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ADVANCES IN THE USE OF ENTANGLEMENT-REDUCING DRIFTING FISH AGGREGATING DEVICES (DFADS) IN TUNA PURSE SEINE FLEETS

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SUMMARY

Early drifting fish aggregation device (DFAD) designs characteristically used large-meshed purse seine net in their floating and submerged components. Unintentional entanglement of sharks, primarily silky sharks (*Carcharhinus falciformis*), and to a lower degree turtles has been observed in this type of DFAD. Since 2005 scientists and tuna purse seiner fishers have been collaborating to design DFADs that minimize the likelihood of entanglement. The acceptance level of entanglement-reducing DFADs by fishers and ship-owners has progressed rapidly since 2010. Fleets like those of the European Union have replaced traditional FADs with lower entanglement risk (LER) and non-entangling (NE) FADs, while experiencing no decrease in tuna catches. This article describes entanglement-reducing DFAD adoption by key fleets documented through ISSF Skipper Workshops. At present, progress toward the adoption of LER and NE FADs appears to be highest in the Indian and Atlantic Oceans, medium in the Eastern Pacific and lowest in the Western and Central Pacific. Currently, all tuna regional fishery management organizations (RFMOs) except for the Western and Central Pacific Fisheries Commission (WCPFC) adopted requirements or recommendations for a transition towards NE DFADs.

Keywords: Gear selectivity; fishing nets; purse seining; tuna fisheries; by catch; sharks; DFADs.

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1. INTRODUCTION

Many pelagic species, including tropical tunas, exhibit an associative behavior towards floating objects such as drifting logs and seaweed (see review by Castro et al., 2002). Tuna fishers utilize man-made floating objects, referred to as fish aggregating devices (FADs), purposely constructed to attract tuna and increase fishing opportunities (Fonteneau et al. 2013; Hall and Roman, 2013). FADs can be moored to the sea bottom (anchored FADS; AFADs) or free-drifting, and equipped with an electronic buoy for remote location (drifting FADS; DFADs). Purse seine sets on FADs provide advantages over free school sets such as a higher average catch per set, fewer null sets because the school is “fixed” by the association with the object, and lower fuel consumption because there is no need to search for the schools (Dagorn et al., 2012). Currently the largest portion of tropical tuna catches worldwide is made in association with FADs (Miyake et al., 2010; ISSF, 2015). Scott and Lopez (2014) estimate that about 12,700 AFADs and 97,000 DFADS are used annually in industrial tuna fisheries. The primary users of DFADs are purse seine vessels, while other gears such as pole and line, handline or gears used by small-scale fisheries are known to also utilize AFADs, as well as purse seiners in some regions.

Design, size, and structure of DFADS can vary between oceans and fleets but often share common features. For example all DFADs require a floating structure (e.g. bamboo raft, purse seine corks, PVC pipes, etc.). Traditionally most DFAD floating structures have been covered with netting to increase structural integrity of the raft and to reduce visibility by other vessels. Open net panels are also typically suspended beneath the floating structure of DFADs (**Figure 1**). There is high variation in the depth of the DFADs’ submerged appendage, ranging from 10 to 120 m depth, depending on fleet and ocean. In recent years there has been a tendency to increase the depth of this appendage. The submerged structure is utilized to reduce the drifting speed of the DFAD and to produce shelter and shade for associated non-tuna finfish. Fishers consider that these factors favor fish aggregation. Most tuna purse seine fishing companies worldwide use old tuna purse seine netting in their DFAD construction due to its low price and availability in large volumes. The nets used by large scale tuna purse seiners for fishing and later for DFAD construction have relatively large mesh sizes (e.g. around 8-10 inch or 200-400 mm stretched mesh) compared to the purse seine nets used for small pelagic species like anchovy, herring, or sardine. An exception is the eastern Pacific, where frequently old dolphin safety panels (mesh size 1.25 inch or 30 mm) are used. An undesirable impact of DFADs constructed with this kind of wide mesh netting is the unintentional entanglement of sharks and turtles (Filmalter et al. 2013).

Figure 1. Examples of early high risk entanglement DFADs with loosely tied purse seine wide-mesh on the raft and open mesh panels hanging in the submerged structure.

Turtle entanglement has been primarily observed near the surface or on top of the DFADs' floating structure. Turtle entanglement events with DFADs are believed to be infrequent, and survival of released individuals very high (Hall and Roman, 2013). For example, based on observations Clermont et al. (2012) reported over 80% survival of turtles entangled in purse seiner's net or at DFADs in the Indian Ocean. The very low encounter rate of turtles accidentally caught by tuna purse seiners when setting (fewer than 250 per ocean per year, the majority released alive as well, **Table 1**), which is several orders or magnitude lower than other gears such as longline, would suggest that turtle DFAD entanglement incidents are possibly low as well.

Table 1. Estimates of sea turtles and sharks caught per ocean by purse seiners (PS), long liners (LL), and FAD entanglement. Note: survival of caught individuals released can be very high for some species and gears. Sources: *Hall and Roman 2013,** Filmalter et al. 2013, ***Kettemer 2012, ^Molony et al 2005, ^^Clermont et al. 2012, ^^^Bourjea et al. 2014, [†]Lewison et al. 2004, [† †] Honig et al. 2008, [† † †] Nel et al. 2012, [◊] Lawson et al. 2011, [◊◊]Amande et al. 2008.

<table>
<tr><th rowspan="3">OCEAN</th><th colspan="6">Number of individuals (x1000)</th></tr>
<tr><th colspan="3">SEA TURTLES</th><th colspan="3">SHARKS</th></tr>
<tr><th>Catch PS net</th><th>DFAD entanglement</th><th>Catch LL</th><th>Catch PS net</th><th>DFAD shark entanglement</th><th>Catch LL</th></tr>
<tr><td>WCPO</td><td>0.10^</td><td>-</td><td rowspan="2">30-75[†]</td><td>53.8[◊]</td><td>-</td><td>2000[◊] (WCPO)</td></tr>
<tr><td>EPO</td><td>0.08*</td><td>0.09*</td><td>45.0*</td><td>-</td><td>11,999*** (WCPO+EPO)</td></tr>
<tr><td>ATL</td><td>0.22^^</td><td>-</td><td>40[††]</td><td>14.0[◊◊]</td><td>-</td><td>10,967***</td></tr>
<tr><td>IO</td><td>0.25^^^</td><td>-</td><td>3.5[†††]</td><td>82.0**</td><td>480-960**</td><td>667***</td></tr>
</table>

Regarding sharks, not many species show aggregative behavior with floating objects. Sharks associating with DFADs are almost exclusively silky sharks (*Cacharhinus falciformis*), with a high proportion of juveniles in some oceans, and to a lesser extent oceanic white tip sharks (*Cacharhinus longimanus*) (Hall and Roman, 2013). These two species compromise more than 90% of all sharks captured in tuna purse seine fisheries (Amandè et al., 2008; Hall and Roman, 2013). Shark entanglement is difficult to evaluate because it occurs in the submerged netting. Only if the entanglement takes place near the sea surface (e.g. 0-10 m depth) or if the DFAD is lifted out of the water for repairs or to move it to a new area can the shark be identified (if the shark body does not detach during this procedure). Shark DFAD entanglements were known of, but because it was infrequently observed many fishers believed that the issue was more a problem of bad image negative publicity (e.g. anti-DFAD campaigns) than a serious impact to shark populations at least in some oceans. Many fishers consulted in ISSF Skippers Workshops acknowledged finding sharks entangled in DFADs, although the range reported varied widely (globally, 1-25 per cent of DFADs with a shark entangled). However, in the Indian Ocean, Chanrachkij and Loog-on (2003) examined visually (with no electronic tagging) the net appendage of 20 DFADs and found that 40 per cent had an entangled shark. Only one study, conducted in the Indian Ocean, has attempted to quantify shark entanglement mortality combining visual diver inspection and information from shark satellite tagging (Filmalter et al., 2013), but sample size was low due to high difficulties and costs associated with research in open pelagic waters. Data from popup archival tags (PAT) that transmit information on swimming depth and mortality by satellite transmission was critical in discovering that entangled dead sharks did not remain enmeshed for many days in the DFAD's net and soon detached and sank to the sea floor. Therefore visual inspection of DFADs by captains or observers, even when lifting the whole DFAD out of the water, may only encounter recently entangled sharks and fail to account for older entanglement events. Moreover, examining DFAD appendages for entangled animals is not a regular practice in some oceans where DFADs are rarely lifted out of the water. Filmalter's et al. (2013) study estimated that shark mortality caused by DFAD entanglements in the Indian Ocean during the time of the study (480,000 – 960,000 individuals annually) could be five to ten times higher than that resulting from the fishery itself. However, it should be noted that the study took place during a time when DFADs were routinely constructed with large mesh net panels. There is a high degree of uncertainty on how this level of shark entanglement in DFADs applies to other ocean basins as no more similar studies exist and the extrapolation is based in a small sample size of the Indian Ocean. For example, in some fishing areas of the eastern Pacific, the average capture of silky sharks per set (not entangled) is very low, ranging from 0.1 to 0.5 sharks per set, suggesting that the shark densities are not as high in these areas as in others from the Indian Ocean (Amande et al. 2011).

Since the mid-2000s scientists and fishers have been developing and testing prototypes of DFADs constructed to minimize entanglement while retaining desired traits of traditional DFADs such as the ability to aggregate tunas, low cost of materials and durability in the water (Delgado de Molina et al. 2005, 2007; Franco et al., 2012). Initial trials with non-entangling (NE) DFADs were conducted with very small numbers (e.g. less than 50 DFADs per trial) and experiments to determine their ability to aggregate tuna while reducing entanglement risk were inconclusive as many of these DFADs were lost or stolen. Uncertainty regarding the tuna aggregating ability of

NE DFADs blocked their adoption by the tuna industry at this time. However, in 2010 the French fleet in the Indian Ocean conducted a series of trials with a much larger sample size of approximately 1000 units of entanglement-reducing DFADs, which had been designed collaboratively by fishers and scientists. These trials provided information that tuna catches from traditional and NE DFADs where similar, while shark and turtle entanglement was greatly reduced (Goujon et al., 2012). Modifications to reduce risk of entanglement included the use of small mesh net (e.g. < 2.5 inches or 70 mm) tightly strapped on the raft to reduce chances of turtle entanglement and submerged netting tied into bundles or “sausages” to reduce shark entanglement (**Figure 2**). Only in very limited instances (0.4 % of DFADs tested) did sharks appear entangled when the twine used to tie the net into bundles had become undone. These positive results encouraged French purse seine companies to adopt these lesser entangling style of DFADs.

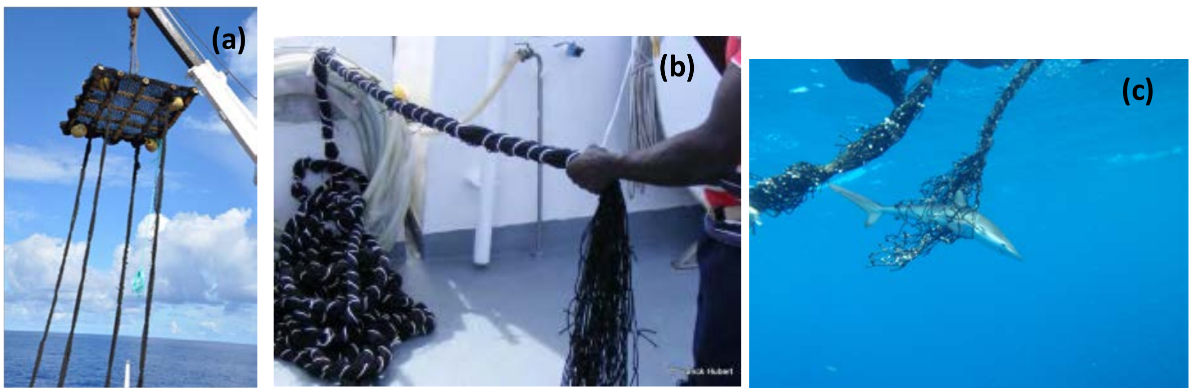

Figure 2. French fleet (a) LER DFADs used in the Indian Ocean with “sausage” tied netting and (b) detail of tying net into sausage bundles, (c) shark entangled in poorly tied “sausage” netting.

In 2012, ISSF published an illustrated guide containing recommendations from the ISSF Bycatch Mitigation Steering Committee for the construction and use of NE FADs. This guide encouraged fishers to develop their preferred NE FAD design, recognizing that different FADs could work better for different oceans or fleets. Changing from old style entangling FADs to NE FADs requires some time as new designs and materials need to be tested and all DFADs used by a vessel cannot be replaced at once.

The first version of the ISSF NE FAD Guide recommended that netting should not be used in FAD construction but acknowledged that small mesh netting and net “sausages” or bundles could be used during a transition period toward the use of fully NE DFADs. The guide was updated in 2015[1] and it now describes four categories of DFADs as: Highest Entanglement Risk FADs, Lower Entanglement Risk FADs, Non-Entangling FADs and Biodegradable Non-Entangling FADs (**Figure 3**). In 2012 the Spanish tuna purse seine fleet and associated vessels signed a voluntary Code of Good Practices that established the adoption of non-entangling DFAD designs during 2013 and 2014. This change was facilitated by the support of their ship-owners who had agreed to make

[1] For the full guide in several languages, visit http://iss-foundation.org/knowledge-tools/guides-best-practices/non-entangling-fads/

the transition during this two-year period. After some modifications and adjustments in DFAD designs, Spanish vessels operating in the Indian, Pacific and Atlantic Ocean have adopted almost entirely the use of LER and NE DFADs while tuna catches have been maintained (Goñi et al., 2015).

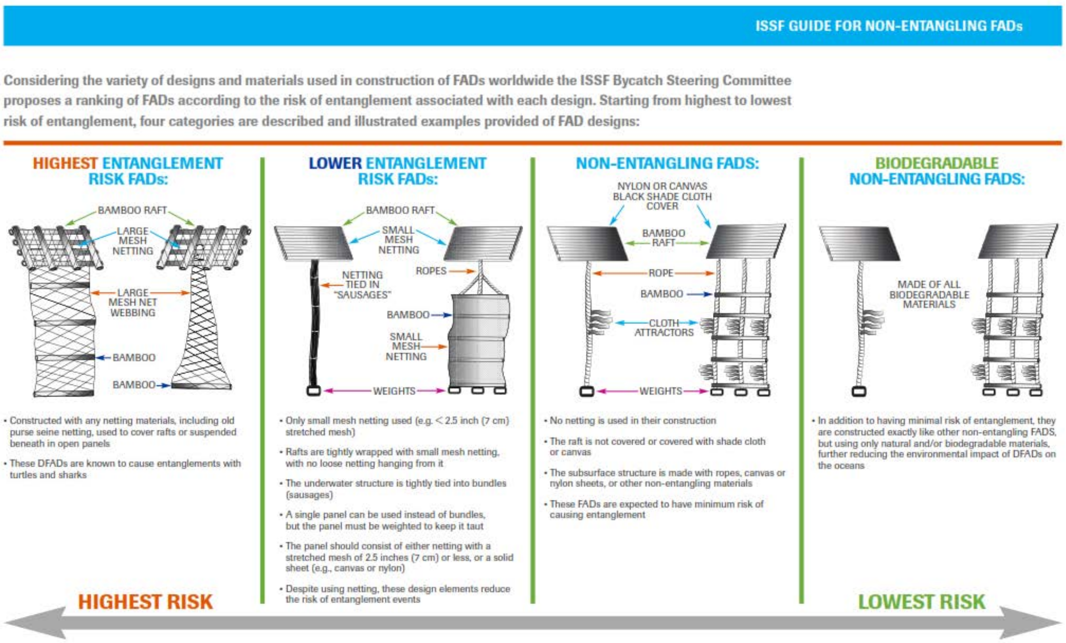

Figure 3. FAD entanglement categories from ISSF Guide to Non-Entangling FADs.

Three tuna regional fisheries management organizations (RFMOs; Indian Ocean Tuna Commission (IOTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Inter-American Tropical Tuna Commission (IATTC)) have included NE FAD recommendations in their measures since 2013 (**Table 2**). Since then, voluntary adoption of NE FADs has been spreading across fleets and companies in different oceans. This document illustrates the use of entangling and NE FADs in some of the principal purse seine tuna fisheries of the world as of early 2016 based on information provided by fishers and scientists working in collaborative bycatch reduction workshops.

Table 2. Tuna RMFO management resolutions covering the use of NE FADs (as of 2015)

RFMO	DOCUMENT	WEB LINK
IATTC	Res. C-15-03	http://www.iattc.org/PDFFiles2/Resolutions/C-15-03-Amendment-C-13-04-FADs.pdf
IOTC	Res. 15/08	http://www.iotc.org/cmm/resolution-1308-procedures-fish-aggregating-devices-fads-management-plan-including-more-detailed
ICCAT	Rec. 15-01	http://iccat.int/Documents/Recs/compendiopdf-e/2015-01-e.pdf
WCPFC	N/A	-

2. METHODS

Since 2010, ISSF has been conducting bycatch reduction workshops with tuna purse seine fishers in which FAD entanglement has been presented as a potentially significant issue (ISSF Skippers Workshops, Murua et al. 2014). In the past, fisher knowledge, sometimes referred to as Fishers' Ecological Knowledge (FEK) or Local Ecological Knowledge (LEK), has provided useful insight into various aspects of tuna purse seine fisheries (e.g. Moreno et al. 2007a,b; Lopez et al., 2014) and their ecological processes (e.g. Hall et al., 2007; Silvano et al., 2008). During the ISSF workshops fishing masters and captains complete a questionnaire covering various bycatch issues including the type and design of FADs they utilize. During the 2014-2015 workshops, 66 questionnaires were completed in Manta (Ecuador), 7 in Lima (Peru), 20 in Concarneau (France), 32 in Sukarrieta (Spain), 6 in Tema (Ghana), 5 in Busan (Korea), 5 in Pago Pago (American Samoa) and 1 in Kaoshiung (Taiwan). Completion of these questionnaires is voluntary and skippers have the option of leaving questions blank rather than providing information they do not have or prefer not to present.

The multiple-choice options under which skippers can categorize their FADs were based on the revised 2015 ISSF Guide to Non-Entangling FADs[1]. This guide includes 3 classes of FADs according to entanglement risk and an additional one for NE FADs built with biodegradable materials which would be the FAD with the lowest environmental impact. Note that biodegradability and entanglement are independent matters (e.g. a biodegradable net can entangle, while a synthetic FAD with no netting will be non-entangling). The entanglement categories are the following:

1) Highest entanglement risk FADs (**HER FADs**): constructed with any netting materials, including old large-mesh purse seine netting used to cover rafts or suspended beneath in open panels. These DFADs are known to cause the highest rate of entanglements with turtles and sharks.
2) Lower entanglement risk FADs (**LER FADs**): only small mesh netting used (e.g. < 2.5 inch or 70 mm 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 (70 mm) or less. Despite using netting, these design elements reduce the risk of entanglement events.

3) Non-entangling FADS (**NE FADs**): no netting is used in their construction. The raft is not covered or covered with black shade cloth or canvas. The submerged structure is made with ropes, solid canvas or nylon sheets, or other non-entangling materials. These FADs are expected to have minimum risk of causing entanglement.
4) Non-entangling biodegradable FADS: In addition to having minimal risk of entanglement, they are constructed using only natural and/or biodegradable materials (e.g. bamboo, sisal, yute, palm leaves, coconut fiber, cotton), further reducing the environmental impact of DFADs on the oceans.

FAD information provided by skippers at the workshops can in some instances be verified with programs collecting FAD type information, such as the Code of Good Practices Verification System by the Spanish fleet in the Atlantic, Indian and Pacific Oceans (Goñi et al., 2015). Observer programs from some RMFOs have been collecting this information for many years but others are starting to record FAD construction details such as structure, design and types of materials used in each FAD, which can indicate the likelihood of entanglement. However, for the largest part, obtaining detailed FAD related information from various RMFOs is difficult as this data is not publicly available. This report also includes information on FAD designs from other fleets for which questionnaires were not collected but with which ISSF scientists have interacted and learned firsthand about the FADs utilized by skippers (e.g. Indonesia, Mexico). This information is descriptive rather than quantitative.

During the Skippers Workshops, different bycatch mitigation options are discussed with fishers, and based on their positive or negative comments, an average acceptance level is recorded. Two aspects drive fishers' acceptance; one is the feasibility of implementing the proposed alternative (costs, logistics, etc.), and the other one is their belief in the effectiveness of the approach. High acceptance level indicates that fishers in general like the idea presented and consider it is feasible to implement, whereas low acceptance levels are for options which are not favored. From lower to higher acceptance the categories are: low, mid-low, mid, mid-high, and high. The acceptance levels presented are based on results from the latest workshops conducted between 2014 and 2015. Note that acceptance level per fleet is a useful indicator of fishers' and key stakeholders' opinion that were present at a workshop, but do not necessarily represents the views of all fleet members.

3. ADOPTION OF ENTANGLEMENT-REDUCING FAD DESIGNS BY OCEAN

Figure 4 summarizes the degree of acceptance of NE FADs in different ocean regions as of the end of 2015. **Table 3** shows the evolution in the degree of acceptance of NE FADs by different fleets since 2010. **Table 4** shows the prevalence of different types of FADs currently being used by different fleets, according to surveys with skippers. The text below provides further explanation.

Figure 4. Map of degree of adoption of modified FADs to reduce entanglement (NE and LER types) by ocean. Green: High degree of adoption; Orange: Mid degree; Red: Low degree.

Table 3. Evolution in the acceptance level of fishers for the use of FADs that minimize entanglement by different tuna fleets in ISSF Skipper Workshops between 2010 and 2015. Estimated number of large purse seiners (> 335 m^3 fish holding volume) by fleet and level of use of FADs.

FLEET	OCEAN	LARGE PS	FAD USE	ACCEPTANCE LEVEL				
				2010-11	2011-12	2012-13	2013-14	2014-15
ECUADOR	EPO	86	HIGH	LOW	MID	MID-HIGH	MID-HIGH	MID-HIGH
MEXICO	EPO	41	LOW	-	-	-	-	HIGH
PERU	EPO	8	LOW	-	-	MID	-	MID-HIGH
PANAMA	EPO	17	MID	MID	-	MID-HIGH	-	-
USA	EPO, WCPO	31	MID	HIGH	HIGH	-	MID-HIGH	MID-HIGH
INDONESIA	WCPO	20	HIGH	-	-	-	HIGH	HIGH
KOREA	WCPO, IO	32	HIGH	-	-	-	HIGH	MID
PHILIPPINES	WCPO	73	HIGH	-	MID-HIGH	-	MID-HIGH	MID-HIGH
TAIWAN	WCPO	54	MID	-	-	-	MID-HIGH	-
FRANCE	IO, ATL	20	MID	HIGH	HIGH	-	-	MID-HIGH
SPAIN	IO, ATL, EPO	32	HIGH	MID-HIGH	HIGH	HIGH	HIGH	HIGH
GHANA	ATL	17	HIGH	LOW	LOW-MID	MID	MID	MID-HIGH

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

FLEET	HER DFAD (%)	LER DFAD (%)	NE DFAD (%)
Ecuador	27	70	3
Peru	0	100	0
France	0	73	27
Spain	3	74	23
Ghana	55	45	0
USA	100	0	0
Korea	100	0	0
Taiwan	100	0	0

INDIAN OCEAN

Most tuna purse seine vessels operating in the Indian Ocean belong to the Spanish and French fleets (and associated vessels under other flags like Seychelles or Mauritius but which have European skippers and use the same kind of DFADs) (Ugalde, 2014). These vessels are more than 50 in total. In the Indian Ocean the first large scale experiments with LER and NE DFADs were conducted with the French fleet, in 2010, and the first Spanish companies started using entanglement-reducing DFADs regularly in their commercial fishing trips after 2013. The predominant DFAD type currently used by Spanish and French skippers is the LER FAD (**Table 4**) consisting of small mesh netting tightly fitted on top of the raft, often covered with black canvas with netting tied into sausages in the submerged structure. The depth of most netting appendages in these DFADs reaches 50 meters or less, being shallower than in the Atlantic Ocean. About 20% of consulted Spanish and French skippers report the use of NE FADs with canvas on the raft and no netting being used in the underwater appendage (**Figure 5**). Instead of tied net these fishers use ropes under the raft. In addition to the EU, there are some smaller fleets that use DFADs in this region, namely from Korea and Iran. The DFADs that these smaller fleets use are thought to be in the HER category. Trials are being prepared for 2016 with biodegradable and NE FADs by Korean scientists in the Indian Ocean (Kim Zheung; pers. comm.) as part of the FAD Management Plan required by the IOTC.

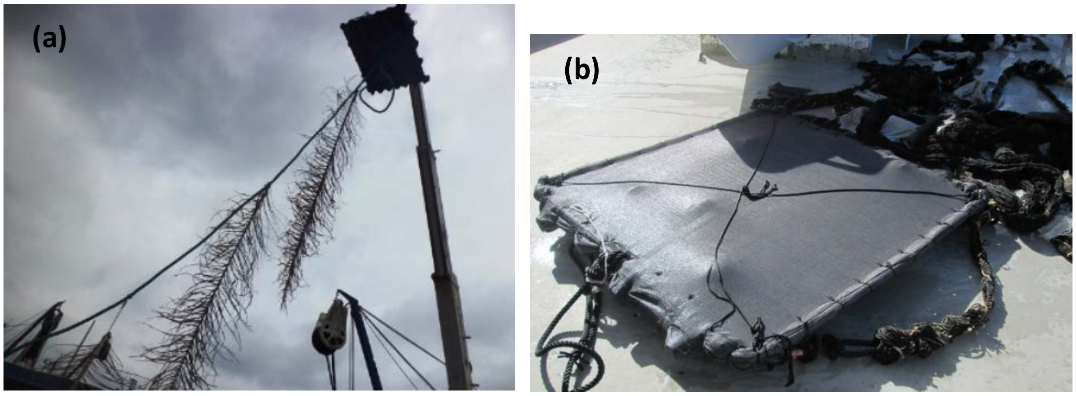

Figure 5. Spanish fleet examples of (a) NE FAD with tail made of rope and palm leave attractors used in the Indian Ocean, and (b) canvas covered raft to prevent turtle entanglement.

ATLANTIC OCEAN

In the Atlantic, the majority of tuna purse seiners belong to the EU fleets (an associated vessel under different coastal nation flags). Over 90% of consulted Spanish and French fishers operating in this area utilize LER DFADs. Initial anti-entanglement DFAD trials in 2013 using in the submerged appendage only rope or netting tied into sausages proved unsatisfactory. This design of DFADs appeared to drift too fast and attract less tuna than DFADs which included some kind of open net panel in the subsurface appendage. Due to the predominant strong westward current moving DFADs out of the fishing area towards the South American continent, fishers prefer floating objects with deeper appendages (e.g. 50-100 m) and open net panels that act as sea anchors slowing down drift. The predominant LER FAD currently includes an initial section of sausage tied net or rope in the first 5-20 m, depth where most shark entanglement is thought to occur, with small mesh netting (< 2.5 inches or 70 mm stretched mesh) panels attached below the sausage or rope that is used to better control rapid drift of DFADs (**Figure 6**). The rafts are typically covered with small mesh netting or with a solid canvas material, both without hanging folds.

Figure 6. Spanish LER DFADs used in the Atlantic combining "sausage" tied netting in the first 15 m of the tail appendage and open small mesh netting underneath. (a) DFADs being built at port of Abidjan (Côte d'Ivoire) and (b) condition of DFAD's small mesh net panels after several months at sea.

About 18 vessels operate in the Atlantic from bases in Ghana. According to questionnaires (n=6) and talk with fleet managers, about half the fleet is using LER FADs (**Table 4**). Several models being utilized by members of the Ghanaian fleet were presented at the first meeting of the ICCAT Working Group on FADs in May 2015 showing designs with small mesh and tied up netting. In 2015 scientists on board a Ghanaian purse seiner during a fishing trip found no instances of entanglement in the LRE DFADs during their visual diving inspections. The Ghanaian fleet is also known to have been using green trawler net in their DFADs for the underwater structure (**Figure 7**). These nets are considered by fishers of lower entangling risk potential as the mesh is more rigid and does not hang loosely. According to fishers shark entanglement with this netting is extremely rare. There are currently no scientific studies to support or contradict these views.

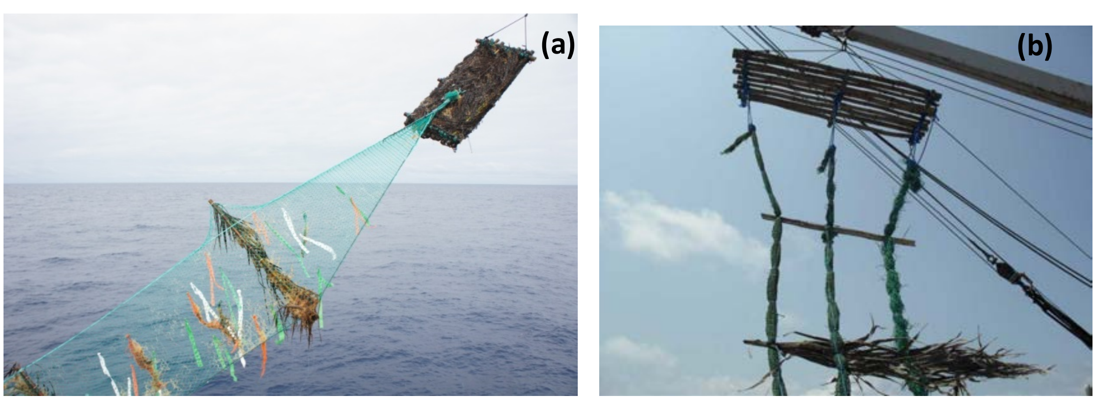

Figure 7. Example of DFADs used by the Ghanaian fleet in the Atlantic, with (a) green trawler netting in the underwater appendage, and (b) a LER DFAD with no netting on the raft and netting tied into sausages in the tail.

EASTERN PACIFIC

There are several fleets operating in the Eastern Pacific region with Ecuador being the most important both by vessel number (87 medium to large purse seiners; Justel-Rubio and Restrepo, 2015) and high use of DFADs. Since 2013, the use of LER and NE DFADs appears to have been increasing in this fleet (**Table 4**). For example, Spanish-owned companies of Ecuadorian flag are subscribed to the Code of Good Practices in which the use of HER FADs is forbidden. Also some of the most important Ecuadorian-owned companies are building an important proportion of their DFADs with small mesh and tied net sausages (**Figure 8**).

Figure 8. Example of LER FAD used in Ecuador (a) with small mesh netting tightly fitted on the raft and sausage tied netting in the tail and (b) construction operation of LER FADs on land in Manta.

There are other fleets in the EPO such as that of Panama, El Salvador, Peru, Mexico or USA which use DFADs. Fleets such as the Peruvian and Mexican have only recently, around 2014, started to use DFADs and the number per vessel is believed to still be relatively low (e.g. < 50 DFADs). At the time of consultation, many skippers from these fleets were not aware of solutions for DFAD entanglement. After receiving information through workshops on designs of DFADs that reduce entanglement fishers were open to the idea of moving towards this type of DFAD as reported in the acceptance levels (**Table 3**). In fact, some of the elements of their DFADs such as the generalized use of small mesh netting (< 2.5 inches or 70 mm) in some fleets would make these DFADs fall in the LER category. For example, to construct DFADs Mexican skippers use recycled dolphin safety net panels, also called Medina panels, and the Peruvian skippers old anchoveta nets, both of which have very small mesh size.

WESTERN AND CENTRAL PACIFIC

In the Western Pacific, in addition to the use of DFADs, there are several fleets, particularly the Indonesian, Philippines and Papua New Guinean ones that harvest most of their tuna from AFADS. These FADs are fixed in position, with a floating structure that is anchored to the seafloor by a long rope or chain with a heavy weight at the bottom. There are different models of AFADs with bamboo, plastic, or metallic foam filled cylinders as floats (**Figure 9**); but one trait

AFADs share is that they are all NE as netting is not used in their construction. Accidental entanglement events in AFADs have not been reported.

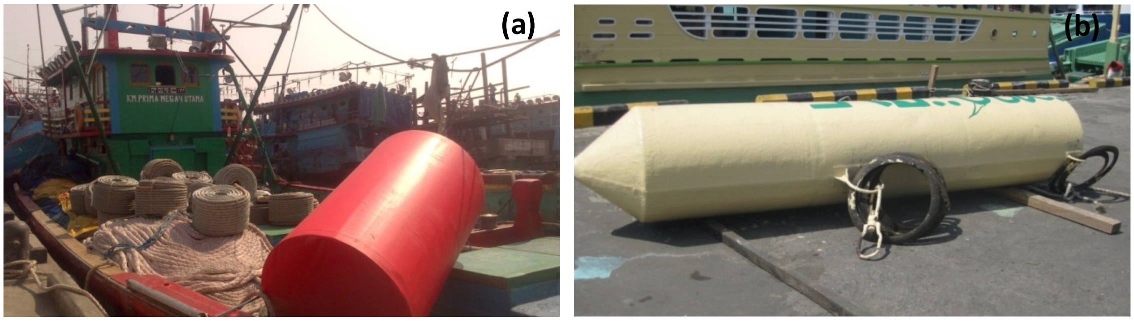

Figure 9. Examples of NE AFADs from Indonesia, (a) foam filled plastic raft and rope use for anchorage, (b) glass fiber cylindrical raft with anchorage points for rope attachment.

DFADs in this region are much more abundant than AFADs, both in numbers (see Scott and Lopez, 2013) and in the fleets that use them (e.g. Korean, Chinese, Filipino, Chinese Taipei, USA and Pacific island nation flags like Kiribati, Vanuatu, etc.). The principal type of DFADs utilized consists of a bamboo raft covered with netting and a complex submerged appendage with open net panels and tied colored strip attractors. Different Asian fleets appear to utilize this kind of DFAD which have also a very deep open net appendage (e.g. > 50 m). Netting on both the raft and submerged appendage is large mesh purse seine net of the HER kind (**Figure 10**). Having a larger surface area of wide-mesh in theory would increase entanglement opportunities. To our knowledge from recent workshops held in the region, including Philippines, Korea, Indonesia, Micronesia, Marshall Islands, or American Samoa, no skippers in this region were using LER or NE DFADs ye (**Table 4**). At present, the WCPFC remains the only tuna RMFO which has not adopted recommendations for the use of NE FADs that could favor their adoption.

Figure 10. (a,b) Traditional HER DFAD often used by Asiatic fleets in the WCPO with long panels of old purse seine mesh, with multiple color strips as attractors.

4. DISCUSSION

ADOPTION PROCESS

Since 2010 with the first large-scale entanglement-reducing DFAD trials in the Indian Ocean, the adoption of these designs has rapidly advanced in many tropical tuna fleets. An element facilitating faster voluntary adoption has been the participatory approach by ship-owners, skippers, and scientists to solve the DFAD entanglement issue. Another accelerating element was the scientific paper by Filmalter et al. (2013) showing the extent of DFAD shark entanglement in the Western Indian Ocean, and therefore the urgency to solve the problem, even in the absence of similar studies in other oceans. Rather than fixed NE FAD designs, scientists provided industry with a series of guidelines, leaving skippers to design their preferred models. This is important because skippers have the technical knowledge to make efficient LER and NE FADs that better suits their needs and resources. For decades captains have relied on traditional purse seine net-built DFADs to attract tuna, so moving to new materials and designs that might not yield the same catch results and put their jobs at risk was initially their major concern. The European purse seine fleets showed from the first workshops in 2010 a mid to high level of acceptance for NE FADs (**Table 3**) and were the first to use them at a commercial scale in their operations. During the Spanish and French fleets' move away from HER DFADs, there has been a process of trial and error and some DFAD designs such as ropes or netting tied in sausages appears to work better in the Indian or Eastern Pacific Oceans compared to the Atlantic. After an early period of widespread experimentation, the number of LER and NE FAD types has settled into a few standard designs per ocean that fishers consider work best. The repeated annual interaction with key fleets to discuss anti-entanglement DFAD improvements and other bycatch issues, such as the ISSF Skippers' Workshops in which more than 1500 fishers and stakeholders have participated, has proven a valuable approach. For example, not all fleets appeared initially receptive to the move to NE FADs (**Table 3**). The process of change is now gaining momentum in most oceans as: (a) fishing companies observe how other companies have successfully moved to LER and NE FADs without adversely impacting their target tuna catches, (b) RMFO legislation is favoring the use of NE FADs, and (c) public pressure from consumer and environmental organizations affects the markets. Support from ship-owners to provide the adequate materials (e.g. canvas, ropes, and small mesh net) to fishers and allowing a period of adaptation until the best designs are found is critical. Note that the acceptance level recorded during ISSF workshops is just a qualitative indicator obtained from fishers and key stakeholders (e.g. ship-owners, fleet managers, fisheries managers, local scientists) attending, and may not necessarily represent the views of all captains and companies in a fleet. In fleets for which the workshops have covered a high proportion of their fishers and ship-owners (e.g. Spain, Ecuador, Mexico) there is more certainty that the acceptance levels obtained are highly representative of the fleet.

The adoption process of biodegradable materials in NE DFAD construction, to further reduce environmental impacts, is still at an early stage in all fleets. Scientists and industry acknowledge the importance of this issue and continue to search for suitable biodegradable materials that can maintain the structural integrity of a DFAD at sea during its working life (e.g. 6-12 months) before decaying (Franco et al., 2012; Moreno et al., 2015).

RMFO NE FAD REGULATIONS

Up to now, the process of adoption of LER and NE DFADs has been largely voluntary (e.g. Code of Good Practices by Spanish fleet), but it may be accelerated by an increasing interest in eco-labeling of tuna products. Three tuna RMFOs (IOTC, ICCAT, and IATTC) have adopted measures that either recommend or mandate a transition to NE FADs (**Table 2**): IOTC Resolution 15/08, points 14 and 15 state that members must provide FAD Management Plans that minimize bycatch, including NE FADs, which should gradually be applied starting in 2014. From 2015 on, members must submit to the Commission, 60 days before the Annual Meeting, a report on the progress of their FAD Management Plans, including reviews of the initially submitted Management Plans, and including reviews of the application of the NE FAD guidelines included in Annex III of the Resolution. For 2016, the IOTC Scientific Committee will analyze the data and consider phasing out FAD designs that do not prevent the entanglement of sharks. Similarly, ICCAT Recommendation 15-01, in point 24.i. establishes that CPCs shall replace existing FADs with NE FADS in line with the guidelines established in Annex 6 of that Recommendation by 2016, while point 24.ii. makes reference to research to phase out non-biodegradable FADs by 2018 if possible. IATTC Resolution C-15-03, in paragraph 10, encourages FADs to be designed as non-entangling.

Perhaps unsurprisingly, the region with the highest degree of HER FADs, the WCPO (**Figure 4**), is also managed by the only remaining RMFO (WCPFC) with no recommendations on a transition to NE FADs. Nonetheless, this situation could rapidly be reversed. For example the EU fleets have shifted from HER to LER and NE DFADs in less than 2 years. The use of NE FADs in commercial fishing is a relatively new concept and some fleets are just starting to learn about it. When consulted in workshops, a high proportion of captains and stakeholders from fleets that are at present using traditional DFADs (e.g. Korea, Philippines, USA) showed mid- to high-acceptance for the idea of moving to less entangling DFADs (**Table 3**). The process of acceptance of new ideas for fishing gear is a gradual one. Not all important fleets were totally convinced about NE FADs when initially consulted in 2010 (e.g. Ecuador, Panama, and Ghana). When first approached with the idea of alternative DFADs, fishers in some fleets were less open, but as they have learned from the experiences from other fleets or encountered NE FADs from other companies in the water, gradually have accepted LER and NE DFADs as a positive viable option.

FUTURE NE FAD PERSPECTIVES

One issue that remains to be clarified is whether LER DFADs are comparable in terms of shark and turtle entanglement to NE DFADs. At present, the number of DFADs that do not use any netting (NE FADs) is still very low compared to LER DFADs (**Table 4**). Only when the small mesh netting starts to degrade making larger holes or the sausage tied netting becomes undone and the mesh opens up, it can occasionally entangle. Accidental shark entanglement in LER DFADs has been observed, but only in very few instances when experimental trials started in 2010. NE and LER DFADs nowadays are being built mostly on land at large ports like Abidjan (Ivory Coast, Atlantic), Port Victoria (Seychelles, Indian Ocean), or Manta (Ecuador, Eastern Pacific) by specialized personnel. This ensures higher construction standards of LER DFADs and permits easier quality controls by those interested. It is the task of scientists and RMFOs to determine the entanglement probability of LER DFADs, through protocols similar to the ones used by Filmalter et al. (2013). New work comparing shark entanglement prior to entanglement-reducing DFADs (e.g. Filmalter et al., 2013) with the current situation with mostly LER and NE DFADs being widely used in the Indian Ocean, would provide a clearer picture on the effectiveness of this change. Also, harmonization of minimum requirements for LER and NE FADs by the different RMFOs, maybe using the NE FAD best guidelines proposed by ISSF as a reference (**Appendix I**), would help industry meet standards and facilitate monitoring.

Finally, given the wide acceptance of entanglement-reducing DFADs by fishers and ship-owners from many fleets (including those in the WCPO), the NE FAD recommendations from most tuna RMFOs, and the successful transition of some of the largest FAD-fishing tuna fleets to LER and NE FADs, it could be expected that in a not so distant future HER FADs will be phased out of all oceans. At the RFMO level, it will be important to monitor the degree with which the required (ICCAT and IOTC) or recommended (IATTC) transitions to non-entangling designs are being met. The FAD regulations in these three RFMOs include requirements for reporting on FAD design and use which should be complied with. WCPFC remains the only RFMO that has not yet addressed this issue and there is no reason for further delay.

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REFERENCES

Amandè, M. J., Ariz, J., Chassot, E., Chavance, P., Delgado de Molina, A., Gaertner, D., Murua, H., Pianet, R., and Ruiz, J. 2008. By-catch and discards of the European purse seine tuna fishery in the Indian Ocean. Estimation and characteristic for the 2003-2007 period. Ecosystem and By-Catch Working Group, Bangkok, Thailand, 2008. IOTC-2008-WPEB-12. Indian Ocean Tuna Commission, 26 pp.

Amandè, M.J., Bez, N., Konan, N., Murua, H., Delgado de Molina, A., Chavance, P., Dagorn, L. 2011. Areas with high bycatch of silky sharks (*Carcharhinus falciformis*) in the Western Indian Ocean purse seine fishery. IOTC-2011-WPEB07-29, p. 1-9.

Anon. 2001. A review of turtle bycatch in the Western and Central Pacific Ocean tuna fisheries. Report prepared for the South Pacific Regional Environment Programme (SPREP) by the Oceanic Fisheries Program, SPC.

Bourjea, J., Clermont, S., Delgado, A., Murua, H., Ruiz, J., Ciccione, S., Chavance, P. 2014. Marine turtle interaction with purse-seine fishery in the Atlantic and Indian oceans: lessons from management. Biological Conservation 178, 74-87.

Castro, J., Santiago, J., and Santana-Ortega, A., 2002. A general theory of fish aggregation to floating objects: an alternative to the meeting point hypothesis. Reviews in Fish Biology and Fisheries 11, 255-277.

Chanrachkij, I., and Loog-on, A. 2003. Preliminary report of ghost fishing phenomena by drifting FADs in the Eastern Indian Ocean. IOTC-2007-WPEB-INF06.

Clermont, S., Chavance, P., Delgado, A., Murua, H., Ruiz, J., Ciccione, S., and Bourjea, J., 2012. EU purse seine fishery interaction with marine turtles in the Atlantic and Indian Oceans: a 15 year analysis. IOTC2012-WPEB08 35 v2, p.1-74.

Dagorn, L., Holland, K. N., Restrepo, V., and Moreno, G. 2012. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish and Fisheries 14(3), 391-415.

Delgado de Molina, A., Ariz, J., Pallarés, P., Delgado de Molina, S., and Déniz, S., 2005., Project on new FAD designs to avoid entanglement of by-catch species, mainly sea turtles and acoustic selectivity in the Spanish purse seine fishery in the Indian Ocean. WCPFC Scientific Committee First Regular Session. 8-12 August 2005, Noumea, New Caledonia. FT WP-2.

Delgado de Molina, A., Ariz, J., Santana, J.C. and Déniz, S., 2007. Study of alternative models of artificial floating objects for tuna fishery (experimental purse seine campaign in the Indian Ocean). IOTC-2006-WPBy-05:28 pp.

Fonteneau, A., Chassot, E., and Bodin, N. 2013. Global spatio-temporal patterns in tropical tuna purse seine fisheries of drifting fish aggregating devices (FADs): Taking a historical perspective to inform current challenges. Aquatic Living Resources 26 (1): 37-48.

Filmalter, J.D., Capello, M., Deneubourg, J-L., Cowley, P.D., Dagorn, L. 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. Frontiers in Ecology and the Environment 11 (6), 291-296.

Franco, J., Moreno, G., López, J., and Sancristobal, I., 2012. Testing new designs of drifting fish aggregating device (FAD) in the Eastern Atlantic to reduce turtle and shark mortality. Collect. Vol. Sci. Pap. ICCAT, 68 (5): 1754-1762.

Goujon, M., Vernet, A-L., and Dagorn, L. 2012. Preliminary results of the Orthongel program "eco-FAD" as June 30th 2012. IOTC-2012-WPEB08-INF21, 1-7 pp.

Goñi, N., Ruiz, J., Murua, H., Santiago, J., Krug, I., Sotillo de Olano, B., Gonzalez de Zarate, A., Moreno, G., Murua, J., 2015. System of verification of the code of good practices on board ANABAC and OPAGAC tuna purse seiners and preliminary results for the Atlantic Ocean. WCPFC-SC11-2015/EB-IP-11.

Hall, M.A., Nakano, H., Clarke, S., Thomas, S., Molloy, J., Peckham, S.H., Laudino-Santillán, J., Nichols, W.J., Gilman, E., Cook, J. and Martin, S., 2007. Working with fishers to reduce by-catches. In By-catch reduction in the world's fisheries (pp. 235-288). Springer Netherlands.

Hall, M., and Roman, M. 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper No. 568. p. 249.

Honig, M., B., Petersen, S.L., and Duarte, A. 2008. Turtle by-catch in longline fisheries operating within the Benguela current large marine ecosystem. Collect. Vol. Sci. Pap. ICCAT, 62 (6): 1757-1769.

ISSF, 2015. ISSF Tuna Stock Status Update. 2015: Status of the world fisheries for tuna. ISSF Technical Report 2015. International Seafood Sustainability Foundation, Washington, D.C., USA.

Justel-Rubio, A. and Restrepo, V., 2015. A snapshot of the large-scale tropical tuna purse seine fishing fleets at the beginning of 2015. ISSF Technical Report 2015-05, International Seafood Sustainability Foundation, Washington, D.C., USA.

Kettemer, L.E. 2012. Global estimate of shark mortality induced by longline fisheries. B. Sc. Thesis. Albert Ludwig University of Freiburg, p. 30.

Lawson, T. 2011. Estimation of catch rates and catches of key shark species in tuna fisheries of the Western and Central Pacific Ocean using observer data. WCPFC-SC7-2011/EB-IP-02.

Lewison, R.L., Freeman, S.A., Crowder, L.B. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecology Letters 7, 221-231.

Lopez, J., Moreno, G., Sancristobal, I., and Murua, J. 2014. Evolution and current state of the technology of echo-sounder buoys use by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. Fisheries Research 155, 127-137.

Miyake, M., Guillotreau, P., Sun, C.H., and Ishimura, G. 2010. Recent developments in the tuna industry: stocks, fisheries, management, processing, trade and markets. FAO Fisheries and Aquaculture Technical Paper. No. 543. Rome, FAO. 125p.

Moreno, G., Dagorn, L., Sancho, G., García, D., Itano, D., 2007a. Using local ecological knowledge (LEK) to provide insight on the tuna purse seine fleets of the Indian Ocean useful for management. Aquatic Living Resources 20, 367-376.

Moreno, G., Dagorn, L., Sancho, G., Itano, D., 2007b. Fish behaviour from fishers knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). Canadian Journal of Fisheries and Aquatic Sciences 64, 1517-1528.

Moreno, G., Ferarios, J.M., Roman, A., Sancristobal, I., Murua, J., Goñi, N., Murua, H., Ruiz, J., and Santiago, J. 2015. Evaluationg potential biodegradable twines for use in FADs. SCRS/2015/088. ICCAT, First Meeting of the Ad Hoc Working Group on FADs. Madrid, Spain.

Murua, J., and Restrepo, V., 2013. Talleres de capitanes ISSF: Identificando las mejores prácticas para reducir la pesca incidental en los atuneros de cerco con la ayuda de los pescadores. Magazine Océano 9, 70-81.

Murua, J., Moreno, G., Hall, M., Itano, D., Dagorn, L., and Restrepo, V., 2014. ISSF Skipper Workshops: Collaboration between scientists and fishing industry to mitigate bycatch in tuna FAD fisheries. ISSF Technical Report 2014-06, International Seafood Sustainability Foundation, Washington, D.C., USA.

Nel, R., Wanless, R., Angel, A., Mellet, B., and Harris, L. 2012. Ecological risk assessment (ERA) and productivity-susceptibility analysis (PSA) of sea turtles overlapping with fisheries in the IOTC region. IOTC-2012-SC15-INF09, p. 68.

Scott, J. and López, J., 2014. The use of FADs in tuna fisheries. Report by Policy Department Structural and Cohesion Policies, European Parliament, P/B/PECH/IC/2013-123.

Silvano, R.A., Valbo-Jorgensen, J. 2008. Beyond fishermen's tales: contributions of fishers' local ecological knowledge to fish ecology and fisheries management. Environment Development and Sustainability 10 (5), 657-675.

Ugalde, R. 2014. Atuneros congeladores vascos: un sector de relevancia económica mundial. Beta III Milenio, p. 208.