SCIENTIFIC COMMITTEE
EIGHTEENTH REGULAR SESSION

ELECTRONIC MEETING
10 – 18 August 2022

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

WCPFC-SC18-2022/EB-IP-17

G. Moreno[1], J. Salvador[2], I. Zudaire[3], J. Murua[3], J. Pelegrí[2]
J. Uranga[3], H. Murua[1], M. Grande[3], V. Restrepo[1]

---

[1] International Seafood Sustainability Foundation (ISSF). 1440 G Street NW Washington DC 20005. U.S. gmoreno@iss-foundation.org

[2] Instituto de Ciencias del Mar (ICM). Passeig Marítim de la Barceloneta, 37, 08003 Barcelona.Spain

[3] AZTI. Herrera kaia, Portualdeal z/g 20110 Pasaia-Gipuzkoa. Spain

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

Gala Moreno[1*], Joaquín Salvador[2], Iker Zudaire[3], Jefferson Murua[3], Josep Luis Pelegrí[2], Jon Uranga[3],

Hilario Murua[1], Maitane Grande[3], Victor Restrepo[1]

[1]International Seafood Sustainability Foundation (ISSF). 1440 G Street NW Washington DC 20005. U.S.
gmoreno@iss-foundation.org
[2] Instituto de Ciencias del Mar (ICM). Passeig Marítim de la Barceloneta, 37, 08003 Barcelona.Spain
[3]AZTI. Herrera kaia, Portualdeal z/g 20110 Pasaia-Gipuzkoa. Spain

SUMMARY

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 conventional 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 conventional dFAD design but made of organic materials, is shorter than that required by most fishers. The short lifespan of those bio-FADs is due to the structural stress suffered by dFAD designs conventionally 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.

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 Pacific 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 and WCPFC CMM-2021-01), 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 dFAD 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 conventional 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 conventional 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 (from 4 to 9 months depending on the region). This is due to the structural stress that bio-FADs with conventional design suffer in the water. Plastic materials allow conventional 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.

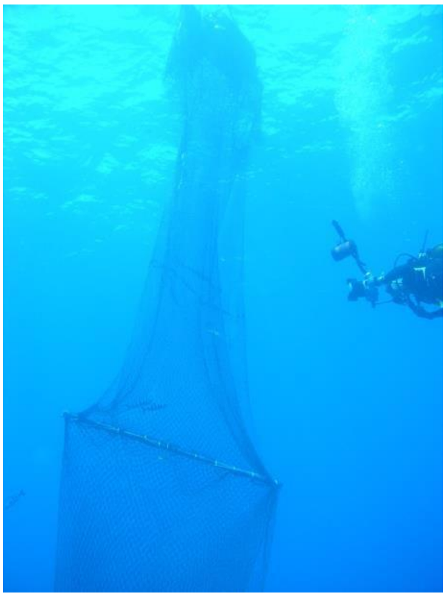


Figure 1. Underwater view of a conventional dFAD
(© Fadio/IRD/ Ifremer/ Marc Taquet)

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. 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 conventional one. The raise in costs to move from conventional 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 2021, 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 conventional 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 do. 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 in time of the density of the organic materials used in the Jelly FAD (**Figure 3**).

The objective of those measurements was to design a bio-FAD for which density was similar to that of seawater, to allow the minimum torsion and shears forces and to decrease the need for floatation. 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 and emerged component of the bio-FAD should be the minimum necessary as to avoid surface drags created by wind and waves.

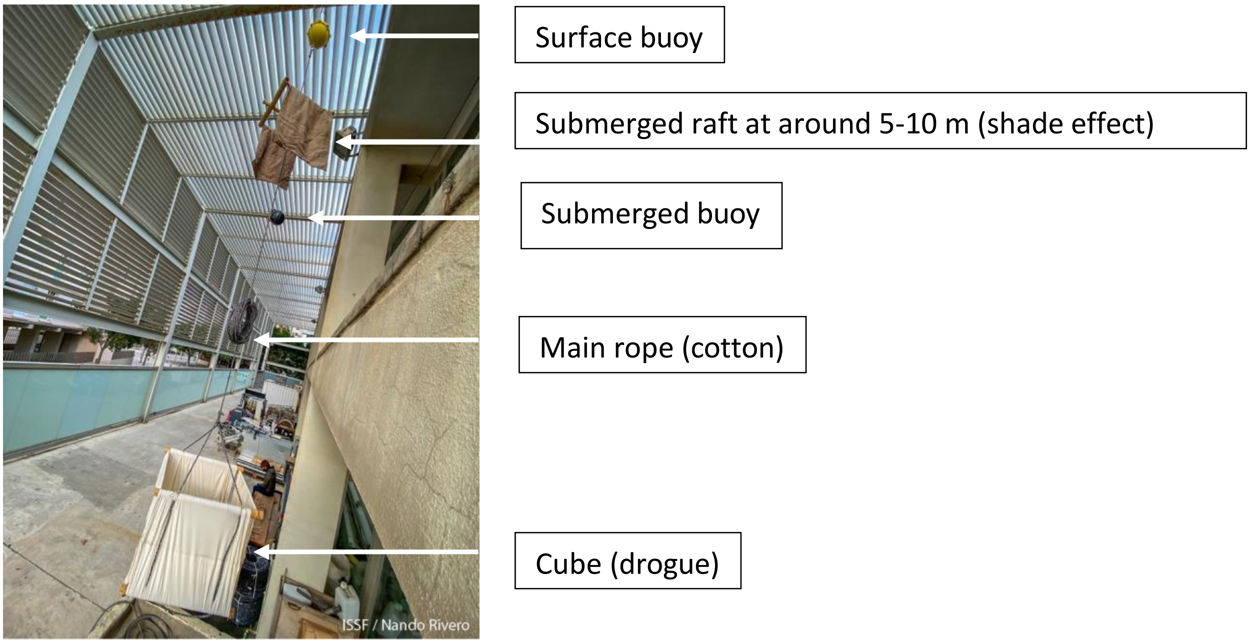


Figure 2. The Jelly-FAD mounted at ICM facilities.

3.1 Main features of the Jelly-FAD[1]

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

(i) *The drogue (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. 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. In the Pacific Ocean, the drogue placed at 50 m depth proved to be successful.

(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 conventional dFADs with flat net panels. Changing the conventional 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) *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 bio-FADs, 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. Note that this measurements are specific for the rope used, but should be assessed for any other organic rope to be used, so that the weight of the structure in sea water and thus the floatation needs are well managed.

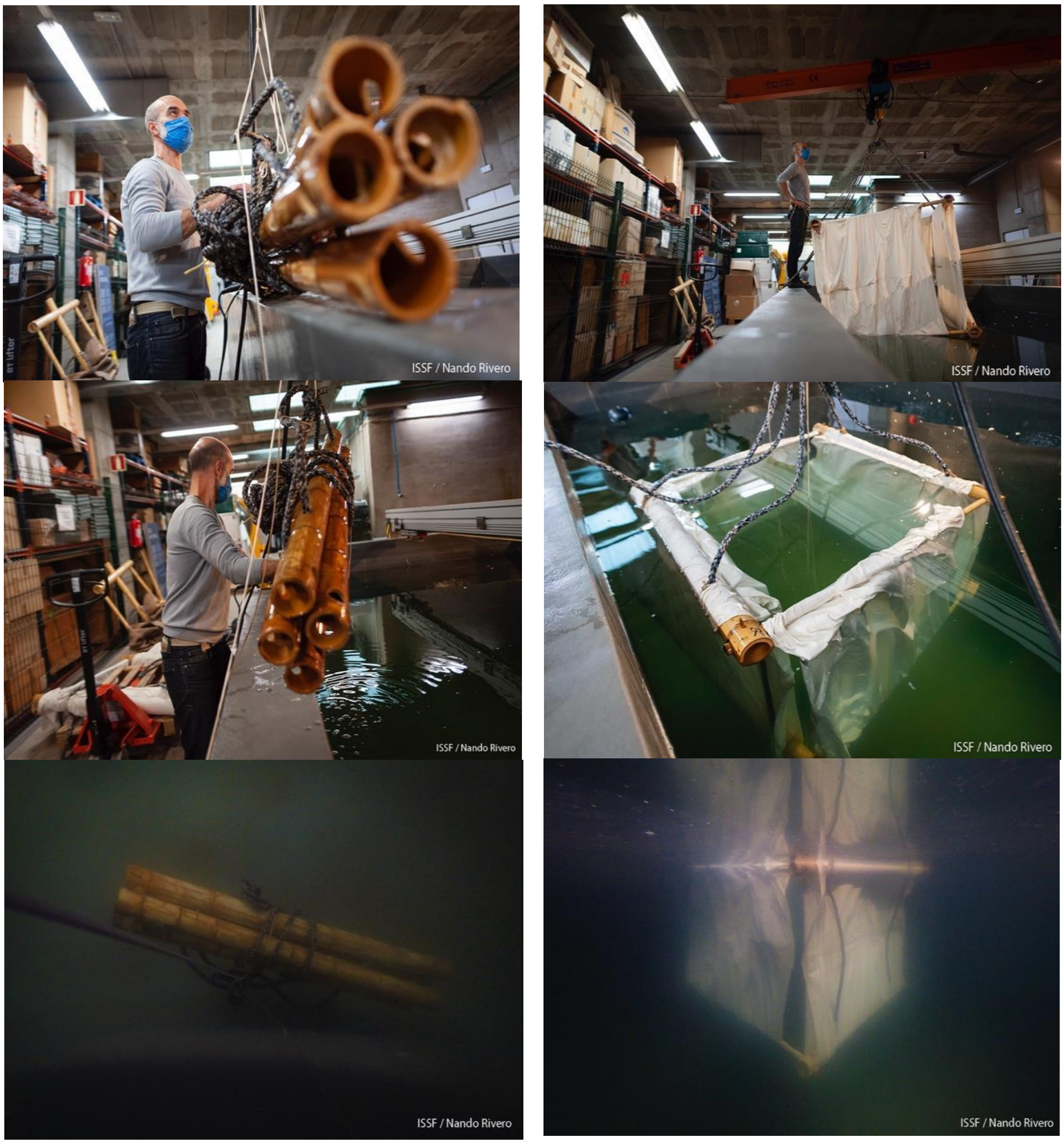


Figure 3. Assessment of the evolution of the density of the organic materials during two months in a seawater tank.

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 50 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 30 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 10 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

a) The Mediterranean Sea (ISSF-ICM-FAO-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. An improved version of the Jelly-FAD was deployed in the Gulf of Lion in May 2022. Ten jelly-FADs, with a lighter configuration, will be monitored till the end of 2022.

b) Western Pacific Ocean with Caroline Fisheries corporation (ISSF-FAO-AZTI), results presented in section 5 below.

c) Eastern Pacific Ocean with Ugavi fleet (ISSF): this fleet started testing Jelly-FADs in 2021. They have deployed 500 Jelly-FADs in one year, tests will continue in 2022. Results are presented in section 5 below.

d) Eastern Pacific Ocean with NIRSA fleet (ISSF-IATTC): a minimum of 100 Jelly-FADs will be tested starting in mid 2022.

e) Atlantic ocean with Ghanaian purse seine and pole and line fleets (ISSF-FAO-AZTI): a total of 133 bio-FADs deployed, 35 Jelly-FADs and 95 conventional dFAD design made of organic materials (cotton ropes and canvas). From the 133 deployed bio-FADs, few visits were made due to the loss of bio-FADs (i.e being stolen or sunk) or beacasue they drifted out of the fishing zone. In order to get results on their performance, echo-sounder buoy trajectories and biomass will be analyzed.

f) Atlantic Ocean with Pevasa fleet (ISSF-FAO): This fleet will trial around 200 Jelly-FADs made of cotton rope and cotton canvas during 2022.

g) Atlantic Ocean with the fleet from Opagac (AZTI- ISSF): 350 jelly-FADs made of cotton rope and cotton canvas will be tested. By May 2022, 84 jelly-FADs were deployed but only 7 were visited, due to the jelly-FAD loss and beacasue they drifted out of the fishing ground. Jelly-FAD deployment will continue during 2022 to complete the 350 deployments.

h) Western and eastern Pacific Ocean with the U.S. tuna purse seine fleet (ISSF-NOAA-SPC) : 216 Jelly-FADs will be deployed by the U.S. fleet starting in mid 2022.

i) Western Pacific Ocean with various fleets (EU-U.S.-SPC-ISSF): 200 bio-FADs (the design and materials to be determined), starting in late 2022.

5. Preliminary results from fleets working in the Pacific Ocean:

5.1 Trials with Ugavi fleet

The fleet from Ugavi deployed 500 jelly-FADs over the course of one year, starting in early 2021. The performance of these 500 deployments of jelly-FADs will be compared with the behavior of other conventional dFADs deployed simultaneously close to them. Some preliminary results for the January to March 2022 period are presented in Table 2.

Table 2. Catches on jelly-FADs between January and March 2022 (courtesy of Ugavi fleet).

JellyFAD	Deployment date	Set date	Days at sea	Months at sea - until set	Catch (tons)
1	29/10/21	15/1/22	78	2,6	40
2	29/10/21	19/1/22	82	2,7	45
3	9/8/21	23/1/22	167	5,6	55
4	29/10/21	1/3/22	123	4,1	120
5	25/1/22	14/3/22	48	1,6	125
6	27/12/21	19/3/22	82	2,7	15
7	18/10/21	24/2/22	129	4,3	45
8	18/7/21	24/11/21	129	4,3	30
9	11/6/21	12/9/21	93	3,1	20
10	9/8/21	4/2/22	179	6,0	10
11	7/8/21	5/2/22	182	6,1	10
12	4/8/21	30/1/22	179	6,0	60
13	24/1/22	27/3/22	62	2,1	85
14	22/1/22	28/3/22	65	2,2	10

A total of 670 tons of fish were caught on 14 jelly-FADs during the first three months of 2022. Except for two jelly-FAD, the remaining 12 were deployed in 2021 (Table 2). The drifting days of the jelly-FAD at sea until the catch happened varied from 1.6 months to 6.1 months. According to fishers in the Pacific Ocean, six months is considered a long enough lifetime period for dFADs to be commercially useful for fishing. Few dFADs older than 6 months are fished in the Pacific Ocean, mainly due to dFADs drifting out of the fishing ground and the appropriation by other vessels. These jelly-FADs lasted up to 6 months until the set, travelling more than 3000 miles in some cases. Furthermore, several of those jelly-FADs were redeployed after the set for further use at sea.

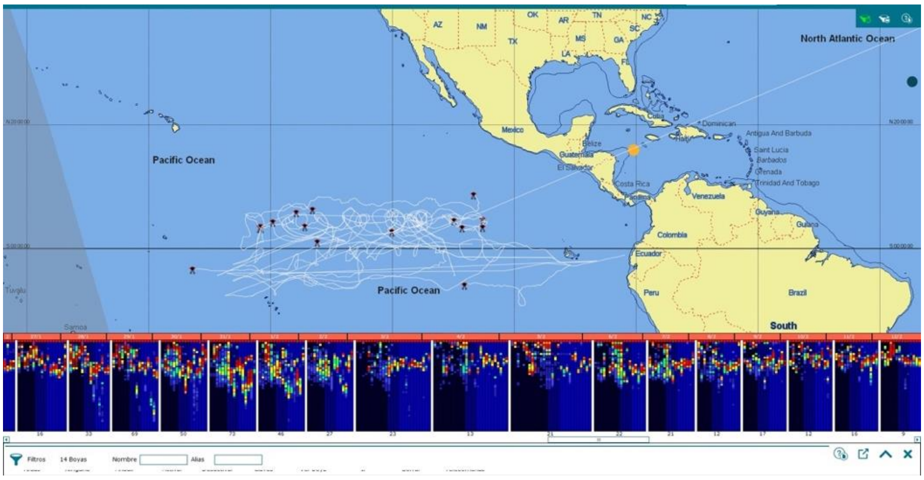


Figure 4. Trajectories of the 14 Jelly-FADs fished from January to March 2022.

5.2 *Trials by the CFC fleet in the western Pacific Ocean*

During the Western Pacific program 73 bio-FADs were deployed: 44 were the biodegradable version of the conventional dFAD (type A) and 29 were jelly-FADs (type B). Close to these experimental bio-FADs, 50 conventional dFADs were also deployed (not every bio-FAD had a conventional one close) (Figure 5). Two catches were reported among the 123 dFADs (biodegradable and conventional) deployed during the trials. Both catches were made on biodegradable dFADs, one set of 95 tons on a jelly-FAD (type B) and one set of 35 tons on a conventional dFAD, 43 and 20 days after deployment respectively. No catches were reported on conventional dFADs during the experiments. The low number of visits and catches does not allow for a more comprehensive analysis of the possible differences in catches between biodegradable and conventional dFADs. Most of the experimental dFADs drifted out of the primary fishing ground or were appropriated by other vessels.

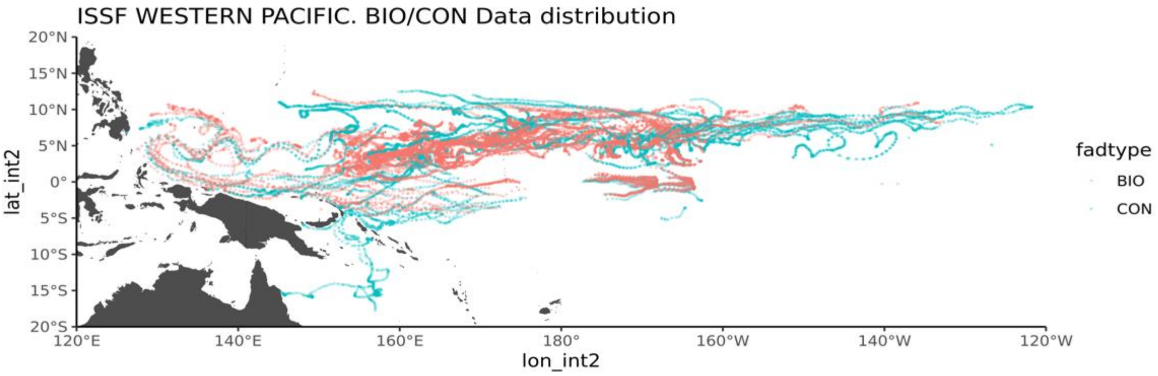


Figure 5. Trajectories of the 123 experimental dFADs deployed by CFC. Conventional, synthetic FADs in green and bio-FADs (both type A and B) in red.

To cope with the lack of visits, we used biomass and trajectory data recorded by satellite linked echosounder buoys from Satlink manufacturers, which fishers use to track dFADs. The methodology to work with biomass estimates from the echosounder buoys is described by Orue et al., 2019, Santiago et al., 2020, and Uranga et al., 2021.

There was not a clear difference in tuna aggregation pattern among biodegradable and conventional dFADs. An increasing aggregation pattern was observed for the biodegradable and conventional dFAD, mainly during the first month. The first three months showed similar increasing trends for the two types of dFADs , with a similar pattern, but later the biomass estimations turned more variable (Figure 6). Similar results were observed in the Indian Ocean bio-FAD trials, where biomass estimation resulted in slightly constant values for both dFAD types during the first months after deployment (biodegradable and conventional), with more variable estimates between dFAD pairs after months five or six.

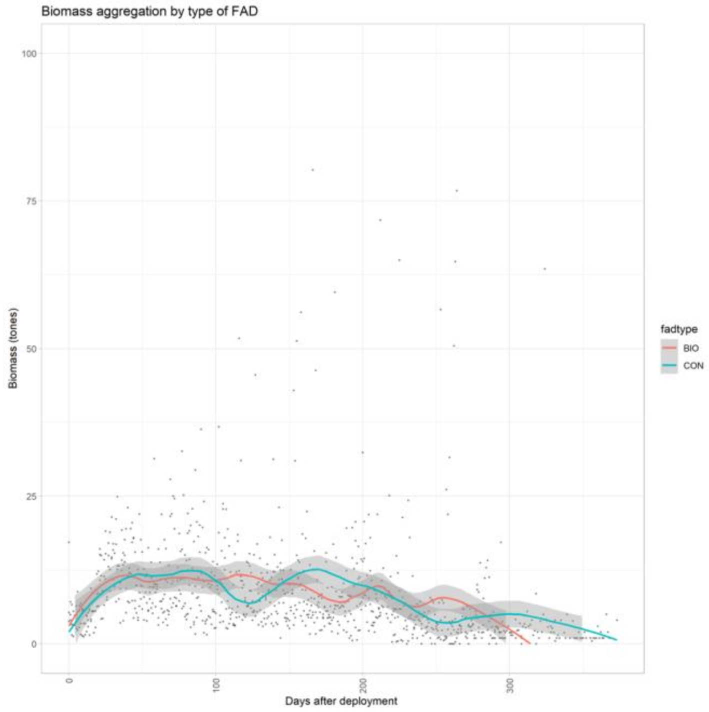


Figure 6. Biomass in tons (Y axis) for soaking time (days at sea). Conventional, synthetic FADs in green and bio-FADs (both type A and B) in red.

Table 3 shows the maximum and mean values of observed speed in the deployed dFADs. The jelly-FAD (type B) has shown the smallest maximum velocity followed by the bio-FAD type A. These data show that both types of bio-FADs have average speeds similar to a conventional dFAD. Even more, the maximum velocities in the bio-FAD are lower than in conventional dFADs, with the jelly-FAD displaying the minimum values.

Table 3. Observed drift speeds (m s-1), by type of dFAD as measured by the buoy used to track FADs.

FAD type	Prototype	N	Number registers	Speed (max)	Speed (mean)
BIO	Type-A	38	149	3	0.7
BIO	Type-B	21	449	2.3	0.7
CON	Type-A	39	265	3.7	0.7

5.3 Experience shared by Ugavi fleet:

a) Learning process:

- The first 150 deployments did not provide any result due to the lack of data:

    (i) Mistakes in the construction and deployment operation, made Jelly-FADs sink or the structure work incorrectly.
    (ii) Fishers rarely visited them due to lack of confidence about their performance.
    (iii) Finally, as it is common in FAD fishery many of them were stolen or drifted out of the fishing zone.

- The shipowners facilitated a continued deployment of Jelly-FADs throughtout 2021. This continued effort, resulted in:
  - (i) Fishers learning how to properly construct and use Jelly-FAD structure, including the deployment operation from the vessel.
  - (ii) Jelly-FADs started working properly and aggregating tuna
  - (iii) More visits due to the presence of tuna and as result of the increased visits, the acceleration of the learning process.
  - (iv) A growing confidence of fishers in Jelly-FAD performance.

b) Some Economic data:

- The cost of a Jelly-FAD varies from \$180 to \$280 depending on the depth of the structure.
- The investment for the 500 Jelly-FADs was around \$500,000, including the buoy.
- This investment was covered with the sets made on Jelly-FADs only.
- The economic returns of this investment started in 2022, after one year of experience.

6. Conclusions on the trials with Jelly-FADs

- Tuna aggregation: Jelly-FADs and other bio-FADs aggregate tuna

- Lifetime: sets were made after 6 months and some sets occurred after 5 months with the FAD being in perfect condition and re-deployed at sea (Figure 7).

- Replacement of Jelly-FAD components: The cube, if damaged after the set, could be replaced by another cube that fishers could have ready onboard for the Jelly-FAD to be re-deployed, as fishers do with the tail and raft of conventional structures.

- Tests at sea: it is crucial to deploy a large number of Jelly-FADs in a continued effort to increase visits to experimental Jelly-FADs and accelerate the learning process, which will result in turn in an increased confidence on the performance of the Jelly-FAD. This effort should be supported by ship-owners.

- At the beginning of the trials, the lack of data, the lack of full performance of Jelly-FADs (due to mistakes in construction and deployment operation) and the lack of visits, makes it difficult to advance on the learning process. The only way to overcome this situation is:

-*Patience*: fishers and shipowners need to understand that new devices rarely work perfectly and are used correctly the first time they are trialed.
-*Constructive visits to jelly-FADs*: part of the success relays on learning from the visits and seeing were Jelly-FADs failed and inform company on how to improve the structure.
-*Perseverance*: as pointed before, a continued effort is needed to overcome the potential difficulties found commonly in most of the trials.

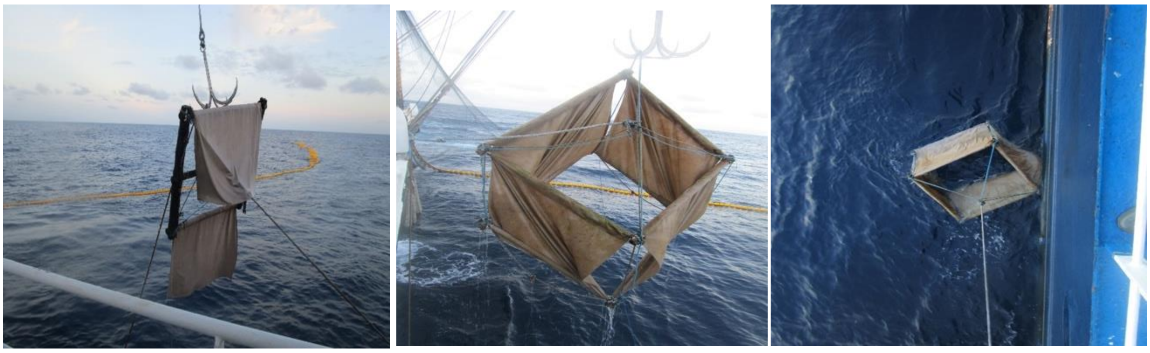


Figure 7. A Jelly-FAD fished after 5 months at sea (45 tons) and re-deployed in the EPO.

7. 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 concept 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 conventional 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.
9. Fishers supported by shipowners should start trialing bio-FAD designs in a continued effort, deploying systematically a percentage of their FADs made of biodegradable materials.

Acknowledgements

We would like to sincerely thank Ugavi fleet for all the efforts done to support this research, in particular Pilar Haz. We are grateful to the fleet from Micronesia, Caroline Fisheries Corporation, especially Neven, Slavko and Marko Kamber for their willingness to advance on the use of biodegradable FADs. We would like to also thank Andoni Zamora from Nautical and Marine Instruments for the support with data provision. Thanks to Patí Vela, Didac Costa and ONA, for the support with the Mediterranean Sea trials. We would like to mention Ghanaian and Pevasa fleets who generously spent their precious time on land with us, to share knowledge on their fishing strategy with dFADs. NORMA for the support provided to conduct trials in the Western Pacific Ocean and Satlink buoy manufacturers for the support with the trials with the U.S. fleet. Finally, this project would have not been possible without the funding of the FAO-GEF Common Oceans Tuna Project and Sarebio project from AZTI.

Cited and other useful references

Escalle, L., Vidal, T., Hare, S., Hamer, P., Pilling, G., PNAO, 2020. Estimates of the number of FAD deployments and active FADs per vessel in the WCPO. WCPFC Sci. Comm. WCPFC-SC16-2020/MI-IP-13

Escalle, L., Scutt Phillips, J., Brownjohn, M. *et al*. 2019. Environmental versus operational drivers of drifting FAD beaching in the Western and Central Pacific Ocean. Sci. rep. nature 9 (1):14005. https://doi.org/10.1038/s41598-019-50364-0

Filmater, J.D., M. Capello, J.L. Deneubourg, P.D. Cowley, and L. Dagorn. 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. Front. Ecol. Environ. 11(6): 291–296. doi: 10.1890/130045. 539(November): 207–223. doi: 10.3354/meps11514.

Gasser, M., Salvador, J., Pelegri, J.L., Sangra, P. (2001). Field validation of a semi-spherical Lagrangian drifter. Scientia Marina 65 (S1):139-143

Hall, M., Roman, M. (2013). Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper No. 568. Rome, FAO. 249 pp. http://www.fao.org/3/i2743e/i2743e00.htm

FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome.https://doi.org/10.4060/ca9229en.

Gershman, D., Nickson, A., O´Toole, M., (2015) Estimating the use of FADs around the world Pew Charitable Trusts. 2015; 1-19. https://www.pewtrusts.org/-/media/assets/2015/11/global_fad_report.pdf

IOTC. 2019. Resolution 19/02 Procedures on a Fish Aggregating Devices (FADs) Management Plan.

ISSF 2019. ISSF Guide to non-entangling FADs. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/guides-best-practices/non-entangling-fads/

Kiwan. AD., Jr., G. McNally, M.S. Chang and R. Molinari.(1975). The effect of wind and surface currents on Drifters. J.Phys. Oceanogr. 5: 361-368.

Maufroy, A., Chassot, E., Joo, R., Kaplan, D.M., 2015. Large-scale examination of spatio-temporal patterns of drifting fish aggregating devices (dFADs) from tropical tuna fisheries of the Indian and Atlantic oceans. PLoS One 10, e0128023.

Maufroy, A., Kaplan, D.M., Bez, N., Molina, D., Delgado, A., Murua, H., Floch, L., Chassot, E., 2017. Massive increase in the use of drifting fish aggregating devices (dFADs) by tropical tuna purse seine fisheries in the Atlantic and Indian oceans. ICES J. Mar. Sci. 74, 215–225.

Maufroy, A., Kaplan, D., Chassot, E., Goujon, M., 2018. Drifting fish aggregating devices (dFADs) beaching in the Atlantic Ocean: an estimate for the French purse seine fleet (2007-2015). ICCAT Collective Volume of Scientific Papers 74, 2219–2229.

Moreno, G., Restrepo, V., Dagorn, L., Hall, M., Murua, J., Sancristobal, I., Grande, M., Le Couls, S. and Santiago, J. 2016. Workshop on the use of biodegradable fish aggregating devices (FADs). ISSF Technical Report 2016-18A, International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2016-18a-workshop-on-the-use-of-biodegradable-fish-aggregating-devices-fad/

Moreno, G., J. Murua, L. Dagorn, M. Hall, E. Altamirano, N. Cuevas, M. Grande, I. Moniz, I. Sancristobal, J. Santiago, I. Uriarte, I. Zudaire, and V. Restrepo. 2018a. Workshop for the reduction of the impact of Fish Aggregating Devices´ structure on the ecosystem. ISSF Technical Report 2018-19A. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2018-19a-workshop-for-the-reduction-of-the-impact-of-fish-aggregating-devices-structure-on-the-ecosystem/

Moreno, G., Murua, J., Kebe, P, Scott, J. and Restrepo, V. 2018b. Design workshop on the use of biodegradable fish aggregating devices in Ghanaian purse seine and pole and line tuna fleets. ISSF Technical Report 2018-07. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2018-07-design-workshop-on-the-use-of-biodegradable-fish-aggregating-devices-in-ghanaian-purse-seine-and-pole-and-line-tuna-fleets/

Moreno, G., Jauharee, A.R., Adam, M.S, Restrepo, V. 2019. Towards biodegradable FADs: Evaluating the lifetime of biodegradable ropes in controlled conditions. ISSF Technical Report 2019-13. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2019-13-towards-biodegradable-fads-evaluating-the-lifetime-of-biodegradable-ropes-in-controlled-conditions/

Moreno, G., Murua, J., Jauharee, A., Zudaire, I., Murua, H., and Restrepo, V. (2020). Compendium of ISSF research activities to reduce FAD structure impacts on the ecosystem. ISSF Technical Report 2020-13. International Seafood Sustainability Foundation, Washington, D.C., USA https://iss-foundation.org/download-monitor-demo/download-info/issf-2020-13-compendium-of-issf-research-activities-to-reduce-fad-structure-impacts-on-the-ecosystem/

Moreno, G. Salvador, J., Murua, J., Phillip, N.B. Jr., Murua, H., Escalle, L., Ashigbui, B., Zudaire, I., Pilling, G., Restrepo, V. (2020). A multidisciplinary approach to build new designs of biodegradable Fish Aggregating Devices (FADs). WCPFC-SC16-2020/EB-IP-08. https://www.wcpfc.int/node/46707

Murua, J., Moreno, G., Hall, M., Dagorn, L., Itano, D., Restrepo, V. 2017. Towards global non-entangling fish aggregating device (FAD) use in tropical tuna purse seine fisheries through a participatory approach. ISSF Technical Report 2017–07. International Seafood Sustainability Foundation, Washington, D.C., USA.

Niiler, P. P., R. E. Davis, and H. J. White (1987), Water-following characteristics of a mixed layer drifter, Deep-Sea Research Part a-Oceanographic Research Papers, 34(11), 1867-1881.

Paryn, N.V., Fedoryako, B.I.1999. Pelagic fish communities qround floating objects in the open ocean. Fishing for Tunas associeated with floating Objects, International Workshop. Inter-American Tropical Tuna Commission (11): 447-458.

Orue, B., Lopez, J., Moreno, G., Santiago, J., Soto, M., Murua, H., 2019. Aggregation process of drifting fish aggregating devices (dFADs) in the Western Indian Ocean: Who arrives first, tuna or non-tuna species? PloS one 14, e0210435.

Orue, B., Pennino M.G., Lopez, J., Moreno, G., et al. (2020) Seasonal Distribution of Tuna and Non-tuna Species Associated with Drifting Fish Aggregating Devices (dFADs) in the Western Indian Ocean Using Fishery-Independent Data. Frontiers in Marine Science 7 (441). DOI: 10.3389/fmars.2020.00441

Pilling GM, Harley SJ, Nicol S, Williams P, & J Hampton. 2015. Can the tropical Western and Central Pacific tuna purse seine fishery contribute to Pacific Island population food security? Food Security, 7, 67–81. https://doi.org/10.1007/s12571-014-0407-8

Restrepo, V., H. Koehler, G. Moreno and H. Murua (2019). Recommended Best Practices for FAD management in Tropical Tuna Purse Seine Fisheries. ISSF Technical Report 2019-11. International Seafood Sustainability Foundation, Washington, D.C., USA. https://iss-foundation.org/knowledge-tools/technical-and-meeting-reports/download-info/issf-2019-11-recommended-best-practices-for-fad-management-in-tropical-tuna-purse-seine-fisheries/

Roman, M., Lopez, J., Hall, M., Robayo, F., Vogel, N., García, J.L., Herrera, M., Aires-da-Silva (2020). Testing biodegradable materials and prototypesfor the tropical tuna fishery on FADs. IATTC SAC-11-11. https://www.iattc.org/Meetings/Meetings2020/SAC-11/Docs/_English/SAC-11-11-MTG_Testing%20biodegradable%20materials%20and%20prototypes%20for%20the%20tropical%20tuna%20fishery%20on%20FADs.pdf

Scott G P, Lopez J. The use of FADs in tuna fisheries. European Parliament. Policy Dep. B: Struct. Cohes. Policies: Fish. IP/B/PECH/IC/2013-123, 70. 2014.

WCPFC 2020. CMM-2020-01 Conservation and management measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean. https://www.wcpfc.int/doc/cmm-2020-01/conservation-and-management-measure-bigeye-yellowfin-and-skipjack-tuna-western-and

Webster F (1967). Vertical profiles of horizontal ocean current, Deep-Sea Research, 1969, Vol 16, pp 85 to 98

Zimmermann, L., Dombrowski, A., Völker, C., & Wagner, M. (2020). Are bioplastics and plant-based materials safer than conventional plastics? In vitro toxicity and chemical composition. Environment International, 145, 106066.

Zudaire, I., Tolotti, M.T., Murua, J., Capello, M., Basurko, O.C., Andrés, M., Krug, I., Grande, M., Arregui, I., Uranga, J., Baidai, Y., Floch, L., Ferarios, J.M., Goñi, N., Sabarros, P.S., Ruiz, J., Ramos, M.L., Báez, J.C., Abascal, F., Moreno, G., Santiago, J., Dagorn, L., Arrizabalaga, H., Murua, H., (2020). Testing designs and identify options to mitigate impacts of drifting fads on the ecosystem. Second Interim Report. European Commission. Specific Contract No. 7 EASME/EMFF/2017/1.3.2.6 under Framework Contract No. EASME/EMFF/2016/008. 193 pp. https://op.europa.eu/en/publication-detail/-/publication/77d2fdc5-7f87-11ea-aea8-01aa75ed71a1/language-en

ANNEX 1

Materials and Method to build the biodegradable DFAD

See also: https://www.youtube.com/watch?v=3JMJH4PKLKA

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 pieces should be 1.35 m in length
- Cotton canvas
- Cotton ropes
- Wooden pins
- Tools
  - Clamp
  - Drill
  - Mallet
  - Saw

Figure 1. Tools and bamboo canes (1.35 cm) needed to build the biodegradable FAD.

B. Material preparation

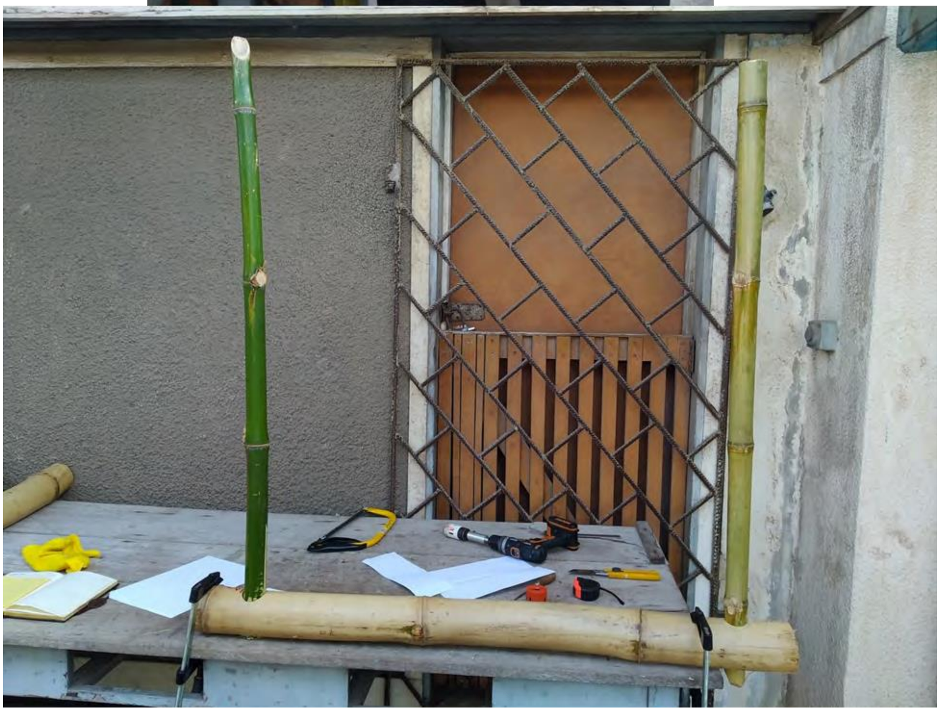
1. Clamp big bamboo canes (100mm diameter) onto work bench

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)

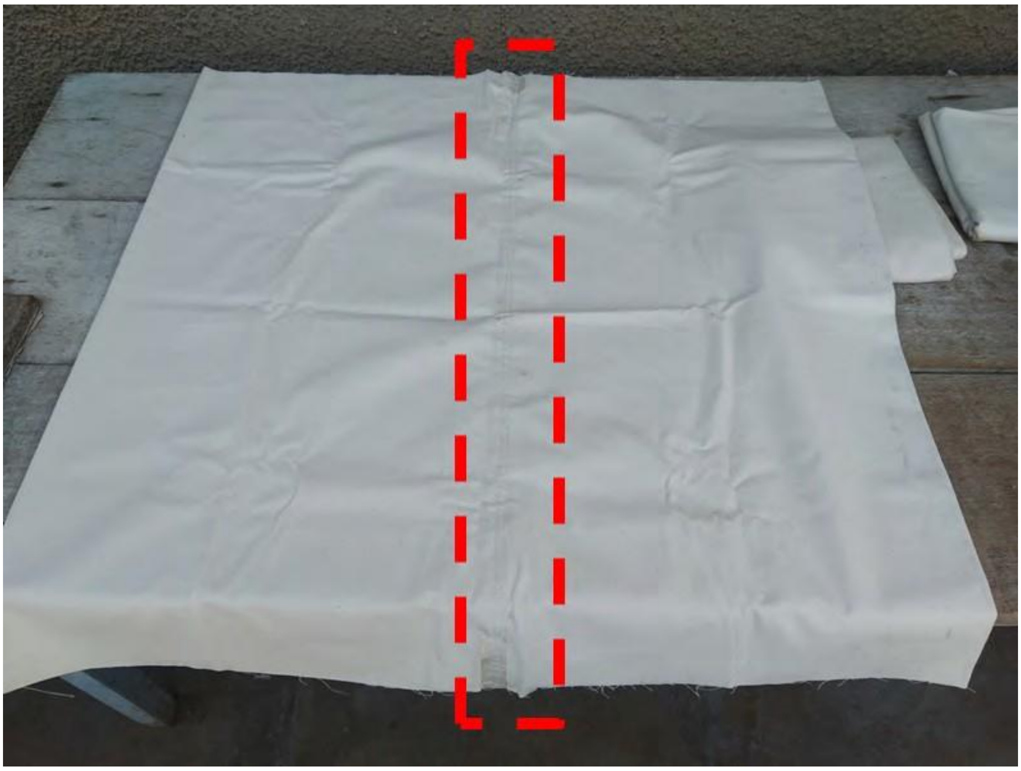
4. Drill a whole of about 20mm diameter through the bamboo cane on both sides (for the rope)

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