THE JELLY-FAD: A PARADIGM SHIFT IN BIO-FAD DESIGN

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ABSTRACT

Fishers and scientists in the three tropical oceans are investigating different designs of biodegradable FADs (bio-FAD) efficient for fishing. The tactic followed by most fishers is to maintain the same traditional drifting FAD (dFAD) design (submerged netting panels hanging from the raft) but made of organic ropes and canvas. Results of those experiences show that the lifetime of bio-FADs that maintain the traditional dFAD design but made of organic materials, is shorter than that required by fishers. The short lifespan of those bio-FADs is due to the structural stress suffered by dFAD designs traditionally used. Thus, in order to use organic materials instead of the strong plastic and increase the lifespan of those bio-FADs, a paradigm shift is needed. Bio-FAD structures should be re-designed to suffer the least structural stress in the water. The present document aims at (i) summarizing what we learned across the different experiences testing bio-FADs in the three oceans, (ii) proposing a new concept in dFAD design, the Jelly-FAD design, and (iii) providing recommendations to reduce the impact of dFAD structures on the ecosystem and for bio-FADs construction and use.

KEYWORDS: Fish Aggregating Devices, Ecosystem impact, ghost fishing, FAD, biodegradable, participatory approach

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1. Introduction

Drifting Fish Aggregating Devices (dFADs), which are comprised by a surface raft and a submerged appendage, are most often made of plastic (nylon nets, buoys and polypropylene ropes). The submerged appendages are mostly made of netting material and can reach up to 80 m depth for some fleets in the Indian Ocean. It is estimated that ~100,000 dFADs are deployed every year by fleets operating in the Indian, Atlantic and Pacific oceans (Gershman *et al*. 2015). Due to the complexity of dFAD fishing strategy, in which dFADs are left drifting with a geo-locating buoy, it is estimated that around 7% - 22% of these dFADs end up stranded (Maufroy et al., 2017; Moreno et al., 2018; Escalle et al., 2020; Imzilen et al. 2021). Impacts caused by lost and abandoned dFADs are ghost fishing (Filmater *et al*. 2013), accumulation of plastic at sea, damage on coral reefs and interference with other economic activities, such as tourism.

Because dFAD fishing strategy implies a risk for dFADs to be abandoned or loss, the reduction of the impact of dFAD structure on the ecosystem, would need various mitigation practices along the chronology of the fishing activity, i.e., reducing the number of dFADs deployed, eliminate the use of netting in their construction (already required by IOTC CMM 19-02), using organic materials, instead of plastic, applying good practices to avoid dFAD loss and abandonment, and collecting non-utilized dFADs, as much as possible. Each fishery should search for solutions best suited to their fishing operations. In the case of dFADs 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, by scientists and research institutes working on dFAD fishing, and by the fishing industry, conscious of impacts of lost and abandoned dFAD structures. A direct outcome are initiatives, both by the fishing sector and research institutes, to develop biodegradable dFAD (Bio-FAD) structures efficient for fishing for around one year. Currently, projects exist in the three oceans to test dFAD prototypes constructed mostly with biodegradable materials (Moreno et al., 2017; Zudaire et al., 2017; Moreno et al., 2018; Roman et al. 2020; Zudaire et al. 2020). But there are also numerous individual initiatives by fishing companies and captains that are trying to find alternatives to the plastic and netting used at dFADs. The present document aims at (i) summarizing what we have learned across the different bio-dFADs experiences in the three oceans, (ii) proposing a new concept in dFAD design, the Jelly FAD design and (iii) providing recommendations to reduce the impact of dFAD structures on the ecosystem and for bio-FADs construction and use.

2. What we learned

2.1 Structural features needed for a drifting FAD to be productive

One of the research questions that drives our work in the search for a bio-FAD, is what structural components are needed for a dFAD to be efficient for aggregating tuna. ISSF Skippers´ Workshops consistently showed over a decade that there are two main dFAD features that fishers consider crucial for it to be productive, the slow drift and the shade (Murua et al. 2014).

a) **Slow drift**: It is not clear if a dFAD that drifts slowly is more attractive for tuna or if fishers need the slow drift to keep it within their fishing area, avoiding dFADs 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 netting panels, for which their submerged components can reach up to 80 meters depth (**Figure 1**). The primary purpose of this large, submerged appendage is to help slow down dFAD´s drifting speed. 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.

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, 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.

2.2 Main difficulties encountered to find an efficient biodegradable FAD and the potential solutions

During our research in the three tropical oceans to find a bio-FAD structure that fulfilled the two main characteristics above (slow drift and shade effect) with diverse fleets (Moreno et al., 2020), we identified three common, main difficulties towards the implementation of bio-FADs. Here we summarize these difficulties and their potential solutions:

1. The tactic followed by most fishers to develop a bio-FAD is to maintain the same traditional dFAD design (submerged netting panels hanging from the raft; **Figure 1**) but made of biodegradable ropes and canvas. Results show that lifetime of those biodegradable dFADs, that maintain the same design but just replace the materials (organic materials for plastic), is shorter than that required by fishers (around one year). This is due to the structural stress that bioFADs with traditional design suffer in the water. Plastic materials allow traditional dFADs persist without breaking despite the tension and structural stress suffered. However, once plastic is replaced by organic materials, the tension and structural stress make the bio-FAD break.
   Proposed solution: in order to use organic materials instead of the strong and durable plastic and allow an efficient lifespan of bio-FADs, a paradigm shift is needed. Bio-FAD structures should be re-designed to suffer the least structural stress.

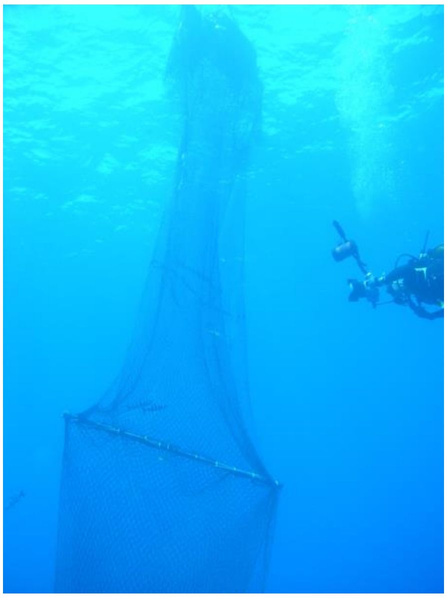

Figure 1. Underwater view of a conventional dFAD
(© Fadio/IRD/ Ifremer/ Marc Taquet)

2. There is no clear alternative for the plastic buoys used for bio-FAD´s flotation. Balsa wood is one of the promising organic alternatives that is under test in the IATTC region but this type of wood is also available in the western Pacific and Africa. Bio-based plastic buoys are also under test in Sarebio project, however the biodegradability benefits of using bio-based plastics instead of plastic buoys are not clear enough yet (Zimmermann et al., 2020).
   Proposed solution: under the lack of a clear alternative for plastic buoys used for flotation, the need for plastic buoys or corks to ensure bio-FADs flotation should be reduced as much as possible, re-designing the structure.

3. As a result of the clear trend to increase the size of the dFAD structure (to slow down the drift), fishers employ higher amounts of netting and other plastics to build large and deep structures. In addition to the increased impact due to bulky structures, because organic materials are more expensive than same components made of plastic, the increase of dFAD structure makes a bio-FAD much more expensive than the traditional one. The raise in costs to move from traditional dFADs to bio-FADs increases with the size of the structure.
   Proposed solution: reduce the size of the structure (i) to reduce the impact, (ii) to allow an easier retrieval and (iii) to reduce the costs to build bio-FADs.

From our research through 2019, we identified the most promising biodegradable materials for dFADs construction, 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, re-designing a dFAD made of organic materials and without netting, reducing its structural stress, reducing its size and the need for flotation, while allowing a slow drift and shade effect, were the challenges to be faced.

3. The Jelly-FAD: a paradigm shift in bio-FAD design

In the past 15 years, we have witnessed the introduction and refinement of advanced technology in large purse seine vessels targeting tropical tunas, allowing remote detection of tuna, the remote tracking of dFADs and its aggregated biomass, the high-resolution satellite derived environmental variables used onboard, etc. The high technology developed in purse seines clashes with the rudimentary and undeveloped structure of the traditional dFAD in use, whose design has evolved very little for decades compared to the technology used on board. Just as we rely on different experts to develop and refine new technology, we identified the need to work with experts on drift behavior to design a new bio-FAD structure, which until now had been left mainly in the hands of fishers. Thus, in order to address the challenges faced to build an efficient bio-FAD, ISSF began a collaboration with physical oceanographers from the Insitute de Ciències del Mar (CSIC, Spain) experts in oceanic current dynamics and drifters´ behaviour. Specifically, we collaborated to better understand the physical behavior of dFADs in the water column in order to find a bio-FAD structure that aggregates tuna but also:

- Reduces dFAD´s structural stress to be used successfully with organic materials
- Reduces presently used large dFAD sizes
- Reduces the need for flotation (plastic buoys)
- Eliminates netting
- Drifts slowly
- Provides shade

The result of this collaboration was an innovative dFAD design that we called the Jelly-FAD (**Figure 2**). The Jelly-FAD is a dFAD that drifts with the least structural stress, like jellyfish. The assessment of the density of the organic materials used in its construction allowed making the Jelly-FAD drift with quasi-neutral buoyancy, like jellyfish. For that, we worked in a sea-water tank in ICM´s facilities to measure the evolution of the density of the organic materials used in the Jelly FAD (**Figure 3**). The objective of those measurements was to design a dFAD for which density was similar to that of seawater. 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.

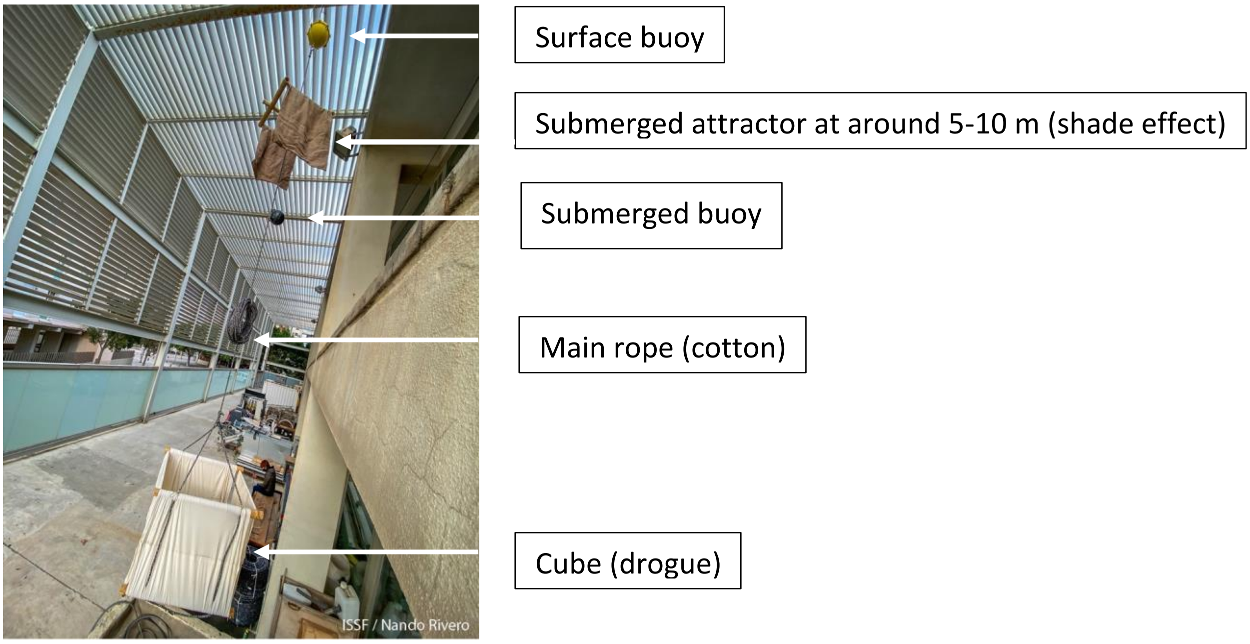

Figure 2. The Jelly-FAD mounted at ICM facilities.

3.1 *Main features of the Jelly-FAD*[1]

The main points to take into account in Jelly-FAD construction:

(i) *The sea anchor*: The dFAD should be "anchored" with a drogue to depths below the mixed layer or at a depth where ocean – atmosphere interactions, such as waves and winds, do not affect the drogue. 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 drogue should be placed only on the deepest part of the dFAD structure.

(ii) *The shape of the drogue:* the drogue causing the dFAD to drift slowly is a symmetric three-dimensional cube structure of 1 m^3 that is hanging from the surface structure with a cotton rope. The drag coefficient of this structure is higher compared to that of traditional dFADs with flat net panels. Changing the traditional two-dimensional structure 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.

(iii) *Drag on the surface components of dFADs:* The dFAD is 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 the oceanographic conditions. Thus, adding or subtracting forces when acting on dFADs´ motion. The wind affects intermittently the raft of the dFAD, but its intensity is much higher compared to that of surface currents. This drag on the surface, if opposed to the underwater drag´s direction could heavily affect the integrity of the dFAD structure, creating structural tension. In the case of dFADs, the ideal situation would be to keep to the minimum the effect of the wind and waves on the surface structure. Thus, it would be beneficial to submerge the raft at 5-10 m depth leaving only the buoys used for floatation out of the sea surface. Minimizing the emerged component of dFAD structures at the surface would allow increasing its lifetime through reduced structural stress.

(iv) *Weight and flotation required for neutral buoyancy:* Results of the tests of density evolution of bamboo and cotton ropes monitored in the seawater tank helped assessing precisely the weigh and flotation needed for the Jelly-FAD to drift with quasi-neutral flotation (**Figure 3**). The results showed that:

- In 20 days the bamboo is saturated in seawater and its density is very similar of that of seawater. Thus, the cubic structure made of bamboo will neutrally drift in the water column and won´t need any extra weight added once is saturated in seawater.
- In 25 days the cotton rope of 20 mm of diameter, will saturate in seawater and its weight after 25 days will be100 gr per 1m rope.

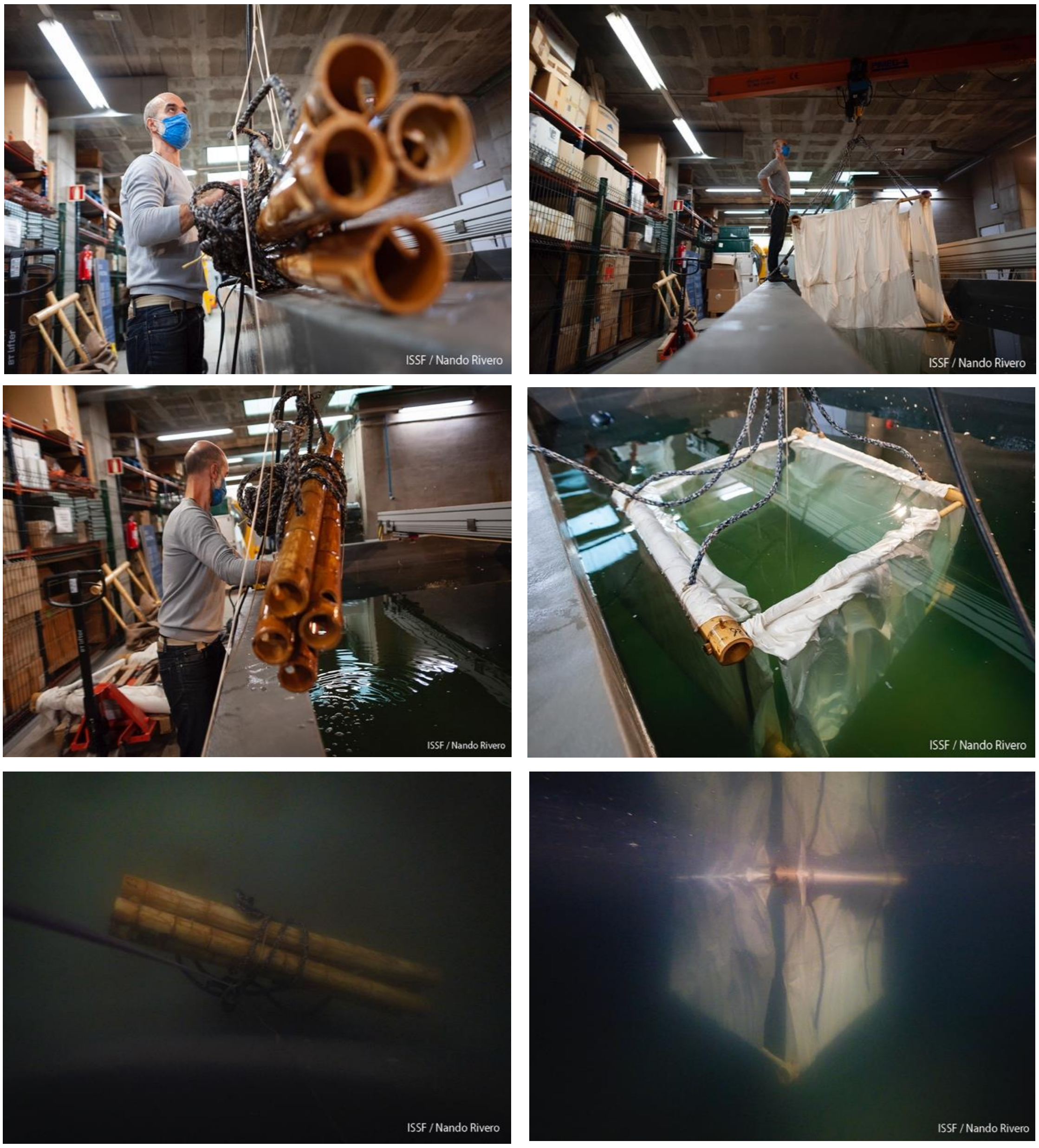

Figure 3. Assessment of the evolution of the density of the organic materials (bamboo canes, rope and cotton fabric) during two months in a seawater tank.

The Jelly-FAD won´t need any extra weight to be added, as once it is saturated in seawater its density will be very similar to that of seawater and remain at sea drifting at 60 m depth or the chosen depth without the need of weight, which in turn reduces the need for flotation (in our case, a maximum of 18 kg buoyancy on the surface and a submerged buoy of 6 Kg below the attractor, **Figure 2**). However, in order to make the bamboo sink until bamboo is saturated in seawater, weight needs to be added. The weight added for a $1m^3$ would be 8 kg of stones in total, (in our case, 2 kg in each corner) hanging in four paper or cardboard bags. The paper degrades in 20 days and releases the stones, so that the structure remains at sea without any extra weight added. It is important to note that the numbers for weights and flotation provided in this paragraph, are specific for the cubic structure made of bamboo and cotton rope in our study (using 70 m of cotton rope and $1m^3$ bamboo cube), those numbers should be recalculated for other shapes and materials used.

4. Ongoing and planned research at sea with the Jelly-FAD

4.1 Currently the Jelly-FAD is under test in controlled conditions in the following regions and fleets:

a) *The Mediterranean Sea* (ISSF-ICM-AZTI): the Mediterranean Sea was selected for our controlled experiments with Jelly-FADs at sea due to the lack of fleets fishing with dFADs. The idea was to monitor their structural integrity over time, without interference from the tuna fleets, for different weight and buoyancy configurations. Ten Jelly-FADs were deployed in the Gulf of Lion in early February 2021 and by the end of August 2021 (7 months later) four are still at sea and the drogue working properly. Three of them sunk and the other three were stolen or ended up stranded.

b) *Western Pacific Ocean with Caroline Fisheries corporation* (ISSF-AZTI): a total of 100 bio-FADs tested, 50% of the experimental dFADs to be tested was a design that copies the traditional dFAD but that uses biodegradable materials (manila hemp rope and jute canvas). The other 50% deployed were Jelly-FADs, a cubic drogue submerged at 60 m depth and as attractor a surface raft instead of the submerged structure proposed by oceanographers. First results show that the Jelly-FAD lasted more than the traditional bio-FAD made of organic materials. Although few visits were made to the bio-FADs, two sets were made around the Jelly-FAD of up to 95 tons of tuna. In a second trial that CFC will start in early 2022 the raft will be submerged and only Jelly-FADs will be tested, made of cotton and jute canvas this time. Further and more detailed analyses will be conducted and results available for late 2021.

c) *Atlantic ocean with Ghanaian purse seine and pole and line fleets* (ISSF-AZTI): a total of 133 bio-FADs deployed, 35 Jelly-FADs and 95 traditional dFAD design made of organic materials (cotton ropes and canvas). Results will be available by the end of 2021.

d) *Eastern Pacific Ocean with Ugavi fleet* (ISSF): this fleet is testing Jelly-FADs in 2021. They trialed around 50 Jelly-FADs by August 2021. Main difficulty found is how to attach a weight to the cube that can be released in 20 days. They trialed different weight configurations, using paper and canvas bags and thin strings of cotton to hang the bags. Results will be available by early 2022.

4.2 Next trials starting in late 2021, early 2022:

a) *Atlantic Ocean with Pevasa fleet* (ISSF): This fleet will trial around 150 Jelly-FADs made of cotton rope and cotton canvas.
b) *Atlantic Ocean with the fleet from Opagac* (AZTI-ISSF): 250 Jelly-FADs made of cotton rope and cotton canvas
c) *Western Pacific Ocean with the U.S. tuna purse seine fleet* (ISSF-SPC): 210 Jelly-FADs (the design and materials to be determined)
d) *Western Pacific Ocean with diverse fleets* (to be determined) (EU-U.S.-SPC-ISSF): 200 bio-FADs (the design and materials to be determined)

5. Recommendations for the construction and use of biodegradable dFADs to reduce ecosystem impacts by dFAD structures, based on this research and previous experiences described in Moreno et al. (2020):

1. Only dFADs 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.
2. To reduce the dFAD structural stress so as to enlarge the lifetime of biodegradable materials for the construction of dFADs, an innovative bio-FAD design named Jelly-FAD is recommended.
3. Biodegradable dFADs should be made of 100% organic 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 dFAD structure and link the surface component of the dFAD with the deeper component (drogue).
4. 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 dFADs situated deeper in the water column.
5. 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.
6. The physical impact of dFAD structures on the ecosystem is proportional to their size. Current dFAD 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 dFAD structures is required. This would also reduce price costs in materials per dFAD.
7. The correct assessment of the flotation and weight distribution in the design of the dFAD is a crucial factor to extend its working lifetime. This is especially important for biodegradable dFADs, 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 dFAD’s lifetime and aggregation effectiveness.
8. Due to the high incidence of dFAD loss through change of hands, sinking, beaching or out-of-reach deactivations, trials of experimental biodegradable dFADs in real fishing conditions need to test great quantities in order to obtain statistically significant results. Fishers when testing individually biodegradable dFADs, should share with scientists data from echo-sounder buoys attached to biodegradableD 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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