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A multidisciplinary approach to build new designs of biodegradable Fish Aggregating Devices (FADs)

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Resumen

Este documento presenta las investigaciones que está realizando ISSF en relación a la disminución del impacto de la estructura de los plantados en el ecosistema, específicamente en la búsqueda de plantados biodegradables eficientes. ISSF está colaborando con oceanógrafos físicos del Insitut de Ciències del Mar (CSIC, España), expertos en corrientes oceánicas y derivadores. Específicamente colaboramos para entender mejor el comportamiento físico de las estructuras de los plantados en la columna de agua con el fin último de buscar un diseño de plantado biodegradable que además de ser eficiente agregando túnidos, sea menos voluminoso y pesado en comparación a las estructuras que se están empleando hoy en día. Manteniendo las mismas características funcionales de los plantados actuales, buscamos un nuevo diseño que requiera menos componentes derivados del plástico. En este documento compartimos información sobre el comportamiento físico de los derivadores, que pueden ser de utilidad para la construcción de plantados biodegradables.

Summary

The present document aims at summarizing ongoing research by ISSF on the reduction of the impacts of Drifting Fish Aggregating Devices´ (DFADs) structure on the ecosystem, particularly on the use of biodegradable DFADs. ISSF is collaborating with physical oceanographers from the Insitut de Ciències del Mar (CSIC, Spain) experts in oceanic current dynamics and drifters. Specifically, we collaborate to better understand the physical behavior of DFADs in the water column in order to find a DFAD structure that aggregates tuna but also reduces presently observed large DFAD sizes and reduces the need for plastic buoys used for flotation. In this report we share information on the physical behavior of drifters, gathered from our collaboration with oceanographers, that could be helpful in the application of biodegradable DFAD structure´s construction.

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1. Introduction

One of the impacts of Drifting Fish Aggregating Devices (DFADs) on the marine ecosystem is related to the DFAD structure itself, which is mainly made of plastic derived components (netting and ropes). Impacts occur when lost or abandoned DFADs damage coral reefs or other benthic ecosystems, cause ghost fishing, create marine litter, or interfere with other economic activities, such as tourism (Maufroy et al. 2015; Escalle et al. 2019).

To reduce those impacts, ISSF — with support from the FAO-GEF Common Oceans Tuna Project — launched a series of actions and projects, including the promotion of biodegradable FADs. Specifically, scientists and fishers are collaborating in three oceans to build FADs that are efficient for fishing purposes but degrade as soon as possible after their useful working lifetime ends (Moreno et al. 2020; Zudaire et al. 2020).

The need for FADs to be constructed with biodegradable materials instead of plastic derived components, so they do not remain at sea for hundreds of years, is clear. The present document presents the results of a recent collaboration by the International Seafood Sustainability Foundation (ISSF) with oceanographers from the Institut de Ciències del Mar (CSIC, Spain) and with funding from FAO-GEF Common Oceans Tuna project. The aim of this collaboration was to build a biodegradable FAD that would minimize environmental impact based on the expertise of physical oceanographers on the physical behavior of drifters and oceanic currents.

2. What structural features does a DFAD need to be productive?

One of the research questions that drives our work in the search for a biodegradable DFAD, is what structural components are needed for a DFAD to be efficient in terms of aggregating tuna. From the scientific point of view, there is no evidence of the effect by different DFAD´s structure components or different designs on the attraction or aggregation process of tunas. Diverse research showed that no major characteristics of DFADs could explain the attraction of tuna species (Rountree 1989, Hall et al. 1992, Nelson 2003, Shaefer et al. 2018). It has been proposed that anchored FADs can more easily attract tuna because of the sounds produced by their anchoring chains or the influence of current on the mooring ropes (Freon and Dagorn, 2000), but scientific literature has also shown that DFADs can attract tuna from considerable distances without these submerged structures (Girard et al 2004).

This implies that the structure or design of DFADs might not play a key role in determining attraction processes, and therefore it has been hypothesized that other factors as (i) the DFAD history or trajectory (Moreno et al. 2007) and (ii) the non-tuna fish aggregations around DFADs (Itano et al. 2004), may play an important role in attracting tuna schools. From the fishers´ point of view, results from the ISSF Skippers´ Workshops consistently showed over a decade that there are two main DFAD features that fishers consider crucial for it to be productive: (i) the slow drift and (ii) the shade (Murua et al. 2014). Interestingly, these two features are related to the two scientific hypotheses mentioned above, on the role of the trajectory and the non-tuna species on DFAD efficiency to aggregate tuna.

From fisher's perspective the main features needed for a DFAD to be productive are:

a) **The slow drift**:

It is not clear if a DFAD that drifts slowly makes it more attractive for tuna or if fishers need the slow drift to keep it within their fishing area, avoiding FADs drifting out from their fishing grounds or if the slow drift serves the two purposes. What is clear is that in order to make the DFADs drift slowly, the tendency worldwide has been to build larger DFAD structures, constructed with net panels, for which their submerged components can reach up to 100 meters depth (Figure 1). The primary purpose of this large submerged appendage is to help slow down DFAD´s drifting speed. One of the principal concerns deriving from the need for slower drift is the fact that fishers employ higher amounts of netting and other plastics to build large and deep structures. Fishers believe these deep DFADs move slower than DFADs with shallow appendages. Importantly, the pollution impact of DFAD structures on the ecosystem is related to their size (i.e. the impact of 5 DFADs of 20 meters depth is proportionately 4 times less than 5 DFADs of 80 meters depth).Thus, in order to decrease the impact of DFAD structures on the ecosystem, reducing their size (i.e. amount of polluting material and netting) would be a significant step.

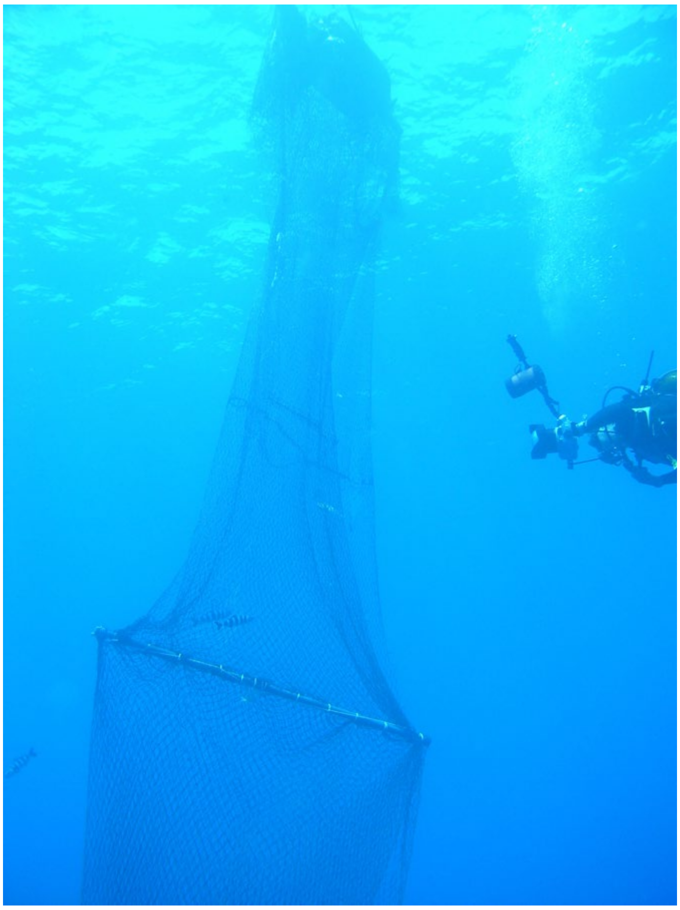

Figure 1. Underwater view of a DFAD (© FADIO/IRD/ Ifremer/ Marc Taquet)

b) **Shade effect:**

Fishers believe the DFAD should provide shade. This shade is provided both, by the floating surface of the DFAD, also known as raft[2], and also by the submerged net panels, strips, flags and palm leaves that fishers add to the submerged part of the DFAD. Some fleets have totally submerged their rafts and instead of providing shade at the sea surface, they deploy the raft submerged a couple of meters below the surface (Murua et al. 2019, Zudaire et al. 2020). The latter are as efficient at aggregating tuna as traditional DFADs but the probability of being detected by other purse seine vessels, and thus being stolen, is lower. In any case, for fishers, the purpose of these attracting structures is to provide shelter and shade to marine fauna, which for fishers is like "creating an artificial reef in oceanic waters", a heterogeneity attracting fish in the vast and homogeneous oceanic waters.
Non-tuna species, which likely influence the attraction and retention behaviors of tuna at DFADs, could first be attracted and retained because of the specific design of the DFAD, in this case the shade or shelter provided.

The shade produced by the floating structure of the DFAD as well as the attractor strips and flags that are usually added to the shallow part of the submerged structure, are considered by fishers crucial to attract those species that occupy the space closest to the DFAD structure (i.e. within 2 m), named *intranatans* (*Lobotes surinamensis*, *Abudefduf saxatilis*, etc.). *Intranatant* species in turn, may play the role of attractors of other species that occupy the space at greater distances from the DFAD (i.e from 50 m to several nautical miles from the FAD), such as tunas (Paryn and Fedoryako, 1999). For instance, fishers report that rough triggerfish plays a key role in the attraction of tunas, as this species emits loud grunt-like sounds. It may be that once the DFAD is colonized by *intranatant* species, the structure of the FAD (colour, shade, etc.) loses importance on the ability to attract tunas. *Intranatant* species once present at DFADs, may serve as a more powerful attractor than the FAD structure itself (Moreno et al. 2016).

3. What modifications could be done to DFAD structures to reduce their impact while still being productive for fishing?

Basically, to decrease the impact of DFAD structures on the ecosystem there are three main modifications to address (i) eliminate the netting materials to avoid ghost-fishing when DFADs are lost, abandoned or discarded. The small-mesh net used in low entanglement risk DFADs, will reduce the chances of shark and turtles entanglement, but after long periods of time at sea the net will start to break down and larger holes will appear, thus increasing the potential to entangle marine fauna (ISSF, 2019) (ii) replace plastic derived components by biodegradable materials to build FADs and (iii) reduce the size of the structure so that the impact when a DFAD is lost is minimized and also to facilitate the logistics to retrieve them.

[2] In this report we adopt the term raft to refer to any type of surface structure used in DFADs, such as bamboo rafts, metal frames, "burrito" shape surface structures, etc.

From our research through 2019, we have identified the most promising biodegradable materials to be used at DFADs, and various biodegradable DFAD designs that could be used successfully in some regions, such as the Indian Ocean (Moreno et al. 2020; Zudaire et al. 2020). Yet, reducing the size of the DFAD while allowing a slow drift and reducing the plastic needed for the flotation[3] are challenges to be faced.

In order to address these challenges ISSF is collaborating with physical oceanographers from the Insitute de Ciències del Mar (CSIC, Spain) experts in oceanic current dynamics and drifters. Specifically, we collaborated to better understand the physical behavior of DFADs in the water column in order to find a DFAD structure that aggregates tuna but also:

1-Reduces presently observed large DFAD sizes
2-Reduces the need for extra flotation (plastic buoys)
3-Drifts slowly
4-Provides shade
5-Its working lifetime reaches one year

Apart from the features listed above, new DFAD designs should be cost-effective or at least costs be similar to traditional DFADs. Also, they should allow easy transportation and storage onboard.

4. Physical behavior of DFADs in the water column

In this section we share information on the physical behavior of drifters, gathered from our collaboration with oceanographers, that could be helpful in the application of biodegradable DFAD structure´s construction:

a) An effective drag for the slow drift

The physical concept of drag is a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid. In the case of DFADs, the drag is created by the submerged structure, which we will call "drogue", the component of the DFAD that makes them drift slowly.

The shape of the drogue:

The drag coefficient denotes how much an object resists movement through a fluid such as water and is determined by the shape of the drogue. The higher the drag coefficient the higher the resistance to move (Figure 2). These drag coefficients are independent from the area or size of the drogue (Niiler et al. 1987).

The resistance to movement of an object, is calculated as the drag coefficient (determined by its shape) multiplied by its area (determined by the size of the structure). Thus, in the case of DFADs, selecting a shape with a high drag coefficient would allow a good performance (resistance to motion) which would allow for a decrease in the total area of the structure.

[3] there is no clear biodegradable alternative for the plastic buoys used for DFAD´s flotation, balsa wood is one of the promising alternatives that is undertest in the IATTC region.

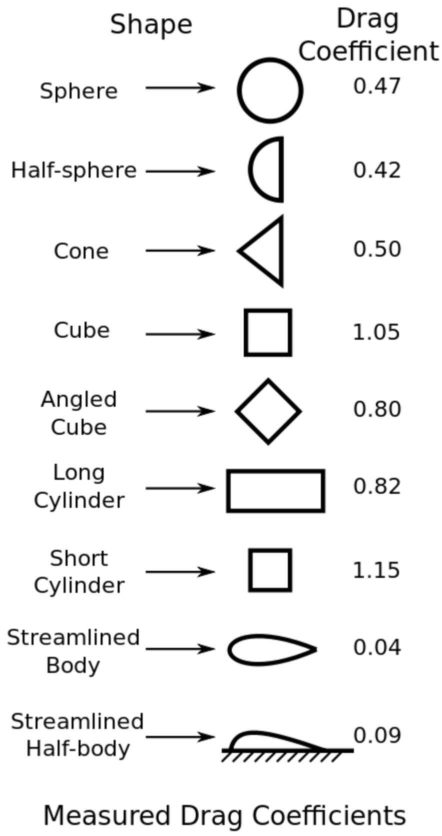

Figure 2. Measured drag coefficients for different shapes

The DFAD´s shape should have as much drag coefficient as possible to reduce motion. Thus, an effective drogue for DFADs should be **three-dimensional**. Also, the drogue should be **symmetric** so that the drag created is independent from the orientation of the drogue.

From this physics information we conclude that the traditional two-dimensional DFADs (Figure 1) currently in use in the tuna fishery worldwide have a very inefficient and low drag coefficient. Changing its shape to a three-dimensional and symmetric structure of a smaller size, would allow the desired slow drift avoiding the need for massive and bulky structures.

b) Forces affecting DFAD structures

The emerged and submerged components of DFADs are subject to various forces: wind, waves, surface currents and deeper currents in the water column. These forces can act independently having different or similar intensities and directions depending on oceanographic conditions. Thus, adding or subtracting forces when acting on DFADs´ motion.

Drag in the surface components of the DFAD

Forces on the surface components of the DFADs (flotation buoys, raft and geolocating tracker) are mainly due to waves, surface currents and wind. These forces will affect the DFAD depending on the DFADs′ raft shape and area (as seen before) (Kiman et al. 1975). The wind affects intermittently the raft of the DFAD, but its intensity is much higher compared to that of surface currents. In the case of DFADs, the ideal situation would be to keep to the minimum the effect by the wind and waves on the surface structure. Thus, it would be beneficial to have a raft shape with a low drag coefficient and the least emerged area out of the sea surface to reduce tension on the structure created by wind forces affecting the surface component and the currents affecting the underwater drogue.

Waves can affect and drag intermittently the DFAD´s surface structure. This drag, if opposed to the underwater drag´s direction could heavily affect the integrity of the DFAD structure. In order to reduce wave generated drag, the raft and floats in the surface should freely ride on the waterline, with little tension from the tether connecting the raft with the submerged appendage. If there is tension in the line that connects the raft on the surface and the underwater drogue, the raft and floats would sink and be much more affected by the wave´s drag (case of the drifter on the left in Figure 3, from Niiler et al. 1987). DFAD´s rafts should oscillate in the waterline without tension from the underwater appendage connecting line, the smaller the tension the smaller the drag (case of the drifter on the rigth in Figure 3). Therefore, the correct assessment of the weight and flotation needed by a given structure to reduce tension in the main line is critical to ensure lower stress on materials and a greater DFAD lifetime.

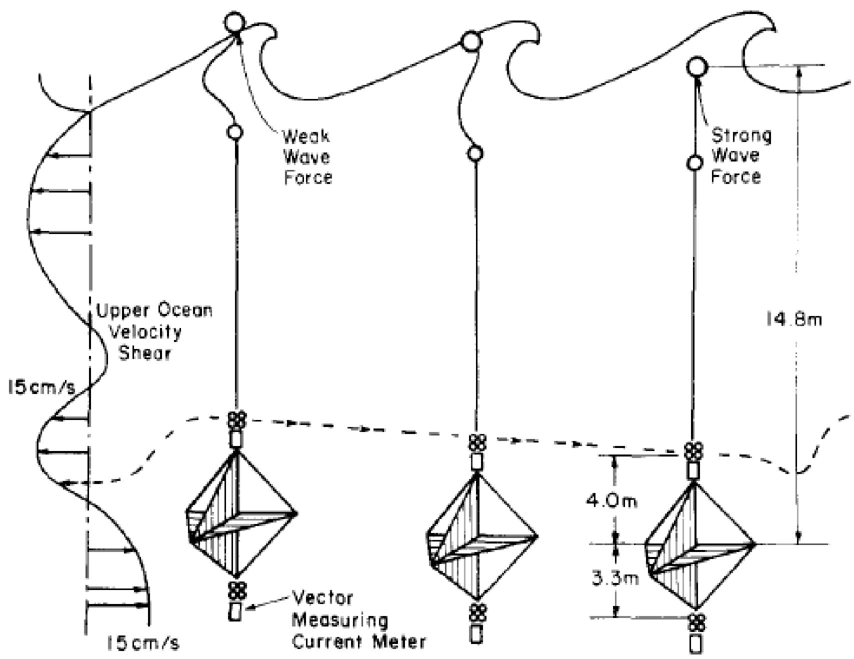

Figure 3. Diagram of the observed motion of a drifter in surface waves (from Niiler et al. 1987)

Drag in the water column:

The submerged appendage of DFAD´s structure may be subject to different current intensities and directions. The deeper the drogue is located in the water column the slower the drift, as in general, current speed decreases with depth (Webster el al. 1967; Gasser et al 2000). The depth at which the drogue should be located in the water column is a matter of finding a compromise between DFAD´s life span and the desired slow drift.

In the case of DFADs the idea is to "anchor" it to depths below the mixed layer or at a depth where ocean – atmosphere interactions, such as waves and winds, do not affect the drogue (Figure 4). This depth will be different depending on the oceanographic conditions of each oceanic region, such as depth of the mixed layer, thermocline etc. In order for the DFAD to match the slow currents below the mixed layer, the highest drag coefficient of the drogue should be placed on the deepest part of the DFAD structure.

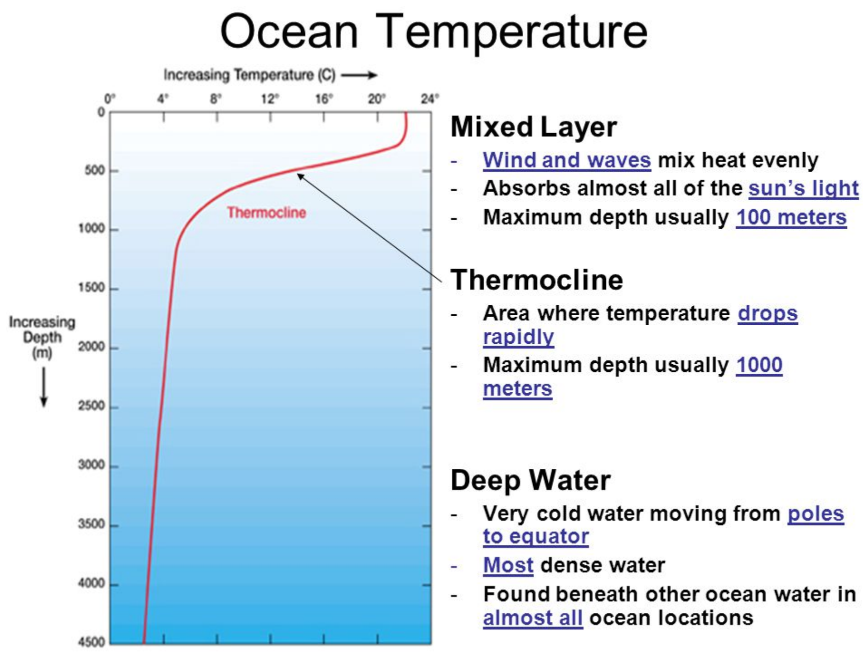

Figure 4. Illustration of the different layers in the water column.

The purpose is to make the DFAD drift slow anchoring it below the mixed layer. However, it is important to note that placing drogues along the different depths of the DFAD´s structure would weaken it. These drogues at different depths would be subject to different current directions and intensities producing torsion and shearing forces that would make the DFAD suffer structural stress and thus decrease its lifetime.

c) The assessment of weight and flotation for the DFAD

The objective here is that the DFADs´ underwater structures have a similar density to that of water. This would allow the minimum torsion and shears forces and thus increase the lifetime of the DFAD. A correct assessment of the weight and flotation is key for the DFAD to suffer the least structural stress and allow the tension of the line to be minimum, which would also avoid the drag created by waves. The flotation should be the minimum necessary as to avoid surface drags created by wind and waves.

5. New biodegradable FAD structure proposed

From this collaboration a biodegradable DFAD was designed, that should fulfill all the conditions listed before: slow drift, creating drag but with reduced size, reduces the need for plastic flotation and provides shade working during one year at sea. The conceptual drawing is shown in Figure 5 and the guide to build this biodegradable DFAD is provided in Annex 1.

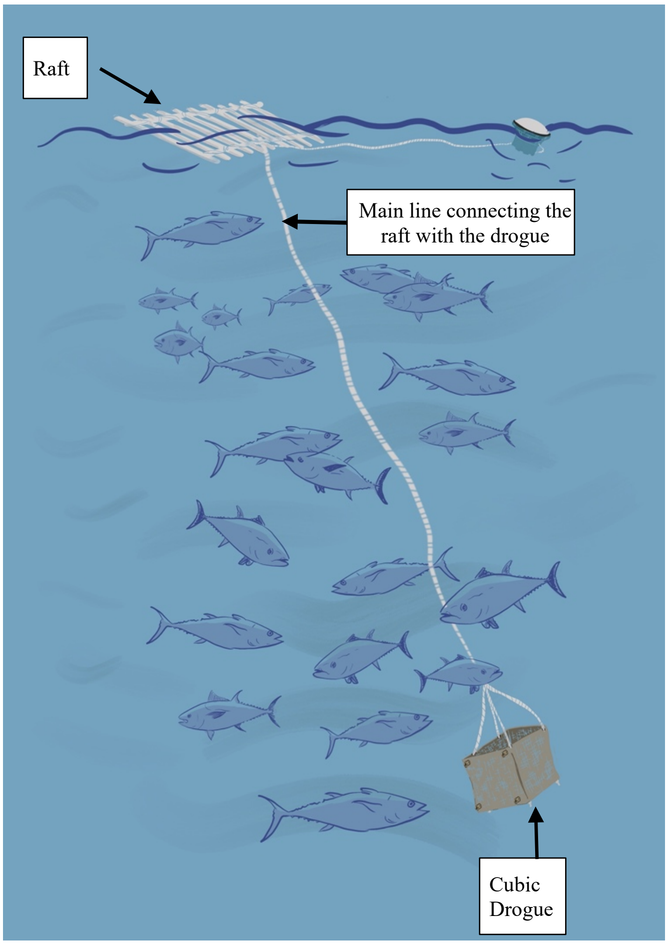

Figure 5. Conceptual drawing of the new DFAD design

The drogue:
The selected drogue to make the DFAD drift slowly is a symmetric three-dimensional cube structure that is hanging from the surface structure with a rope to a depth below the mixed layer (this depth varies depending on the oceanic area, could be from 60 m to 100 m). The drag coefficient of this structure is higher compared to that of traditional flat net panels DFADs (see guide in Annex 1 for more details).

The weight and flotation required:

The cubic structure of 1 m^3 (1m x1m x1m) was weighed down with 8 kg of stones in order to make it sink. The weight of the drogue (cubic structure) in the water, was monitored until the materials absorbed saltwater to saturation. At this point the structure did not gain more weight. The maximum weight of the drogue in the water was 4.6 kg (including the 8 kg added for the structure to sink) and the flotation needed was estimated as that weight (4.6 kg) multiplied by three. So that the flotation needed would be to sustain a weight of 14 kg, which is a similar flotation to that provided by just the echo-sounder buoy used to track DFADs.

Fishers, when constructing traditional DFADs add extra weight, as it is believed that the weight creates the drag and maintains the DFAD in vertical position. However, with this new structure the drag is created by the three-dimensional structure and there is no need to add extra weight, just that to make the DFAD sink. Therefore, the need for floatation is also significantly reduced, resulting in less plastic buoys used for flotation and thus, reducing the plastic components of the DFAD.

Fishers could use more than one cubic structure to create more drag (this would increase the area of the drag), in this case, flotation should be multiplied by the number of cubic structures used. We recommend placing the 2 drags at the end of the line, the deepest part of the DFAD, as placing different drogues along the line at different depths, would result in stronger shear forces due to the different current directions and intensities that may be affecting the DFAD at different depths, and thus making it weaker.

The surface components and attractors:

Minimizing the emerged component of DFAD structures at the surface would allow increasing its lifetime through reduced structural stress. Thus, we recommend placing the minimum emerged components or those with the lowest drag coefficient (just the components that provide buoyancy). In the shallow part of the line, different attractors including biodegradable ropes, canvas and palm leaves could be attached to the line to create shade. Another possibility could be placing a smaller cubic structure as attractor at a depth of 15- 20 m, where the influence of waves is less than that on the surface.

6. Ongoing research with the new design of biodegradable DFAD

Currently these structures are undertest in the Western Pacific Ocean, 100 DFADs deployed by Caroline Fisheries Corporation a purse seine fleet from the Federate States of Micronesia (Figure 4) and in the Atlantic Ocean, 600 DFADs will be deployed by the Ghanaian pole and line and purse seine fleets under Ghanaian Tuna Association. Traditionally in these two regions DFADs have been especially deep compared to DFADs used in the Indian and Eastern Pacific Oceans, which is one of the reasons why particular efforts to find DFADs with biodegradable drogues are being made in those regions. Results will be available by the end of 2020-early 2021.

Figure 4. Trials in the western Pacific Ocean with the new FAD design

7. Recommendations for the construction and use of biodegradable DFADs, based on this research and previous experiences described in Moreno et al. (2020):

1. 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 (drogue).
2. 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.
3. For DFADs to drift slowly, the drogue should be three-dimensional and symmetric and should be "anchored" below the mixed layer. The design of the DFAD is crucial to reduce stress on the structure and increase their lifetime.
4. 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 retrieval and storage difficult. Research to reduce the mass (i.e., size, volume and weight) of traditional and biodegradable FAD structures is required. This would also reduce price costs in materials per FAD.
5. 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 parameters are not well calculated, the tension and torsion suffered by the structure will result in substantial damages, and the submerged appendage is more likely to detach from the raft — reducing its lifetime and aggregation effectiveness.
6. 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.
7. 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 in order to obtain statistically significant results. Fishers when testing individually biodegradable FADs, 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.

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ANNEX 1

Materials and Method to build the biodegradable DFAD

In this annex we propose the materials and method to build the drogue for the new biodegradable DFAD design. This is an example; fishers could find other methods and materials to successfully construct a biodegradable drogue.

A. Material for the biodegradable FAD construction

- Select 4 bamboo with below specifications:
  - 2 big bamboo canes with diameter of 100 mm
  - 2 small bamboo canes with diameter 40 mm
  - 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 1. Tools and bamboo canes needed to build the biodegradable FAD.

B. Material preparation

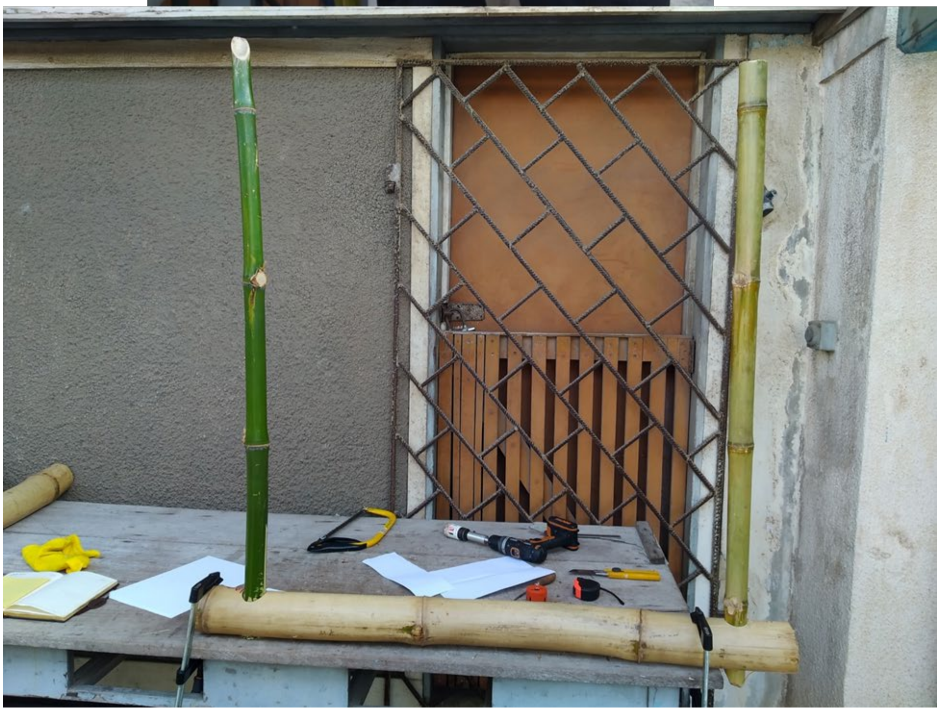
1. Clamp big bamboo canes (100mm diameter) onto work bench

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)

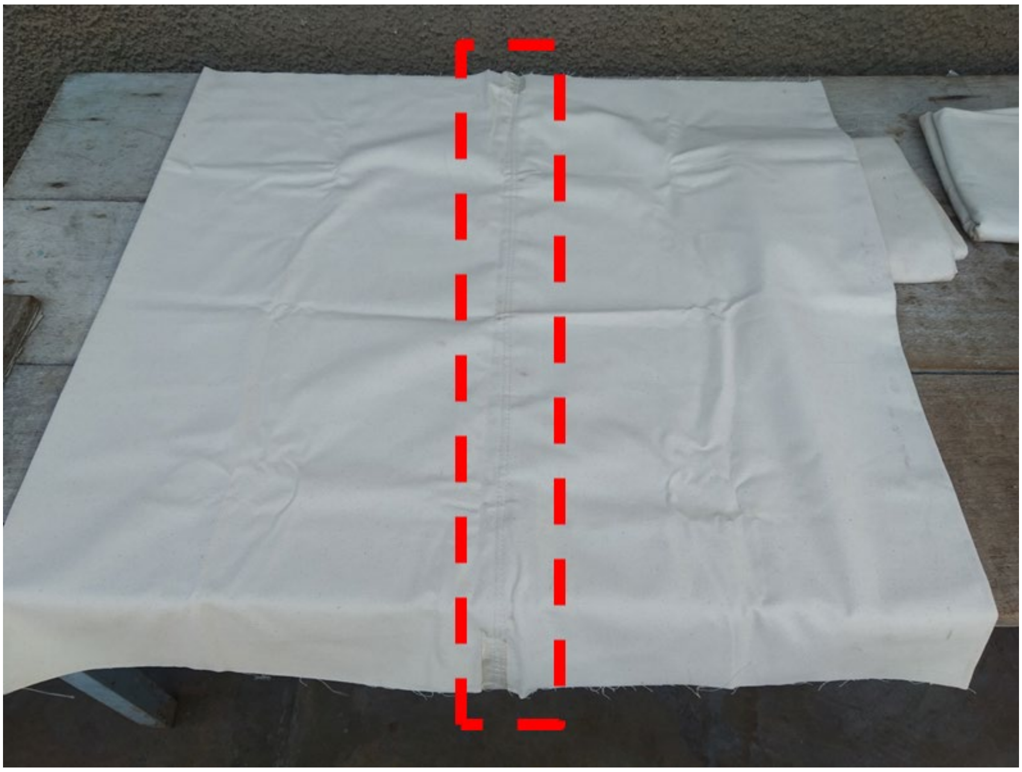
4. Drill a whole of about 20mm diameter through the bamboo cane on both sides (for the rope)

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 and Hammer the 9mm diameter wooden pins

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

12. Blast join

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