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Bycatch trend and its fate of the Spanish-owned tuna purse seiners fleet from the Atlantic and Indian oceans: Impacts of the implementation of good practices

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A R T I C L E I N F O

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A B S T R A C T

This study examines the fate of species caught as bycatch in the tropical tuna purse seine fishery across the Atlantic and Indian Oceans from 2003 to 2022, focusing on the impact of the industry-implemented Code of Good Practices (CGP) and bycatch mitigation measures from Tuna Regional Fisheries Management Organisations (t-RFMOs). Data were sourced from scientific observers under both Spain's National Data Collection Framework (DCF, Regulation (EU) No 2017/1004) and the OPAGAC-AGAC observer program, which covers other flags as well. Following the adoption of CGP and t-RFMO regulations, statistical tests reveal significant improvements in the live-release rates of sharks and rays after 2014 in both oceans, but no significant differences in live-release rates for marine turtles, which were already high. Despite these positive trends, interactions with certain species, such as billfish, experiences an increase in discard rates during the last years of the study period. The study identifies coastal regions near Gabon and Angola in the Atlantic, and northern Indian Ocean fishing areas as potential hotspots for some sensitive species, which may be confirmed as information from other fisheries come to light.

1. Introduction

Between 2003 and 2022 global yearly catches of tropical tunas have ranged between four and five million tonnes, of which 28–35 % have come from the Atlantic and Indian oceans, depending on the year [24]. Indeed, both yellowfin tuna (*Thunnus albacares*) (abbreviated according to the FAO 3-Alpha Species Codes as YFT, thereafter), and skipjack tuna (*Katsuwonus pelamis*) (SKJ, thereafter) are among the ten fish species with the highest annual catch volumes in the world [14]. In this period, the contribution of purse seine fisheries in the areas of competence of the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Tuna Commission (IOTC) was 9 and 13 %, respectively, of the global purse seine catches of these species. Catches are very significant in terms of global food security [4,28,6] and in regards to its socioeconomic importance for coastal communities, particularly for those countries considered as tuna-dependent states [19].

The industrial fleet of tropical purse seiners target tuna using different fishing modes, generally classified under two major types of sets: sets on free-swimming schools (FS) and sets on tuna schools associated with Floating Objects (FOB) [22]. The main species caught by this fishery and commercially traded are YFT, SKJ and, to a lesser extent, bigeye tuna (*Thunnus obesus*) (BET).

Purse seine fishing activities may involve interactions with non-

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target species, some of them highly susceptible to exploitation due to low fertility or growth rates, including marine turtles, marine mammals, and pelagic sharks, among other sensitive species groups [1,26,27,36,40]. As such, data collection, assessment and management of incidental catches, commonly known as bycatch, are areas of great importance to t-RFMOs. These organizations bear the responsibility not only to manage fisheries and promote the sustainable use of stocks under their mandate, but also to address other impacts of fishing on the ecosystem. In this sense, Article 5 of the United Nations Fish Stocks Agreement (UNFSA) requires flag States of fishing vessels harvesting highly migratory species to minimise impacts on bycatch species. Both t-RFMOs have incorporated the monitoring of bycatch as part of their objectives and adopted various regulations throughout the study period (2003 and 2022) (Fig. 1). t-RFMO may adopt binding and non-binding regulations, termed Recommendations and Resolutions,[1] respectively, in the case of ICCAT, and the other way around in IOTC.

Regarding groups of endangered, threatened and protected species (ETP), although there was no specific regulation for cetaceans in ICCAT during the years covered in this study, all bycatch interactions should be reported as mandated by Recommendation 11–10. IOTC prohibited setting on cetaceans and whale sharks (*Rhincodon typus*) in 2013 under Resolutions 13/04 and 13/05, respectively, and have also provided guidelines for release practices in the event of accidental capture.

In the case of sea turtles, in the Atlantic Ocean, ICCAT Resolution 03–11 encouraged flag States to promote the release of marine turtles captured alive, to share all information on technical measures and to collect all information on these interactions. Later, Recommendation 10–09 prohibited setting on this group of species, a regulation updated in Recommendations 13–11 and 22–12 to incorporate several additional mitigation measures, release practices and reporting requirements. In the Indian Ocean, IOTC adopted Recommendation 05/08 to encourage countries, among others, to implement measures to minimize purse seine interactions with marine turtles and to safely release encircled or entangled specimens. Later, Resolution 12/04 adopted this requirement on a mandatory basis.

Concerning mobulids and rays, ICCAT had no regulation in place for this group in the study period, while IOTC prohibited the targeting and retention of *Mobulid* species under Resolution 19/03.

In the case of sharks, prior to the analysis period, ICCAT Resolution 01–11 required members to submit catch and effort data, including dead discard estimates for several species. It also encouraged the live release of sharks, to minimize waste and discards from shark catches and to limit the fishing effort on some species. This Resolution was amended, and adopted on a mandatory basis, under Recommendation 04–10, which establishes that, among other provisions, countries shall annually report data on shark catches; take the necessary measures to require full utilization of shark catches, excepting head, guts, and skins; as well as require their vessels not to have onboard fins that total more than 5 % of the weight of sharks onboard. In fisheries that do not target shark species, CPCs shall encourage the release of live sharks. Following this, numerous Recommendations were approved to protect different families or species of sharks: Recommendation 05–05, by which countries shall reduce North Atlantic shortfin mako shark (*Isurus oxyrinchus*) mortality; Recommendation 07–06 concerning porbeagle (*Lamna nasus*) and North Atlantic shortfin mako sharks; Recommendations 08–07 and 09–07 regarding bigeye thresher sharks (*Alopias superciliosus*); Recommendation 10–07 for oceanic whitetip sharks (*Carcharhinus longimanus*); Recommendation 10–08 for the family Sphyrnidae; Recommendation 11–08 for silky sharks (*Carcharhinus falciformis*); Recommendation 15–06 for porbeagle sharks; and Recommendations 19–06, 21–09, and 22–11, which relate to the prohibition and limits on shortfin mako shark retention onboard. Despite the existence of more regulations regarding sharks, those cited are considered the most representative for the fishery and the objective of this study.

In the Indian Ocean, IOTC established a regulation on sharks in 2005 with Resolution 05/05, by which countries shall annually report data on shark catches and take measures to require that fishermen utilise the entire catch of sharks, including the establishment of measures to prevent discards of shark carcasses following the removal of fins. Resolution 10/12 prohibited the retention onboard, transhipping, landing, storing, selling or offering for sale of any part or whole carcass of all the species of the family *Alopiidae* (thresher sharks), with countries requiring vessels to promptly release these species unharmed. This regulation was superseded by Resolution 12/09, which encouraged the collection of further biological information related to the aforementioned family group. Resolution 13/06 adopted the requirement to promptly release unharmed, to the extent practicable, oceanic whitetip sharks. Resolution 17/05 established that countries shall encourage the live release of sharks and require that fishermen are aware of and use identification guides. Resolution 18/02 required countries to record data on blue shark (*Prionace glauca*) catch and also to provide information on scientific research relating to this species.

Regarding billfish species, which are not considered as ETP, ICCAT Recommendation 16–11 established that countries shall take or maintain appropriate measures to limit Atlantic sailfish (*Istiophorus albicans*) mortality and to enhance data collection. Recommendation 18–05 was established to improve the compliance review of measures for the conservation of this group. Later, Recommendation 19–05, established rebuilding programmes for blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*) and roundscale spearfish (*Tetrapturus georgii*) and also developed minimum standards for safe handling and live release procedures for these species. In the Indian Ocean, IOTC Resolution 15/05 encouraged flag States to reduce the level of catches of their vessels for striped marlin (*Kajikia audax*), black marlin (*Istiompax indica*) and blue marlin. Three years later, Resolution 18/05 established catch limits for striped marlin, black marlin, blue marlin, and Indo-Pacific sailfish (*Istiophorus platypterus*).

Fleets are also subject to national regulations that may go beyond tRFMO requirements. For example, the European Union adopted an anti-finning measure in 2013 whereby all *Elasmobranchii* species should be landed with their fins/wings naturally attached to their bodies (Regulation (EU) Nº 605/2013). European Union Council Regulation (EC) Nº 520/2007 establishes that Member States shall encourage the release of live sea turtles, mobulids and rays, and sharks, and the prompt release unharmed, to the extent practicable, of all non-target species, as well as additional measures to improve the selectivity of fishing gears. This regulation also prohibits the encirclement with purse seines of any school or group of marine mammals. Therefore, EU purse seiners were subject to a prohibition to encircle marine mammals during the period covered by this study, in spite of the lack of measures at the RFMO level.

In relation to target species, ICCAT adopted Recommendation 17–01, which prohibits discards of target species with certain exceptions. Those include cases where the catch is unfit for human consumption due to being meshed or damaged or caught during the final set of a trip when there is insufficient well space left to accommodate all the catch. IOTC, through the adoption of Recommendation 10/13, called for countries to encourage all purse-seine vessels to retain and land all catch of target and some bycatch fish species, with similar exceptions as those for ICCAT. This was made mandatory through the adoption of Resolution 13/11 and Resolution 19/05, which extend the obligatory retention on board and landing of several bycatch species, maintaining the exceptions applicable.

It is important to mention that other conservation measures affecting fisheries directly impact bycatch, especially those regulating Fish Aggregation Devices (FADs). One significant measure is the prohibition on the use of entangling FADs, first included in ICCAT's Recommendation 16–01 (although the first time the term "non-entangling FAD" was mentioned was in Recommendation 14–01) and later amended in

[1] All the Recommendations and Resolutions of ICCAT and IOTC mentioned in this study are compiled in the Compendiums of each t-RFMO [21,25].

ATLANTIC	INDIAN
RESOLUTION 01-11 (ICCAT): Among other points, countries should encourage the release of live sharks, to the extent possible, that are caught incidentally; minimize waste and discards from shark catches (requiring the retention of the entire shark); submit catch and effort data, including dead discard estimates	
2003	
RESOLUTION 03-11 (ICCAT): Countries must encourage to release marine turtles and share all information of technical measures, collecting all information on interaction	
2004	
RECOMMENDATION 04-10 (ICCAT): Among other points, countries shall: annually report data for catches of sharks; take the necessary measures to require the landing of entire catches of sharks excepting head, guts and skins; require their vessels to not have onboard fins that total more than 5% of the weight of sharks onboard; In fisheries that are not directed at sharks, CPCs shall encourage the release of live sharks	
2005	
RECOMMENDATION 05-05 (ICCAT): add to Recommendation 04-10 that countries shall reduce North Atlantic shortfin mako shark (*Isurus oxyrinchus*) mortality	RESOLUTION 05/05 (IOTC): Countries shall annually report data for catches of sharks; take measures to require that fishermen utilize the entire catch of sharks; and establish anti-finning measures (maximum 5% of fins' weight of the entire weight)
...	
2007	
RECOMMENDATION 07-06 (ICCAT): Among other points, countries shall take appropriate measures to reduce fishing mortality in fisheries targeting porbeagle (*Lamna nasus*) and North Atlantic shortfin mako sharks	
(EC) No 520/2007 (European Union): The encircling with purse seines of any school or group of marine mammals shall be prohibited	
(EC) No 520/2007 (European Union): Purse seine vessels shall promptly release unharmed, to the extent practicable, all non-target species	
(EC) No 520/2007 (European Union): Purse seine vessels shall promptly release unharmed, to the extent practicable, all rays	
(EC) No 520/2007 (European Union): EU countries shall encourage the release of live of sea turtles	
(EC) No 520/2007 (European Union): EU countries shall encourage the release of live sharks captured accidentally and improving the selectivity of fishing gears	
2008	
RECOMMENDATION 08-07 (ICCAT): Countries shall require vessels to promptly release unharmed, to the extent practicable, bigeye thresher sharks (*Alopias superciliosus*)	
2009	
RECOMMENDATION 09-07 (ICCAT): Among other points, countries shall: prohibit, retaining onboard, transshipping, landing, storing, selling, or offering for sale any part or whole carcass of bigeye thresher sharks; their promptly release unharmed and report data	RESOLUTION 09/06 (IOTC): Countries will implement the FAO Guidelines and shall collect all data of marine turtles
2010	
RECOMMENDATION 10-07 (ICCAT): Among other points, countries shall: prohibit, retaining onboard, transshipping, landing, storing, selling, or offering for sale any part or whole carcass of oceanic whitetip sharks (*Carcharhinus longimanus*)	RECOMMENDATION 10/13 (IOTC): Countries should encourage to retain and land all catch of target fish and bycatch fish, with some exceptions
RECOMMENDATION 10-08 (ICCAT): Among other points, countries shall: prohibit, retaining onboard, transshipping, landing, storing, selling, or offering for sale any part or whole carcass of sharks of the family *Sphyrnidae*; their promptly release unharmed and report data	RESOLUTION 10/12 (IOTC): Prohibition of retaining on board, on board, transhipping, landing, storing, selling or offering for sale any part or whole carcass of thresher sharks of all the species of the families *Alopiidae*, and countries shall require vessels to promptly release unharmed
RECOMMENDATION 10-09 (ICCAT): Countries shall require that vessels are avoid encircling sea turtles and follow the FAO's Guidelines to Reduce Sea Turtle Mortality in Fishing Operations	
RECOMMENDATION 10-10 (ICCAT): minimum of 5% observer coverage of fishing effort for all fisheries	
2011	
RECOMMENDATION 11-01 (ICCAT): The ICCAT Regional Observer Program shall be established in 2013 to ensure observer coverage of 100% in the area/time closure	RESOLUTION 11/04 (IOTC): 5% of minimum coverage of scientific observer programs
RECOMMENDATION 11-08 (ICCAT): Countries shall require vessels to release silky sharks (*Carharinus falciformis*) alive or dead, prohibiting their retention on board, transshipment, or landing of any part of this species	
RECOMMENDATION 11-10 (ICCAT): Countries shall require to vessels the collection of bycatch and discard data	
2012	
CGP (AGAC): Non entangling FADs	
CGP (AGAC): Process to 100% observation coverage	
CGP (AGAC): Guidelines for released practices of incidental capture of cetaceans	
CGP (AGAC): Guidelines for released practices of incidental capture of whale sharks	
CGP (AGAC): Guidelines for released practices of incidental capture of *Mobulidaes*	
CGP (AGAC): Guidelines for released practices of incidental capture of marine turtles	
CGP (AGAC): Guidelines for released practices of incidental capture of sharks	
	RESOLUTION 12/04 (IOTC): Vessels must apply all necessary techniques for proper release of marine turtles and reduce the incidence of entanglement on FADs
	RESOLUTION 12/09 (IOTC): Add to Resolution 10/12 that it is necessary to collect more biological information
2013	

Fig. 1. Timeline of Regulations in the Atlantic and Indian Oceans from 2003 to 2022. Colours indicate the regulatory subject, as follows: light pink (sharks, except the whale shark), dark green (whale shark), light green (marine turtles), light blue (marine mammals), light yellow (mobulids and rays), light turquoise (billfish), light orange (general bycatch), lilac (target fish discards, including or not the non-target catch), grey (observation coverage & general data collection), yellow (artificial lights), dark orange (FAD characteristics), red (compilation).

RECOMMENDATION 13-11 (ICCAT): Adds more safe-handling points in the release of turtles from Recommendation 10-09: use a basket lift or dip-net to remove the turtle from the water; vessels shall carry on board line-cutters and use these tools to safely remove gear, and release sea turtles	RESOLUTION 13/04 (IOTC): Countries shall prohibit sets on cetaceans
	RESOLUTION 13/05 (IOTC): Prohibition intentional setting on whale sharks & guidelines for release practices
	RESOLUTION 13/06 (IOTC): Countries shall require to their vessels to promptly release unharmed, to the extent practicable, of oceanic whitetip sharks
	RESOLUTION 13/08 (IOTC): Need to gradually reduce FAD entanglement characteristics
	RESOLUTION 13/11 (IOTC): Making the provisions of Recommendation 10/13 mandatory
REGULATION (EU) Nº 605/2013 (EUROPEAN UNION): All elasmobranch species should be landed with their fins/wings naturally attached to their bodies	
2014	
RECOMMENDATION 14-01 (ICCAT): 100% coverage with national observers during the area/time closure period	
2015	
CGP (AGAC): 100% observation coverage (human and/or electronic)	
RECOMMENDATION 15-06 (ICCAT): Countries shall require their vessels to promptly release unharmed, to the extent practicable, porbeagle sharks (*Lamna nasus*)	RESOLUTION 15/05 (IOTC): Countries are encouraged to reduce the level of catches of their vessels for striped marlin (*Tetrapturus audax*), black marlin (*Makaira indica*) and blue marlin (*Makaira nigricans*)
	RESOLUTION 15/07 (IOTC): Artificial lights to attract fish are prohibited
2016	
RECOMMENDATION 16-01 (ICCAT): Prohibition of entangling FADs	RESOLUTION 16/07 (IOTC): Updated version of Resolution 15/07, adding a provision that some vessels can use lights until 2017, and clarifying that navigation lights are not affected by the resolution
RECOMMENDATION 16-11 (ICCAT): Countries shall take or maintain appropriate measures to limit sailfish (*Istiophorus albicans*) mortality. Such measures could include releasing live sailfish (...)	
2017	
RECOMMENDATION 17-01 (ICCAT): Prohibition of discards of target fish, with some exceptions	RESOLUTION 17/05 (IOTC): Countries shall encourage the release of live sharks and require that fishers are aware of and use identification guides
	RESOLUTION 17/08 (IOTC): Fully prohibited entangling FADs
2018	
RECOMMENDATION 18-05 (ICCAT): Establishes compliance review measures for the conservation of billfish	RESOLUTION 18/02 (IOTC): Countries shall ensure to record data of blue shark (*Prionace glauca*) catch and require information to scientific research
	RESOLUTION 18/05 (IOTC): Establishes catch limits for striped marlin, black marlin, blue marlin, and Indo-Pacific sailfish (*Istiophorus platypterus*)
2019	
RECOMMENDATION 19-02 (ICCAT): minimum coverage required for the purse seine fleet has remained at 100% for the complete year	RESOLUTION 19/03 (IOTC): Countries shall prohibit fish and retention of *Mobulidae*, being necessary safe handling and release practices
RECOMMENDATION 19-05 (ICCAT): Minimum standards for safe handling and live release procedures & countries aim to prevent the commercialization of blue marlin (BUM) and white marlin (WHM) caught as bycatch	RESOLUTION 19/05 (IOTC): Update the discards resolution
RECOMMENDATION 19-06 (ICCAT): Related to limits on shortfin mako shark retention onboard	
...	
2021	
RECOMMENDATION 21-09 (ICCAT): Prohibition on retaining on board shortfin mako shark, being necessary safe handling release	
2022	
(EU) Nº 2022/2343 (EUROPEAN UNION): Gather the measures of the IOTC	
RECOMMENDATION 22-01 (ICCAT): Guidelines to non-entangling FADs, and constructed from biodegradable materials, including non-plastics, with the exception of materials used in the construction of FAD tracking buoys	RESOLUTION 22/04 (IOTC): Establishes a Regional Observer Scheme with a Minimum Standard Data Fields on data collection
RECOMMENDATION 22-11 (ICCAT): Safe handling and release of shortfin mako. Only possible retention when dead being confirmed by observer and the Commission has specially allowed the country for it	
RECOMMENDATION 22-12 (ICCAT): Establishes a safe handling and release practices for sea turtle's manual, and require specific minimum data collection about the interaction	
2023	

Fig. 1. (*continued*).

Recommendation 22–01, which also established guidelines for non-entangling FADs, along with the endeavour to construct FADs using biodegradable materials of plant origin. Despite noting in Resolution 13/08 the need to gradually reduce FAD entanglement characteristics, IOTC did not fully prohibit entangling FADs until Resolution 17/08 was adopted. Additionally, the use of artificial lights to attract fish is prohibited in IOTC's Resolution 15/07, later updated in Resolution 16/07 by adding a provision that some vessels could use lights until 2017 and clarifying that navigation lights were not affected by the measure.

ICCAT has adopted under Recommendation 11–10 that countries shall require vessels to collect bycatch and discard data. Recommendation 10–10 established a minimum of 5 % observer coverage of fishing effort for all fisheries, while Recommendation 11–01 increased observer coverage for the purse seine fleet to 100 % during the time-area closure (similarly, since the adoption of the Recommendation 14–01 all purse seine vessels targeting tropical tunas, including supply vessels, and fishing in the geographical area of the area/time closure, were required to embark an observer). Finally, since the entry into force of Recommendation 19–02, the minimum coverage required for the purse seine fleet has remained at 100 % for the complete year, either human or electronic) [37]. In the Indian Ocean, IOTC Resolution 11/04 established a 5 % minimum coverage of scientific observer programmes, for all fisheries.

The European tuna purse seine fleet voluntarily adopted a Code of

Good Practices (CGP) in 2012, aimed at mitigating, as much as possible, the impacts of the fishery on ETP species. The fleets that have adopted it specifically belong to two Spanish associations, ANABAC and OPAGAC-AGAC, and the French association ORTHONGEL. They self-regulated their activity through the adoption of non-entangling Fish Aggregating Devices (FADs) ahead of RFMO measures. Equally, they adopted guidelines on the proper release of ETP species such as cetaceans, whale sharks, mobulids and rays, sea turtles, and sharks. They also introduced measures that go beyond t-RFMO requirements, including 100 % observer coverage (human or electronic) for all purse seiners and supply vessels, which was achieved in 2015 [29].

The implementation of these measures was aimed at reducing the mortality of ETP species, by reducing retention rates and increasing the survival of these species through proper handling and quick release. For non-ETP groups, discard levels are expected to decrease considerably, following the adoption of prohibitions on discards for some species groups by the t-RFMO.

To date, several studies have attempted to assess the amount of bycatch taken by tropical tuna purse seine fleets in the Atlantic and Indian oceans ([1,3,38,39]). However, these studies do not provide a detailed account of the trend and fate of each bycatch group over the study period. This study assesses bycatch rates and its condition at the time of release over 20 years of on-board observation programmes in the management areas of ICCAT and IOTC, as well as the potential impact of the implementation of t-RFMO regulations and the CGP. Fig. 1 graphically summarizes the most relevant measures related to bycatch management that have been described in this section.

2. Material and methods

2.1. Study area and fisheries data sources

This study covers the activity of Spanish purse seiners sourced from different public scientific programmes, notably the Data Collection Framework (DCF), as well as the activity of vessels from different nations registered with OPAGAC-AGAC under flag states, coastal states or the CGP observer programme in the tropical Atlantic and Indian Oceans between the 2003 and 2022. Data for the Indian Ocean were not collected between 2010 and 2014 due to the piracy issue [7]. This choice is based on data availability, primarily sourced from different scientific programmes such as the Data Collection Framework (DCF) on Spanish flagged vessels, other programmes from flag and coastal states, and the Spanish shipowners' associations OPAGAC-AGAC observer programme.

The European fleet fulfils RFMO requirements for minimum observer coverage, as described in the previous section, through the DCF. This framework is supported by Regulation (EU) 2017/1004 of the European Parliament and of the Council of 17 May 2017 on the establishment of a Union framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the common fisheries policy. The regulation aims to set rules for collecting data from EU fisheries. For vessels flying the Spanish flag, this data collection is managed by the Spanish Institute of Oceanography (IEO-CSIC) and AZTI.

Data have also been collected through various observer programmes implemented by flag states or coastal states that grant access to OPAGAC-AGAC purse seiners to fish in their EEZ. Additionally, this coverage is complemented by an OPAGAC-AGAC observer programme, which is intended to monitor the implementation of the Code of Good Practices (CGP), through the coverage of 100 % of fishing activities. At present, AZTI is responsible for assessing the conformity of the OPAGAC-AGAC fleet with the Code of Good Practices initiative (CGP) [5].

The observer programmes referred to above collect various types of information, including details on fishing activities, such as the location of fishing sets, the type of set or the fishing mode (free school (FSC) and FOBs); the amount of catch that is retained and discarded by species, and the condition at release of the fish that are discarded [23].

Observers identify specimens at the lowest possible taxonomic level-generally at the species level (Annex-Table 7). For the purpose of the present study, bycatch was grouped under the following categories: cetaceans, whale sharks, sharks (other than whale sharks), mobulids and rays, billfish species, marine turtles, neritic & temperate tunas, and other bony fish.

2.2. Data analysis

As a characterization, the species composition of each bycatch group was analysed for the whole study period, and rates on bycatch and fate by group were studied by ocean. The annual trend of groups has been calculated by ocean in absolute terms of weight (in tonnes) or number of individuals, as well as relative to the catch of the target species.

The weights of the cetaceans, mobulids and rays, turtles and whale sharks are considered to be rough estimates, since the observers mainly record the number of individuals observed, and an average weight by individual (based on published literature) has been assigned. Therefore, these groups of species are provided in number of individuals, instead of weight.

The fate categories have been grouped into released alive, released dead, retained, and unknown. Alive or dead releases are based on visual assessment of the physical condition and behaviour of the animal at the moment of release [23]. The retained category covers the part of the bycatch sold in local markets and used for human consumption [20,35]. All releases of live individuals have been grouped, without further categorization of their condition, given the lack of objective criteria to assess animal condition and survival probability. The annual percentage of each fate category for each species group in each ocean has been calculated.

Annual bycatch rates have been calculated for each group, distinguishing between FSC and FOB sets. By default, the sets with whale shark interactions (*Rhincodon typus*) are considered as sets on FOBs [13]. Therefore, in this study, the term FOB is employed to encompass fishing sets on man-made FADs, sets on natural floating objects, as well as sets where whale sharks were encircled or present associated to the schools just before the set. Same for FOBs (second set on the same school not caught in the first one). Then, annual bycatch rates, measured in tonnes or number of specimens per 1000 t of target tuna catch, were calculated for each group and set typology (FSC and FOB).

The cetacean group is distinctive due to the considerable size of these species, which enables most individuals to avoid net entrapment prior to the complete pursing of the net. Consequently, these encounters are classified primarily as interactions rather than as bycatch. All the tuna schools interacting with cetaceans are considered FSC schools and only when there is a presence of a FAD are they considered as FOB schools.

Heatmaps showing the relative rate of bycatch in the Atlantic and Indian Oceans by group are presented. The average bycatch rates were estimated at a 2.5 degrees resolution in longitude and latitude and, for illustration purposes, are shown on a logarithmic scale. The results, to avoid noise related to low observation coverage, are shown only for cells where the catch of target species is over 1000 tonnes. Additionally, heatmaps illustrating the spatial distribution of the observed target catch in absolute terms, represented in thousands of tonnes, are also provided.

Finally, to assess the impact of the CGP or different t-RFMOs regulations on the bycatch rate and fate of different species groups, comparisons were made between observation before and after their implementation using a student's *t*-test or the Mann-Whitney *U* test when normality or homoscedasticity assumptions were not met. Rates were compared on a fishing trips basis. The regulation selected for the analyses was, in the case of the Atlantic, the CGP for sharks, turtles, mobulids and rays, and whale sharks, assessing whether there were significant differences in live release rates from 2014 onwards, as well as interactions of turtles with FADs from the same year. For the Indian Ocean, for billfish species, other bony fish, and other tunas, retention rates were analysed according to Resolution 13/11, with 2014 marking the separation of periods. In the case of sharks, marine turtles, mobulids and rays, and whale sharks, live release rates were evaluated from 2014 onwards, similar to the Atlantic, through the CGP framework, as well as interaction rates with FADs for sea turtles. Additionally, the interaction rate was calculated for whale sharks under Resolution 13/05 with 2014 as the separating year. Finally, for cetaceans, interactions with purse seines were evaluated according to Resolution 13/04, also using 2014 as the period separator.

The analysis, data extraction and visualization were conducted in R environment [34].

3. Results

The observer coverage, in terms of target catch, increased steadily from the beginning of the time series (Table 1), transitioning from an observation of 1.25 and 6.01 thousand tonnes captured in the observed trips in the Atlantic and Indian Oceans, respectively, in 2003, to 61.54 and 40.65 thousand tonnes in 2022, with peaks in 2015 in both oceans at 110.8 thousand and 58.49 thousand tonnes, respectively. In the Indian Ocean, the observer programmes were suspended from 2010 to 2014 due to safety issues arising from piracy incidents in the western Indian Ocean during this period. The leap to greater data coverage occurred in 2015, with the adoption of the CGP.

The period before 2010, observer coverage from Spain's regular observer programme represented 5 % of the total purse seine catch, from all purse seine fleets, in both oceans (Fig. 2). Then, when the OPAGAC-AGAC observer programmes started in the Atlantic Ocean in 2013 and 2014, coverage rose to around 30 % of the total purse seine catches, reaching a maximum of approximately 40 % in 2014, and declining thereafter to values around 25 % in the final years. In the Indian Ocean, 2015 also represented a peak, with target tuna catches representing nearly 20 % of the total, but in recent years, coverage has decreased and fluctuated around 10 % of the total purse seine catches.

Total bycatch per 100 tonnes of target tuna catch was estimated at 6.5 and 2.9 in the Atlantic and Indian Oceans respectively, excluding cetaceans, whale sharks and marine turtles (Table 2).

3.1. Atlantic Ocean

The group of neritic & temperate tunas constituted the majority of bycatch in weight, at over 69 % (Table 2) of the observed bycatch during the study period. Frigate (*Auxis thazard*) and bullet (*Auxis rochei*) tunas represented over three-quarters of the catches of this group. Little tunny (*Euthynnus alletteratus*) accounted for one fifth of the group. Regarding fate (Fig. 3), a substantial portion, ranging between 75 % and 95 %, was retained throughout the study period, especially in the last 4 years, where retention rates were above 90 %. The rest was released dead, with a higher proportion of dead discards observed in the period 2008–2010. Catch rates (Fig. 4 and Table 3) were higher in FOB than in FSC sets, with values ranging from less than 10 tonnes to 25 tonnes per 1000 tonnes of target tuna and without any evident temporal trend.

Billfish species accounted for 2.61 % of the total bycatch in weight (Table 2). Blue marlin and Atlantic sailfish (*Istiophorus albicans*) were by far the most important bycatch, at 96 % of the group. Swordfish (*Xiphias gladius*) represented less than 2 % of this group. Concerning fate (Fig. 3), prior to 2018, most of the catch was retained, and probably sold in local markets. However, from 2018 onwards, there was an increasing trend in discarding dead fish, reaching nearly 70 % in 2021 and 2022. The percentage of live discards was minimal, reflecting low live release rates, as billfish species often arrive lifeless on deck, as recorded by scientific observers. The rates of billfish species bycatch (Fig. 4 and Table 3) in FOB sets hover around 2–2.5 tonnes per 1000 tonnes of target tuna. In contrast, for FSC-related sets, a decreasing trend is noticeable, with a progressive decline from a peak of over 3 tonnes in 2006–2007 to less than 1 tonne per thousand tonnes of target tuna in the most recent

Table 1
Time series of observer target tuna catches, in thousands of tonnes, in the Atlantic and Indian Oceans between 2003 and 2022.

Ocean	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Atlantic	1.25	0.71	1.79	0.49	1.2	4.87	4.59	4.66	6.2	20.81	71.77	78.97	110.8	106.92	95.84	99.82	83.45	67.13	53.77	61.54
Indian	6.01	7.89	9.45	7.37	11.11	4.72	1.03	0	0	0	0	0	58.49	39.63	41.43	61.73	42.4	12.71	33.9	40.65

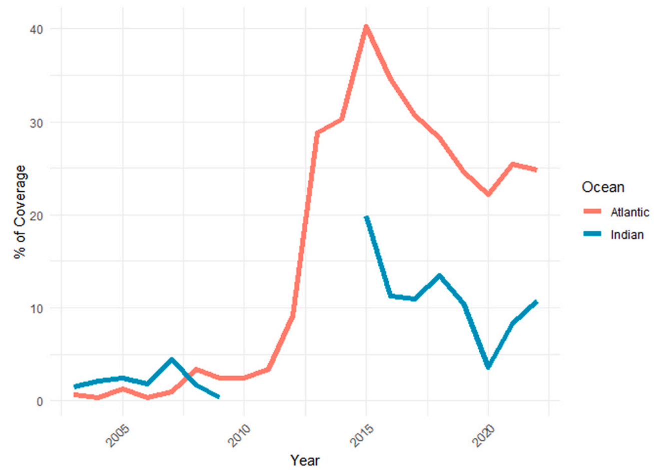

Fig. 2. Time-series of observer coverage, expressed as the percentage of observer vs total target species catch, of the study fleet in the Atlantic and Indian Oceans between 2003 and 2022.

Table 2
Percentage of observed bycatch composition by species group and the total bycatch rate between 2003 and 2022 in the Atlantic and Indian Oceans.

	Atlantic	Indian
Tonnes Bycatch s/ 100 tonnes of Target Catch	6.46	2.87
Neritic and temperate tunas	69.40 %	59.04 %
Other bony fishes	19.04 %	26.52 %
Sharks	7.93 %	11.48 %
Billfish species	2.61 %	2.27 %
Mobulids and rays	1.02 %	0.7 %

period.

The group of other bony fish (OBF), consisting of 90 species, amounted to over 19 % of the total bycatch weight (Table 2). Five species, namely blackfin jack (*Caranx crysos*), rainbow runner (*Elagatis bipinnulata*), ocean triggerfish (*Canthidermis maculata*), wahoo (*Acanthocybium solandri*), and dolphinfish (*Coryphaena hippurus*) represented most of the catches of this group (at 95 % of the total). The majority has been retained since 2008 (between 50 % and 80 % depending on the year) (Fig. 3). The remaining portion was either released alive or dead, with dead fish accounting for a slightly higher proportion than live discards. Catch rates (Fig. 4 and Table 3) have remained relatively constant throughout the study period, with FOB-related sets showing a higher interaction rate, reaching values above 10 tonnes per thousand tonnes of target tunas for most of the time series.

Sharks accounted for almost 8 % of the bycatch weight (Table 2) with five of them making for 98 % of the total catches of this group, namely the silky shark (72.37 %), followed by scalloped hammerhead (*Sphyrna lewini*) (11.42 %) and smooth hammerhead (*Sphyrna zygaena*) (6.75 %), blue shark (*Prionace glauca*) (2.67 %) and shortfin mako (1.16 %). As for their fate (Fig. 3), before 2013, most catches were retained onboard and live releases were relatively minor. After the implementation of several regulations, the percentage of live releases increased, achieving a 75 % of discards being alive at release in recent years. Interaction rates (Fig. 4 and Table 3) were similar in FOB and FSC sets, generally fluctuating around 5–8 tonnes per thousand tonnes of target tunas since 2013, the year from which observer coverage increased due to the Data Collection Framework (DCF) implementation, allowing for more robust and stable estimates over time.

Due to the limited published length-weight (L-W) relationships for some species and the difficulty to accurately measure some of the specimens, the weights in the groups of mobulids and rays, cetaceans, turtles, and whale sharks cannot be generally estimated accurately from observers' records. Therefore, the percentage by weight they represent in the total bycatch is a rough estimate and provided for contextualization. Mobulids and rays comprise constitute 1 % of the weight of bycatch (Table 2), with pelagic stingray (*Pteroplatytrygon violacea*), devil ray (*Mobula mobular*), *Mobula tarapacana*, *Mobula birostris* and other unidentified mobula species (*Mobula spp*) representing most of this group (97 % of the group weight). In 2013, the first year with a significant increase in observer coverage (Fig. 2), mortality exceeded live releases (Fig. 3). The percentage of live discards steadily increased, particularly after 2012, with the last 3 years yielding an average of 93 % of fish discarded alive. Their rates (Fig. 4 and Table 3) were similar in FOB and FSC, generally hovering around 5 specimens per thousand tonnes of tunas, except for a few years in which unusually high rates were recorded.

Over the whole study period, 274 interactions with cetaceans were observed, including 12 species or species groups. In addition, interactions with whale sharks accounted for 206 observed specimens. According to the observer records, the practical totality of cetaceans and whale sharks were released alive (Fig. 3). After the t-RFMO regulations and the implementation of the CGP, the number of observed interactions with cetaceans decreased from 87 in 2016–3 individuals in the last 4 years of the study. Most interactions took place in FSC sets, and interaction rates (Fig. 4 & Table 3) decreased from almost 9 specimens per thousand tonnes of target tuna in FSC in 2004 to zero from 2018, except in 2022, with 0.14 specimens per thousand tonnes of tuna. Whale shark interaction rates (any set with whale is classified as a FOB set) peaked in 2004 with 30 specimens per thousand tonnes of target tuna, while from 2012 onward, they have been close to zero.

In the group of marine turtles, observers recorded 5457 interactions, dominated by olive ridley (*Lepidochelys olivacea*) and loggerhead (*Caretta caretta*) turtles, which accounted for over 80 % of the bycatch of this group. The practical totality of interactions involved live discards throughout the entire study period, with only a few minor exceptions (Fig. 3). Their rates (Fig. 4 and Table 3) show that the interaction with FOB-related sets is slightly higher than with FSC, both ranging between 3 and 9 specimens per thousand tonnes of tunas.

Paired tests (Table 4) yielded significant differences in the average live release rates for sharks (p-value = 9.18e-26) and mobulids and rays (p-value = 3.23e-04), while no significant differences were found for the other groups. Similarly, there was no significant differences in the average turtle interaction rates between the two periods.

In terms of spatial distribution, the heatmaps (Fig. 5) suggest that, except for billfish and other bony fish, in the tuna purse seine fishery there is a higher probability of presence of all groups in coastal areas, especially in areas of Gabon, Angola, Senegal, Guinea, Cape Verde, etc. The group of other bony fish appears to be evenly distributed throughout the entire ocean, with a slightly higher occurrence closer to the equator. Billfish presence seems to be concentrated west of Cape Verde and especially around Angola but also in high seas areas, showing a higher relative presence compared to coastal areas.

3.2. Indian Ocean

In the Indian Ocean, the neritic and temperate tuna group is the most abundant, constituting over 59 % of the total bycatch weight (Table 2). Bullet and frigate tunas represented a little more than 50 % of the group, followed by albacore tuna (*Thunnus alalunga*) at almost 40 %. In smaller proportions, kawakawa (*Euthynnus affinis*) accounted for 5 %, and the remainder consisted of undetermined tuna species (less than 5 %). Retention rates of this group increased from round 35 % in the first years of the study to 50 % after the resumption of observer programmes in this ocean (Fig. 6). As for the catch rates (Fig. 7 and Table 5), in the period prior to 2009, similar rates were estimated for FSC and FOB sets, reaching almost 40 tonnes per thousand tonnes of target tunas. However, in the period after 2015, with a greater observation coverage, rates in FOB sets were significantly higher than those with FSC. Averaging 10

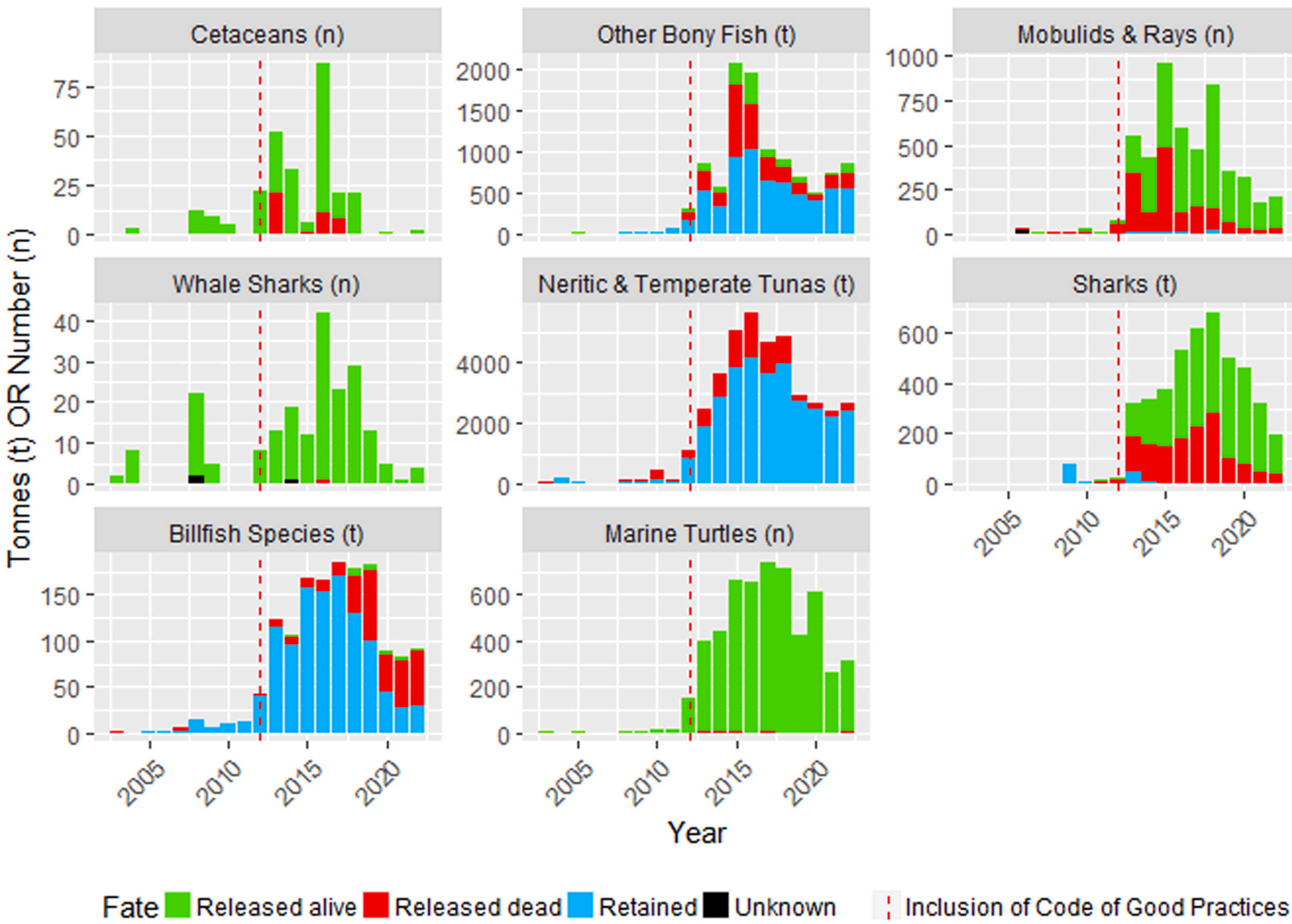

Fig. 3. Atlantic Ocean: Time series (2003–2022) of bycatch by species group and fate. Depending on the group, bycatch has been estimated in terms of weight (t-weight in tonnes) or number of individuals (n), as specified in each figure title.

and 20 tonnes per thousand tonnes of target tuna for FSC and FOBs, respectively.

Other bony fish, at 26.50 % of the bycatch in weight (Table 2), comprise a wide range of species, but five of them make up over 90 % of the group's weight. Rainbow runner and dolphinfish represented almost 75 % of this group bycatch, followed by ocean triggerfish, wahoo and chub mackerel (*Decapterus macarellus*). For this group, in the first observation period, most catches were discarded (Fig. 6), with a small portion retained and some of live releases. This contrasts with the second period, where 45 % of the catches were retained, on average. In relation to bycatch rates (Fig. 7 & Table 5), the species in this group were associated almost exclusively with sets on FOB. Bycatch rates showed a decreasing trend from nearly 15 tonnes per thousand tonnes of target tuna in 2009 to values below 5 in 2020 and 2021.

Groups of sharks accounted for 11.48 % of the bycatch in weight (Table 2). Silky sharks alone accounted for more than 90 % of the group's weight, followed by oceanic whitetip shark at almost 3 %. Blue sharks and shortfin makos accounted for 0.09 and 0.12 %, respectively. Regarding their fate (Fig. 6), in the first period, the vast majority of catches were either retained or discarded dead. After 2013, the number released alive increased significantly to values between 42.67 % and 69.67 %. Regarding bycatch rates (Fig. 7 and Table 5), they were around 4 times higher in FOB than in FSC sets, with no clear temporal trend. Catch rates in FOB sets fluctuated around 2–4 tonnes per thousand tonnes of target tunas throughout the period, except for 2022, when the rate was estimated at 7.19. In the case of FSC sets, the rate is below one tonne, except for 2007, 2008 and 2016, when the rates were 1.77, 2.45 and 1.42, respectively.

Billfish species accounted for a little more than 2 % of the total bycatch weight (Table 2), during the study period, and included 9 species or species groups. The most representative ones were blue marlin and black marlin, accounting more than three-quarters of the bycatch of this group, followed by striped marlin at 10 %, swordfish with almost 5 %, and then unidentified marlins (*Istiophoridae*). Most of the billfish species are already dead when brought on board (Fig. 6). In the initial years, the majority of the catches were discarded dead, contrasting with the beginning of the second observation period, the majority of the bycatch of this group was retained. However, in recent years, dead discards have increased and accounted for around 40 % of the catch in 2022. Regarding interaction rates (Fig. 7 and Table 5), there is a higher probability of encounters in sets on FOBs compared to FSC sets. In 2015, the ratio for FOB sets was in the range of 0.75–1 tonne per thousand tonnes of tunas, but it has decreased to values below 0.5 tonnes in the latest three years analysed. For FSC sets, the ratio has decreased from 0.35 to 0.5 tonnes in 2015 to values below 0.25 tonnes per thousand tonnes of tunas in the latest period.

Mobulids and rays together accounted for 0.7 % of the bycatch in weight (Table 2), with the giant manta ray being the most observed (23.77 %), followed by the pelagic stingray (21.11 %) and unidentified mantas (*Mobula spp*) (22.34 %). Concerning their fate (Fig. 6), the number of individuals released dead decreased from 61.56 % or higher in the first period to 21.52 % after 2015. Bycatch rates for this group (Fig. 7 and Table 5) were higher in the period up to 2009 compared to the most recent years for both fishing types. With FOB, the rates are between 0.39 and 3.02 units per thousand tonnes of tunas, while with FSC they are between 0.68 and 13.64 individuals per thousand tonnes of

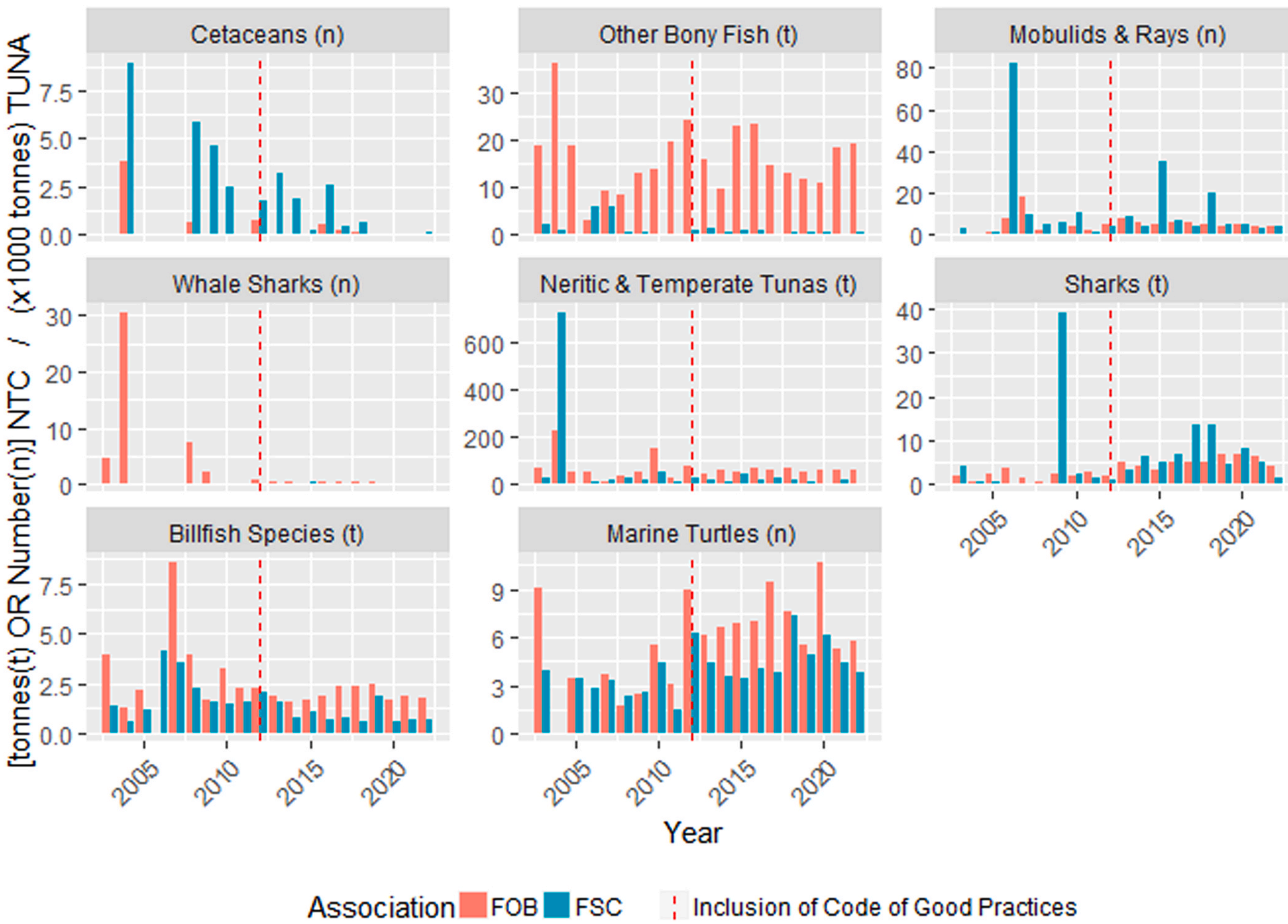

Fig. 4. Atlantic Ocean: Time series (2003–2022) of bycatch rate. Depending on the group, bycatch has been estimated in terms of weight (t- weight in tonnes) or number of individuals (n), as specified in each figure title. expressed as the amount of bycatch observed by species group per 1000 tonnes of target tuna fished.

tunas. In the period after 2015, both rates are generally lower, being 1.2 and 4.77 as maximums for FOB and FSC respectively.

A total of 33 whale shark specimens were observed during the study period. All interactions with whale sharks ended up in live releases, except for 2016 and 2022, when one animal was released dead (Fig. 6). Rates peaked at 1.03 animals per thousand tonnes of target tuna. (Fig. 7 and Table 5).

Interactions with cetaceans were observed sporadically, with 14 specimens observed in three of the 15 years of observation. Nine of the interactions involved false killer whales (*Pseudorca crassidens*) and five involved (*Balaenoptera physalus*). All cetacean interactions were recorded as live releases (Fig. 6).

Finally, marine turtles included 223 observed specimens, the most frequent one being the olive ridley sea turtle, accounting for almost 50 % of observed individuals, followed by green turtle (*Chelonia mydas*) (36 specimens), loggerhead (33 specimens), unidentified sea turtles (*Testudinata*) and hawksbill turtles (*Eretmochelys imbricata*) (24 individuals both), and leatherback (*Dermochelys coriacea*) (1). Concerning their fate (Fig. 6), in the first period, it was observed that the majority were discarded alive, but there were percentages of dead discards, mostly below 20 %, except for 2003, which reached almost 75 %, having observed five specimens. In the second period, it is observed that, except for 2016, where there is a percentage of around 5 % of dead releases, 100 % of the specimens with which there was an interaction were released alive. Bycatch rates (Fig. 7 and Table 5) mainly occurred in FOB sets, and were higher in the first period, with an average of 1.67 animals per thousand tonnes of target tuna than in the second with an average of 0.57.

The paired tests (Table 6) yielded significant differences in the percentage of live releases in sharks (p-value = 3.57e-13) and rays/mantas (p-value = 4.47e-03), but not for the other groups. Additionally, there were no significant differences in turtle interaction rates between the two periods. Significant differences in increased retention rates were found for billfishes (p-value = 7.99e-19) and other bony fishes (p-value = 7.15e-12), while no significant differences were found for neritic & temperate tunas between the two periods. There were no significant differences detected in the interaction rates with whale sharks and cetaceans.

The analysis of the spatial distribution of bycatch rates suggested a higher relative abundance of almost all species groups in the northern area of the fishing ground, an area with relatively lower target tuna catches (Fig. 8).

4. Discussion

This study was conducted to assess the impact of the measures implemented over the past 20 years in the ICCAT and IOTC management areas on bycatch species. It examines the interaction rates and the fate of bycatch, understood as retained, released alive or discarded dead, and evaluates the potential influence of t-RFMO regulations on ETP species. These measures are expected to reduce retention rates and dead discards and increase survival of ETP species by promoting better handling and faster release. For non-ETP species, the study investigated whether discard levels have significantly decreased, and retention rates have risen following the enforcement of discard bans for certain species groups by the t-RFMOs.

Table 3
Atlantic Ocean: Time series (2003–2022) of bycatch rate. Depending on the group, bycatch has been estimated in terms of weight (t- weight in tonnes) or number of individuals (n), as specified in each figure title. expressed as the amount of bycatch observed by species group per 1000 tonnes of target tuna fished.

Group	Association	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Billfishes (t)	FOB	4	1.28	2.18		8.62	3.96	1.65	3.27	2.25	2.26	1.85	1.59	1.7	1.86	2.4	2.35	2.42	1.69	1.83	1.8
Billfishes (t)	FS	1.39	0.55	1.19	4.17	3.56	2.26	1.57	1.5	1.54	2.06	1.58	0.77	1.06	0.68	0.83	0.58	1.85	0.56	0.7	0.73
Cetaceans (n)	FOB		3.82				0.67				0.73	0.04	0.02	0.02	0.48	0.19	0.07		0.02		
Cetaceans (n)	FS		8.94				5.81	4.63	2.42		1.77	3.18	1.85	0.24	2.55	0.38	0.63				0.14
Neritic & Temperate Tunas (t)	FOB	67.23	227.53	48.27	51.86	5.97	31.97	46.9	152.72	23.36	73.75	41.74	59.23	49.34	65.31	60.15	64.78	46.82	55.03	55.66	58.42
Neritic & Temperate Tunas (t)	FS	21.45	726.74	0.78	4.64	13.18	23.92	20.47	50.55	9.91	26.87	13.78	11.87	39.39	13.32	21.15	14.51	9.41	2.32	12.9	4.33
Other Bony Fishes (t)	FOB	19.02	36.48	18.95	2.93	9.21	8.45	13.15	13.74	19.6	24.46	15.92	9.81	23.23	23.54	14.66	12.87	11.66	10.77	18.32	19.25
Other Bony Fishes (t)	FS	1.97	1.01	0.19	6.01	6.09	0.53	0.38	0.14	0.11	0.83	1.27	0.37	0.83	0.94	0.1	0.28	0.32	0.29	0.16	0.31
Rays & Manta Rays (n)	FOB			1.13	7.86	18.13	2.33	0.4	3.71	2.02	4.45	7.69	6.08	4.36	5.66	5.5	4.97	4.2	5.14	3.42	3.56
Rays & Manta Rays (n)	FS	2.64		1.15	82.36	9.89	4.64	6.17	10.17	1.42	3.81	8.96	4.28	34.58	6.84	4.26	19.44	4.96	4.54	3.36	3.54
Sharks (t)	FOB	1.75	0.37	2.4	3.68	1.27	0.55	2.42	1.77	2.66	1.69	5.09	3.95	3.29	4.94	4.81	4.94	6.82	6.91	6.44	3.93
Sharks (t)	FS	3.97	0.45	0.28	0.2	0.04	0.21	39.29	2.46	1.41	0.89	3.19	6.45	5.06	6.59	13.34	13.37	4.51	7.98	5.18	1.24
Turtles (n)	FOB	9.07		3.4		3.63	1.66	2.41	5.56	3.03	8.99	6.16	6.56	6.82	6.98	9.45	7.57	5.47	10.7	5.24	5.78
Turtles (n)	FS	3.96		3.46	2.84	3.3	2.32	2.57	4.36	1.42	6.26	4.38	3.58	3.45	4.02	3.79	7.34	4.87	6.16	4.39	3.75
Whale Sharks (n)	FOB	4.54	30.59				7.32	2.01			0.65	0.24	0.33	0.09	0.49	0.33	0.42	0.22	0.11	0.02	0.09

Table 4
Results of paired analyses on survival, retention, or interaction rates before and after the implementation of the Code of Good Practices (CGP) or relevant ICCAT conservation and management measures. The year measures entered into force was, in all cases 2014, being the cutoff year for comparing periods.

Species	Analysis	Corresponding regulation/measure	Pvalue U-Mann-Whitney
Sharks	Survival release rate	CGP	9,18E−26
Turtles	Survival release rate	CGP	3,45E+ 04
	Interaction rate (only FADs)	CGP	1,03E+ 04
Rays and mantas	Survival release rate	CGP	3,23E−04
Whale Shark	Survival release rate	CGP	2,09E+ 05

This study also focuses on the impact of the initiative by European purse seine shipowners to implement self-regulated conservation and data collection measures (the CGP). This effort has set a significant precedent in tropical tuna purse seine fisheries worldwide, with several measures, such as the use of non-entangling FADs and specific release guidelines for ETP species, later adopted by the t-RFMOs. At present, some initiatives, like achieving a 100 % observer coverage in the Indian Ocean, continue to exceed RFMO requirements, which only mandated a minimum of 5 % coverage.

Despite the relatively good coverage, the data used in the current study present several limitations: the initial years of the study period had a low observer coverage. Thus, estimated bycatch rates generally showed the highest interannual variability during the first years. It should also be stated that the data in this analysis comes from the Spanish and the OPAGAC-AGAC fishing fleet, which, along with other European purse seiner fleets [16], are the only ones that have implemented the CGP. As such, the results obtained in this analysis, as well as the outcomes, are not necessarily applicable to the rest of the purse seine fleets. Moreover, estimates of live releases, bycatch and retention rates for other fleets could also differ from those estimated here due to other factors, such as the areas fished or operational differences in the fishing activity. Finally, there is also the possibility that some interactions are unnoticed by observers. As an example, [31] showed how in some trips where observers had not recorded any shark retention, some silky shark individuals, mainly belonging to small size classes, were found in the wells during unloading, suggesting that the bycatch and retention rates of this group may be slightly higher than estimated.

The findings of this study suggest that the implementation of the code of good practices (CGP) by OPAGAC-AGAC vessels and the enforcement of various t-RFMO regulations have improved live release rates for many sensitive species. The species groups showing the most notable improvement in terms of at-vessel survival include sharks, rays, and mantas, while cetaceans, marine turtles, and whale sharks already exhibited near-complete live release rates before the implementation of the CGP.

The heatmaps illustrate the areas with the highest probability of purse seine fisheries interacting with each species group. These maps show that coastal waters near Gabon and Angola have much higher probabilities of interaction with several sensitive groups, including cetaceans, whale sharks, sea turtles, sharks, mobulids and rays, as well as neritic species. Additionally, mobulids and ray groups have a high probability of being encountered in the coastal area of Mauritania. In the case of the Indian Ocean, no clear hotspots for cetaceans and whale sharks were identified. However, for sea turtles, sharks, billfishes, neritic tunas and other bony fishes, the northern fishing areas (between latitudes 10 and 20 North) show a higher relative abundance, which could have implications in terms of bycatch management. For mobulids and rays, their presence seems to be widespread, with slightly higher rates north of Seychelles.

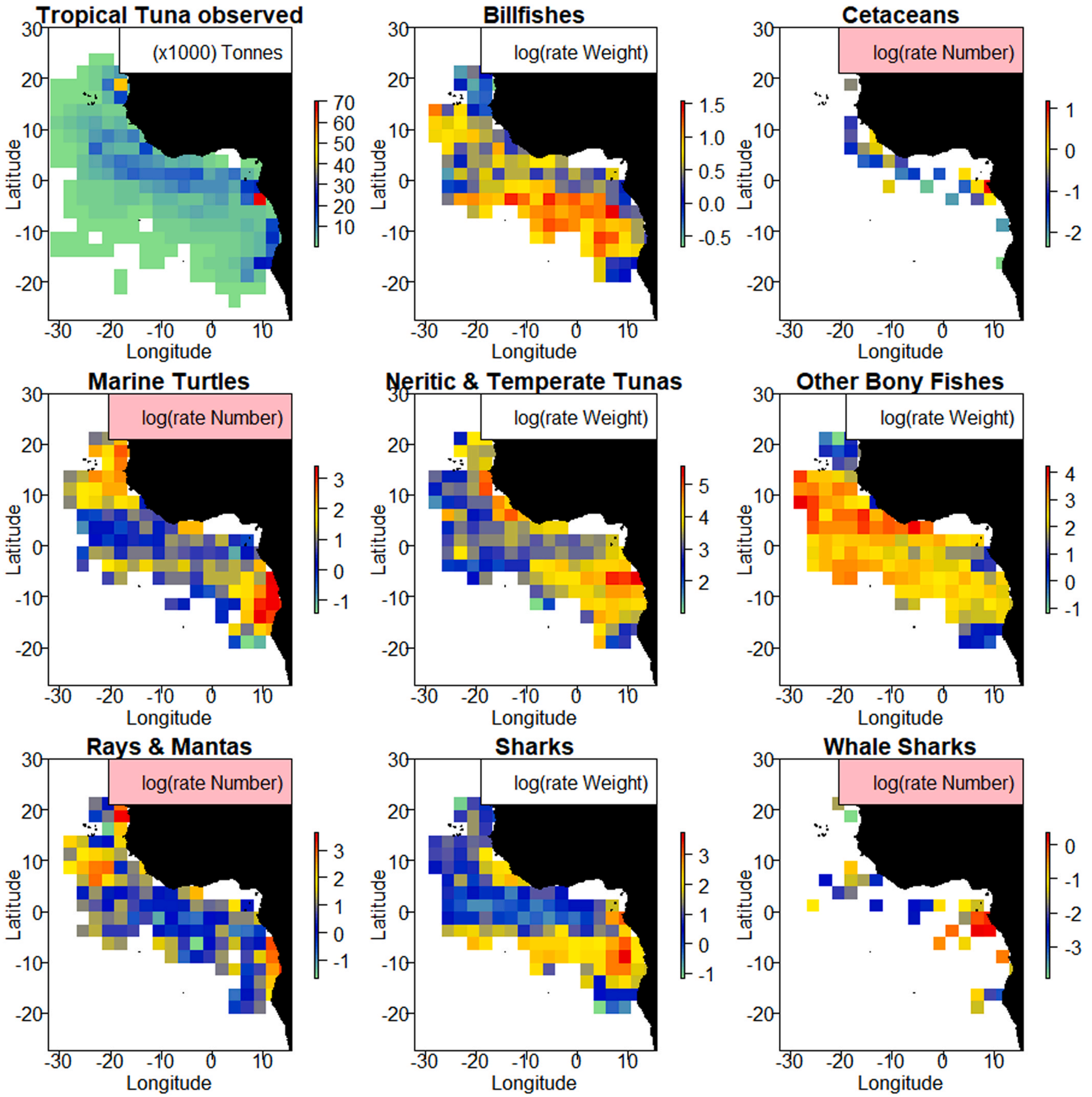

Fig. 5. Atlantic Ocean: Heatmaps showing the amount of Tropical tunas observed (in units of 1000 tonnes, top left) and bycatch rates (logarithm of the catch weight or number per 1000 tonnes of target tuna species, all other figures), by species group, for the period 2003–2022. Catches (in number or tonnes per group) from 2003 to 2022 have been aggregated into a 2.5º grid raster, spanning from 32 W to 15E longitude and 30 N to 28S latitude. Subsequently, bycatch logarithmic rates per 1000 tonnes of target tuna were calculated for each grid cell on the map. The calculation was performed only in those grids where a minimum observation of 1000 tonnes of target catch was recorded.

Excluding cetaceans, whale sharks, rays and mantas, and marine turtles, the bycatch rates for this fishery were estimated at 6.27 % and 2.82 % for the Atlantic and Indian Oceans, respectively, figures lower than those reported in previous studies such as [1] (although these studies do not exclude any groups), which reported 7.5 % (for the period 2003–2007) and 4.7 % (for the period 2003–2009) in the Atlantic and Indian Oceans, respectively. This could indicate an improvement in fishing practices due to changes during the analysis period, and/or a variation in the relative proportion of the bycatch groups and the target species populations. In comparison with other fisheries, bycatch rates for the purse seine fleet seem to be relatively low. Davies et al. [9] estimated a 40.4 % bycatch rate for global fisheries. It is also considered that the discard rates for this fishery are relatively low, as this study estimated that dead discards represent 1.73 % of the fishery (21.19 % of the bycatch), for the Atlantic and Indian Oceans combined, excluding groups such as cetaceans, whale sharks, mobulids and rays, and sea turtles, while Pérez Roda et al. [30] estimated a value of 10.8 % of discards for global fisheries.

The bycatch composition in the Atlantic Ocean in the present study showed some differences compared to those from a previous study

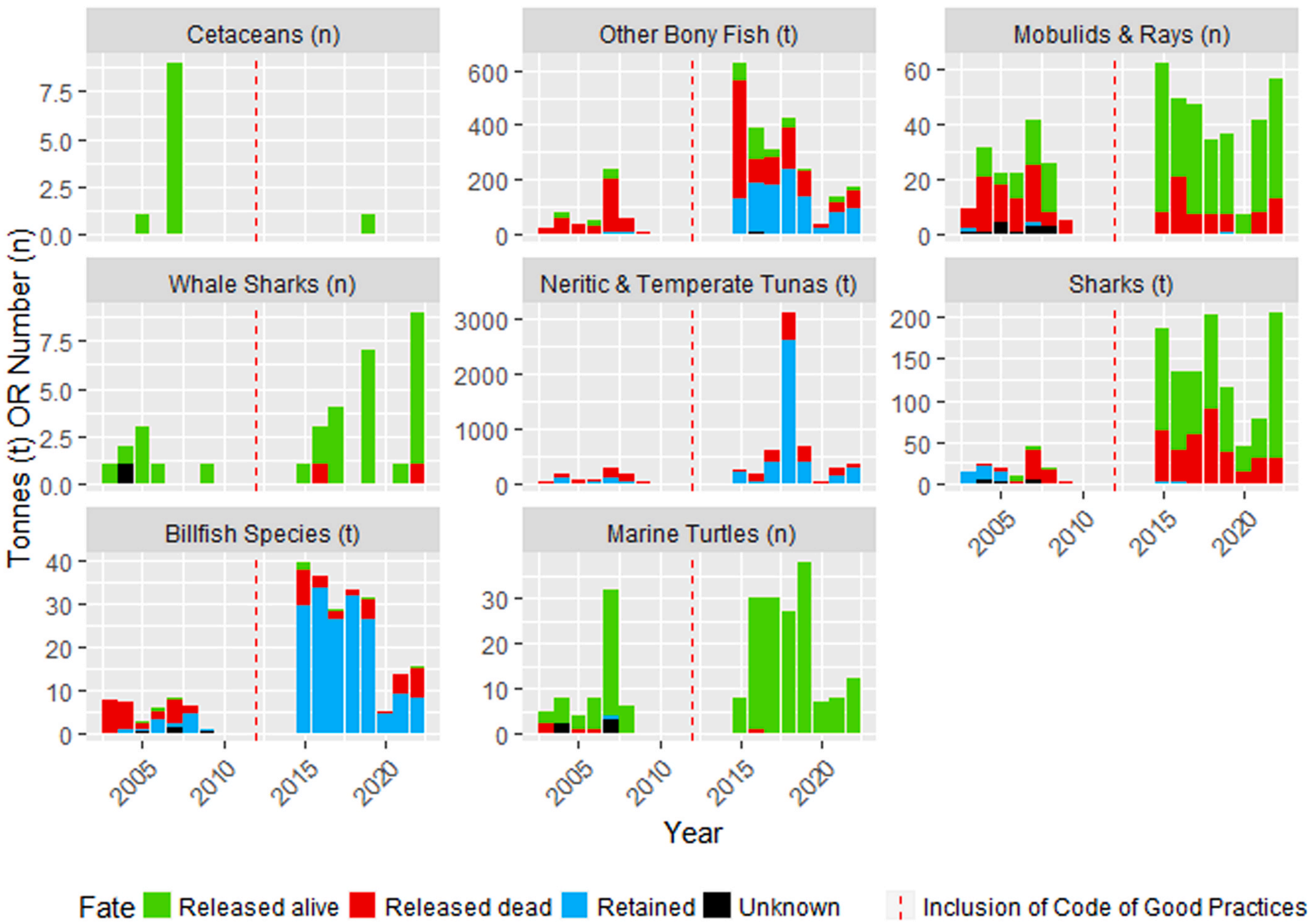

Fig. 6. Indian Ocean: Time series (2003–2022) of bycatch by species group and fate. Depending on the group, bycatch has been estimated in terms of weight (t-weight in tonnes) or number of individuals (n), as specified in each figure title.

(Amandé et al., 2010). Current estimates for neritic and temperate tunas (69 %) and billfish (2.61 %) were lower than the estimates by Amandé et al. (83 % and 5 %, respectively). On the contrary, estimates for other bony fish (19 %) and sharks (8 %) are higher than those reported in that previous work (10 % and 1 %, respectively). Estimates for mobulids and rays were similar (1 %).

In the Indian Ocean, Amandé et al. (2012) estimated a species group composition very similar to the one obtained in this study: 59 % for neritic and temperate tunas and 2 % for billfish in both studies; 29.9 % vs 26.5 % for other bony fish; 8.3 % vs 11.5 % for sharks and 0.5 % vs 0.7 % for mobulids and rays. It is important to note that this study detected a significant proportion of catches within the group of neritic and temperate tunas in the Indian ocean were recorded as albacore tuna in the AGAC observer programme (associated vessels not flagged in Spain) in 2018 and 2019. Due to the contrast with the trend in the time-series and the conflicting results with other data sources (port sampling data), it is considered to be an artefact, and a result of misnaming or misidentification by observers. If the albacore sum is not considered for both years, the representation of the group within the total bycatch is reduced to 43.24 %. Furthermore, if these two years are excluded from the analysis, the species composition within this group would change: frigate tuna would represent 56 %, bullet tuna 15 %, kawakawa 4 %, and albacore tuna would decrease to 24 %.

Changes in trends for cetacean and whale shark catch rates were expected in the IOTC area starting in 2014 due to Resolutions 13/04 and 13/05. However, according to the Mann-Whitney *U* test, no significant differences were observed. In the case of the Atlantic Ocean, CGP could expected changes in whale sharks, but no significant differences were observed, while for the cetacean group, no tests were calculated because there were no ICCAT regulations or CGP initiatives covering this ocean during the study period. The lack of statistical significance may be attributed to the fact that interactions with cetaceans and whale sharks are rare events based on the analysed data: in the Indian Ocean, interactions with cetaceans were only observed during three years of the entire study period, while in the Atlantic, despite the absence of specific regulations prohibiting sets on this group, rates have been decreasing since the beginning of the analysis, with very few cases reported in recent years. Regarding whale shark interactions, the rates were very low in both oceans, with only few cases observed. In addition, cetaceans and whale sharks already exhibited near-complete live release rates before the implementation of the CGP. Escalle [10] estimated mortality rates of 1.4 % for whale sharks across the Atlantic and Indian Oceans, although Escalle et al. [11] estimated 0 % mortality through data from pop-up tags in the Atlantic Ocean, while in this study it is estimated at around 0.16 % and 4 % for the Atlantic and Indian Oceans, respectively. Similarly, Escalle et al. [12], observed high rates of survival for cetaceans encircled by purse seiners, at 92 % and 100 % in the Atlantic and Indian Oceans, respectively, similar to the values estimated in the present study, of 97.72 % and 100 %, respectively. According to observers on board, these species typically escape from the net by breaking through it. In relation to spatiotemporal interaction patterns, Escalle et al. [12] determined that the highest interaction with baleen whales occurred east of Seychelles during the northeast monsoon and in the Mozambique Channel during the southwest monsoon. In the eastern Atlantic, they documented a higher frequency of this species in coastal waters of Gabon between April and September. These findings coincide

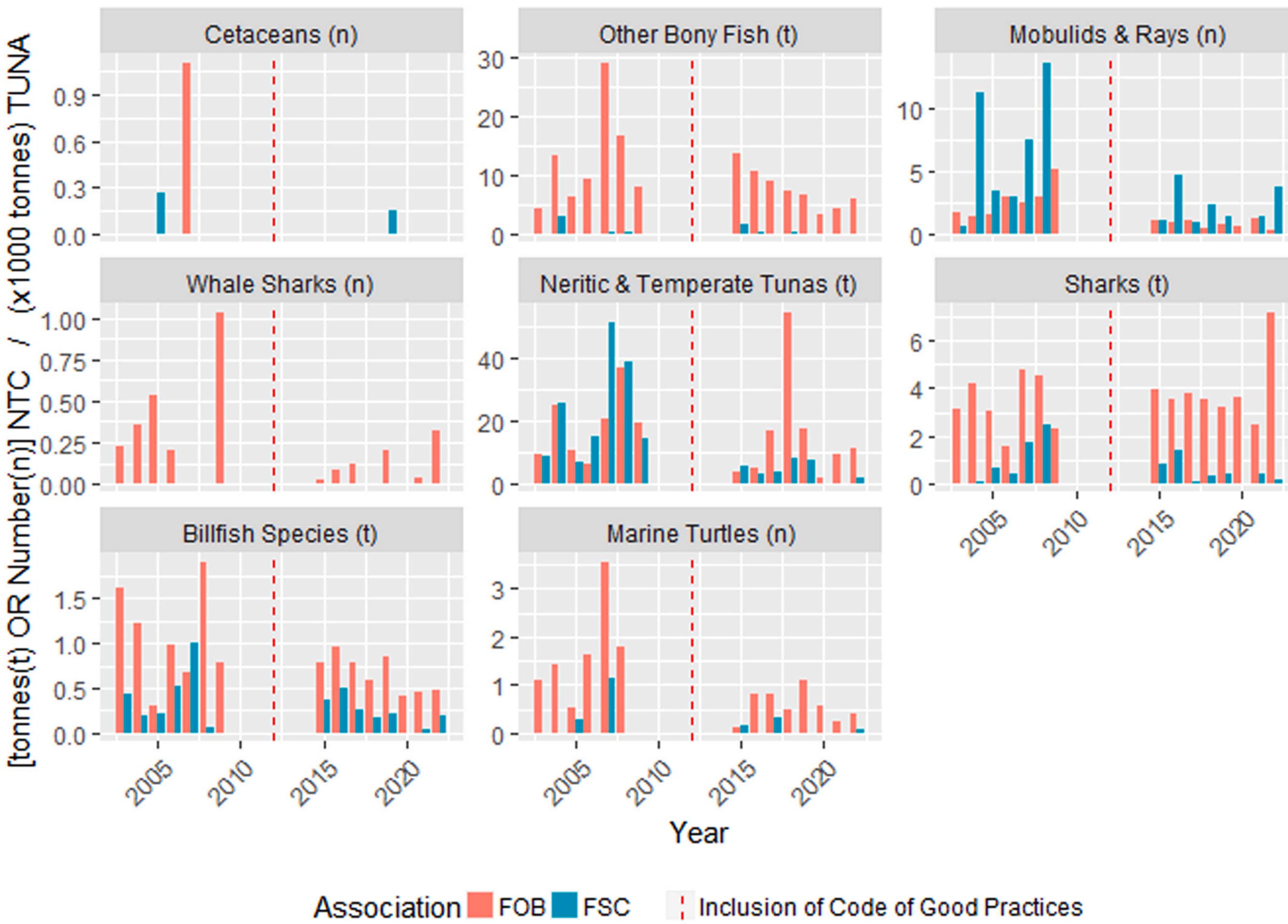

Fig. 7. Indian Ocean: Time series (2003–2022) of bycatch (NTC) rate. Depending on the group, bycatch has been estimated in terms of weight (t- weight in tonnes) or number of individuals (n), as specified in each figure title. expressed as the amount of bycatch observed by species group per 1000 tonnes of target tuna fished.

Table 5
Indian Ocean: Time series (2003–2022) of bycatch (NTC) rate. Depending on the group, bycatch has been estimated in terms of weight (t- weight in tonnes) or number of individuals (n), as specified in each figure title. expressed as the amount of bycatch observed by species group per 1000 tonnes of target tuna fished.

Group	Association	2003	2004	2005	2006	2007	2008	2009	2015	2016	2017	2018	2019	2020	2021	2022
Billfishes (t)	FOB	1.62	1.21	0.31	0.97	0.68	1.9	0.79	0.78	0.96	0.78	0.58	0.85	0.42	0.45	0.47
Billfishes (t)	FS	0.43	0.2	0.21	0.53	0.99	0.07		0.37	0.49	0.25	0.18	0.23		0.05	0.19
Cetaceans (n)	FOB					1.1										
Cetaceans (n)	FS			0.27									0.15			
Neritic & Temperate Tunas (t)	FOB	9.11	24.93	10.94	6.41	20.35	37.15	19.27	3.66	5.15	16.9	54.52	17.6	1.6	9.25	11.47
Neritic & Temperate Tunas (t)	FS	8.86	25.38	6.97	15.09	50.97	38.93	14.29	5.34	3.19	4.03	8.35	7.31		0.02	1.67
Other Bony Fishes (t)	FOB	4.51	13.37	6.5	9.49	29.14	16.8	8.1	13.58	10.66	8.89	7.51	6.87	3.21	4.39	6.12
Other Bony Fishes (t)	FS	0.01	3.05	0.13	0.13	0.41	0.48		1.83	0.23	0.01	0.5	0.1		0.13	0.04
Rays & Manta Rays (n)	FOB	1.78	1.41	1.6	3.02	2.57	2.96	5.18	1.04	0.98	1.18	0.53	0.74	0.57	1.2	0.39
Rays & Manta Rays (n)	FS	0.68	11.34	3.49	2.99	7.57	13.64		1.15	4.77	1.01	2.39	1.48		1.42	3.73
Sharks (t)	FOB	3.17	4.17	3.07	1.6	4.81	4.55	2.27	3.95	3.52	3.82	3.55	3.24	3.62	2.46	7.19
Sharks (t)	FS		0.07	0.63	0.41	1.77	2.45		0.85	1.42	0.09	0.34	0.39		0.38	0.2
Turtles (n)	FOB	1.11	1.41	0.53	1.61	3.55	1.78		0.14	0.82	0.8	0.47	1.09	0.57	0.26	0.39
Turtles (n)	FS			0.27		1.14			0.14		0.34					0.08
Whale Sharks (n)	FOB	0.22	0.35	0.53	0.2			1.04	0.02	0.08	0.11		0.2		0.03	0.32

Table 6
Results of paired analyses on survival, retention, or interaction rates before and after the implementation of the Code of Good Practices (CGP) or relevant IOTC conservation and management measures. The year measures entered into force was, in all cases, 2014, being the cutoff year for comparing periods.

Species	Analysis	Corresponding regulation/measure	Pvalue U-Mann-Whitney
Billfishes	Retention rate	IOTC Resolution 13/11	7,99E−19
Other Bony Fishes	Retention rate	IOTC Resolution 13/11	7,15E−12
Sharks	Survival release rate	CGP	3,57E−13
Turtles	Survival release rate	CGP	1,78E+ 01
	Interaction rate (only FADs)	CGP	6,12E+ 03
Rays and mantas	Survival release rate	CGP	4,47E−03
Whale Shark	Interaction rate	IOTC Resolution 13/05	4,97E+ 05
	Survival release rate	CGP	2,09E+ 05
Other Tuna	Retention rate	IOTC Resolution 13/11	7,15E+ 03
Cetaceans	Interaction rate	IOTC Resolution 13/04	3,27E+ 05

with those in this study.

No significant changes in the percentage of live releases of marine turtles were observed in both oceans, given the fact that they were already being released alive in almost 100 % of the cases before the implementation of any conservation measure or the adoption of the CGP. It is notable that, despite the implementation of non-entangling FADs, no significant differences were observed in catch rates between the periods before and after the CGP adoption in 2014. Bourjea et al. [8] estimated that more than 75 % of sea turtles captured in the Atlantic and Indian Oceans were released alive during the period 1995–2011, a figure that slightly differs from our study, where it reached levels close to 100 %.

For mobulids and rays, and sharks, increases in survival rates after the adoption of measures are evident as reflected by the Mann-Whitney *U* test, which yielded significant differences in the average live release rates between fishing trips in 2014 and earlier compared to those in subsequent years in both oceans. The recorded shark retention in the early years of analysis corresponds to partial retention, mostly likely related to finning.

Regarding the group of rays and mantas, it is worth noting that it includes species with very different characteristics. For example, it includes *Mobulidaes*, which are ETP species, and others that are not, such as the pelagic stingray.

In contrast with the results observed for ETP species, a greater retention of neritic & temperate tunas and other bony fish species was observed in both oceans in the most recent period compared to the early years of the study (for example, in the last year of the study, 75 % of neritic & temperate tunas in the Indian Ocean was retained), making this catch commercially productive. Otherwise, their fate would have been dead discards, as there is no survival. During the study period, no t-RFMO regulation in the Atlantic required retention for these groups, so no test for significant differences was conducted. In the case of the Indian Ocean, where Resolution 13/11 bans the discard of many bycatch species, significant differences were observed on other bony fish. On the contrary, no significant impact was estimated on neritic and temperate tunas, which might be linked to these species being retained for commercial purposes before the implementation of the measure. It is also important to note that their catch rates in FOB sets are generally much higher than in free-school sets, which might have management implications highlighting the need to continue efforts towards finding mechanisms to mitigate FAD interactions.

In the case of billfish species, there are significant differences in the Indian Ocean when comparing periods before and after 2014 in terms of greater retention, but discards have increased in recent years across both oceans. The observed increase in discard rates in most recent years may be attributed to the establishment of catch limits by IOTC Resolution 18/05 and ICCAT Recommendation 19–05. Despite the conservation intentions of these regulations, it should be noted that billfish species survival rates are near zero, and there is no indication interactions with this group can be avoided. This suggests retention bans on purse seine fisheries might not be an appropriate conservation measure for this group.

It is important to note that the mortality data addressed in this analysis refers to the moment of release from the vessel, but there is the potential for additional mortality at a later stage (known as post-release mortality). For example, Filmalter et al. [15] estimated that in the absence of best release practices the overall survival rate of silky sharks is 10 %, as compared to 42 % at the time of release. Other studies estimated total survival rates of 14.4 %, compared to 61 % at the time of release [32,33]. More recently, Grande et al. [18] and Grande et al. [17] suggested that the post-release survival of sharks, ascertained through pop-up satellite tags, increased significantly when the best handling and release practices are applied and fauna handling/release mechanisms are incorporated on-board as dictated by the CGP. These authors estimated a maximum survival rate of approximately 61.29 %.

It must also be noted that while a measure may have not resulted in changes that are statistically significant, this does not necessarily mean it is ineffective, since it may help cover other fisheries, improve awareness and ensure the best possible results beyond the indicators analysed, among others. In some cases, such as marine turtles, even without detailed regulations, high live release rates were already common, but the adoption of conservation measures possibly improve practices onboard and are likely to further reduce post-release mortality rates. Similarly, the analyses of some of the results aid in learning and suggest the need for regulatory flexibility, as is the case for billfish species, where regulations may have resulted in the loss of resources with a minimum conservation impact on the group. This case illustrates how management must continuously adapt to changing conditions and knowledge.

In addition to the measures adopted and enforced during the study period, additional regulations aimed at mitigating the impact of the fishing activity on ETPs have been recently adopted in both ICCAT and IOTC, such as ICCAT's Recommendation 23–12, which requires countries to prohibit the fishing and retention of whale sharks and to enforce safe handling and release. Recommendation 23–14, which includes the prohibition of retaining any species from the family *Mobulidae* and establishes best handling practices for the safe release of this group (note that this is not yet in force and will come into effect in 2025 if approved by the Commission), is not expected to lead to significant changes in at-vessel survival rates in the study fleet, as they have already implemented measures through the CGP. However, for other fleets, it could represent a substantial change and, overall, it may reduce mortality of this group. ICCAT Resolution 23–15 encourages countries to prohibit their vessels from intentionally setting on cetaceans, but this requirement is not mandatory and may therefore have a limited impact. If confirmed and established as a Recommendation, this should result in a completely null interaction rate for all fleets operating in the ocean. This Resolution is quite like the IOTC Resolution 23/06. With Resolution 24/02, IOTC further regulate non-entangling and biodegradable FADs, but no significant changes are anticipated in interaction and fate rates, given the provisions already in place under Resolution 19/02. In relation to discard bans, the current Resolution 19/05 is set to be amended, with the draft document still under preparation ([25]-S28-PropQ rev5), and it is expected to come into force in January 2025. The amendment will likely prohibit the discarding of fish, meaning that any fish caught and found dead must be brought ashore to support food security. This measure is expected to ensure that non-ETP species in the Indian Ocean are retained at high levels, thereby reversing the recent trend of increased billfish species' dead discards observed in past years.

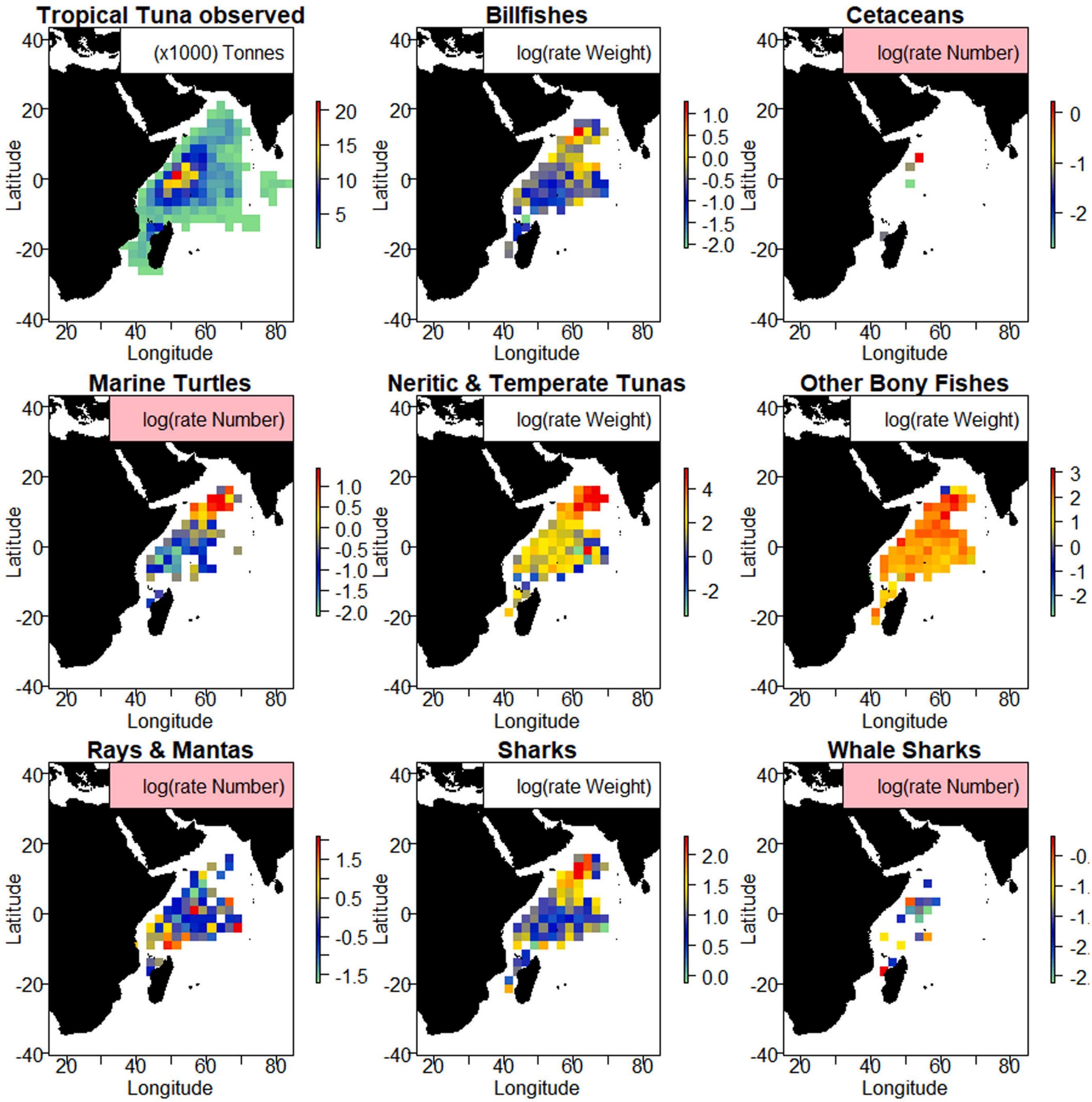

Fig. 8. Indian Ocean: Heatmaps showing the amount of tropical tunas observed (in thousand tonnes, top left) and bycatch rates (logarithm of the catch weight or number per 1000 tonnes of target tuna species, all other figures), by species group, for the period 2003–2022. Catches (in number or tonnes per group) from 2003 to 2022 have been aggregated into a 2.5º grid raster, spanning from 15E to 85E longitude and 30 N to 28S latitude. Subsequently, bycatch logarithmic rates per 1000 tonnes of target tuna were calculated for each grid cell on the map. The calculation was performed only in those grids where a minimum observation of 1000 tonnes of target catch was recorded.

Although the current study shows significant improvements in the mitigation of the fishing impact of purse seine activity on non-target species, there is still the need for continued research. This paper characterizes the bycatch and rates for an important fishery, but it would also be important to conduct similar studies for other fisheries to better assess and understand their impact and develop efficient management measures. Additionally, it is recommended to further investigate the trends observed in the present study, since other drivers, such as variations in population abundance or habitat shifts in response to climate change cannot be ruled out at this stage.

Efforts to continue developing mechanisms to further reduce bycatch interactions and to improve the survival rates of ETPs must remain as one of the key roles of tRFMOs. Similarly, the optimal utilization of bycatch is central, given its importance in terms of socio-economic impact and food security for coastal states [2] and should also be a key component of future management measures.

CRediT authorship contribution statement

Acevedo-Iglesias Sergio: Writing – review & editing, Writing –

original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Herrera Miguel:** Writing – review & editing, Visualization, Supervision, Resources, Formal analysis. **Ramos María Lourdes:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Báez José Carlos:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Investigation, Formal analysis. **Ruiz Jon:** Writing – review & editing, Visualization, Supervision, Resources, Formal analysis. **Rodríguez-Rodríguez Gonzalo:** Writing – review & editing, Visualization, Supervision. **Rojo Vanessa:** Writing – review & editing, Resources. **Pascual-Alayón Pedro J:** Resources. **Abascal Francisco Javier:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Annex

Table 7
All species composition group, showing the relationship between Alpha3 Code, Study Group, Scientific Name, English name, Author, Family and Order

Alpha3 Code	Study Group	Scientific Name	English name	Author	Family	Order
BIL	Billfish species	*Istiophoridae*	Marlins, sailfishes, etc. nei		ISTIOPHORIDAE	SCOMBROIDEI
BIL*	Billfish species					
BLM	Billfish species	*Istiompax indica*	Black marlin	(Cuvier 1832)	ISTIOPHORIDAE	SCOMBROIDEI
BUM	Billfish species	*Makaira nigricans*	Blue marlin	Lacépède 1802	ISTIOPHORIDAE	SCOMBROIDEI
MLS	Billfish species	*Kajikia audax*	Striped marlin	(Philippi 1887)	ISTIOPHORIDAE	SCOMBROIDEI
SAI	Billfish species	*Istiophorus albicans*	Atlantic sailfish	(Latreille 1804)	ISTIOPHORIDAE	SCOMBROIDEI
SFA	Billfish species	*Istiophorus platypterus*	Indo-Pacific sailfish	(Shaw & Nodder 1792)	ISTIOPHORIDAE	SCOMBROIDEI
SPF	Billfish species	*Tetrapturus pfluegeri*	Longbill spearfish	Robins & de Sylva 1963	ISTIOPHORIDAE	SCOMBROIDEI
SSP	Billfish species	*Tetrapturus angustirostris*	Shortbill spearfish	Tanaka 1915	ISTIOPHORIDAE	SCOMBROIDEI
SWO	Billfish species	*Xiphias gladius*	Swordfish	Linnaeus 1758	XIPHIIDAE	SCOMBROIDEI
WHM	Billfish species	*Kajikia albida*	Atlantic white marlin	Poey 1860	ISTIOPHORIDAE	SCOMBROIDEI
BRW	Cetaceans	*Balaenoptera edeni*	Bryde's whale	Anderson 1878	BALAENOPTERIDAE	MYSTICETI
DLP	Cetaceans	*Delphinidae*	Delphinidae nei		DELPHINIDAE	ODONTOCETI
FAW	Cetaceans	*Pseudorca crassidens*	False killer whale	(Owen 1846)	DELPHINIDAE	ODONTOCETI
FIW	Cetaceans	*Balaenoptera physalus*	Fin whale	(Linnaeus 1758)	BALAENOPTERIDAE	MYSTICETI
HUW	Cetaceans	*Megaptera novaeangliae*	Humpback whale	(Borowski 1781)	BALAENOPTERIDAE	MYSTICETI
MAM	Cetaceans	*Mammalia*	Aquatic mammals nei			MAMMALIA MISCELLANEA
MEW	Cetaceans	*Peponocephala electra*	Melon-headed whale	(Gray 1846)	DELPHINIDAE	ODONTOCETI
MYS	Cetaceans	*Mysticeti*	Baleen whales nei			MYSTICETI
ODN	Cetaceans	*Odontoceti*	Toothed whales nei			ODONTOCETI
PIW	Cetaceans	*Globicephala melas*	Long-finned pilot whale	(Traill 1809)	DELPHINIDAE	ODONTOCETI
SHW	Cetaceans	*Globicephala macrorhynchus*	Short-finned pilot whale	Gray 1846	DELPHINIDAE	ODONTOCETI
3CUH	Other bony fish					
3CUX	Other bony fish					
3DEY	Other bony fish					
3FLF	Other bony fish					
3MOP	Other bony fish					
3RAU	Other bony fish					
9XXX	Other bony fish					
ABU	Other bony fish	*Abudefduf saxatilis*	Sergeant-major	(Linnaeus 1758)	POMACENTRIDAE	PERCOIDEI
AJS	Other bony fish	*Abalistes stellaris*	Starry triggerfish	(Bloch & Schneider 1801)	BALISTIDAE	TETRAODONTIFORMES
ALM	Other bony fish	*Aluterus monoceros*	Unicorn leatherjacket filefish	(Linnaeus 1758)	MONACANTHIDAE	TETRAODONTIFORMES
ALN	Other bony fish	*Aluterus scriptus*	Scribbled leatherjac. filefish	(Osbeck 1765)	MONACANTHIDAE	TETRAODONTIFORMES
BAF	Other bony fish	*Ablennes hians*	Flat needlefish	(Valenciennes 1846)	BELONIDAE	BELONIFORMES
BAO	Other bony fish	*Platax teira*	Longfin batfish	(Forsskål 1775)	EPHIPPIDAE	ACANTHUROIDEI
BAT	Other bony fish	*Platax spp*	Batfishes		EPHIPPIDAE	ACANTHUROIDEI
BAZ	Other bony fish	*Sphyraenidae*	Barracudas, etc. nei		SPHYRAENIDAE	OTHER PERCIFORMES
BEN	Other bony fish	*Belonidae*	Needlefishes, etc. nei		BELONIDAE	BELONIFORMES
BON	Other bony fish	*Sarda sarda*	Atlantic bonito	(Bloch 1793)	SCOMBRIDAE	SCOMBROIDEI
BRZ	Other bony fish	*Bramidae*	Pomfrets, ocean breams nei		BRAMIDAE	PERCOIDEI
BSX	Other bony fish	*Serranidae*	Groupers, seabasses nei		SERRANIDAE	PERCOIDEI

(*continued on next page*)

Table 7 (*continued*)

Alpha3 Code	Study Group	Scientific Name	English name	Author	Family	Order
BTS	Other bony fish	*Tylosurus crocodilus*	Hound needlefish	(Péron & Lesueur 1821)	BELONIDAE	BELONIFORMES
BVP	Other bony fish	*Balistes punctatus*	Bluespotted triggerfish	Gmelin 1789	BALISTIDAE	TETRAODONTIFORMES
CFW	Other bony fish	*Coryphaena equiselis*	Pompano dolphinfish	Linnaeus 1758	CORYPHAENIDAE	PERCOIDEI
CGX	Other bony fish	*Carangidae*	Carangids nei		CARANGIDAE	PERCOIDEI
CNT	Other bony fish	*Canthidermis maculata*	Rough triggerfish	(Bloch 1786)	BALISTIDAE	TETRAODONTIFORMES
CUP	Other bony fish	*Cubiceps spp*			NOMEIDAE	STROMATEOIDEI, ANABANTOIDEI
CXS	Other bony fish	*Caranx sexfasciatus*	Bigeye trevally	Quoy & Gaimard 1825	CARANGIDAE	PERCOIDEI
CZT	Other bony fish	*Canthidermis sufflamen*	Ocean triggerfish	(Mitchill 1815)	BALISTIDAE	TETRAODONTIFORMES
DDD	Other bony fish	*Abudefduf vaigiensis*	Indo-Pacific sergeant	(Quoy & Gaimard 1825)	POMACENTRIDAE	PERCOIDEI
DIO	Other bony fish	*Diodontidae*	Globefish, porcupinefish		DIODONTIDAE	TETRAODONTIFORMES
DIY	Other bony fish	*Diodon hystrix*	Spotted porcupinefish	Linnaeus 1758	DIODONTIDAE	TETRAODONTIFORMES
DOL	Other bony fish	*Coryphaena hippurus*	Common dolphinfish	Linnaeus 1758	CORYPHAENIDAE	PERCOIDEI
DOX	Other bony fish	*Coryphaenidae*	Dolphinfishes nei		CORYPHAENIDAE	PERCOIDEI
DSF	Other bony fish	*Pomacentridae*	Damselfishes		POMACENTRIDAE	PERCOIDEI
DVH	Other bony fish	*Cyclichthys orbicularis*	Birdbeak burrfish	(Bloch 1785)	DIODONTIDAE	TETRAODONTIFORMES
ECN	Other bony fish	*Echeneidae*	Suckerfishes, remoras nei		ECHENEIDAE	PERCOIDEI
EHN	Other bony fish	*Echeneis naucrates*	Live sharksucker	Linnaeus 1758	ECHENEIDAE	PERCOIDEI
EXQ	Other bony fish	*Euleptorhamphus velox*	Flying halfbeak	Poey 1868	HEMIRAMPHIDAE	BELONIFORMES
FFX	Other bony fish	*Monacanthidae*	Filefishes, leatherjackets nei		MONACANTHIDAE	TETRAODONTIFORMES
FIT	Other bony fish	*Fistularia spp*	Flutemouth		FISTULARIIDAE	SYNGNATHIFORMES
FLY	Other bony fish	*Exocoetidae*	Flyingfishes nei		EXOCOETIDAE	BELONIFORMES
GBA	Other bony fish	*Sphyraena barracuda*	Great barracuda	(Walbaum 1792)	SPHYRAENIDAE	OTHER PERCIFORMES
GES	Other bony fish	*Gempylus serpens*	Snake mackerel	Cuvier 1829	GEMPYLIDAE	SCOMBROIDEI
HTL	Other bony fish	*Phtheirichthys lineatus*	Slender suckerfish	(Menzies 1791)	ECHENEIDAE	PERCOIDEI
JHX	Other bony fish	*Molidae*	Ocean sunfishes nei		MOLIDAE	TETRAODONTIFORMES
KYC	Other bony fish	*Kyphosus cinerascens*	Blue sea chub	(Forsskål 1775)	KYPHOSIDAE	PERCOIDEI
KYI	Other bony fish	*Kyphosus incisor*	Yellow sea chub	(Cuvier 1831)	KYPHOSIDAE	PERCOIDEI
KYP	Other bony fish	*Kyphosus spp*	Kyphosus sea chubs nei		KYPHOSIDAE	PERCOIDEI
KYS	Other bony fish	*Kyphosus sectatrix*	Bermuda sea chub	(Linnaeus 1766)	KYPHOSIDAE	PERCOIDEI
KYV	Other bony fish	*Kyphosus vaigiensis*	Brassy chub	(Quoy & Gaimard 1825)	KYPHOSIDAE	PERCOIDEI
LAG	Other bony fish	*Lampris guttatus*	Opah	(Brünnich 1788)	LAMPRIDAE	LAMPRIFORMES
LGH	Other bony fish	*Lagocephalus lagocephalus*	Oceanic puffer	(Linnaeus 1758)	TETRAODONTIDAE	TETRAODONTIFORMES
LOB	Other bony fish	*Lobotes surinamensis*	Tripletail	(Bloch 1790)	LOBOTIDAE	PERCOIDEI
LUK	Other bony fish	*Selene dorsalis*	African moonfish	(Gill 1863)	CARANGIDAE	PERCOIDEI
LVM	Other bony fish	*Luvarus imperialis*	Luvar	Rafinesque 1810	LUVARIDAE	ACANTHUROIDEI
MAS	Other bony fish	*Scomber japonicus*	Pacific chub mackerel	Houttuyn 1782	SCOMBRIDAE	SCOMBROIDEI
MAW	Other bony fish	*Scomberomorus tritor*	West African Spanish mackerel	(Cuvier 1832)	SCOMBRIDAE	SCOMBROIDEI
MAX	Other bony fish	*Scombridae*	Mackerels nei		SCOMBRIDAE	SCOMBROIDEI
MAZ	Other bony fish	*Scomber spp*	Scomber mackerels nei		SCOMBRIDAE	SCOMBROIDEI
MOP	Other bony fish	*Mola spp*	Sunfish		MOLIDAE	TETRAODONTIFORMES
MOX	Other bony fish	*Mola mola*	Ocean sunfish	(Linnaeus 1758)	MOLIDAE	TETRAODONTIFORMES
MRW	Other bony fish	*Masturus lanceolatus*	Sharptail mola	(Liénard 1840)	MOLIDAE	TETRAODONTIFORMES
MSD	Other bony fish	*Decapterus macarellus*	Mackerel scad	(Cuvier 1833)	CARANGIDAE	PERCOIDEI
MZZ	Other bony fish	*Actinopterygii*	Marine fishes nei			PISCES MISCELLANEA
NAU	Other bony fish	*Naucrates ductor*	Pilotfish	(Linnaeus 1758)	CARANGIDAE	PERCOIDEI
NGT	Other bony fish	*Carangoides orthogrammus*	Island trevally	(Jordan & Gilbert 1882)	CARANGIDAE	PERCOIDEI
NXI	Other bony fish	*Caranx ignobilis*	Giant trevally	(Forsskål 1775)	CARANGIDAE	PERCOIDEI
NXU	Other bony fish	*Caranx lugubris*	Black jack	Poey 1860	CARANGIDAE	PERCOIDEI
OIL	Other bony fish	*Ruvettus pretiosus*	Oilfish	Cocco 1833	GEMPYLIDAE	SCOMBROIDEI
POA	Other bony fish	*Brama brama*	Atlantic pomfret	(Bonnaterre 1788)	BRAMIDAE	PERCOIDEI
PSC	Other bony fish	*Psenes cyanophrys*	Freckled driftfish	Valenciennes 1833	NOMEIDAE	STROMATEOIDEI, ANABANTOIDEI
PUX	Other bony fish	*Tetraodontidae*	Puffers nei		TETRAODONTIDAE	TETRAODONTIFORMES
REO	Other bony fish	*Remora remora*	Shark sucker	(Linnaeus 1758)	ECHENEIDAE	PERCOIDEI
REY	Other bony fish	*Remora brachyptera*	Spearfish remora	(Lowe 1839)	ECHENEIDAE	PERCOIDEI
REZ	Other bony fish	*Remora osteochir*	Marlin sucker	(Cuvier 1829)	ECHENEIDAE	PERCOIDEI
RRL	Other bony fish	*Remorina albescens*	White suckerfish	(Temminck & Schlegel 1845)	ECHENEIDAE	PERCOIDEI
RRU	Other bony fish	*Elagatis bipinnulata*	Rainbow runner	(Quoy & Gaimard 1825)	CARANGIDAE	PERCOIDEI
RUB	Other bony fish	*Caranx crysos*	Blue runner	(Mitchill 1815)	CARANGIDAE	PERCOIDEI
RZV	Other bony fish	*Ranzania laevis*	Slender sunfish	(Pennant 1776)	MOLIDAE	TETRAODONTIFORMES
SDX	Other bony fish	*Decapterus spp*	Scads nei		CARANGIDAE	PERCOIDEI
SPA	Other bony fish	*Ephippidae*	Spadefishes nei		EPHIPPIDAE	ACANTHUROIDEI
TRG	Other bony fish	*Balistes capriscus*	Grey triggerfish	Gmelin 1789	BALISTIDAE	TETRAODONTIFORMES
TRI	Other bony fish	*Balistidae*	Triggerfishes, durgons nei		BALISTIDAE	TETRAODONTIFORMES
UBP	Other bony fish	*Cubiceps capensis*	Cape fathead	(Smith 1845)	NOMEIDAE	STROMATEOIDEI, ANABANTOIDEI

(*continued on next page*)

Table 7 (*continued*)

Alpha3 Code	Study Group	Scientific Name	English name	Author	Family	Order
UDD	Other bony fish	*Uraspis helvola*	Whitetongue jack	(Forster 1801)	CARANGIDAE	PERCOIDEI
UKK	Other bony fish	*Uraspis spp*			CARANGIDAE	PERCOIDEI
URU	Other bony fish	*Uraspis uraspis*	Whitemouth jack	(Günther 1860)	CARANGIDAE	PERCOIDEI
USE	Other bony fish	*Uraspis secunda*	Cottonmouth jack	(Poey 1860)	CARANGIDAE	PERCOIDEI
WAH	Other bony fish	*Acanthocybium solandri*	Wahoo	(Cuvier 1832)	SCOMBRIDAE	SCOMBROIDEI
XXX*	Other bony fish					
YTC	Other bony fish	*Seriola lalandi*	Yellowtail amberjack	Valenciennes 1833	CARANGIDAE	PERCOIDEI
YTL	Other bony fish	*Seriola rivoliana*	Longfin yellowtail	Valenciennes 1833	CARANGIDAE	PERCOIDEI
ZAO	Other bony fish	*Zanclus cornutus*	Moorish idol	(Linnaeus 1758)	ZANCLIDAE	ACANTHUROIDEI
_ZY	Neritic & Temperate Tuna					
_ZZ	Neritic & Temperate Tuna					
ALB	Neritic & Temperate Tuna	*Thunnus alalunga*	Albacore	(Bonnaterre 1788)	SCOMBRIDAE	SCOMBROIDEI
BLT	Neritic & Temperate Tuna	*Auxis rochei*	Bullet tuna	(Risso 1810)	SCOMBRIDAE	SCOMBROIDEI
FRI	Neritic & Temperate Tuna	*Auxis thazard*	Frigate tuna	(Lacépède 1800)	SCOMBRIDAE	SCOMBROIDEI
FRZ	Neritic & Temperate Tuna	*Auxis thazard, A. rochei*	Frigate and bullet tunas		SCOMBRIDAE	SCOMBROIDEI
KAW	Neritic & Temperate Tuna	*Euthynnus affinis*	Kawakawa	(Cantor 1849)	SCOMBRIDAE	SCOMBROIDEI
LTA	Neritic & Temperate Tuna	*Euthynnus alletteratus*	Little tunny (=Atl. black skipj)	(Rafinesque 1810)	SCOMBRIDAE	SCOMBROIDEI
MAE	Rays and Mantas	*Aetobatus narinari*	Spotted eagle ray	(Euphrasen 1790)	AETOBATIDAE	MYLIOBATIFORMES
MAN	Rays and Mantas	*Mobulidae*	Mantas, devil rays nei		MOBULIDAE	MYLIOBATIFORMES
MNT	Rays and Mantas					
MYL	Rays and Mantas	*Myliobatis aquila*	Common eagle ray	(Linnaeus 1758)	MYLIOBATIDAE	MYLIOBATIFORMES
PLS	Rays and Mantas	*Pteroplatytrygon violacea*	Pelagic stingray	(Bonaparte 1832)	DASYATIDAE	MYLIOBATIFORMES
RMB	Rays and Mantas	*Mobula birostris*	Giant manta	(Walbaum 1792)	MOBULIDAE	MYLIOBATIFORMES
RMJ	Rays and Mantas					
RMM	Rays and Mantas	*Mobula mobular*	Devil fish	(Bonnaterre 1788)	MOBULIDAE	MYLIOBATIFORMES
RMO	Rays and Mantas	*Mobula thurstoni*	Smoothtail mobula	(Lloyd 1908)	MOBULIDAE	MYLIOBATIFORMES
RMT	Rays and Mantas	*Mobula tarapacana*	Chilean devil ray	(Philippi 1892)	MOBULIDAE	MYLIOBATIFORMES
RMV	Rays and Mantas	*Mobula spp*	Mantas, devil rays, etc. nei		MOBULIDAE	MYLIOBATIFORMES
RRY	Rays and Mantas	*Rhina ancylostomus*	Bowmouth guitarfish	Bloch & Schneider 1801	RHINIDAE	RHINOPRISTIFORMES
SRX	Rays and Mantas	*Rajiformes*	Rays, stingrays, mantas nei			RAJIFORMES
STT	Rays and Mantas	*Dasyatidae*	Stingrays, butterfly rays nei		DASYATIDAE	MYLIOBATIFORMES
TOD	Rays and Mantas	*Torpedinidae*	Electric rays nei		TORPEDINIDAE	TORPEDINIFORMES
0	Sharks					
2FOD	Sharks					
2REX	Sharks					
ALV	Sharks	*Alopias vulpinus*	Thresher	(Bonnaterre 1788)	ALOPIIDAE	LAMNIFORMES
BRO	Sharks	*Carcharhinus brachyurus*	Copper shark	(Günther 1870)	CARCHARHINIDAE	CARCHARHINIFORMES
BSH	Sharks	*Prionace glauca*	Blue shark	(Linnaeus 1758)	CARCHARHINIDAE	CARCHARHINIFORMES
BTH	Sharks	*Alopias superciliosus*	Bigeye thresher	(Lowe 1841)	ALOPIIDAE	LAMNIFORMES
CCE	Sharks	*Carcharhinus leucas*	Bull shark	(Valenciennes 1839)	CARCHARHINIDAE	CARCHARHINIFORMES
CCL	Sharks	*Carcharhinus limbatus*	Blacktip shark	(Valenciennes 1839)	CARCHARHINIDAE	CARCHARHINIFORMES
CVX	Sharks	*Carcharhiniformes*	Ground sharks			CARCHARHINIFORMES
DUS	Sharks	*Carcharhinus obscurus*	Dusky shark	(Lesueur 1818)	CARCHARHINIDAE	CARCHARHINIFORMES
FAL	Sharks	*Carcharhinus falciformis*	Silky shark	(Bibron 1839)	CARCHARHINIDAE	CARCHARHINIFORMES
LMA	Sharks	*Isurus paucus*	Longfin mako	Guitart Manday 1966	LAMNIDAE	LAMNIFORMES
LMP	Sharks	*Megachasma pelagios*	Megamouth shark	Taylor, Compagno & Struhsaker 1983	MEGACHASMIDAE	LAMNIFORMES
LMZ	Sharks	*Lamniformes*	Mackerel sharks			LAMNIFORMES
MAK	Sharks	*Isurus spp*	Mako sharks		LAMNIDAE	LAMNIFORMES
MSK	Sharks	*Lamnidae*	Mackerel sharks, porbeagles nei		LAMNIDAE	LAMNIFORMES
OCS	Sharks	*Carcharhinus longimanus*	Oceanic whitetip shark	(Poey 1861)	CARCHARHINIDAE	CARCHARHINIFORMES
POR	Sharks	*Lamna nasus*	Porbeagle	(Bonnaterre 1788)	LAMNIDAE	LAMNIFORMES
RSK	Sharks	*Carcharhinidae*	Requiem sharks nei		CARCHARHINIDAE	CARCHARHINIFORMES
SHX	Sharks	*Squaliformes*	Dogfish sharks, etc. nei			SQUALIFORMES
SKH	Sharks	*Selachimorpha (Pleurotremata)*	Various sharks nei			PISCES MISCELLANEA
SMA	Sharks	*Isurus oxyrinchus*	Shortfin mako	Rafinesque 1810	LAMNIDAE	LAMNIFORMES
SPK	Sharks	*Sphyrna mokarran*	Great hammerhead	(Rüppell 1837)	SPHYRNIDAE	CARCHARHINIFORMES
SPL	Sharks	*Sphyrna lewini*	Scalloped hammerhead	(Griffith & Smith 1834)	SPHYRNIDAE	CARCHARHINIFORMES
SPN	Sharks	*Sphyrna spp*	Hammerhead sharks nei		SPHYRNIDAE	CARCHARHINIFORMES
SPY	Sharks	*Sphyrnidae*	Hammerhead sharks, etc. nei		SPHYRNIDAE	CARCHARHINIFORMES

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Table 7 (*continued*)

Alpha3 Code	Study Group	Scientific Name	English name	Author	Family	Order
SPZ	Sharks	*Sphyrna zygaena*	Smooth hammerhead	(Linnaeus 1758)	SPHYRNIDAE	CARCHARHINIFORMES
THR	Sharks	*Alopias spp*	Thresher sharks nei		ALOPIIDAE	LAMNIFORMES
TIG	Sharks	*Galeocerdo cuvier*	Tiger shark	(Péron & Lesueur 1822)	GALEOCERDONIDAE	CARCHARHINIFORMES
4TOE	Turtles					
DKK	Turtles	*Dermochelys coriacea*	Leatherback turtle	(Vandelli 1761)	DERMOCHELYIDAE	TESTUDINES
LKV	Turtles	*Lepidochelys olivacea*	Olive ridley turtle	(Eschscholtz 1829)	CHELONIIDAE	TESTUDINES
LKY	Turtles	*Lepidochelys kempii*	Kemp's ridley turtle	(Garman 1880)	CHELONIIDAE	TESTUDINES
TTH	Turtles	*Eretmochelys imbricata*	Hawksbill turtle	(Linnaeus 1766)	CHELONIIDAE	TESTUDINES
TTL	Turtles	*Caretta caretta*	Loggerhead turtle	(Linnaeus 1758)	CHELONIIDAE	TESTUDINES
TTX	Turtles	*Testudinata*	Marine turtles nei			TESTUDINES
TUG	Turtles	*Chelonia mydas*	Green turtle	(Linnaeus 1758)	CHELONIIDAE	TESTUDINES
RHN	Whale Shark	*Rhincodon typus*	Whale shark	Smith 1828	RHINCODONTIDAE	ORECTOLOBIFORMES

Data availability

The data that has been used is confidential.

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