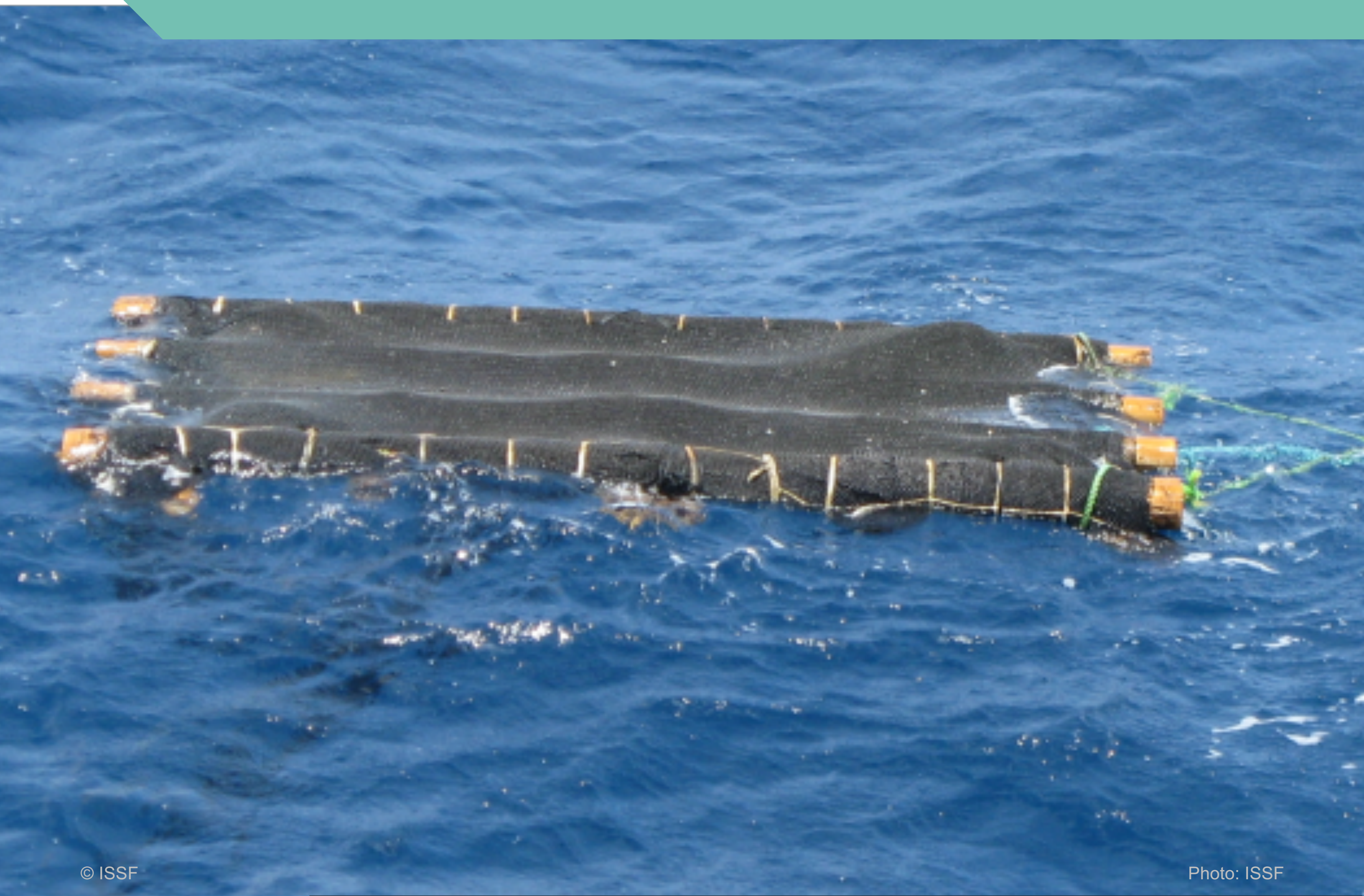
ISSF INTERNATIONAL SEAFOOD SUSTAINABILITY FOUNDATION

ISSF Technical Report 2021-11

QUESTIONS AND ANSWERS ABOUT FADS AND BYCATCH



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Topic Categories: FADs, Bycatch, Purse seine

Abstract

This work presents answers to key questions about Fish Aggregating Devices, or FADs — man-made floating objects used to aggregate tunas. The authors compare the catch composition of target tuna species in both FAD and free-swimming school purse-seine sets, consider the bycatch of non-target species, discuss fishing effects in relation to juvenile tunas, and address other FAD issues. This document updates two earlier versions of the report (Dagorn and Restrepo, 2011 and Restrepo et al., 2017) with more recent data and findings.

June 2021

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Executive Summary

Tropical tunas (skipjack, yellowfin and bigeye) are caught by a variety of fishing gears, including by purse seining. Purse seiners use two main fishing methods, usually within the same fishing trip: setting on fish aggregating devices (FAD) and setting on free-swimming schools (FS) of tuna. A third fishing mode, setting on tuna-dolphin associations, also takes place but is only common in the Eastern Pacific Ocean. FAD use has been increasing steadily since the 1980s-1990s, and many FADs are now equipped with sophisticated electronics that make them very efficient. In 2015-2019, for example, 38% of the total tropical tuna catch (BET, YFT, and SKJ), combining all gears, was made with FADs, and around 45% of the catch of skipjack, the most abundant tuna species, was caught with FADs.

There are many questions about FAD use and impacts. This paper updates a 2017 ISSF publication with the most recent data and findings. Here are some of the main conclusions reached:

- FAD target catches consist of skipjack tuna (from 65% to 79%, depending on ocean region) as well as yellowfin and bigeye tuna. Combining all oceans, the catches in FAD sets are 73% SKJ, 18% YFT, and 9% BET. Sets on free-swimming schools (FS) are often mono-specific (but not always). Skipjack and yellowfin tuna represent the main catch on FS. There is more variability by ocean region in FS sets than in FAD sets (for example, the catch of skipjack varies between 20% and 75% in FS sets). Combining all oceans, the catches in FS sets are 68% SKJ, 30% YFT, and 2% BET.
- There are several types of associated sets depending on the characteristics of the “object” associated with the school of tuna. These types include natural logs, drifting FADs, anchored FADs, associations with marine mammals, and associations with whale sharks.

Key Findings:

1. **Combining all oceans, the catches in FAD sets are 73% SKJ, 18% YFT, and 9% BET. Catches in free-swimming school sets are 68% SKJ, 30% YFT, and 2% BET.**
2. **Different fishing gears have different relative impacts on the non-target species caught in tuna fisheries.**
3. **Reducing bycatch rates and ecosystem impacts can be achieved by a combination of (a) technological changes in gear and equipment, (b) changes in FAD deployment and retrieval practices, (c) skipper training, and (d) management regulations.**

- Tropical tunas are not only caught by purse seining on FADs and FS. In the Eastern Pacific Ocean, large amounts of yellowfin are also caught by purse seine sets on tuna-dolphin associations. Longliners catch large amounts of bigeye in all oceans (about 17% of total YFT and BET catches), and pole-and-line fishing catches primarily skipjack (10% of total catch) but also bigeye and yellowfin. Gillnet and handline fisheries are also important in the Indian Ocean, where they target mainly yellowfin.
- The average percentage of the total catch that corresponds to non-target species in FS sets is 0.3% versus 1.1% in FAD schools in the Western Pacific Ocean, 0.7% versus 1.4% in the Eastern Pacific Ocean, 0.8% versus 3.1% in the Indian Ocean, and 1.8% versus 7.4% in the Atlantic Ocean. The main difference in the Atlantic Ocean is due to the high catches of other tuna species (e.g., little tunny, bullet tuna), which are targeted and retained opportunistically.
- In terms of weight, the species groups that make up most of the non-target species bycatch in FAD-set purse seining are tunas other than SKJ, BET and YFT (e.g., little tunny, bullet tuna, kawakawa); other bony fishes

(e.g., mahi-mahi, triggerfish, rainbow runners); billfishes; and sharks and rays. Other tunas and bony fishes make up between 77% and 92%, respectively, of non-target species bycatch.

- Some FAD-caught species can be a conservation concern, although their catches in purse-seine fisheries tend to be small compared to other fisheries. These include (a) some billfish stocks, which are thought to be overfished (e.g., Atlantic marlins); (b) some sea turtles and sharks, which may get entangled in traditional FADs that use open netting with large mesh size for the floating and/or hanging structures; and (c) some shark species, primarily silky sharks and oceanic whitetip sharks, which are encircled and caught together with the tunas. Tuna RFMO conservation measures as well as best practices to mitigate bycatch exist in most cases.
- Different fishing gears have different relative impacts on non-target species caught in tuna fisheries. While some non-target species are a common bycatch for some fishing methods, other gears may have a much lower impact on them.
- Practically all tuna fishing gears catch juveniles (immature individuals). A high percentage of the BET and YFT catch in purse-seine sets on FADs consists of juvenile individuals, similar to pole-and-line catches in all ocean regions. There are two potential impacts from catching juvenile tunas: overfishing and loss in potential yield. A stock can be overfished by catching too many juveniles, too many adults, or too many of both. Catching fish of different sizes leads to changes in potential yield. The question of what is the right mix of gears that catch small vs. large fish, or juveniles vs. adults, is not a scientific one. It is a largely political management decision of allocation between gears, which is difficult to tackle because different countries tend to mainly have fisheries of one gear type.
- Reducing bycatch rates can be achieved by a combination of (a) technological changes in gear and equipment, (b) changes in FAD deployment and retrieval practices, (c) skipper training, and (d) management regulations.
- Reducing FAD impacts on the marine ecosystem can be achieved by a combination of actions, such as (a) using fewer FADs than those adopted by the RFMO, (b) modifying FAD structures to build without netting and with organic materials, (c) implementing best practices to reduce FAD loss and abandonment, and (d) promoting retrieval of lost and abandoned FADs at sea or when beached.
- Tropical tuna purse-seine fisheries can and should be managed so that all of their operations are sustainable. This includes monitoring and managing FAD impacts on the target tuna stocks and associated bycatch species, the ecosystem due to lost and abandoned FADs, and on marine pollution. ISSF published a series of actions and best practices for better FAD management (Restrepo et al., 2019). ISSF also adopted in 2019 Conservation Measure 3.7 on Transactions with Vessels or Companies with Vessel-Based FAD Management Policies, with the aim to help fishers improve the management of FAD fisheries through six best practices: (i) Comply with flag state and RFMO reporting requirements for fisheries statistics by set type; (ii) Voluntarily report additional FAD buoy data for use by RFMO science bodies; (iii) Support science-based limits on the overall number of FADs used per vessel and/or FAD sets made; (iv) Use only non-entangling FADs to reduce ghost fishing; (iv) Mitigate other environmental impacts due to FAD loss, including through the use of biodegradable FADs and FAD recovery policies; and (vi) for silky sharks (the main bycatch issue in FAD sets) implement further mitigation efforts.
- All tuna RFMOs are making progress towards better FAD management by implementing the recommended best practices. This includes non-entangling FADs (IATTC, ICCAT, IOTC and WCFPC), limits on the number of active FADs per vessel (IATTC, ICCAT, IOTC and WCPFC), and time/area prohibitions on FAD sets (ICCAT and WCPFC). Still, more needs to be done, in particular to set scientifically based limits that are commensurate with the productivity of the tuna stocks and to reduce FAD impacts on the ecosystem.

1. What are FADs?

The term FAD stands for "fish aggregating device", which is supposed to strictly refer to man-made floating objects. FADs can be freely drifting in the ocean, and are usually constructed to have a surface structure (usually bamboo rafts) with underwater materials (traditionally, old nets hanging underneath; more recently, ropes or other non-entangling materials) and deployed by fishers, in which case they are referred to as drifting FADs (DFADs). Other FADs are anchored to the ocean bottom and are used in semi-industrial fisheries (e., the Western Pacific and some areas of the Indian Ocean) or artisanal fisheries (small islands in all oceans).

However, the term "FAD" is sometimes used to refer to any floating object, including natural ones such as logs or vegetal debris, on which fishers can set their gears to catch fish. These floating objects attract and aggregate fish, including schools of tropical tunas (skipjack SKJ–*Katsuwonus pelamis*, yellowfin YFT–*Thunnus albacares*, and bigeye–BET *Thunnus obesus*). After first discovering that tunas aggregate around natural floating objects, tuna fishers started to fabricate and deploy bamboo rafts. Fishing on floating objects has existed for a long time, but the practice of using artificial FADs grew in the 1990s and has become increasingly important in all oceans.

Fishers have learned that setting their nets on DFADs is very efficient; they tend to catch more tons of tunas more quickly during a trip than if they were looking for free-swimming tuna schools (FS). DFADs allow them to find tunas more easily and quickly. Sets on FADs are almost always successful, while in FS sets there is only about a 50% chance of success (schools often escape from the net-setting maneuver). The tonnage per set also is higher in DFAD sets than in FS sets (Floch *et al*., 2020).

Fishers commonly equip drifting FADs with satellite buoys so they can be tracked remotely. Most DFAD buoys are also equipped with sonar buoys that estimate the amount of fish under them, which helps fishers decide the most efficient strategy for when and where to maximize their catch during a trip. Ongoing research at ISSF is focused on developing acoustic methods to discriminate species, so that fishers can remotely obtain not only an estimate of the total fish biomass under a DFAD but also the relative proportion of each tuna species and their sizes as well as of non-tuna species. In some oceans (e.g., the Indian and Atlantic Oceans), purse seiners use supply vessels to maintain their FAD network (deploying or visiting them). In other regions, the use of supply vessels is forbidden (e.g., Eastern Pacific Ocean) or limited (e.g., Western and Central Pacific and Indian Ocean).

2. What is the difference between a FAD and a "Floating Object"?

A floating object (FOB) is any object that floats at the surface of the ocean, aggregates fish underneath, and is fished by fishers. An FOB could be natural (e.g., a log or a dead whale), natural but altered by fishers, or artificial (man-made). The following broad categories of floating objects are (adapted from Gaertner et. al. 2016):

FAD (fish aggregating device): A man-made FOB specifically designed to encourage fish aggregation at the device.

DFAD (Drifting FAD): A DFAD typically has a floating structure (such as a bamboo or metal raft with buoyancy provided by corks, etc.) and a submerged structure (made of old netting, canvas, ropes, etc.).

AFAD (Anchored FAD): AFADs usually consist of a very large buoy, or a set of many small buoys, anchored to the bottom with a chain and a rope. AFADs are called "**payaos**" in some regions.

LOG: A natural (branches, carcasses, etc.) or artificial (wreckage, nets, washing machines, etc.) log.

FALOG (Artificial log resulting from human fishing activity): Artificial logs are usually abandoned or lost materials related to fishing activity (nets, wreck, ropes, vessels that act as FADs, etc.).

HALOG (Artificial log resulting from human non-fishing activity): Other artificial logs (e.g., a washing machine, oil tank, etc.)

ANLOG (Natural log of animal origin): A natural log such as a whale carcass.

VNLOG (Natural log of plant origin): A natural log such as a branch, trunk, palm leaf, etc.

WHALE SHARK: In some regions, sets on whale sharks are seen as being similar to FAD sets, whereas in other regions they are seen as more similar to free-swimming school (FS) sets.

Some people use the term "FAD" for any floating object as long as it is used to catch tunas. With few exceptions (e.g., in the Western Pacific), fishery statistics do not distinguish between purse-seine sets made on natural objects and artificial objects. Most statistics differentiate between FS sets (or "unassociated" sets) and sets on floating objects (or "associated" sets). In the Eastern Pacific fishing statistics, sets on tuna-dolphin associations are also distinguished from other sets. In recent years, following resolutions adopted by some t-RFMOs, some countries have developed national FAD Management Plans that require linking FAD activities to a wider range of FAD categories (e.g., using the categories above), which will potentially lead to more detailed t-RFMO statistics and improved FAD management.

In this document, we use the term "FAD" for DFADs and any other drifting floating objects because it is more commonly understood by a non-technical audience. However, it would be more accurate to use the term "floating object."

3. What is “bycatch”?

There is no universally agreed definition of the term “bycatch.” Different people use "bycatch" to mean different things in different contexts. Very generally speaking, bycatch is the catch of any species that is not the main reason for which the skipper is fishing, whether the catch is retained or discarded.

In the case of tropical tuna fisheries, any species that is not the target species (i.e., skipjack, yellowfin, or bigeye tuna) is considered bycatch. Moreover, some target tuna catches are discarded at sea (because of small fish size, for instance), and some people consider dead discards of target tuna to be bycatch while others do not. This is important to keep in mind, as accounting for (or not) of discards of target species could greatly affect bycatch estimates and therefore bycatch rate comparisons both in a given fishery and among fisheries.

It is important to define how the term is being used in each context. Otherwise, a bycatch of x% of the target species catch in one fishery and a bycatch of y% in another fishery may not be comparable, because each study may be using different "bycatch" definitions.

In this document, we consider “bycatch” only to refer to the catch on non-target species, thus excluding the discards of target species (SKJ, YFT and BET).

4. What is the catch composition of target tuna species in FAD and free-swimming school purse-seine fisheries?

Tropical tuna purse seine fisheries target three main species — Skipjack (SKJ), yellowfin (YFT) and bigeye (BET) — and occasionally albacore (*Thunnus alalunga* - ALB). FAD sets (including those using both artificial and natural objects) and free-swimming school (FS) sets perform differently in different ocean regions, depending on variables such as the relative abundance of the different species and their availability to the fishing gear. **Table 1** shows total catches of tropical tuna by species, ocean and fishing gear (object-associated purse-seine sets, sets on free-swimming schools, and other gears) for 2015-2019.

Table 1. Total catches of tropical tuna species (tons) in all oceans in purse seine fisheries (object associated and free-swimming school sets) and other fisheries (2015-2019). This includes purse seiners' unclassified set catch: unclassified catches were split into free school and FAD sets based on their relative percentage in catches for which set type information is available.*

Atlantic Ocean											
Object Associated Sets (tons)				**Free School Sets (tons)**				**All Other Gears (tons)**			
Year	YFT	SKJ	BET	Year	YFT	SKJ	BET	Year	YFT	SKJ	BET
2015	28530	181980	21992	2015	60692	15081	3192	2015	39076	44842	54340
2016	35345	187039	24444	2016	66651	19078	5161	2016	46878	51172	49504
2017	28249	199290	23751	2017	60944	17613	4097	2017	46672	51604	50736
2018	23423	204949	21533	2018	69465	43288	6802	2018	42218	58401	44609
2019	28229	194914	22022	2019	63682	21245	4989	2019	40247	48236	47080
Indian Ocean											
Object Associated Sets (tons)*				**Free School Sets (tons)***				**All Other Gears (tons)**			
Year	YFT	SKJ	BET	Year	YFT	SKJ	BET	Year	YFT	SKJ	BET
2015	83407	169639	19400	2015	68052	10671	12020	2015	251452	220366	64975
2016	104201	225652	24615	2016	51918	8506	3170	2016	271588	236029	59065
2017	101543	251439	23783	2017	54491	7427	12520	2017	265791	246619	54561
2018	127926	337016	47395	2018	18862	6968	4009	2018	294046	265195	42836
2019	98365	279627	22302	2019	40332	38687	8337	2019	288543	228934	42525
Eastern Pacific Ocean											
Object Associated Sets (tons)				**Free School Sets (tons)**				**All Other Gears (tons)**			
Year	YFT	SKJ	BET	Year	YFT	SKJ	BET	Year	YFT	SKJ	BET
2015	43603	206515	60975	2015	41529	116784	1936	2015	14203	1444	41545
2016	58673	248190	55269	2016	36919	86192	1458	2016	12679	931	35563
2017	67167	224422	65443	2017	31280	98681	1529	2017	13166	1049	35402
2018	66122	213626	63815	2018	25000	72739	707	2018	13879	1634	29083
2019	52706	226173	69861	2019	21751	117243	655	2019	13265	659	27247
Dolphin Associated Sets (tons)											
Year	YFT	SKJ	BET								
2015	160595	5608	2								
2016	146526	3179	4								
2017	112533	1656	1								
2018	147859	2456	1								
2019	153252	3698	28								
Western and Central Pacific Ocean											
Object Associated Sets (tons)				**Free School Sets (tons)**				**All Other Gears (tons)**			
Year	YFT	SKJ	BET	Year	YFT	SKJ	BET	Year	YFT	SKJ	BET
2015	120958	606737	40842	2015	201209	768027	11900	2015	269981	389663	87649
2016	138602	608629	52144	2016	274066	736415	12813	2016	245786	405565	82680
2017	154858	623133	47794	2017	348234	641184	11196	2017	201973	337756	64058
2018	141170	745963	53189	2018	242403	699257	12556	2018	311869	383745	78913
2019	126628	728099	36096	2019	219931	974354	9059	2019	334481	326253	82069

FAD target catches comprise not only skipjack tuna (from 65% to 79%, depending on ocean region — see **Figure 1**) but also yellowfin and bigeye tuna. Combining all oceans, the catches by species in FAD sets are 73% SKJ, 18% YFT, and 9% BET.

Sets on free-swimming schools are often mono-specific (but not always). Skipjack and yellowfin tuna represent the main catch on free-swimming schools. There is more variability by ocean region in FS sets than in FAD sets (**Figure 2**). For example, the catch of skipjack varies by ocean between 20% and 75% in FS sets. In the Pacific Ocean (both Eastern and Western), around 75% of catches in free school sets are skipjack and around 25% are yellowfin, while in the Indian and Atlantic Oceans, it is the other way around (closer to 75% yellowfin and 25% skipjack). Combining all oceans, the catches in FS sets are 68% SKJ, 30% YFT, and 2% BET.

The catch composition of both FAD and free-school sets for the period studied here (2015-2019) are similar to those described in Restrepo *et al*. (2017), which used an earlier dataset (2011-2015). In both FAD and FS sets in the Indian Ocean, the skipjack tuna component slightly increased in comparison to yellowfin tuna, and skipjack composition also slightly increased in free-school sets in the Atlantic Ocean (from 19% to 24%).

When looking at changes in the global percentages compared to Restrepo *et al.* (2017), there are no differences in FAD set composition, and in FS sets there is only a slight decrease of skipjack tuna catches (from 71% to 68%), which translated into an increase in yellowfin (from 27% to 30%).

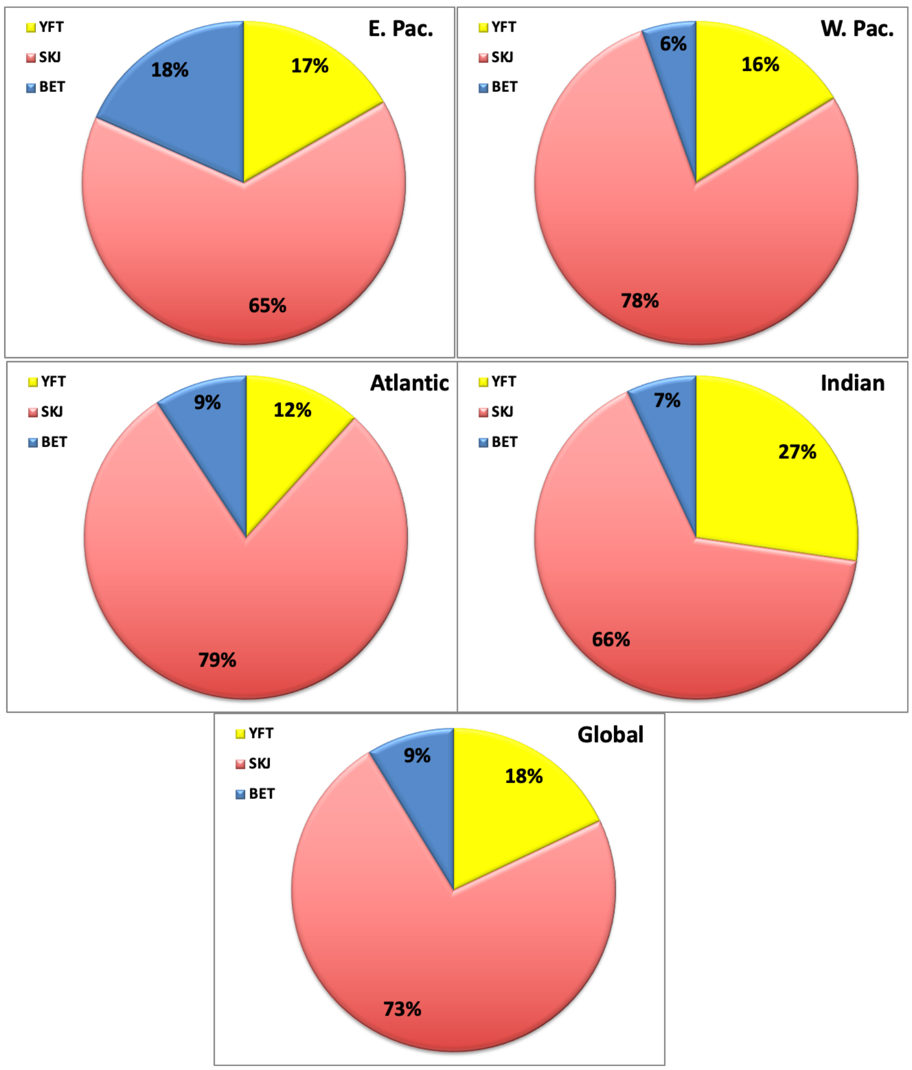

Figure 1. Composition of tropical tuna species in FAD sets, by ocean region. Data are from the tuna RFMOs for the period 2015-2019. For the Indian Ocean, FAD set catches include catches of purse seiners' unclassified sets (see Table 1).

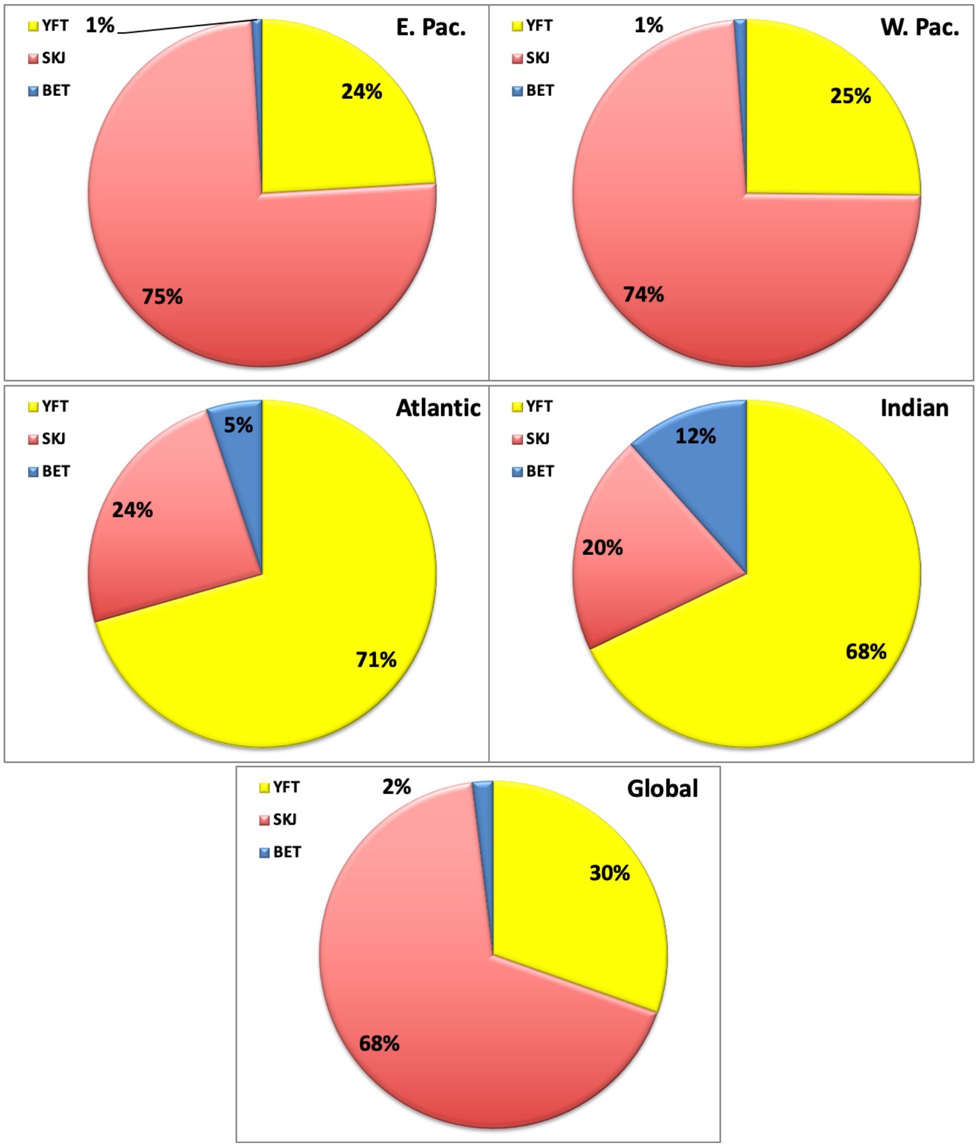

Figure 2. Composition of tropical tuna species in free-swimming school sets, by ocean region. Data are from the tuna RFMOs for the period 2015-2019. For the Indian Ocean, free-school set catches include catches from purse seiners' unclassified sets (see Table 1).

There are several types of associated sets depending on the characteristics of the object associated with the school of tuna is (see Q2). These types include natural logs (NLOGs), drifting FADs (DFADs), anchored FADs (AFADs), associations with marine mammals, and associations with whale sharks. **Figure 3** represents the percentages of catches of BET, SKJ and YFT in the Western and Central Pacific Ocean for each type of associated set as well as for sets on free-swimming schools. Free-school and drifting FAD sets comprise between 86% and 91%, respectively, of the total catches for the three species in the Western and Central Pacific Ocean. While skipjack and yellowfin are mostly caught in free-school sets (54% and 65% of the total catch, respectively), bigeye is mainly caught in drifting FAD sets (66% of total catches).

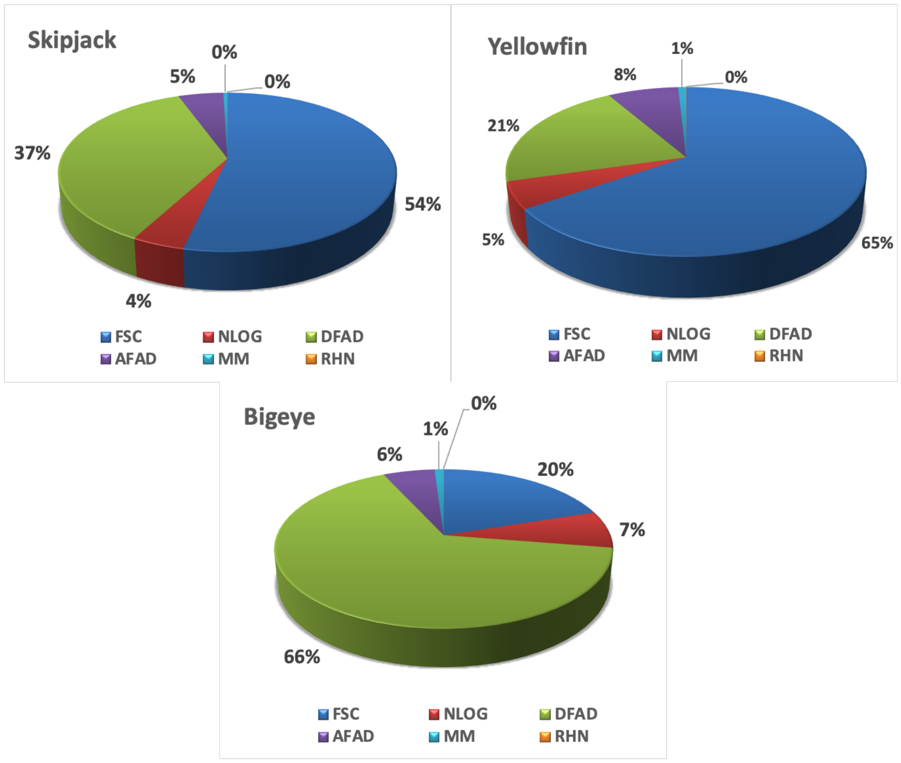

Figure 3. Composition of tropical tuna species in free-swimming school and different types of associated sets in the Western and Central Pacific Ocean (WCPFC Convention Area minus overlap with IATTC Convention Area). Data are from the SPC for the period 2015-2019 (Peter Williams, pers. comm). FSC = free-swimming school, NLOG = natural log, DFAD = drifting FAD, AFAD = anchored FAD, MM = association with marine mammal, RHN = association with whale shark.

As an illustration of the frequency of different set types, **Figure 4** shows the number of different purse-seine set types in the Eastern Pacific Ocean for the period 1958-2020.

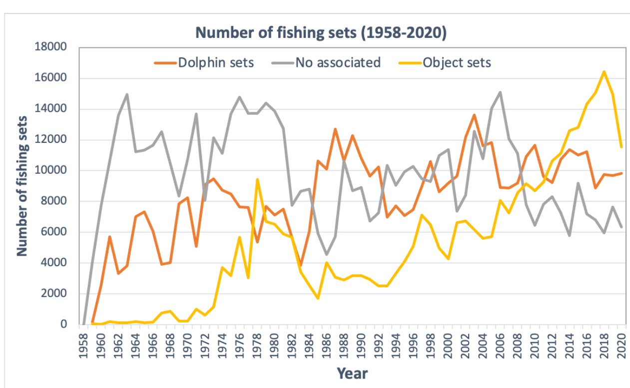

Figure 4. Number of sets by type in the Eastern Pacific Ocean (1958-2020) — Dolphin, free-swimming or unassociated (NOA) school and FAD sets. Data taken from the IATTC public domain data (https://www.iattc.org/PublicDomainData/IATTC-Catch-by-species1.htm)

5. How does the catch of tropical tuna species in FAD and free-swimming school purse seine fisheries compare to other fishing gears?

Tropical tunas are caught not only by purse seining on FADs and free-swimming schools (FS). In the EPO, large amounts of yellowfin are also caught by purse seine sets on tuna-dolphin associations (see **Table 2** and **Figure 4**). Longliners catch large amounts of bigeye in all oceans, and pole-and-line fishing catches primarily skipjack but also about 10% of bigeye and yellowfin globally. Gillnet and handline fisheries are also important in the Indian Ocean, where they target mainly yellowfin.

The catch of skipjack by gear type is variable depending on ocean region. FADs account for 37% to 72% of skipjack catches (**Figure 5**). Combining all oceans, skipjack catches are 45% by FAD sets, 31% by FS sets, and 24% by a variety of other gears.

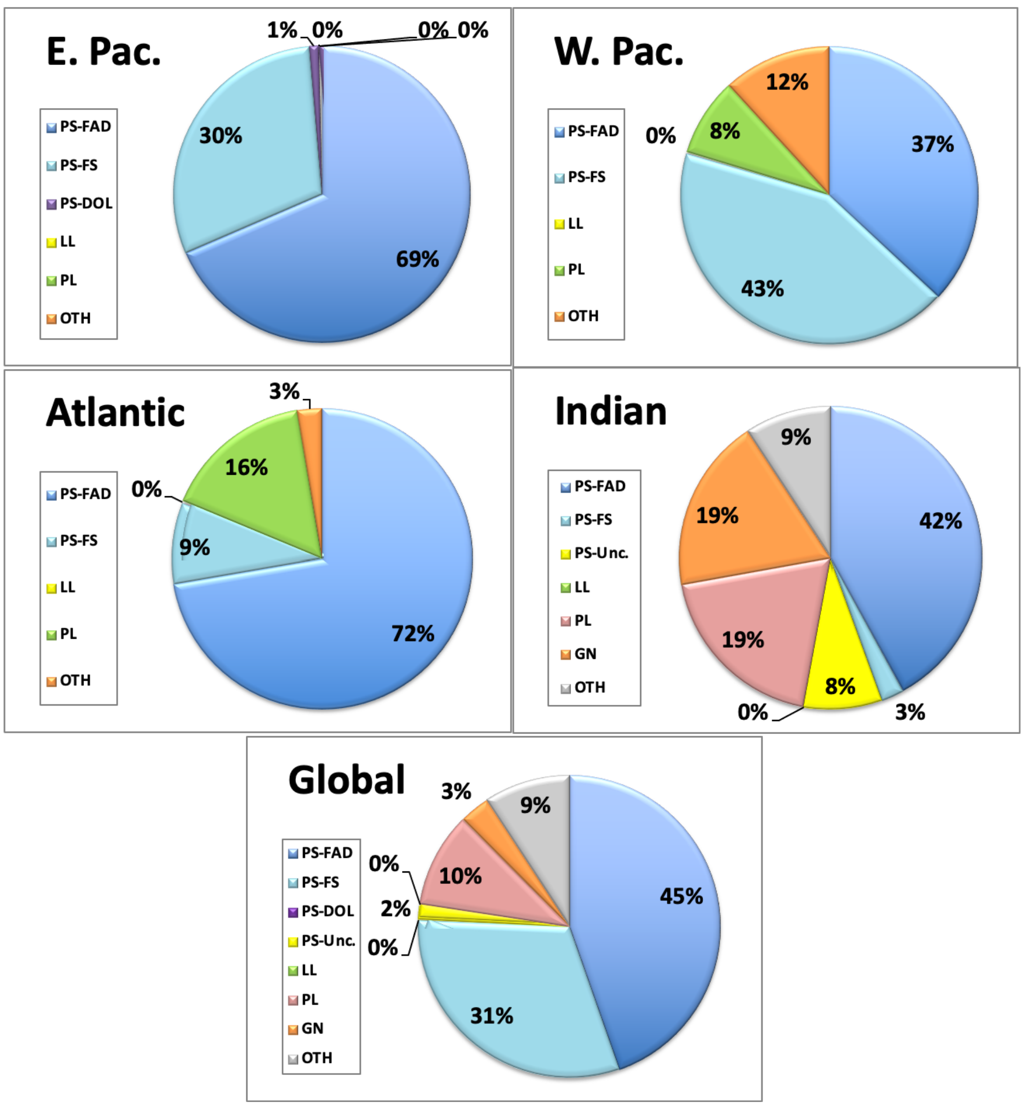

Figure 5. By ocean region, catch of skipjack tuna by gear type (Purse seine FAD, Purse seine Free-Swimming School, Purse seine unclassified (only in the Indian Ocean), Purse seine Dolphin (only in the Eastern Pacific), Longline, Pole and Line, Gillnet and Other gears). Data are from the tuna RFMOs for the period 2015-2019.

The catch of the three tropical species together by gear type is also variable depending on ocean region. FADs account for 32% to 51% of the catches of skipjack, yellowfin and bigeye combined (**Figure 6**). Combining all oceans, the catches of tropical tunas are 37% by FAD sets, 28% by FS sets, and 35% by a variety of other gears.

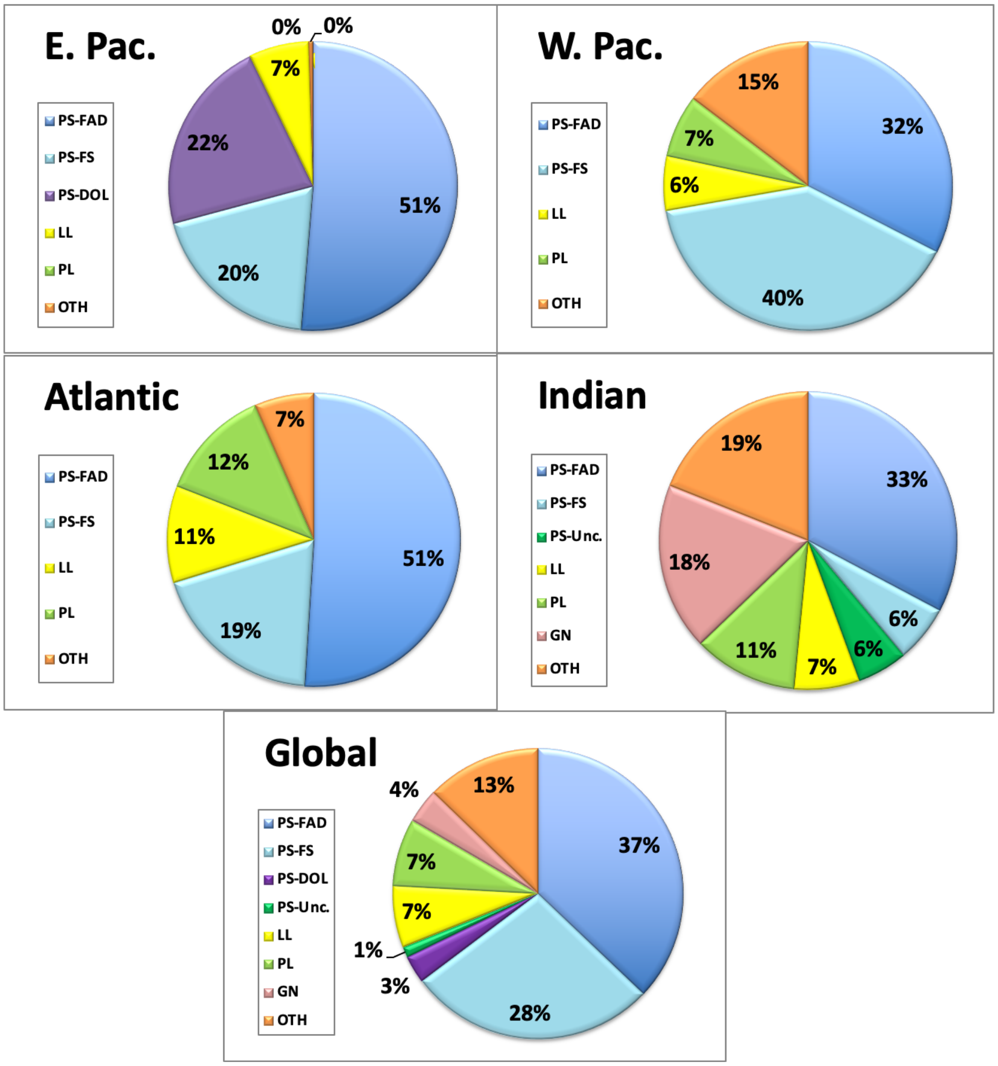

Figure 6. By ocean region, catch of skipjack, yellowfin and bigeye tunas combined, by gear type (Purse seine FAD, Purse seine Free-swimming School, Purse seine unclassified (only in the Indian Ocean), Purse seine Dolphin (only in the Eastern Pacific), Longline, Pole and Line, Gillnet and Other gears). Data are from the tuna RFMOs for the period 2015-2019.

6. What is the magnitude of non-target species caught in FAD and free-swimming school sets in purse-seine fisheries?

Both FAD and free-swimming school (FS) fishing practices result in bycatch of non-target species. Data collected by independent scientific observers onboard purse seiners indicate that FAD sets usually have a higher catch of non-target species (**Figure 7**). In three ocean regions, the catch of non-target species in FAD sets is 2 to 4 times higher than it is on FS sets.

The average percentage of the total catch comprised of non-target species in FS sets is 0.3% versus 1.1% in FAD schools in the Western Pacific Ocean, 0.7% versus 1.4% in the Eastern Pacific Ocean, 0.8% versus 3.0% in the Indian Ocean, and 1.8% versus 7.4% in the Atlantic Ocean. The main difference in the Atlantic Ocean comes from the high catches of other tuna species (e.g., little tunny, bullet tuna; Amandé *et al*., 2010, 2016a, 2016b). These figures correspond to catches expressed as weight (not in numbers of individuals).

The accuracy of these data depends on the observer program coverage in each ocean. Coverage is 100% on large purse seine vessels only in the Pacific Ocean, as required by IATTC and WCPFC. In contrast, RFMO-mandated observer coverage is less than 10% in the Atlantic and Indian Oceans. However, the figures below of the Atlantic and Indian Oceans are coming from fleets that have 100% observer coverage to meet voluntary commitments or to comply with ISSF Conservation Measure 4.3.

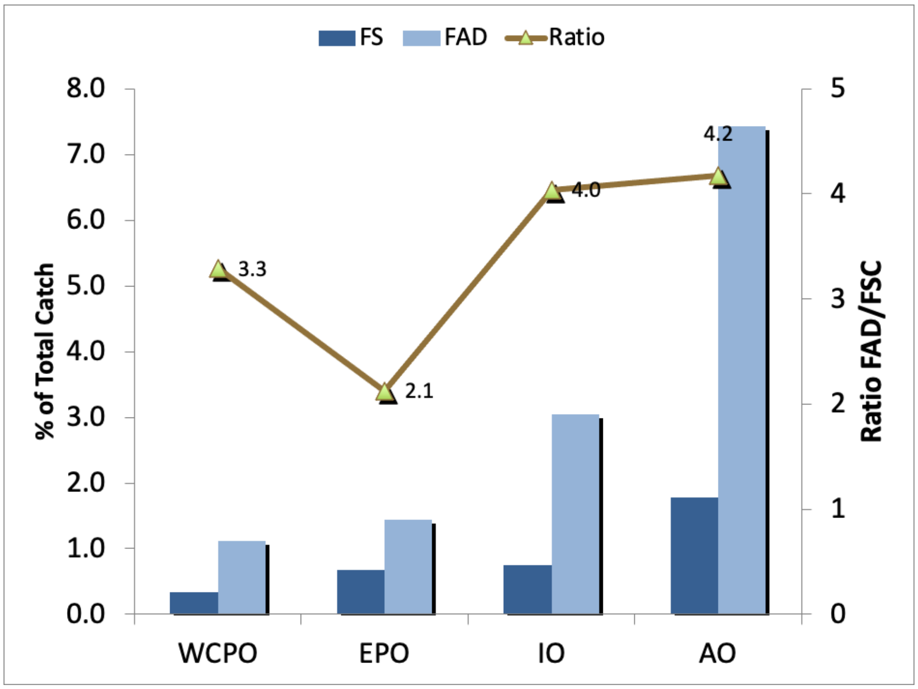

Figure 7. Amount of non-target species bycatch as a percentage of total catch (target and non-target species), with information on the ratio of bycatch between FAD and FS sets (average 2015-2020). Data sources: WCPO: 2015-2020 observer data by P. Williams (SPC, pers. comm.). EPO: 2015-2020 observer data by N. Vogel (IATTC, pers. comm.). IO: 2015-2020 and AO: 2015-2020 EU PS observer data by IEO, IRD, and AZTI (pers. comm).

7. What are the non-target species caught in FAD sets?

The categories of non-target bycatch species for tuna fisheries are:

- Tunas other than SKJ, BET and YFT (e.g., little tunny, bullet tuna, kawakawa)
- Other bony fishes (e.g., mahi-mahi, triggerfish, rainbow runners)
- Billfishes
- Sharks and rays
- Marine mammals

- Sea turtles
- Seabirds

In terms of weight, the first four categories — tunas other than SKJ, BET, and YFT as well as other bony fishes, billfishes, and sharks and rays — make up most of the non-target species bycatch in FAD as well as FS sets by purse seines globally (**Figure 8**). Other tunas and bony fishes make up between 77% and 92% of these non-target species catches. Minor tuna species are a considerable proportion of the non-target catch in the Atlantic Ocean, where they are generally utilized. Sharks and rays make up between 0.19% and 0.44% of the total FAD catches and range from 6% and 19% of the total bycatch in FAD sets, which is very small compared to other fishing gears. Note that mobulid rays are more commonly caught on free-swimming school sets than in FAD sets.

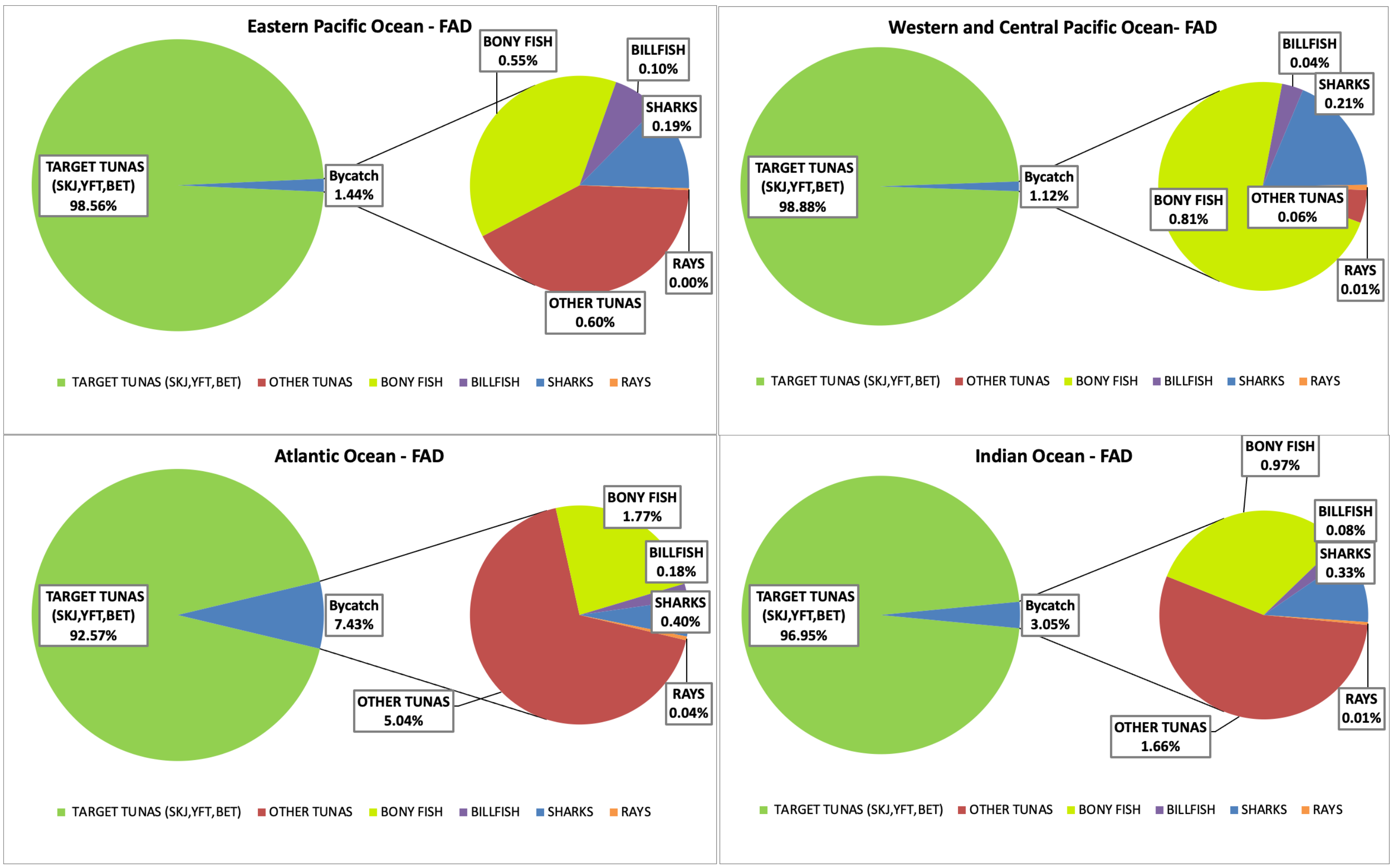

Figure 8. Composition of non-target species bycatch in FAD fisheries, by ocean region. Data sources: WCPO: 2015-2020 observer data by P. Williams (SPC, pers. comm.). EPO: 2015-2020 observer data by N. Vogel (IATTC, pers. comm.). IO: 2015-2020 and AO: 2015-2020 EU PS observer data by IEO, IRD, and AZTI (pers. comm).

8. Which FAD-caught bycatch species are of conservation concern?

Other fishes. In purse seine fisheries, most of the non-target species bycatch (around 85%) is represented by other (minor) tuna species and bony fishes (see Question 7 above). These species are generally considered fast growing, and highly fertile with high natural mortality rates, which makes them resilient to overexploitation. Therefore, the main concern with these species is that they are not utilized if discarded. However, they are being utilized in some regions (Amandè *et al*. 2016a, 2016b).

Seabirds. Seabird bycatch is not a concern in purse seine fisheries (Gilman, 2011).

Marine mammals. Marine mammal interactions on FADs can occur, but mortalities are rare (Anderson 2014; Escalle *et al.*, 2015; Peatman *et al.*, 2018; Williams *et al.*, 2020).

Billfishes. Some billfishes are of concern because they are thought to be overfished (e.g., Atlantic marlins). Catches of billfishes are relatively small in purse seine fisheries compared to other gears such as longlining (Justel-Rubio and Restrepo, 2015).

Turtles. Sea turtles are caught in small numbers by purse seiners and can be released alive relatively easily. However, traditional FADs that use open netting with large-size mesh in the floating and/or hanging structures can cause turtle entanglement through ghost fishing.

Noting that turtles are rated by IUCN from Vulnerable (Olive Ridley, Leatherback, and Loggerhead) to Endangered (Green) to Critically Endangered (Hawksbill and Kemp's Ridley), there have been efforts to develop mitigation measures. For instance, ISSF-collaborating scientists have created guidelines for the design of non-entangling FADs (ISSF 2019). IATTC, ICCAT, IOTC, and WCPFC now require that FAD fishing fleets deploy non-entangling designs.

Sharks. FAD fisheries catch sharks, primarily silky and oceanic whitetip sharks. These species are also caught in other tuna fisheries (e.g., estimates reported by Gilman, 2011, indicate that the total catch of silky sharks by purse seiners in the Pacific is about ten times lower than the catch by longliners). IUCN lists the silky shark as Vulnerable and lists the oceanic white tip shark as Endangered or Critically Endangered depending on the ocean. These species usually have a slow growth, low fertility, and low natural mortality rates, which make them sensitive to overexploitation. For that reason, the four tuna RFMOs responsible for managing tropical tuna fisheries have adopted conservation measures that specifically prohibit the retention of oceanic whitetip sharks and silky sharks by purse seine vessels (except for the IOTC on silky sharks, where their release is encouraged). Fleets in some fisheries still use FADs whose submerged structure is made up of old nets that can entangle sharks and other fauna. Filmalter *et al*. (2013) estimated that the magnitude of shark mortality due to this type of "ghost fishing" could have been very high in the Indian Ocean at the beginning of this decade. Since then, many fleets introduced non-entangling FADs (see ISSF 2019) voluntarily, and the IATTC, IOTC, ICCAT and WCPFC now require that newly deployed FADs be non-entangling — thus reducing or eliminating this problem.

9. Are undesired catches discarded? Are all discards dead?

"Undesired" catches consist of very small and/or damaged tunas as well as some non-target species. All tuna RFMOs have adopted mandatory measures for the full retention of yellowfin, skipjack and bigeye tuna unless the fish are unfit for human consumption. In the Atlantic Ocean, catches of very small tunas as well as non-tuna species are frequently kept and sold in local markets in western Africa (as fish called "*faux poisson*"), playing an important role in food security in this region. *Faux poisson* landings have been estimated in recent years by ICCAT (see Chavance *et al*. 2010, Amandè *et al*. 2016). But information from other regions is sparse (Lewis, 2016).

Traditionally, while a small portion of non-target bony fish is kept and used for consumption onboard (e.g., dolphinfish), non-tuna species are often discarded at sea (except in some places; see Amandè *et al*. 2016 and Lewis 2016). In recent years, many fleets have been keeping their catches of non-target species onboard and landing them as "byproducts" that have an important commercial value. For instance, this is the case for dolphinfish ("dorado" or "mahi-mahi") in the EPO, whose discards have decreased from 55% in 2001 to 13% in 2019 (**Figure 9**).

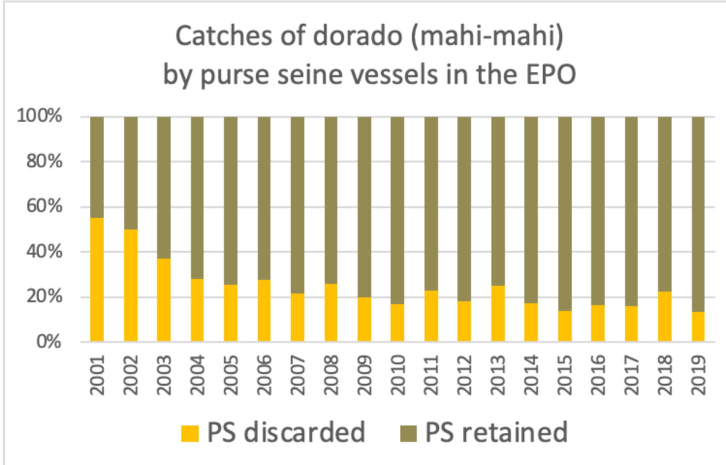

Figure 9. Estimated retained catches and discards by purse seine vessels of more than 363 t carrying capacity of dorado in the Eastern Pacific Ocean. Source: IATTC 2020.

Most sea turtles and some sharks are alive when encircled in purse seine operations. Tagging studies showed to an overall estimate of 15-43% survival for all sharks that are encircled and brought onboard, if good practices are put in place to release them (Poisson *et al.* 2014, Eddy *et al*. 2015, Hutchinson *et al*. 2015, Restrepo *et al*. 2016, Onandia *et al.* 2021). This survival rate corresponds to the combination of two factors: (i) 30-60% of the sharks arriving on the deck are alive, and (ii) 50-70% of these live sharks released from the deck can survive if they are released promptly following best practices.

Research has shown that most turtles survive if they are released promptly and following best practices (Poisson *et al*.2014.) For example, in the EPO purse seine fishery, which caught over 615,590 tons of tropical tuna in 2020, 527 interactions with sea turtles were recorded but only two turtles were observed dead (IATTC 2021).

10. How does the bycatch of non-target species in purse seine fisheries compare to other major global fisheries?

Bycatch occurs in almost all fisheries, not only in tuna fisheries. **Table 2** below from Kelleher (2005) illustrates the rates of discards in different fisheries globally. They range widely, from less than a tenth of a percent to over 60%, with tuna purse seine fisheries' discard rate being around 5% at the lower part of the list. These percentages represent only discards (which Kelleher defined as "bycatch"), so they are not comparable to the percentages shown in previous questions above, which represent bycatch over total catch, whether the bycatch is retained or discarded. Also, these statistics correspond to a time period before RFMOs adopted mandatory retention for tropical tuna purse seiners.

Table 2. Discard rates for different fisheries (from Kelleher, 2005)

Fishery	Landings	Discards[1]	Weighted average discard rate (%)	Range of discard rates (%)
Shrimp trawl	1 126 267	1 865 064	62.3	0-96
Demersal finfish trawl	16 050 978	1 704 107	9.6	0.5-83
Tuna and HMS longline	1 403 591	560 481	28.5	0-40
Midwater (pelagic) trawl	4 133 203	147 126	3.4	0-56
Tuna purse seine	2 673 378	144 152	5.1	0.4-10
Multigear and multispecies	6 023 146	85 436	1.4	n.a.
Mobile trap/pot	240 551	72 472	23.2	0-61
Dredge	165 660	65 373	28.3	9-60
Small pelagics purse seine	3 882 885	48 852	1.2	0-27
Demersal longline	581 560	47 257	7.5	0.5-57
Gillnet (surface/bottom/trammel)[2]	3 350 299	29 004	0.5	0-66
Handline	155 211	3 149	2.0	0-7
Tuna pole and line	818 505	3 121	0.4	0-1
Hand collection	1 134 432	1 671	0.1	0-1
Squid jig	960 432	1 601	0.1	0-1

More recently, and following the same approach as Kelleher (2015), Pérez Roda *et al.* (2019) and Gilman *et al.* (2020) estimated a discard rate of 4.7% for purse seines, which was the second lowest among the gears studied. They also estimated that fisheries targeting tunas have the lowest discard rate, at 5.4 % (**Figure 10**). Although they did not estimate specific discard rates for purse seines targeting tropical tunas, from the figures above it can be inferred that the discard rate of purse seines targeting tunas will be very low — among the lowest of the gears studied. All tuna RFMOs prohibit discards of tropical tuna species by purse seines; additionally, IOTC prohibits discards of other non-target species.

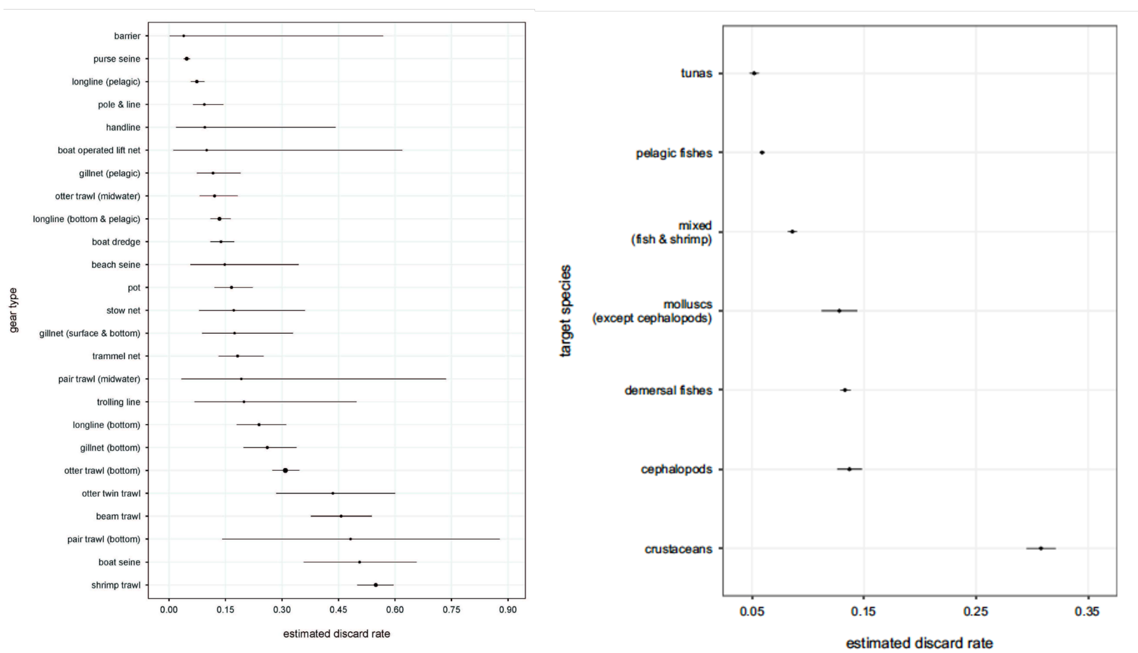

Figure 10. Mean discard rates and 95% confidence interval by gear (left) and target species (right), in tonnes of discards per tonnes of total catch (from Pérez Roda et al. (2019) and Gilman et al. (2020)).

Justel-Rubio and Restrepo (2015) compared the relative fishery impacts on non-target species caught in various tuna fisheries. While some non-target species are common bycatch for some fishing methods, other gears may have a much lower impact on them (**Figure 11**).

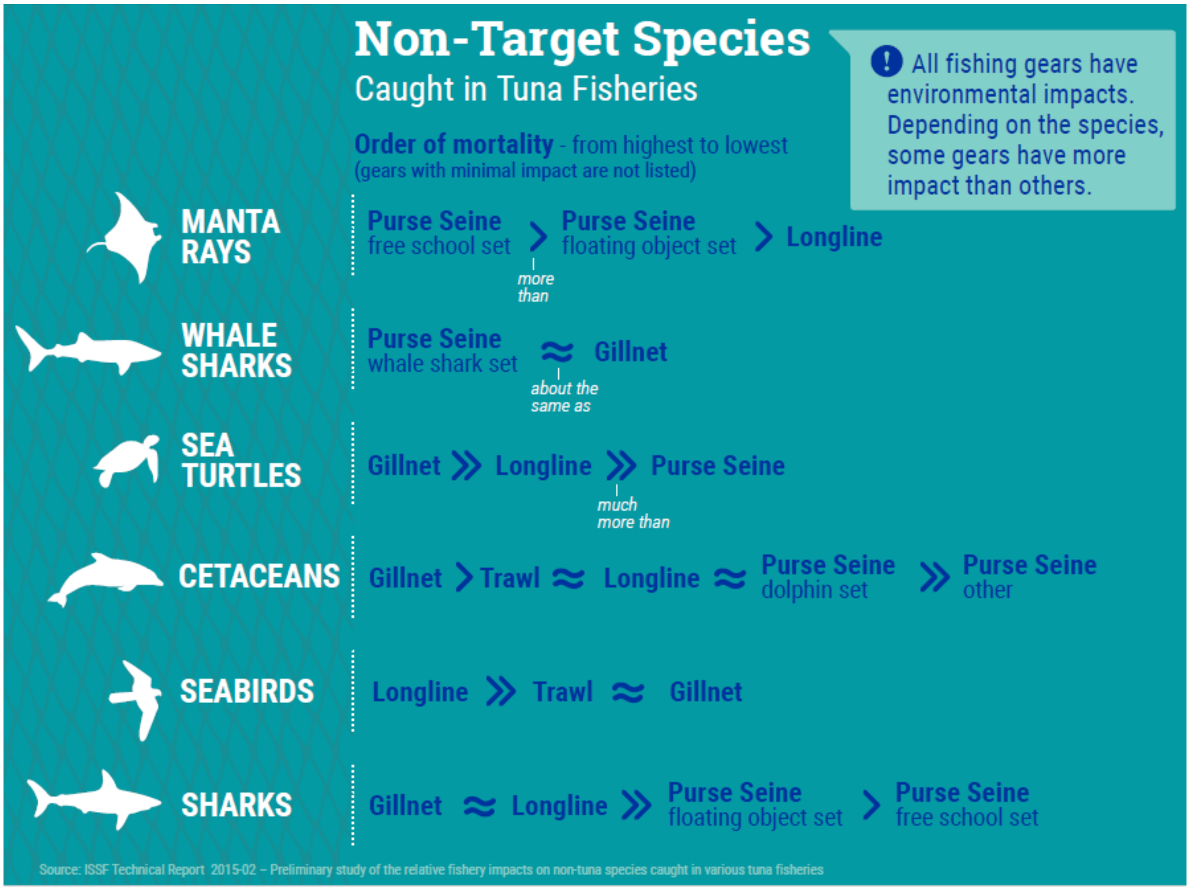

Figure 11. Relative impact of tuna fishing methods on non-target species in tuna fisheries.

11. Do sets on FADs and other fishing methods catch juvenile tunas? What are their impacts?

Practically all tuna fishing gears catch juvenile tunas (immature individual fish). But some gears catch more juveniles than others.

Figure 12 shows the percentage of the catch comprised of juvenile bigeye (BET), yellowfin (YFT) and skipjack (SKJ) caught by four fishing methods (purse seine sets on FADs; purse seine sets on free-swimming schools (FS) of tuna; pole and line; and longline) in the Eastern Pacific, Western and Central Pacific, Atlantic, and Indian Oceans.

BET become sexually mature at a size around 119 cm, YFT matures at around 97 cm, and SKJ at around 43 cm. The estimates of size at maturity published in the literature vary by region and by study. But these sizes taken as the mid-point of the size ranges at maturity (ISSF, 2021) should suffice as an approximation to illustrate juvenile catches of these three species.

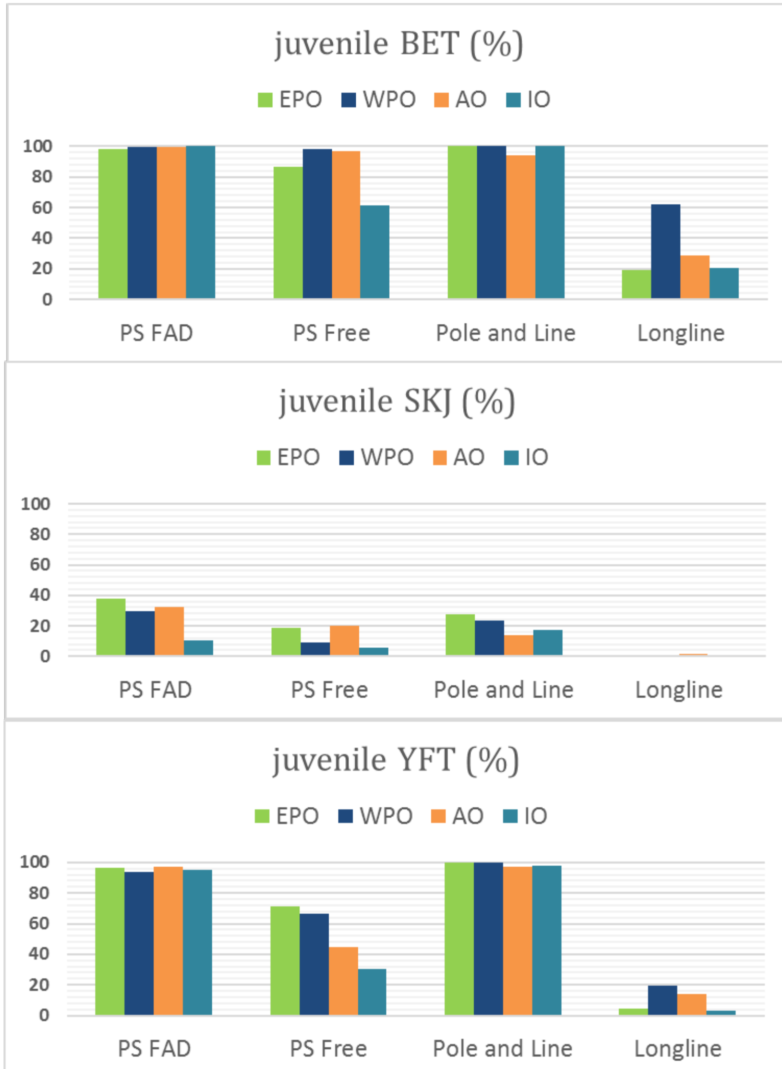

Figure 12. Percentage of the catch comprised of juvenile individuals of bigeye (BET), yellowfin (YFT) and skipjack (SKJ) caught in purse seine FAD sets, purse seine FS sets, pole and line, and longline fisheries in different ocean regions for the period 2011-2015. Data are from IATTC (EPO), SPC (WCPO), ICCAT (AO) and IOTC (IO), and available from the stock assessment or from the corresponding RFMO database.

Most of the catch of bigeye and yellowfin in purse seine sets on FADs consists of juvenile individuals, similar to pole and line catches in all ocean regions. Juvenile BET and YFT are also caught in purse seine sets on free-swimming schools and in longline fisheries, but in a lower proportion. Juvenile SKJ are less common overall in purse seine and pole-and-line catches, and are very scarce in longline catches.

There are two potential impacts from catching juvenile tunas: **Overfishing** and **loss in potential yield**.

Many people believe that catching juveniles automatically leads to **overfishing**. But this is not necessarily the case. A stock can be overfished by catching too many juveniles, too many adults, or too many of both. In a way, catching adults impacts the reproductive potential of the stock in the short term, while catching juveniles impacts reproduction at some time in the future.

These impacts can be measured in the stock assessments. For example, **Figure 13** shows how the "spawning potential" of the WCPO bigeye stock has been impacted by various fishery types over the years (from Ducharme-Barth *et al*., 2020). Longline fisheries (in green below), which catch largely adults, have been impacting WCPO bigeye spawning potential since they started in the 1950s. The purse seine-associated (FAD) fisheries (in dark blue), which catch mostly juveniles, had an increasing impact on the stock's spawning potential since they began in the 1990s. Today, both purse seine-associated or FAD fisheries and longline fisheries have a similar impact on the spawning potential of the WCPFC bigeye stock.

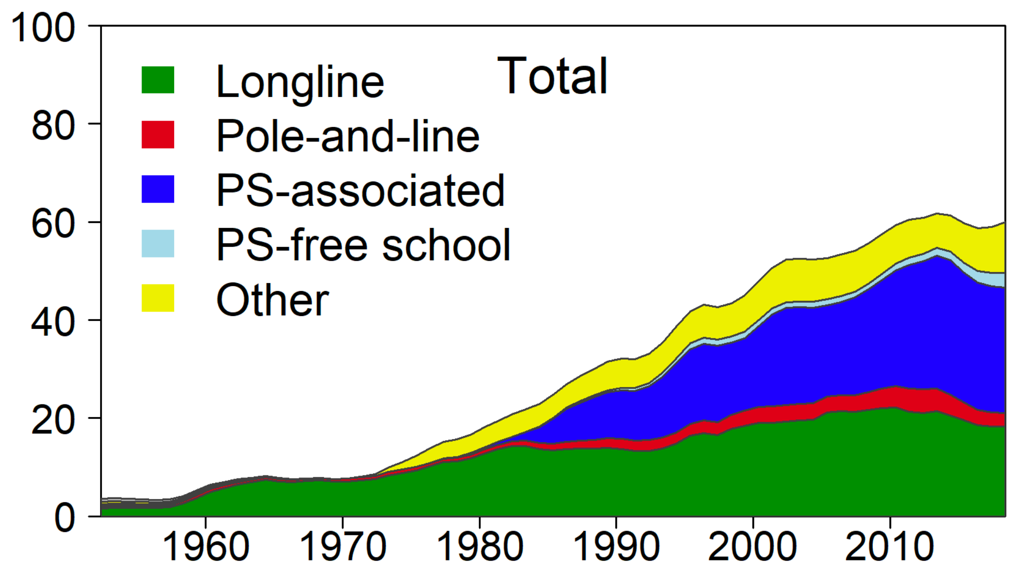

Figure 13. Estimates of reduction in spawning potential due to fishing for the WCPO bigeye stock attributed to various fishery groups (from Ducharme-Barth et al., 2020).

Catching fish of different sizes leads to changes in **potential yield**. From a theoretical point of view, there is an optimum size at which MSY would be highest if all the fish were caught at that size, depending on the life history of the species (growth, maturity and natural mortality). This optimum can never be achieved exactly because it is not possible to design a fishing gear that will catch all of the tuna at the same size. But there are fisheries (e.g., longline) whose size selectivity will be close to this optimum size. If those fisheries are the main source of fishing for the stock, then MSY will be close to the theoretical optimum. However, it may be possible that those fisheries cannot wholly catch the MSY, and therefore a loss in yield will occur.

In contrast, if the main source of fishing is from fisheries that catch fish at sizes away from the optimum (i.e., either too small or too large), then MSY will be less than the optimum. This is illustrated in **Figure 14** for the WCPO bigeye stock (from Ducharme-Barth et al., 2020). In this case, when most of the fishing was from longlining (until about 1970), MSY was over 300,000 tons. As fishing increased in the Indonesian and Vietnamese small-fish fisheries and the Indonesian-Philippines ex-EEZ purse seine fishery (the "Other" fisheries shown in yellow in the figure), MSY decreased substantially, to around 150,000-200,000 tons. Starting in the early 1980s, as industrial purse seine fisheries were introduced, MSY has fluctuated around 150,000 tons.

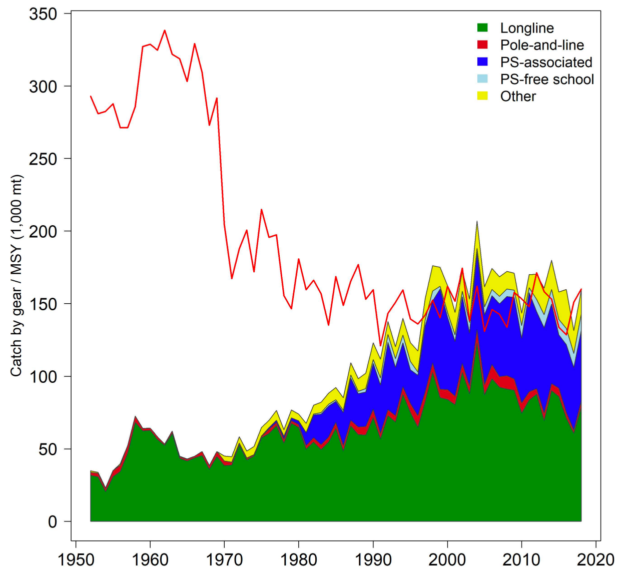

Figure 14. History of the annual estimates of MSY (red line) compared with annual catch split by the main gear types for the WCPO bigeye stock (from Ducharme-Barth et al., 2020).

The question of what is the right mix of gears that catch small vs. large fish, or juveniles vs. adults, is not a scientific one. It is largely a political management decision, which is difficult to tackle because different countries tend to have fisheries of one type. Some people consider juvenile yellowfin and bigeye to be bycatch. But in our minds, this is neither correct nor useful. Bigeye and yellowfin make up to 10% and around 25%, respectively, of the catch in purse seine-associated sets, which is not insignificant. These catches are retained, sold, canned and consumed. And the catches from other fisheries that catch juveniles (e.g., pole and line fisheries) are also commercialized and constitute an important component of food security. Thus, rather than labeling small bigeye as bycatch, we see it as a targeted catch that needs to be actively managed, as do the catches from all other fishing gears.

12. Can bycatch in FAD fishing be reduced?

We are convinced that bycatch in FAD fishing can be decreased. As Hall *et al*. (2000) show, reductions in bycatch rates can be achieved by a combination of (a) technological changes in gear and equipment, (b) changes in FAD deployment and retrieval practices, (c) skipper training, and (d) management regulations. For example, Restrepo *et al.* (2016) outline four actions that, in combination, can increase silky shark survival in purse seine fisheries by an estimated 62%.

ISSF launched in 2009 an ambitious research program to inform and train skippers and crew and address (a) and (b) above, focusing on reducing the catch of small bigeye tuna, as well as turtle and shark bycatches. Restrepo *et al*. (2018) presents all research and progress achieved to date. ISSF has carried out numerous training workshops (c) in 23 different countries, including Ecuador, Mexico, Ghana, Samoa, USA, Seychelles, Indonesia, Philippines, France, Spain and Panama (**Figure 15**), and is planning to continue doing so as one of its priority efforts (Murua *et al*. 2020). And ISSF's potential to advocate policy changes at RFMOs (d) should be fully utilized so that more complete bycatch data are reported and known mitigation techniques are adopted as mandatory requirements.

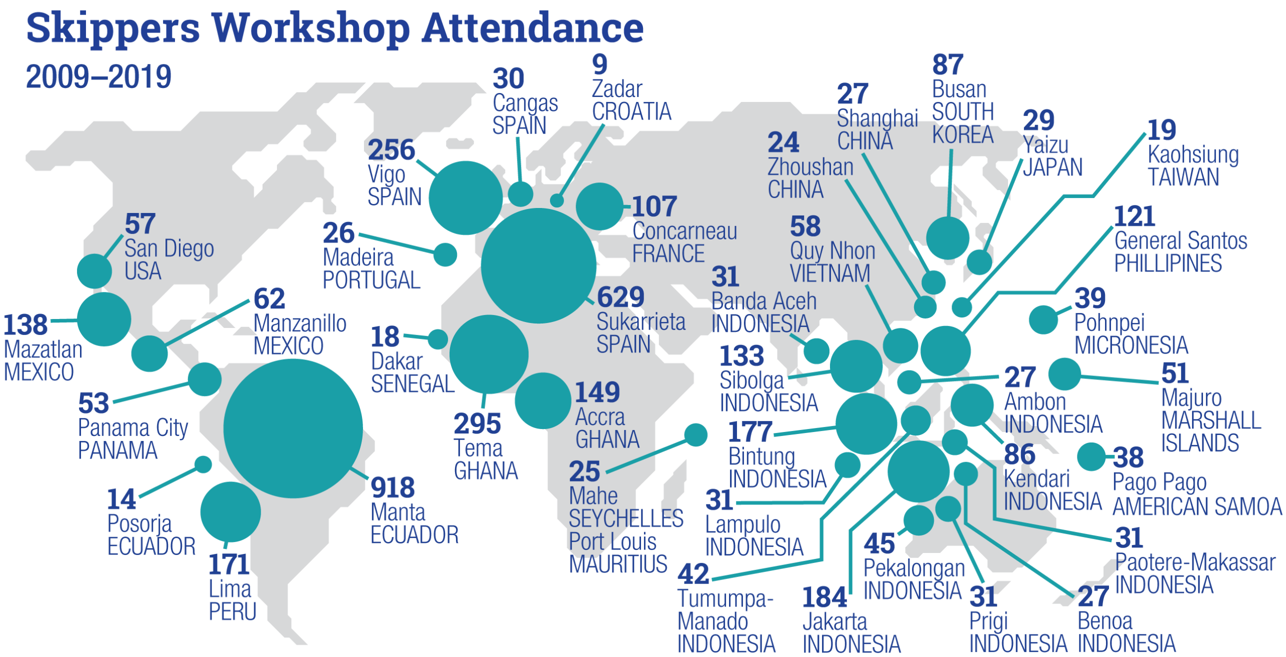

Figure 15. Locations and attendance of ISSF skippers workshops (2009-2019).

Significant pressure is being exerted by some environmental NGOs to call attention to bycatch issues in FAD fisheries. This can be a driver for improvement in these very efficient fisheries that harvest a very large quantity of tuna for human consumption. We note, however, that FAD fisheries are not the only tuna fisheries with bycatch issues (in fact, some of the bycatch issues in FAD fisheries are very minor compared to those of other fisheries; see Justel-Rubio and Restrepo, 2015). Therefore, the bycatch of species of concern (especially some sharks and turtles) needs to be tackled for all major fishing gears. The first step towards this is to improve bycatch data collection and reporting to the RFMOs.

13. Can FADs' ecosystem impacts be reduced?

To describe more sustainable FAD designs, some people use the term "eco-FAD," but there is no official definition for one. Instead, it is best to talk about different actions that can mitigate FADs' ecosystem impacts. This requires thinking about three main elements: Ghost fishing, marine pollution, and tuna habitat modification.

13.1 CAN FAD GHOST FISHING BE MITIGATED?

Ghost fishing, primarily of sharks, but also of other marine taxa such as sea turtles, can occur when the surface and submerged structure of a FAD has been made with open net panels whose mesh size is large enough to entangle fauna. This was demonstrated by Filmalter *et al.* (2013) in the Indian Ocean.

Quantification of entanglements at FADs is difficult, as entanglement processes typically go unobserved at short time scales (i.e., fishers may visit a FAD only once or a few times in its lifetime even though it can drift in the open ocean for years). Also, detecting entanglements in the submerged part of the FAD is very difficult from the deck of a purse seiner.

Fortunately, the solution is quite straightforward, as FADs can be constructed to be non-entangling (partially or completely) and still attract tunas, as shown in the ISSF Non-entangling and biodegradable FAD guide (2019). All tuna RFMOs have adopted non-entangling FAD requirements. Current conservation measures in three tuna RFMOs (the IATTC, C19-01, the WCPFC CMM 2020-01, and the ICCAT Rec 19-02) still allow using netting to construct FADs. In the Pacific, if netting is used for the submerged appendage, it can be of any mesh size as long as it is tightly tied into sausage-like bundles. If open panel netting is used, it must have a small mesh size (< 2.5 inch). According to the ISSF guide mentioned above, these types of FADs are considered to be Low Entanglement Risk (LER) FADs.

However, although using LER FADs can reduce the entanglement of marine fauna at FADs if the structures are newly built and monitored by fishers, netting on lost and abandoned FADs can become untied and broken and persist at sea, which means LER FADs may eventually become High Entanglement Risk FADs (ISSF, 2019).

Only FADs without netting can completely prevent ghost fishing. The Indian Ocean Tuna Commission (IOTC, 2019) is the only tuna RFMO that prohibits netting in FAD construction.

13.2 CAN MARINE POLLUTION BY FADS BE REDUCED?

Marine debris can be of concern when FADs are constructed with materials that degrade very slowly, such as PVC pipes for the rafts or nylon nets and polypropylene ropes. In addition, lost or abandoned FADs can drift and beach in sensitive areas such as coral reefs, or pollute commonly encountered habitats (e.g., shore, seabed) (Maufroy *et al.* 2015; Escalle *et al.* 2019; Izmilen *et al.* 2021).

There are three actions at different stages of the fishing operation that can reduce the FAD structure's impact on the ecosystem. The first action is limiting the number of FADs. All tuna RFMOs have adopted a limit on the number of active FADs allowed per vessel. IOTC has also limited the number of instrumented buoys acquired annually and in stock for each purse seine vessel.

Secondly, research efforts have focused on ways to modify FAD structure and develop biodegradable FADs so that if FADs are lost or abandoned at sea, their impact on the ecosystem is reduced. ISSF has been working since 2009 to test various organic materials and designs for biodegradable FADs (**Figures 16** and **17**).

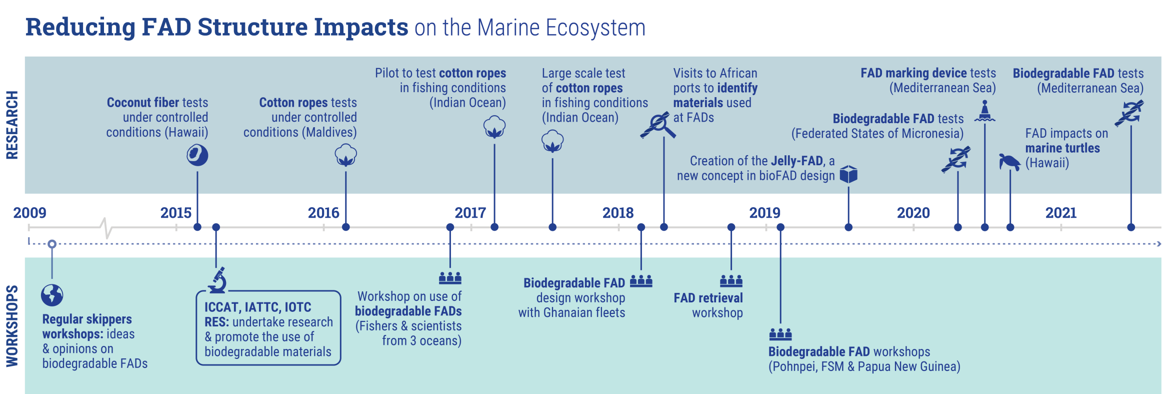

Figure 16. Timeline of the research conducted by ISSF to reduce FADs' impact on the ecosystem

The aim is to design FADs that use biodegradable, organic materials as much as possible but that also last long enough to be effective for fishers (i.e., about 6-12 months). Examples of these efforts are given in Moreno *et al.* (2017) and Restrepo (2016), and preliminary results are very promising and summarized in Moreno *et al.* (2020) (**Figure 17**). To help fishers shift from traditional to biodegradable FADs, ISSF is researching not only non-plastic, organic materials but also appropriately durable designs (Moreno *et al.*, 2021). As such, ISSF suggests that Bio-FAD structures should be re-designed to suffer the least structural stress in the water, and proposes the "jelly-FAD," a new concept in DFAD design (Moreno *et al.*, 2021). The smaller-sized jelly-FAD, which uses organic materials, can eliminate ghost fishing, have less impact if stranded in coastal sensitive habitats (e.g., reefs), and create less marine pollution and debris if lost.

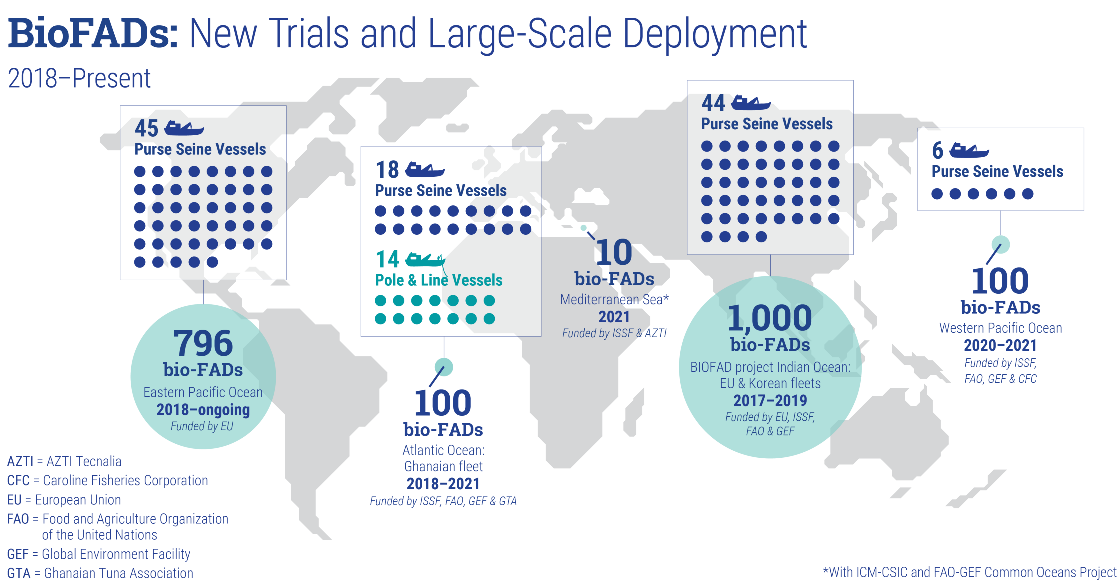

Figure 17. Trials with biodegradable FADs in the three tropical oceans

Finally, once FADs drift out of the fishing zone, they could be retrieved at sea or when beached. During an ISSF workshop focused on FAD retrieval, a number of possibilities were discussed to retrieve FADs at sea or on land (Moreno *et al.,* 2018). One of the important prerequisites for FAD retrieval would be having quantitative data to determine the priority zones for collecting FADs at sea or from land, taking into account the area's vulnerability and the number of FADs that typically end up stranding. For this, the use of real trajectories (not necessarily in real time), or collaboration with companies supplying satellite buoys to obtain positions once they have been deactivated, would be the best options.

Lost FADs should be managed. Tuna RFMOs need to clearly define FAD ownership rules and responsibilities and implement measures to reduce FAD loss and abandonment. For instance, all fleets could be required to recover a certain percentage of their FADs each year or at the end of a season, as the IATTC now requires.

13.3 DO FADS ACT AS ECOLOGICAL TRAPS?

We do not have enough knowledge yet to know if FADs act as ecological traps.

First, we need to define "ecological trap." Animals sometimes consider certain features of an environment when judging the quality of a potential habitat, which is beneficial as long as the environmental cues are highly correlated with the true habitat quality. Anthropogenic changes in animal habitats, however, can mean that cues are no longer reliable indicators of habitat quality. When animals continue to rely on those cues, they can be misled by them — which may have consequences for their growth, survival and reproduction. This situation is called an ecological trap (Schlaepfer et al. 2002, Battin 2004, Swearer et al. 2021).

To know whether FADs act as an ecological trap for tuna, the first condition is to verify whether FADs have modified the pelagic environment. Originally, tuna fishers took advantage of natural floating objects (e.g., logs) in oceans, which aggregate fish, enabling them to be found and caught more easily, but without altering the pelagic environment. By the 1990s, however, in intensively deploying man-made FADs, fishers did begin to modify the marine environment simply by adding more floating objects into the ecosystem. In many offshore regions, for example, there are now far more FADs than logs (Cf. Dagorn et al. 2013).

The second condition is to verify if this environmental change (increased number of floating objects) has modified tuna behavior, with potential consequences for tuna growth, survival and reproduction.

One hypothesis to explain tunas' associative behavior with floating objects is that natural objects, like logs, originated from the coasts and were mainly found in nutrient-rich coastal waters (the so-called "indicator-log hypothesis" Hall et al. 1992). For tuna, then, the presence of floating objects may suggest to them that an area is favorable. When FADs, either drifting or anchored, appear in "poor areas," however, the cue that relates floating objects with nutrient-rich areas is misleading, potentially constituting an "ecological trap." Tuna that follow those FADs can become trapped in poor productivity areas.

Comparing tuna behavior at different anchored FAD arrays close to shore, Pérez et al. (2020) showed that as FAD density increases, tuna visit more FADs and spend more time associated with them — staying longer in the area.

However, we do not know about tuna behavior in offshore areas with drifting FADs, because monitoring a drifting FAD array to track tuna movements is much more difficult than in anchored FAD arrays. Conventional tagging data in the Atlantic Ocean, which provides data on only two points on the path of an animal, revealed different migratory directional patterns between recaptured tuna associated with FADs and those in free-swimming schools (Hallier & Gaertner, 2008). Electronic tagging in the Pacific Ocean, however, showed that migrations of bigeye tuna do not seem to be influenced by FADs (Schaefer and Fuller 2009, Schaefer and Fuller 2010). Reaching scientific consensus on FADs' effects on tunas' large-scale movements between oceanic regions is challenging due to the difficulty of disentangling FADs' effects from environmental factors.

We do not know if tuna have the ability to leave an area when it is no longer favorable to them, even if there are many floating objects, or if they remain trapped by these objects, moving from one to the other. A research study of tuna behavior at FADs using Local Ecological Knowledge found that for most fishing masters, the whole tuna aggregation left FADs when FAD direction dramatically changed (Moreno et al. 2007). This hypothesis could be better tested now that FADs are equipped with echosounder buoys.

In other words, we do not understand tuna physiology and associative behavior well enough to know whether tuna change their propensity to associate and stay with floating objects based on their physiological condition or on the richness of the area.

There is agreement, however, that condition factors are lower for tunas when they are associated with a floating object than in a free-swimming school. We do not know if this difference existed before the large use of FADs, if poor condition factors are the result of the association, or if the association is the result of poor conditions (Robert et al. 2014). For instance, the Japanese fishing industry has preferred skipjack tuna caught on floating objects for decades, which has less fat than in free-swimming schools, for preparing katsuwobushi (shaven dried tuna).

Increasing the number of floating objects due to FADs may also affect tuna schooling behavior. The meeting point hypothesis (Dagorn and Fréon 1999 and Fréon and Dagorn 2000) suggests that tuna may use floating objects for social benefits, such as improving schooling. An increase in the number of FAD floating objects thus could facilitate schooling in some areas or, on the contrary, decrease school size if too many meeting points are present, which could have either negative and positive impact on tunas' ability to forage, escape predators, or even reproduce. However, no scientific results, apart from a theoretical modeling approach (Sempo et al. 2013), exist on this issue.

Therefore, we cannot be certain of the impacts that increases in the number of floating objects by FADs have on tuna behavior and biology.

In summary, it is important to manage the number of FADs in the oceans to control fishing effort, tuna catches, and bycatch as well as to mitigate potential environmental and ecological effects. Currently, tuna RFMOs (IATTC, ICCAT, IOTC and WCPFC) have requirements for non-entangling FADs, encourage the use of biodegradable material in FAD construction, and have FAD limits per vessel, although limits may not necessarily reduce the number of FADs in the water. As they collect more accurate data on FAD use and densities — and as scientific knowledge increases – RFMOs should review and adopt science-based limits to manage FAD impacts. ISSF is researching the development of a methodological framework to help fisheries managers assess the multi-criteria consequences of different FAD management scenarios.

14. Can FAD use in purse seine fisheries be sustainable?

Yes, FAD use in purse seine fisheries can be sustainable. Tropical tuna purse seine fisheries can and should be managed so that all of their operations are sustainable. This includes monitoring and managing FAD impacts on both target tuna stocks and associated bycatch species, on sensitive areas due to stranded FADs, and on marine pollution. Hampton *et al*. (2017) discussed the elements that constitute a well-managed FAD fishery in the context of the overall purse seine fishery.

ISSF has published a series of actions and best practices for better FAD management (Restrepo et al., 2019) and also adopted its Conservation Measure 3.7 on Transactions with Vessels or Companies with Vessel-Based FAD Management Policies to improve the FAD fisheries management following six best practices: (i) Comply with flag state and RFMO reporting requirements for fisheries statistics by set type; (ii) Voluntarily report additional FAD buoy data for use by RFMO science bodies; (iii) Support science-based limits on the overall number of FADs used per vessel and/or FAD sets made; (iv) Use only non-entangling FADs to reduce ghost fishing; (iv) Mitigate other environmental impacts due to FAD loss, including through the use of biodegradable FADs and FAD recovery policies; and (vi) For silky sharks (the main bycatch issue in FAD sets), implement further mitigation efforts.

All tuna RFMOs are making progress towards better FAD management by implementing recommended best practices (see **Table 3**). This includes, among others, non-entangling FADs (IATTC, ICCAT, IOTC and WCPFC), encouraging the use of biodegradable FADs, limits on the number of active FADs per vessel (IATTC, ICCAT, IOTC and WCPFC), and time/area prohibitions on FAD sets (ICCAT and WCPFC). Still, more needs to be done, in particular to set scientifically based limits that are commensurate with the productivity of the tuna stocks and to reduce the impacts of FAD structures on the ecosystem.

Table 3. The level of progress in each tuna RFMO in implementing the recommended ISSF's best practices for FAD management.

Color Coding Key		
	Element(s) are consistent with recommended best practices.	
	Some element(s) are present, but amendments or a change in procedure is needed to be consistent with best practices.	
	Element (s) are missing or inconsistent with best practices.	

RFMO	*Sustainable Fish Stocks and Effective Management*				*Minimizing Environmental Impact*						
	FAD data reporting by set type required and flag State compliance assessed	*Providing data on FAD use to RFMO science bodies (e.g., buoy tracks, echosounder estimates of biomass, etc.) even if not required*	*Science-based limits on FAD deployments and/or FAD sets*	*Time/Area FAD closure*	*Require the use of NE FAD designs*	*Promote the use of biodegradable FADs*	*Established FAD marking scheme consistent with FAO guidelines*	*Established FAD recovery policy, including mechanisms to alert coastal States of derelict FADs that may impact sensitive habitats*	*Require mitigation measures for silky sharks (main bycatch species in FAD sets)*	*Adopt safe handling and release practices for sharks, rays and sea turtles*	*Prohibit intentional setting on whale sharks and cetaceans*
IOTC	*Data required, but IOTC compliance assessment weak*	*Data of tracks of all buoys be provided to the IOTC Secretariat for compliance purposes. Data complied at monthy intervals with a time delay of at least 60 days but not longer than 90 days*	*Active FAD Limit = 300; Maximum buoy acquired annually = 500. Not science-based / No FAD set limit*	✗	✓	✓	*FAD buoy must contain a unique reference ID and IOTC vessel registraton number. New FAD marking scheme to be considered by Commission in 2022.*	*FAD tracking and recovery policy to be developed in 2021.*	*No binding requirement for silky sharks.* *Encourages live release of live sharks and use of handling practices in Res.17/05.*	✓	✓
IATTC	*Data required, but IATTC compliance assessment weak*	*Provided voluntarily*	*Active FAD Limits — vary by vessel size[1] / Not science-based / No FAD set limit*	✓ *Closure for all purse seine fishing (FADs or free school)*	✓	*Res. C-18-05 includes provisions for considering recommendations on use of biodegradable materials*	*FADs (buoy or raft) to be marked with unique identifier code*	*Res. C-17-02 includes some provisions for FAD recovery (para 13(b))*	*Retention prohibition*	✓	*No prohibition on intentional cetacean setting*

[1] Class 6 (1,200 m3 and greater): 450 FADs / Class 6 (< 1,200 m3): 300 FADs. / Class 4-5: 120 FADs / Class 1-3: 70 FADs

Continued on next page

RFMO	*Sustainable Fish Stocks and Effective Management*				*Minimizing Environmental Impact*						
	FAD data reporting by set type required and flag State compliance assessed	*Providing data on FAD use to RFMO science bodies (e.g., buoy tracks, echosounder estimates of biomass, etc.) even if not required*	*Science-based limits on FAD deployments and/or FAD sets*	*Time/Area FAD closure*	*Require the use of NE FAD designs*	*Promote the use of biodegradable FADs*	*Established FAD marking scheme consistent with FAO guidelines*	*Established FAD recovery policy, including mechanisms to alert coastal States of derelict FADs that may impact sensitive habitats*	*Require mitigation measures for silky sharks (main bycatch species in FAD sets)*	*Adopt safe handling and release practices for sharks, rays and sea turtles*	*Prohibit intentional setting on whale sharks and cetaceans*
ICCAT	*Data required, but flag state compliance weak*	✗	*Active FAD Limit per vessel = 300 / Not science based / No FAD set limit*	✓	✓	✓	✗	✗	*Retention prohibition*	*For sea turtles*	✗
WCPFC	*Data required, but WCPFC compliance assess-ment is not transparent*	*PNA members voluntarily provide to the SPC available buoy track data for vessels operating under the PNA VDS*	*Active FAD Limit = 350 / Not science based / No FAD set limit*	✓	✓ *Required lower entangling designs as of 1 Jan 2020. At the 2020 annual session, the Commission will consider the adoption of measures for non-entangling and/or biodegradable material on FADs.*	✓	✗	*No WCPFC FAD recovery policy.* *However, recovery of FADs is being trialed by the PNA.*	*Retention prohibition*	✓	✓

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