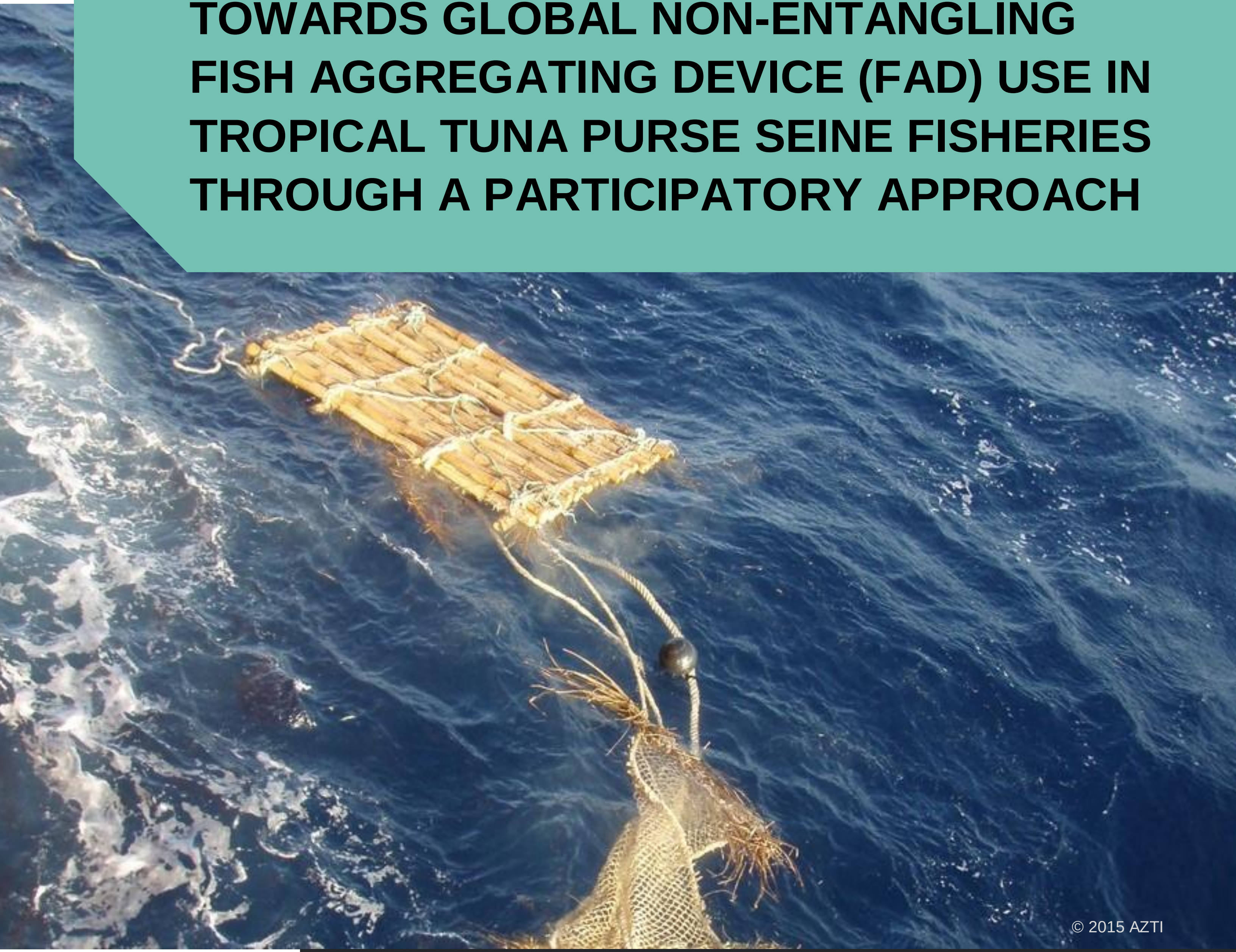
ISSF Technical Report 2017-07

TOWARDS GLOBAL NON-ENTANGLING FISH AGGREGATING DEVICE (FAD) USE IN TROPICAL TUNA PURSE SEINE FISHERIES THROUGH A PARTICIPATORY APPROACH



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Abstract

Impact of bycatch caused by cryptic fishing, including ghost fishing by gear lost at sea, is poorly understood. Since the 1980s, purse seine fishers have deployed floating objects at sea, with ten to a hundred meters deep large mesh net panels hanging beneath a floating structure, to aggregate tuna schools. Known as drifting fish aggregating devices (dFADs) their numbers have rapidly increased globally. Unexpectedly high shark entanglement levels in dFAD netting were first identified in the Indian Ocean in 2012, when all dFADs had loosely hanging large mesh size net panels with potential for higher entanglement risk of dFAD associated species (HERFADs). Many fleets since have adopted lower entanglement risk FADs (LERFADs) and non-entangling FADs (NEFADs), which were initially designed by fishers in collaboration with scientists to minimize entanglement. The move to more sustainable FAD designs has not affected target tuna catches in any of the oceans. These advances have been supported by FAD entanglement-mitigating management measures adopted by regional fisheries management organizations (RFMOs) in the Indian, Atlantic and Eastern Pacific Oceans. Only the Western and Central Pacific region has no FAD entanglement preventive recommendations put forth by its RFMO at present. Information gathered in workshops held in all RFMO regions with skippers and vessel visits at key tuna ports indicate that LERFAD and NEFAD implementation is almost one hundred percent in the Indian and Atlantic Oceans, and very high in the Eastern Pacific Ocean. On the other hand, in the Western and Central Pacific Ocean, except for anchored FADs (aFADs), most are HERFADs. Ocean-specific studies examining shark ghost fishing rates by different FAD types are currently lacking. In addition, harmonization of NEFAD definitions and observer data collection methods across RFMOs would be useful to scientists and industry. Given the increasing number of dFADs and the vulnerable life history and poor population status of sharks, the replacement of HERFADS in the Western and Central Pacific Ocean, the largest tuna fishery in the world, for entanglement reducing designs should be promoted.

November 2017

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I. Introduction

Minimizing incidental mortality of non-target species, referred to as bycatch, has become a principal element of fisheries governance (Hall, 1986, 2015; Gilman and Ludin, 2010; Gilman, 2011) in the framework of the ecosystem-based fisheries management (Pikitch et al. 2004). Lack of comprehensive and reliable fishery data, mainly in small-scale fisheries or fisheries with poor observer coverage, is a widespread problem that prevents accurate evaluation of bycatch impacts (Komoroske and Lewison, 2015). This is especially true for cryptic fishing mortality, which is difficult to estimate even in data-rich fisheries (Gilman et al., 2012, 2014). An important source of cryptic bycatch is ghost fishing caused by abandoned, lost or otherwise discarded fishing gear (ALDFG) that continue to capture fauna while at sea (Matsuoka and Nagasawa, 2005; Macfadyen et al., 2009). Unattended fishing nets, longlines, fish pots and traps, and other fishing gear are capable of ghost fishing for extended periods as most modern gears are built with highly durable synthetic materials. Due to their life history characterized by slow growth rate and limited fecundity sharks, manta rays, marine turtles and marine mammals may be especially vulnerable to indirect fishing mortality, including ghost fishing (Myers et al., 2007; Cortés, 2008; Lewison et al., 2014). However, a recent review by Stelfox et al. (2016) highlights the large knowledge gaps related to ghost fishing impacts in marine megafauna.

Man-made floating objects used to attract fish, termed fish aggregating devices (FADs), are utilized mostly by tropical tuna purse seiners, but also by other gears such as pole and line or handline, to aggregate pelagic fish and increase target species catchability (Fonteneau et al., 2013). FADs are used globally, and while in specific regions (e.g. Philippines, Maldives, Mauritius, French Polynesia, Hawaii) the main FADs used by small-scale fisheries and also some large-scale ones (e.g. around PNG, Indonesia), are anchored (aFADs) the majority of the fisheries use drifting FADs (dFADs) that freely drift across the open ocean (Scott and Lopez, 2014). Together with bamboo canes for floatation, used or surplus purse seine netting has traditionally been the principal component in dFAD construction across all oceans (Itano, 2007). Reused purse seine netting comes usually at no cost to the vessels, is durable, and widely available to tuna fishers. Netting is often used to wrap the dFAD's surface flotation materials (e.g. bamboo and net corks) for structural strength, lower visibility and increased shade, which are all desirable traits in a dFAD for most of fishers. In addition, the underwater hanging net panels functions as a sea anchor to slow down drift speed or track productive underwater currents, and possibly increase detectability by tuna schools. From early on in this fishery dFAD "tail" appendages were made of large stretched mesh size of 10–20 cm (4–8 inches) and depth can vary from 10 to 100 meters depending on fleet and ocean (Franco et al., 2009; Hall and Roman, 2013). A GPS buoy, often with an echo-sounder incorporated to quantify fish presence (Lopez et al., 2015), is tethered to the floating raft to continuously track the dFAD's position. For this reason, technically speaking, dFADs may not enter in the ALDFG category because they are constantly monitored, as an active fishing gear would. Only in cases when a dFAD drifts too far from the fishing zone, the buoy malfunctions, it beaches on the coastline or sinks to the seabed could they be considered lost or abandoned gear (Davies et al., 2017). The precise number of dFADs at sea is unknown as presently there are no unique FAD identification management schemes implemented by RFMOs, but some estimate 90,000–120,000 FADs per year globally (Scott and Lopez, 2014; Gersham et al., 2015).

Given the considerable amount of open surface large mesh netting material used in some traditional dFADs, there is potential for accidental ensnarement of animals swimming around them (hereafter referred to as higher entanglement risk FADs; HERFADs). Turtle entanglements have also been reported. The latter are easier to observe as they frequently occur when individuals climb to rest on wide-base rafts wrapped in netting material. The number of turtles observed entangled in HERFADs has been consistently low across oceans (e.g. under 300 individuals per year per ocean), with over 75 per cent of them being released alive when found (Hall and Roman, 2013; Bourjea et al., 2014). On the other hand, when sharks become entangled in the HERFAD's underwater netting appendage, they are hard to detect. Shark dFAD aggregative behavior is almost exclusively observed in two species, oceanic whitetip sharks (*Carcharhinus longimanus*) but mainly silky sharks (*C. falciformis*), the later constituting 75 to 90 per cent of all sharks found in FADs (Hall and Roman, 2013). As most sharks, these two species are obligate ram ventilators (i.e. must keep swimming to breathe) and if entangled will die from suffocation within minutes; thus, survival after ensnarement is considered null (Hutchinson et al., 2015). Unless the dFAD is lifted out of the water or the shark entanglement occurs close enough to the sea surface to be seen, the incident may go undetected. Most captains do not lift dFADs out of the water when checking for fish or making a set, as it is simpler to tow dFADs out of the purse seine net with an auxiliary speedboat. Until recently, fishers and scientists considered that dFAD entanglement was negligible for FAD fishing and had no substantial impacts on shark populations. However, the only study to-date examining shark ensnarement levels in dFADs, through diving censuses combined with electronic tag data, estimated that shark entanglement in HERFADs could be causing five to ten times higher shark mortality than active purse seine fishing itself in the western Indian Ocean (Filmalter et al., 2013). Crucially, the archival tagging information revealed that often dead entangled sharks would detach from the dFAD's tail and sink to the seabed after just 1.2 days on average (Filmalter et al., 2013), which makes these events even more difficult to observe. As a result, a large part of the cryptic mortality goes unnoticed unless underwater observations are conducted (through divers or cameras) or the dFAD is lifted out of the water and inspected during that brief period when the shark remains entangled. It is however important to note that when a dFAD is lifted out of the water, it is possible that the dead body (or the part of the body that remains attached) falls and is not observed. At the time of that study, between 2010 and 2012, most dFADs in the Indian Ocean were HERFADs constructed with loosely hanging open large mesh nets (e.g. 7–8 inches), a diameter large enough for the head and fins of juvenile pelagic sharks to fit through.

Various small-scale pilot studies by the tropical tuna European Union purse seine fleet (e.g. Spain and France) testing entanglement-minimizing designs had already started prior to 2010 with low entanglement risk FAD prototypes (LERFADS) that had tails made from very small mesh netting (e.g. <2.5 inches stretched mesh) or normal purse seine netting but tightly tied into rope-like coils. Both configurations prevent shark body parts from physically fitting through the submerged dFAD's mesh, although rare accidents can happen when knots tying the netting loosen. Other designs tested were the completely non-entangling FADs (NEFADs) using no netting in their construction, and replacing it by ropes or canvas to create the underwater appendage (see ISSF, 2015 for FAD entanglement category details) (Delgado de Molina et al., 2006; Franco et al., 2009). Despite recent improvements by some RFMO in observer collected data on FAD design and material, currently it is not possible to determine if a FAD is completely non-entangling based on this information for many fleets. In the case of the Spanish fleet (Goñi et al., 2015), observers' logbooks have been adapted to track compliance with a voluntary Code of Good Practices (http://opagac.org/wp-content/uploads/2017/05/GP-OPAGAC-ANABAC-feb-2017-definitivo-ingles.pdf); these logbooks specifically record detailed raft and tail entanglement potential. Similar information is now being also collected by the French fleet, and other observer programs like that of the Inter-American Tropical Tuna Commission (IATTC) record some FAD design characteristics. But for many fleets worldwide, similar sources of information are lacking and NEFAD use is unobserved in regular fisheries monitoring programs.

The International Seafood Sustainability Foundation, which promotes science-based tuna fisheries sustainability, has facilitated participatory-approach bycatch reduction workshops with tropical tuna purse seine fishers since 2009, commonly referred to as ISSF Skippers' Workshops (Murua et al., 2014; Murua et al., 2017). In these workshops scientists and fishers exchange knowledge on FAD related fishing, including type of FAD structure used, providing an alternative source of information to understand the scale of NEFAD implementation worldwide. The purpose of this document is to provide an overview of FAD use in tropical tuna purse seine fisheries by fleet and ocean according to their entanglement risk, as of 2017, and document the important advances towards the reduction of ghost fishing by FADs.

II. Methods

Between November 2009 and July 2017, over 60 ISSF Skippers Workshops in 17 countries have been conducted with more than 2,000 participants (**Table 1**); the majority being large-scale vessel tropical tuna purse seine fishing masters and captains, hereafter referred to as skippers. These workshops were modelled after the IATTC bycatch reduction workshops started in 1988 (Bratten and Hall, 1997). Other important stakeholders such as fleet managers and ship-owners, who can take important company decisions, are frequently present. The workshops' main objective is to discuss ways to improve selectivity and mitigate incidental catches in tuna fisheries, and passive bycatch mitigation with NEFADs is now a key component in the agenda. Detailed information on the kinds of FADs used by each skipper are widely discussed during these meetings. At some workshops, fishers also fill in an anonymous multiple-choice questionnaire that has a section dedicated to types of FADs they use (e.g. construction materials, dimensions, designs). The questionnaires enable anonymous feedback contribution of quantitative and qualitative data by fishers. In reports, these are aggregated by flag but cannot be used to identify individual respondents or vessels. Questionnaire data for some fleets which operate in more than one RFMO are grouped, rather than shown by individual ocean. Specific questions on types of FADs according to entanglement characteristics were added in 2015 (**Fig. 1**). Therefore, FAD information comes from the discussion during workshops between 2009–2017, and NEFAD specific questionnaire answers between 2015–2017.

Acceptance levels for various bycatch mitigation activities by fleet, including use of NEFADs, have also been recorded at each workshop between 2009 to 2017. These are based on the predominant opinion expressed by fishers and stakeholders present at the meeting, which are thought to be representative of these fleets' general perceptions. For example, if most participants support an activity, it is considered as being of high acceptance. Conversely, if most think that an activity will not work or is not worth pursuing, then it receives a low acceptance score.

When workshops are conducted near key ports (e.g. Manta, Manzanillo, or Mazatlan in the Eastern Pacific Ocean, Port Victoria, Banda Aceh or Sibolga in the Indian Ocean, Tema in the Atlantic Ocean, or Jakarta, Pago Pago, Majuro and Pohnpei in the Western and Central Pacific), workshop moderators also carry out vessel visits. As most FADs are now constructed at the main ports, or if not, vessels often carry FADs onboard, FAD designs can be observed first hand. Also, ISSF research cruises onboard vessels of different fleets have permitted examination of diverse kinds of FADs in all oceanic regions, not only for the FADs used by the purse seine company with whom the research was conducted, but also for FADs encountered at sea belonging to other companies (Restrepo et al., 2016). Currently, several programs like the Spanish "Code of Good Practices" gather observer-collected information on FAD entanglement characteristics in the Indian and Atlantic Ocean, and collaborate with the observer programs of the IATTC and the WCPFC (e.g. Goñi et al., 2015).

Table 1. *Number of ISSF Skippers' Workshops by region, oceans in which fishers operate, and participants by profession.*

CONTINENT	LOCATION	WORKING OCEANS[1]	WORKSHOPS	FISHERS	STAKEHOLDERS[2]
Europe	Spain (Sukarrieta, Vigo, Cangas)	IO, AO, EPO	9	450	67
	France (Concarneau)	IO, AO	1	20	6
	Portugal (Madeira)	WCPO, EPO	1	23	3
North America	USA (San Diego)	WCPO, EPO	4	5	4
South America[3]	Mexico (Manzanillo, Mazatlan)	EPO	2	165	15
	Ecuador (Manta, Posorja)	EPO, WCPO	9	438	50
	Panama (Panama City)	EPO	2	14	27
	Peru (Lima)	EPO	2	15	64
Africa	Ghana (Accra, Tema)	AO	7	101	195
	Seychelles (Mahe)	IO	2	18	1
	Mauricius (Port Louis)	IO	1	5	1
Asia	Philippines (General Santos)	WCPO	2	60	29
	China (Shanghai)	WCPO	1	19	22
	South Korea (Busan)	WCPO, IO	2	25	62
	Taiwan (Kaohsiung)	WCPO	1	1	13
	Vietnam (Quy Nhon)	WCPO	1	42	16
	Indonesia (Jakarta, Bitung, Sibolga, Kendari, Benoa, Banda Aceh, Ambon)	WCPO, IO	16	420	132
Oceania	Micronesia (Pohnpei)	WCPO	2	18	8
	Marshall Islands (Majuro)	WCPO	2	11	4
	American Samoa (Pago Pago)	WCPO	3	16	22
Total number			70	1857	708

[1] *AO – Atlantic Ocean; IO- Indian Ocean; EPO – Eastern Pacific Ocean; WCPO – Western and Central Pacific Ocean.*

[2] *Includes ship-owners, fleet managers, fisheries managers, fisheries scientists, NGO members, etc.*

[3] *Workshops co-hosted with the IATTC.*

1. Select the type of FAD you use:

   (a) Traditional FADs with open wide mesh size, **(b)** FADs with net tied into bundles or net with very small mesh size, **(c)** FADs with no netting, **(d)** Others

2. What proportion of proportion of entangling FADs, lower risk entanglement FADs and non-entangling FADs do you use in a year?

   (a) % Entangling FADs (e.g. traditional FADs), **(b)** % Lower risk entanglement FADs (net tied or small meshed), **(c)** % Non-entangling (with no net)

3. What materials do you use in the construction of the raft?

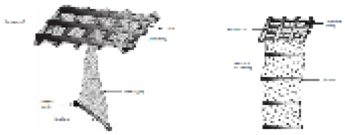
   (a) Bamboo, **(b)** Metal, **(c)** I do not use a raft, only corks tied up (“burrito style”), **(d)** Others (specify)

4. What materials do you use for the flotation of the raft?

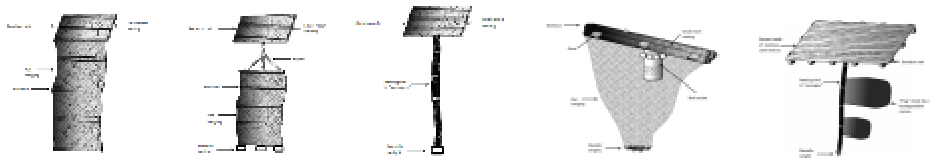
   (a) Corks, **(b)** Plastic bottles/containers, **(c)** PVC tubes, **(d)** Others (specify)

5. What kind of design do you use in your FADs?

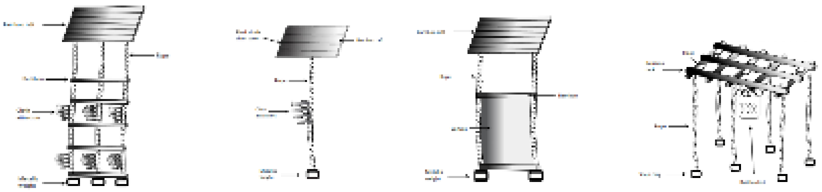
   Entangling



   Lower risk entanglement



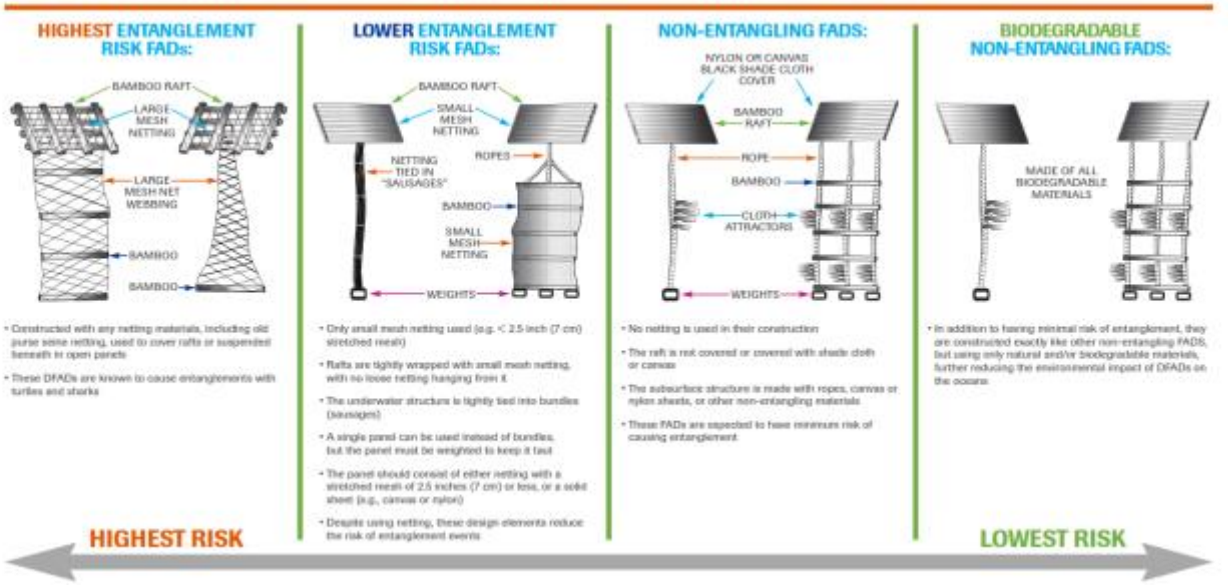
   Non-entangling



   Others (draw sketch)

Figure 1. *Questions on FAD construction and design from ISSF Skippers Workshops questionnaires collected between 2015–2017.*

Based on the ISSF guide for NEFADs (ISSF, 2015; **Fig. 2**), three categories of FADs are defined according to entanglement likelihood: (1) High Entanglement Risk (HER) FADs constructed with open panels of large mesh netting (e.g. > 2.5-inch mesh); (2) Lower Entanglement Risk (LER) FADs which use either small mesh netting (e.g. < 2.5-inch mesh), or net tightly tied into coils or bundles; and (3) Non-Entangling (NE) FADs which have no meshed elements. The distinction between LERFADs and NEFADs is made because, over time, netting tied into coils in LERFADs can become loose or small mesh breaks down into larger holes, thus potentially increasing entanglement opportunity. Note, though, that many organizations place LERFADs in the same category as NEFADs, because they consider them to be virtually entanglement-free. While this might be correct for newly built and well maintained LERFADs, tied netting and small mesh in lost or stranded LERFADs will start to deteriorate over time increasing their entanglement potential.



- Constructed with any netting materials, including old purse seine netting, used to cover rafts or suspended beneath in open panels
- These DFADs are known to cause entanglements with turtles and sharks

- Only small mesh netting used (e.g. < 2.5 inch (7 cm) stretched mesh)
- Rafts are tightly wrapped with small mesh netting, with no loose netting hanging from it
- The underwater structure is tightly tied into bundles (sausages)
- A single panel can be used instead of bundles, but the panel must be weighted to keep it taut
- The panel should consist of either netting with a stretched mesh of 2.5 inches (7 cm) or less, or a solid sheet (e.g., canvas or nylon)
- Despite using netting, these design elements reduce the risk of entanglement events

- No netting is used in their construction
- The raft is not covered or covered with shade cloth or canvas
- The subsurface structure is made with ropes, canvas or nylon sheets, or other non-entangling materials
- These FADs are expected to have minimum risk of causing entanglement

- In addition to having minimal risk of entanglement, they are constructed exactly like other non-entangling FADS, but using only natural and/or biodegradable materials, further reducing the environmental impact of DFADs on the oceans

Figure 2. *FAD categories based on entanglement and environmental impact (ISSF, 2015)*

III. Results

Between 2015 and 2017, there were 398 questionnaire responses registering the type of FADs utilized by 8 fleets (**Table 2**). Note that in some workshops, there were no questionnaires. Instead, captains, fleet managers and ship-owners answered questions on FAD types verbally during the workshops. Repeated visits to the principal tuna purse seine ports of these fleets in the Western and Central Pacific (see **Table 1** of workshop locations) support the FAD information provided by skippers at the workshops.

Table 2. *Number of ISSF Skippers Workshops questionnaires on types of FADs completed by fleet between 2015 and 2017.*

FLEET	NO. QUESTIONNAIRES
Ecuador	164
Spain	122
Ghana	30
France	20
South Korea	10
Peru	7
USA	5
Mexico	4
TOTAL	398

1. NEFAD Acceptance Levels

Reported proportion of FAD types and acceptance levels for NEFADs is presented for 13 tuna purse seine fleets, covering many of the major purse seine tropical tuna fleets in the four-tropical tuna RFMO regions. Initial low level of acceptance for NEFADs by some fleets were obtained during the early phases of change towards these new, as of yet, and unheard of dFAD designs in 2010. Nevertheless, as shown in **Table 3**, over time in the last five years, the tendency has generally been for an increase in acceptance for most fleets. For Western and Central Pacific Ocean fleets not using NEFADs, mid to mid-high acceptance levels were recorded.

Table 3. *Evolution in the acceptance level of fishers for the use of FADs that minimize entanglement by different tuna fleets in ISSF Skippers' Workshops between 2010 and 2017.*

FLEET	OCEAN PRESENCE[1]	LARGE PS[2]	FAD USE	ACCEPTANCE LEVEL[3]						
				2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
Ecuador	EPO	86	H	L	M	M-H	M-H	M-H	H	H
Spain	IO, AO, EPO	32	H	M-H	H	H	H	H	H	H
Ghana	AO	17	L	L	L-M	M	M	M-H	H	H
France	IO, AO	20	M	H	H	-	-	H	-	H
South Korea	WCPO, IO	32	M	-	-	-	H	M	-	-
Peru	EPO	8	L	-	-	M	-	M-H	-	H
USA	EPO, WCPO	31	M	H	H	-	M-H	M	-	L
Mexico	EPO	41	L	-	-	-	-	H	-	-
Panama	EPO	17	M	M	-	M-H	-	-	-	-
Taiwan	WCPO	54	M	-	-	-	M-H	-	-	-
China	WCPO	20	M	-	-	-	-	-	M	L
Indonesia	WCPO	20	H	-	-	-	H	H	H	H
Philippines	WCPO	73	H	-	M-H	-	M-H	M-H	-	-

[1] *AO – Atlantic Ocean; IO- Indian Ocean; EPO – Eastern Pacific Ocean; WCPO – Western and Central Pacific Ocean.*
[2] *Estimated number of large purse seiners (> 335 m^3 fish holding volume) by fleet and level of use of FADs.*
[3] *Acceptance level: L – low; M – mid; H – high.*

2. Adoption rates of NEFAD by ocean

The Spanish and French fleets (including associated vessels under different flags) make up the bulk of vessels operating in the Atlantic and Indian Oceans. Both fleets through voluntary agreements, mediated by their respective fishing associations, made the switch to LERFADs and NEFADs in 2012–2013. The only other remaining large tropical tuna purse seine fleet in the Atlantic Ocean is Ghana, with approximately 17 boats (Justel-Rubio and Restrepo, 2015). This fleet has now moved entirely to entanglement minimizing designs as Recommendation 16-01 by the International Commission for the Conservation of Atlantic Tunas (ICCAT) required HERFADs to be phased out by the end of 2016 (**Table 4**). The 4% HERFADs recorded in the Ghana questionnaires referred to entangling dFADs deployed in 2016, as on average the working life of a FAD ranges between 3 to 12 months. Ghana vessel captains indicated at the time that if those remaining HERFADs were to be encountered they would tie the open net in coils to transform them into LERFADs to comply with ICCAT's requirements.

Table 4. *Use of DFAD type by fleet according to entanglement characteristics. Source: ISSF Skippers' Workshop fishing master and captain questionnaires. High Entanglement Risk (HER); Low Entanglement Risk (LER); Non-entanglement (NE).*

FLEET	OCEAN PRESENCE[1]	HERFAD (%)	LERFAD (%)	NEFAD (%)
Ecuador	EPO	39	43	21
Peru	EPO	0	100	0
Mexico	EPO	0	100	0
Spain	EPO, IO, AO	3	61	36
USA	EPO, WCPO	100	0	0
South Korea	WCPO	100	0	0
Taiwan	WCPO	100	0	0
China	WCPO	100	0	0
Indonesia[2]	WCPO, IO	0	0	100
France	IO, AO	0	73	27
Ghana	AO	4	88	16

[1] *AO – Atlantic Ocean; IO- Indian Ocean; EPO – Eastern Pacific Ocean; WCPO – Western and Central Pacific Ocean.*
[2] *Uses NE Anchored FADs (not drifting FADs).*

The Indian Ocean Tuna Commission (IOTC) and the Inter-American Tropical Tuna Commission (IATTC) also provide for recommendations that encourage or will require in the future the use of NEFADs (**Table 4**; in discussion). Questionnaires from Ecuador in the Eastern Pacific indicate that the number of LERFADs and NEFADs has been increasing rapidly in the last three years. Now fishers using LERFADs (41%) and NEFADs (21%) add up together more than those using HERFADs (39%) in this fleet. Other important Eastern Pacific Ocean fleets such as Peru and Mexico construct LERFADs by making use of the abundant small mesh netting deriving from their anchoveta seines and Medina panel nets (used in the dolphin area of the fishery for the backdown maneuver), respectively. Recently, Resolution C-17-02 passed by the IATTC, establishes that by January 2019 all FADs shall be constructed following entanglement minimizing principles (specified in Annex II of Resolution C-16-01).

The dominant type of artificial floating object in the Western and Central Pacific region are dFADs, with a conservative estimate of 30,000–54,000 dFADs annually deployed in 2013 (Scott and Lopez, 2014; Gersham et al., 2015). These FAD numbers have probably been increasing every year. Since 2010, a total of 13 workshops have been conducted with fleets of the Western and Central Pacific using dFADs. Ship-owners, fleet managers and fishers from these reported that the kind of dFADs they use are of the conventional HERFAD type. Consulted companies from various key fleets using dFADs in the Western and Central Pacific had not tried yet LERFADs or NEFADs to our knowledge, as of early 2017. Most of these dFADs have flotation consisting of a line of net corks tightly wrapped with purse seine 4–5 inch mesh (**Fig.3.a**), and a deep tail (40–80 m) built with netting of the same mesh size, which is crossed by bamboo canes at 10–15 m intervals to keep the net structure open with a metal weight at the end. Sometimes segments of wide-mesh green trawler net are also added. Frequently, numerous colored streamers, presumably used as fish attractors, are also tied to the netting by many Asian fleets. (**Fig. 3.b**).

Small-scale vessels of Indonesia on both its Indian and Western Pacific Ocean EEZ fishing areas, employ only traditional anchored FADs (aFADs), also known as rumpons, which fall under the NEFAD category due to total absence of netting in their construction. ISSF scientists have conducted workshops and vessel visits at the principal tuna purse seine Indonesian ports between 2012 and 2017 that confirm the absence of netting materials for these aFADs. Presumably, similar aFADs used by other fleets in the Western Pacific region are also non-entangling, as the absence of netting in their structure is well documented (Désurmont and Chapman, 2000; Macusi et al., 2015). According to estimates by Scott and Lopez (2014) there are about 12,000 aFADs in the Western and Central Pacific.

Figure 3. (a) *Stack of dFAD floats built with a line of 6–8 corks covered by a sheet of plastic and wrapped in 4–5 inches netting,* ***(b)*** *piled up dFAD tail materials showing purse seine netting, palm leaves, white salt bags and colored attractor strips. Photos taken at port of Majuro (Marshall Islands, WCPO) in 2017.*

IV. Discussion

1. Fisher-scientist collaboration to transition towards NEFADs

The discovery of significant shark ghost fishing potential by conventional FADs in the Indian Ocean around 2012 prompted the transition away from open large-mesh netting HERFADs in the tropical tuna purse seine fisheries of the Atlantic, Indian and Eastern Pacific Oceans, but not yet in the Western and Central Pacific Ocean yet (Pilling et al., 2017). The development of LERFADs and NEFADs has been a direct result of active collaboration efforts by fishers and scientists. Successful participatory fisher-scientist bycatch reduction precedents exist in the tuna fishery, including the development of dolphin-safe fishing gear and techniques in the Eastern Pacific in the late 1980s (Bratten and Hall, 1997; Hall et al., 2000, 2003). Successful examples of selective technology designed with captains' inputs in other fisheries include turtle excluder devices (TEDs) in trawlers or streamer lines in long lines among others (Kennelly, 2007).

Significant advances in fisheries sustainability usually result from a continuous process rather than leaps and bounds. There have been several transitional steps from the initial voluntary trials by individual skippers with entanglement-minimizing FADs to the full implementation of LERFADS and NEFADs. Changing the *status quo* of conventional dFAD construction, which had virtually retained the same designs since their start in the 1980s, was at first a challenge. Given the strong reliance of tuna fishers on FAD-caught skipjack, drastic alterations to conventional net-built FAD designs known to work would have led to poor acceptance. LERFADs which have traditional purse seine netting tied into coils or use small mesh netting were the preferred option by fishers as they are made with materials they already have, with no extra costs. The LERFAD designs appeared to be a necessary step in the process to move from HERFADs to NEFADs. Experienced captains provided much of the initial construction and design inputs required for these alternative FADs (LERFADs) to correctly work at sea, ensuring a balanced weight distribution to prevent FADs sinking and an optimal drift speed to aggregate fish. The compromise with LERFADs has likely permitted fishers to avoid most entanglement-related problems associated with HERFADs without having to dramatically reconfigure the materials and design of their FADs. For example, no shark entanglement has been observed in the Indian and Atlantic Oceans by the Spanish fleet using LERFADs and NEFADs between 2015 and 2016 (Lopez et al., 2017), although studies similar to Filmalter et al. (2013) could be conducted to scientifically validate the results.

Allowance for an adaptive transition testing period (e.g. 2–3 years) towards novel lower-impact FADs has been critical in the success of their voluntary adoption. Several years have been needed to fine-tune LERFADs and NEFADs and understand which designs work better under particular oceanographic conditions. Between 2010 and 2012, European fleets conducted the first large-scale LERFAD and NEFAD test with over 1,000 dFADs deployed in the Indian and Atlantic Oceans, to select most promising prototypes and actively involve more vessels in trials (Franco et al., 2012; Goujon et al., 2012). Spreading trial efforts over the entire fleet, meant that initially each captain was testing a small proportion of alternative dFADs (e.g. < 10% LERFAD/NEFADs), thus minimizing risks of poor tuna catches if the new dFADs were ineffective. Importantly, the combined larger sample number provided robust results showing that average tuna yields from entanglement reducing dFADs were similar, or even slightly higher, than for classical HERFADs (Chassot et al., 2011; Goujon et al., 2012; Hernandez-García et al., 2014). These positive results encouraged purse seiner companies from these two fleets to sign voluntary agreements, like the 'Code of Good Practices' (Goñi et al., 2015; Lopez et al., 2017), which established HERFAD replacement by 2013. The leading role of these purse seine fleets in the transition to NEFADs was not coincidental, but rather a result of a long-standing mutually respectful working relationship between industry and scientists developed through multiple collaborative projects over the last decade (e.g. FADIO, MADE, ECOFAD, GAP1, GAP2, NETMO, ISSF Skippers' Workshops) (Poisson et al., 2014; Murua et al., 2014).

Other stakeholders have played a substantial role in the NEFAD process too. Pressure by environmental non-governmental organizations (NGOs), canneries and retailers to mitigate FAD fishing impacts strongly incentivized the tuna fishing industry to move away from HERFADs. Recently ISSF adopted Conservation Measure 3.5. stating that ISSF Participating Companies shall conduct transactions only with those purse seine vessels whose owners have a public policy regarding the use of only non-entangling FADs. The policy should refer to the ISSF Guide for Non-Entangling FADs and shall apply to all new FAD deployments, regardless of the type of vessel that deploys the FADs. ISSF Conservation Measure 3.5 also states that non-entangling FADs should meet the minimum specification in the ISSF Guide for Non-Entangling FADs. Vessel owners shall not deploy FADs that meet the description of "highest entanglement" contained in the ISSF Guide. In addition, many tuna fishing companies that use FADs are seeking nowadays eco-certification to better meet sustainability demands by many markets and consumers and understand that entangling FADs may be viewed as being incompatible with this objective.

Other fleets, like those of the Eastern Pacific, have been following this example and are gradually increasing their use of lower entangling dFADs. Direct communication between fishers and scientists from different oceans at collaborative platforms, such as the ISSF Skippers Workshops, since 2009 have resulted in productive "cross-pollination" on dFAD ideas and experiences, yielding faster knowledge transfer between fleets. In this sense, fishing companies have shown an open and collaborative relationship with scientists, and other competing companies, by readily sharing information of their latest NEFAD advances (e.g. design details, photos), to the benefit of the industry as a whole. The transition time for fleets which are more recently moving towards NEFADs should be shorter as they can gain insight and try FAD models shown to work for multiple fleets.

2. NEFAD designs by ocean and rate of adoption

It is worth pointing out that dFAD turtle and shark entanglement rates across oceans are likely to be different as regional shark abundances and dFAD designs and materials used by fleets in each ocean vary. The rate of shark entanglement by dFADs has only been investigated in the Indian Ocean, and this was at a time when all conventional dFADs in that ocean were HERFADs with very large mesh netting (e.g. 7–8 inches). At ISSF Skippers' Workshops fishers in the Indian Ocean have frequently commented they do not see turtle or shark entanglements anymore whereas before it used to be more frequent (ISSF, 2014). Similarly, captains in the Atlantic Ocean and fishers working with LERFADs and NEFADs in the Eastern Pacific Ocean report they have stopped observing shark entanglement events (ISSF, 2016). Observer data collected from programs like the "Code of Good Practices" confirm this ghost fishing reduction trend (Goñi et al., 2015). A follow up study in the Indian Ocean using the methodology by Filmalter et al (2013), with divers and electronic tags, to directly compare the before and after entanglement rates would be desirable to examine how effective LERFADs and NEFADs are at reducing shark ghost fishing. Such studies should also be conducted in other oceans. Entanglement events depend on both the abundance of sharks and the abundance of HERFADs (and to a lesser extent LERFADs). Consequently, low observations of entanglements (from observers or divers) could come from very low abundance of sharks, but still with high risks (high abundance of FADs with designs causing entanglements). On the opposite, following the behavior of a silky shark through electronic tagging (see Filmalter et al. 2013 for details) would only assess the risk of entanglement, independent of the abundance of sharks. Such a method would therefore be used in all oceans as a monitoring of risks of entanglements in different regions.

Adoption of LERFADs in the Indian and Atlantic Oceans enabled an important transformation in perception of more conservative skippers, showing them that not only conventional dFADs can aggregate tuna successfully. At the beginning, it was younger open-minded captains who led the change to alternative FADs (J. Murua, pers. obs.). NEFAD designs with no large netting structures in the tail have still been yielding similar tuna catches as traditional FADs in several oceans like the Indian or Eastern Pacific Oceans, but not the Eastern Atlantic (ISSF, 2014). This oceanic region is known for its strong westerly currents that rapidly move dFADs out the west African rich upwelling region to less productive waters in the central Atlantic. Tests with coil-tied netting LERFADs or NEFADs with rope tails in the eastern Atlantic did not work well in aggregating tuna as they drifted away from nutrient-rich waters and they were too fast for fish to follow according to captains (ISSF, 2014). Fishers had to switch to deep reaching (e.g. 50–100 m depth) open small-mesh netting LERFADs to maintain open panels that could act as drogues to slow down dFAD speed. Because numbers of entanglement-minimizing dFADs per vessel during initial trials had been limited, loss of catch through use of “sausage” net LERFADs in the Atlantic was contained and skippers rapidly adjusted to open small-mesh panel LERFADs.

In other oceans, skippers sometimes currently deploy two or three types of dFADs depending on seasonal and regional oceanographic conditions. For example, in the Indian Ocean various skippers have confirmed they use shallow reaching NEFADs with a tail made of rope to follow desirable superficial productive currents, and a deeper reaching open small-mesh LERFAD tail to track deeper nutrient rich currents (Murua et al., 2016). A general view expressed in many skipper questionnaires is that dFAD location is far more important than dFAD structure itself, meaning that the key to aggregate tuna is having the dFAD in the most productive areas where tunas concentrate (Lennert-Cody et al., 2008). Skippers try to build dFADs that once deployed in the right area, can drift with the speed and direction of nutrient rich currents to yield the highest tuna catches.

For the Western and Central Pacific fishers using aFADs were the most accepting as their FADs lack any netting. Meanwhile, skippers using dFADs have shown at least medium acceptance levels for NEFADs in workshops up to 2016. In 2017 NEFAD acceptance decreased for two fleets as some captains argued that their 4–5 inch mesh nets did not entangle many sharks. It should be mentioned that it is possible that a proportion of dFAD shark ghost fishing events go unnoticed. In addition, the issue of how small a mesh must be to qualify as a LERFAD (at present being 7 cm or 2.5 inches) can be debated. Nevertheless, consulted Western and Central Pacific fishers think of NEFADs as a positive concept in principle, but are worried about possible reductions in tuna catches if they switch to dFADs designs not tested before in their oceanic region (for example, the thermocline is deeper in that region than in other Ocean regions where tropical tunas are caught). Given that multiple fleets fishing with LERFADs and NEFAD designs in the rest of oceans have not reported reductions in target tuna catches, it is reasonable to think that these dFADs will aggregate tuna in the Western and Central Pacific as well. NEFADs adapted to the local conditions in the Western and Central Pacific, such as the deep thermocline, could be constructed; in an equivalent way to the deep tail LERFADs that were adopted in the Eastern Atlantic to work in the prevailing strong currents. Note that the initial transition process, from low to high acceptance scores, also took place previously in other fleets which are now using mostly LERFADs and NEFADs. Repeated interactions with fleets like Spain, Ghana or Ecuador with seven years of consecutive ISSF Skippers’ Workshops have resulted in fishers becoming more familiarized with NEFADs and more willing to test them voluntarily. Other factors such as fishers becoming more aware of mounting cannery and retailer pressures for FAD-caught tuna that mitigates ecosystem impacts have also increased their willingness to try NEFADs. From recent interviews with captains at key Western Pacific ports like Majuro (Marshall Islands) and Pohnpei (Federated States of Micronesia), it is clearly evident that many fishers are mostly unaware about the overall potential scale of shark ghost fishing by dFADs and are not well informed about current market sustainability demands and available NEFAD designs as solutions. To-date, ISSF Skippers Workshops with some of the Western and Central Pacific fleets have been less frequent. This is partly due to the difficulties associated with conducting workshops in this Ocean as access to fishers is limited. These fleets are widely dispersed across this large region and many spend extended periods at sea (e.g. > 1 year) and very little time in port or at home (e.g. 1–2 months). The best option with these fleets has been to go to the major Western and Central Pacific ports (e.g. Pago Pago, Majuro, Pohnpei) and wait for fishers to arrive there to unload and speak to them then; but still only a limited number of fishers are reached using this method.

Lack of awareness of the real scale of FAD entanglement is exacerbated by the fact that most entanglement events possibly go unobserved as many dFADs are unchecked for weeks or months. This would imply missing a considerable proportion of past entanglement events if we consider that entangled sharks are only retained 1–2 days in the FAD's net before becoming detached and sinking (Filmalter et al., 2013). Despite this reduced chance of encountering FAD entangled sharks, all skippers interviewed in the Western and Central Pacific have seen at some point a shark entangled in the tail of their dFADs, as had the rest of fishers in the other oceans prior to NEFADs. Some Western and Central Pacific fishers at workshops provided rough estimates of 10% dFADs being observed with a shark entangled. Note that this is one of the few sources of shark entanglement estimations as observers in this ocean are not required to record entanglement events. The precise number of FADs in the oceans is unknown but taking Scott and Lopez (2014) approximation of 50,000 dFADs deployed per year in this ocean, shark FAD entanglement could prove to be significant. Focused dFAD entanglement surveys at high-density shark hotspots could help estimate maximum scale of impact in each ocean.

3. NEFAD construction costs

A factor considered by ship-owners, especially for fleets using larger dFAD numbers per vessel, is the cost per dFAD unit. Traditional HERFADs are relatively cheap as are mostly built with old tuna purse seine net and corkline flotation, both being freely recycled from old nets. Construction of a conventional dFAD can cost between 100–200$ (Franco et al., 2009), mostly to pay for raft materials such as bamboo, PVC, or metallic frames. Note that much more expensive than the dFAD itself is the accompanying GPS buoy. For example, an echo-sounder GPS buoy can cost between 1,000–1,800 US $ depending on brand and model. Even though some vessels make use of several hundred dFADs per year, other costs such as fishing permits, fuel or crew salaries make up the largest share of running costs for a tuna purse seiner (Miyake et al., 2010).

Material and provisioning costs of LERFADs and NEFADs are similar to those of conventional HERFADs. Often the same materials are used but in a different configuration (e.g. purse seine net tied into coils or bundles). Other LERFAD designs incorporate cheap second-hand small mesh nets originating from small pelagics like anchoveta or mackerel fisheries. Fleets in the Atlantic Ocean have been importing small-mesh second-hand nets, and although construction cost of LERFADs were slightly higher than purse seine net HERFADs, they were still comparable according to fleet managers. Note that companies using a high number of dFADs, usually do not have enough old purse seine netting of their own to construct the dFADs and so have to buy the netting material from other sources. However, fleets without a ready access to small mesh or large diameter ropes might have somewhat higher costs, and economic cost comparisons per fleet should be evaluated for each case. In the case of NEFADs, many designs also require low costs in materials and are easier to assemble and store onboard, as they have a simpler construction with ropes and no raft cover is required.

4. Tuna RFMO measures on NEFADs

The lower rate of FAD-oriented fisher-scientist collaborative exchanges in the Western and Central Pacific is not the only factor influencing the marked difference in NEFAD uptake rate between this ocean and the others. The absence of guidelines or recommendations by the WCPFC on FAD entanglement prevention has also probably played a key role. Three tuna RFMOs have adopted measures in the last five years supporting the move away from HERFADs (Murua et al., 2016; see **Appendix I**), which has been a major incentive for the rapid advances in NEFAD implementation in their Convention areas. At present ICCAT has adopted binding measures requiring the use of NEFADs since January 2017

(Rec. 16-01), meanwhile IOTC regulations provide for a gradual adoption of NEFADs since 2014 (Resolution 15/08), and IATTC has established January 2019 as the deadline for full NEFAD implementation (C-17-02).

Given the multiple and sometimes conflicting definitions and measures for NEFADs, an attempt at standardization would be desirable. Note that in some cases vessels operate in more than one RFMO region. Ship-owners and fishers need to clearly understand what constitutes or not a NEFAD, as sometimes FADs with small mesh netting or tied netting are considered NEFADs by some organizations but not by others. When ISSF first published its guide for NEFADs to encourage faster voluntary adoption it suggested a transition period in which tied netting or small mesh net could be used until "truly" NEFADs (i.e. FADs with no netting) were adopted (ISSF, 2012). The revised ISSF guide in 2015 distinguished between HERFADs, LERFADs and NEFADs (ISSF, 2015). Scientific research to evaluate if the rate of turtle or shark entanglement in LERFADs and NEFADs is significantly different would be desirable. Entanglement data recorded by observers for the "Code of Good Practices" program in the Spanish fleet indicate that visible entanglement in LERFADs is below 0.1 percent in all oceans (Lopez et al., 2017). However, we know this methodology could be missing an important proportion of the entanglement events and adequate studies with underwater visual observations and tag data are necessary to determine differential effects between dFAD types. Another critical knowledge gap is at which rate LERFADs beached or abandoned at sea become entangling again if the tying of net bundles becomes undone or small mesh netting rips and creates larger openings over time. In recent years scientists and some fleets are working on NEFADs constructed with no netting and biodegradable natural materials (e.g. cotton, sisal, bamboo, etc.) that break down after several months to minimize both pollution and chances of entanglement by lost FADs (Moreno et al., 2016).

To date the only tuna RFMO which has not formally adopted a NEFAD or LERFAD requirement is the WCPFC. Even in the absence of binding management measures, as fishers become more aware of the idea of NEFADs through workshops or other means, and understand adoption benefits (e.g. lower impact on shark populations, better fishery public image and market opportunities), it is likely these fleets will end up applying them, perhaps even before WCPFC mandates it. In the rest of oceans, the fleets moved to LERFADs and NEFADs ahead of their RFMO conservation measures, and this could be the case again in the Western and Central Pacific. For example, in the latest workshop with the USA fleet in 2017, while some captains were unsure, others expressed their intention to test some NEFADs in upcoming trips. Companies from the USA fleet, and possibly other HERFAD using fleets, are considering or have adopted the use of NEFADs to comply with ISSF's recent NEFAD measure (ISSF Conservation Measure 3.5.). If fishers in the Western and Central Pacific start encountering tuna aggregations under LERFADs and NEFADs from other vessels, it is likely that acceptance and application will start to increase.

V. Conclusions

Despite detailed knowledge on past HERFAD entanglement impacts on sharks for only the Indian Ocean, a Precautionary Approach should prevail as numbers of dFADs in all oceans have been increasing in recent decades (Scott and Lopez, 2014; Maufroy et al., 2017) and shark populations worldwide continue to decline due to cumulative human impacts (Lewison et al., 2014). In the Eastern Pacific, Indian and Atlantic Oceans, tuna purse seine companies and RFMOs have adopted management measures to mitigate this impact. Conservation measures on NEFADs adopted by ICCAT, IOTC and IATTC have provided guidance and a powerful incentive for industry to move in the right direction to eliminate FADs capable of ghost fishing. Collaborative fisher-scientist initiatives have also proven a powerful tool to promote bycatch mitigation. Given that the Western and Central Pacific is the principal tuna fishing ground in the world and dFAD use in this region is widespread, it would be desirable to phase out highly entangling dFADs to help prevent cryptic negative impacts on shark populations. This is what the Precautionary Approach is about: Embracing measures which use the best available scientific information, ensure prudent foresight and reduce risks, taking explicitly into account existing uncertainties and the potential consequences of being wrong.

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Appendix I. Tuna RFMO NEFAD measures

Table 1. *Non-entangling FAD related measures adopted by the different tuna RFMOs for the Eastern Pacific Ocean by IATTC, Indian Ocean by IOTC and Atlantic Ocean by ICCAT.*

RFMO	DOCUMENT	WEB LINK
IATTC	Res. C-17-02	https://www.iattc.org/PDFFiles2/Resolutions/C-17-02-Tuna-conservation-in-the-EPO-2018-2020-and-amendment-to-Res.-C-17-01.pdf
IOTC	Res. 15/08	http://www.iotc.org/cmm/resolution-1308-procedures-fish-aggregating-devices-fads-management-plan-including-more-detailed
ICCAT	Rec. 16-01	http://iccat.int/Documents/Recs/compendiopdf-e/2016-01-e.pdf
WCPFC	N/A	–

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