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RECOMMENDED BEST PRACTICES FOR FAD MANAGEMENT IN TROPICAL TUNA PURSE SEINE FISHERIES – Update to ISSF Technical Report 2019-11

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Abstract

Many purse seiners use Fish Aggregating Devices (FADs) in tropical tuna, including industrial fisheries operating with drifting FADs (dFADs) and semi-industrial/artisanal operating with anchored FADs (aFADs). Management of the FAD component of these fisheries is an important focus of Regional Fishery Management Organizations and stakeholders such as ISSF. ISSF and other NGOs have put together lists of the elements that they consider to be most important for effective management of FADs. This paper expands upon the six elements of management that ISSF considers to be of utmost importance for a proper management of dFAD and aFAD fisheries: (i) Complying with flag state and RFMO reporting requirements by set type, (ii) voluntarily reporting additional FAD buoy data for use by RFMO science bodies, (iii) supporting science-based FAD limits, (iv) using non-entangling FADs to reduce ghost fishing, (v) mitigating other environmental impacts due to FAD loss including through the use of biodegradable FADs and FAD recovery policies, and, (vi) implementing further mitigation efforts for silky sharks. We provide practical examples that fleets could adopt as their FAD management policies.

This technical report replaces ISSF 2019-11, and includes more information on best practices for aFADs.

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1. INTRODUCTION

Restrepo and Justel-Rubio (2018) developed a series of recommendations for tropical tuna purse seine fisheries that might be proposed for certification by the Marine Stewardship Council (MSC). Their approach consisted of examining the MSC scoring guidance to obtain an unconditional pass (SG80) in every MSC Performance Indicator and recommending practices that the fleets could implement in order to achieve those scores. A high-level summary of those best practices relating to drifting Fish Aggregating Devices (dFADs) was developed by Restrepo and Justel-Rubio (2018) as follows:

- Comply with flag state and RFMO reporting requirements for fisheries statistics by set type;
- Voluntarily report additional FAD use for use by RFMO science bodies;
- Support science-based limits on the overall number of FADs used and/or FAD sets made;
- Use only non-entangling FADs and promote the use of biodegradable FADs;
- Develop a FAD recovery policy, including arrangements to alert coastal countries of derelict FADs that may impact sensitive areas;
- For silky sharks (the main bycatch issue in FAD sets) implement further mitigation efforts.

Similar lists of actions as above have also been identified by a symposium organized in 2017 by PEW with participation by 31 scientists and other experts (Hampton *et al.*, 2017) and by a group of NGOs including ISSF (NGO Tuna Forum, 2021).

The objective of this document is to expand on the best practices advice above, based on the latest scientific knowledge, and provide practical examples that fleets could adopt as their FAD management policies. Examples of best practices are summarized in text boxes. While the principal focus of this document is the management of dFADs, this document also includes best practices for aFADs where they have been identified.

In this document, the six practices identified above have been reorganized as follows in order to more neatly separate ghost fishing (item d) from other environmental impacts (item e):

a) Comply with flag state and RFMO reporting requirements for fisheries statistics by set type;
b) Voluntarily report additional FAD buoy data for use by RFMO science bodies;
c) Support science-based limits on the overall number of FADs used per vessel and/or FAD sets made;
d) Use only non-entangling FADs to reduce ghost fishing;
e) Mitigate other environmental impacts due to FAD loss including through the use of biodegradable FADs and FAD recovery policies;
f) For silky sharks (the main bycatch issue in FAD sets) implement further mitigation efforts.

The recommendations provided here are not to be confused with the FAD Management Plan requirement that some RFMOs have adopted, which must be reported by member states that have purse seine fisheries. Rather, this document focuses on best practices that a purse seine vessel-owning company could implement to improve its sustainability.

2. BEST PRACTICES FOR FAD MANAGEMENT

2.1. Comply with flag state and RFMO reporting requirements for fisheries statistics by set type

The types of general fishery data, and particularly for dFADs and aFADs, required are summarized in Tables 1 and 2. In most cases, the data are submitted by the flag state to the RFMO.

Each tuna RFMO that manages tropical tunas requires the submission of dFAD-related data as per the following conservation and management measures:

- IATTC C-19-01 and C-21-04
- ICCAT Rec. 22-01
- IOTC Res. 23/02
- WCPFC CMM 2021-01

And for aFAD-related data, both ICCAT and IOTC have data requirements:

- ICCAT Rec. 22-01
- IOTC Res. 23/01

Table 1. Types of dFAD-related data currently required by tuna RFMOs. Note that most, if not all, dFADs are tracked by fishers with a satellite linked buoy equipped with an echo-sounder which capture/transmit position and biomass data.

Type of data	Source	Example uses	RFMO requirement
Catch and effort data by set type	Logsheets or observers	Catch and effort indicators by set type	**IATTC** and **WCPFC**: Already required, set-by-set **ICCAT** and **IOTC**: Already required, aggregated
FAD-related activities and dFAD structure characteristics • deployments • visits • sets (owned vs encountered FADs) • loss • retrieval • FAD structure characteristics (materials, net mesh size, design, etc.)	Logsheets or observers	Vessel and dFAD interaction indicators (dFAD logbook; dFAD inventory); dFAD-related fishing strategy; dFAD structure impacts	**IATTC** and **WCPFC**: Already required, set-by-set **ICCAT** and **IOTC**: Already required, aggregated
Processed buoy data on buoy inventory and activity • type of buoy (brand, model) • deployed • operative (active at sea) • deactivated	Fishing companies via buoy provider	Coastal impacts (stranding); effort indicator (operative/active dFADs); density of dFADs at sea	**IATTC**: Raw dFAD buoy data required, with position and biomass data from echosounder buoys. **IOTC**: disaggregated, one position per day for each buoy. **ICCAT**: Already required, aggregated **WCPFC**: Not required. However, PNA does require buoy track data from vessels operating under the PNA VDS

Note that sometimes the same types of data are collected by both observers and in vessel logsheets. This redundancy is often criticized as creating unnecessary work, but it shouldn't. The redundancy is actually desirable because it allows comparison of both data sets for the purpose of verification. Furthermore, observers are not always used (100% coverage is only in place in the Atlantic and Pacific Oceans for large scale purse seine vessels) or are not always able to determine elements such as set type, which makes it useful for vessel operators to record the data in logsheets.

Table 2. Types of aFAD-related activity data currently required by tuna RFMOs (ICCAT and IOTC). Note that fishers do not attach to aFADs a satellite linked buoy to track them as aFADs are anchored in specific deployment sites.

Type of data	Source	Example uses	RFMO requirement
Catch and effort data by set type	Logsheets or observers	Catch and effort indicators	**WCPFC/IATTC**: Already required, set-by-set **IOTC/ICCAT**: Already required, aggregated
aFAD related activities and aFAD structure characteristics • deployment position • visits • sets • loss • retrieval/repair • aFAD marking/identifier • aFAD structure characteristics (materials, anchored system and weight, design, etc.) • reflectors, radio buoys, satellite transceivers (if any)	Logsheets or observers	Vessel and aFAD interaction indicators (aFAD logbook; aFAD inventory); aFAD-related fishing strategy; aFAD structure impacts	**ICCAT** and **IOTC**: Already required, aggregated

Catch and effort by set type

The language used to describe set types varies between tRFMOs. The tRFMOs have held joint working group meetings where they have discussed the possible harmonization of set-type terminology (e.g. as recommended by Gaertner *et al.*, 2018), but this has not been achieved to date. In broad terms, observers record the following set types, although not uniformly in all RFMOs (Anon., 2012):

- **School set**: Sets on schools where there are no indications of tuna association with floating objects, marine mammals or whale sharks.
- **Drifting FAD set**: Sets on tuna associated with floating objects constructed and deployed or encountered and modified by the fishers to attract fish to facilitate their aggregation and capture. This may include using the vessel (or its support boats) to act as the FAD.
- **Log set**: Sets on encountered floating objects, including from natural origin (branches, logs, algae) or anthropogenic origin, dead animals, etc., as far as they are not intentionally deployed or modified by human intervention.
- **Anchored FAD (payao) set**: Sets on human-made floating objects that are anchored.
- **Whale set**: Sets are made in association with whales, that is, close to or encircling the live whale(s).

- **Whale shark set**: Sets are made in association with whale shark, that is, close to or encircling the live whale shark.
- **Dolphin set**: Common only in the eastern Pacific. There is a clear association, and the set is preceded by a chase of the dolphin herd.
- **Baitboat set**: Sets occur in association with a baitboat (pole and line boat). The baitboat drifts or sails slowly, attracts a tuna school, and may keep it by throwing live baitfish (chumming) into the water. They are left as a separate class because of the potential effect of chumming that makes it different from a regular floating object.

FAD design and FAD-related activities

This information is recorded by operators in what are known as "FAD logbooks" and is also complemented by observers records. The aim is to record information on FAD structure and FAD-related activities: FAD deployments, FAD visits (with or without a set) and FAD losses. The following, based on ICCAT Rec. 22-01 and IOTC Resolution 23/01 and 23/02, are the general types of information that should be recorded for each FAD, both for drifting and anchored FADs (if relevant):

- **FAD structure characteristics**: design and materials used for the different components of dFAD and aFAD structures (i.e. for the flotation and sub-surface component), dimensions of the FADs, and the nature of materials used (biodegradable and non-biodegradable and entangling or non-entangling), as well as the weight and materials of the aFAD anchoring system.
- **FAD activities:**
    - **FAD deployment**: vessel, position, date, and FAD structure type (e.g., drifting FAD, anchored FAD, log).
    - **FAD identifier:** For both dFADs and aFADs, any of these FAD marking options identifying the FAD structure: buoy ID, plastic or metal plates, printed floats, metal stamping, radio frequency identification tags or acoustic transponders. These marking methods should have readable letters or codes identifying the origin or owners of FADs.
    - **FAD encounter/visit**: vessel, position, date, FAD type, FAD identifier, and the type of activity around FADs
        - deployment of an electronic tracking buoy in dFADs: deploying/transferring a buoy on an appropriated dFAD (which changes the FAD's owner) and changing the buoy on an owned dFAD (which does not change the FAD’s owner).
        - repairing, strengthening or consolidation of FAD,
        - retrieval of FAD and/or buoy,
        - opportunistic encounter (without fishing) of a FAD belonging to another vessel, visit (without fishing) of a FAD belonging to the vessel.
    - **FAD sets:** owned or encountered FAD and the results of the set in terms of catch and bycatch, whether retained or discarded dead or alive.
    - **FAD buoy deactivation:** for dFADs, provide fisher´s tracking buoy deactivation reason and date.
    - **FAD loss**: Last registered position, date of the last registered position, FAD identifier.

Processed dFAD buoy data from drifting FADs

Assuming that each dFAD is equipped with a satellite buoy, processed buoy data complement the information recorded in dFAD logbooks in terms of dFAD activity (e.g. deployment location, number of dFADs deployed, etc.). A differential characteristic of the processed buoy data is that are obtained directly from the satellite buoy providers (with permission from the buoy owner) without the intervention of the vessel operator or the observer**.**

Recommended best practices for complying with flag state and RFMO reporting requirements by set type:

- **Logsheets**: Commit to filling out completely and accurately the logsheets required by the flag state, licensing authority, and/or RFMO for each set on a trip. The data should include catch and bycatch by FAD and set type.
- **FAD activity**: Provide data on FAD activity (deployments, position, visits, sets, deactivation of dFADs and loss) through "FAD logbooks" for both anchored and drifting FADs.
- **FAD numbers**: Provide data on number of active or deployed dFADs per vessel and number of deployed aFADs per vessel.
- **FAD structure**: Provide data on the design and materials used (biodegradable and non-biodegradable) and the netting used (entangling or non-entangling) for both anchored and drifting FADs.
- **Observer coverage**: For industrial purse seiners (dFADs) commit to 100% observer coverage (either human or electronic) and for purse seiners operating with aFADs achieve RFMO observer coverage requirement. If electronic monitoring is used, follow best-practice minimum standards (Murua *et al*., 2022).

2.2. Voluntarily report additional drifting FAD buoy data for use by RFMO science bodies

There are numerous potential scientific uses of data provided by the buoy used to track dFADs that can help improve stock assessments and evaluation of the ecosystem impacts of dFAD-related fishing activities (Moreno et al., 2016). The types of data that could be provided to science bodies voluntarily are positional data and acoustic data from the echo-sounder buoys used to track dFADs. **Note that this element only applies to drifting FADs**. aFADs are not monitored using geo-locating buoys since they are anchored in a specific location. However, there is potential for electronic devices to be employed in the future to track aFADs in case they end up lost to facilitate retrieval.

Buoy positional raw data

Buoy positional data can be used to develop indicators of fishing effort spatially over time as well as to characterize the "floating object" environment of tunas, which can be useful to assess various impacts of the fishery on the ecosystems. This is important especially in the context of understanding dFAD densities in a given area at a given time, and how that may influence catch per unit of effort (CPUE) as well as other possible impacts. Also importantly, FAD tracks can help identify impacts on vulnerable marine ecosystems such as coral reefs where dFADs may end up beaching. dFAD tracks are currently only required by IATTC (C-21-04) and IOTC (Resolution 19/02), in the latter, CPCs shall report daily information on all active dFADs to the Secretariat to support the monitoring of compliance with the dFAD limitation, which started on 1 January 2020. Similarly, dFAD tracking data are required by the Parties to the Nauru Agreement (PNA) where much of the purse seine fishing activity in the western Pacific Ocean takes place (see Escalle *et al*., 2019). Provision of dFAD track information to science bodies require a certain capacity by the science body to receive and assimilate large amounts of data. Thus, in cases where the RFMO Secretariat or Science Provider are not ready to receive such data, arrangements can be made with other scientific institutions such as national research institutes.

Raw acoustic data from echo-sounder buoys

Most buoys used by many fleets to track dFADs are equipped with echo-sounders that estimate the biomass of fish aggregated under a dFAD and transmit this information to the vessel and ship-owners via satellite. Skippers use this information remotely to help inform their fishing strategy, e.g. what area to visit and what dFADs to set on. But this information can also be very valuable to address several scientific questions as well as to construct indices of tuna abundance which are used in stock assessments. For the latter, typically, the acoustic signal at specific depth ranges, time of the day and period of the FAD drift are required (Santiago *et al.*, 2019). Recent research on tuna species acoustic discrimination would allow in the near future obtaining indices of abundance by tuna species, as well as improving current biomass estimates provided by the echo-sounder buoys (Moreno *et al.*, 2019). dFAD buoy echosounder acoustic biomass data is currently only required by IATTC (C-21-04). This information can be reported directly by the satellite provider to the tRFMO Secretariat, tRFMO science providers or any science institution in charge of monitoring the fisheries, with consent from the buoy owner. In the case of the tRFMO Secretariat, they must be able to assimilate large volumes of data. Alternatively, arrangements can be made with other science institutions where necessary.

Recommended best practices for voluntary reporting of additional drifting FAD buoy data for use by RFMO science bodies[1]:

- **Buoy positional and acoustic raw data**: Participate in scientific programs that require the recovery of historical data and use of dFAD position data and acoustic records from the echo-sounder buoys (with a time lag, as needed for time-sensitive confidentiality) either at the RFMO level or with specialized research institutions. The recovery of historical information should receive high priority. Ideally, information on position and acoustic record for the whole track should be provided; alternatively, one position and echosounder record per day as a minimum.

2.3. Support science-based limits on the overall number of FADs used per vessel and/or FAD sets made

The four tRFMOs have adopted limits to the number of active or operational instrumented dFADs at sea, at any one time, allowed per vessel. Currently these are 64-340 in IATTC (depending on vessel size), 300 in ICCAT, 350 in WCPFC and 250 in IOTC. There was no scientific basis for any of these limits and it is believed that they would result in a reduction in the number of FADs per vessel only in some fleets. For example, Escalle *et al.* (2019) estimated that few or no vessels operated as many as 350 FADs in the WCPO. And, if all large-scale purse seine vessels fishing for tropical tunas in the world (~652 according to Justel-Rubio and Recio, 2023) used 300 FADs each, the number of FADs in the oceans would be about twice as many as the most recent estimation (80,000 to 121,000 FADs) by Scott and Lopez (2014) and Gershman *et al.* (2015). Clearly, the current FAD number limits are not very limiting to most fleets depending on the region (e.g. they could be limiting in the Indian Ocean and not in the Pacific Ocean). Only one tRFMO (IOTC) has adopted a limit on the number of FADs that can be acquired annually, for each purse seine vessel operating in its region. This limit is set at no more than 300 FADs purchased per year.

Currently, there are no limits to the number of active anchored FADs by tuna RFMOs, as usually anchored FADs are deployed in coastal country archipelago waters or within its EEZs and, thus, the management of the deployment (e.g., number, location, and design) and maintenance of FADs is done by national governments. For example, in the Maldives the government maintains, owns and manages a network of around 50 anchored FADs defining the location and recording the deployments, characteristics, marking and anchored systems of the aFADs as well as information about loss, retrieval and reuse (Adam et al., 2019). In Indonesia, although Proctor et al (2019) reported difficulties in accurately estimating the numbers and locations of anchored FADs due to the ineffective implementation of the government registration system and high loss rates (e.g., from storms, strong currents, vandalism, vessel collisions and wear and degradation of anchored FADs), they estimated between 5000 and 10,000 anchored FADs being used in Indonesian tuna

[1] This best practice element does not apply for purse seiners operating with anchored FADs.

fisheries. However, a more recent study estimated that there could be 10,000 to 50,000 aFADs in operation (Widyatmoko et al., 2021).

The following practices may reduce the number of FADs:

For drifting FADs:

- **Limit number of active FADs/buoys**: Set company limits of number of dFADs per vessel that are lower than those adopted by the RFMO. This could be done, for example, by using the same number of FADs used at some previous time (e.g. average of last 5 years).
- **Limit the number of deployments**: currently, limits are on active buoys (which is different from the actual numbers of dFADs at sea). The number of dFADs at sea is managed indirectly through active geolocating buoys because is practical and cost-effective. However, instead of restricting the number of active dFADs, a more efficient approach would be to limit the overall deployments of dFADs in order to effectively reduce their presence in the ocean.
- **Limit the purchase of buoys or buoys in stock**: reducing not only the number of dFADs that are active at sea but the number of purchases or number of buoys in stock would allow reducing the number of dFADs that are at sea.
- **Maintain dFAD activated**: The RFMO dFAD limits are based on "active" buoys, i.e. buoys that are making satellite transmissions. When a dFAD drifts out of the fishing zone or connection is lost, the owner can deactivate that buoy and deploy a new dFAD with another buoy. Thus, the number of dFADs in the water could be greater than the limit. Fishing companies could maintain buoys active to allow buoys to report at least once per day while they are in the water.
- **Share dFAD information through dFAD networks:** Sharing dFAD information (position and echosounder biomass information) among vessels of the same company, within a fishery improvement project (FIP) or in a broader network of vessels/fleets reduces the number of lost and abandoned dFADs, increases the recovery of dFADs, and, hence, lowers the overall number of dFADs at sea.

For aFADs:

- **Regulate aFADs**: abide by all national or provincial laws in relation to aFAD usage including, but not necessarily limited to, the permissible number of aFADs used per vessel, the deployment distance between aFADs, aFAD time area closures in designated fishing areas.
- **Limit number of aFADs:** Commit to limiting the deployment of aFADs per vessel, establishing clear aFAD deployment and sharing rules between vessels or fishing companies.

For both, anchored and drifting FADs:

- **Promote FAD marking schemes and FAD ownership rules**. Many of the FADs deployed by one vessel are found opportunistically or by active search by other vessels that appropriate them. In some cases, the majority of sets are made on other vessels' drifting FADs (Lennert-Coddy *et al.*, 2018; Snouck-Hurgronje *et al.*, 2018). Companies should work collectively to develop FAD marking schemes and adopt FAD ownership and FAD share rules, which will foster strategies for reducing the number of FADs at sea.
- **Reduce loss or abandonment of FADs.** Promoting good practices that reduce and manage the abandonment and loss of FADs, including their retrieval, would reduce the number of FADs at sea. This could be done following a code of good practices and also working in cooperation with other vessels and stakeholder to reduce loss and retrieve FADs.

In terms of dFAD sets, RFMOs have used either direct or indirect limits with varying degrees of effectiveness. The WCPFC has a 3 and 5 months (in the Convention Area and in the high seas, respectively) prohibition on deploying and setting on dFADs. IATTC has a 72-day closure for all large-scale purse seine vessels (all set types). ICCAT has a 72-day dFAD moratorium in the Convention Area. These measures appear to be effective in the Pacific Ocean in terms of reducing the impact of dFAD fishing on small bigeye catches from what it would be otherwise.

In terms of FAD sets, companies could voluntarily:

- **Promote effective time/area closures in the RFMOs**. Companies could support the adoption of meaningful FAD closures that will mitigate impacts of FAD fishing on target tuna stocks. By 'meaningful' it is understood that the FAD closures should be large enough and long enough to be effective.

In addition, the provision of required and voluntary FAD data (sections 2.1 and 2.2) will ultimately enable scientists to accurately assess fishing effort, estimate fishery-independent tuna abundance, evaluate impacts on marine ecosystems, and make management recommendations for science-based limits.

Recommended best practices for science-based limits on the overall number of FADs and/or FAD sets made:

- **Limit number of dFADs**: Commit to not increasing the number of dFADs per vessel even if the RFMO would allow for an increase. Commit to other practices that limit the number of dFADs such as:
  - ⇒ Deploying only FADs with satellite tracking buoys,
  - ⇒ Not activating remotely the buoys of dormant FADs, and
  - ⇒ Allowing buoys to report at least once per day while they are in the water
- **Limit number of aFADs**: Commit to limiting the deployment of aFADs per vessel, the permissible number of aFADs used per vessel, and manage the deployment distance between aFADs.
- **FAD marking and ownership rules**: Support the development of FAD marking and ownership rules so that the responsibility and accountability for dFADs and aFADs is clearly established, including rules for FAD sharing.
- **Time/area closures**: Support the adoption of meaningful FAD closures that will mitigate impacts of FAD fishing on target tuna stocks. From a point of view of monitoring and compliance, a complete closure would be preferred.

2.4. Use only non-entangling FADs to reduce ghost fishing

Ghost fishing is an impact caused by FAD structure that has received considerable attention in recent years. Comprised by a surface raft and a submerged appendage, dFADs are mostly made of decay-resistant plastics (e.g., nylon nets, plastic buoys, PVC pipes, and polypropylene ropes). The dimensions of submerged appendages can be considerable, with dFADs extending down an average of 50 m but reaching up to 80-100 m depth in some fleets working in the Atlantic and Pacific Oceans. In the past, fishers reused large mesh-sized netting panels from the purse seine net to construct dFADs, but tuna Regional Fisheries Management Organizations (RFMOs) prohibited their use due to the risk of sharks and sea turtles ghost fishing (Filmater et al. 2013). Nowadays low risk entanglement dFADs (i.e., with small mesh sized netting below 2.5 inches) are used in the Pacific (WCPFC - CMM 2021-01; IATTC – C19-01 and C-21-04), and Atlantic Oceans (ICCAT - Recommendation 21-02), while in the Indian Ocean, the use of netting in dFAD structures is forbidden since 2020 (IOTC - Resolution-19-02), and in the western Pacific it will be forbidden from 2024 onwards. In certain regions, fishers also incorporate netting in the surface component of aFAD structures, although it represents a minor component compared to its utilization in dFADs, where netting panels are commonly used to construct the majority of the tail sections.

Today, all tropical tuna RFMOs have adopted some type of non-entanglement requirement that is consistent with the guidelines published by ISSF (ISSF, 2019) and fleets have progressed in the use of non-entangling FADs (Murua *et al.*, 2016). However, the time by which a full transition has to be made from traditional to fully non-entangling FADs (without netting) is not yet required in IATTC or fully clear in ICCAT.

Non-entangling FADs, both aFAD and dFADs, have the following characteristics:

- **Raft or surface component**: The surface structure should not be covered with any netting or meshed materials. Covering the raft with netting and putting cloth or tarpaulin on top is not a lasting solution because, when those fabrics degrade, the underlying netting becomes exposed.
- **Tail or submerged component (including the anchoring line for aFADs)**: Only FADs constructed without netting can completely eliminate the unintentional entanglement of turtles, sharks and finfish species and be considered totally non-entangling FADs. The submerged component should not have any netting added to provide shade effect or shelter effect to attract fish.

Recommended best practices for using non-entangling FADs:
• **Non-entangling FADs**: Commit to using non-entangling FADs (without any netting) only. Commit to removing FADs with netting that are found in the water.

2.5. Mitigate other environmental impacts due to FAD loss including through the use of biodegradable FADs and FAD recovery policies

Marine debris produced by lost and abandoned FADs and impacts on sensitive areas due to stranded FADs are two impacts caused by FADs that are receiving considerable attention in recent years.

Marine debris due to FAD loss and abandonment

Petroleum-derived plastic products such as PVC and nylon nets are commonly used to construct dFADs. Main components of a dFAD are the floatation component made of plastic corks or buoys, the surface attractor which can be a bamboo raft, steel or PVC pipes, the tail made of small mesh netting or wrapped net, and the weight. AFADs are constructed with a surface component made of steel, plastic or bamboo rafts, an organic attractor (palm leaves), and the anchoring system (mainly nylon ropes, steel chains, and concrete). Eventually, petroleum-derived materials break up and end up contributing to ocean pollution as macro- and micro-plastics. AFAD's lifetime varies from 6 to about a maximum of 24 months (Proctor et al 2019), depending on its maintenance and area of deployment, which can reach up to 5 to 8 years in areas where aFADs are well constructed, with the appropriate design for the deployment site, and well maintained (Adam et al., 2019). When an aFAD is lost or its surface component breaks, the anchoring system employed in aFADs remains in the seabed. In the case of dFADs, they remain at sea without any owner tracking its trajectory, if deactivated, once they drift out of the fishing zone.

Biodegradable aFADs and dFADs have the following characteristics:

- **FAD flotation**: the use of plastic buoys and containers should be reduced as much as possible (e.g., reducing the weight and volume of the FAD structure would require less flotation). FAD mass should be reduced as much as possible to reduce flotation (plastic needs) and its impact when lost or abandoned.
- **Raft or surface component:** Rafts should be constructed using bamboo, balsa wood or other natural materials that degrade without producing pollution on the marine environment.
- **Tail or submerged component:** Only natural and/or biodegradable materials (cotton ropes and canvas, manila hemp, sisal, coconut fiber, etc.) should be used, so that they degrade without causing impact on the ecosystem. Similar to the flotation, the mass of the submerged component should be reduced as much as possible; which is particularly important for the aFAD anchoring system.

A new concept in biodegradable FAD designs, the jelly-FAD, is being tested in dFAD fisheries. The jelly-FAD, inspired by jellyfish, drifts with quasi-neutral buoyancy, enabling the use of organic materials and reducing the weight and plastic flotation required (Moreno et al. 2023). The same concept should be tested in aFADs.

Impacts on sensitive areas due to FAD stranding

dFADs are deployed in specific areas according to each skipper's fishing strategy, which includes an understanding of how dFADs will drift towards productive fishing zones. However, oceanic currents are difficult to predict and therefore the resulting dFAD trajectories are not always well controlled. As a result, dFADs can drift away from the fishing zone and end up being lost or abandoned by the vessel. In many cases, dFADs end up beaching in vulnerable areas such as coral reefs (recent studies estimated that 7% in West Pacific, 10% in the Indian/Atlantic Ocean, and 2 % in a limited area of Seychelles of the deployed FADs ended up stranded -Maufroy *et al.*, 2015; Escalle *et al.*, 2019; Zudaire *et al.*, 2018). In addition, dFAD structures have evolved towards more complex and deeper structures 60-80 meters deep. Naturally, the impacts of these deep dFADs are greater compared to those 5-20 meters deep used in the past (Moreno *et al.*, 2018).

Regarding certain type of aFADs, out of the total materials weighing between 3,000 to 4,000 kg used in their construction, only the palm leaves, accounting for approximately 5-10 kg, are biodegradable. The main reasons for aFAD loss are bad weather or strong currents, degradation of old and poor materials, and sabotage by other fishers (Proctor et al., 2019). To our knowledge, few aFAD fisheries implement recovery programs where fishers are incentivized to retrieve aFADs (Adam et al., 2019) and there has not been any research on the potential impacts and solutions of aFAD loss and abandonment. They might have a greater impact on vulnerable ecosystems, such as coral reefs, than anticipated.

Discussions at a recent international workshop (Restrepo *et al.*, 2019) indicated that there is no unique solution to reduce the impacts of FAD material and structure on marine ecosystems. A combination of solutions adapted to each ocean and region may be necessary.

The following are practices that can mitigate the impact of FAD loss on the environment:

- **Reduce the number of FADs**: Limiting the number of FADs (see section 2.3) will also mitigate impacts from stranding or sinking.
- **Simplify FAD structure**: Deep and heavy FAD structures may not be necessary in every area/season. Fleets should investigate using lighter FADs.
- **Build biodegradable FADs**: Use biodegradable materials in the construction of anchored and drifting FADs.
- **Provide drifting FAD track data**: Data on the position of drifting FADs should be accessible to scientists or RFMOs in order to quantify their impacts on coastal environments, develop models of risk-seeding areas, and measure the effectiveness of the initiatives taken to mitigate the loss and abandonment of dFADs. If the fishing company decides to deactivate dFADs when they drift out of the fishing zone, these buoys can still communicate position to buoy providers, which can report these data in a cost-effective manner, e.g. by providing less detailed and frequent data such as one position for every x days.

- **Provide aFAD position data**: Data on the position of aFADs should be accessible to scientists or RFMOs in order to quantify their impacts on coastal environments, develop models of risk deployment areas, and measure the effectiveness of the initiatives taken to mitigate the loss and abandonment of FADs.
- **Recover FADs from the water**: Fleets could adopt a policy to retrieve a percentage of the dFADs that are deployed before they are lost or drift out of the fishing zone. Initiatives could include (i) removing from the water every dFAD encountered that is an entangling dFAD or (ii) removing a given number of dFADs towards the end of a trip or the end of the fishing season. Provision of positional satellite buoy data on stranded FADs would facilitate recovery. Similarly, fleets could adopt a policy to recover lost and broken aFADs.
- **Recover stranded dFADs from vulnerable habitats**: Various NGOs undertake activities to clean up beaches or protect reefs. Fishing companies should explore collaborating with such NGOs in order to alert them of dFADs that are drifting in the direction of the area where they work.
- **Avoid high-risk deployment areas**: If there are known deployment areas that are identified as having a high risk that the dFADs will end up beaching, these should be avoided.

Recommended best practices for mitigating environmental impacts due to FAD loss including through the use of biodegradable FADs and FAD recovery policies:

- **Limit number of FADs**:
  - For drifting FADs, commit to not increasing the number of dFADs per vessel even if the RFMO would allow for an increase.
  - For aFADs, commit to limiting the deployment of anchored FADs per vessel, the permissible number of aFADs used per vessel, and manage the deployment distance between aFADs.
- **FAD construction and deployment**:
  - **Biodegradable FADs**: Deploy and use simpler, smaller biodegradable FADs that effectively aggregate tunas. Use local materials if possible. Participation in research collaborative projects to test biodegradable FADs is encouraged.
  - **Repair and recycle FADs**: maintain, repair and recycle aFAD and dFAD components instead of replacing the FADs.
  - **Participate in research programs to determine deployment areas** that are highly likely to result in stranding.
    - For dFADs, provide dFAD track data to identify areas of high incidence of stranding events and positional data on stranded dFADs to enable targeted recovery.
    - For aFADs, participate in research to determine the incidence and impact of aFAD loss and stranding.
- **FAD abandonment and loss**: Promote good practices to reduce the loss and abandonment of FADs, such as:

  ⇒ Increase storing capacity onboard purse seiners for dFADs that are retrieved,

  ⇒ Develop a program to remove a percentage of dFADs from the water, relative to the number deployed,

  ⇒ Participate in cooperative efforts to remove stranded dFADs.

  ⇒ Participate in cooperative efforts to recover lost and broken aFADs.

2.6. For silky sharks (the main bycatch issue in FAD sets), implement further mitigation efforts

Pelagic sharks are not targeted by tropical tuna purse seine fisheries, but they are caught incidentally, especially around floating objects like dFADs but also in anchored FADs. Over 90% of the shark bycatch is composed of silky sharks, *Carcharhinus falciformis,* in dFAD operations. In the case of aFADs, shark bycatch is composed of different species although silky shark is also the main component (Nicol et al. 2009, Widodo et al., 2016). Because of their low reproductive rates and other life history characteristics, silky sharks are a vulnerable species. Other gear types such as longlines or gillnets have a larger impact on silky sharks than purse seine fisheries do. The contribution of purse seining to the total catch of this species varies by Ocean: from 4% in the Indian and eastern Pacific Oceans, to about 25% in the western and Central Pacific Ocean. Nevertheless, the global magnitude of catch of the purse seine fishery is quite large, so reducing the mortality caused by these fisheries can contribute towards global conservation efforts of silky shark. Restrepo *et al.* (2016) have identified this as the main bycatch issue in tropical tuna purse seine fisheries.

Restrepo *et al.* (2016) have identified actions that can reduce shark mortality in purse seine fisheries:

- **Non-entangling FADs**: Use only non-entangling FADs without netting in any part of the FAD (see section 2.4)
- **Switch some effort to free school**: In areas where shark bycatch is higher on FAD sets, switching some effort to free swimming school sets would reduce shark mortality.
- **Avoid setting on small tuna aggregations**: Because the number of sharks around FADs is independent of the size of the tuna aggregations, targeting larger tuna aggregations will result in a lower shark:tuna catch ratio (Dagorn *et al.*, 2012).
- **Release from the net**: ISSF research cruises have shown that small sharks, the most common sizes found at FADs, can easily be caught by handline during FAD sets and released out of the net. This procedure requires good weather, training for safety and large commitment from the fishermen; but can save 15-35% of the encircled sharks.
- **Release from the deck**: Using safe handling and release practices to release live sharks from the deck can increase shark survival (ISSF, 2016). Crew safety is of utmost importance, especially with larger sharks. Using a hopper will facilitate life release. This practice can save up to 20% of encircled sharks.
- **Avoid shark hotspots**: commit to avoiding areas/periods of high concentration of sharks.

Recommended best practices for mitigating bycatch of silky sharks:

- **Adopt best practices to reduce shark bycatch and increase survival**: Commit to using non-entangling FADs only. Adopt a combination of practices that can reduce mortality and increase shark survival amongst the following:
  - ⇒ Making fewer FAD sets,
  - ⇒ Avoiding small sets (e.g. under 10 tons),
  - ⇒ Releasing sharks from the net, when safe and practical, and
  - ⇒ Practicing live and safe release of sharks (and rays) from the deck using Bycatch Release Devices (e.g., hoppers, ramps, etc.).

3. CONCLUDING REMARKS

The recommended best practices are intended to be comprehensive, although it is understood that not all of them will be practical for every purse seine fleet to implement. In some cases, the practices are already mandated by RFMOs (e.g. fully non-entangling FADs) and the aim here is to ensure that fleets implement them correctly. However, while other recommended best practices are not yet required by tRFMOs, voluntary implementation by fleets, including through FIPs and MSC certified fisheries, will have positive impacts on reducing pollution in the marine ecosystem, supporting efforts to rebuild overfished stocks, strengthening monitoring and stock assessment and reducing impacts on habitats and sensitive non-target species.

Some of these practices can help mitigate several impacts at once. For instance, limiting the number of FADs can be beneficial for overfished stocks and also mitigate impacts on habitats and on vulnerable bycatch species like sharks. Also, some practices can help mitigate a given type of impact across all set types (e.g., following best practices for safe live release of sharks and rays).

It should also be noted that some of the practices would be most impactful if they are implemented collectively by most or all fleets in a region. An example, again, is limiting the number of FADs. In the context of MSC certification, fishing companies should be mindful that some elements of the MSC Fisheries Standard (version 3.0) require the consideration of the cumulative impacts of all overlapping fisheries that are certified. In v.2.0 of the standard – still in use until all fisheries are required to transition to v.3.0 – this is the case for PIs 2.1.1 on Primary Species, 2.2.1 on Secondary Species, 2.3.1 on Endangered, Threatened or Protected Species, and 2.4.2 on Habitats. Therefore, fisheries should have a better basis to be certified if best practices for FAD management are implemented collectively.

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Appendix 1. Version log

VERSION	DATE	TECHNICAL[2] REPORT	AUTHORS
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[2] Earlier versions of the report can be requested by e-mail (info@iss-foundation.org)

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