BIODEGRADABLE DFADS: CURRENT STATUS AND PROSPECTS.

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Abstract

Until recently, dFAD structure, materials and designs have remained quite rudimentary and virtually the same since their discovery, characterized by the increase of the dimensions and prevailing heavy use of plastic components. Biodegradable materials are called to be an important part of the solution, as they can faster degrade in the environment, free of toxins and heavy metals, reducing their lifespan, and preventing them from accumulating in sensitive areas once they are abandoned, lost or discarded. During last decades, regulatory measures at tRFMOs have advanced in the gradual implementation of biodegradable materials in dFAD constructions together with other measures limiting the number of active dFADs and the use of netting materials. However, more clarity is needed starting with a standardised definition of biodegradable dFADs among tRFMOs, to provide operational guidance. Research with those natural and synthetic materials is required, along with updated data collection for monitoring standards, as well as alternative and complementary actions need to be explored to contribute to minimising dFAD adverse effects on environment. Acknowledging the current difficulties for the implementation of fully biodegradable dFADs a stepwise process towards the implementation of fully biodegradable dFADs should be considered.

KEYWORDS: Fish Aggregating Devices, Biodegradable materials, Marine litter,

1. Context.

The use of drifting Fish Aggregating Device (dFAD) in tropical tuna fisheries has been increasing since the 1980s globally. Since then, relevant progress in dFAD-related technology such as echo-sounder buoys, real-time monitoring of the geospatial position, and other fishing equipment have progressively improved dFAD-fishing efficiency (Itano et al., 2004). However, dFAD structure, materials and designs have remained quite rudimentary and virtually the same since the beginning of their use (Murua et al., 2018). In the early days, fishers randomly looked out for natural floating objects like tree trunks and branches (Gaertner and Pallares, 2002). Soon after, fishers started adding artificial elements to the logs to increase tuna attraction (e.g., attaching purse seine net to provide an underwater structure for fish to shelter, or cork line buoys to add flotation to the waterlogged objects) finally moving to fully man-made dFAD constructions, characterized by increased dimensions and heavy use of recycled nylon purse seine netting, other plastic components (e.g., bait buckets, sub-surface attractors, colourful plastic ribbons, tattered salt sacks), floating materials like bamboo and net corks, and pieces of metal wire or metal rings for ballast (Murua et al., 2018).

Designs and structures of dFADs can vary among fleets and regions, but basically all consist of two parts: a floating (raft) and a submerged (tail) structure. The raft is generally built using several bamboo canes as floatation, i.e., canes tightly bound together, or rafts constructed with a basic frame shape with additional flotation with net corks or floats. Recently, square or octagonal metallic shape frames are being used in some regions (e.g., Atlantic and Indian oceans) (Murua et al., 2014). The raft is usually wrapped in large black-coloured mesh recycled from purse seine netting (often 13-21-cm mesh) and/or smaller mesh size netting (<7-cm mesh) to provide structural strength and reduce visibility to other vessels. Synthetic raffia or canvas are commonly used in addition to the netting, but rarely replaced it completely (e.g., Indian Ocean). The submerged appendage or tail can also be diverse in shape and material, but generally consists of open panels of small mesh size netting,

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canvas hanging underneath (mainly in the Atlantic and Pacific Oceans); or old purse seine netting hanging in tight coils. Some fleets have recently replaced these coils with polyester ropes (mainly in the Indian Ocean) (ISSF, 2017; Escalle et al., 2018, Zudaire et al., 2020).

The long lifespan of petroleum-based plastic materials and the large amount of material used for dFAD construction contribute negatively to increasing the impacts that dFADs have on the ecosystem (Filmater et al., 2013; Maufroy et al., 2015; Moreno et al., 2017; Moreno et al., 2018; Escalle et al., 2019; Imzilen et al., 2021). Depending on the ocean and fleet, fishers consider that their dFADs have a functional life of 6-12 months (Moreno et al., 2016; Murua et al., 2018), with few dFADs used over a year. In fact, dFAD exchange or appropriation is occurring in all regions and areas at different degree, leading to skippers losing track of their dFADs much faster (e.g., < 3 months in some regions). It is also estimated that a significant proportion of those dFADs end up lost, abandoned or discarded (Maufroy et al., 2015; Imzilen et al., 2021; Escalle et al., 2021), which can in turn end stranding in sensitive areas such as coral reefs (Scott and Lopez 2014; Balderson and Martin, 2015; Davies et al., 2017; Zudaire et al., 2018; Escalle et al., 2019). Once dFAD track is lost, it becomes marine litter, a global environmental concern that is present in all oceans and marine environmental compartments, which is an increasing problem worldwide (Cózar et al., 2014; Morales-Caselles et al., 2021). The competent management bodies and the fishing industry itself, have adopted various sets of measures to reduce the impact of dFAD structures on the ecosystems. These include reducing the number of daily active dFADs at sea monitored by a vessel (IOTC Res 19/02[7]; ICCAT Rec. 20-01[8]; IATTC C-20-05[9]; and WCPFC CMM-2020-01[10]), prohibiting FAD activities during particular areas and seasons (IATTC C-20-05, OTHERS), limiting the use of netting material with small mesh size (< 7 cm) (ICCAT Rec. 19-02[11]; IATTC C-19-01[12]; and WCPFC CMM-2020-01) or directly prohibiting the use of netting material in dFAD construction (IOTC Res 19/02) and promoting the use of natural or biodegradable materials (IOTC Res 19/02; ICCAT Rec. 19-02; IATTC C-19-01; and WCPFC CMM-2020-01). However, the problem of marine litter is still unresolved, and circular economy, including alternative designs and materials such as natural biodegradable materials (e.g., bamboo canes, cotton), are being promoted to be an important part of the solution, as they can degrade faster in the environment and are free of toxins and heavy metals, reducing their lifespan, and preventing them from a long-term accumulation in sensitive areas once they are lost (Zudaire et al., 2020). Several stakeholders, including fishing companies are testing biodegradable materials, and some are already constructing part of the dFAD using these materials (e.g., bamboo rafts or cotton ropes for the submerged structure) (Zudaire et al., 2020). However, except for some specific cases, dFADs are still mostly constructed out of highly durable synthetic materials such as nylon nets, PVC and EVA floatation or metal rafts and weights (Murua et al., 2018; Phillip and Escalle, 2020). The only natural biodegradable materials used regularly are bamboo rafts and, in some cases, coconut or nipa palm leaves as attractors attached to the appendance (Moreno et al., 2020).

2. Different tRFMOs regulations regarding the use of biodegradable dFADs.

All tuna Regional Fisheries Management Organizations (tRFMO) have made progress towards addressing these impacts and adopted several recommendations and resolutions to gradually replace existing “conventional” dFADs with non-entangling dFADs and promote research and use of biodegradable materials in dFADs constructions for the reduction of synthetic marine litter (IOTC Res 19/02; ICCAT Rec. 19-02 and IATTC C-19-01; WCPFC CMM-2020-01).

In this regard the most ambitious resolution was adopted by the IOTC in Resolution 19/02, which states that dFAD must be constructed with non-meshed materials from the 1st of January, 2020. In addition, it encourages the use of biodegradable materials in dFADs construction from 1st of January, 2022: “*CPCs shall encourage their flag vessels to use biodegradable dFADs in accordance with the guidelines at Annex V with a view to transitioning to the use of biodegradable dFADs, with the exception of materials used for the instrumented buoys, by their flag vessel from 1 January 2022*”. In the Atlantic Ocean, ICCAT has also adopted, in Recommendation 19-02, measures for the use of non-entangling dFADs and use of more sustainable materials. The designs of non-entangling rafts and

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[7] IOTC Res 19/02
[8] ICCAT Rec 20-01
[9] IATTC C-20-05
[10] WCPFC CMM-2020-01
[11] ICCAT Rec. 19-02
[12] IATTC C-19-01

subsurface structures were aimed at reducing the entanglement of sharks, sea turtles or any other species. In the ICCAT recommendation the definition of the non-entangling material is less precise as it does not include any reference to the presence of meshed materials or mesh size as it has been included in other measures at tRFMOs. In addition, to diminish the amount of synthetic marine litter, CPCs should "endeavour that as of January 2021 all dFADs deployed are non-entangling, and constructed from biodegradable materials, including non-plastics, with the exception of materials used in the construction of dFAD tracking buoys".

In the case of the Pacific, both the IATTC and the WCPFC encourage to avoid the use of entangling net. If open mesh nets are used the mesh size is restricted to <7 cm for the raft and tail. In the former case, it must be well wrapped around the whole raft so that there is no netting hanging below the dFAD when it is deployed, and in the latter case, it must always be tied tightly in bundles or "sausages" with weights attached to minimize the entangling potential of the dFAD (IATTC C-19-01 and WCOPFC CMM-2020-01). In the IATTC area, all dFADs must meet previously mentioned criteria of low-entanglement risk and encourage the use of biodegradable dFADs as of 1st January, 2019 (C-19-01) and in the WCPFC area as of 1st January, 2020 (CMM-2020-01).

3. Biodegradable dFAD definition.

The terms "natural" and "biodegradable" are used interchangeably to refer to these new alternative materials for dFAD by tRFMOs (IOTC Res. 19/02; ICCAT Rec. 19-02; IATTC C-19-01, and WCPFC CMM-20-01). However, its implementation when constructing dFADs is not so straightforward, as a biodegradable material is subject to certain preconditions (Zudaire et al., 2018) and the definitions currently used by tRFMOs are vaguely described and lack clear specification. Thus, despite adopted resolutions and recommendations, more clarity is needed starting with a standardised definition of biodegradable dFADs to provide guidance among tRFMOs, which can be ideally harmonized in the context of the Joint tRFMOs FAD Working Group. This is indispensable to find suitable materials and to establish realistic measures for their implementation and monitoring, that will depend on the state of development and testation of these materials. In parallel, tRFMOs should make provisions on updated data collection that would help monitor the evolution of biodegradable dFAD use under specific definition and standards.

Biodegradable dFAD definition should consider the international standards in place, regulatory framework and address minimum indispensable conditions for materials (e.g., permitted materials, derived-components and environmental considerations). In addition, it should be specified whether the term biodegradable should be applied to the materials themselves or to the final product (i.e., the dFAD, composed by various parts). In the latter, each of them may have different functionality/duration (timeframe), shape (thickness) and environmental impacts, as the dFAD can become a potential residual as whole or disaggregated into parts. Also, it should be recommended to limit to those materials biodegrading in marine environments, due to lost dFAD will be hardly recovered. In this regard, Zudaire et al. (2018) proposed a tentative definition, also presented at the second meeting of the joint tRFMO FAD Working Group (Anon., 2019), that considered aspects like type of materials and configuration, the environmental impacts, durability and functionality, and practical and economic viability, as follows:

"*A biodegradable dFAD would be composed of non-netting form renewable lignocellulosic materials (i.e., plant dry matter - here describe as natural material) and/or bio-based biodegradable plastic compounds, prioritizing those materials that comply with international relevant standards or certification labels for plastic compostability in marine environments. In addition, the substances resulting from the degradation of these materials should not be toxic for the marine and coastal ecosystems or include heavy metals in their composition. This definition does not apply to electronic buoys attached to dFADs to track them.*"

4. Biobased plastics: current state.

Plastic materials are evolving to polymers derived from renewable biological resources (biobased) and polymers that are considered biodegradable (Lambert and Wagner 2017). Any material that meets those conditions, being fully or partially bio-based or biodegradable, is considered to be a bioplastic. In this sense, although bioplastic materials are not specifically described as an alternative to conventional plastics by the EU Directive 2019/90, they may be an option to consider in the future, if certified as biodegradable in the marine environment. However, the production of bioplastics currently represents a percentage of around 1% of global plastics production, and plastics certified as biodegradable in marine conditions are still limited with very limited functionality. Among those found with marine biodegradability certification (e.g., Novamont's Mater-Bi (complying with ISO 19679); NuplastiQ's BioBlend MB; NuPlastiQ CG (complying with ASTM D6691 and certified as "OK Marine" by TÜV Austria) are based on biopolymers with very limited functional properties (no more than 2 to 4 months). Furthermore, these marine biodegradability standards are a guideline and there is a lack of information on clear requirements for conditions and time frames. Marine biodegradation standards are under research and development, so that relevant bioplastic products can be introduced to the market.

It is important to note that just because a bioplastic is biodegradable in soil, it does not mean that it is biodegradable in a marine environment, as the physical and chemical conditions in each environment (soil and marine) are different. Besides the certification and market limitations, the toxicity of chemical additive used in the production of bioplastic and their potential impacts and extent on the environment are not clear enough yet (Zimmermann et al., 2020). In this line, oxo-degradable plastics (i.e., conventional plastic mixed with an additive that quickly fragment into smaller and smaller pieces but without break down at the molecular or polymer level) should not be considered as potential materials for dFAD construction as they can breakdown quickly by oxidative chemical reagents and continue to impact marine ecosystems by entering the food chain as they breakdown (Eljarrat, 2021).

5. Results on tested materials and designs.

In the last decade, public and private funded projects have tested suitable natural (lignocellulosic) materials to build biodegradable dFADs prototypes. Studies conducted on new biodegradable dFAD designs dates to the early 2000s (Armstrong and Oliver, 1996; Delgado de Molina *et al.*, 2004; Delgado de Molina *et al.*, 2007). However, most of these initial at sea tests with biodegradable dFADs were very limited in scale, yielding inconclusive results and a slow rate of improvement. These first trials with non-entangling biodegradable dFADs were mainly looking for natural suitable materials testing an array of different options like jute, sisal and palm leaves (Delgado de Molina et al., 2004). Further, small pilot projects with few deployments of experimental biodegradable dFADs were tested in the Indian and Atlantic oceans, with bamboo rafts, sisal and jute ropes seeking to move towards ecological dFADs (Franco et al., 2009, 2012). Similarly, the IATTC conducted a set of biodegradable anchored FAD tests in a controlled environment in Achotines (Panama) built with a common floating structure made of bamboo canes and coconut shells and a tail either made with agave ropes with bamboo frames, high-resistance cotton canvas or a combination of both (Roman et al., 2020). Other biodegradable dFAD trials were deployed by the private sector, with various purse seine companies (e.g., European Union, United States of America, Korea) testing them at sea during commercial fishing operations. These trials have experimented with ropes and canvas made from coconut fiber and high-resistance cotton. In addition, EU purse seine companies sponsored a study to evaluate the best biodegradable twine materials and their structural configuration (e.g., twisted, braided and bulked) for use in dFAD appendages (Lopez et al., 2019). Several plant-origin fibres such as cotton, sisal, hemp and linen were analysed under controlled conditions for the construction of ropes, and parameters like potential biodegradation, resistance, reproducibility, and availability in the market were assessed (Lopez et al., 2019). Similarly, the International Seafood Sustainability Foundation (ISSF) tested various ropes made of organic materials (cotton, sisal and linen) under controlled conditions in Maldives, in collaboration with the Marine Research Centre in the Maldives and FAO Common Oceans Tuna project. The research showed that 100% cotton rope (20 mm diameter, 4 strands in torsion Z) fulfilled the criteria to support the weight of the dFAD structure and link the surface component of the dFAD with the deeper components (Moreno et al., 2019). ISSF in collaboration with an EU fleet also deployed 85 biodegradable dFADs with cotton rope tails in the Indian Ocean (Moreno et al., 2017a). Other natural biodegradable materials that have been tested at small-scale experiments to make ropes and canvas were agave and abaca, coated, or not, with natural origin components (Tunacons, 2017). Other options for materials, which have not yet been tested and may be good candidates, include bamboo-derived textile fabric for the tail and other bamboo components for the raft/floatation. Balsa wood is available in some Latin-American countries, and has shown promising results in the eastern Pacific Ocean experiment (Roman et al 2020). However, this material is not available in other parts of the world, making difficult a generalized and regular access to it by all fleets.

These initial small-scale trials provided a foundation to develop the larger-scale experiments launched in recent years in the Indian Ocean (Zudaire et al., 2020), eastern (TUNACONS 2017; Roman et al., 2020) and western (Moreno et al. 2021) Pacific Ocean. The Indian Ocean project BIOFAD funded by the European Union, ABNJ Common Ocean project, coordinated by AZTI (in consortium with IRD, IEO, SFA and ISSF) and the collaboration of the EU and Korean purse seine fleets, deployed 770 biodegradable dFADs built using natural materials like resistant cotton ropes/canvas and bamboo canes (Zudaire et al., 2020). Similarly, the Eastern Pacific Ocean project for biodegradable dFAD (named NEDs), funded by the EU and coordinated by IATTC, and framed within the Fishery Improvement Projects of EU (OPAGAC) and Ecuadorian (TUNACONS) shipowners' associations, deployed 631 biodegradable dFADs up to date (still ongoing, target to deploy 796 biodegradable experimental FADs by the end of 2021) built using hemp, cotton, balsa wood and bamboo canes (Roman et al., 2020). In the EPO, where 3 prototypes are being tested, the condition of the materials used in one of them seems to be between 'excellent' to 'good' after, at least, two months of soak time period. Preliminary results for the EPO experiment also showed similar catch per set rates between biodegradable dFADs and traditional paired control dFADs (Roman et al 2020).

With the experience gained in prior actions in which cotton material showed the most promising results, ISSF has recently developed the JellyFAD (Moreno et al., 2021), which is a new and innovative design of a dFAD, based on drifters used by physical oceanographers. Results of previous experiences testing biodegradable dFADs showed in general that the lifetime of biodegradable dFADs that maintain the traditional dFAD design but made of organic materials, may be shorter than that required by fishers in most occasions. The short lifespan of those biodegradable dFADs may be mainly due to the structural stress suffered by dFAD designs traditionally used. Thus, in order to use organic materials, instead of the persistent plastic, and increase the lifespan of those biodegradable dFADs, a paradigm shift may be beneficial. Biodegradable dFAD structures could be re-designed to suffer the least structural stress in the water. The innovation in the JellyFAD is that it drifts with quasi-neutral buoyancy and thus reduces the structural stress and the need for flotation (i.e., plastic buoys), and it is made basically with bamboo raft, cotton ropes and canvas for the submerged structure. Recently, 70 JellyFADs have been deployed in the western Pacific Ocean in a ISSF project with the collaboration of a fleet from Federal States of Micronesian (Moreno et al., 2021). During this year, a new project has been launched by OPAGAC to deploy around 350 JellyFADs in the Atlantic Ocean, as well as in the eastern Pacific Ocean.

6. Other actions to reduce the impact of dFAD structure on the ecosystem.

Despite the regulatory measures and the use of biodegradable materials, alternative and complementary actions need to be explored to minimise dFAD adverse effects on the environment. dFADs recovery initiatives have been limited in time and space due to the associated high cost and logistic difficulties related to working in remote areas with limited resources (Moreno et al. 2018; Escalle et al. 2021). However, dFAD retrieval programs implemented on specific regions like the FAD-Watch pilot project, a multi-stakeholder regional cooperation and the commitment of purse seiner vessel operators, implemented in 5 atolls in Seychelles, in the Indian Ocean, could be a potential solution to partially reduce stranding events, including beaching (Zudaire et al., 2018). This is also currently under development in Palmyra atoll in the WCPO (Escalle et al., 2021). These programs should be defined considering environmental information, such as ocean modelling and buoy trajectories, and waste management plans, including ways to transport and proper disposal and/or recycling in accordance with MARPOL (Annex V).

Other actions focused on avoiding the stranding to occur could be more cost-effective. Evaluating the trade-off between the beaching rate associated with each deployment area and dFAD use (Imzilen et al., 2021; Escalle et al., 2021b), could help in decision making for the adoption of alternative measures of dFAD spatio-temporal dFAD activity closures or the adaptation of the ones in place (e.g., FAD closure in the Atlantic by Rec. 19-02). In addition, development of multi-stakeholder programs (with the commitment of purse seiner vessel operators) for dFADs reuse or exchange, by sharing tracking positions before deactivating could help in reducing the number of lost or abandoned of dFADs.

Science-industry collaboration, like the ISSF Skippers Workshop program (Murua et al., 2017), the regular skippers' workshops organized by the IATTC and collaborators, or the tuna industry's Codes of Good Practice (Grande et al., 2019), are essential to make progress both in the implementation of biodegradable materials and in the implementation of management measures and operational fishing practices necessary to minimise dFADs impacts on environment.

7. **Recommendations**

- A harmonised definition, across tRFMOs, is urgently needed to establish guidelines and a timeline for biodegradable dFAD construction and implementation, as well as define updated data collection programs. An effective replacement of non-biodegradable dFADs by those partly/fully biodegradable still requires investigation to solve important practical/technical aspects for the operationalization of biodegradable dFADs. Further research with those natural and synthetic materials that meet the agreed biodegradable dFAD definition is required.

- Acknowledging the current difficulties for the implementation of fully biodegradable dFADs as biodegradable materials for all dFAD components are not available yet (e.g., floating parts); a stepwise process, including a timeline, towards the implementation of fully biodegradable dFADs should be considered based on the current state of the art of materials available, similar to ISSF's classification for dFAD entanglement risk (ISSF, 2019).

- Considering the degradable nature of the components used in biodegradable dFAD construction, i.e., material more vulnerable to the environmental conditions and crew manipulation than traditional (Roman et al. 2020), it might be necessary certain modifications in the fishing strategies by considering the biodegradable dFADs shorter soak time (e.g., rough maneuvers, lifting them up the sea surface during the set, etc) not to compromise its integrity.

- Based on the recommendation made in the Indian Ocean BIOFAD project (Zudaire et al., 2020) different options/categories could be discussed in this stepwise and gradual process:
  - Category I. This category corresponds to 100% biodegradable dFADs. This means all parts (i.e., raft and tail) of a dFAD are built with biodegradable materials. Used materials should fulfil the biodegradable dFAD definition proposed as part of the BIOFAD project.
  - Category II. This category corresponds to dFADs using biodegradable materials for the whole dFAD except for the floating component (i.e., plastic floats). This means that all parts (i.e., raft and tail) of a dFAD are built with biodegradable materials fulfilling the BIOFAD proposed definition for biodegradable dFAD but have additional non-biodegradable floatation elements.
  - Category III. This category corresponds to dFADs using only biodegradable materials in the construction of the tail but non-biodegradable materials in the raft (e.g., synthetic raffia, metallic frame, plastic floats). This means all underwater hanging parts (i.e., tail) of a dFAD are built with biodegradable materials fulfilling the BIOFAD proposed biodegradable dFAD definition.
  - Category IV. This category corresponds to dFADs with all parts (i.e., raft and tail) only built partly or with non-biodegradable materials.

- Progressively, as soon as new biodegradable materials become available in the market, the percentage of biodegradability should be increased for the construction of other parts of the dFADs (e.g., floats, buoy) in order to target 100% biodegradability for the dFAD as per the biodegradable definition above. In the meantime, plastic based materials should be reduced as much as possible. Gradual modification of current dFAD designs, in terms of reductions in the amount of material (e.g., depth of tails) and the synthetic fraction used in their construction, should be promoted in the short-term using results and lessons learnt from all the global initiatives while medium- to long-term implementation of biodegradable dFADs is in progress.

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