ISSF Technical Report 2020-13

Compendium of ISSF Research Activities to Reduce FAD Structure Impacts on the Ecosystem

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Abstract

The present document summarizes the activities organized and conducted by ISSF with the support of the FAO GEF Common Oceans Tuna Project to reduce the impact of the structure of Fish Aggregating Devices (FADs) on the ecosystem. ISSF's research activities to reduce the impact caused by FAD structures and move towards the use of biodegradable FADs are: (i) workshops that gather fishers and scientists working in the three oceans to evaluate the potential solutions to minimize the impacts and identify the challenges to be faced, (ii) selection and testing of biodegradable materials in controlled conditions, (iii) pilot tests of experimental biodegradable FADs at sea, and (iv) large scale tests of biodegradable FADs in real fishing conditions. The present report shows the results and recommendations derived from the research completed through December 2019.

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Executive Summary

One of the impacts that Fish Aggregating Devices (FADs) have on the marine ecosystem is related to the FAD structure itself, which is mainly made of plastic. Impacts occur when lost or abandoned FADs damage coral reefs or other benthic ecosystems, cause ghost fishing, create marine litter, or interfere with other economic activities, such as tourism.

To reduce those impacts, ISSF — with support from the FAO-GEF Common Oceans Tuna Project — launched a series of actions and projects, including to promote the use of biodegradable FADs. Specifically, scientists and fishers are collaborating in three oceans to test new materials for building FADs that are efficient for fishing purposes but degrade as soon as possible after their useful working lifetime ends. This report summarizes those main research activities.

The need for FADs to be made of biodegradable materials instead of plastic to minimize their impact, so they do not remain at sea for hundreds of years, is clear. However, until biodegradable FADs are successfully implemented, there are other options to reduce FAD ecosystem impacts, such as FAD recovery.

ISSF organized workshops with scientists and fishers working in the three oceans to identify and evaluate potential solutions to reduce those impacts, including the use of biodegradable FADs. During the workshops, participants assessed from a technical point of view these different options: FAD recovery, simplifying FAD design, modifying FAD deployment areas, using FADs that do not leave the fishing grounds (FADs with navigation capability, FADs that could be sunk and anchored FADs), and limiting FAD numbers. Based on their experience, fishers also identified the main likely FAD beaching areas in the three oceans as well as FAD accumulation areas in the open ocean. Finally, the feasibility of the different potential solutions was assessed in the short and long term.

The workshops revealed a scarcity of global quantitative data on FAD stranding events and the necessity of studying FAD trajectories globally to have a clear picture of the FAD beaching, sinking, and stranding events. Although knowing real FAD trajectories would be desirable for this purpose, models of oceanic drifts could also be used to estimate those events. The workshops highlighted a range of solutions that could be used in the short term to minimize the impact of FADs' structures. These solutions need to be customized for each ocean, because oceanographic conditions and fleet FAD strategies are region-specific. During the workshops, difficulties in implementing each solution were identified, perhaps the most evident being that FAD structures nowadays are very large and bulky, which complicates the logistics of recovery and storage.

Key Findings:

1. **Global quantitative data on FAD stranding events is scarce. It is necessary to study FAD trajectories globally to have a clear picture of the fate of FADs.**
2. **There are a range of solutions to reduce the ecosystem impact of FAD structures, but they need to be customized for each ocean. Workshops with fishers to fully understand FAD operations and effects at regional level are crucial to find solutions.**
3. **Decreasing the bulky size of FAD structures to facilitate at-sea retrieval and generate less marine waste is key.**
4. **Decreasing the size of FAD structures and using non-entangling biodegradable materials, particularly replacing the submerged appendages, would be a huge step toward reducing the impacts caused by FAD structures.**

Pilot studies were also identified to find other solutions, such as studying FAD trajectories to find efficient FAD deployment sites (for fishing and to minimize the impact), or studies to technically evaluate FADs with autonomous navigation capability as well as the strategy to be used for fishing purposes.

Field research revealed a biodegradable solution for the submerged structure of the FAD, also called by fishers "the tail." It is estimated that globally 100,000 FADs are deployed every year (Gershman et al. 2019). The tail component has the most impact on the ecosystem, because it is usually made of netting and, in many fleets, reaches around 60-80 m in length and 2 m in width. Replacing a plastic tail with a biodegradable material in 100,000 FADs/year would be a huge step to reduce FAD impacts and especially the amount of plastic lost at sea. The estimated amount of plastic that would be reduced at sea worldwide if biodegradable tails were used to build FADs would be 14,000 Km^2 of plastic per year.[1]

From ISSF research activities, we propose various recommendations.

[1] An average of 70 meters length FAD per 2 meters wide multiplied by the estimate of 100,000 FADs deployed every year.

Research Questions

The research questions underlying the work presented in this report are diverse:

Quantifying impact:

- How many stranded FADs exist?
- What are the principal FAD stranding areas in each ocean?
- What are the data needs to quantify FAD beaching events and better understand the starting point so that the efficiency of different measures can be evaluated?
- How much non-biodegradable material (e.g., in Kg) does a FAD contribute per ocean?

Selection of biodegradable materials:

- What is the desired lifetime for a FAD for successful fishing in each ocean?
- What is the best definition for a biodegradable material to be used in FADs?
- What are the features needed for a given biodegradable material to be used successfully in FADs?

Biodegradable FAD designs:

- What structural features does a FAD need to be productive?
- Is there a single FAD design that suits all fleets and regions?
- Is there a FAD design, regardless of the materials, that decreases the impact on the ecosystem?

Trials at sea:

- What is the best strategy to test biodegradable FADs in real fishing conditions?
- What is the lifetime of biodegradable materials used in the open ocean?
- What is the lifetime of biodegradable materials when they arrive at the coast and/or are stranded?

Other actions to decrease FAD structure impact:

- Besides the use of biodegradable FADs, what can be done to minimize the impact of FAD structures that are lost or abandoned?
- What is the feasibility of the potential recovery measures in the short and medium term?
- What are the potential recovery areas of FADs at sea? And from land?
- What are the logistical requirements for a FAD recovery program?

1. INTRODUCTION

One of the ecosystem impacts that Fish Aggregating Devices (FADs) have results from their own physical structure (**Figure 1**). Abandoned or lost FADs can end up stranded on and damaging coasts, sometimes in vulnerable ecosystems such as coral reefs (Maufroy et al. 2015). In addition, after stranding, FADs with netting in their submerged structure can cause ghost fishing, even when netting is tied in bundles to prevent entanglement; with time, the netting becomes unraveled. In these ways, FAD structures can interfere with other economic activities, such as tourism, marine transportation, or aquaculture.

Perhaps beaching is the most visible FAD ecosystem impact, but another impact with lost and sinking FAD structures — which are mostly built with plastics (polyethylene nets and ropes) — is the accumulation of plastics at sea. This problem affects all fishing gears at a global level, adding to the enormous production of anthropogenic plastic marine debris. Growing concerns over this problem have spurred projects such as ISSF's work to develop biodegradable FADs, the Global Ghost Gear Initiative, and The Ocean Clean Up Project, which try to lessen this impact.

Plastic-based nets can take centuries to degrade. They accumulate year after year, and they finally break down into smaller microparticles that enter the marine food web. According to United Nations reports, it is estimated that 640,000 tons of fishing gear are lost at sea yearly. This is a global issue for which it is difficult to predict future consequences.

In the case of FADs used by tuna fleets in the tropical zones of the Indian, Atlantic and Pacific Oceans, the impact caused by their structure has triggered a response by coastal countries affected by beaching, by scientists and research institutes working on FAD fishing, and by the fishing industry, conscious of potential impacts derived from FAD loss and abandonment.

The first steps taken were some initiatives, both by the fishing sector and research institutes, to develop biodegradable FAD structures that work for fishing during a set time and thereafter degrade, thereby minimizing the effect of their loss. Among other experiments, trials with FADs made of materials from natural origin were conducted in real fishing conditions (Franco et al. 2012; Goujon et al. 2012). One of the main difficulties encountered during these trials at sea was the lack of sufficient observations during the life of experimental biodegradable FADs. Fishing companies in general deployed few of these experimental FADs to test at sea. This is mainly because a given vessel cannot rely on a high number of experimental FADs to fish, as their success is under trial and not yet known. In addition, the cost of FADs' tracking buoys and the communications needed to track FADs is high, so the number of experimental FADs vessels can trial is usually limited. A high percentage of FADs that a vessel deploys are fished and appropriated by other vessels or end up lost or sinking. The number of experimental FADs deployed by fishing companies individually was not sufficient to gain statistically significant results on the fate of biodegradable FADs or on their lifetime usefulness for fishing.

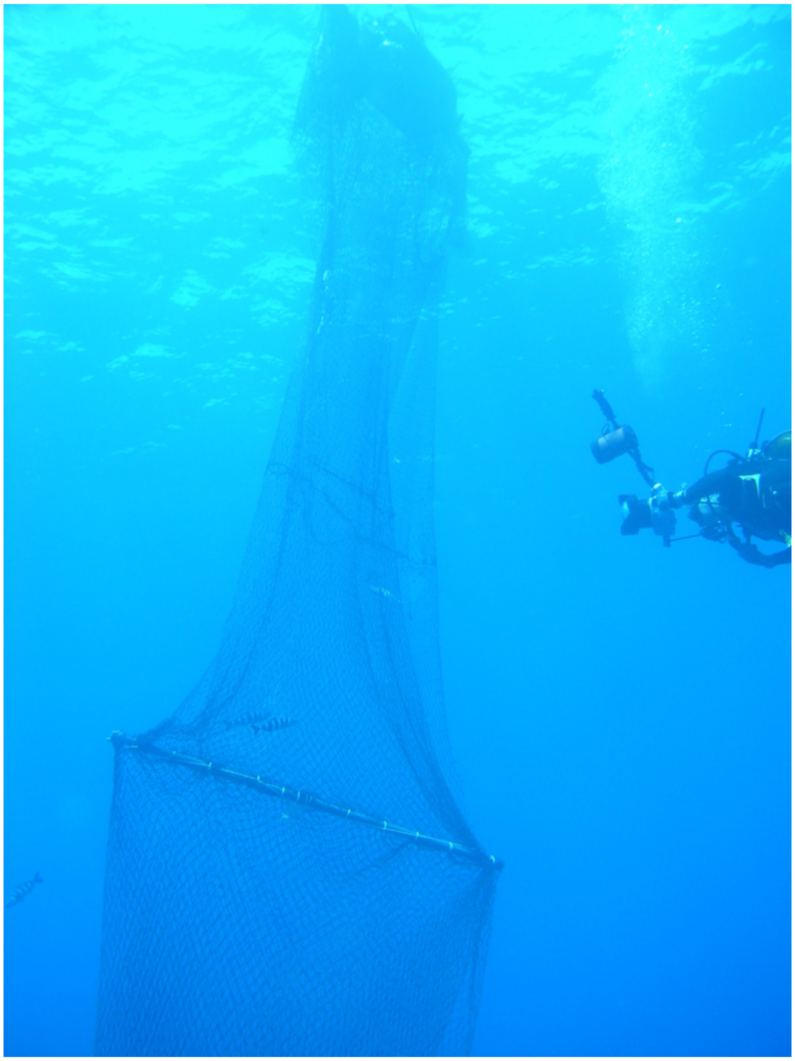

Figure 1. Underwater view of a FAD (© FADIO/IRD/ Ifremer/ Marc Taquet)

Due to the lack of data on the behavior of biodegradable materials while testing experimental FADs in real fishing conditions, ISSF designed a roadmap to help fishers move toward the use of biodegradable FADs (**Figure 2**). The desired medium-term result of our roadmap is replacing all plastic components of FAD structures with biodegradable materials. However, until a 100% biodegradable FAD structure is found, a progressive replacement of some plastic components, such as the submerged appendage, would still be a significant step to decrease the amount of plastics at sea and the FAD impacts on the marine habitat. Furthermore, until biodegradable FADs are successfully implemented, it is necessary to evaluate other options to reduce these impacts, to preferably solve the problem of lost and stranded FADs. ISSF, in collaboration with FAO-GEF Common Oceans Tuna Project, launched a series of actions and projects to help reduce the impact of FAD structures on the ecosystem, including the use of biodegradable FADs and FAD retrieval. Specifically, the activities summarized in this report are:

(i) Workshops to tackle possible options that minimize the impact of lost or abandoned FAD structures, including the use of biodegradable materials and FAD retrieval. Because each ocean has particular characteristics and FAD difficulties and solutions can be different in each one, workshops gathered scientists working in three oceans; skippers working in the Pacific, Indian and Atlantic; and Fisheries Improvement Projects (FIPs) coordinators from the three oceanic regions.

(ii) Evaluating the lifetime, under controlled conditions, of biodegradable ropes being considered for FADs. The biodegradable ropes need to be assessed in controlled conditions due to the difficulty of getting results in real fishing conditions.

(iii) Pilot trials at sea to test the biodegradable materials on FADs in real fishing conditions and understand potential difficulties of the large-scale deployment of biodegradable FADs.

(iv) Large-scale deployments of FADs in the Indian Ocean (EU and Korean fleets) and Atlantic Ocean (Ghanaian fleets).

The solution must include finding alternatives to plastics, applying good practices to avoid fishing gear abandonment and loss, and retrieving unutilized fishing gears at sea. Each fleet that uses FADs should search for solutions best suited to their fishing operations.

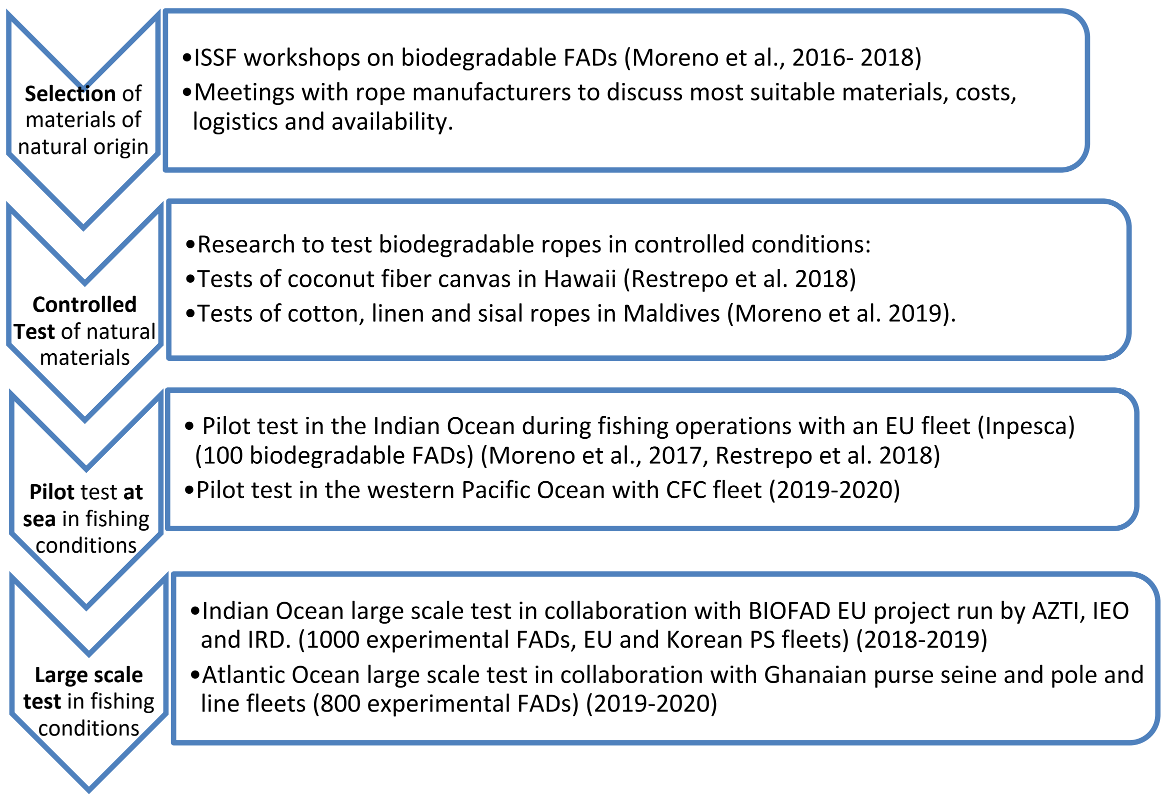

Figure 2. Diagram showing ISSF´s road map towards the use of biodegradable FADs

2. COMPLETED ACTIONS TO REDUCE THE IMPACT OF FAD STRUCTURE

ISSF, with the support of the FAO-GEF Common Oceans Tuna Project, launched the following activities and projects to help reduce the ecosystem impacts of FAD structures:

2.1 International workshop on the use of biodegradable FADs

2.2 International workshop for the reduction of the impact of FAD structure on the ecosystem

2.3 Design workshop on the use of biodegradable FADs in Ghanaian purse-seine and pole-and-line tuna fleets

2.4 Evaluating the lifetime of biodegradable ropes in controlled conditions

2.5 Pilot project to test biodegradable ropes at FADs in real fishing conditions in the western Indian Ocean

2.6 BIOFAD project (IOTC Resolution 18/04): large scale testing of biodegradable FAD designs in the Indian Ocean

2.1. International workshop on the use of biodegradable FADs (2016)

Background

A workshop on the use of biodegradable FADs, or FADs made with natural materials, was organized by ISSF November 3-4, 2016, in the Aquarium of San Sebastian (Spain). This workshop was organized to propose solutions for reducing the amount of plastic and other non-natural materials u in FADs to avoid ocean pollution when FADs sink or beach in coastal areas. Recent research conducted in the Indian Ocean, using information from the trajectories of the buoys utilized to geo-locate FADs, showed that 10% of the deployed FADs ended up in stranding events (Maufroy et al 2015). In the western Pacific Ocean, around 8% of the deployed FADs were estimated to end up beaching, but 29-39% were estimated to be drifting deactivated (without any owner tracking their trajectories), so the fate of those FADs was unknown (Escalle et al. 2019). Unretrieved FADs probably end up sinking or stranding. Since the main components of FADs are petroleum products such as plastic, PVC, and nylon nets etc. that degrade slowly, there is a growing accumulation of these products in coastal areas and the seabed year after year. FAD beaching events cause damage in coral reefs and contribute to marine pollution and ghost fishing.

2.1.1. Objectives

The objective of the workshop was to join efforts, through the collaboration of scientists and fishers, to find solutions to reduce the environmental impacts of FADs sinking in the ocean or beaching in coastal areas.

Specific objectives, in accordance with the development of biodegradable FADs, were to:

1. Determine the structural features needed for a FAD to be productive
2. Determine a FAD's lifetime as an efficient fishing tool in the different oceans
3. Review the different alternatives available in the market, tested through experiments: from natural origins (biodegradable) and other alternatives from non-natural origin
4. Design new biodegradable FAD structures for the different oceans
5. Define the protocol (or strategy) to test biodegradable FADs in real fishing conditions through the cooperation of the fleets in the three oceans

2.1.2 Results

A. STRUCTURAL FEATURES NEEDED FOR A FAD TO BE PRODUCTIVE

A review was conducted to determine the structural features biodegradable FADs would need to efficiently aggregate tunas.

First of all, fishers agreed that any type of floating object can be efficient for tuna aggregation purposes if it is located in the right place at the right time. Since FAD location and time are the key issues for successful tuna attraction, the FAD structure should be designed so that it will drift to good areas at the right time. The FAD's drifting speed and trajectory are the main variables to control for aggregating tunas. In regions where the FAD needs to drift slowly to effectively aggregate tunas, a deep FAD structure is needed to create a greater anchoring drag effect. For other regions, the drift needs to be driven by surface currents. In such contexts, the FAD structure should be shallow. Thus, two types of FAD structures need to be addressed, a shallow one and a deep one, basically in relation to the oceanographic conditions of the area and probably to other factors such as the vertical distribution of tuna prey.

The shadow produced by the floating structure of the FAD, as well as the strings and flags that are usually added to the shallow part of the submerged structure, were considered necessary to attract those species that initially occupy the space close to the FAD, named *intranatants*[2] (*Lobotes surinamensis*, *Abudefduf saxatilis*, etc.). *Intranatant* species, in turn, may play a role as attractors of other species that occupy the space at greater distances from the FAD, such as tunas. It may be that once the FAD is colonized by *intranatant* species, the structure of the FAD (color, shadow, etc.) loses importance in the ability to attract tunas, as *intranatant* species once present at FADs may be a more powerful attractor than the FAD structure itself. Although tunas' visual and hearing abilities are not well understood yet, it is likely that the noise, odor, and movement of *intranatant* and *extranatant* (*Aluterus monoceros*, *Kyphosus cinerascens*, *Caranx sp*., etc.) species at FADs could be detected further away than stimuli produced by the FAD itself — unless there is an element of the structure that produces noise, as it has been mentioned for the case of anchored FADs with the anchoring chain.

Finally, the importance of the depth of the FAD structure was attributed solely for achieving the desired drift.

B. LIFETIME OF A BIODEGRADABLE FAD TO BE USEFUL FOR FISHING

Given the complexity of FAD fishing strategy, and the particularities of each ocean in the way FADs are deployed, FAD maturation time, and fishing, the required lifetime for a FAD was specified by ocean:

- Eastern Pacific Ocean: From 6 months to 1 year
- Western Pacific Ocean: 1 year
- Indian Ocean: 1 year
- Atlantic Ocean: From 5 months to 1 year

A FAD is not usually used beyond the times specified above. Thus, FADs older than these thresholds should be able to degrade as fast as possible.

C. REVIEW OF THE DIFFERENT BIODEGRADABLE MATERIALS TESTED BY SCIENTISTS AND FISHERS

During the meeting, we reviewed the different experiments conducted by both scientists and fishers. The behavior, resistance, biofouling, price and other issues were discussed for materials of natural origin as well as for other alternatives that are non-natural in origin. The following items were discussed and agreed upon:

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[2] Those species that move within 2 m range from the FAD. Parin, N.V., and Fedoryako, B.I 1999. Pelagic fish communities around floating objects in the open ocean. Fishing for Tunas associated with floating Objects, International workshop. Inter-American Tropical Tuna Commission (11): 447-458

The concept of biodegradable

- Although the definition of biodegradable is "capable of being broken down (decomposed) by the action of microorganisms," the time required for this biodegradation is an important issue. The challenge for the current objective is to design a biodegradable FAD that aggregates fish and can last up to the above time thresholds (from 5 months to 1 year, depending on the ocean) and be capable of biodegrading as fast as possible after this time.
- Other alternatives of non-natural origin such as plastics, metal, and oxo-biodegradable plastics were eliminated. Although these materials could have a lesser impact in the manufacturing and transportation stages of their life cycle than materials of natural origin, their slow degradation and durability and the end of their life cycle can have such a significant impact on coastal ecosystems that they were not considered as options.

Submerged structure of the FAD

- Some of the materials of natural origin were eliminated due to their fragility and short lifetime, such as coconut fibre and jute in fabric configuration, as fish ended up feeding on the fabric.
- Up to now, ropes made from cotton are the ones that have shown higher breaking strengths and durability in time. There are 2 types of cotton ropes that have been tested — one with the capability of adhering biofouling (with loops similar to those used to grow mussels in ropes), and ones that do not allow the biofouling (**Figure 3**). The latter would allow the structure of the FAD to be more stable over time while the ones that adhere biofouling will aggregate encrusting organisms that will decrease the floatability of the structure with time. However, the barnacle-encrusting ropes could be helpful for attracting intranatants in the first stages of the FAD colonization process (this hypothesis has not been tested). Other ropes have not been tested yet, such as tencel ropes available in the market made from eucalyptus.

Figure 3. Different rope types from natural origin analyzed during the workshop.

- Canvas made from cotton used for activities that require high resistance, as in military activities, were identified as a good alternative to be used as flags attached to the main structure of the FAD — both to create more volume as a "drifting reef" as well as to use them as drift anchors to make the FAD drift slower (**Figure 4**). The first prototypes of

FADs using this canvas as drifting anchors have recently been deployed at sea. These canvases have different numbering categories for their thickness. One of the thickest (number 12) was the preferred one for the fleet that is testing them.

Figure 4. Biodegradable canvasses of various thickness configurations made from cotton

Surface structure of the FAD

- One of the most critical factors when constructing a FAD is the buoyancy of the structure. Their lifetime depends in many cases on the adequate assessment of the buoyancy needed for a given structure to prevent sinking. Thus, it is necessary to precisely calculate the buoyancy for the FAD so it can be active during the required time. Biodegradable alternatives to floating materials currently used in FADs such as PVC pipes, purse seine net corks, plastic buoys, containers or drums are scarce. One of the few alternatives presented during the workshop was balsa wood (*Ochroma pyramidale*) (**Figure 5** and **6**). Balsa is well known for its great buoyancy and could be a biodegradable alternative for the floats of FADs. Tests at sea using this wood together with bamboo canes as floats are in progress in the Eastern Pacific Ocean (EPO). Hopefully results for these first FADs will soon be available (**Figure 7**).

Figure 5. Fisher evaluating balsa wood

Figure 6. Detail of the balsa wood blocks

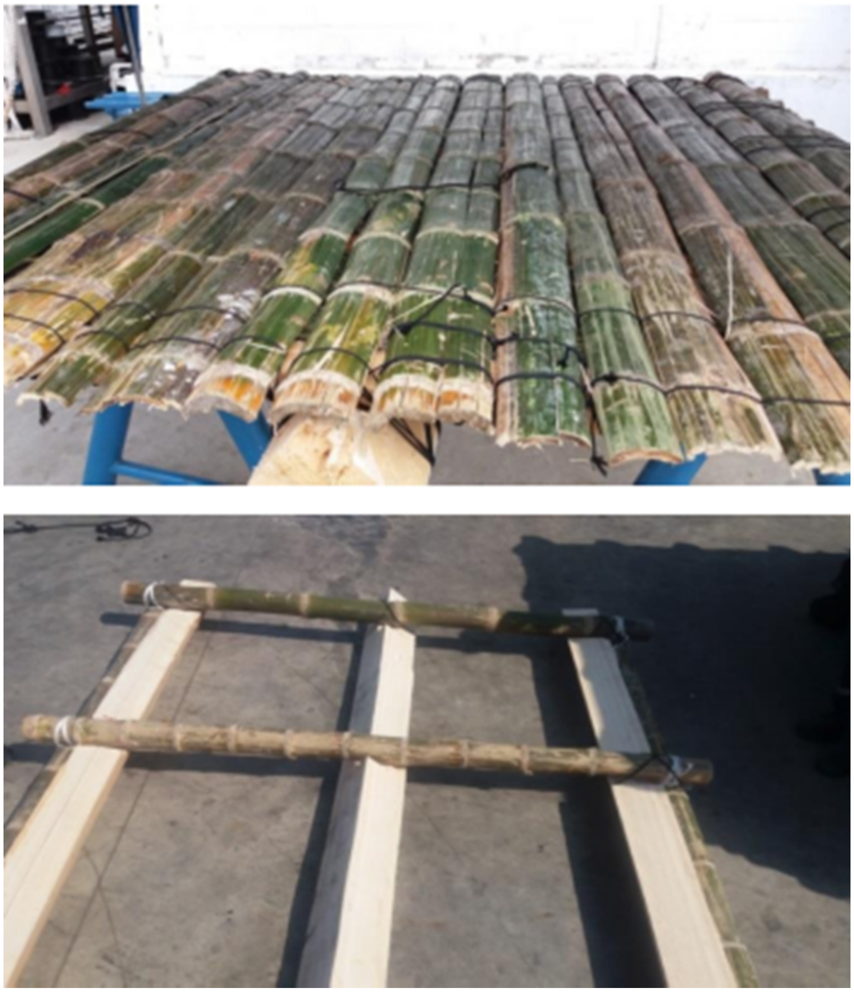


Figure 7. First prototypes deployed at sea using as floats balsa wood and bamboo canes

- Bamboo canes have been used for many years to build FAD rafts. One of the main difficulties with bamboo is that it loses buoyancy over time as water seeps inside the canes´ air chambers, eventually making the FAD gain weight and sink. Fishers prefer green canes or recently cut canes due to their lower permeability and longer lifetime. However, they still need to add extra plastic flotation elements (e.g., corks, bottles, etc.) to prevent the FAD from sinking. Other alternatives worth exploring are natural oils, varnishes, waxes or other treatments that are already used in some countries to enhance the lifetime of bamboo canes. Perhaps an appropriate treatment of bamboo canes would extend their working lifetime up to the required FAD life expectancy (a maximum of one year would be required).
- The potential use of coconuts to add flotation to bamboo canes was presented during the workshop.
- Although they have not been tested yet at FADs, new polymers from natural origin (potatoes, algae, etc.) used to manufacture containers may open up a series of alternatives for flotation at FADs in the near future.

- Canvas made from cotton described earlier was also identified as a good alternative to cover the raft in order to provide consistency to the structure and create shadow to attract fish.
- A range of colors is available for the needs of fishers — for instance, dark colors to decrease the likelihood of being detected by other vessels that are looking for FADs.
- The possibility of using a hydrostatic release unit for the FAD's geo-location buoy was also considered. This unit would allow releasing or cutting off the tethered buoy before it sinks with the FAD structure. The buoy could be retrieved, reducing pollution at sea. Some of the issues to be solved will be retrieving the buoys as well as making sure they are not counted as an active FAD in oceans where there is a limit on FAD numbers per vessel.

D. BIODEGRADABLE FAD DESIGNS TO BE TESTED IN DIFFERENT OCEANS

One of the main objectives of the workshop was to design biodegradable FADs that could be tested at sea in the near future, using materials available in the market. Mixed groups of fishers and scientists were formed to propose FAD designs.

Selected materials for the different FAD designs were:

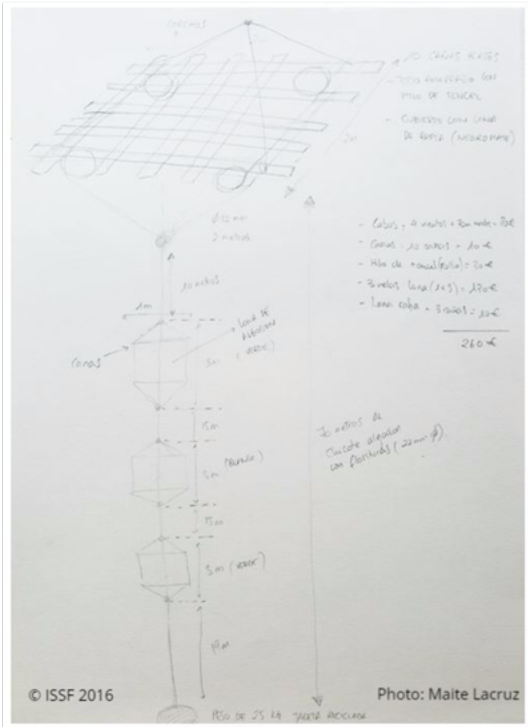
- Balsa wood (buoyancy)
- Bamboo canes (buoyancy and submerged structure)
- Pinewood (surface structure)
- Cotton canvas (cover of the raft, submerged flags and drift anchor)
- Cotton rope with loops (submerged structure)
- Cotton rope without loops (submerged structure and to assemble canes and balsa wood for the raft)
- Tencel ropes (to assemble different components of FADs)
- Stone (weight)
- Sand (weight)
- Hydrostatic release (to release the buoy when the FAD sinks)
- Buoys or purse seine corks[3]

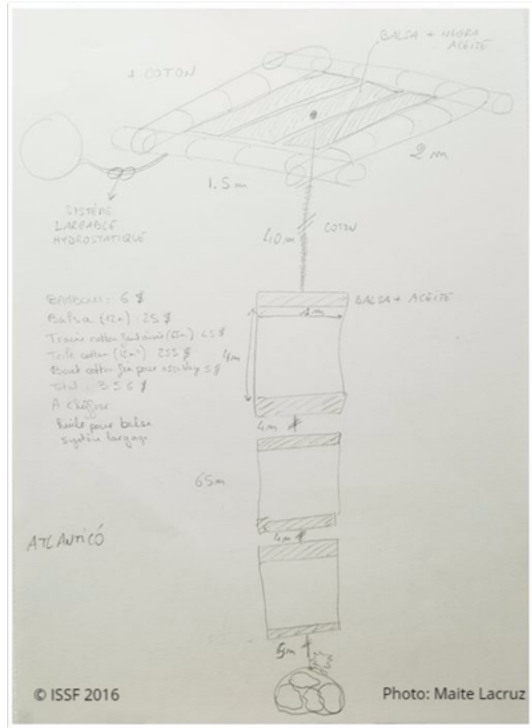
In total, 7 biodegradable FADs were designed (**Figure 8**). The deepest structures reached 60-80 m, with one design of 40 m, and were mainly designed for the Atlantic Ocean. Very shallow FADs were designed for the Indian Ocean, with only 2 m depth. Such shallow FADs could also be effective in the Pacific and in the Atlantic Oceans where tunas are feeding in

[3] Although buoys or purse seine corks are not biodegradable, they were considered necessary during the trials to get data from the diverse biodegradable materials in test. Some of the experiments at sea failed because all the FADs sunk and no data was retrieved. The buoyancy needed for a given structure needs to be tested by monitoring the biofouling adhered to the different parts of the FAD. To avoid the potential sinking of experimental FADs during the first trials, plastic buoys could be added to obtain extra buoyancy and assure data is gathered for this experimental FADs.

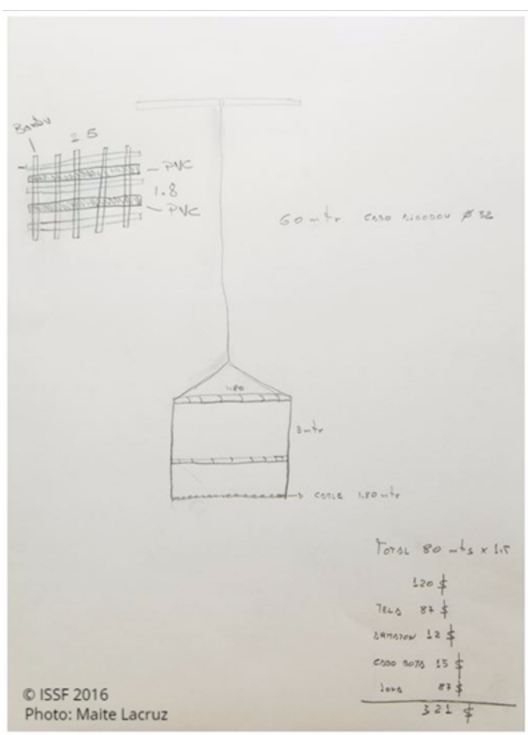
surface currents, as in upwellings in Peru and Gabon waters. Of the 7 FADs designed, 5 used biodegradable structures and plastic buoys as floats (to avoid FAD sinking during the first trials) while 2 were 100% biodegradable.

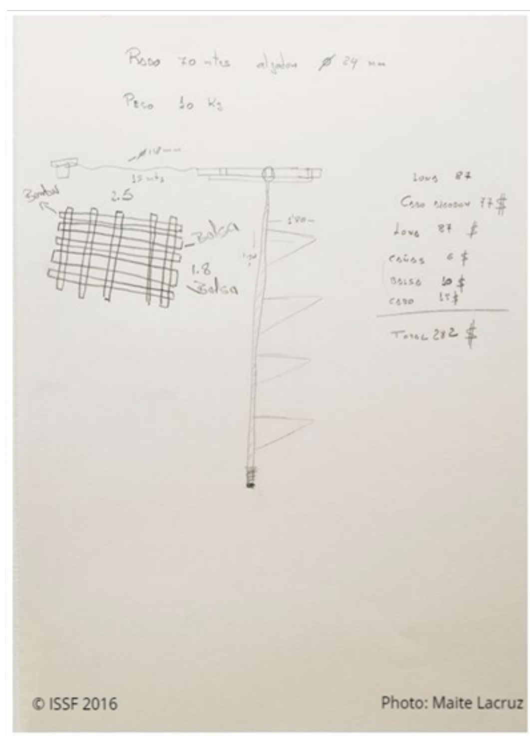
Atlantic ocean



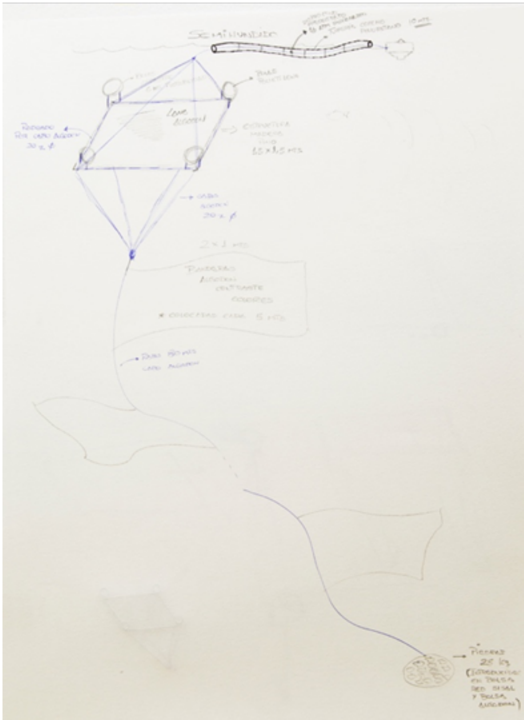


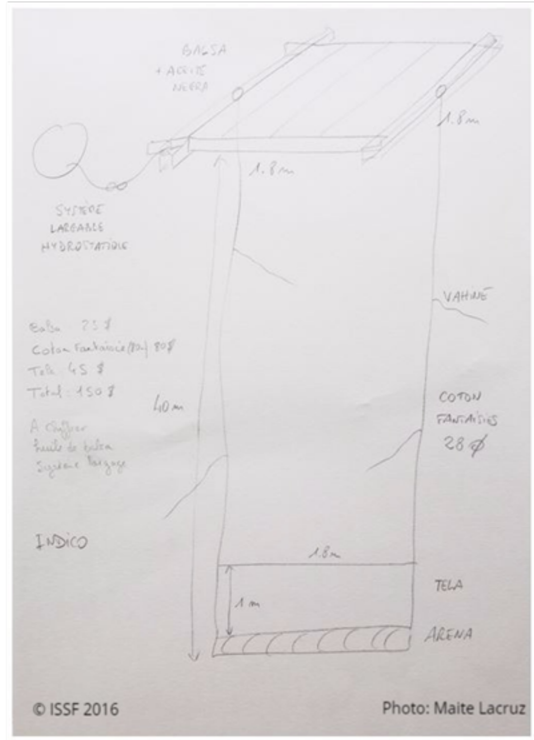
Pacific ocean





Indian ocean





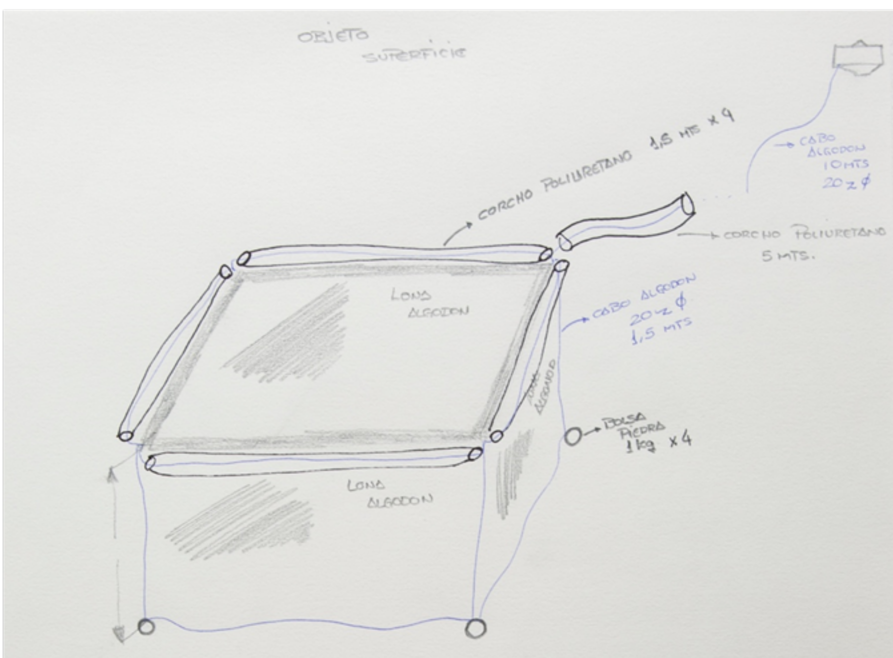


Figure 8. Different biodegradable FADs designed during the workshop for Atlantic, Pacific and Indian Oceans.

E. STRATEGY TO TEST BIODEGRADABLE FADS DURING FISHING OPERATIONS

Once the different biodegradable FADs were designed, discussions were driven to define an effective strategy to test them in real fishing conditions. Until now, the experiments to test new designs at sea have been conducted by individual companies deploying a reduced number of FADs. This strategy was not successful, as stated earlier in this document, due basically to the difficulty of revisiting and getting information on the low number of experimental FADs. Frequently, a single FAD changes ownership in its lifetime, which makes it difficult to monitor a given FAD structure over time. It is thus necessary to be able to monitor FADs in a coordinated way. Moreover, the different owners add or repair some elements of the structure that have degraded so that the FAD can be different from the original FAD first deployed. Thus, it was clear that the collaboration of the different fleets and purse seine companies was necessary to achieve an efficient monitoring of the evolution of the FAD structure over time. Hence, for the success of the trials with biodegradable FADs, the following protocol was proposed:

- Fleets should collaborate by deploying FADs and providing information on the evolution of biodegradable FADs encountered at sea over time.
- Fleets deploy a given number of biodegradable FADs per vessel (e.g., 10-20 FADs per vessel to reach a significantly large number of FADs). These numbers should be determined during the meetings with the different fleets (i.e., fleet-owners and fishers).
- In order to obtain a meaningful result, 3 to 4 standardized designs maximum per ocean should be tested, so that enough data is retrieved per design type. Ideally, experimental FADs should be built in port and deployed in the same area as traditional, non-experimental FADs, so their effectiveness could be compared with that of the traditional FADs for the same spatial and temporal strata.
- Since the objective is to monitor the time evolution of biodegradable materials and assess the buoyancy of the FAD, non-biodegradable flotation could be added at the beginning to guarantee that FADs do not sink and that data will be collected.
- Deployment site, type of biodegradable design, and the code of the geo-locating buoy should be registered. Every FAD should be well identified so that data can be retrieved and followed by the different owners.
- If a biodegradable FAD is encountered at sea, the following data should be registered: the catch (if any), the condition of the FAD, and the new code for the buoy if the original has been replaced.
- Having access to the trajectories and echo-sounder of the buoys attached to biodegradable FADs would allow assessing the capability of biodegradable FADs to aggregate tunas, even if they are not visited or fished by purse seiners, as well as following their lifetime if they are not retrieved.
- Echo-sounder data should not be provided for scientific purposes in real time but with a given time delay and should be subject to a confidentiality agreement.
- An entity should be in charge of collecting and analyzing the data in a centralized manner. It was suggested that ISSF could fulfill this role.

F. RETRIEVING FADS

Even if biodegradable FADs will considerably reduce the impacts on the ecosystem, they will not completely eliminate all impacts. Retrieving FADs that beach in critical areas of particular vulnerability, such as coral reefs, was discussed.

See Section 2.2 for further information on FAD retrieval

2.1.3 Conclusion

First of all, the workshop showed the importance of involving the different stakeholders of the fishery, e.g., fishers and scientists, to find practical solutions to reduce impacts that FADs have on the ecosystem. The combination of empirical knowledge of fishers and scientific knowledge by scientists was of great value.

The workshop participants agreed that biodegradable FADs would be as productive as traditional FADs, as long as they drift to the good places at the right time, which also means that they must last long enough. Different designs of FADs have been proposed, depending on the oceanic regions. The main challenge is to find a successful biodegradable alternative to the floats (purse seine corks, buoys, etc.). Fishers were keen to collaborate in at-sea trials to collectively test new FAD materials and designs.

2.1.4 Visual documentation of the workshop

2.2. International workshop for the reduction of the impact of FAD structure on the ecosystem (2018)

Background

A workshop was organized by ISSF to tackle possible options that minimize the impact of lost or abandoned FAD structures other than the use of biodegradable FADs. Because each ocean has particular characteristics and the difficulties and solutions can be different in each one, the workshop gathered scientists working in the three oceans; skippers working in the Pacific, Indian and Atlantic; and FIP coordinators from the three oceanic regions. During the workshop, options to minimize the impacts of FAD structures were assessed in the short- and medium-term for each ocean.

Currently, there are several Fisheries Improvement Projects (FIPs) of tuna fleets operating in the tropical regions of the three oceans, and all have identified FAD retrieval as a key task. Although some experiences on FAD retrieval exist in the Indian Ocean by fleets such as OPAGAC (Organización de Productores Asociados de Grandes Atuneros Congeladores), there are still many doubts on how to approach retrievals and its effectiveness, as well as how to define difficulties and logistical, economic, and administrative challenges emerging during FAD retrieval programs.

2.2.1. Objectives of the workshop

The objective of the workshop was to evaluate different options to reduce the impact of lost and abandoned FAD structures on the ecosystem. Fishers and scientists participated to provide expertise on the potential measures to minimize the impact in each ocean. Before these options were considered, data on the fate of FADs was discussed in relation to beaching, sinking, and lost or abandoned FADs. Assuming that the use of biodegradable FADs is one of the main solutions to avoid the impacts of FAD structure on the ecosystem, and the fact that there are other specific workshops and projects to address this specific solution, the workshop did not address the use of biodegradable FADs.

The following options were evaluated during the workshop (in chronological order from the construction of a FAD until they end up lost, abandoned or stranded):

- Limiting number of FADs
- Simplifying FAD structures
- Avoiding FAD deployment areas that imply high risk of stranding
- Building FADs with navigation capability
- Building FADs that could be sunk
- Using anchored FADs
- Recovering FADs at sea
- Recovering FADs from land

2.2.2. The fate of FADs

Before assessing the potential solutions to minimize the impact of FADs, an exercise was done to understand the fate of FADs in the three oceans. Currently data on FAD loss, abandonment, sinking and beaching events are very limited. Maufroy et al. 2015 were able to quantify FAD beaching events from data provided by the French fleet in the Indian and Atlantic Oceans. Following the trajectories of FADs, they estimated that 10% of the FADs deployed by the French fleet ended up in beaching events. The study was possible thanks to the data shared by the French fleet on FAD trajectories; without these data it is difficult to quantify the issue of lost and abandoned FADs. However, even with data on FAD trajectories, it is not always easy to estimate those events. Once a FAD has drifted away from the fishing zone, fishers deactivate the FAD positioning system (to avoid paying for satellite communications), so that communication is stopped before the FAD beaches and, as result, those FADs remain at sea. Without any owner tracking FAD trajectories, it is difficult to quantify the potential beaching events and areas.

Recently, due to the limits on actively transmitting FADs per vessel set by all RFMOs, FAD deactivations have increased. This is because deactivating a FAD that is far from the fishing zone or from the vessel allows for activating a new one within the fishing zone when a vessel is operating near its FAD limit number. The cost of a FAD is less than that of the fuel needed to travel to retrieve it. Therefore fishers do not navigate to areas far from where they are fishing in order to recover a FAD. In any case, the last position provided by the FAD could be a good proxy of the beaching area by modelling local currents.

Since 2009, ISSF has been organizing skippers' workshops with purse seine fishers fishing with FADs worldwide (Murua et al. 2018). ISSF has conducted more than 100 workshops with 25 different fleets operating with purse seiners in main ports all over the world. During these workshops, a questionnaire is distributed to gather fishers´ knowledge and opinions. Recently, a new question was included related to the topic of this workshop: Which percentage of your FADs end up beaching, sinking or removed by other vessels? The results of these questionnaires are shown in **Figure 9**. In general, for all oceans, but specially for the Indian Ocean, which is a relatively small fishing ground with a high density of fishing vessels, the majority of FAD losses for a given owner is due to appropriation by other fishing vessels (around 50% of the FADs). Secondarily, FAD losses in Indian and Atlantic Oceans are due to beaching events. The fishing ground in the Western Indian Ocean is surrounded by islands that stop the drift of the FADs towards the east, and by the continental mass in their trajectory to the west. Finally, sinking events in the Indian and Atlantic Oceans represent a minor proportion of FAD losses as, from fishers' point of view, before sinking they are taken by other vessels or stranded. In contrast, in the Eastern Pacific Ocean (EPO), it is estimated from questionnaires that sinking events are higher than beaching events. This could be mainly due to the fact that current drift patterns in the tropical region of the EPO is from the east to the west, thus those FADs deployed in the east need to traverse a large mass of water before they end up beaching. Hence fishers from the EPO believe that FADs sink before they arrive to an island. Likewise, the fleets operating in the Western Pacific Ocean believe that FAD sinking events are greater than beaching events.

As indicated by fishers' questionnaires, the relative importance of sinking and beaching events varies depending on the ocean. In order to better understand the fate of FADs, it is also important to consider the strategy and the type of FAD structure used in each fleet. For instance, in the EPO (**Figure 9**), the Ecuadorian fleet operates primarily in waters closer to the American continent, where high density of vessel exists. The Spanish fleet operates in waters closer to the central Pacific where vessel density is low, and thus fishers fish mainly on their FADs and appropriation of others' FADs is less frequent. The same result appeared in a study conducted by Lennert-Coddy et al. 2018, in relation to the strategy working with FADs for the different fleet segments operating in the EPO. In the Atlantic Ocean it can be observed that Ghanaian fleets that operate in a relatively small fishing area visit, repair and retrieve their FADs more often compared to other fleets. This is probably due to the fact that the distance to retrieve FADs is shorter and that they need to recover them in order to maintain a given number of FADs within the fishing area.

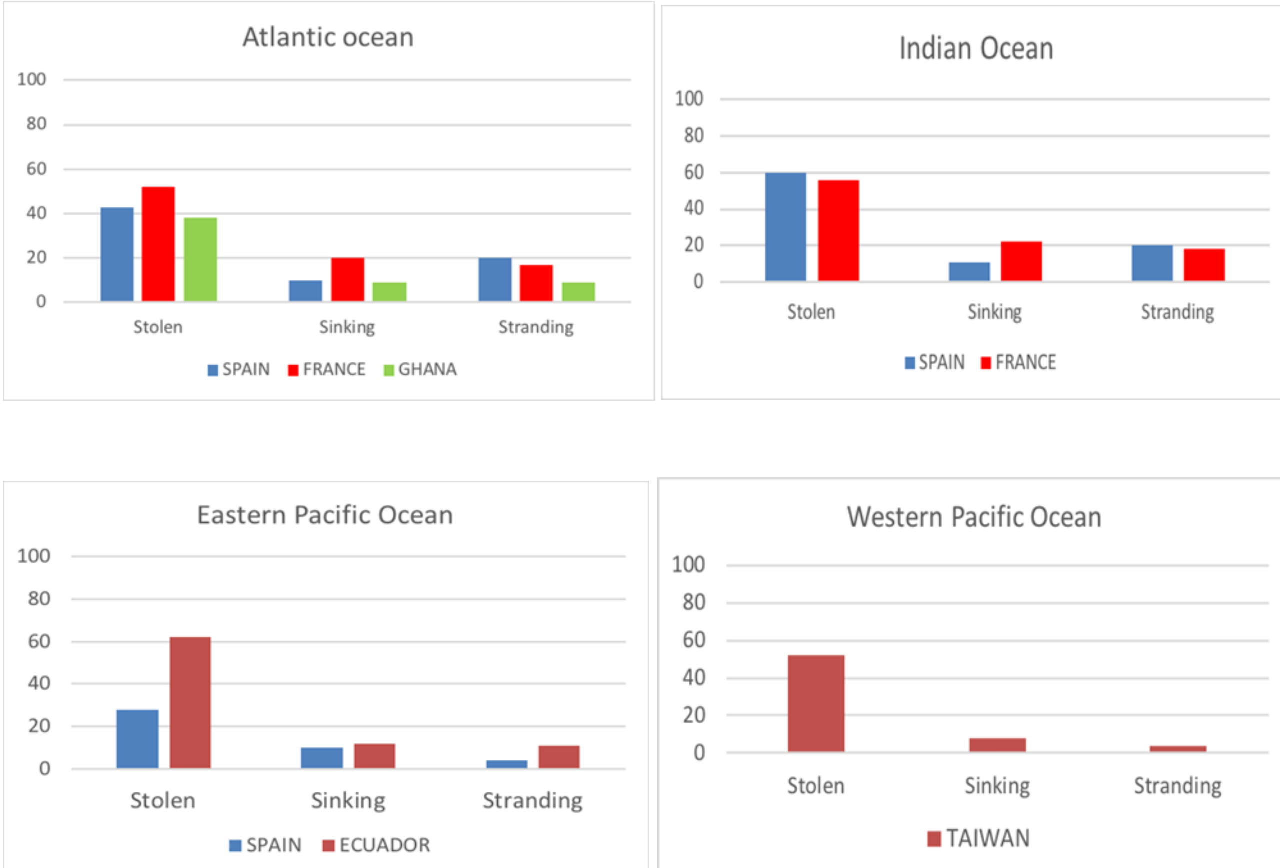


Figure.9 Percentage of FADs stranded, sunk and stolen by ocean and fleet, according to skippers. Data from ISSF skippers workshops.

During the workshop, these figures were discussed as well as existing data from the French fleet´s FAD trajectories. Fishers participating in the workshop reported that, from their point of view, beaching events were more than 20% of the deployments. The fact that FADs are deactivated before they end up beaching could bias the perception of the real number of FADs stranded, probably being more than what they assumed. During the workshop fishers said that, even when they have access to FAD trajectories, the fate of FADs is not always clear. They reported difficulties to distinguish sinking events from buoy positioning systems failures and stolen FADs. Nevertheless, there are clearer cases as for example when a FAD with a fish aggregation disappears in an area where other vessels are fishing. However, other cases are less evident, such as when the buoy starts transmitting intermittently, which could be either a sinking event or a communication system failure.

The fact that there are vessels (both purse seiners and from other gears) that cut the line tethering the buoy to the FAD structure makes the fate of FADs more uncertain. Sometimes this practice can be malicious, but other times it could be necessary — such as when a FAD becomes entangled in other fishing gears (e.g., a longline). Although not very common, this occasionally happens.

POTENTIAL ACTIONS

The absence of data on the fate of FADs precludes an accurate estimation of the magnitude of the problem. Furthermore, it makes it difficult to evaluate the effectiveness of a given mitigation measure, due to the lack of information at the starting point.

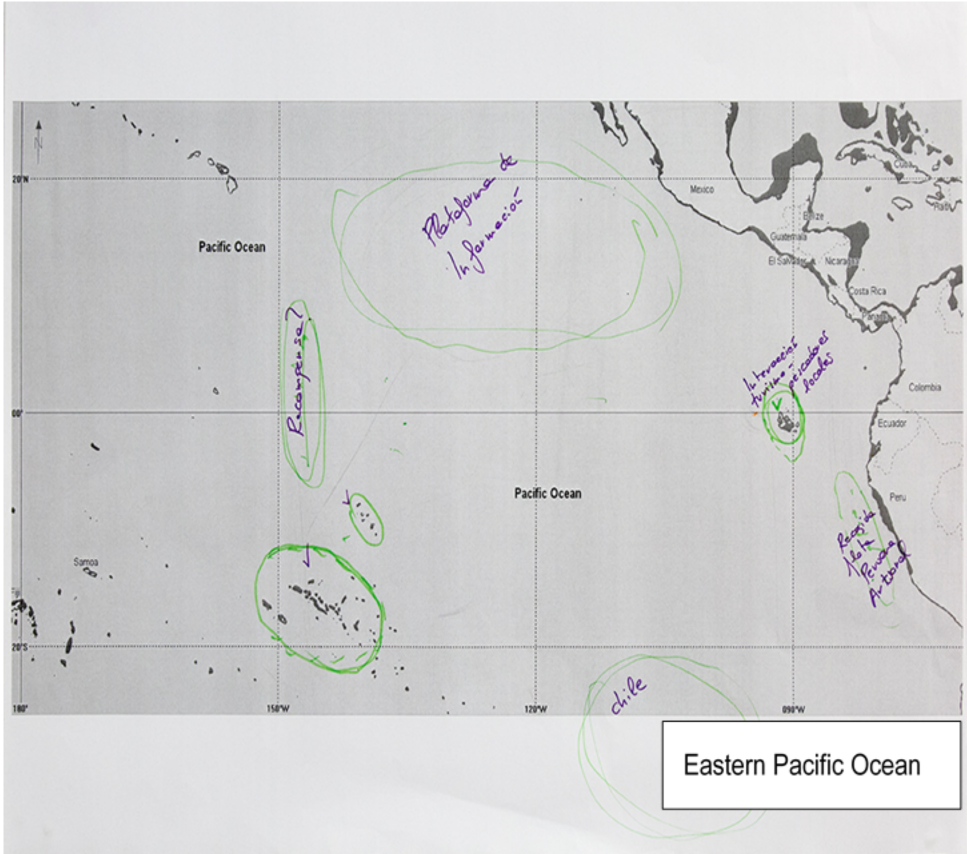
- One of the potential solutions for collecting data on lost and abandoned FADs could be the provision of data directly by buoy manufacturers, as important stakeholders of FAD fishing. Although satellite communications are expensive, once the FAD is lost, there is no need for high frequency data reception. Buoy manufacturers could provide a single position per day, with the consent of shipowners. The collaboration among buoy manufacturers, shipowners and scientists would be crucial to design the most appropriate data collection framework to allow accurate estimations of FAD beaching events as well as to inform the strategy to retrieve them.
- High definition oceanic current modelling to simulate FAD drifts could help quantify and identify the most important FAD beaching areas. For that, using the last positions of the FAD before deactivation and predicting its drift with the model would be the most appropriate approach. One of the issues with drift models is that they are best suited for oceanic waters but less accurate when closer to the coast, as they are influenced by local tidal currents, which are more difficult to predict.

2.2.3. FAD accumulation areas

DATA ON BEACHING AREAS AND FAD ACCUMULATION IN THE OPEN OCEAN

During the workshop, scientists presented a sample of real FAD trajectories from French and Spanish FADs in the Atlantic and Indian Oceans as well as models simulating FAD trajectories in the EPO from their deployment position.

Lacking real data to identify FAD beaching and accumulation areas in the open ocean, workshop participants worked in mixed groups of scientists and fishers to identify those areas with a likely high incidence of beaching events as well as areas of FAD accumulation in the open ocean. **Figure 10** shows the result of this exercise.



20°N
Pacific Ocean
Plataforma de Información
Mexico
Belize
Guatemala
El Salvador
Nicaragua
Costa Rica
Panama
Colombia
00°
Ecuador
Pacific Ocean
Peru
Samoa
20°S
180°
150°W
120°W
090°W
chile
Eastern Pacific Ocean

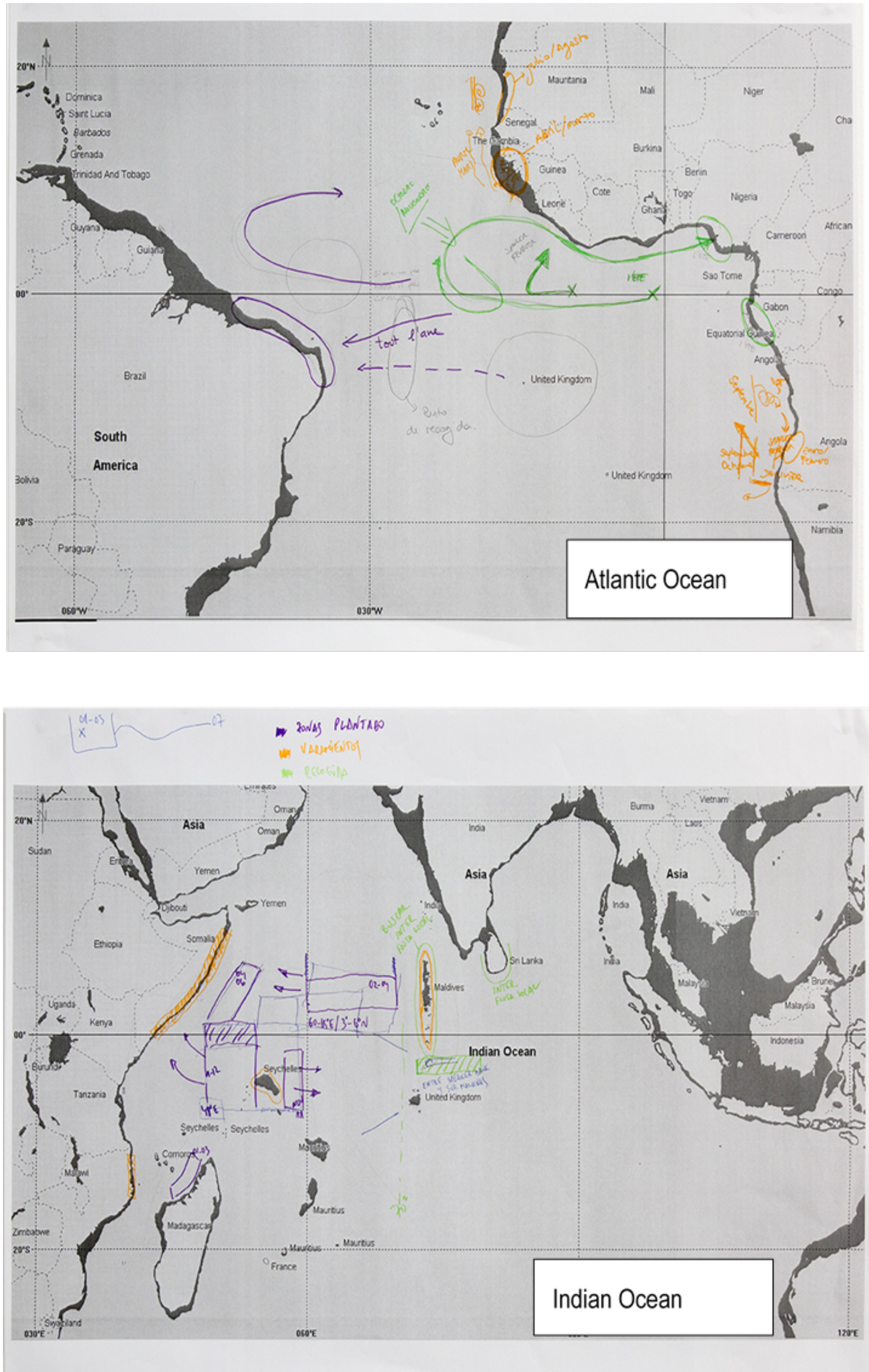


Figure 10. Maps by ocean identifying main FAD beaching areas and accumulation in the open ocean.

The following areas were identified as potential areas of FAD retrieval:

West Indian Ocean:

Main likely beaching areas:

- Somalia
- Maldives
- Chagos
- Seychelles

Areas of potential FAD retrieval at sea:

- Between the south of Laquedivas (India) and Chagos islands there is a stream of FADs crossing those waters towards the Eastern Indian Ocean.
- Maldives before FADs arrive to the coast (coral reefs)
- South of Sri Lanka
- Some areas in Seychelles

Atlantic Ocean:

Main likely beaching areas:

- Brazil
- Nigeria
- Mauritania
- Equatorial Guinea

Areas of potential FAD retrieval at sea:

- Around Longitude 25º West, before arriving to Brazilian waters
- From the coast in those areas where the stranding is estimated greater, and where it interferes with other economic activities or vulnerable ecosystems.

Eastern Pacific Ocean:

Main likely beaching areas:

- Galapagos
- French Polynesia
- Peru
- Marquesas Islands

Areas of potential FAD retrieval at sea:

- Before arriving at Galápagos, French Polynesia and Marquesas islands.
- Latitude 10-15 N of Central Pacific Ocean, those FADs that drift North out of the fishing zone tend to accumulate in that latitude.

FAD accumulation areas identified in this workshop have been determined through the empirical knowledge of fisher participants. It is necessary to better study, by ocean, those beaching and FAD accumulation areas at sea, by following real FAD trajectories if possible. Although FADs are deactivated when drifting out of the fishing zone, the last position provided by the positioning system together with oceanic current models could be a good proxy for the beaching zones.

2.2.4. Potential solutions to the impact of FAD structures on the ecosystem

Potential solutions to reduce the impact of FAD structures on the ecosystem were discussed and evaluated. The workshop only considered technological solutions in relation to the fishing operation, fishing strategy, and tactics. Here, those options are summarized in chronological order in relation to the lifetime of a FAD, from the construction of the FAD until they end up lost, abandoned or stranded. Following a precautionary approach viewpoint, the sooner those measures are taken during the FAD´s lifetime, the lower the FAD consequences on the ecosystem.

A. LIMITING FAD DEPLOYMENTS

The use of FADs has increased worldwide, not only because fleets already working with them have increased the number they use but also because fleets that were not relying on FAD fishing have moved towards the use of FADs (Lennert-Cody et al 2018). Recently, the 4 tuna RFMOs have adopted a limit of active FADs per vessel, and in the Indian Ocean IOTC has additionally limited the annual purchase of buoys per vessel.

It is clear that limiting the number of FADs used also limits the various impacts that FADs can have on the ecosystem, including those derived from the loss and abandonment of FAD structures. It is worth mentioning that the limits for the 3 oceans are on active buoys at sea and not on the actual numbers of FADs at sea. When buoy transmissions for a given FAD are deactivated, it stops counting as an active FAD at sea according to the conservation measures, but unless retrieved its structure remains at sea with its consequent impacts for the ecosystem. Nonetheless, further limiting the numbers of active FADs at sea would limit the impact of FADs and this measure could be equally implemented in the 3 oceans.

One of the challenges that researchers face now is estimating the optimal number of FADs at sea for sustainable harvesting based on science. The ideal sustainable number of FADs at sea would allow fishing efficiently at maximum sustainable yields (MSY) while minimizing the non-effective fishing effort that thousands of FADs drifting out of the fishing zone may be causing with deleterious effects for the environment.

In relation to the non-effective effort caused by lost and abandoned FADs, during the workshop FAD set maps were compared to the spatial distribution of FADs in the 3 oceans. Those maps clearly revealed that the spatial distribution of FADs is much wider than the fishing zone. One of the few studies that estimated the time spent by FADs out of the fishing zone is that of Maufroy et al. 2015, in which non-effective time out of the fishing zone was calculated using FAD trajectories from the French fleet. Without such tracking information, it would be very hard to estimate non-effective effort caused by lost and abandoned FADs. A greater understanding of FAD trajectories would allow estimating not only an effective and sustainable number of active FADs at sea but also identifying the most suitable FAD deployment areas as well as those areas with higher FAD loss risk.

There are limits on active buoys for FADs used per vessel. However, the effectiveness of these measures is unknown. Further limiting the number of FADs would limit all impacts that FADs can cause, including those derived from lost and abandoned FADs.

B. SIMPLIFYING FAD STRUCTURE

In the last decade, an increase in the depth reached by FAD structures has been observed worldwide (Murua et al. 2017). Large, deep-reaching FADs were originally used in the Atlantic and Western Pacific Oceans by Korean and Ghanaian fleets, so the FADs would drift slowly. Nowadays this practice has extended to other regions. The submerged appendages of FADs have increased significantly, reaching sometimes 100 m depth and occasionally exceeding this depth (Hall and Roman, 2013). Apart from the increase in depth, FADs have evolved to be more sophisticated and complex, having net panels acting as anchors to allow drift speed decrease.

Logically, a longer and more voluminous FAD structure made with synthetic materials will have a greater impact on the ecosystem when it strands on the coast or sinks. While a limit on the number of FADs could limit these impacts, the fact that the structures have increased in size reduces the expected positive effect of the decrease in the FAD numbers.

From the fishers' point of view, in general, FADs with deeper structures are more likely to aggregate tuna, and their success is related to deeper FADs causing slower drift. This is true except for areas where tunas are feeding near the sea surface layers, in which case FADs with shallow submerged structures would be more effective. There is little scientific evidence on the effect of different FAD depths on the ability to aggregate tuna. A study by Lennert-Cody et al (2007) showed that FAD depth could be a significant factor in explaining the catch of bigeye tuna (*Thunnus obesus*) in the EPO, but factors such as the area and time of fishing also were significant. It is difficult to know the depth at which a FAD´s structure actually works, because currents may modify the depth reached by FAD's tail. On the one hand, it is possible that over time the structure changes its configuration and breaks, or loses or gains weight, changing the depth reached. On the other hand, the drift would change depending on the structure of the water column. The depth of the mixed layer and the currents in the water column could cause two FADs of different depths to drift the same — or they could, in areas where internal waves are generated, drift differently. ISSF conducted an experiment in the EPO with 300 FADs to compare the ability to aggregate bigeye between the traditional FADs used in the EPO of 36 and 47 meters deep and FADs with 5-meters-deep appendages (Restrepo et al., 2018). This experiment resulted in no significant differences in drift velocity between the two types of FADs, nor in their ability to aggregate tuna and species composition. The area of this experiment was a region where the thermocline is shallow, so it is not known if these results could be extrapolated to other regions. At least for the study area of this experiment, it seems that a much simpler structure could provide the same catch result as a deep FAD structure. Deep and more complex FAD structures are more expensive and, from the logistical point of view, are more difficult to construct, handle, retrieve and store.

Therefore, one of the potential solutions to the impact of the structure of FADs is to simplify it by reducing both the volume (m^3) and weight (kg) of materials used in its construction. Studies examining the ability of simpler FAD structures to aggregate tuna would be desirable. During the workshop, participating fishers indicated that although they are accustomed to using deep FADs, especially in the Atlantic, they agreed that any type of structure could aggregate tuna, provided that this structure drifted slowly. From the point of view of oceanographers working with drifting structures to study oceanic currents at different depths, for a FAD to drift slowly it is not strictly necessary that it be a very sophisticated and deep structure reaching 100 m depth. According to them, it would be enough to have a rope hanging from the surface of the FAD to below the mixed layer (up to 60 m depending on the region of the ocean), and at its end a simple sail or structure similar to a floating anchor would have to be added. Possibly, a FAD of this type would derive equally slowly and its impact without the use of large net panels would be much lower.

Finally, a simpler FAD structure would allow much more efficient FAD retrieval and storage logistics. Currently the main problem when retrieving FADs, both from the coast and offshore, is the large volume and weight of the structures used. In order to retrieve FADs by hoisting a 50–100 m long structure, a mechanical crane is necessary. And for its subsequent storage onboard, a vessel large enough to carry multiple FADs is necessary. Therefore, simplifying the structure of FADs would allow not only less impact when FADs are lost, but also simplify their collection and storage process. It would be desirable to conduct studies to test the effectiveness of simpler FADs for all the reasons above.

C. AVOIDING FAD DEPLOYMENT IN AREAS THAT IMPLY HIGH RISK OF STRANDING

There are some areas that are more susceptible to stranding because the predominant currents cause the FADs to derive towards them, as can be the case of the Maldives. But there are also deployment sites that make FADs more susceptible to beaching, for example in areas where the continental slope is closer to the coast, or where there is high productivity near the coast due to upwellings, productive estuaries, etc. FADs that are deployed in these areas that also have currents with variable directions or that mainly drift to the coast, have a high probability of ending up stranded. This is the case, for example, in Mauritania or Angola, where FADs are deployed closer to the coast.

It would be desirable to identify, by ocean, which fishing areas associated with the continental slope (or more coastal) exist, study these cases in particular, and look for solutions that minimize stranding in hotspots. Some of the short- and long-term solutions could be: (i) setting deployment limits according to proximity to the coast, (ii) searching for, based on oceanographic current models, other deployment strategies in areas that minimize stranding, (iii) in the long term, to use anchored FADs in these specific high-risk areas, as is done in many other places. In the latter case, it would also be necessary to consider how the FADs anchored in those areas would be managed.

During the meeting it became clear that it would be very useful to be able to study the trajectories of the FADs to determine the FAD deployment zones that reduce stranding events and prevent ineffective effort caused by FADs that derive outside the fishing area.

D. USE FADS THAT REMAIN IN THE FISHING AREA

During the meeting, the possibility of using FADs that do not leave the fishing zone was discussed — that is, to reduce those FADs that derive far from the fishing area so that they would not have an impact on the environment or produce non-effective fishing effort. The different options that were contemplated were the following:

- ✓ <u>Use FADs with navigation capability</u>

Today, there are autonomous vehicles with navigation capacity that could be one of the solutions to FAD loss and abandonment. These autonomous vehicles that could resemble a FAD could be deployed as is done with conventional FADs and left adrift. The difference is that these, given their navigational capacity, could be redirected before they left the fishing area or before they strand on the coast. From the fishers´ point of view, the advantage provided by the navigation capacity was not clear in times of adverse sea conditions. One of the solutions that the fishers proposed was the possibility of not redirecting the FAD back to the starting point, resulting in a long way to travel to where the fisher might be interested, but rather leave them "waiting" in an area where they can go to with an auxiliary boat or another tuna boat from the company to pick them up. It would be a question of not navigating but of remaining "stationary" in an area, or at least slowing down its drift.

Another limitation of self-propelled FADs could be the price. At the moment, a FAD is cheaper than an autonomous platform with navigation capability. It was also discussed that in the case of FADs with navigation capability, the number of FADs needed would be smaller since they would be reused. Also, it would not be necessary to deploy FADs in many areas but rather to move them from one area to another.

The technology exists, and these FADs could be tested in pilot projects to know their real navigational capacity, what would be the tactic for fishing with them, and how to retrieve them in the different oceans. These pilot project results would provide feedback to improve the technology.

✓ Use FADs that could be sunk

Another alternative so that FADs do not impact the coasts could be using FADs that could be sunk at will. Considering that the largest volume of the structure is the submerged part, the tail or submerged component of the FAD could be sunk before it reaches ashore. That is to say, as done with some marine animal tracking tags, a mechanism could be added by means of which the submerged part of the FAD is freed from the superficial floating part and falls to the bottom of the oceanic floor (e.g., 3,000-6,000 m deep), preventing FAD tails from arriving at sensitive coastal ecosystems such as coral reefs or mangroves.

Although technically this solution would be possible, it did not have much acceptance among the workshop participants, basically because it is not a solution to marine pollution. It would amount to depositing all FADs on the seabed, where degradation is very slow due to lack of light and reduced availability of oxygen. There would still be an impact, even in the case of biodegradable FADs, since they would also be modifying the habitat of the seabed.

✓ Use of anchored FADs

Anchored FADs are successfully used to fish for tuna in the 3 oceans, although the vast majority of these are found in the Western Pacific Ocean. Some anchored FADs, such as those used in Southeast Asia, have proven very effective for tuna aggregation and were even exploited before the drifting FADs existed.

One potential solution to the loss and abandonment of FADs is the use of anchored FADs. Currently, as in the case in Hawaii or Indonesia, a FAD can be anchored at depths over 3000 m. The cost of an anchored FAD is a function of its anchoring depth; in Hawaii, it can be around USD 7,500 (Holland et al., 2000). This would equate to the cost of 6 drifting FADs, including the buoy, but it should be borne in mind that the anchored FADs would have a maintenance cost to add.

During the meeting, this alternative was not well received because the way in which the anchored FADs would be exploited and managed at a large scale left too many unknowns to move in that direction.

Although this is not a short-term solution, a socioeconomic study could elucidate the potential cost in terms of structures, anchoring, fuel, and fishing surveillance systems with anchored FADs compared to the costs of using hundreds of drifting FADs per vessel. An important part of the study would be to determine how anchored FADs could be managed between the various fleets and even within the companies that exploit them. There is technology that could be used for the surveillance and exploitation of anchored FADs. On a much smaller scale, there are currently large purse seine vessel companies that exploit seamounts and use auxiliary vessels that act as anchored FADs.

The use of anchored FADs, although not feasible for the total replacement of drifting FADs, could be an option for areas where fishing is more associated with the coast and where there is a high risk of stranding. These zones should be studied for each ocean.

E. RECOVER FADS AT SEA

It is inevitable that FADs will drift out of the fishing zone using today's technology. If the FAD's owner vessel is not nearby to retrieve it, most likely the owner will deactivate the satellite tracking buoy and the vessel will stop receiving its position. One of the potential solutions to FAD loss is their retrieval at sea. During the workshop, the following possibilities were discussed:

- Carry out good practices, once the FAD is fished on, in collecting the entire structure if it is not going to be productive anymore in that area or if it is at risk of drifting out of the fishing zone.

- Share the location information with other fishers, either from the same company or create a "stock exchange" of the FADs that are beyond the reach of the owner. This option does not guarantee that the FAD will be retrieved if good practices are not followed and another vessel could fish on it but not pick it up.
- The capacity of a ship to collect FADs is limited, given the large volume that FADs have today. Therefore, a simpler structure would make FAD retrieval more efficient.
- The logistics necessary to store and recycle these structures should exist on land.
- There are convergence zones where FADs accumulate in the open ocean. FADs could be collected in those high seas areas cooperatively, using an auxiliary vessel chartered by several purse seine companies for that purpose.
- The collection at sea should be studied for each ocean. In the case of the Pacific, which is very large, the cost of fuel can be an important limitation.

F. RECOVER FADS FROM THE COAST

Even following good practices, some FADs will continue beaching. Today there are projects to retrieve FADs, such as ”FAD Watch” from OPAGAC in the Indian Ocean. During the meeting, the following points were discussed in relation to the collection of FADs from the coast:

- First, quantitative data to determine priority zones for the collection of FADs from land would be necessary, taking into account both the vulnerability of each area, as well as the number of FADs that end up stranding. For this, the use of real trajectories (not necessarily in real time), or collaboration with companies supplying satellite buoys, to obtain positions once they have been deactivated would be the best options. If obtaining this information is not possible, modeling of FAD trajectories from the last position provided by the FAD would be an alternative to calculate the stranding areas.
- FADs outside the fishing zone could be picked up by artisanal fleets by sharing the position, so they could fish on and later retrieve them. This option does not guarantee the collection of the FAD, as there are already small fleets that fish opportunistically on the FADs they find near their coasts, but do not pick them up. The collection of FADs, given their large weight and volume, requires a vessel size that is not available to many of the artisanal fleets. In addition, the vessel that would act as a collector, needs to have the technology to know the FAD position in real time which many artisanal fleets lack.
- Projects in which NGOs or community-based cleanup efforts collaborating on FAD collection could be another option, but it also requires boats with communications, space, and sufficient autonomy to be effective for FAD retrieval. FADs that are constantly drifting are not easy to find even knowing their position; the sea and weather conditions and the experience of the seeker are crucial. Also, it appears that the distance between FADs, on many occasions, is too distant for a single vessel to collect a significant number of them.
- For the two previous options, there should be a plan for the management of FADs on land since there are many islands that are not prepared to process or recycle the volume of FADs that could be disembarking to their coasts.

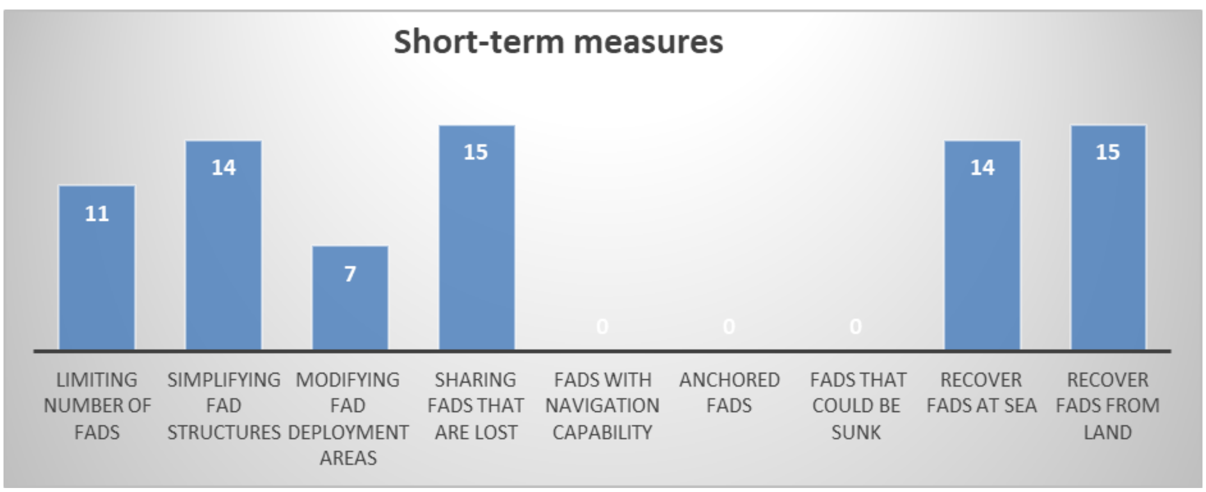
2.2.5. Feasibility of the potential solutions over time

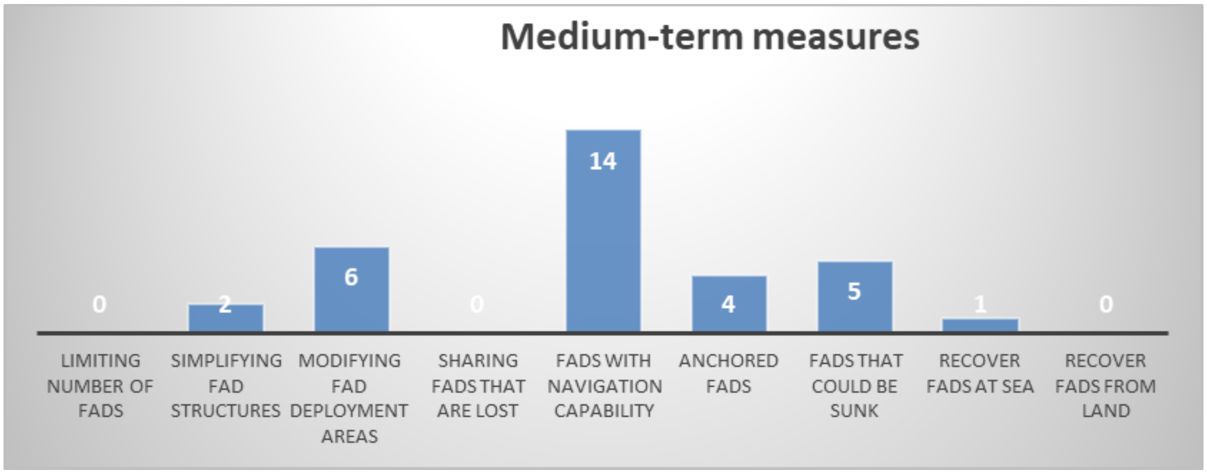
To conclude the workshop, a survey was conducted with the 16 participants, both fishers and scientists, on the feasibility of the different options that had been discussed. To this end, each of the participants was asked to identify those measures that could be implemented in the short term, those that could be implemented within a period of 10 years (once more studies have been done or the technology is available), and finally, those options that should be completely discarded — that is, options that they thought would never be effective or viable.

The different options they were given to consider were:

1. Limiting number of FADs
2. Simplifying FAD structures
3. Avoiding FAD deployment areas that imply high risk of stranding
4. Sharing FADs that are lost or out of the range of the owner
5. FADs with navigation capability
6. FADs that could be sunk
7. Anchored FADs
8. Recover FADs at sea
9. Recover FADs from land

Figure 11 shows the results of the options chosen by the 16 participants based on the time necessary for their implementation, measures that could be used in the short term, medium-term measures and measures that should be completely discarded:





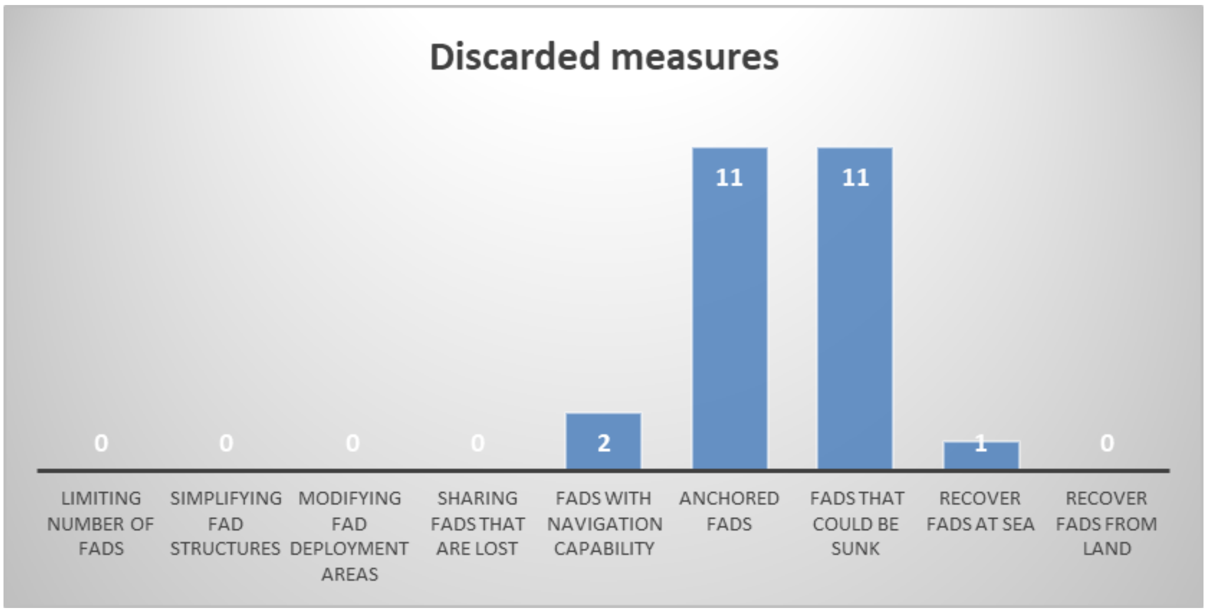


Figure 11. Options selected by the workshop participants to reduce the impact of FADs, based on the time of implementation of the measures

The result of the survey clearly shows that most of the measures could be implemented in the short term, except the use of anchored FADs, FADs with navigation capability, and FADs that could be sunk. Most of the participants considered that FADs with navigability could be used in the medium term once tests have been carried out and the technology is evaluated. In the case of anchored FADs, most of the participants discarded them because of the difficulty of managing fishing access to them and assigning them to the different fleets and vessels within each company. The few participants that opted for the implementation of the anchored FADs in the medium term did so considering their use only in very specific high stranding zones, rather than as a complete replacement of drifting FADs by anchored ones. In the case of the FADs that could be sunk, most of the participants discarded them because they considered that they did not solve the problem of marine litter. The few participants who chose to place FADs that could be sunk as an alternative in the medium term thought that biodegradable FADs would not have an impact on the deep-sea ecosystem. One participant completely discarded FAD collection in the open ocean as an option — in this case, it was a skipper fishing in the Pacific Ocean whose opinion was that the distances to travel are too long to make it viable. The modification of deployment areas to avoid stranding and make the life of the FAD more effective was selected by some participants as a short-term measure and for other participants as a longer-term measure. The latter thought that studying real FAD trajectories was necessary to develop this idea appropriately.

Finally, **Figure 12** provides a synoptic view, from the surveys to the workshop participants, of the different measures that could be used to reduce the impact of the FADs that are lost or abandoned, taking into account the implementation time, as well as those ideas discarded completely.

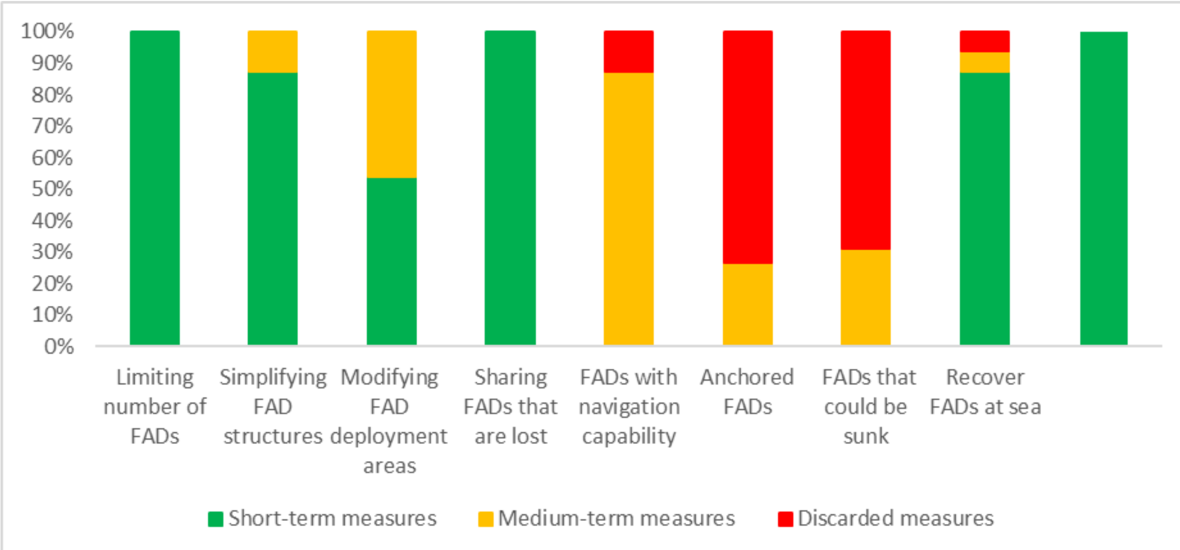


Figure 12. Synoptic view, from the surveys to the workshop participants, of the different measures that could be used to reduce the impact of lost and abandoned FADs.

2.3. Design workshop on the use of biodegradable FADs in Ghanaian purse seine and pole and line tuna fleets

Background

The present section summarizes a workshop conducted by ISSF with the Ghanaian purse-seine and pole-and-line tuna fleets, to design biodegradable Fish Aggregating Devices (FADs). This workshop is one of the first steps of a project funded by the FAO-GEF Common Ocean Project to test biodegradable FADs with one of the most important fleets in the Eastern Atlantic, with 26 vessels fishing with FADs. The aim of the workshop was to find an appropriate FAD structure to be tested with biodegradable materials available nowadays as well as to find the best strategy to test those FADs with the collaboration of the Ghanaian fleets. Fishers worked separately in groups to design 5 biodegradable FAD prototypes. The number of experimental FADs to deploy as well as the protocol to monitor them at sea was also set during the workshop.

2.3.1. Objectives

Specific objectives in accordance with the development of biodegradable FADs were:

- To determine the structural features needed for a FAD to be productive in Ghanaian tuna fleets.
- To determine the minimum lifetime required for a FAD to be used in Ghanaian tuna fleets.
- Review the different biodegradable materials tested by scientists and fishers in previous science-industry projects.
- To design new biodegradable FAD structures appropriate to the fishing needs of the Ghanaian fleets.
- To define the protocol (or strategy) to test biodegradable FADs in real fishing conditions through the cooperation of the fleets in Ghana, with a timetable on the gradual implementation of these FADs by vessel.
- To define the data collection procedure to gather information that compares biodegradable and artificial material FAD results.

2.3.2. Results

A. PARTICIPATION

A total of 69 participants attended the workshop. Ghanaian fleets fish for tuna on FADs using two types of fishing gears, purse seine and pole-and-line. We had fishers (captains, officers and deck bosses) from the two types of fishing gears from 12 different fishing companies representing the vast majority of these fleets: D-H Fisheries, Laif Fisheries, G-L Fisheries, Trust Allied Fisheries, Rico Fisheries, BSK Marine, Africa Star Fisheries, Agnespark Fisheries, Dong Sheng Co. Ltd, World Marine Co., Panofi Co. Ltd, Asante Fisheries Co. Ltd. We also had representatives from the Ghanaian Fisheries Commission, Ghana Tuna Association (GTA), Pioneer Food Cannery, Signotrade Ltd and 3 ISSF scientists conducting the workshop.

There was high participation of fishers during plenary discussions, working in groups and later presenting their ideas on biodegradable FADs. Once again, the workshop showed the importance of involving different fishery stakeholders, e.g., fishers and scientists, to find practical solutions to reduce FAD ecosystem-associated impacts and managers — and for ship-owners to provide regulatory and economic support, respectively, for their implementation. Fishers' sum of knowledge about FAD designs specific to the Atlantic, together with that acquired by ISSF scientists in previous projects on biodegradable FADs, was of great value.

B. STRUCTURAL FEATURES NEEDED FOR A FAD TO BE PRODUCTIVE IN THE GHANAIAN FLEET

First, a discussion was conducted to determine the structural features needed for FADs to be efficient in aggregating tuna for the purse-seine and pole-and-line Ghanaian fleets. As identified in other workshops (e.g., ISSF Skippers Workshops, Biodegradable FAD Workshop in San Sebastian), FAD drift speed and trajectory was the main variable to control for an efficient fishing tool (Moreno et al. 2016). In particular, for Ghanaian fleets a slow drift of the FAD is especially important not only to aggregate tunas but also to maintain FADs within Ghanaian waters for a longer time, as many Ghanaian pole-and-line vessels only operate within their EEZ. A shallow FAD would cause FADs to drift out from the Ghanaian fishing area very fast, preventing most of the Ghanaian vessels from fishing on them. Thus, Ghanaian fleets employ especially deep FAD structures (e.g., 60-150 m) compared to other fleets to "anchor" down the FAD and achieve the slow drift needed (**Figure 13**). These deep FAD designs (sometimes referred to as "Korean-style FADs" because Korean skippers operate Ghanaian fleet vessels) were copied by other fleets like the Spanish and French in the Atlantic, and later derived to other oceans in the belief that deep FAD designs were more successful at aggregating tuna than shallower ones.

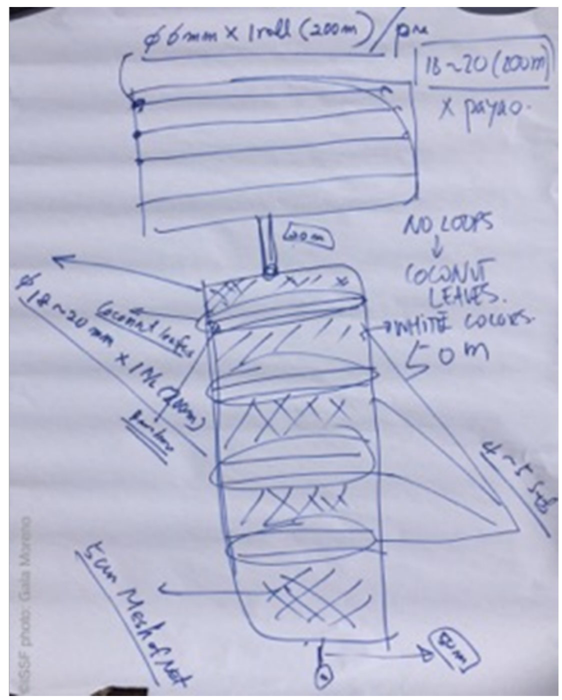


Figure 13. Left: Traditional "Korean Style" FAD design used by Ghanaian fleets. Right: Diagram of same FAD type with technical details provided by fishers during the workshop.

The traditional Ghanaian FAD is constructed with bamboo canes in the raft and plastic cork-line buoys to achieve the flotation needed. The shadow produced by the floating and submerged structure is also considered important for Ghanaian fleets in order to aggregate species that occupy the space close to the FAD, named *intranatants*[4] (*Lobotes surinamensis*, *Abudefduf saxatilis*, etc.), as they may play the role of attractors of tuna species. In general, fishers in Ghana use palm leaves to cover the raft, while strings and strips with colors are usually added to the shallow part of the

[4] Those species that move within 2 m range from the FAD. Parin, N.V., and Fedoryako, B.I 1999.Pelagic fish communities around floating objects in the open ocean. Fishing for Tunas associated with floating Objects, International workshop. Inter-American Tropical Tuna Commission (11): 447-458

submerged structure. In general, Ghanaian fleets use in the submerged part of the FAD open net panels (average size of the mesh used is 4 inches [approx. 100 mm]) as shown in **Figure 13**, to create extra-surface area for drag. Fishers said they do not use different kinds of FADs in different areas of the Atlantic. They use the same design for all their traditional FADs, the only difference being the depth of the tail appendage, which generally range between 50 to over a 100 m in depth. After the International Commission for the Conservation of Atlantic Tunas (ICCAT) adopted regulation 16/01, establishing obligatory use of non-entangling FADs by January 2017, fishers have substituted wide open net with smaller mesh sized net (e.g., small pelagic net with < 2.5 inches mesh), but the deep open-panel structure remains the same.

The purse-seine company Africa Star is the only one using another type of FAD structure, using net tightly tied into coils or "sausages" in the subsurface, which makes it a lower entanglement risk (LER) FAD (**Figure 14**). FADs are made on land and then distributed to the boats. The use of this LER FAD is not a fishers' choice but rather a company policy. Fishers do not like the "sausage" FADs because they think that the drift is too fast and that they attract less tuna than open panel traditional "Korean style FADs." For the raft they have decided to not use any kind of netting or cover, just the bamboo and corks. This makes the raft a non-entangling (NE) one. When asked if they have more FADs stolen due to greater visibility of rafts without a dark cover, the answer was no.

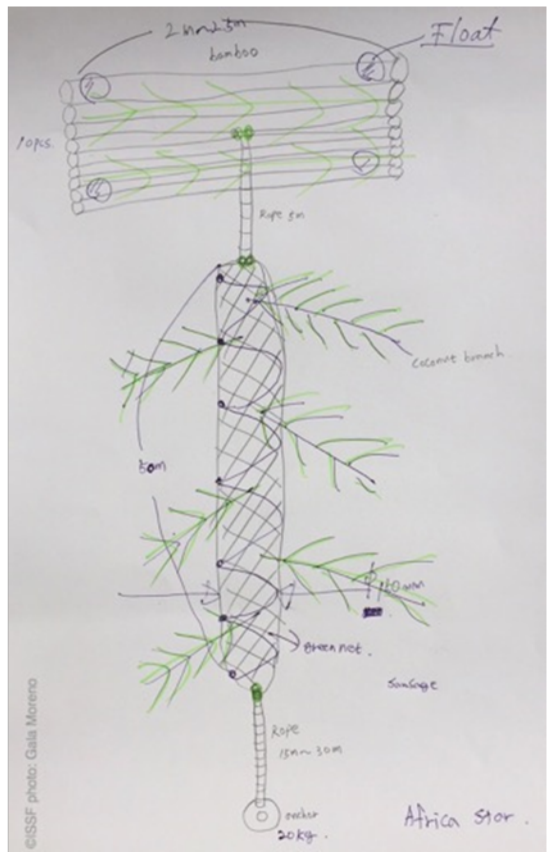


Figure 14. Left: Net tied in "sausage" Low Entanglement Risk FAD used in Ghana (©F.Iriarte). Right: Diagram of same FAD with technical details provided by fishers during the workshop.

C. LIFETIME OF A BIODEGRADABLE FAD TO BE USEFUL FOR FISHING BY GHANAIAN FLEETS

The required lifetime of a FAD (i.e., time the FAD remains working adequately at sea from deployment before significantly deteriorating) for a given fleet/ocean heavily relies on FAD fishing strategy of the fleet. The life duration of the Ghanaian FADs is between 9 months and one year, and this is what fishers expect the working life of a biodegradable FAD should be. The longer duration of FADs for this fleet compared to others (e.g., EU fleets say FADs last 3-9 months) is probably associated with the regular maintenance work (i.e., repairing deteriorated parts by replacing with new materials) Ghanaian fishers do on each FAD at least every 3-4 months. Pole-and-line fishers explained that they retrieve their FADs before they drift out of Ghanaian waters (approximately every 2 months), so that they can refurbish them to redeploy them. A FAD is considered no longer in a sufficiently good working state worthy of repair beyond the times specified above. Thus, after a working period of a year, FADs should degrade as fast as possible.

D. REVIEW OF THE DIFFERENT BIODEGRADABLE MATERIALS TESTED BY SCIENTISTS AND FISHERS IN PREVIOUS PROJECTS AND THEIR ADEQUACY TO THE TUNA GHANAIAN FLEETS

During the meeting, a review of the different experiments conducted by both scientists and fishers was done (Franco et al., 2012; Goujon et al., 2012; Moreno et al., 2019; Murua et al., 2018). The behavior, resistance, biofouling, price and other issues were discussed for materials from natural origin as well as for other alternatives that come from non-natural origin. The following items were discussed and agreed from the results of this review:

Submerged structure of the FAD

Biodegradable ropes made with cotton have shown higher breaking strengths and durability over time. Fishers participating in large-scale biodegradable FAD experiments in the Indian Ocean are using them, as well as some of the experimental biodegradable FADs tested in the Eastern Pacific Ocean. There are 2 types of cotton ropes that have been tested so far, one with the capability of adhering biofouling (similar to ropes used to grow mussels in aquaculture) and others that do not enhance biofouling (**Figure 15**). The latter would allow the structure of the FAD to be more stable over time, while the biofouling adhering type will aggregate encrusting organisms, which some fishers believe is good for fish attraction during the FAD colonization phase — but could also incrementally increase the weight of the structure over time (these hypothesis (fish attraction and increased weight of the FAD due to biofouling, have not been tested yet).

Figure 15. Left: 20 mm cotton rope; Right: Cotton rope with loops to allow bio-fouling

Ghanaian fleet fishers at the workshop liked the cotton rope without loops (e.g., no biofouling) to support the main submerged structure of the FAD. However, they did not consider necessary the rope with the loops as they use other “attractors” as palm leaves submerged and attached to the main structure (**Figure 13**). Thus, for the Ghanaian fleets, biodegradable FADs only made from plain cotton rope without loops would be required.

Biodegradable canvasses made from cotton were identified as a good alternative for underwater flags or “sails” attached to the submerged structure of the FAD, both to create more volume and shadow as well as to function as drift anchors that slow down FAD movement (**Figure 16**).

Surface structure of the FAD

One of the most critical parts of constructing a FAD is the buoyancy of the whole structure. A FAD’s lifetime depends in many cases on the adequate assessment of the buoyancy needed for a given FAD structure and weight. Thus, it is necessary to precisely calculate FAD buoyancy requirements (including the weight it will gain over time through water absorption and biofouling) to be actively working during the desired time period. Currently biodegradable alternatives to artificial floating materials used in FADs such as PVC pipes, purse-seine net corks, plastic buoys, containers or drums are scarce. These are the main flotation components that were discussed for the Ghanaian case:

Bamboo canes have been used for many years to build FAD rafts. One of the principal difficulties with using only bamboo is that it loses buoyancy over time due to water absorption through the canes’ pores, eventually making the FAD sink. Fishers in Ghanaian fleets use bamboo canes in the raft; however, they still need to add plastic flotation to prevent the FAD from sinking. Perhaps an appropriate treatment of bamboo canes with natural varnishes or other protective methods would extend their lifetime up to the required time (e.g., one year), but this possibility has not been tested yet.

One of the few alternatives presented during the workshop was balsa wood (*Ochroma pyramidale*). This wood well known for its great buoyancy could be the best biodegradable alternative identified at present for the floats of FADs. Fishers at the workshop were surprised about the characteristics of this wood unknown to them. However, it is not clear if this wood is available in sufficient quantities in Ghana or neighboring African countries.

In previous workshops with other fleets (e.g., Spanish, French), dark-colored cotton canvas was also identified as a good biodegradable alternative to cover the raft to provide consistency to the structure and shadow to attract fish. Fishers from Ghana did not consider it necessary to cover the FAD´s raft, so this possibility was discarded.

Figure 16. Cotton canvasses of various thicknesses

E. BIODEGRADABLE FAD DESIGNS TO BE TESTED IN GHANAIAN FLEETS

One of the main objectives of the workshop was to design biodegradable FADs that could be tested at sea in the near future, using biodegradable materials available in the market. As a workshop activity, fishers were divided into 5 working groups to propose their best biodegradable FAD designs (**Figure 17**). Selected materials for the different FAD designs were:

- Bamboo canes (floating and submerged structure)
- Cotton rope without loops (submerged structure)
- Cotton canvas (submerged flags and drift anchor)
- Palm leaves (submerged structure)
- Plastic buoys or purse seine corks[5] (floating structure)

[5] Although buoys or purse seine corks are not biodegradable, they were considered necessary during the trials to get data from the diverse biodegradable materials being tested. Some of the experiments at sea conducted in the Atlantic failed because all the FADs sank, and no data was retrieved. The buoyancy needed for a given structure needs to be tested by monitoring the bio-fouling adhered to the different parts of the FAD. To avoid potential sinking of experimental FADs during these initial trials, plastic buoys could be used to provide extra buoyancy and ensure data is gathered for these experimental FADs.

In total, 5 biodegradable FAD prototypes were designed (**Figure 18-22**). Most of the FADs reached more than 100 m depth. The shallower FAD was 60 m depth, and the deepest FAD structure reached 120-170 m total depth. All FADs were designed using biodegradable structures for tail and rafts, except for the plastic buoys as floats (to prevent experimental FAD sinking during initial trials to test biodegradable structures and thus get results on their performance). Although fishers worked in 5 different groups separately to design 5 biodegradable FAD structures, the designs converged towards a similar structure for pole-and-line and purse-seine fleets, a non-entangling Korean Style FAD with biodegradable materials.

Figure 17. Ghanaian fishers designing biodegradable FADs.

The following biodegradable FAD designs are the result of the work in groups:

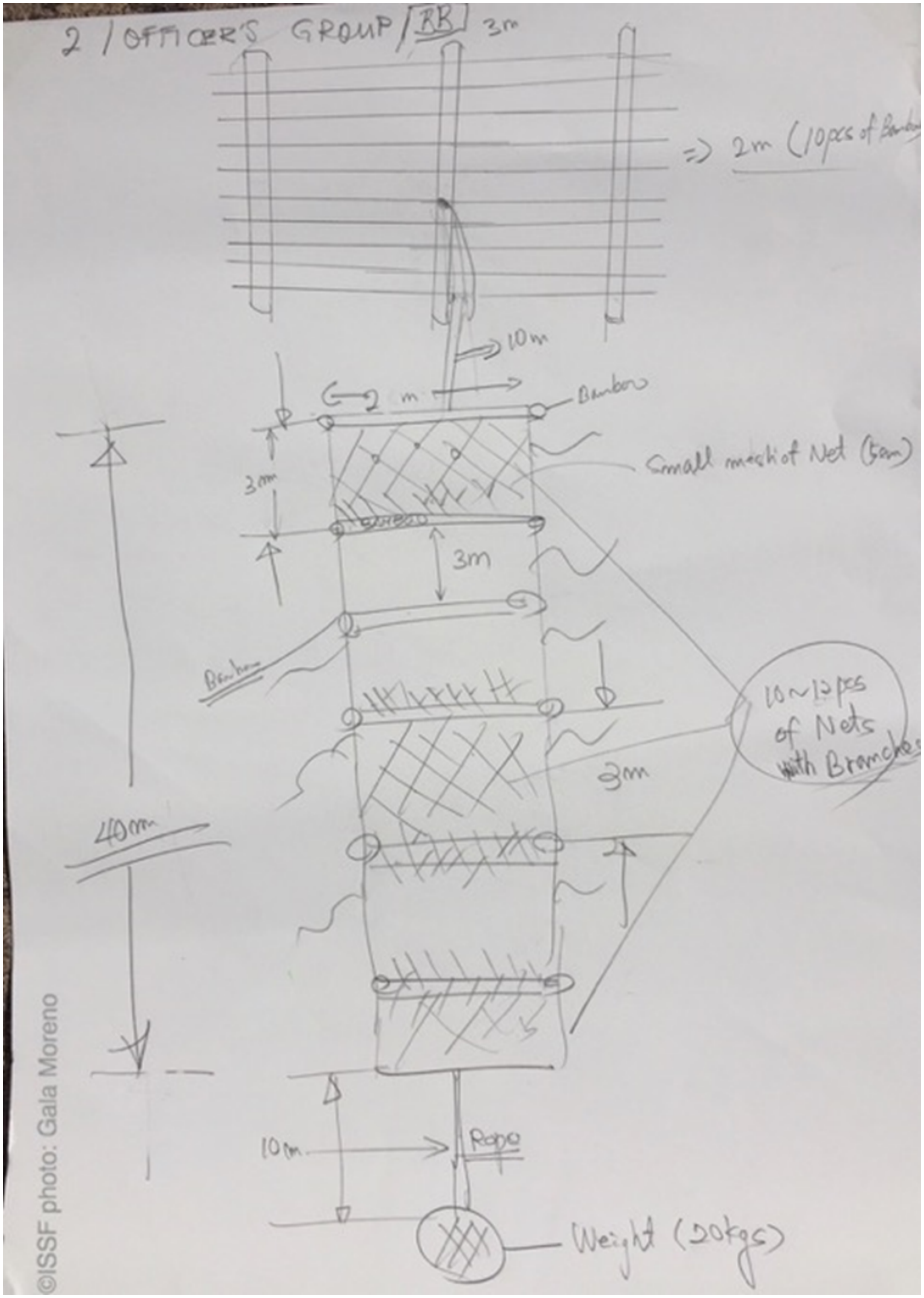


Figure 18. Biodegradable FAD designed by group 1.

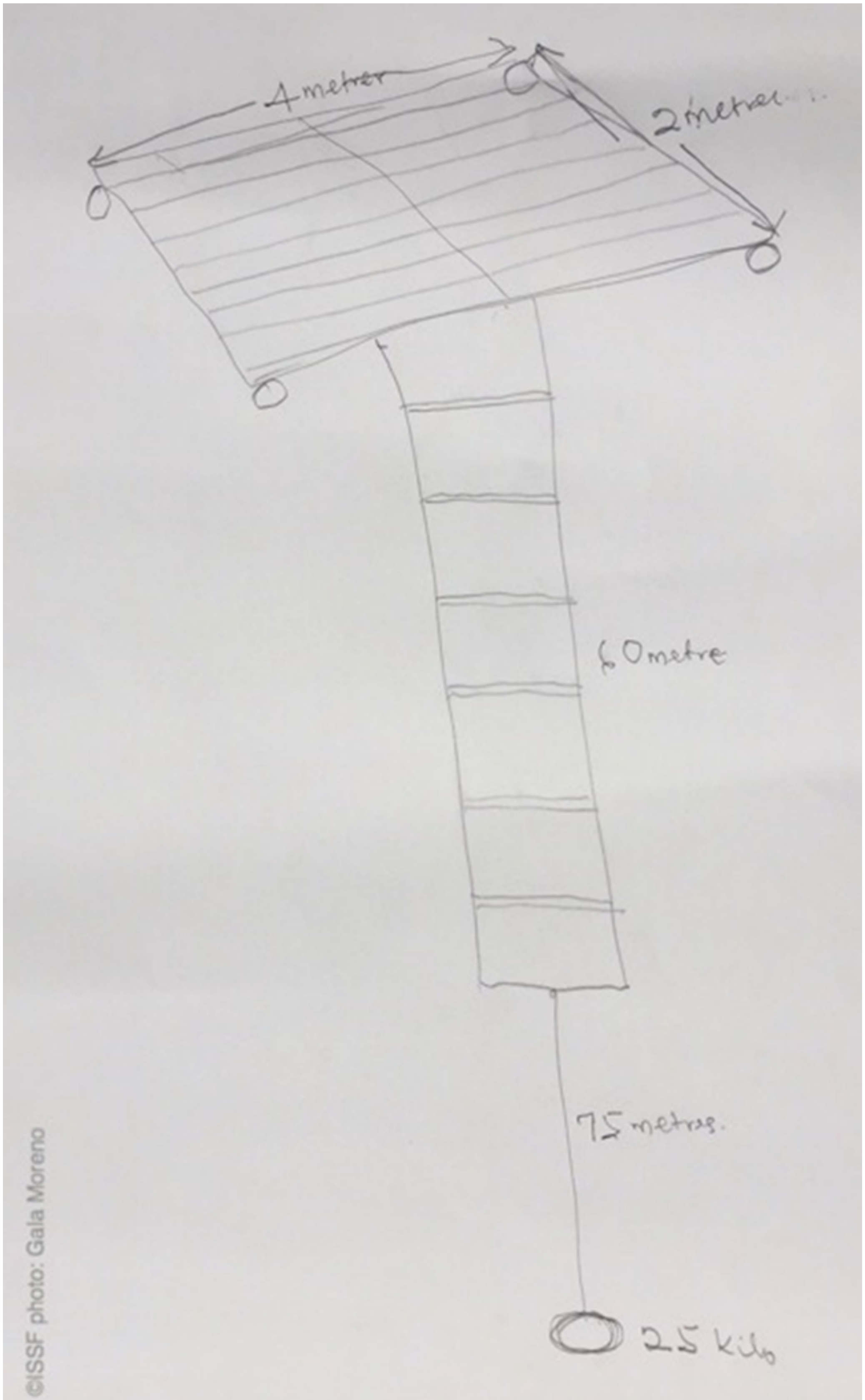


Figure 19. Biodegradable FAD designed by group 2.

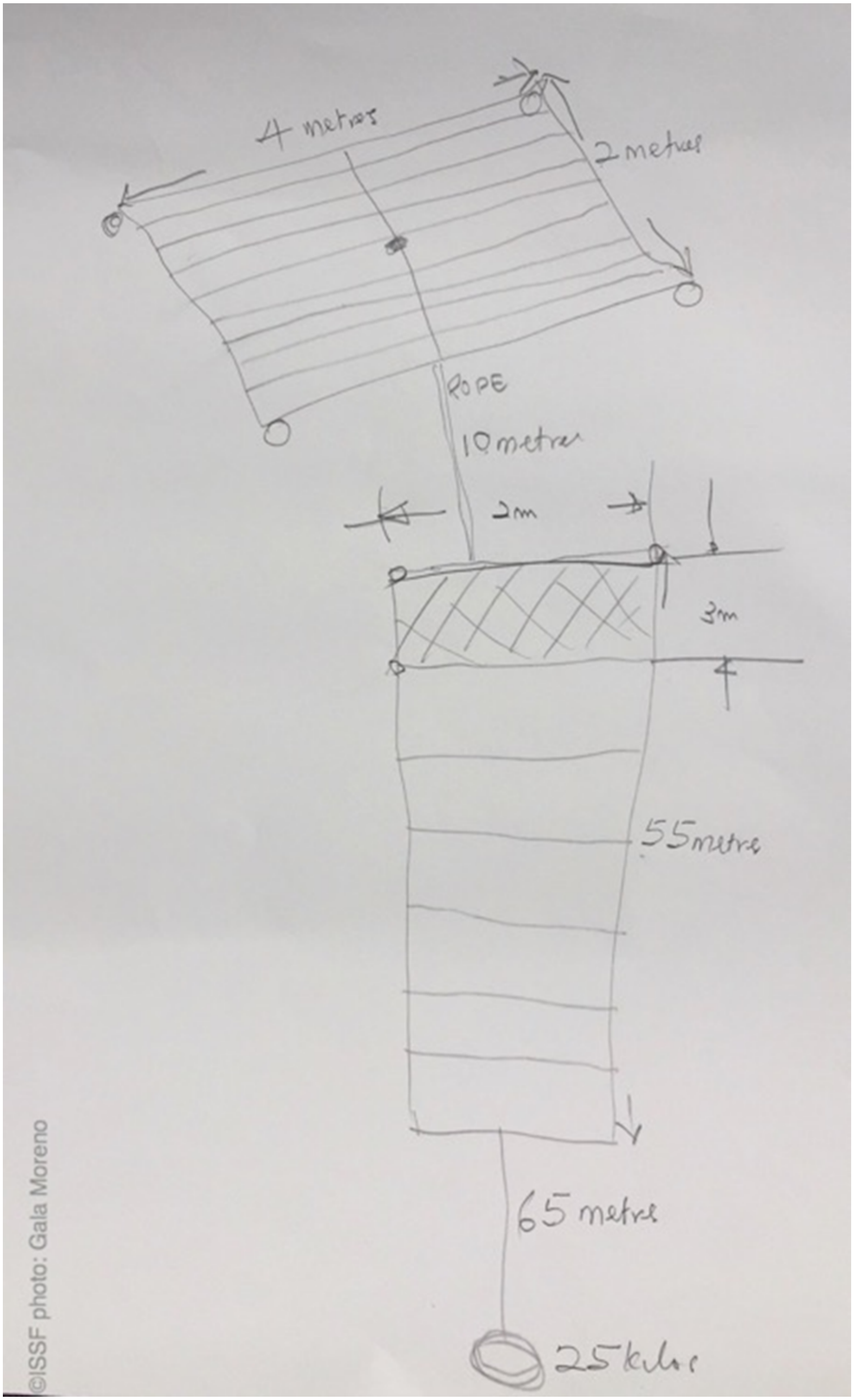

4 metres
2 metres
ROPE
10 metres
2m
3m
55 metre
65 metre
25 kilos
©ISSF photo: Gala Moreno

Figure 20. Biodegradable FAD designed by group 3.

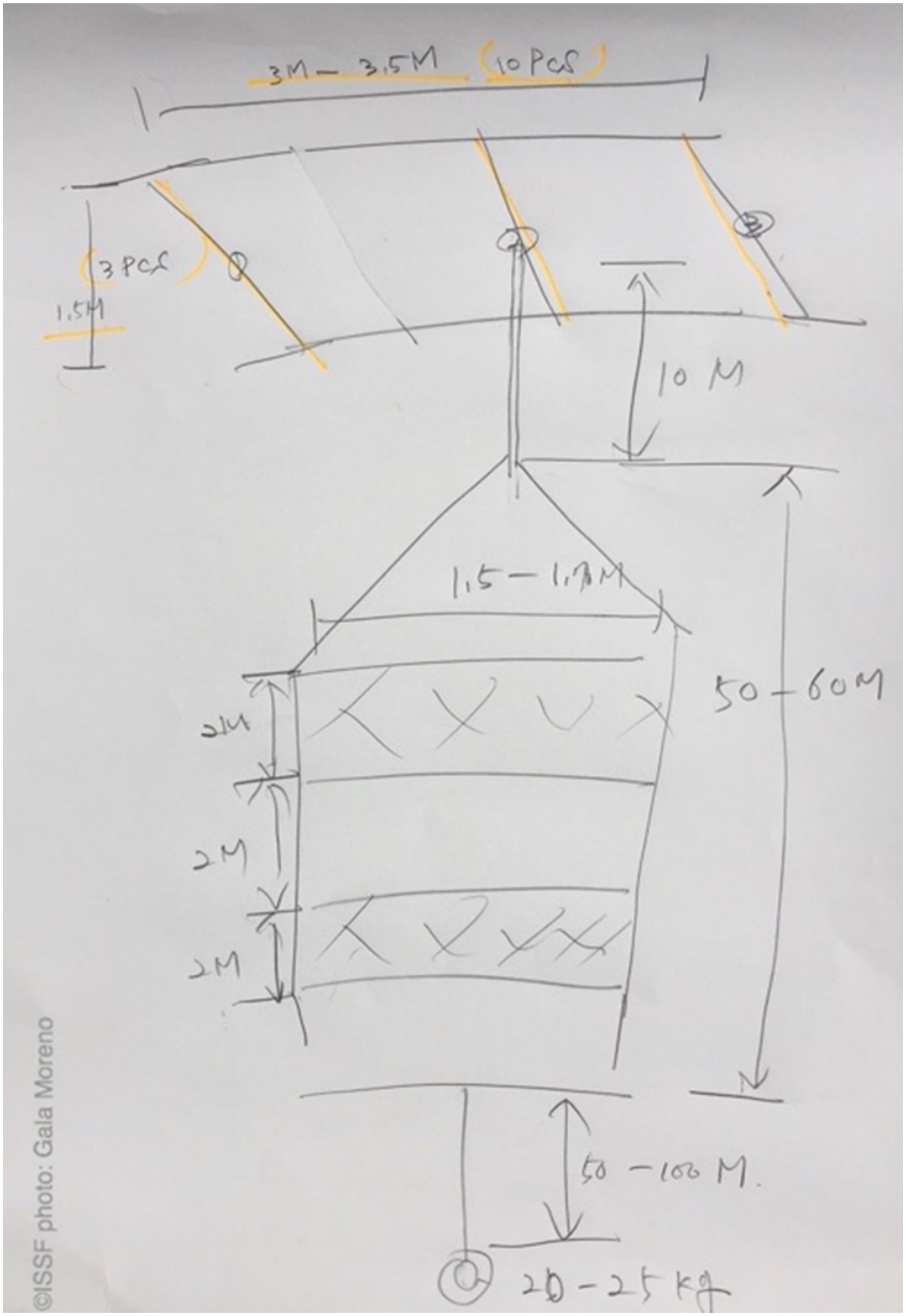


Figure 21. Biodegradable FAD designed by group 4.

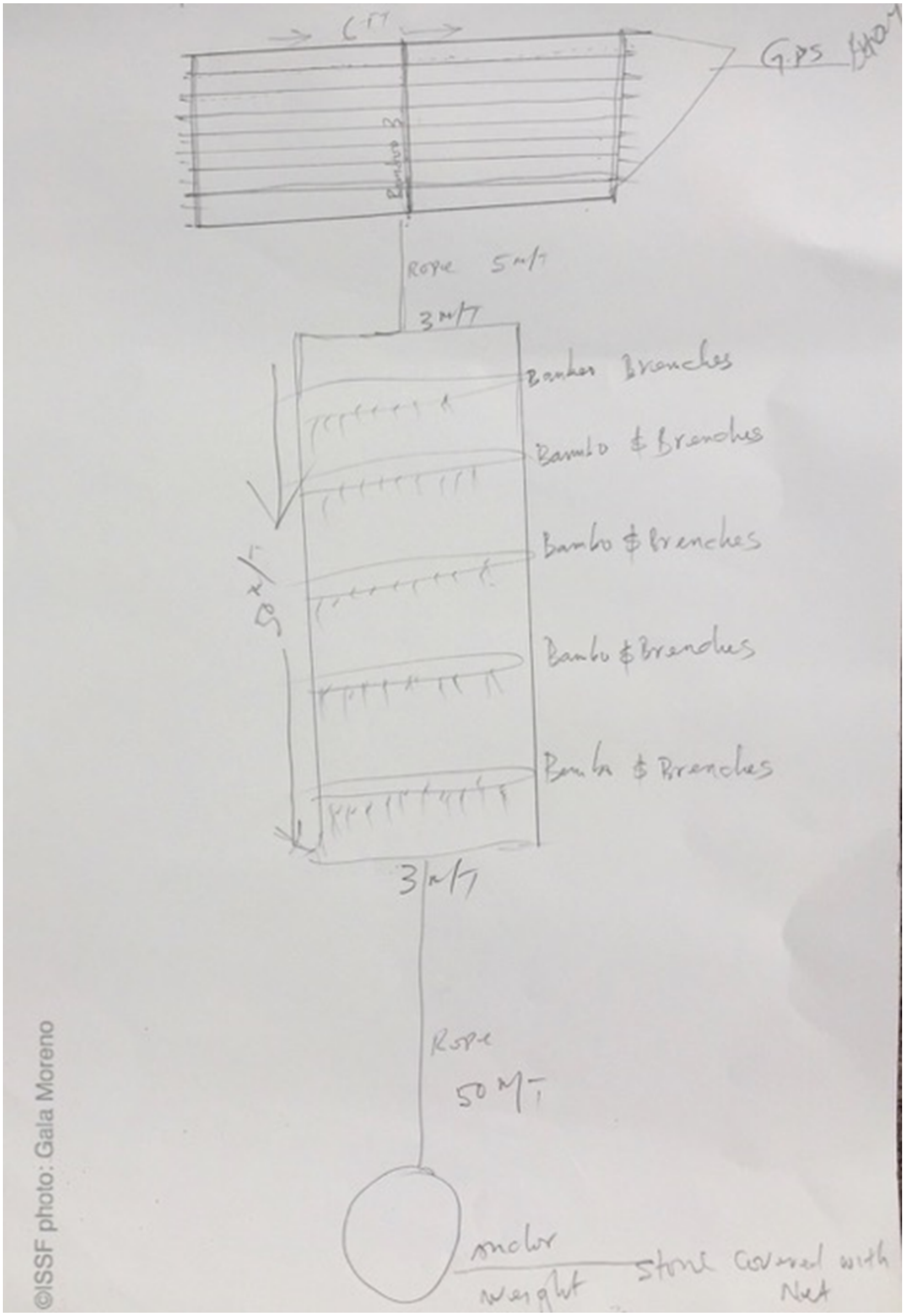


Figure 22. Biodegradable FAD designed by group 5.

F. STRATEGY TO TEST BIODEGRADABLE FADS DURING FISHING OPERATIONS

Once the different biodegradable FADs were designed and presented to the rest of the participants, discussions were driven to define an effective strategy to test them in real fishing conditions. Until now the strategy of deploying a reduced number of experimental FADs has consistently been unsuccessful, as stated earlier in this document, due to the difficulty of revisiting and getting information on few experimental FADs when FAD loss rates are substantial (e.g., loss to other vessels, through sinking, beaching, etc.). Thus, for all participants it was clear that a large enough threshold number of FADs should be deployed, and that the collaboration of the different fleets was necessary to achieve an efficient monitoring of the evolution of the FAD structure over time. Hence, for the success of the trials with biodegradable FADs, the following protocol was proposed:

- Every vessel from the Ghanaian Fleet should build and deploy 5 biodegradable FADs every trip (approximate trip length estimated at 45 days), during 4 consecutive trips. Thus, a total of 20 FADs would be deployed per vessel over 6 months for the project.

- ISSF would provide the material to build the submerged part of the biodegradable FADs (i.e., rope and canvas). ISSF will also provide extra biodegradable material to allow experimental FAD repairs when needed.

- Bamboo canes and palm leaves for the raft would be provided by fishing companies as well as the buoy to track the FAD. These are materials they are already buying for traditional FADs.

- Fishers will repair biodegradable FADs, if needed, using the extra biodegradable material provided by ISSF or biodegradable materials of their own (e.g., bamboo).

- Since the objective is to monitor the time evolution of biodegradable materials and assess the buoyancy of the FAD, non-biodegradable flotation could be added at the beginning to guarantee that FADs do not sink and that data will be collected.

- Experimental FADs should be deployed in the same area and time as traditional FADs, so their effectiveness could be compared to traditional FADs for the same spatial and temporal strata.

- Provide information on the time evolution of biodegradable FADs encountered at sea, both through a template filled by the officer and by the observer. The project aims at following the structural state and tuna attraction ability of biodegradable FADs over one year, if possible.

- Deployment site, type of biodegradable design and the code of the geo-locating buoy should be registered. Every FAD should be well identified so that data can be retrieved and followed by the different owners.

- If a biodegradable FAD is encountered at sea, the following data should be registered: the catch (if any), the structural condition of the FAD and the new code for the buoy if the original one has been replaced.

- Ghanaian fishers agreed to provide the trajectories and biomass of echo-sounder buoys attached to biodegradable FADs, this data would allow assessing the capability of biodegradable FADs to aggregate tunas even if they are not visited or fished on, as well as following their lifetime if they are not retrieved by the owner vessel.

- A Ghanaian consultant hired by ISSF through ABNJ funding would be in charge of gathering experimental biodegradable FAD results from the boats, monitoring that the correct information is being collected by fishers and observers, creating a database, and analyzing the data.

- The deployment to test biodegradable FADs would start as soon as the biodegradable materials arrive in Ghana. Meanwhile, a database would be created and meetings with Ghanaian fleets conducted to inform about the progress of the project and data collection protocols.

G. RETRIEVING FADS

Even if biodegradable FADs will considerably reduce the ghost fishing and pollution impacts on marine ecosystems, it will not completely remove all impacts. Retrieving FADs that beach in critical areas of particular vulnerability, such as coral reefs, was discussed in a separate workshop (ISSF Skippers Workshop) the following day. Several alternatives such as having specialized clean-up groups on land or vessels at sea, or each boat collecting their derelict FADs before they sink, were mentioned.

2.3.3. Conclusion

Participants at the workshop, primarily fishers and ship-owners, were very collaborative in explaining their types of FADs and fishing strategies and trying to find new designs for biodegradable FADs to be tested in Ghana. Fishers worked in 5 different groups to design 5 biodegradable FADs. However, those designs converged towards a very similar biodegradable FAD design, which resembles the structure of the FADs they commonly use (i.e., open panel deep-tail “Korean style”) but with plant-based natural materials. Biodegradable materials will be sent to Ghana so that fishers in collaboration with ISSF can test them during fishing conditions in large quantities (e.g., $\approx$ 600 biodegradable FADs). The main challenge for now is to find a successful biodegradable alternative to the artificial floats (purse seine corks, buoys, etc.). However, having 90% of the structure of the FAD constructed with biodegradable materials such as cotton would be a huge step towards minimizing FAD impacts on the ecosystem. Fishers clearly understood the benefits of using biodegradable FADs and were keen to collaborate at sea to collectively test new biodegradable materials and designs for non-entangling FADs.

2.4. Evaluating the lifetime of biodegradable ropes in controlled conditions

Background

Scientists working on FAD research as well as the fishing industry are well aware of the impacts that FAD stranding events can cause on reefs and in coastal ecosystems, and have been working since 2007 to develop FAD structures that minimize this impact (Franco et al. 2012; Goujon et al. 2012; Lopez et al. 2016; Moreno et al. 2016, 2017, 2018, 2019). Among other experiments, trials with FADs made of diverse materials from natural origin were conducted in real fishing conditions. One of the main difficulties encountered during the trials at sea was the lack of sufficient observations during the life of experimental biodegradable FADs. Fishing companies in general deployed few FADs to test at sea. This is mainly due to the fact that a given vessel cannot "risk" using a high number of experimental FADs to fish, as their success is under trial. In addition, the cost of FAD tracking buoys and the communications needed to track them is high, so the number of experimental FADs they trialed is usually limited. A high percentage of FADs deployed by a given vessel is found and appropriated by other vessels, or end up lost or sinking. As a result, the number of experimental FADs deployed by fishing companies individually has not been sufficient to obtain significantly robust results on the evolution of biodegradable FADs as well as on their operational lifetime.

Due to the lack of data on the behavior of biodegradable materials while testing experimental FADs in real fishing conditions, ISSF in collaboration with FAO Common Oceans Tuna Project launched a project to evaluate the fate of 3 different types of biodegradable ropes under controlled conditions. The present section summarizes the results of a project to test the lifetime and robustness of biodegradable ropes to be used on FADs.

2.4.1. Objectives

The general objective of the project was to identify the most promising biodegradable materials to be used in FADs. This objective would allow moving towards the second step: fishers testing biodegradable FADs in real fishing conditions, with a greater chance of success.

Specific objectives to achieve the general aim of the project were:

(i) to select the most appropriate biodegradable material and ropes among those with potential to be used on FADs

(ii) to study in controlled conditions the behavior of selected materials with time, measuring their breaking strength.

2.4.2. Material and methods

A. BIODEGRADABLE ROPES SELECTION FOR THE TESTS

Which is the best definition for a biodegradable material to be used at FADs?

This is one of the first questions to address when looking for an alternative to current plastic components in FADs. The term "biodegradable" is broadly applied to materials or substances that are subject to a chemical process in which microorganisms in the environment convert the original material into natural substances such as water, carbon dioxide, etc. The process of biodegradation depends on the surrounding environmental conditions (e.g., location, composition of the medium and temperature) and on the material and on the application (i.e., thickness). It is necessary to account for the time frame required to consider it biodegradable. In the case of FADs, a workshop with scientists and fishers on biodegradable FADs showed that the time needed for a biodegradable FAD at sea to be useful for fishing was a maximum of one year (Moreno et al. 2016, 2018). Thus, after being operational for one year, the FAD should degrade as fast as possible.

Although the time frame needed for a FAD to be useful for fishing is known, the absence of a clear regulatory framework defining the standards of what constitutes a biodegradable material in the marine environment prevents a clear definition for the type of materials that could be permitted in biodegradable FADs construction (Zudaire et al. 2018).

To move forward on the use of biodegradable FADs, we adopted the following criteria of a biodegradable material for our tests at sea:

"A non-entangling material made of 100% plant fibers that are sustainably harvested."

What are the features needed for a given biodegradable material to be used successfully in FADs?

To select the most appropriate materials to be tested in controlled conditions, a series of meetings with fishers, rope manufacturers and scientists was held. In addition, during regular skippers' workshops, ISSF scientists discussed with fishers the potential for different materials as well as the features needed for a given material to be used in FAD construction (Murua et al. 2018).

Many different materials from natural origin were considered, such as linen, cotton, manila hemp, sisal, coconut fiber, jute, bamboo, etc. From what we learned during workshops and from previous experience testing coconut fibers in Hawaii (Restrepo et al. 2018), to select the most appropriate biodegradable materials for tests the following criteria was taken into account:

- 100% natural origin: ropes should be made from 100% plant-based or other natural materials.
- Accessible & available in great quantities: The material should be available in sufficient quantities to replace current materials used at FADs.
- Available as close as possible to fishing grounds: to avoid ecological and economic transportation costs.
- Processing qualities: Feasibility to be processed for rope-making. To replace current materials used at FADs and avoid the use of nets (to follow non-entangling FADs design criteria), ropes were considered the most appropriate configuration of natural fibers to be tested.
- User-friendly: Rope diameter and materials should be easy to handle onboard. In order to construct FADs, the diameter as well as the material of the rope should be flexible and ductile enough to allow easy handling onboard.
- Cost: The cost of a regular non-entangling FAD without the buoy is around $300- $500 depending on the size of the FAD. In order to replace current FADs, biodegradable FAD costs should not be significantly higher than for traditional FADs.
- Strength durability: Most of the fleets in the workshops held by ISSF set a maximum of one year as the ideal lifetime for a FAD to be productive for fishing.

Based on these criteria, the following ropes were selected as the most suitable for our tests (**Figure 23**):

- Type 1: Twisted 100% Raw cotton rope: 20 mm diameter, 4 strands in torsion Z, 1645 Kg breaking strength
- Type 2: Twisted 50% cotton and 50% sisal rope: 20 mm diameter 4 strands in torsion Z, 1144 Kg breaking strength

- Type 3: Cotton, Sisal and linen rope with loops (similar to those used in mussel farming but made of natural origin): 16 mm diameter core with loops, 194 Kg breaking strength.

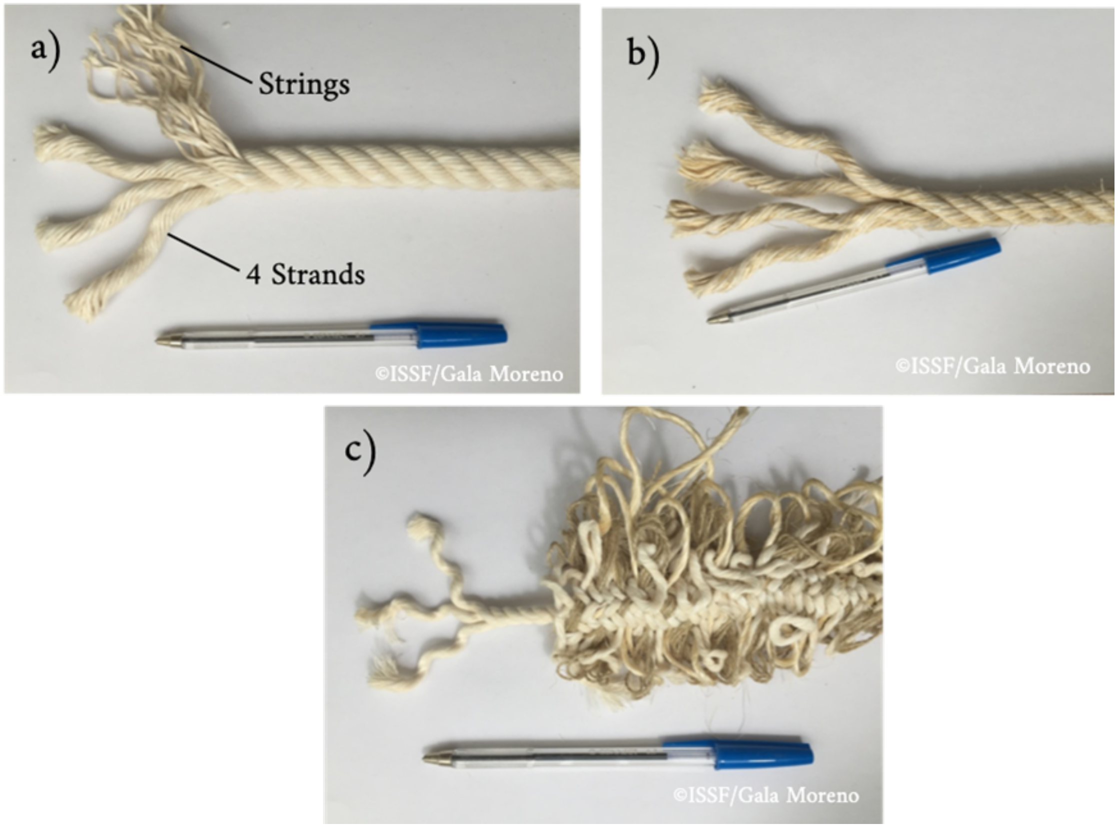


Figure 23. Selected ropes to be tested in controlled conditions.

The rope with loops (**Figure 23c**) was chosen by fishers due to the surface provided for fouling organisms, such as barnacles. Some fishers consider FADs that accumulate more biofouling to have greater fish aggregating potential.

B. STUDY SITE AND DATA COLLECTION

Maldivian waters were selected for a test to monitor the evolution of biodegradable ropes in controlled conditions. On one hand, their light and water characteristics were similar to those of tropical tuna purse-seine fishing grounds found in the Western Indian Ocean. On the other, the facilities of Maldives Marine Research Center allowed for close monitoring of the experimental ropes.

Samples were deployed in June 2016 in 2 different sites simultaneously (**Figure 24**): (i) in offshore waters attached to a mooring rope, experiencing tropical pelagic environment conditions and (ii) in a shallow lagoon close to the reef in Maniyafushi island, simulating the arrival of a FAD to the coast. These 2 different environments allowed monitoring the behavior of the ropes to simulate a FAD while in oceanic waters as well as when a beaching event occurs, checking the time that the rope remains in the reef.

The three ropes were monitored at sea for one year to measure degradation with time. In total 6 bags made of netting were deployed in each site containing 3 samples of each rope type. Two extra bags were also deployed in each site, in case one of the bags was lost or to avoid any unforeseen event that could jeopardize the completion of the experiment.

Once every 2 months, samples were retrieved from the 2 sites by a diver and the breaking strength in Kg (defined as the weight at which the strings breaks) for the 3 samples of each rope type was measured using a dynamometer.

Measurements were taken on sets of strings (cf. **Figure 23a**) — at least 3, but sometimes 4 or 5 strings. However, strings became too degraded at the end of the sixth month for rope type 3, making it impossible to use the dynamometer. From the 6th month onward, measurements were taken both on strings and strands for rope types 1 and 2. It should be noted that cotton strings in type 2 were so degraded by the end of the second month that only sisal strings were considered for data analyses throughout the study period. The amount of biofouling accumulated was also assessed and the weight of the ropes with time at sea measured.

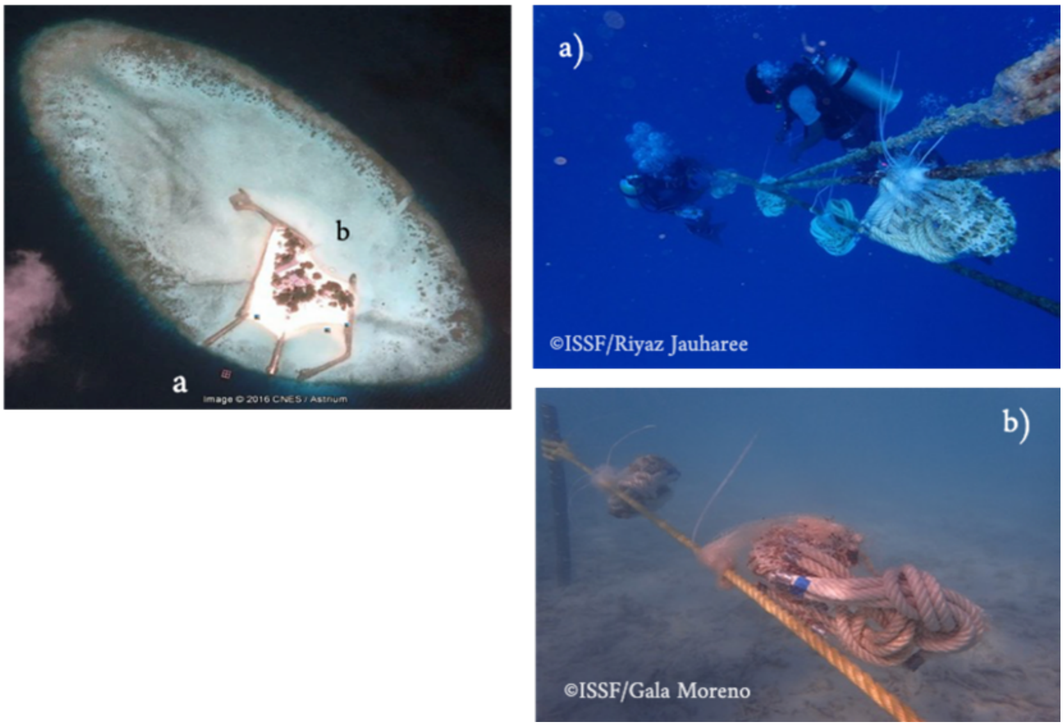


Figure. 24. Biodegradable ropes deployment sites in Maniyafushi island (Maldives) a) anchored in offshore waters , b) within the lagoon.

2.4.3. Results

Results on the breaking strength of the strings clearly showed that the most resistant rope in terms of breaking strength was the cotton-and-sisal twisted rope followed by the 100% cotton rope that had a similar degradation pattern in time (**Figure 25**). The weaker rope appeared to be the cotton looped rope, as it suffered a steep drop in the breaking strength over time, presenting after 6 months at sea a poor performance.

From month 6 onward, measurements of the breaking strength of the strands were conducted for ropes type 1 and 2 (**Figure 26**). Measurements with the strands for cotton rope and mixed cotton-and-sisal ropes, showed that the sisal-and-cotton rope was stronger than the one made of 100% cotton.

The breaking strength curve related to the time at sea for both samples in the lagoon and samples anchored offshore showed similar behavior, although degradation occurred slightly faster in the lagoon (**Figure 25 and 26**).

Type 3 rope with the loops allowed biofouling faster than the other 2 rope types in both sites. However, the 3 types of ropes were colonized by barnacles, shrimps, algae and small fish during the experiment. The ropes tested in offshore waters allowed more biofouling compared to those in the lagoon, probably due to the accumulation of sediments in the ropes at the lagoon.

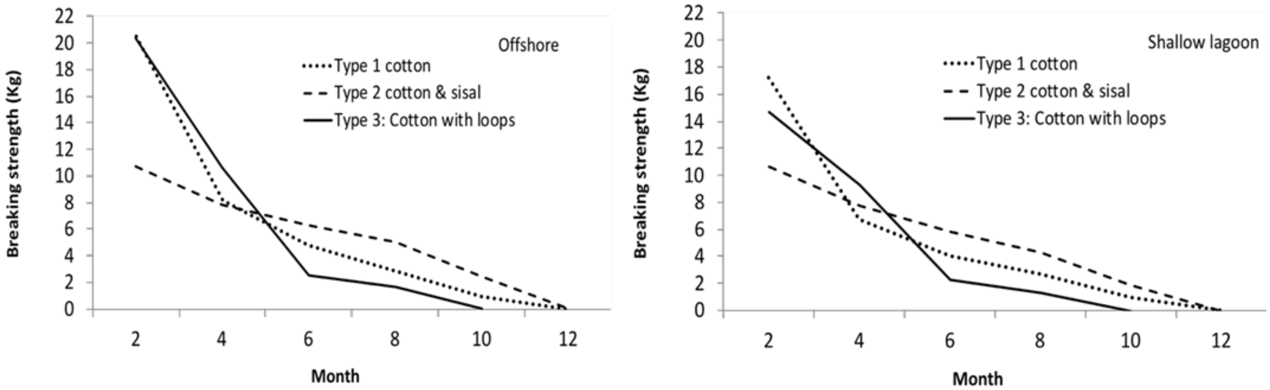
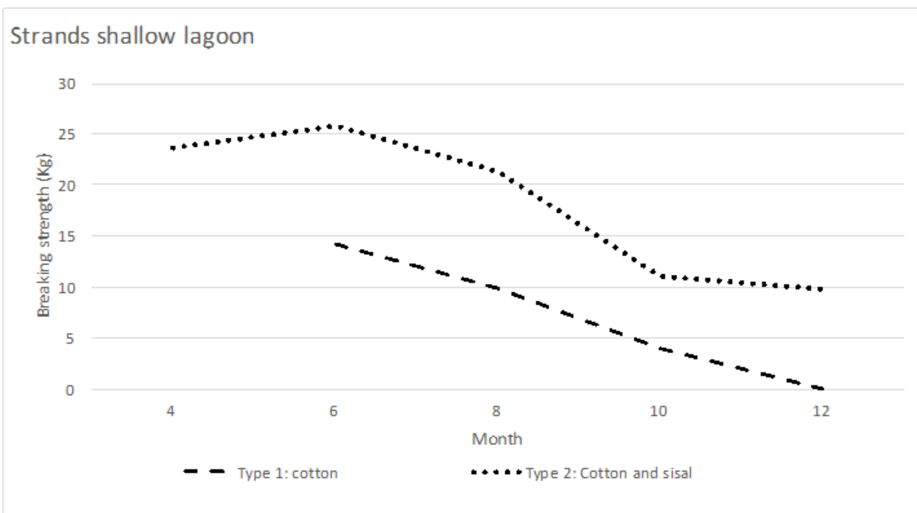


Figure 25. Biodegradable ropes' strings degradation with time at sea. For ropes anchored in offshore waters (a) and within the lagoon (b).



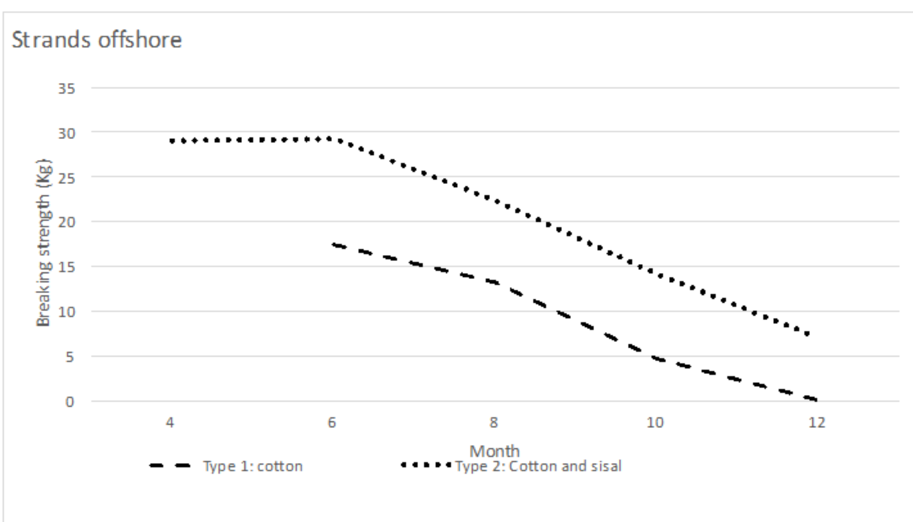


Figure 26. Biodegradable ropes' strands degradation with time. For those anchored in the lagoon (top) and in offshore waters (bottom).

2.4.4. Discussion

Breaking strength measurements showed that mixed cotton-and-sisal rope of 20 mm diameter (**Figure 26**) was the strongest rope after one year at sea. However, to select the most appropriate rope to be used on FADs, more than robustness and resistance to degradability is important. Following the criteria set for the selection of natural fibers, being easy to handle, cost, availability close to fishing grounds and degradation after one year also need to be taken into account.

Fishers found 100% cotton rope was easier to handle compared with the cotton-and-sisal rope. In addition, from the results of this experiment on breaking strength as well as the criteria mentioned above, the 100% cotton rope seems to better fulfill the characteristics needed to be used on FADs. The cotton rope's breaking strength is not as strong as the mixed sisal-and-cotton rope. However, its useful lifetime matches that desired by fishers for FADs: i.e., around one year. Our results suggest that the mixed sisal-and-cotton rope would remain strong after 1 year at sea, which is more than the maximum time estimated by fishers for working FADs.

The rope with the loops was the weakest in our experiments, as it was found to be not strong enough to last for a year at sea. The initial breaking strength of this rope was 194 Kg, which is an order of magnitude lower than the other 2 ropes (cotton rope and cotton-and-sisal rope). The results obtained support the need for ropes that have at least an initial breaking strength above 200 Kg. We did not test the performance of ropes that have between 200 Kg and 1000 Kg breaking strength. However, it should be noted that the breaking strength is not the only feature determining the degradability of the ropes at sea; resistance to torsion and abrasion suffered as well as capacity to stretch are important features that determine the lifetime of a rope. For instance, the cotton rope (type 1), which initially had the higher breaking strength (1645 Kg), performed worse than type 2, which had a lower breaking strength (1144 Kg).

The looped rope (type 3) would allow biofouling (as used in mussels farming). The fact that biofouling has the capacity of aggregating non-tuna species at the same time as tuna species has not been scientifically proven. While some fishers support this hypothesis, others do not — believing that biofouling makes the FAD heavier and weaker due to accumulation of weight, eventually making the FAD sink or the ropes unravel and break. However, experts on physical oceanography suggest that the weight acquired by the structure due to biofouling is insignificant in terms of the need for extra flotation and increasing stress to the structure from physical forces, arguing that attaching organisms (i.e., algae, barnacles, etc.) have almost neutral buoyancy in seawater.

Some components of the FAD need to support most of the weight of the structure, as is the case with the ropes that connect the surface raft with the metal weight (e.g., chains or cable) hanging at the end of the submerged section of the FAD. Those components are at more risk of breaking and need to be strong enough for the FAD to be useful for a year. Other components do not necessarily need to be so strong, as they are used just to provide more volume (or presence) to the FAD structure. These smaller "attractor" appendages are simply considered by fishers to make the FAD more enticing to non-tuna and tuna species. For example, palm leaves and strips made out of colored plastics or salt bags are commonly attached to the main structure of the FAD to provide shadow and lure fish.

In the case of biodegradable ropes tested in this study, a good compromise could be using the 100% cotton rope to support the main structure of the FAD, due to its robustness, and the looped rope just to provide volume to the FAD, hanging them from the raft in small pieces. In this way, the degradation of these ropes would not severely affect the integrity of the main structure and thus the breaking resistance of the FAD.

Other projects working with biodegradable twines have shown that variations in manufacturing processes, or possibly variations in cotton blends appear to have a significant effect on degradation rate (Winger et al. 2015). This shows that not all cotton ropes with the same specifications (diameter, twisted, number of strings, strands and yarns etc.) may be expected to behave and degrade in the same way. Research on biodegradable twines made from cotton, in other fisheries, show the strength of the rope is dependent on the manufacturing process and the quality of the cotton. Therefore, it is likely that the results of this experiment may be different from ropes made by different manufacturers. The quality of the material and its configuration, including its unique manufacturing process, are key to finding the most suitable biomaterial for FADs.

One example of the importance of this variation in quality are bamboo canes for FAD flotation. Not every bamboo cane works equally in FADs. Fishers clearly stated that the performance at sea of green bamboo canes is better than those canes that have dried. Also, different species of bamboo with various physical characteristics behave differently. Less permeable green bamboo canes allow FADs to float for longer, which is key for a robust FAD lifetime. Fishers have learned through trial and error that FAD utility is directly linked to the quality of a given material, in this case bamboo. The same quality selection learning process is expected to happen for new biodegradable materials used for the hanging structure of FADs (e.g., ropes made with various cotton types and configurations).

In addition, not only the configuration of the material and its quality will be important for the degradation of the biodegradable material. The surrounding environmental conditions have a strong influence. In the case of the ropes tested in this experiment, the behavior with time in both sites, i.e., lagoon and offshore sites, was similar for the 3 different ropes tested. We expected having much greater degradation within the lagoon due to abrasion with the seabed, but this was not the case. However, sea temperature, light exposure and levels of oxygen might have been very similar in both experimental sites and thus degradation was similar.

Finally, it should be noted that the ropes in this experiment were not used in real drifting FADs, so breaking strength and lifetime of the ropes could be different in real fishing conditions. However, our results provide a reference for comparing the robustness and degradability of 3 types of ropes that fulfill the criteria set by scientists and fishers to successfully replace current plastic components at FADs.

2.4.5. Conclusion

One of the main difficulties encountered when testing new materials on drifting FADs is the lack of sufficient observations during the life of experimental biodegradable FADs because of difficulties in revisiting them. The experiment conducted in Maldives to test different biodegradable rope types shows the usefulness of these alternative experiments under controlled conditions. The study compared different rope materials and configurations and assigned different uses to these ropes for FAD construction. In our case, the strongest rope in terms of breaking strength, type 2 cotton-and-sisal rope, was discarded because it was not as good for handling as 100% cotton rope. The cotton-and-sisal rope was more difficult to handle due to the less flexible mix of cotton and sisal. Type 3 rope with loops, although structurally weaker, was considered to be of value as an attractor to provide shadow and lure intranatant species during the first steps of FAD colonization. Meanwhile, type 2 rope was considered the best principal component to assemble the main structure of the FAD.

In conclusion, this experiment allowed selecting appropriate alternative biodegradable materials and configurations to be used for FADs, allowing advancements in the use of biodegradable FADs with tests at sea in real fishing conditions. This material preselection decreases the chance of failure in more costly trials at sea, which in many cases have been unsuccessful due to lack of knowledge of the behavior and characteristics of these materials in the marine environment.

2.5. Pilot project to test biodegradable ropes at FADs in real fishing conditions in the Western Indian Ocean

Background

The present section summarizes the results of a pilot project to test biodegradable ropes at FADs in real fishing conditions. One of the difficulties when testing experimental FADs in the purse-seine fishery is that fishers can fish on any FAD found at sea, so that FADs change hands very often. This makes it difficult for a vessel to maintain long-term ownership of its FADs, thus drastically reducing the chances of revisiting experimental FADs to collect data and get significant results. The main objective of the pilot study was learning from this experience to best develop a large-scale deployment of biodegradable FADs at sea, by detecting potential difficulties and issues related mainly to effective data gathering of FADs under test. In order to compare the performance of biodegradable and non-biodegradable FADs, the International Seafood Sustainability Foundation (ISSF) deployed — in collaboration with 6 purse seiners from the INPESCA fleet in the Western Indian Ocean — a total of 174 FADs, 89 non-biodegradable and 85 biodegradable.

2.5.1. Objective

One of the difficulties when testing experimental FADs in real fishing conditions is data gathering. Fishers can fish on any FAD found at sea and swap the original buoy with theirs. In this way, FADs change hands very often, especially in small fishing grounds such as the Western Indian Ocean. It is difficult for a vessel to revisit a FAD deployed months ago to get data on the performance of new materials unless a significant number of experimental FADs are deployed (i.e., to increase chances of finding a long-term owned FAD not taken by other vessels).

The main objective of the pilot was identifying the potential difficulties that could be found in a subsequent large-scale experiment to test biodegradable FADs as well as learning from the behavior of fishers to help design the experiment. Other specific objectives were comparing biodegradable and non-biodegradable FADs on their ability to aggregate fish and having an estimate of the lifetime of both biodegradable and non-biodegradable FADs used in this project.

2.5.2. Material and methods

A. FAD DESIGNS AND DEPLOYMENT

To compare the performance of biodegradable and non-biodegradable FADs, ISSF in collaboration with 6 purse seiners from the INPESCA fleet deployed in the Western Indian Ocean a total of 174 FADs, 89 non-biodegradable and 85 biodegradable (**Table 1**).

Table 1. Biodegradable FADs (BIO FADs) and Non-biodegradable FADs (Non-Bio FADs) deployments in 2017.

Deployments	BIO FADs	NON-BIO FADs	Total
February	13	6	19
March	22	22	44
April	32	22	54
May	18	39	57
Total	85	89	174

The experiment started in February 2017 to find a biodegradable solution for the submerged part of the FAD, replacing the submerged structure of traditional FADs (usually made of plastic-derived netting tied in sausages or synthetic ropes) with biodegradable ropes. Among the different components of a FAD, namely surface structure or raft and submerged ropes or nets, the latter has the most impact. The underwater component of a FAD represents by size the principal portion of the FAD and is the segment that becomes entangled in coral reefs and has ghost fishing potential if built with netting. On the other hand, a recent workshop held with fishers on ways to test biodegradable FADs (Moreno et al. 2016, 2018) recommended allowing synthetic floats when testing biodegradable components at FADs. This is because buoyancy is key for FADs to remain operative (i.e., any loss in floatability can quickly result in the whole FAD structure sinking) and the use of plastic floats would ensure data gathering on biodegradable ropes by preventing experimental FADs ending down in the seafloor. We did not construct the raft with biodegradable materials only, allowing fishers to use the same raft they normally had, using bamboo canes (biodegradable), metal frames and plastic floats (non-biodegradable). Two different biodegradable ropes were used to replace the submerged structure, one with cotton loops similar to the ropes used in mussel farming and the other twisted without loops (**Figure 27**). Both were made from 100% cotton by rope manufacturers Itsaskorda.

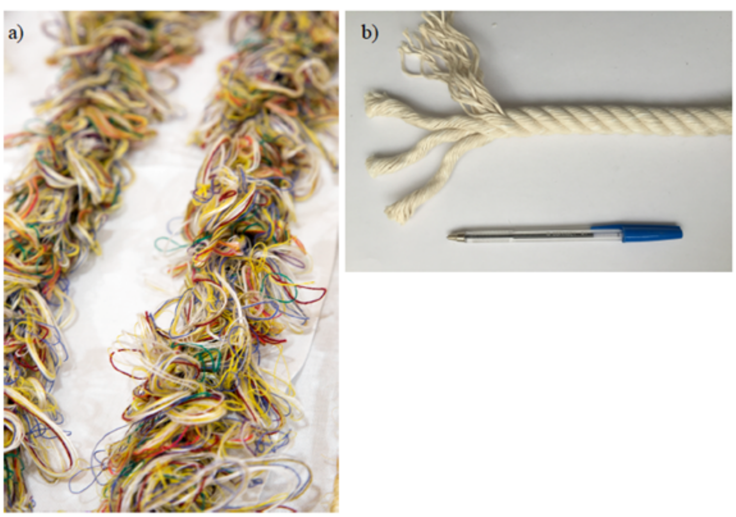


Figure 27. Biodegradable ropes used in the submerged structure of FADs a) 100% cotton rope with loops b) 100% twisted cotton rope.

These ropes were used in 2 different FAD designs working at different depths — design type 1 working at shallower depths between 10 m and 30 m (**Figure 28**), and the other, design type 2, working deeper at depths of 30 m, 50 m and 70m (**Figure 29**). To compare the ability of biodegradable and non-biodegradable FADs to aggregate tunas, as well as their structural longevity, identical designs of biodegradable and conventional, non-biodegradable FADs were tested in pairs.

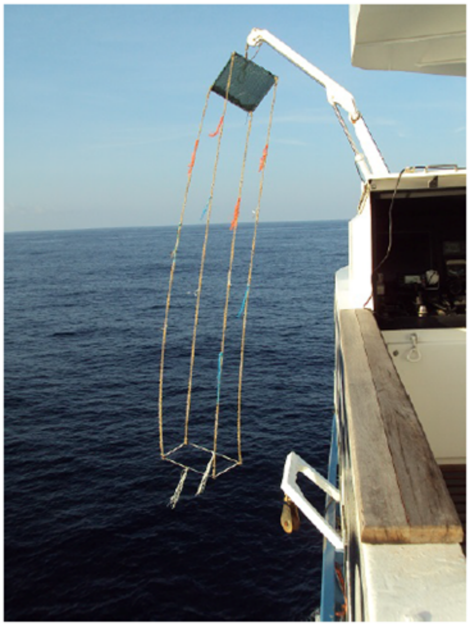


Figure 28. FAD type 1: 4 biodegradable cotton ropes hanging from the raft. This design was used at 10m and 30m depth.

Figure 29.FAD type 2: A single rope hanging from the center of the rope. This design was used at 30m, 50m and 70m depth.

B. DATA ANALYSIS

The 174 FADs deployed for this project had an attached GPS-equipped echo-sounder buoy, indicating both FAD position and an estimate of the biomass aggregated. Fishers shared their echo-sounder buoy data for the 174 FADs with a 2-month delay. Three types of echo-sounder buoys were used to track the 174 FADs. One of the brands was used in 89.5% of the total number of FADs tested. Thus, our analysis on the biomass aggregation pattern for non-biodegradable and biodegradable FADs was done using only the dominant brand, to be able to compare biomass samples, as biomass estimates are calculated differently by each brand.

The dataset contained 74,913 acoustic samples from the 174 buoys followed from February–May 2017. Information for each sample included date and position of deployment, buoy (code and type), position (latitude and longitude), GMT hour, and biomass estimation. Data cleaning was done following the protocol proposed by Orue et al. 2019 using R Studio (R Core Team, 2016). Our analysis of the aggregative pattern of fish for biodegradable and non-biodegradable FADs was conducted using Generalized Additive Mixed Models (GAMM) (Wood, 2006) with a Gaussian error distribution and identity link function. The trend of biomass was assessed for 60 days. FAD identification was included as random-effect because there is a dependency structure in the data, as they are collected repeatedly for each DFAD. In order to avoid model overfitting, the maximum degree of freedom (k) was limited by k=4. All the GAMM models were fitted using gamm4 package (Wood and Scheipl,2013) in R Studio (R Core Team, 2016). The mathematical notation for the fitted GAMM was:

Biomass ~ s (Day, k=4) + random= ~ (1 | ID_DFad)

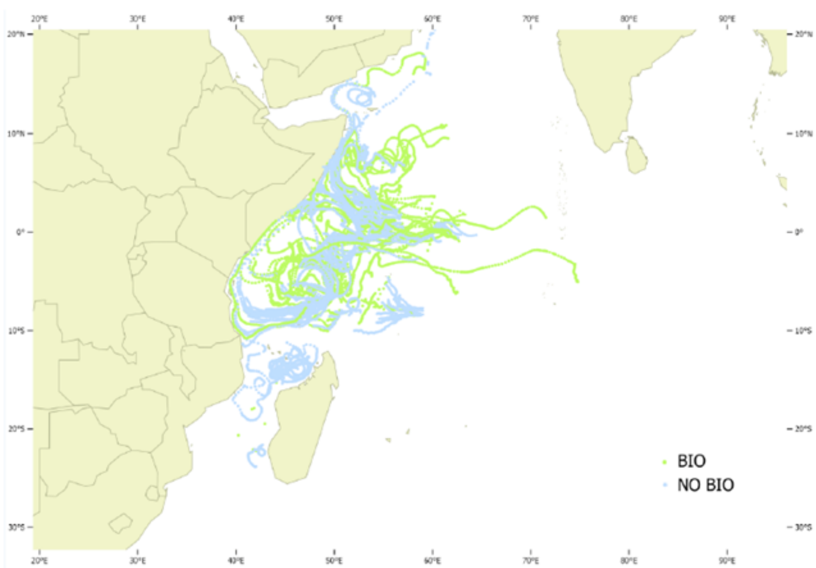
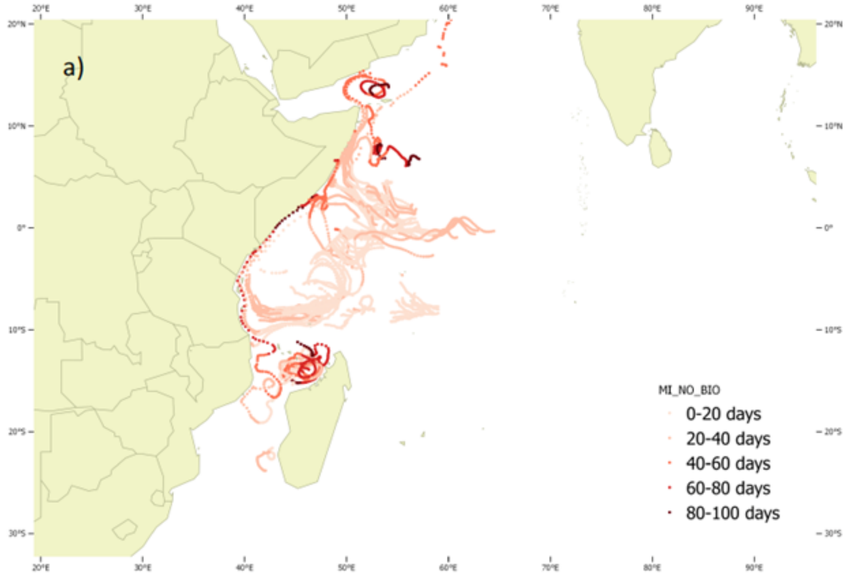


Figure 30. Spatial coverage of FADs deployed in the present project from February to May 2017, both biodegradable (in green) and non-biodegradable FADs (in blue).



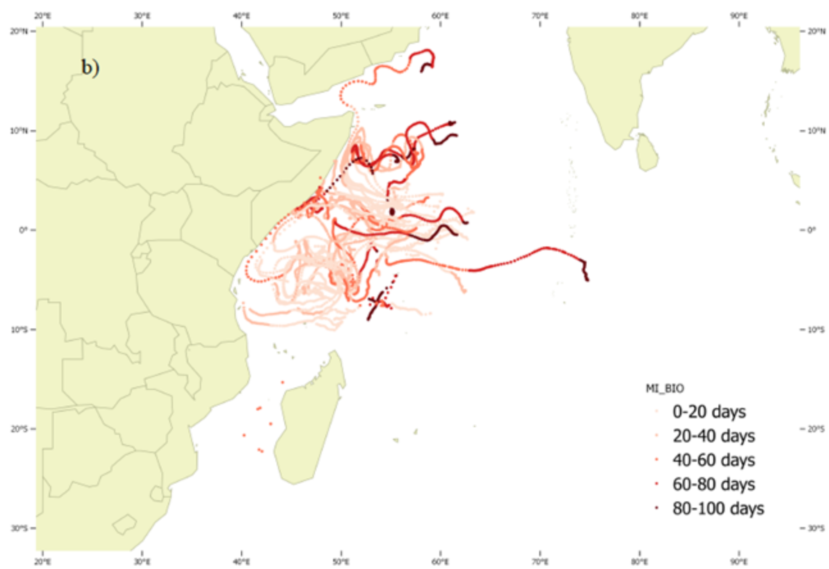


Figure 31. Trajectories followed by a) non-biodegradable FADs and b) biodegradable FADs

2.5.3. Results

The 174 FADs deployed in this project covered the main fishing grounds in the western Indian Ocean (**Figure 30**).

The results presented here represent 3 months of FAD monitoring, from February to May 2017. Data collection continued after for those FADs that remained at sea. **Figure 31** shows the trajectories for non-biodegradable and biodegradable FADs. A white color represents the deployment position that changes to red with days at sea. For the period of observation, there were 5 fishing activities on non-biodegradable FADs, with catches ranging from 5 to 80 tons. There were no fishing activities on non-biodegradable FADs deployed by this project. Maximum time at sea observed for a biodegradable FAD up to the end of August 2017 was 6 months. It is important to note that in 3 months, an average of

46.5% of biodegradable FADs and 82% of non-biodegradable FADs were not available to the vessel that deployed them. These lost FAD events were mainly due to FADs being stolen and maybe fished by other vessels, but sinking and beaching events also occurred.

An analysis to compare aggregation patterns of tuna and non-tuna species related to days at sea showed no significant differences between the 2 kinds of FADs tested, biodegradable and nonbiodegradable (**Figure 32**). In our preliminary results, the time at sea at which maximum biomasses are reached at FADs appears to be shorter for biodegradable FADs compared to non-biodegradables.

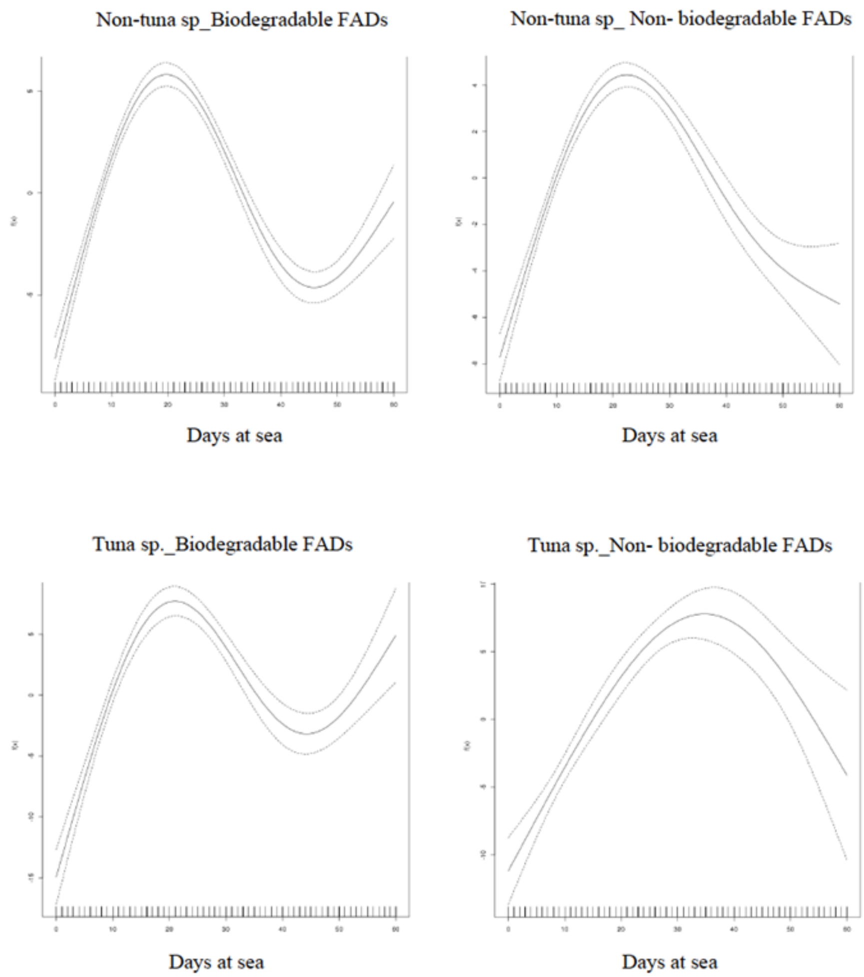


Figure 32. GAMM analyses showing the non-parametric relationship between non-tuna species biomass (top) and tuna species biomass (bottom) and days spent at sea by the FAD with 95% confidence intervals (dashed lines).

2.5.4. Discussion

A. ABILITY OF BIODEGRADABLE FADS TO AGGREGATE TUNA AND NON-TUNA SPECIES

From our results, there is no doubt that FADs using biodegradable components in the submerged structure are as effective as non-biodegradable FADs in aggregating tuna and non-tuna species. Similar aggregative patterns were observed for the non-biodegradable and biodegradable FADs, even reaching maximum biomasses earlier on biodegradable FADs compared to non-biodegradable FADs in this experiment. However, the results shown are for all biodegradable FADs and non-biodegradable FADs pooled together, so information on the type of FAD design, depth of the FAD, drift, area, time at sea, etc. was not taken into account. Further analysis will include all the factors that could affect the aggregation dynamics for the two types.

B. LIFETIME OF FADS AND FUTURE EXPERIMENTS

For the 174 FADs deployed by the project, in 3 months, 46.5 % of the biodegradable FADs and 82% of the non-biodegradable FADs were no longer available to the vessel that deployed them. The Western Indian Ocean is a small fishing ground where FADs change hands very often, as observed in our sample. Most of the FADs were stolen and probably re-used by other vessels, but we do not have access to this data. Deploying a significant number of FADs at sea and the collaboration of the different fleets operating in the area of the experiment are required, to collect enough data to follow the performance of experimental FADs over time. The fact that there is a limit on the active number of FADs at sea in the Indian Ocean (325 at the time of the experiment) made it more difficult to deploy FADs following a fixed protocol, as fishers had a given number of active FADs at sea and needed to wait until an owned FAD was lost before they were able to deploy another one. For large-scale deployments of FADs, it would be desirable to find a solution for the experimental FADs to be deployed following a protocol. For example, the few experimental biodegradable FADs per vessel deployed for scientific studies could be exempt from counting toward the IOTC's active buoy limits.

By the end of August 2017, the maximum lifetime for a biodegradable FAD at sea was 6 months. Taking into account this information, we could expect to have other appropriated biodegradable FADs still alive at sea but monitored by other vessels that did not participate in this project. This preliminary result on the maximum lifetime of a biodegradable FAD at sea provides an estimate of at least the maximum time that a biodegradable FAD could be efficient for fishing. Fishers participating in the project stated that in the Western Indian Ocean, a FAD with 6 months at sea was considered old, which could provide an idea of the appropriate lifetime of a FAD in this region. However, it is known that fishers maintain FADs and make them last longer through maintenance, by replacing the components that are not efficient after a given time. It could also be the case when working with biodegradable FADs that fishers could replace the biodegradable components that are not working properly. Thus, it may be that the lifetime of the original structure is not 1 year but that material replacements can make the biodegradable FADs last longer than 12 months. A survey aimed at understanding the frequency of FAD refurbishments with material replacements by fishers would be useful to understand the required lifetime of biodegradable materials and well-maintained biodegradable FADs. It is also important to note that the rafts used in this experiment were the same as those used in non-biodegradable FADs, allowing the use of plastic floats in order to assure data collection.

Once the efficiency of the biodegradable ropes, as the submerged structure of FADs, is validated, the next step should be testing a biodegradable raft. Finding biodegradable materials for the raft does not seem complex, as bamboo and other woods have already been used with success in FADs. However, fully replacing plastic materials like corks, bottles, or PVC pipes has been proven to be difficult. The buoyancy needed for a FAD to remain afloat is one of the key issues regarding its lifetime, as insufficient floatability quickly leads to sinking FAD events. In any case, replacing in the near future conventional FADs by FADs with 100% biodegradable non-entangling materials in the submerged structure as well as some elements in the raft (e.g., bamboo) would by itself be a huge step towards the reduction of the environmental impacts caused by lost FADs, until a suitable solution is found for 100% biodegradable buoyancy materials in the raft.

2.6. Results of BIOFAD project: testing designs and identifying options to mitigate impacts of drifting FADs on the ecosystem

Background

The BIOFAD experimental project in the Indian Ocean (IOTC Resolution 18/04), funded by EU (EASME/EMFF/2017/1.3.2.6/07/SI2.761047), FAO-GEF Common Oceans ABNJ Tuna Project, and ISSF was launched in August 2017. This 28-month EU project was coordinated by a Consortium comprising three European research centers: AZTI, IRD (Institut de Recherche pour le Développement) and IEO (Instituto Español de Oceanografía). FAO Common Oceans and the International Seafood Sustainability Foundation (ISSF) supported by providing the biodegradable materials needed to test biodegradable drifting FADs as well as expertise on the topic.

2.6.1. Objectives

Following the Indian Ocean Tuna Commission (IOTC) and other tuna RFMO recommendations and resolutions to promote the use of natural biodegradable materials for dFADs, this project sought to develop and implement the use of dFADs that were both non-entangling and biodegradable in the IOTC Convention Area. The Consortium planned a large-scale experiment with the deployment of 1000 BIOFADs to obtain enough data to conduct reliable scientific research.

2.6.2. Material and methods

The BIOFADs were to be deployed, in pairs, along with 1,000 traditional non-entangling FADs (i.e., NEFADs constructed mostly with plastic-based components) for comparison purposes. The deployment of BIOFADs started in April 2018, with deployments organized by trimesters, and finished in June 2019 (14 months), thus covering possible seasonality effects. The project had the active collaboration of the whole European purse-seine industry — 42 purse seiners and several supply vessels — and participation from two Korean purse seine vessels operating in the Indian Ocean. Each PS vessel had to deploy 24 BIOFADs (6 BIOFADs per trimester). This deployment strategy was planned by the Consortium to try to avoid the limitations previously identified in the earlier small-scale trials described previously (Moreno et al., 2017).

The methodology used for BIOFAD (i.e., construction, selected biodegradable materials, prototype designs, BIOFAD deployment strategy, comparison with NEFADs, BIOFAD monitoring, data collection and reporting) was defined by the Consortium after being agreed upon by all collaborators (Zudaire et al., 2020). Three prototypes (**Figure 33**) were designed by the Consortium based on designs previously identified for the Indian Ocean in the ISSF Workshop held in San Sebastian in 2016 (Moreno et al., 2016) and corroborated by fishers in the first workshop of this project in Sukarrieta. Fishers' requirements and FAD construction needs were considered for those designs covering the different drifting performances sought by fishers with their conventional NEFADs: superficial FADs (BIOFAD prototype C), superficial FADs with intermediate-depth tails (BIOFAD prototypes A1 and A2), and submerged FADs with long deep-reaching tails and "cage type" submerged FAD (Figure 33. BIOFAD prototypes B1 and B2, respectively). Details regarding materials, dimensions, and construction of these 3 prototypes were provided in Zudaire et al. (2020). In a recent 2nd BIOFAD workshop held in April 2019 in Spain, some modifications in the prototypes and the configuration of their components were agreed upon among the Consortium and participants. Among these changes to increase the durability of the canvas and provide the cage type BIOFAD design, a multilayer cotton cover and the use of metallic frames for BIOFAD's raft construction were accepted.

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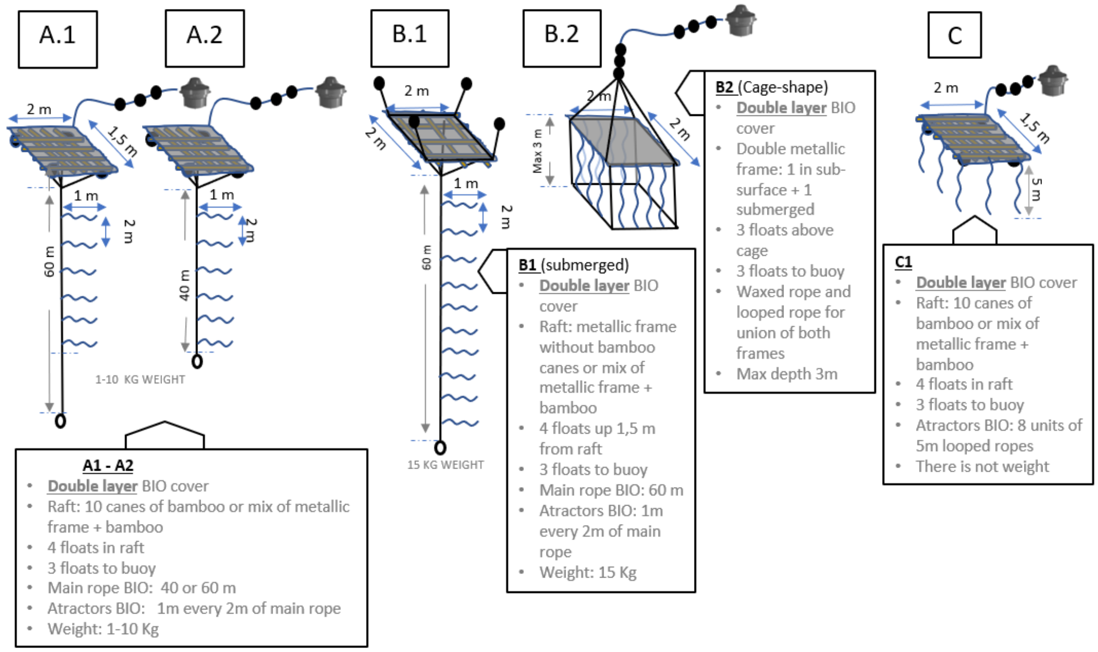


Figure 33. BIOFAD prototypes´ designs and dimensions.

Traceability of BIOFADs and their pairing traditional NEFADs during their entire lifecycle was ensured throughout a metallic number plate identification system and deployment strategy agreed by the Consortium and participants (Zudaire et al., 2020). All the information related to the activities (i.e., new deployment, visit, buoy exchange, set, recovery, redeployment and elimination) with experimental FADs, including conventional paired FADs, were reported by the fleet and collected by observers onboard. This information was reported to the Consortium using an email template and a specifically designed form for skippers and observers, with the aim of making data available to scientists quickly. Besides the activity information, these forms were also used to gather the information regarding BIOFAD and NEFAD structure status controls, by using a simple scale value to assign a degradation stage to each of the components (Zudaire et al., 2020).

2.6.3. Results

A. BIOFAD DEPLOYMENTS, SPATIAL DISTRIBUTION AND DRIFTING PERFORMANCE (SUMMARIZED FROM ZUDAIRE ET AL. 2020)

771 BIOFADs were deployed together with their conventional traditional NEFAD pairs by the participating fleet. This represented 77% of the initially planned goal for BIOFAD deployments. From the total of 771 BIOFADs deployed, 71% corresponded to A1 prototype, 18% to A2, 4% to B1, 2% to B2, and 5% to C1. As shown in **Figure 34**, the deployment effort was not homogeneous through the experimental period, with few BIOFADs being deployed by the fleet during the first months of the trial for different reasons — including vessel reparations at dry dock, stoppage of fishing activity due to quota limitations, or delays in the coordination of fishing companies involved in the construction of the experimental FADs. Afterwards, during the second trimester, deployments increased up to 87% of the planned objectives. In the following trimesters, the effort decreased again to 65%, 47%, and 50%, respectively. Some vessels kept deploying BIOFADs beyond the established trial period to recover for accumulated delays in previous months (deployments in July and

August 2019). The specific locations where BIOFAD deployments occurred during the study period are shown in **Figure 35**. The distribution of the experimental FADs deployed between April 2018 and August 2019 covered all key fishing areas of the Western Indian Ocean tuna fishery, and the deployment effort was balanced seasonally through covered trimesters.

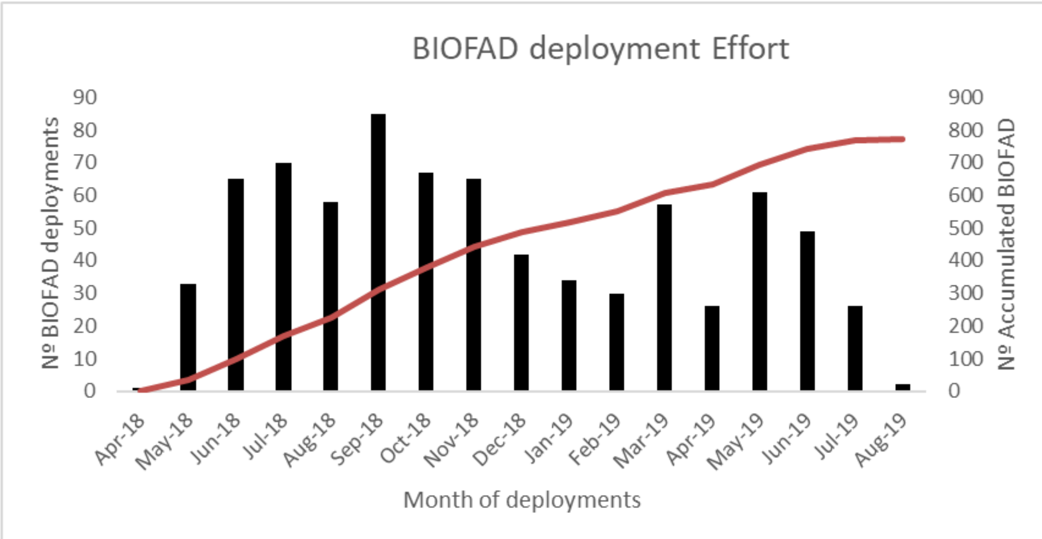


Figure 34. The number of BIOFAD deployed by month (bars) and accumulated number of deployments (red line).

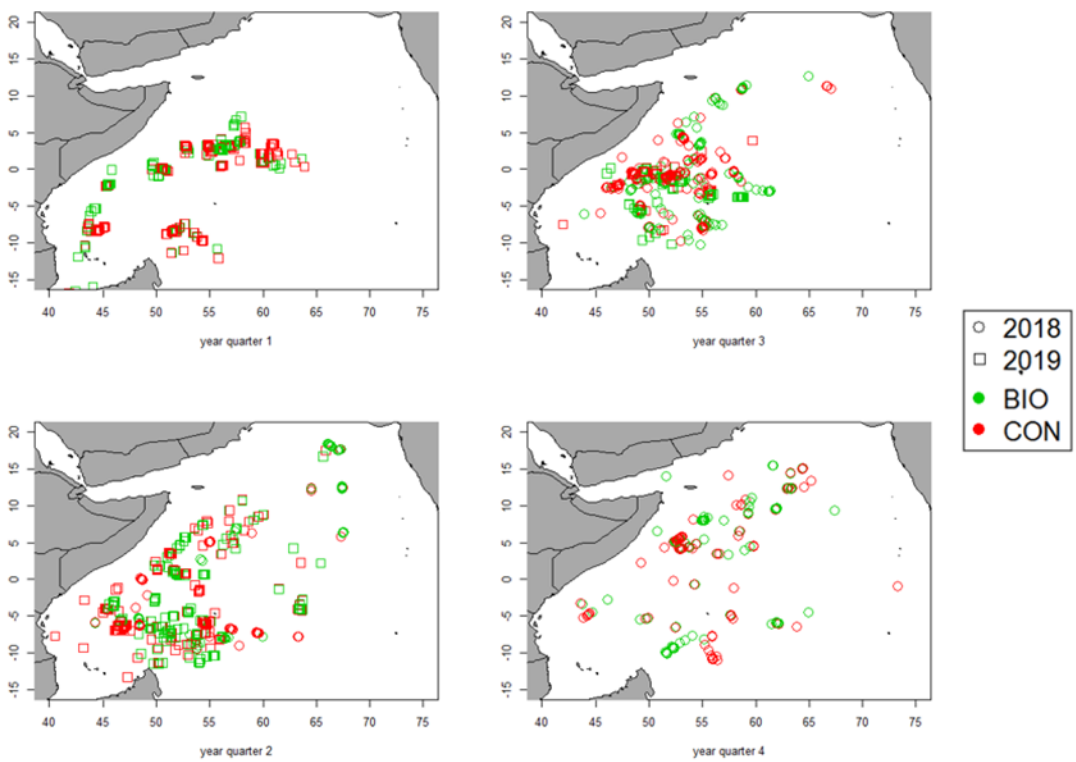


Figure 35. Representation of BIOFAD deployments´ distribution based on echo-sounder buoy data provided by the EU PS fleet.

The use of BIOFAD prototypes by the fleet was also assessed in terms of total material and synthetic material used for BIOFADs and their equivalent traditional paired NEFADs construction. For that, both BIOFAD prototypes and their equivalent traditional NEFADs were characterized, describing the type of material and dimensions for each FAD component. As shown in **Table 2**, BIOFAD prototypes A1, A2 and B2, in comparison to their equivalent NEFADs, required less material (i.e., fewer Kgs) for their construction, with a reduction of 44%, 50%, and 11%, in weight respectively. In the case of BIOFAD prototypes B1 and C1, an increase in total material weight (27% and 1%, respectively) was observed in comparison with their equivalent NEFADs. However, all BIOFAD prototypes reduced the amount of synthetic materials used for their construction. Prototype A1, the most used by the participating fleet, required 81% less synthetic materials than its equivalent traditional NEFADs. These results show that BIOFAD prototypes significantly contribute to the reduction of the quantity of synthetic material used in FAD construction. Consequently, this will also enable fishers to mitigate the potential contribution of lost and abandoned FADs to marine litter, thus also reducing many related impacts on the ecosystem, which is the objective promoted by IOTC resolution 18/04.

Table 2. Data on total weight of material used for BIOFAD and equivalent traditional NEFAD construction. Weight of biodegradable and synthetic materials used in both type FAD construction. Comparison (in percentual variation) between BIOFAD and equivalent traditional NEFAD in terms of total and synthetic materials.

	TOTAL weight (kg)	Biodegradable Material (Kg)	Synthetic Material (Kg)	Total Weight in BIOFAD (Kg)	Total Synthetic weight in BIOFAD (kg)
A1- BIOFAD	67,6	47,1	20,5	↓ 44%	↓ 81%
NEFAD_1	121,4	12	109,4		
A2-BIOFAD	60,1	39,6	20,5	↓ 50%	↓ 81%
NEFAD_1	121,4	12	109,4		
B1-BIOFAD	79,4	48,9	30,5	↑ 27%	↓ 51%
NEFAD_2	62,6	0	62,6		
B2-BIOFAD	48,4	15,9	32,5	↓ 11%	↓ 40%
NEFAD_3	54,4	0	54,4		
C1-BIOFAD	46,4	30,9	15,5	↑ 1%	↓ 54%
NEFAD_4	45,9	12	33,9		

The drifting pattern of experimental FAD was assessed by pairs (BIOFAD vs traditional NEFAD) without considering the effect of area, season of deployment, or prototype at this stage of the analysis. Variability in the patterns was examined showing patterns with i) pairs following totally different drift, ii) pairs following partly similar drifts, and iii) pairs following same patterns. **Figure 36** shows the results considering the distance (miles) between pairs of experimental FADs (BIOFAD vs traditional NEFAD) after the deployment. As observed in this figure, the distance between pairs can increase and decrease along their lifecycle, although overall an increase of distance between pairs with days after deployment was shown.

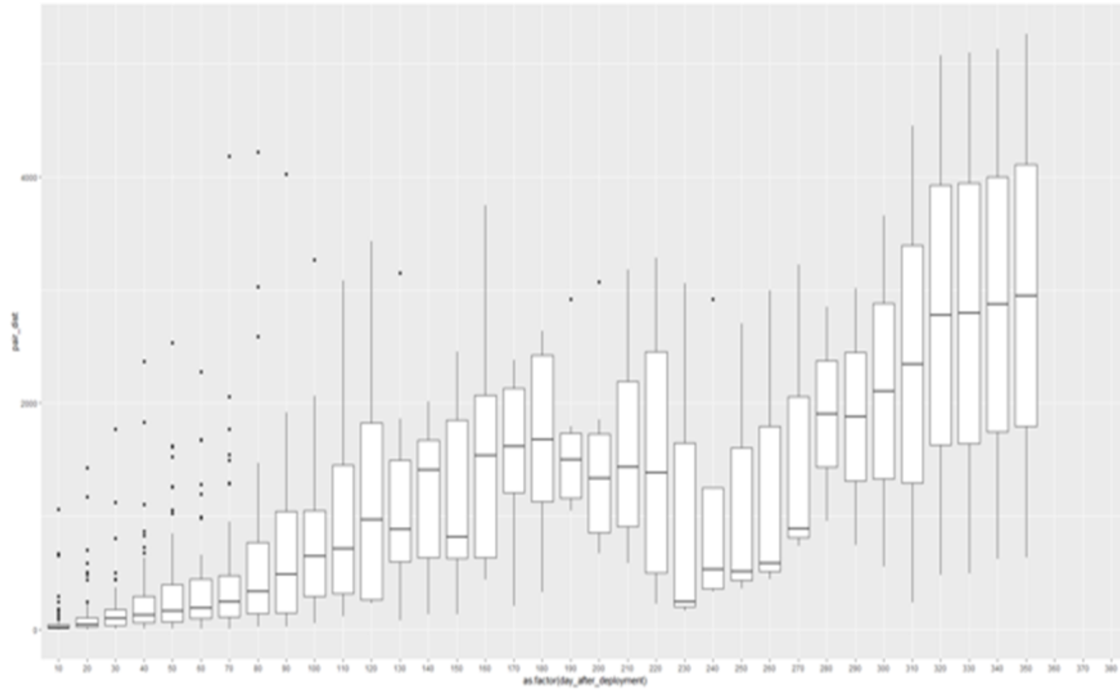


Figure 36. Distance between pairs (in miles; y-axis) relative to the time after deployment (in days; x-axis).

B. BIOFAD EFFICIENCY: LIFESPAN, MATERIAL DEGRADATION, CATCH AND BIOMASS INDICATOR

BIOFAD efficiency was assessed by analyzing and comparing different parameters between experimental FADs (BIOFAD vs. traditional NEFAD): lifespan, material degradation process, catch data, tuna presence/absence, and biomass indicators given by echo-sounder buoys.

The lifespan of experimental FADs (BIOFAD and traditional NEFAD) was defined as the period (in days) between the day of first deployment and the day when the FAD was considered no longer active. The latter was estimated by the day when the FAD was eliminated/retrieved and/or the attached buoy was deactivated, and the Consortium was no longer able to track the FAD. This information was provided by the vessels and/or buoy suppliers. **Figure 37** shows the lifespan estimations by FAD type (BIOFAD and traditional NEFAD) and prototype. All the prototypes, for both FAD types, showed a maximum lifespan longer than 1 year (max lifespan for a BIOFAD of 483 days and for a traditional NEFAD of 493 days), except for the prototype B2 with limited number of deployments during the experiment. Highest mean lifespan values were observed in BIOFAD B1 and A1, 242 and 191 days, respectively (**Table 3**). In the case of traditional NEFADs, prototype A1 and C1 showed the highest mean lifespan values with 209 and 182 days, respectively (**Table 3**). This analysis did not consider the degradation process of the FADs' components, so it was not possible to assess the final condition of those FADs. In addition, the differences in the number of FADs tested by model are in some cases significant and, thus, inter-model comparison should be considered with caution.

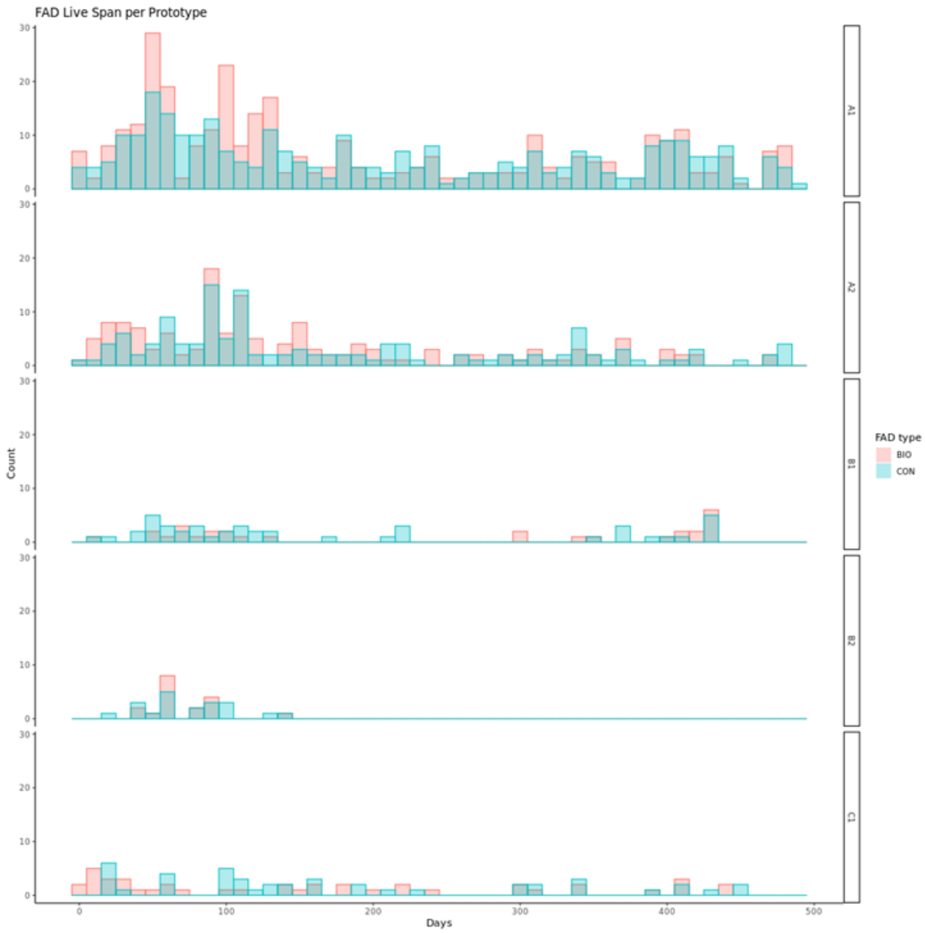


Figure 37. Lifespan results by FAD type (BIO= BIOFAD and CON=NEFAD) and prototypes.

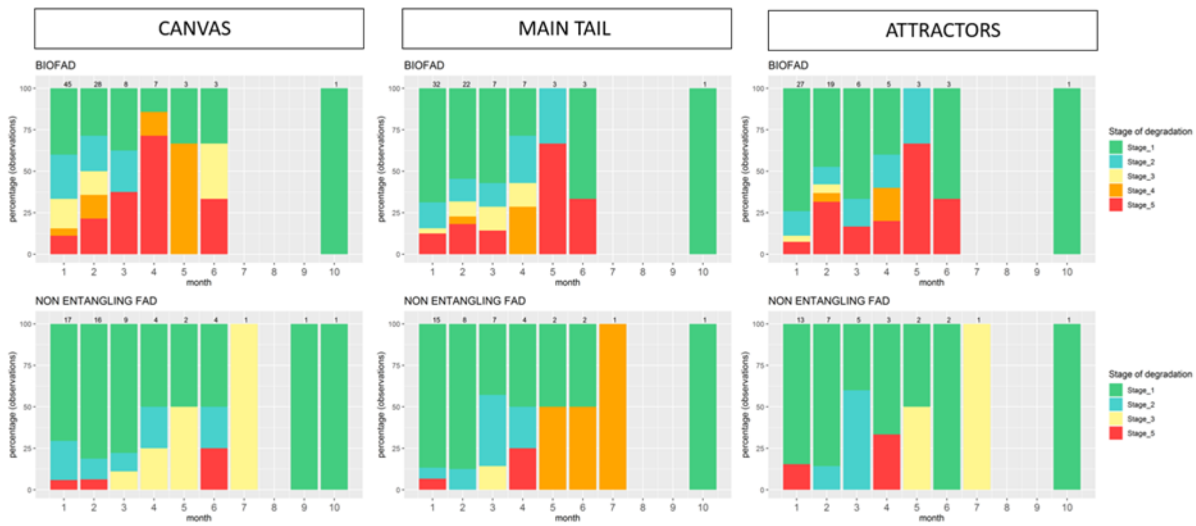


Figure 38. Status assessment for the cotton canvas, main cotton rope and the cotton rope used as attractors for BIOFADs (top figures) and synthetic materials used as cover, tail and attractors for traditional NEFADs (down figures). Estado_1 =Very good; Estado_2 = Good; Estado_3 = Bad; Estado_4 = Very bad; and Estado_5 = Absent.

Table 3. Lifespan data by FAD type (BIO= BIOFAD and CON=NEFAD) and prototypes.

FAD type	Prototype	Mean (days)	Min	Max	st_dev
BIO	A1	191	1	483	145
BIO	A2	151	1	472	119
BIO	B1	242	15	432	166
BIO	B2	70	37	139	24
BIO	C1	161	3	436	146
CON	A1	209	1	493	146
CON	A2	177	5	483	132
CON	B1	180	15	432	147
CON	B2	75	22	139	31
CON	C1	182	16	448	135

To identify the pros and cons of each biodegradable material (i.e., cotton canvas, and two types of cotton ropes), and to compare them with their synthetic equivalent, the quality status control for each component in FAD construction was used. The crew members onboard were requested to collect this information during their activities with experimental FADs. However, fewer status reports were reported by the fleet, which could be due to the predominant fishing practices in which FADs visited are not usually lifted from the water, preventing at least adequate examination of the submerged component. This has limited the material degradation assessment in those months when observations were especially low. As shown in the **Figure 38**, the degradation of the cotton canvas — i.e., the component used to cover the raft as the alternative to netting material or synthetic raffia — started to suffer significant degradation already by the first and second months at sea. This degradation increased in the third and fourth months, when more than 50% of the observations were deemed to be in a “bad,” “very bad,” or “absent” states. A similar pattern was also observed in the fifth and sixth months at sea. Contrarily, the synthetic material used to cover the raft in traditional NEFADs showed better performance than the biodegradable component and remained in good condition until the sixth month at sea. Afterwards the observations were too low to make any conclusion.

The degradation of the cotton rope (i.e., component used in the submerged part of the FAD as main tail) was less pronounced compared to the cotton canvas (**Figure 38**). The status control for the cotton ropes showed them to be in "very good" or "good" quality until the fourth month at sea. However, in 10-20% of the observations the "absence" of this material was reported during the first, second and third months at sea. In the fifth month, the observations at the absence state increased up to 70%. Contrary to what was expected, the synthetic alternative used as the tail in traditional NEFADs was also considered to be in "very bad" condition by the sixth month at sea. Similar results were observed for the looped cotton rope (i.e., component used as attractor tied to the main tail). The status control for this secondary rope was estimated to be in "very good" or "good" quality until the fifth month at sea. However, this component also showed high percentages of "absence" during the first months at sea, especially during the fifth month when values increased up to 70% of the observations.

Overall, and contrary to the perception of the cotton canvas, and according to the feedback received during the 2nd and 3rd BIOFAD Workshops from scientists and some fishers, the absence of the cotton ropes from the BIOFAD rafts has been related to failures at attachment between the tail and the raft rather than to a high degradation of the material. If not correctly attached, these components could be lost, resulting in the reported absences. Overall, the fishing industry had positively valued the performance of these two rope components. Certain parts of the fleet were expecting longer lifetimes for those materials, while other companies have already incorporated them into their current FAD construction. According to the aforementioned results and feedbacks, tested cotton ropes could be considered as a feasible solution for FAD tails, and thus as a replacement of netting materials used in the tail tied into sausage-like bundles. This result will help to eliminate a large amount of nets for FAD construction, and provides viable options for industry to partly comply with Annex V requirements in the IOTC resolution 19/02.

The BIOFAD efficiency in comparison with paired NEFADs was further analyzed through the catch data. In total, from April 2018 to August 2019, 68 sets were associated with these experimental FADs, 36 to BIOFADs and 32 to paired NEFADs. This is a positive result in and of itself, as the rate of fishing on BIOFAD and homologous NEFAD seems to be similar. There was not significant difference found in catches (tons of tuna by sets) between FAD types, however, as NEFADs caught 13% more than BIOFADs. The spatiotemporal effect was not considered at this stage of the analysis. **Table 4** shows the overall catch information by FAD type and prototype. Most of the sets were conducted on A1 prototypes in both FAD types, which could be due to the higher number of deployments of this prototype. Indeed, when the number of sets by each prototype was analyzed relative to the number of deployments of each prototype, differences among them were not observed. The low number of sets performed on some of the prototypes does not allow us to perform comparative analysis between prototypes.

Table 4. Catch data (maximum and mean in tons), number of sets, number of deployments and % of use by FAD type and prototype.

	BIOFAD	CONFAD
Max (tons)	150	225
Mean (tons)	27,96	44,2
Sets	36	32
Deployments	771	736

BIOFAD	A1	A2	B1	B2	C1
Max (tons)	150	75	0	0	0
Mean (tons)	32,21	40	0	0	0
Sets	26	5	2	0	2
Deployments	545	142	29	18	37

CONFAD	A1	A2	B1	B2	C1
Max (tons)	98	225	0	0	70
Mean (tons)	29,38	75,71	0	0	67,5
Sets	21	8	0	0	3
Deployments	497	128	43	20	42

Tuna Presence/Absence estimation through echo-sounder buoy data only considered one buoy model (i.e., M3i). The data filtering process followed the protocols defined in the RECOLAPE project (Baidai et al., 2018; Grande et al., 2019) to keep a uniform working procedure between the Consortium members and to take advantage of the work being done within the Framework Contract. Tuna Presence/Absence assessment (Baidai et al., 2018; Uranga et al. 2019) to study the colonization time and lifetime of the aggregation was conducted by pairs (BIOFAD and its pair NEFAD). **Figure 39** shows the values of first detection day between FAD type. The presence of tuna appeared to be faster in traditional NEFADs than in BIOFADs. In terms of FAD occupation by tuna aggregation, the percentage of paired NEFADs occupied by tuna was higher than for BIOFADs (**Figure 40**). Finally, pairs were compared regarding the distance between both in a given time. Estimated distance differences were then grouped in determined distance ranges, such as less than 50km, 100Km, 150Km etc., with the successive ranges being accumulative (i.e., the next larger distance group includes the previous ones). **Figure 41** shows a higher proportion of FAD colonization at traditional NEFADs than in the BIOFADs throughout the different range of distances between pairs.

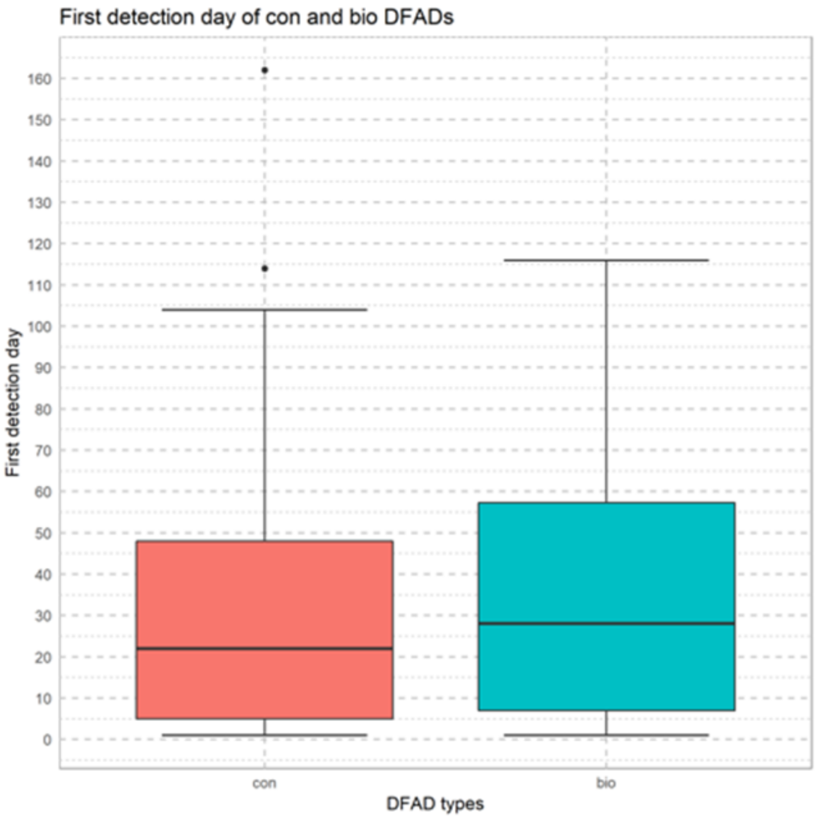


Figure 39. First day of tuna detection by type of FADs between pairs.

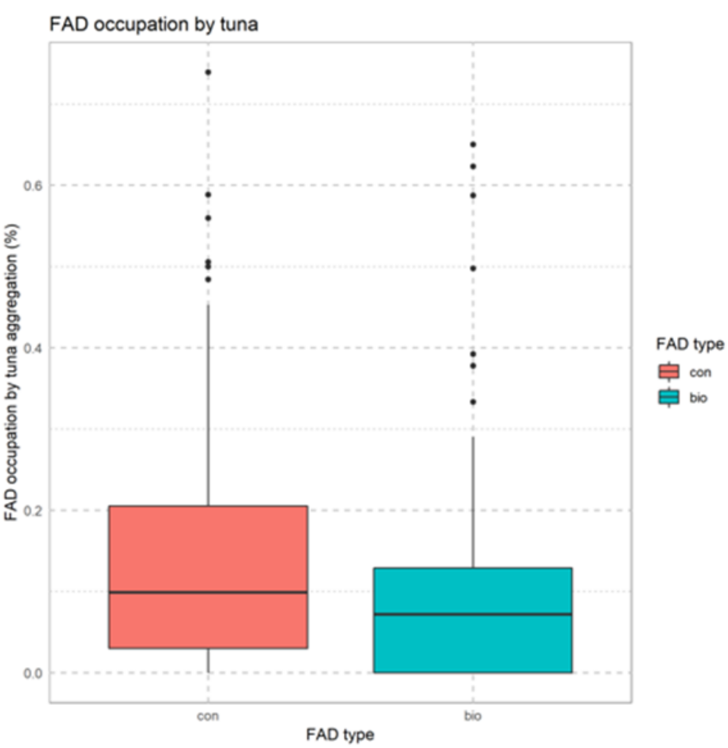


Figure 40. Proportion of FAD occupation by tuna aggregation (y-axis) by FAD type (x-axis).

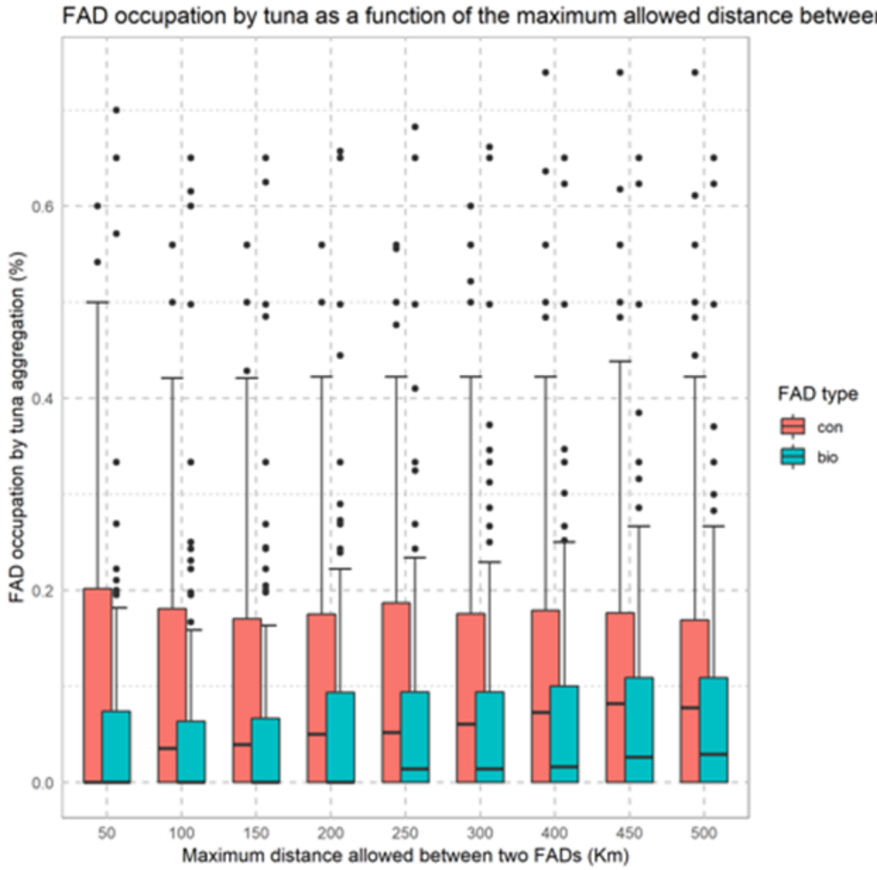


Figure 41. Proportion of FAD occupation by tuna aggregation by FAD type and by range of distance between pairs (in km).

Echo-sounder buoy data was also used to estimate the tuna biomass from acoustic energy values. Acoustic data was analyzed by pairs (when acoustic data for both FADs in a pair existed) and grouped by months having as a reference the deployment day. For the analysis the information derived from different buoy models was analyzed separately, i.e., data from M3i, M3i+ and ISL+ models. Biomass was estimated as the 99 percentile of the daily estimation and grouped by month after deployment. Only those samples obtained around sunrise, between 4 a.m. and 8 a.m., were considered for the analysis. Overall, very low tuna biomass estimations for both FAD types were observed in the three buoy models (**Figures 42-44**). In the M3i model analysis, higher values of biomass were observed in pair NEFADs than in BIOFADs during the first months after deployment. However, this pattern changed after the ninth month showing higher biomass values in BIOFADs than in traditional NEFADs (**Figure 42**). The M3i+ model did not show differences between pairs during the first months and only after the fifth month at sea the values observed at BIOFADs were slightly higher than in their NEFAD pairs (**Figure 43**). The ISL+ models did not show differences between pairs through the period analyzed (**Figure 44**).

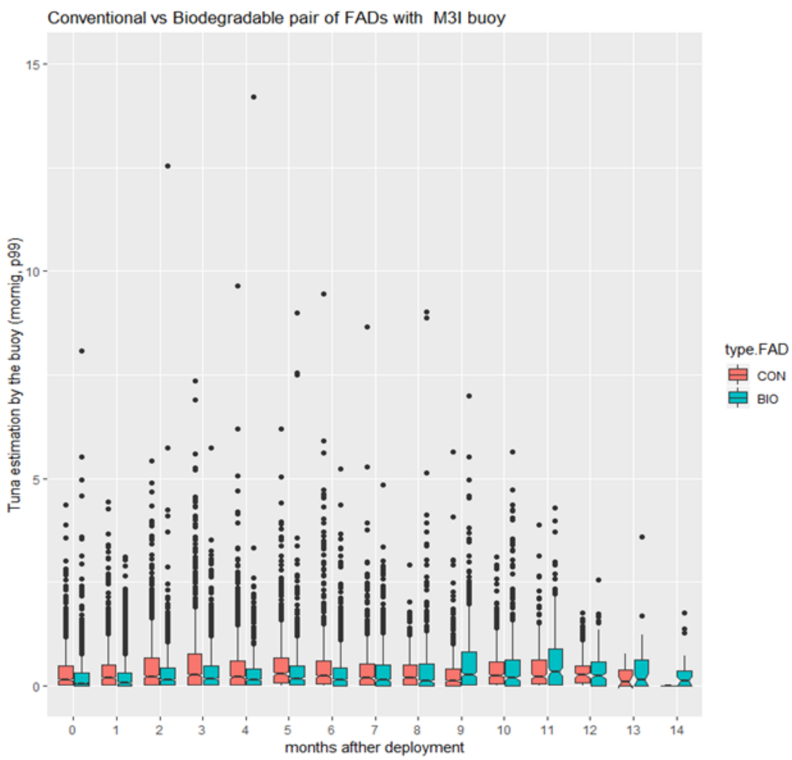


Figure 42. Tuna biomass estimation through echo-sounder data (M3i) by FAD type and by group of months since first deployment.

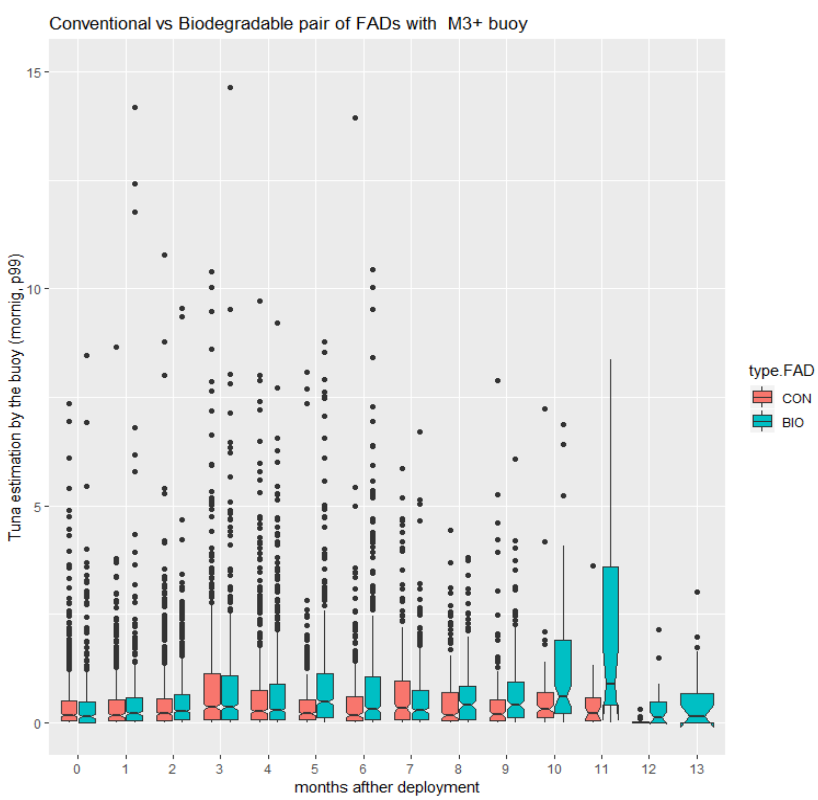


Figure 43. Tuna biomass estimation through echo-sounder data (M3i+) by FAD type and by group of months since first deployment.

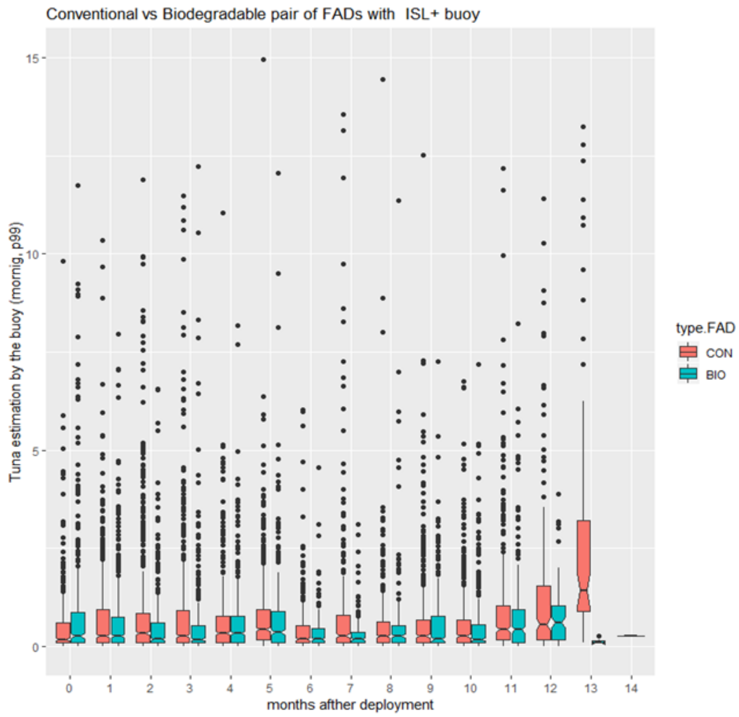


Figure 44. Tuna biomass estimation through echo-sounder data (ISL+) by FAD type and by group of months since first deployment.

2.6.4. Conclusions

The conclusions from the BIOFAD experimental project (Zudaire et al., 2020) were the following:

- The distribution of the experimental FADs deployed covered all of the Western Indian Ocean purse seiner fishing grounds, and the deployment effort was balanced seasonally.
- BIOFAD prototypes reduce significantly the amount of synthetic material used in FAD construction.
- High variability in the drifting patterns of experimental FADs was observed: i) pairs following totally different drift, ii) pairs following partly similar drifts and iii) pairs following same patterns.
- Except prototype B2, deployed in low numbers, all prototypes showed a maximum lifespan longer than 1 year in both FAD types without considering the degradation status.
- The cotton canvas showed high degradation during the first months at sea, while cotton ropes were less degraded until the fifth month.
- Few sets were observed in both FAD types, with the number of sets slightly higher in BIOFADs. No significant differences were observed in tuna catch data by FAD type.

- Tuna presence/absence data showed faster colonization and higher FAD occupation by tuna aggregation in traditional NEFADs than in BIOFADs.
- Variability in biomass estimation by FAD type was observed in the analysis of different buoy models. Overall, traditional NEFADs had higher values of biomass during the first month, while BIOFADs showed higher biomass values after the ninth month at sea.

3. ONGOING RESEARCH TO REDUCE THE IMPACT OF FAD STRUCTURE

3.1. Large-scale deployment of biodegradable FADs with Ghanaian fleets in the Atlantic Ocean

The Ghanaian tuna purse-seine and pole-and-line fleets will test 600 biodegradable FADs in 2020. In section 2.3 of this report, we share the work being done through workshops to design together with the Ghanaian fleets the biodegradable FADs to be tested in real fishing conditions. The present sections show results from a recent workshop held at the Tema fishing port (main port in Ghana for tuna purse-seine and pole-and-line fleets) conducted on the 2nd to 4th of December 2019. The aim of the workshop was to build a biodegradable FAD together with fishers, primarily members of the fishing crew in charge of constructing biodegradable FADs onboard. Recent collaborations with Instituto de Ciencias del Mar (CSIC) in Spain enabled working together with physical oceanographers who have expertise on oceanographic drifting buoys to calculate the drag created by different FAD shapes as well as flotation and weight necessary for the different types of structures. An oceanographer was invited to the workshop to help build the biodegradable FAD. The deployment of the experimental FADs started in March 2020, after the moratorium on FADs finishes, as the moratorium prohibits any activity with FADs, including deployments.

3.1.1. Objectives

The objective of the workshop was to build a biodegradable FAD together with the Ghanaian fleets and calculate flotation and weight needed to increase the experimental FAD lifetime.

3.1.2. Material and method to build the FAD

A. MATERIAL FOR THE BIODEGRADABLE FAD CONSTRUCTION

- Select 4 bamboo with below specifications:
  - 2 big bamboo canes with diameter of 100mm
  - 2 small bamboo canes with diameter 40mm
  - Maintain middle partition of the bamboo cane
  - All bamboo canes should be 1.2m in length
- Cotton canvas
- Cotton ropes
- Wooden pins
- Tools
  - Clamp
  - Drill
  - Mallet
  - Saw

Figure 45. Tools and bamboo canes needed to build the biodegradable FAD.

B. MATERIAL PREPARATION

1. Clamp big bamboo canes (100mm diameter) onto work bench

2. Measure 10cm from both ends of the bamboo cane and mark

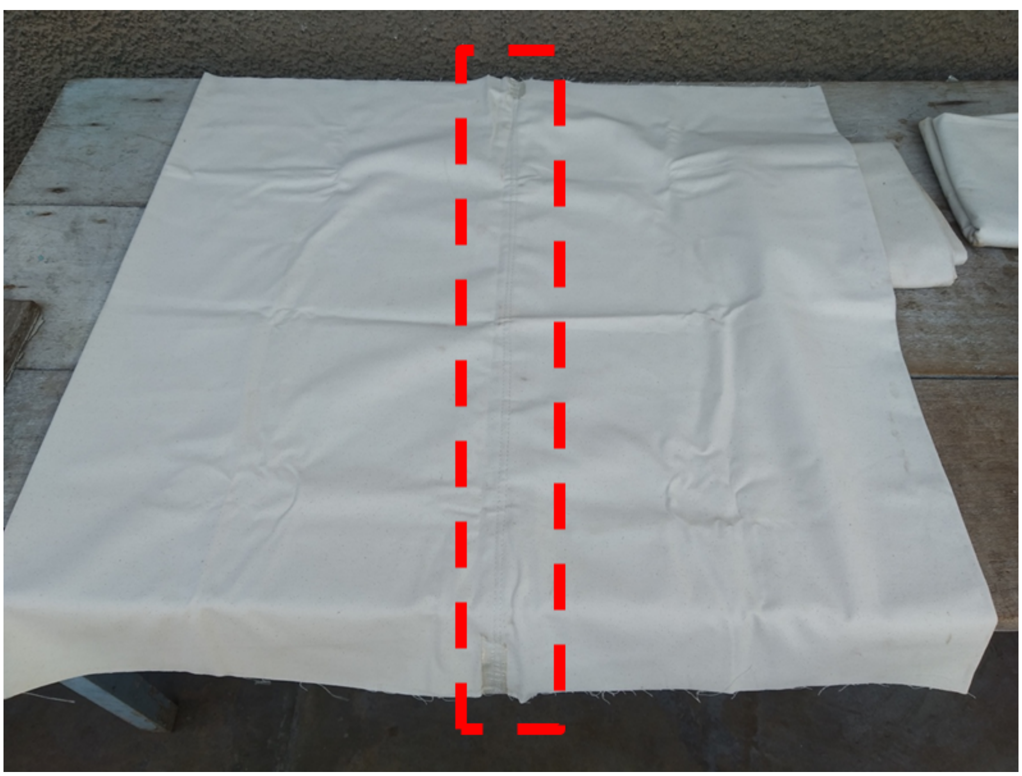
3. Drill a whole of 40mm through the bamboo cane on both sides (to insert the small bamboo canes)

4. Drill a whole of about 20mm diameter through the bamboo cane on both sides (for the rope)

5. Interlock bamboo canes to form a cross joint to ensure holes have been made to specifications

6. Cut cotton canvas to fit bamboo canes: 1m per 2m pieces canvas

7. Fold and sew both ends of the canvas in the middle



8. Pass bamboo canes through the cotton canvas

9. Load 4kg of stones into each thick base bamboo on both sides of the cane, making a total of 8kg of weight added for the structure

10. Drill a hole through the interlock: 8mm hole
11. Hammer the 9mm diameter wooden pins


12. Pass the cotton rope through the bamboo canes and cotton canvas in a continuous loop and terminate with a blast joint.

13. Blast join

14. The entire structure is supported by the cotton rope, not the cotton canvas

3.1.3. Results

There were around 30 attendees from the Ghanaian fleets at the workshop to build a biodegradable FAD. The biodegradable FAD structure will remain in Tema so that fishers who were at sea when the workshop was held will be able to see it and have a reference point when arriving on land. The guide to building the FAD created during the workshop will be shared with fleets testing biodegradable FADs in other regions (e.g., EU fleets working in the three oceans with FADs, and the fleets in the Eastern and Western Pacific).

VISUAL DOCUMENTATION OF THE WORKSHOP



3.2. Pilot test of biodegradable FADs in the Western Pacific Ocean

Background

The WCPFC established a regulation for non-entangling FADs that became effective in 2020. Although the conservation measure in place (CMM 2018-01) does not refer to any specific materials, it states: “To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials for FADs should be promoted. The use of non-plastic and biodegradable materials in the construction of FADs is encouraged.” Further, this CMM provides that, at its 2020 annual session, the Commission shall consider the adoption of measures on the implementation of non-entangling and/or biodegradable material on FADs.

The Caroline Fisheries Corporation (CFC) fleet based in Pohnpei is engaged in a trial to test 100 biodegradable FADs in the Western Pacific Ocean, together with ISSF and in collaboration with National Oceanic Resource Management Authority (NORMA) and the support of the FAO Common Oceans ABNJ Tuna Project. The model of setting up initially small-scale trials by one company in a region proved very useful in the Indian Ocean with the INPESCA trials, as previously described (section 2.5). This approach allows to identify practical lessons in an ocean before larger-scale experiments take place. The experiment started in January 2020.

The first step of this pilot to test biodegradable FADs was the workshop on biodegradable FADs that ISSF conducted in Zadar (Croatia). Zadar is home to the fishing masters and navigators of the CFC fleet, a purse-seine company based in Pohnpei, Federated States of Micronesia (FSM), and operating in the Western Pacific. The following sections show progress made through the workshop as well as the first biodegradable FADs built in Pohnpei (FSM).

3.2.1. Objectives of the workshop

The general objective of the workshop was to promote the use of non-entangling and biodegradable FADs and set the protocol to test 100 biodegradable FADs with the CFC fleet. The workshop allowed ISSF scientists to present the latest results on biodegradable FAD initiatives in the Indian, Atlantic and Eastern Pacific Oceans. They also gathered feedback from the CFC fleet in the Western Pacific on the type of FADs used, the difficulties that could be encountered when changing the structure of their traditional FADs, and how to best proceed with experimental work to test and find non-entangling and biodegradable FADs that are productive for fishing in the WCPO.

3.2.2. Results of the workshop

The workshop in Zadar was held with 8 skippers (5 fishing masters and 3 navigators) from 6 vessels at CFC. An oceanographer expert on oceanographic instrumentation and drifting buoys from the Institute de Ciències del Mar (CSIC) in Spain was also invited to provide his expertise on the drift behavior of the FADs related to the shape of the structure.

A. PROTOCOL TO TEST 100 BIODEGRADABLE FADS

Most of the fleets in the Western Pacific Ocean, including the CFC fleet, are using corks wrapped tightly with netting for the purse-seine FAD raft flotation. The submerged part of the FAD is made of recycled purse-seine net, palm leaves, nylon ropes and bamboo canes.

During the workshop, discussions were mainly focused on the technical features of FAD structures related to their drift behavior. Based on these comments, the protocol to test biodegradable FAD prototypes in the Western Pacific Ocean was discussed. The following guideline and protocol were set.

Biodegradable FAD structure design and materials

In the FAD structure, the submerged tail has the most impact on the environment, as it can become entangled in coral reefs and remain at sea for hundreds of years when built with plastic components (nylon nets and ropes). Fleets have generally increased the depth of the submerged part of the FAD, and these structures are very large (60–80 m in length). Thus, priority should be given to using biodegradable materials for the tail so they degrade fast when FADs are lost or abandoned. The replacement of synthetic with natural tails would decrease FAD impacts while alternatives for the flotation are under research. Currently there are no reliable biodegradable flotation alternatives to plastic buoys or purse-seine corks, although some, such as balsa wood, are under test.

a) Raft

Previous experiments have shown that a FAD's flotation is perhaps its principal factor for effectiveness, because if floatability is not well calculated the FAD can easily sink. To assure that biodegradable FADs under test remain afloat for the duration of the experiment and provide results on the performance of the tail, the raft of the prototype will remain the same as used in traditional FADs. Thus, for this project, the traditional raft made of purse-seine corks wrapped in small-mesh net (less than 2.5" mesh size) will be used.

b) Tail

- Experimental FADs' tails should not use any plastic component.
- The materials used for the tail will be bamboo, manila rope, jute canvas, palm leaves and stones or sand.
- 2 types of biodegradable FADs will be constructed (Design A and B, see visual documentation below). 50% of the experimental FADs to be tested will be a design that copies the traditional FAD (Design A) but uses biodegradable materials. The other 50% will be a biodegradable FAD designed during the workshop with fishers, an oceanographer, and ISSF scientists (Design B).

The construction of the FADs would be done in port to ensure that all the designs are constructed in the same way.

Biodegradable FADs deployment

- A total of 100 biodegradable FADs will be deployed. Each experimental FAD will be deployed close to a traditional FAD, so that the 2 types of FADs can be compared in terms of drift, tuna aggregation and life span.
- The number of FADs per vessel was set as follows: 20 biodegradable FADs deployed by each of the 4 large purse seiners and 10 biodegradable FADs deployed by each of the 2 small purse seiners from CFC.
- Flexibility is allowed to improve this strategy if necessary. For instance, if some vessels are in a better area and season to test biodegradable FADs, those vessels could deploy more biodegradable FADs and some others less. A minimum of 100 biodegradable FADs must be deployed to get results.
- The area and season of deployment will be decided once FADs are constructed and onboard purse seiners. The best area and season for the success of the experiment has to be determined related to the density of other fleets in the area of deployment and the best conditions for fishing, which must be decided closer to the deployment dates.

Data collection of the FADs under test

- A data collection form in Excel was designed and agreed to during the workshop. This data form will be filled by fishers and observers both when deploying the biodegradable FADs as well as when visiting or encountering them.
- Data from the echo-sounder buoys used to track biodegradable FADs and their traditional pairs will be shared with scientists. This data will be delivered by Satlink buoy manufacturers directly to ISSF scientists with the agreement of the fishers and ship owner. This data will be used with a 1-month delay from the deployment of the FADs.
- The National Oceanic Resource Management Authority (NORMA) in Pohnpei will help with the data collection through observers onboard purse seiners, especially when a vessel that is not from CFC encounters a biodegradable FAD.

B. VISUAL DOCUMENTATION OF FIRST BIODEGRADABLE FADS CONSTRUCTED AND DEPLOYMENTS IN POHNPEI

FAD structure Design A

FAD structure Design B

3.2.3. Conclusion

The workshop in Zadar was very productive, as fishers were very participative and aware of the need to move towards a FAD that reduces ecosystem impacts by using non-entangling materials and reducing the plastic used. During the workshop, discussions among fishers, an oceanographer expert on floating object drift behavior, and ISSF scientists produced a new biodegradable FAD structure that will be tested by the fleet. The protocol to successfully test 100 biodegradable FADs also was determined. The project started deploying the first biodegradable FADs in January 2020.

4. GENERAL CONCLUSION

One of the ecosystem impacts Fish Aggregating Devices (FAD) have is caused by its structure, which is mainly made of plastic. Lost and abandoned FADs can damage coral reefs or other benthic ecosystems, cause ghost fishing and marine litter, and interfere with other economic activities, such as tourism. In the last four years, a great effort has been made to advance the use of biodegradable FADs. ISSF with the support of FAO-GEF Common Oceans Tuna Project worked with fleets operating in the three oceans (Atlantic, Pacific and Indian Ocean) to move toward reducing the impacts of FAD structures on the marine environment.

ISSF organized workshops with scientists and fishers working in the 3 oceans to evaluate the starting point and define potential solutions to reduce those impacts. During those workshops, participants assessed, from a technical point of view, different options: FAD recovery, simplifying FAD design, modifying FAD deployment areas, the use of FADs that do not abandon the fishing grounds (FADs with navigation capability, FADs that could be sunk and anchored FADs), and limiting FAD numbers. Fishers also identified main FAD beaching areas in the 3 oceans as well as FAD accumulation areas in the open ocean. Finally, the feasibility of the different potential solutions was assessed in the short and long term.

One of the main focuses of the research was moving toward the use of biodegradable FADs so that their structures degrade as fast as possible once their effective lifetime for fishing is over. The first step was fisher education through workshops and identifying materials that would fulfill the requirements for use in biodegradable FADs. Then, designs for biodegradable FAD structures were made by fleets for different oceans, as each fishing fleet has its own preferred FAD structures.

Controlled experiments evaluated different vegetal materials to select ones with greater potential for FADs. Small-scale pilot tests at sea revealed the difficulties to face in testing biodegradable FADs in large quantities, which is needed in order to get statistically significant results.

Thanks to this research, a biodegradable solution for the submerged structure of the FAD — also called by fishers “the tail” — was found. It is estimated that 100,000 FADs drift at sea globally (Gershman et al. 2019). The FAD tail, which has the most ecosystem impact, makes up the bulk of the whole structure: in many fleets, it reaches around 60-80 m in length of synthetic netting material. The replacement of a plastic tail with a biodegradable one in 100,000 FADs would be a huge step toward reducing FAD structures’ impacts and especially the amount of plastic lost at sea. The estimated amount of plastic that would be reduced at sea if biodegradable tails were used to build FADs worldwide is 14,000 Km^{2}[*] per year.

Yet there are some important issues to be addressed to lower FAD structures’ impacts as much as possible, such as reducing the currently required plastic-made flotation in FADs. Plastic containers, pipes and corks are used to provide flotation and finding a biodegradable alternative for them is difficult, although some materials like balsa wood have been identified as potential substitutes. ISSF’s strategy to reduce the amount of plastic used for flotation has been to collaborate with physical oceanographers — experts on drifting buoys and currents — to decrease as much as possible the need for flotation in FAD structures. Currently, the newest biodegradable FAD designs minimize the need for flotation by carefully calculating the weight and floats needed for simpler biodegradable FAD designs. However, these need to be tested in real fishing conditions to check their performance for fishing purposes. The year 2020 will be devoted to testing those type of FAD structures with the Ghanaian fleets and CFC fleet operating in the Atlantic Ocean and the Western Pacific Ocean, respectively.

[*] An average of 70 meters length FAD per 2 meters wide multiplied by the estimate of 100,000 FADs deployed every year.

Although the need for FADs to be made from biodegradable materials to minimize their impact is clear — to prevent FAD structures from remaining at sea for hundreds of years — there are other mitigation options that have not been considered and tested in depth, such as:

- Avoiding FAD deployment in high-risk stranding areas
- Building FADs with autonomous navigation capability
- Using anchored FADs instead of drifting FADs in stranding hotspots
- Retrieving FADs at sea
- Recovering beached FADs from land

While solutions for FADs made from 100% biodegradable materials are still under research, it would be necessary to evaluate the options above to reduce the impact of FAD structures, if possible, by taking action before FADs are lost or abandoned.

5. RECOMMENDATIONS

Many recommendations have surfaced from the research and workshops summarized in this report. They may not all be suitable or feasible for each specific fleet or ocean region, and more work may be required to tailor them to specific situations in an optimal way. Nevertheless, it is clear that we have sufficient knowledge to start mitigating FAD impacts on the environment.

Quantifying impact:

Recommendation 1:

- Data on the entire trajectory of tracking buoys during the FAD's lifetime, (i.e., from the FAD deployment to the sinking, stranding, beaching or loss events) should be available to tuna RFMOs, flag-state fishing authorities, or research institutes to facilitate the assessment of the impact.

Recommendation 2:

- Quantify strandings: Identify main beaching hotspot zones and establish priority areas based on the vulnerability of the ecosystem and the degree of stranding. If possible, based on real FAD trajectories, collaborate with shipowners and buoy manufacturers or, failing that, use FAD drift models.

Recommendation 3:

- Study the trajectories of FADs based on the position and time of deployment to know the deployment areas with the highest risk of FAD loss and ineffective fishing effort. Special emphasis should be placed on high-risk deployment areas close to shore to better manage those areas (change deployment zone, limit deployment according to distance to coast, or season of the year — with reference to currents — use anchored FADs, etc.).

Selection of materials:

Recommendation 4:

- Biodegradable materials for FADs should be made of 100% plant-based fibers or bio-based materials, for which the product of their degradation is non-toxic for the marine environment, and sustainably harvested and preferably provisioned from local or regional sources. From our research, 100% cotton ropes (20 mm diameter, 4 strands in torsion Z) fulfill the criteria to support the weight of the FAD structure and link the surface component of the FAD with the deeper components (weight, drag).

Recommendation 5:

- When selecting a biodegradable material, not only the type of plant-based material should be taken into account but also its quality, its configuration, and manufacturing process, as these factors will determine the degradation.

Recommendation 6:

- Currently there are no biodegradable materials to replace plastic flotation to provide long-lasting FAD buoyancy. Research is needed to find (i) alternative biodegradable materials to provide long-term reliable buoyancy for FADs and (ii) FAD structures that reduce the need for extra flotation.

Recommendation 7:

- The degradation suffered by biodegradable materials on the sea surface and immediate subsurface (i.e., 0 to 10 m depth) is higher compared to that suffered below, deeper in the water column. Thus, the poor performance of some materials on the sea surface or subsurface layers of the water column should not prevent new experiments from testing the same materials in the tail components of FADs situated deeper in the water column.

FAD structure design:

Recommendation 8:

- The physical impact of FAD structures on the ecosystem is proportional to their size. Current FAD structures are very large and bulky, which makes the logistics for their recovery and storage difficult. Research to reduce the mass (i.e., size, volume and weight) of traditional and biodegradable FAD structures is required.

Recommendation 9:

- The correct assessment of the flotation and weight distribution in the design of the FAD is a crucial factor to extend its working lifetime. This is especially important for biodegradable FADs, as materials might be more susceptible to physical stress. If those are not well calculated, the tension and torsion suffered by the structure will result in damages, and the submerged appendage is more likely to detach from the raft — reducing its lifetime and aggregation effectiveness.

Recommendation 10:

- Only FADs constructed without netting can completely eliminate the entanglement of turtles, sharks and finfish species. New biodegradable materials should not be configured in a net format; instead, they should use other forms such as ropes or canvas.

Trials at sea:

Recommendation 11:

- Tests under controlled conditions at sea are necessary to better understand the behavior of different plant-based and bio-based fibers prior to larger scale trials under fishing conditions.

Recommendation 12:

- Due to the high incidence of FAD loss through change of hands, sinking, beaching or out-of-reach deactivations, trials of experimental biodegradable FADs in real fishing conditions need to test great quantities to obtain statistically significant results.

Recommendation 13:

- During the experiments in real fishing conditions, fishers should share with scientists data from echo-sounder buoys attached to biodegradable FADs (i.e., position and biomass associated), to follow remotely the evolution of the biodegradable FADs that are not visited by fishers, and thus still get results on their performance.

Recommendation 14:

- Pilot studies at sea of FADs with navigation capacity (“drone” FADs) should be conducted to study the possible strategy for their utility to avoid FAD loss.

FAD recovery:

Recommendation 15:

- Once the FAD is fished, the entire structure should be retrieved if it is not going to be productive anymore in that area or is at risk of drifting out of the fishing zone.

Recommendation 16:

- There are convergence zones where FADs accumulate in the open ocean. The FADs could be retrieved by fishing fleets or cooperatively chartered helper vessels in those areas of the high seas.

Recommendation 17:

- In the projects aiming at FAD retrieval from the coast, to ensure the efficiency of the collection system, there is a need to determine the minimum requirements (e.g., size, storage capacity, crane equipment) for the vessels that would recover FADs.

Recommendation 18:

- There should be a management plan on land for the retrieved FADs, both to recycle FAD components and manage waste.

General recommendations:

Recommendation 19:

- Limiting the number of FADs deployed would limit the various impacts that FAD structures can have on the ecosystem, preventing large numbers of FAD losses and promoting the control and repair of owned FADs.

Recommendation 20:

- Developing a guide of good practices for tuna purse seiners and auxiliary vessels would be necessary to reduce FAD loss and abandonment and facilitate FAD retrieval.

Recommendation 21:

- The use of FADs that could be sunk was discarded as a solution to marine pollution, even for biodegradable FADs. Depositing all FADs on the seabed, where degradation is very slow due to the lack of light and reduced oxygen, would also impact the ecosystem.

Recommendation 22:

- Following the preliminary definition proposed in the context of this project for biodegradable FADs (Zudaire et al., 2018), it is essential to find an agreed-upon BIOFAD definition by t-RFMOs. This will help to provide clear guidance and clarity for fleets and industry on which materials qualify for the construction of biodegradable FADs.

Recommendation 23:

- The definition of BIOFAD could consider, acknowledging the current state of the art for biodegradable materials and their availability, different levels/categories of BIOFAD biodegradability, similar to ISSF's classification for FADs' entanglement risk (ISSF, 2019).

Recommendation 24:

- Carry out workshops in each ocean with the participation of key stakeholders to define the potential solutions and recommendations of this document, based on the peculiarities of each ocean. Reducing FAD structures' impacts on the ecosystem requires the collaboration of all stakeholders, the fishing industry, FAD tracking buoy manufacturers, fisheries managers, and research centers, including experts in material development.

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