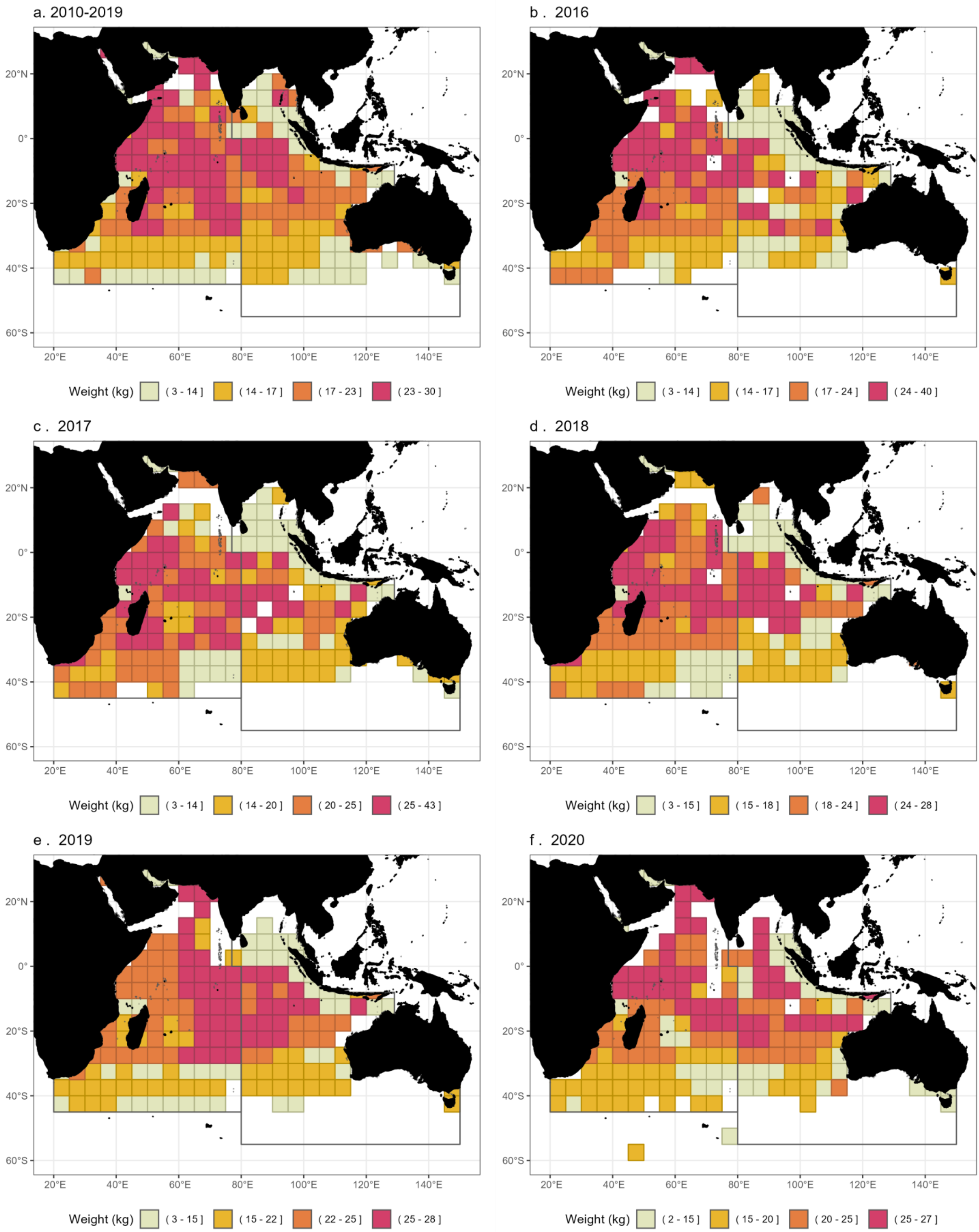

Figure 20: Estimated average weight (kg / fish) in the catch of Indian Ocean albacore by 5x5 grid and year during 2016-2020 and for the decade 2010-2019, all fisheries combined

Uncertainties in size data

The reporting quality of size frequency data shows high interannual variability and an increasing trend in recent years (**Fig. 21**). Almost no size data are available prior to the 1980s and the percentage of nominal catch with sufficient size data (scores 0-2; **Table 3**) has strongly varied over the years, from a maximum of about 85% in the early 1980s to less than 20% in 1990 and 2007-2008. The reporting quality has showed a substantial increase since the late 2000s, the percentage of nominal catch of scores 0-2 exceeding 80% in 2020 (**Fig. 21**).

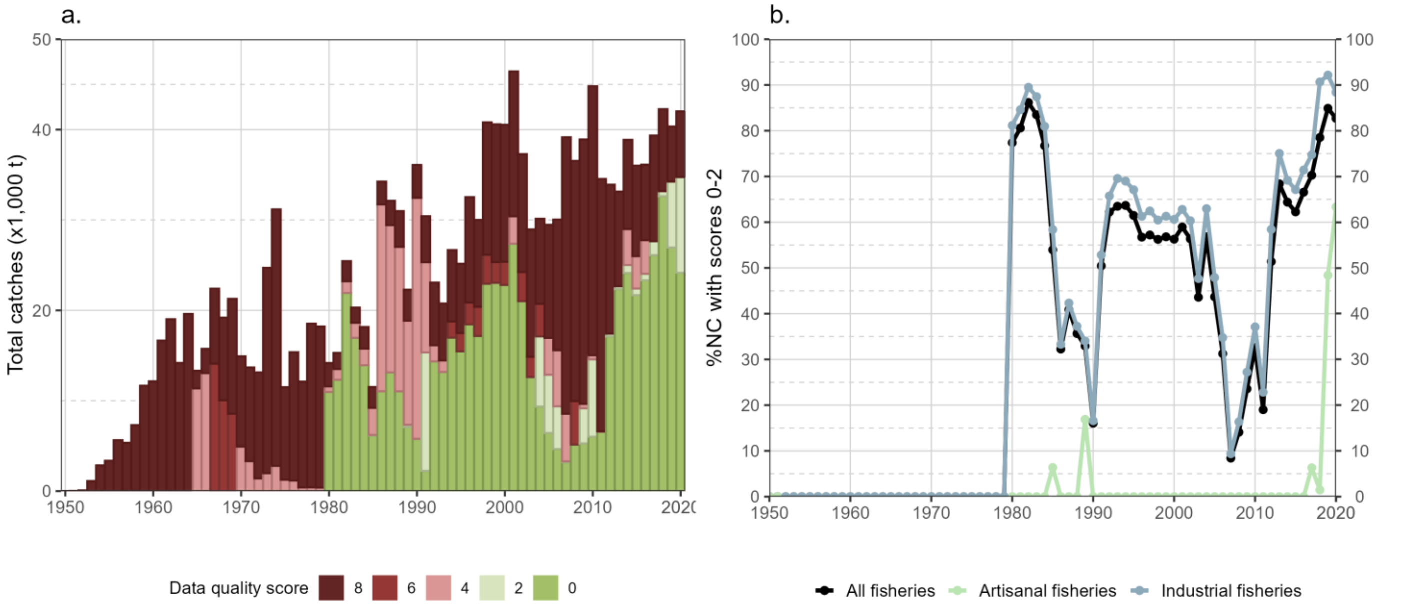

Figure 21: (a) Annual nominal catches (t) of albacore estimated by quality score and (b) percentage of nominal catches by type of fishery with good quality information (i.e., >1 fish per metric ton caught and compliant with IOTC standards) for the corresponding geo-referenced size frequency data reported to the IOTC Secretariat

The following points of uncertainty in the size-frequency data of albacore should be noted:

- Although some size data are available for the large-mesh size driftnet fishery of Taiwan,China that operated over the period 1982–92, the sampling coverage was low and well below the sampling target of 1 fish per metric ton for all years of activity of the fishery;
- Size data for the fresh-tuna longline fishery of Indonesia have been reported for a limited number of years, during the mid-2000s. However samples, where available, cannot be fully disaggregated by month and fishing area (5x5 grid) and refer mostly to the component of the catch that was unloaded fresh. For this reason, the quality of the samples in the IOTC database is considered low;
- A large data set of size samples is available for the deep-freezing longline fishery of Taiwan,China since 1980. However, the length distributions of albacore available from 2003 have been found to be different when compared to earlier years (Geehan and Hoyle 2013). In addition, since 2003 higher average weights derived from length data have also been reported, compared to average weights from catch and effort (for the same time-periods and areas), which suggests changes in the sampling protocols of specimens measured for lengths – particularly the proportion of smaller sized fish (Hoyle et al. 2021). Size data collected by observers since 2002 are considered to be of better quality and have been given preference over the size data collected by the crews since the early 2000s;
- The number of size samples available for the Japanese deep-freezing longline fleet has shown large fluctuations over the years following a large decline in the late 1980s and was well below the sampling target between 1994 and 1996;
- No size data have been reported to the Secretariat for the longline fisheries of India (2004-2011), Oman (2014-2020), and Philippines (1998-2014) while Malaysia (2005-2020) only started reporting data in 2018.

Acknowledgements

We are grateful to all the people from the CPCs involved in the collection and curation of the data included in this report. Many thanks to Chris Reid and FFA for the collation and processing of fish price for albacore, to Colin Millar (CCSBT) for providing information and data on southern bluefin tuna and Zahirah Dhurmeea, Nathalie Bodin, and Sylvain Bonhommeau for sharing biological data on albacore.

Appendix I: Best scientific estimates for 2020

The preparation of the best scientific estimates of nominal catches of albacore for 2020 required some processing performed by the Secretariat in agreement with the re-estimation procedures endorsed by the IOTC Scientific Committee (see section Data processing).

First, an estimation was made for the IOTC CPCs and non-members which have not reported nominal catches of albacore to the Secretariat for the year 2020: in this case, the amount of catch fully estimated in 2020 was very small and only concerned the handline and purse seine fisheries of Mozambique (for which catches from 2019 were used, resulting in an increase of 106 t).

Second, an estimation process of the catch composition of the Indonesian artisanal fisheries was performed, building on a comprehensive review conducted in the early 2010s to revise the time series of artisanal fisheries catch and improve the information available to the IOTC (Moreno et al. 2012). In brief, a fixed proportion of the annual total catch derived from catch composition samples collected during 2003-2011 is used to estimate the annual nominal catch of each species by fishing gear.

The estimation process resulted in an increase of the total catch of albacore by the artisanal fisheries of Indonesia (compared to what submitted to the Secretariat) from 5,099 t to 10,569 t. Samples available during the 2000s indicated the presence of albacore in the catch of Danish seines (DSEI), gillnets (GILL), liftnets (LIFT), and small-scale purse seines (PSS) while no albacore was officially reported to have been caught by these gears in 2020 (**Fig. 22**). Furthermore, the estimation process decreased the albacore catch for handlines (HAND) while increasing the catches of albacore taken with coastal longlines (LLCO) and trolling lines (TROL).

Third and finally, a disaggregation process was conducted for the artisanal fisheries of Mauritius and EU,Reunion for which the catches were reported for a gear code (HATR) that is a combination of handline and trolling.

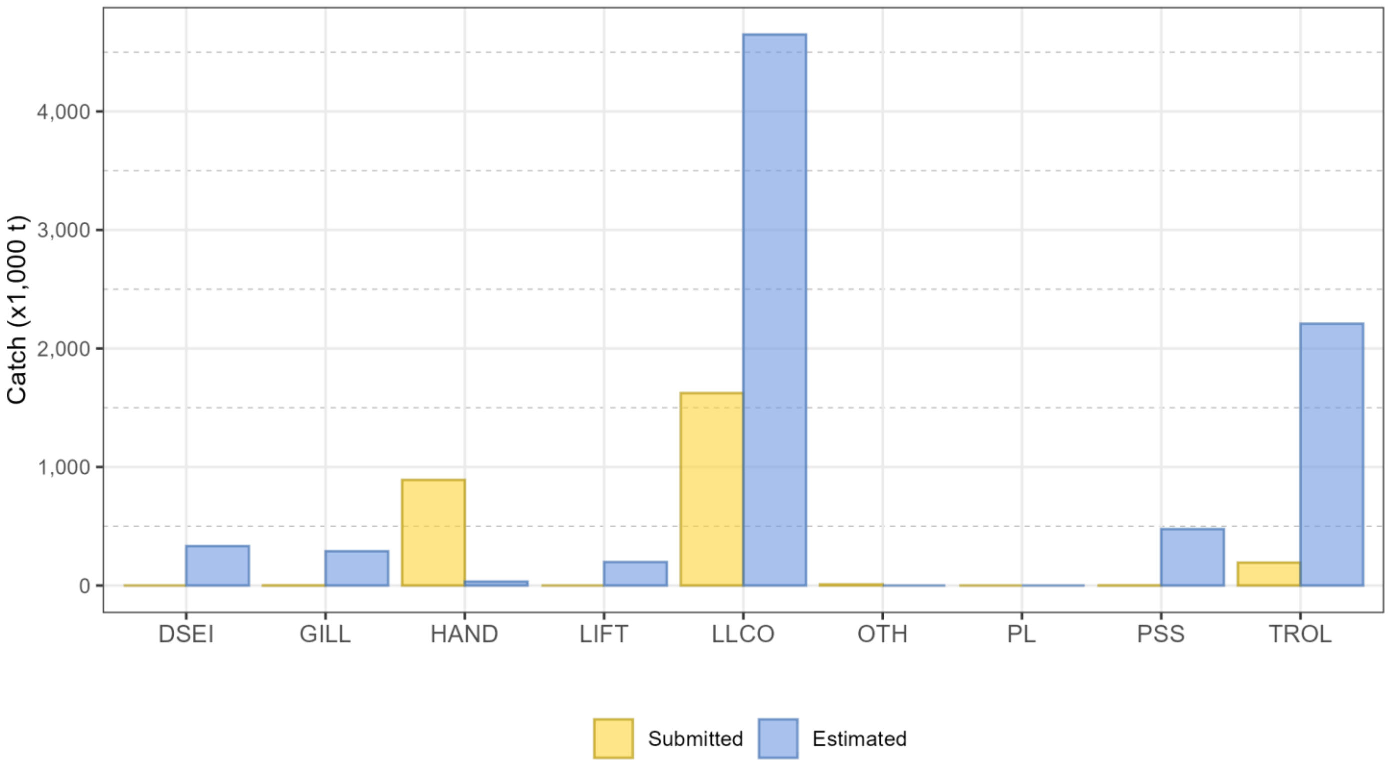

Figure 22: Nominal catches (t) of albacore for the artisanal fisheries of Indonesia as submitted to the IOTC Secretariat and estimated following the approach described in Moreno et al. (2012). DSEI = Danish seine; GILL = gillnet; HAND = handline; LIFT = liftnet; LLCO = coastal longline; OTH = other gears; PL = pole and line; PSS = small-scale purse seine; TROL = trolling line

Appendix II: Changes from previous Working Party

The fisheries data available at the previous data preparatory sesion of the Working Party on Temperate Tunas held in January 2019 covered the period 1950-2017. Very minor changes have occurred in the nominal catch of albacore during that period except for small increases of about 30 t and 230 t of catch in 2016 and 2017, respectively (**Fig. 23**).

For 2016, the increase was due to an update provided by Japan for their deep-freezing longline fishery while for 2017 the increase was due to a revision of the catch of the Seychelles deep-freezing longline fishery (+150 t) and to the Secretariat's re-estimation of the composition of catches reported as the species aggregate "Tunas nei" (**Table 2**) for an Omani-flagged longliner operating in the south western Indian Ocean which resulted in a further increase of 80 t.

Ancillary information available from the monitoring of the landings of this vessel through Port State Measures confirmed the catch of albacore by the vessel.

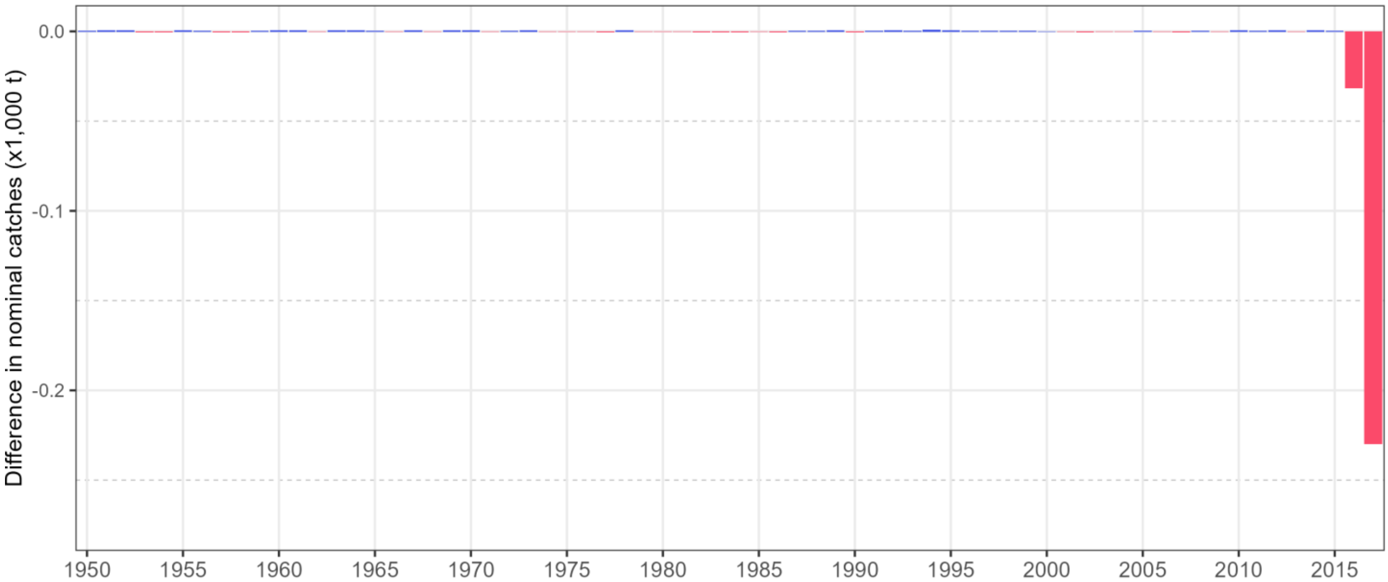

Figure 23: Differences in nominal catches of albacore (t) between the 7th and 8th sessions of the IOTC Working Party on Temperate Tuna

Appendix III: Effort trends for tropical tuna fisheries

Longline fisheries, by decade (1950-2009)

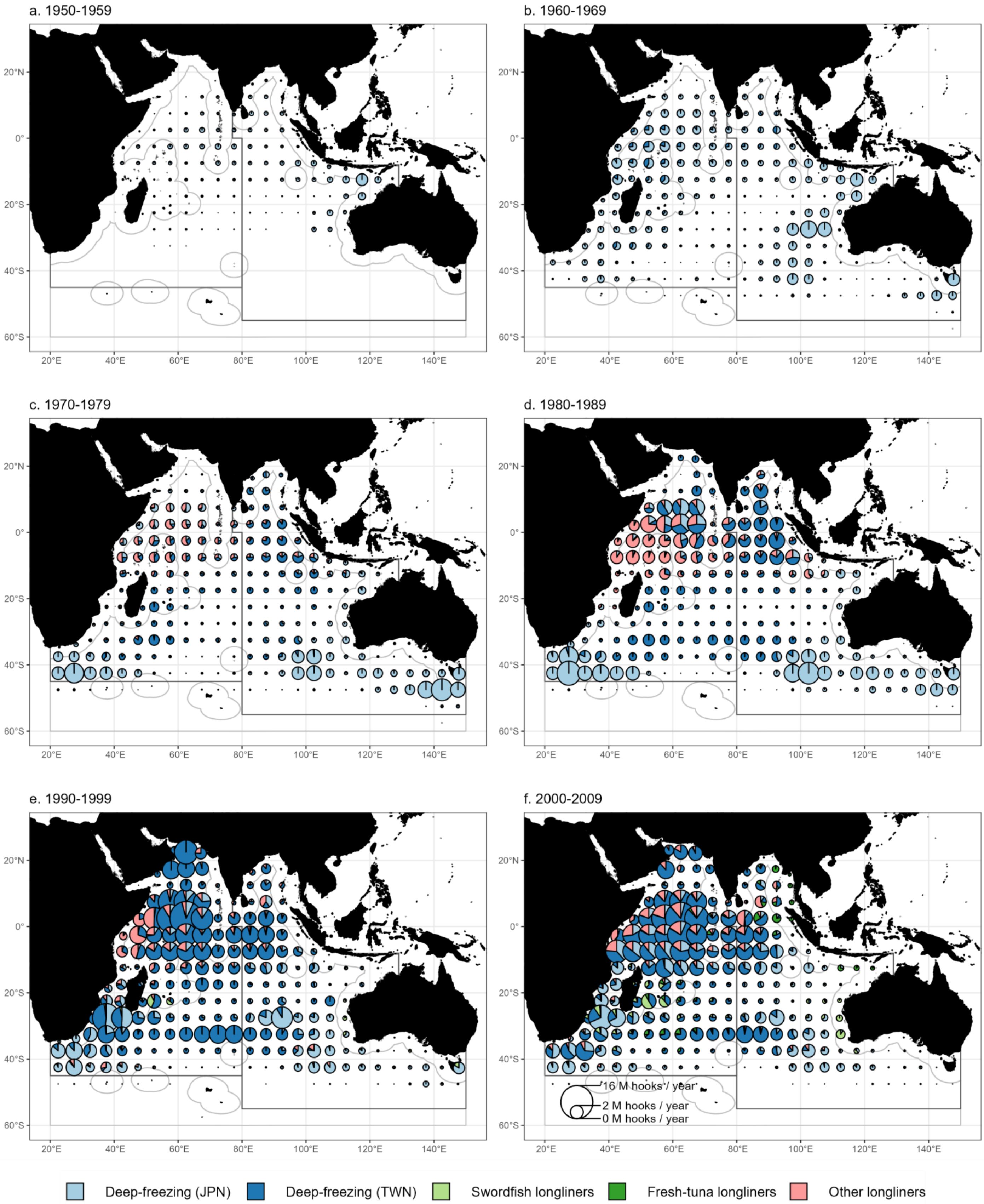

Figure 24: Average annual effort exerted by industrial longline fleets in millions of hooks set / year, by decade, 5x5 grid and fleet. Data source: time-area effort dataset for longline fisheries (Res. 15/02)

Longline fisheries, by last years (2016-2020) and decade (2010-2019)

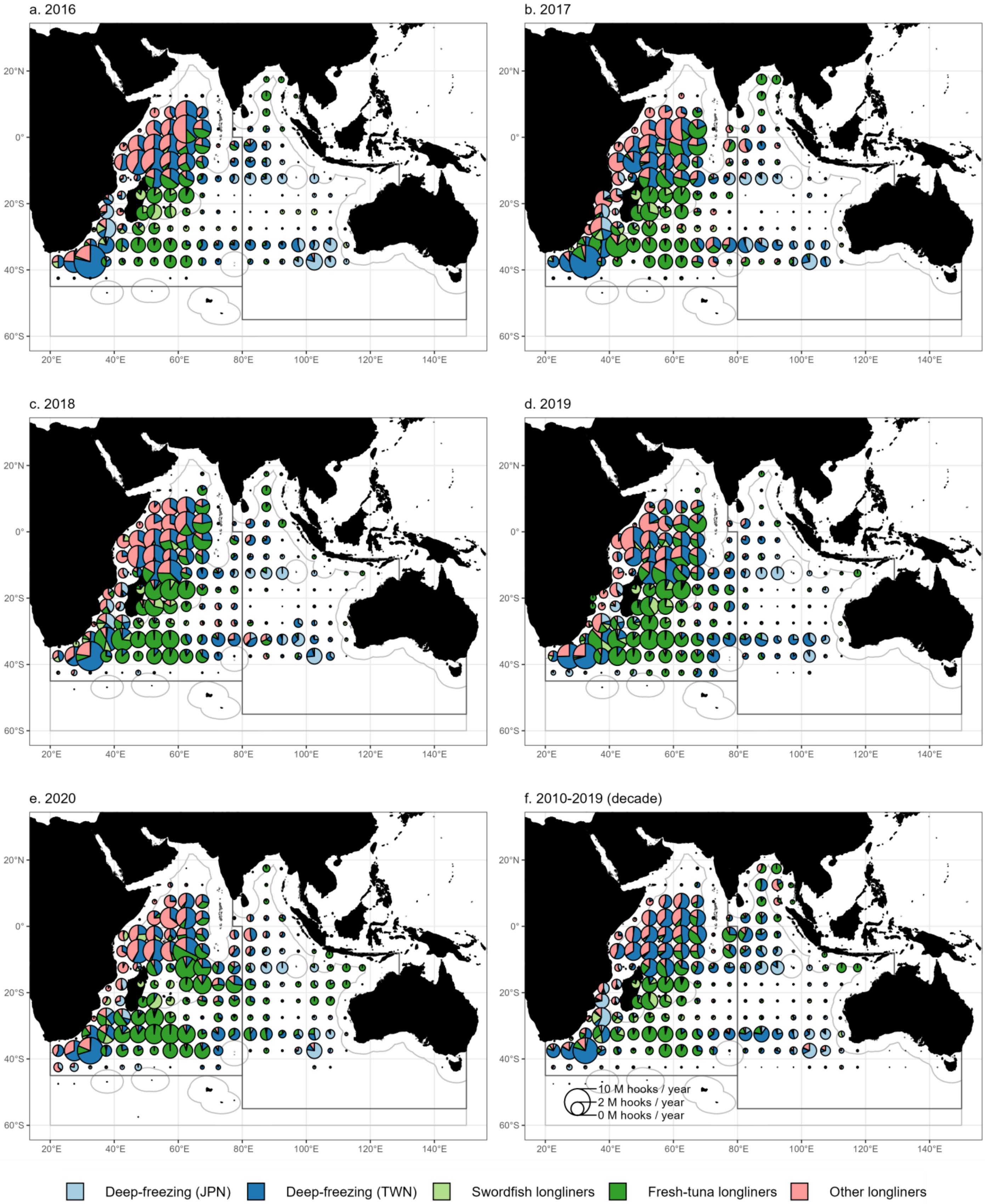

Figure 25: Average annual effort exerted by industrial longline fleets in millions of hooks set / year, by year / last decade, 5x5 grid and fleet. Data source: [time-area effort dataset for longline fisheries](#) (Res. 15/02)

Purse seine fisheries, by decade (1980-2009)

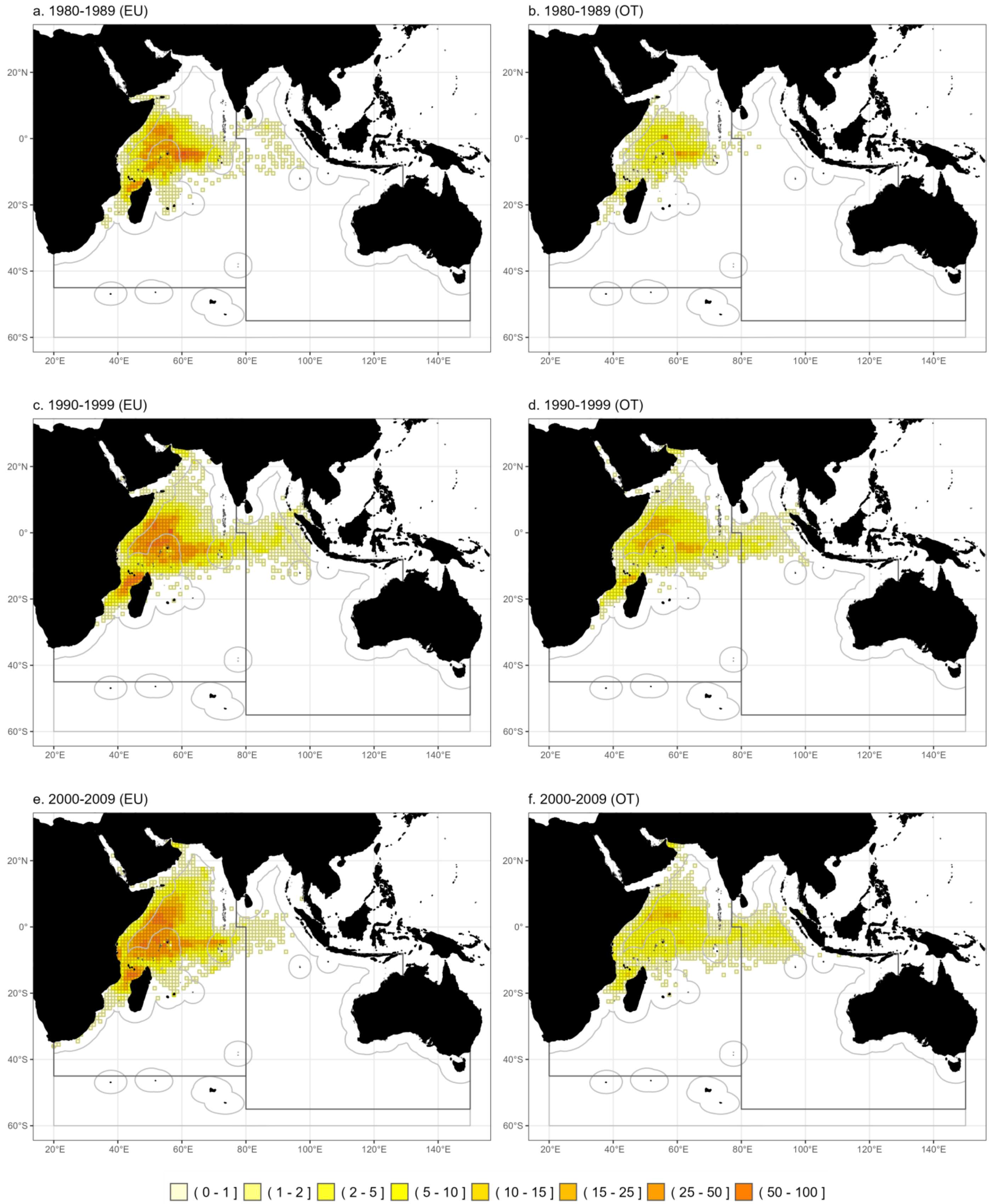

Figure 26: Average annual effort exerted by the industrial purse seine fleets of the European Union and assimilated flags (EU) vs. all other flags (OT) in fishing days / year, by decade, 1x1 grid and fleet. Data source: time-area effort dataset for purse-seine fisheries (Res. 15/02)

Purse seine fisheries (EU) by last years (2016-2020) and decade (2010-2019)

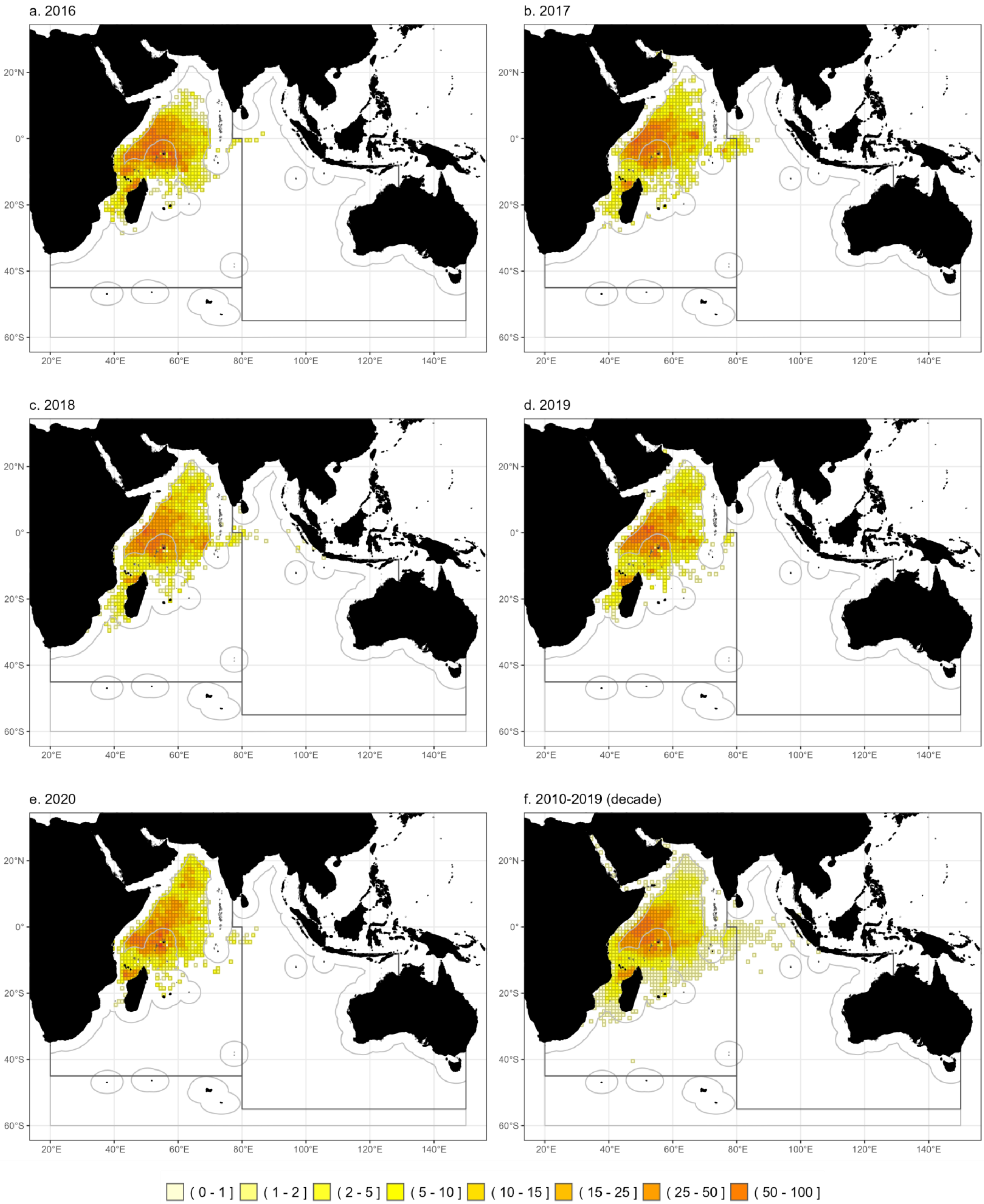

Figure 27: Average annual effort exerted by the industrial purse seine fleets of the European Union and assimilated flags (EU) in fishing days / year, by year / decade and 1x1 grid. Data source: time-area effort dataset for purse-seine fisheries (Res. 15/02)

Purse seine fisheries (OT) by last years (2016-2020) and decade (2010-2019)

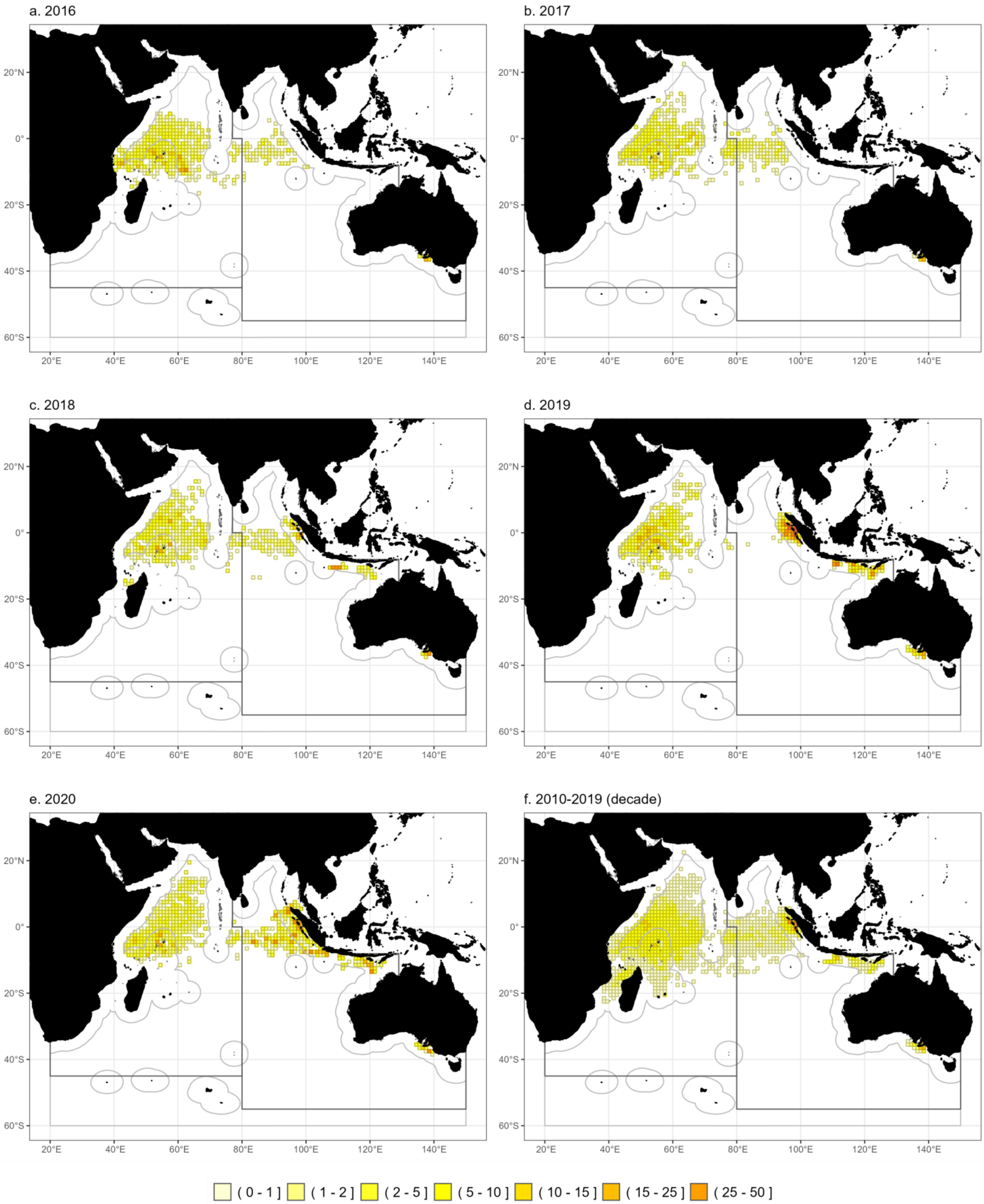

Figure 28: Average annual effort exerted by the industrial purse seine fleets from other flags (OT) in fishing days / year, by year / decade and 1x1 grid. Data source: [time-area effort dataset for purse-seine fisheries]() (Res. 15/02)

Appendix IV: Spatial distribution of average weights in the catch

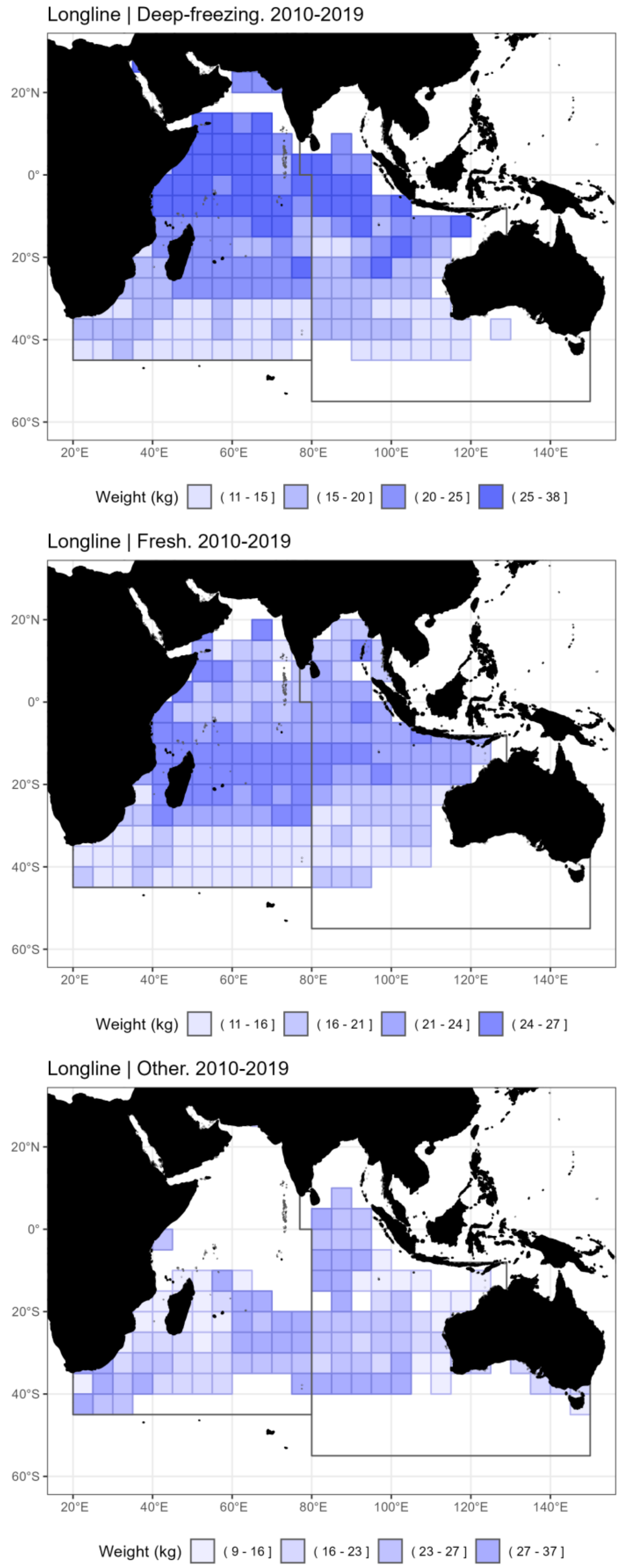

Figure 29: Estimated average weight (kg / fish) in the longline fisheries catch of Indian Ocean albacore by fishery and 5x5 grid, 2010-2019. Longline | Other includes swordfish and shark-targeted longlines

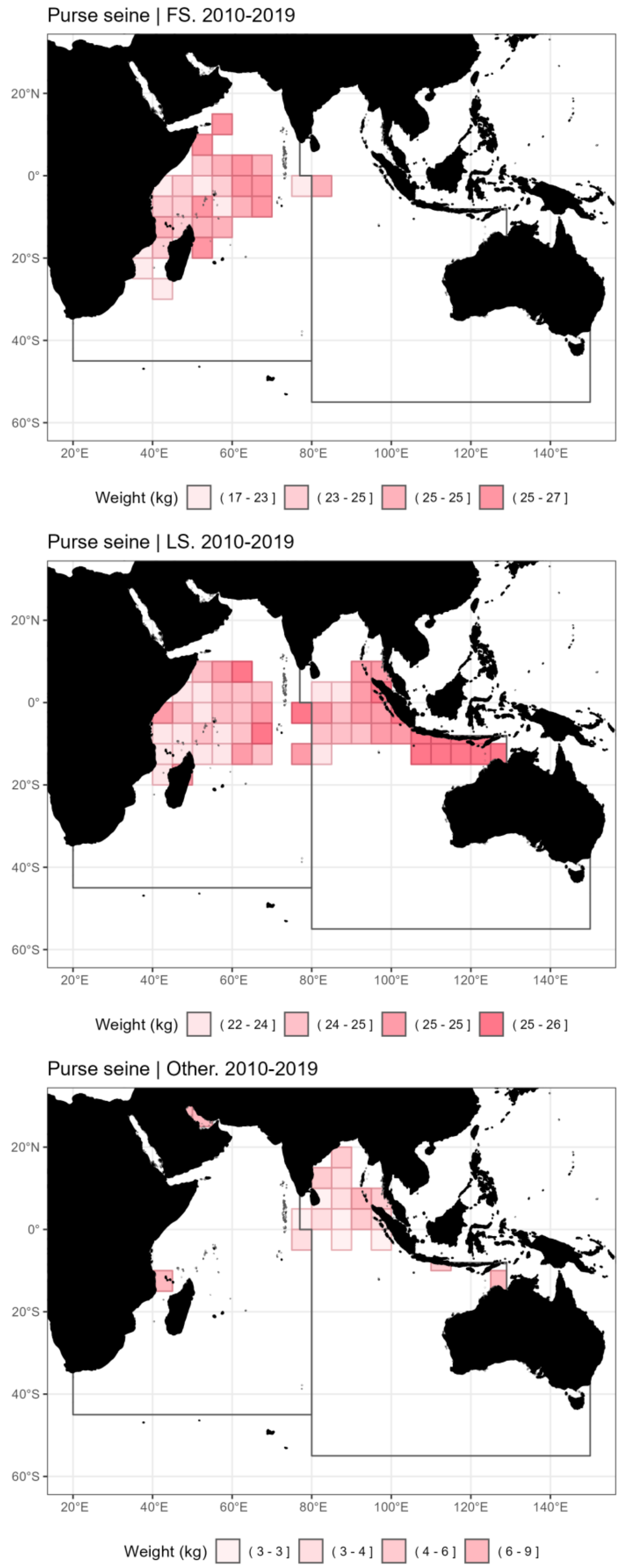

Figure 30: Estimated average weight (kg / fish) in the purse seine fisheries catch of Indian Ocean albacore by fishery and 5x5 grid, 2010-2019. FS = Free-swmming schools; LS = schools associated with floating objects

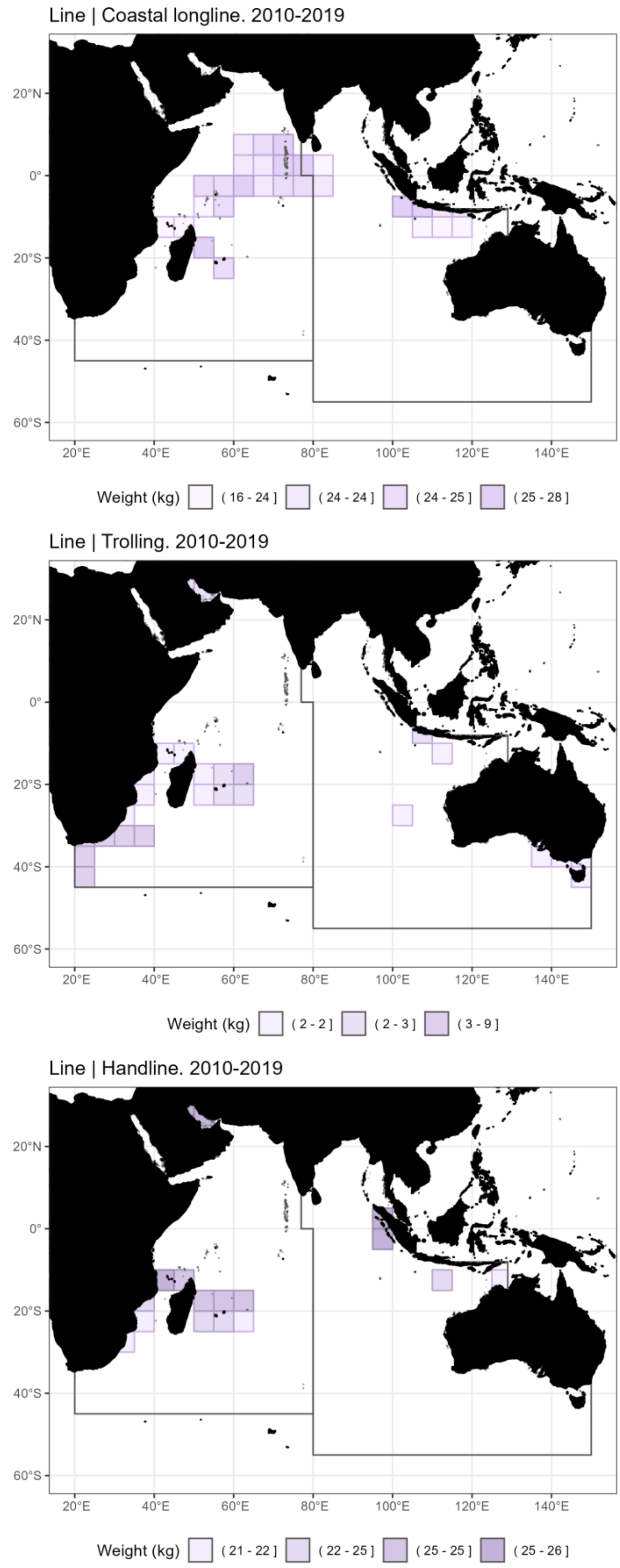

Figure 31: Estimated average weight (kg / fish) in the line fisheries catch of Indian Ocean albacore by fishery and 5x5 grid, 2010-2019

Appendix V: Monthly time series of albacore price and fuel, 2000-2020

Albacore import price

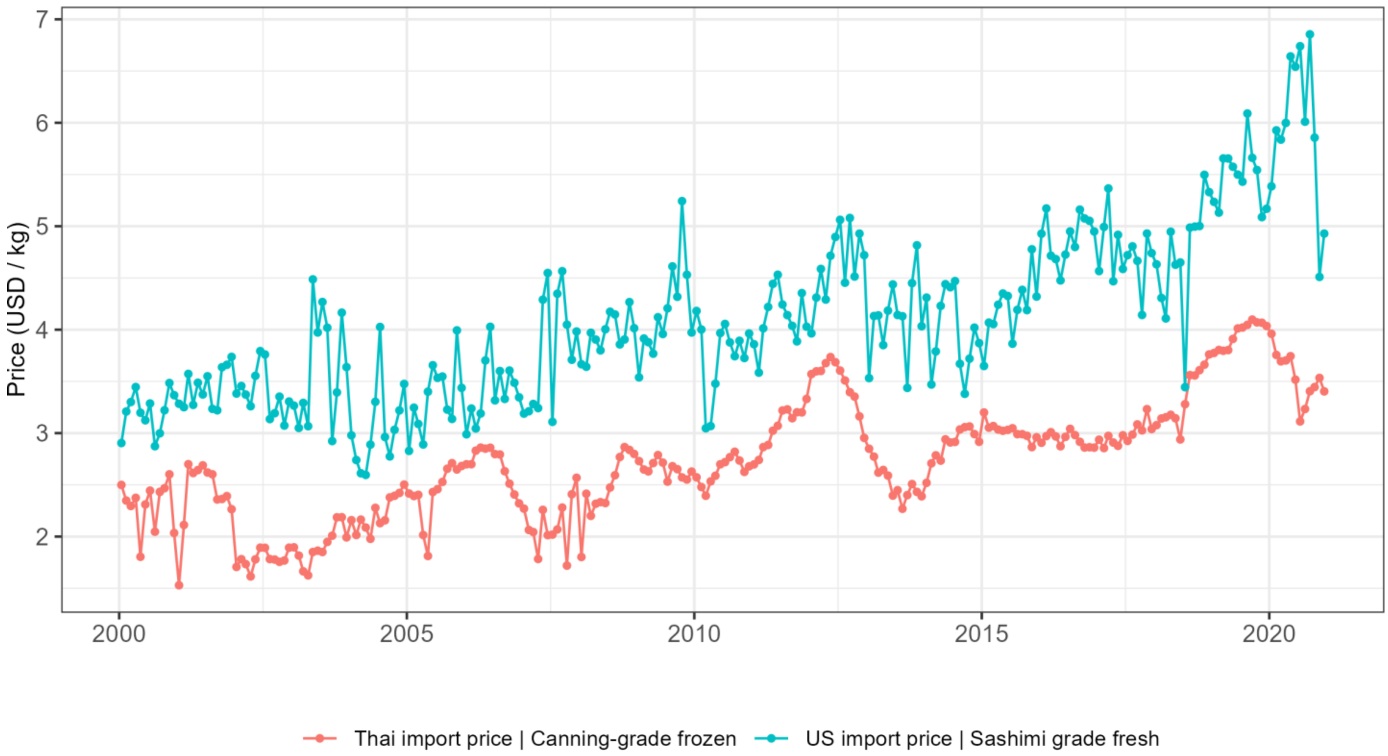

Figure 32: Monthly time series of import prices (USD/kg) for canning-grade frozen (Thailand) and sashimi-grade fresh albacore (USA) during the period 2000-2020 (compiled by the FFA Fisheries Development Division)

Fuel price

Figure 33: Monthly time series of crude oil spot price (USD/barrel) during the period 2000-2020 (compiled by the FFA Fisheries Development Division)

Appendix VI: Length-weight relationship

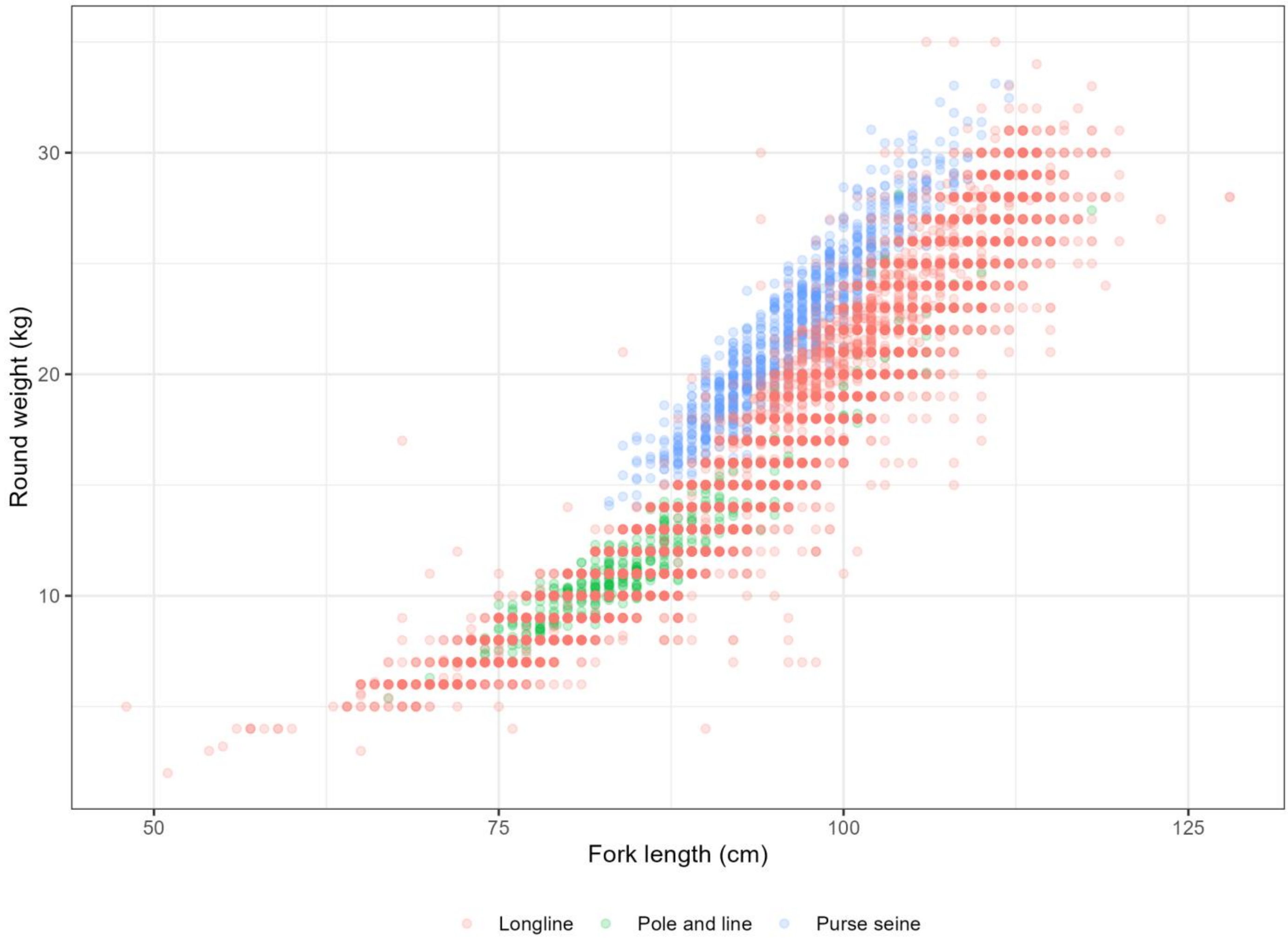

Figure 34: Relationship between fork length (cm) and round weight (kg) data available at the IOTC Secretariat for Indian Ocean albacore by fishing gear group

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