Eco-designed Biodegradable dFAD including new potential biodegradable materials

Deliverable D3.2

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SEARCULAR
Circular Solutions for Fishing Gears

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Executive summary

The SEARCULAR project adopted a structured and iterative eco-design approach to develop improved biodegradable Fish Aggregating Devices (BIOFADs). The process was designed to integrate scientific evidence, industry knowledge, and environmental sustainability principles. The workflow consisted of the following key steps:

1. **Industry Engagement through a Questionnaire**
   The process began with the design and dissemination of a comprehensive questionnaire targeting stakeholders in the tropical tuna purse seine fishery. The objective was to gather detailed information on current FAD construction practices, materials used, deployment strategies, and perceived challenges and opportunities for adopting biodegradable alternatives. This step ensured that the eco-design process was grounded in real-world operational contexts and industry needs.
2. **State-of-the-Art Review of Biodegradable FAD Trials**
   A thorough literature review and analysis of past and ongoing trials involving biodegradable FADs across different ocean basins were conducted. This review provided insights into the performance, limitations, and lessons learned from previous initiatives, helping to identify best practices and avoid repeating past shortcomings.
3. **New Material Identification and Selection**
   Based on the findings from the questionnaire and literature review, a targeted search for new biodegradable materials was initiated. The selection criteria focused on environmental performance, mechanical properties, availability, cost, and compatibility with existing FAD construction methods.
4. **Material Testing and Evaluation**
   Selected materials underwent rigorous laboratory and field testing to assess their durability, buoyancy, degradation behavior, and suitability for use in marine environments. This phase was critical to ensure that the materials could withstand operational conditions while minimizing environmental impact.
5. **Life Cycle Assessment (LCA)**
   A preliminary cradle-to-gate Life Cycle Assessment was performed to evaluate the environmental footprint of the selected materials throughout their entire life cycle—from raw material extraction and manufacturing to deployment, use, and end-of-life. The LCA provided quantitative data to support material selection and design decisions, ensuring that the final BIOFAD models offered a net environmental benefit.
6. **Co-Creation with Industry (Workshops)**
   The final phase involved a co-creation process with industry stakeholders through dedicated workshops. These sessions facilitated collaborative design refinement, incorporating feedback from fishers, FAD builders, and other practitioners. The workshops ensured that the proposed BIOFAD models were not only environmentally sound but also operationally viable and acceptable to end users.

This integrated workflow enabled the SEARCULAR project to develop BIOFAD prototypes that align with ecological sustainability goals while addressing the practical realities of tropical tuna fisheries. The process emphasized stakeholder participation, scientific rigor, and iterative design, setting a precedent for future eco-innovation in fisheries management.

1. Context

1.1 SEARCULAR aims

SEARCULAR aims at reducing the amount of marine litter and microplastic from the most relevant European fishery contributors (demersal trawlers, demersal seiners, tropical tuna purse seiners) and to introduce circular economy practices within the fishing sector value chain including ports, by fostering behavioural change. SEARCULAR will do this by developing/testing/validating 4 close-to-market sustainable and circular solutions (TRL7-9). Three of the solutions are related to the use of more sustainable materials as alternatives to the traditional non-circular plastic used in fishing gears:

- Solution#1 proposes a dolly rope made of recycled polyamide (rPA) from discarded fishing nets (thus it is focused on circularity and more durable materials),
- Solution#2 is based on certified marine-biodegradable materials for demersal seine ropes (the focus is on less impact gears),
- Solution#3 represents an eco-designed biodegradable drifting Fish Aggregating Devices (dFADs) used by tropical tuna purse seine fishery.
- Solution#4 proposes an End-of-Life (EOL) fishing gears solution for ports by promoting a replicable management system that enables the pyrolysis of EOL fishing gears for a plastic2plastic application.

The 4 solutions will be tested under real conditions: onboard commercial vessels (Solutions 1-3) and for the Basque country region (Solution 4), and they will be validated by stakeholders. Therefore, SEARCULAR solutions eliminate waste generated from fishing gears, circulate materials and regenerate nature.

1.2 Biodegradable FADs

The use of FADs in tropical tuna fisheries has increased significantly since the 1980s. The advances in FAD-related technology and other fishing equipment have progressively improved FAD-fishing efficiency. However, FAD structure, materials and designs have remained quite rudimentary and virtually the same since the beginning of their use. Traditional FADs are large in dimension and are made of heavy EOL polyamide (PA) purse seine netting, 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. The long lifespan of petroleum-based plastic materials and the large amount of material used for FADs construction contribute to increasing the negative impacts of FADs on ecosystems. Large proportion of deployed FADs end up lost, abandoned or discarded (Gilman et al., 2021; Syversen et al., 2022), reaching up to 40% of deployed FAD in the case of the Atlantic Ocean, equivalent to 529 t per year of marine litter for the French fleet alone (Imzilen et al., 2022).

These FADs can end up stranding in sensitive areas such as coral reefs. Policy-makers, i.e., tuna Regional Fisheries Management Organizations (tRFMO), i.e., Indian Ocean Tuna Commission (IOTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), have adopted several measures to reduce their impact (See section 1.2.1). These include reducing the number of daily active FADs at sea monitored by a vessel; prohibiting FAD activities during particular areas and/or seasons; limiting the use of small mesh size netting material, banning the use of netting material in FAD construction; and promoting the use of organic or biodegradable materials (IOTC Res 24-02[1]; ICCAT 24-01[2]; CMM-23-01[3]; C-23-04[4]; C-24-01[5]).

Despite FAD evolution towards biodegradable FAD models (Figure 1) and the advances in the use of biodegradable materials (e.g., bamboo canes, cotton, etc.) in their construction, the problem of marine litter is still unresolved. Circular economy, including alternative designs and materials such as more efficient natural biodegradable materials, are being promoted as part of the solution. These materials can degrade faster on the environment and are toxin and heavy metal free, drastically reducing FADs long term accumulation in sensitive areas once they are abandoned, lost or discarded (ALD). Experimental biodegradable FADs are mainly affected by the structural stress suffered at sea, which reduced considerably their lifespan (Moreno et al., 2023).

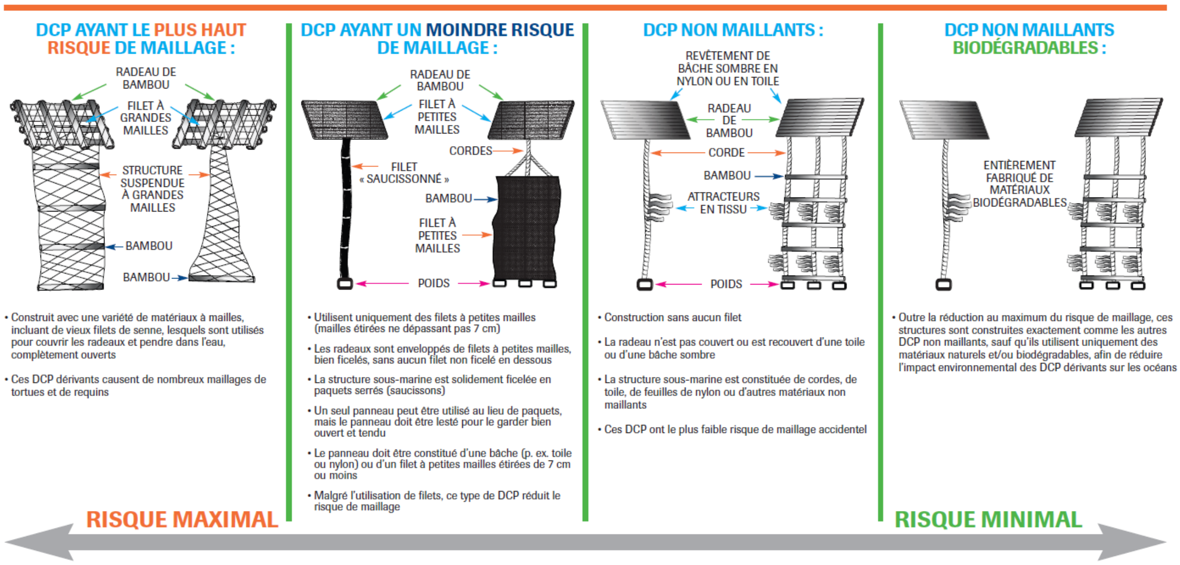


Figure 1. Evolution of the FADs designs (*Source: ISSF, 2015*)

In this context, SEARCULAR proposes an eco-designed version of the biodegradable drifting FAD (BIOFAD) as a third SEARCULAR solution. The design aims to (i) minimize the use of plastic on their construction by replacing it with plant-based fibers or other organic materials, (ii) reduce the size of FADs to use less material, (iii) degrade faster than conventional FADs (with plastic materials) once their useful lifetime for fishing ends, and (iv) eliminate the use of netting in the construction.

This document describes the work carried in Task 3.2 which have been structured as follows:

1. State-of-the-Art Review of Biodegradable FAD Trials
2. Searching for suitable materials and testing.
3. Life Cycle Assessment (LCA)
4. Co-Creation with Industry (Workshops)
5. Final eco-designed model definition

[1] https://www.ofdc.org.tw:8181/web/components/Editor/webs/files/iotc_cmm_2402.pdf
[2] https://iccat.int/Documents/Recs/compendiopdf-s/2024-01-s.pdf
[3] https://cmm.wcpfc.int/measure/cmm-2023-01
[4] https://www.iattc.org/GetAttachment/c4f92d00-b6e3-4e03-84cb-d4e876ce9ab8/C-23-04_FADS-biodegradables.pdf
[5] https://www.iattc.org/GetAttachment/954430dc-ac71-496f-8a59-c7175d500051/C-24-01_Tuna-conservation-in-the-EPO-2025-2026.pdf

1.2.1 Current legislation on biodegradable FAD

Since 2014, the use of FADs, including their design and construction materials, has been subject to regulation. These regulations and recommendations for FAD designs have evolved significantly over time across all tuna RFMO (Figure 2) as shown below and in Table 1.

- In the Indian Ocean, **the IOTC (IOTC Res 15/087)** adopted in 2014, the first resolution to mandate the use of non-mesh material in the construction of FADs. It also fostered a gradual adoption of biodegradable materials (Table 2). The newly adopted **Resolution 24/02** strengthens these requirements. It prohibits the use of mesh materials in any part of a FAD, allowing only non-entangling material and designs. Additionally, the sub-surface structure of a FAD must not exceed 50 meters in length. To further reduce the potential marine litter generated by the use of FADs, the resolution introduces different categories of biodegradable FADs. The use of non-biodegradable materials is now restricted to specific parts, and a timeline for implementation has been set for each category. The ultimate goal is to ensure that all FADs are fully biodegradable by January 1, 2029. Moreover, vessels are required to remove and properly dispose of any non-compliant FADs in port.

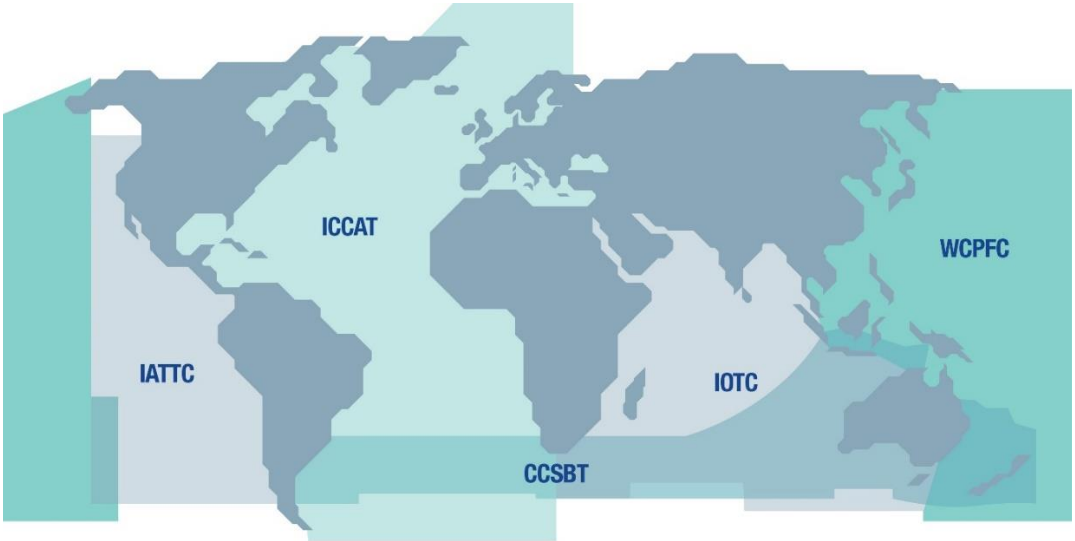


Figure 2. Tuna Regional Fisheries Management Organisations (ISSF-RFMO-map)

- In the Atlantic Ocean, **ICCAT Rec. 19-02** included provisions on the construction of FADs, bearing in mind the potential impacts on both pelagic and coastal habitats, and on Endangered, Threatened and Protected species. Among its measures, Rec. 19-02 promotes the use of non-entangling FADs and biodegradable materials in their construction (Table 2). The use of non-entangling raft and subsurface structures is specially intended to reduce the risk of entanglement of sharks, sea turtles or other species. The principles outlined in Annex 5 of Rec. 19-02 were originally adopted in 2015 under Rec. 14-01 and remain in force. By 2021, Contracting Parties (CPCs) operating in the Atlantic Ocean were expected to ensure that all FADs deployed are non-entangling and made from biodegradable materials, including non-plastics components, except for those used in FAD tracking buoys (Rec. 19-02, p. 40). Recommendation 24-01 introduced new regulations regarding the structure and use of FADs. As of 1 January 2025, the use of netting materials in the construction of FADs has been prohibited. The recommendation also established a stepwise transition plan starting in 2025, requesting fleets to progressively transition to biodegradable FADs by 2028.

- In the Pacific Ocean, both the IATTC and in the WCPFC had regulations in place until 2023 allowing the use of open mesh in the FAD construction, provided the mesh size did not exceed 7 cm. If the mesh was larger than 7 cm, it had to be tightly rolled into coils to minimize the risk of entangling, this applied to both the submerged and floating part of the FAD. However, as of January 2024, the use of netting materials in FADs is no longer allowed under **CMM 2023-01** in the western Pacific Ocean. In the IATTC area, with the entry into force of C-23-05, the CPCs in the eastern Pacific Ocean are now requested, from 1st January 2025, to replace low-risk of entangling FADs with fully non-entangling FADs constructed using no-netting material. In addition, CMM 23-04 have defined categories of biodegradable FADs and requested gradual implementation away from synthetic materials. This process begins with the phased replacement of synthetic components with biodegradable alternatives by 2026.

Tuna processors and retailers have also adopted the use of non-entangling FADs as part of their sustainable fishing standards. For example, ISSF (International Seafood Sustainability Foundation) has implemented conservation measures promoting the use of low-risk or non-entangling FADs, and testing of biodegradable FADs (i.e. measures 3.5[6] and 3.7[7]). Since 2016, all vessels have been expected to avoid the use of entangling materials in FAD construction. By 2023, companies were required to conduct trials with biodegradable FADs and/or implement FAD recovery programs. Looking ahead, by April 2025 purse seiner vessels must exclusively use and deploy fully non-entangling FADs made with no netting, regardless of the ocean in which they operate. ISSF also published an updated guide for non-entangling FADs, classifying them according to the entanglement risk of each design based on the mesh size and configuration (ISSF, 2015, updated in 2019) (Table 3), where non-entangling FADs, included no netting materials, are expected to have no risk of causing entanglement (ISSF, 2015, 2019). In addition, other standards such as the UNE 195006:2016 for Tuna from Responsible Fishing include an obligation to use non-entangling FADs, which defined the non-entangling FADs as having non-meshed materials, or, if it is present in open panels the mesh size should be <7 cm, or if >7cm it should be rolled in coils.

In order to deal with marine litter and foster a progressive implementation of biodegradable material on FADs, BIOFAD categories where defined based on recommendations derived from the first large scale BIOFAD Project conducted in the Indian Ocean (Murua et al., 2023).

The FAD biodegradability categories are common among RFMOs:

- **Category I.** The FAD is made of fully biodegradable materials.
- **Category II.** The FAD is made of fully biodegradable materials except for plastic-based flotation components (e.g., plastic buoys, foam, purse-seine corks).
- **Category III.** The subsurface part of the FAD is made of fully biodegradable materials, whereas the surface part and any flotation components contain non-biodegradable materials (e.g., synthetic raffia, metallic frame, plastic floats, nylon ropes).
- **Category IV.** The subsurface part of the FAD contains non-biodegradable materials, whereas the surface part is made of fully biodegradable materials, except for, possibly, flotation components.
- **Category V.** The surface and subsurface parts of the FAD contain non-biodegradable materials.

6 https://www.iss-foundation.org/vessel-and-company-commitments/conservation-measures-and-auditing/our-conservation-measures/3-bycatch-mitigation/3-5-transactions-with-vessels-that-use-only-non-entangling-fads/
7 https://www.iss-foundation.org/vessel-and-company-commitments/conservation-measures-and-auditing/our-conservation-measures/3-bycatch-mitigation/3-7-transactions-with-vessels-or-companies-with-vessel-based-fad-management-policies/

Table 1. Main resolutions including FAD construction guidelines in the four tuna RFMOs adopted in the last 5 years, regarding to non-entangling and biodegradable material.

RFMO	RESOLUTION(S)	NON-ENTANGLING MATERIAL	BIODEGRADABLE FADS
IOTC	Res. 15-08 Res. 17-08 Res. 18-08 Res. 19-02 Res. 24-02	Res. 24/02: - Mesh materials shall be prohibited for any part of a FAD. - Only non-entangling material and designs shall be used. - The sub-surface structure shall be limited to a length of 50 meters.	To reduce the amount of synthetic marine debris, CPCs shall ensure that their flag vessels: - as of 1 January 2026, use only DFADs of biodegradability categories I, II III, and IV. - no longer deploy any DFADs of category V. - as of 1 January 2027, use only DFADs of categories I and II - as of 1 January 2030, use only DFADs of category I.
ICCAT	REC. 14-01 REC. 15-01 REC. 16-01 REC. 19-02 REC. 21-01 REC. 24-01	- The surface structure of the FAD should not be covered, or only covered with non-meshed material. - If a sub-surface component is used, it should not be made from netting but from non-meshed materials such as ropes or canvas sheets. REC 24-01 in force prohibits the use of netting in any component of the FAD	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials (such as hessian canvas, hemp ropes, etc.) for drifting FADs should be promoted. - endeavor that as of January 2021 all FADs deployed are non-entangling, and constructed from biodegradable materials, including non-plastics, except for materials used in the construction of FAD tracking buoys REC 24-01 in force, regulates the step-wise transition to bio-FADs starting in 2025.
IATTC	C-16-01 C-18-05 C-17-02 C-19-01 C-20-06 C-21-04 C-23-04 C-23-05	By 2019 the floating or raft part (flat or rolled structure) of the FAD can be covered or not. If it is covered with mesh net, it must have a stretched mesh size less than 7 cm and the mesh net must be well wrapped around the whole raft so that there is no loose netting hanging below the FAD when it is deployed. 2. The design of the underwater or hanging part (tail) of the FAD should avoid the use of mesh net. If mesh net is used, it must be tied as tightly as practicable in the form of sausages or have a stretched mesh size less than 7 cm in a panel with weight at the end. By 2025, the design and construction of any FADs to be deployed or redeployed shall comply with the following specifications: a) the use of mesh net shall be prohibited for any part of a FAD; b) only non-entangling FAD materials and designs shall be used.	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials (such as hessian canvas, hemp ropes, etc.) for drifting FADs should be promoted. a) as of 1 January 2026, CPCs shall only allow vessels to deploy or redeploy drifting FADs of biodegradability categories I, II, III or IV; b) as of 1 January 2029, CPCs shall only allow vessels to deploy or redeploy drifting FADs of categories I or II, as defined in Annex I; c) At the annual meeting in 2030, the Commission shall decide whether to require by 2031 CPCs to only allow vessels to deploy or redeploy drifting FADs of Category I.

WCPFC	CMM-18-01 CMM-20-01 CMM 23-01	From 2020, CCMs shall ensure that the design and construction of any FAD to be deployed in, or that drifts into, the WCPFC Convention Area shall comply with the following specifications: - The floating or raft part (flat or rolled structure) of the FAD can be covered or not. To the extent possible the use of mesh net should be avoided. If the FAD is covered with mesh net, it must have a stretched mesh size less than 7 cm (2.5 inches) and the mesh net must be well wrapped around the whole raft so that there is no netting hanging below the FAD when it is deployed. - The design of the underwater or hanging part (tail) of the FAD should avoid the use of mesh net. If mesh net is used, it must have a stretched mesh size of less than 7 cm (2.5 inches) or tied tightly in bundles or "sausages" with enough weight at the end to keep the netting taut down in the water column. Alternatively, a single weighted panel (less than 7 cm (2.5 inches) stretched mesh size net or solid sheet such as canvas or nylon) can be used. - The use of net if no longer allowed in this RFMO since January 2024	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials for FADs should be promoted. The use of non-plastic and biodegradable materials in the construction of FADs is encouraged.

The FAD implementation calendars are tight and ocean specific (Table 2). In a maximum of 7 years period the full implementation should be reached. However, for some oceans the full implementation period is reduced to four years. This is the case of the Atlantic Ocean in which FADs should be practically biodegradable (category II), except for the flotation by 2026. Category II should be implemented by 2027 in the Indian Ocean and by 2029 in the Eastern Pacific Ocean. In the Atlantic and Eastern Pacific Oceans synthetic material could be used for reinforcing the surface and submerged structure. Fully biodegradable FADs should be implemented by 2028 in the Atlantic Ocean and by 2029 in the Indian Ocean. For eastern Pacific, the Commission should decide in 2030 whether the full biodegradable FADs should be implemented by 2031. The western Pacific.

Table 2. BIOFAD implementation calendar by RFMO. BIOFAD categories allowed by year

RFMO	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
IOTC	All	I, II III, & IV	I & II	I & II	I	I	I
ICCAT*	I, II & III	I & II	I & II	I	I	I	I
IATTC*	All	I, II III, & IV	I, II III, & IV	I, II III, & IV	I & II	I & II	I?
WCPFO	All						

*the use of non-biodegradable materials, in particular nylon ropes, can be used exclusively to strengthen the structure of the floating or underwater component of the FAD Categories I and II.

Table 3. Recommendations by relevant stakeholders in place for the use of non-entangling and biodegradable materials on FADs

REFERENCE	DESCRIPTION
HAMPTON ET AL., 2017	For a FAD to be completely non-entangling, it must use no netting materials either in the surface structure (raft) or the submerged structure. Some organizations also consider non -entangling FADs (NEFADs) to be those using netting but built to minimize entanglement such as using netting tied in bundles or using small size netting (<7 cm stretched mesh); these are sometimes called LERFADs (Lower Entanglement Risk FADs).
ISSF 2019	For a FAD to be completely non-entangling, it must use no netting materials either in the surface structure (raft) or the submerged structure. Lower entanglement Risk FADs are those using netting but built to minimize entanglement: use only small mesh netting (< 7 cm stretched mesh) or any mesh size if tightly tied into sausage-like bundles. Non-entangling and biodegradable FADs are constructed with any netting and natural materials that degrade without causing impact on the ecosystem.
UNE 195006:2016 FOR TUNA FROM RESPONSIBLE FISHING **(UPDATED BY UNE 195006:2025)**	RAFT It is agreed that the raft structure that keeps the device afloat must: - be free of elements (uncovered) - or be covered with a non-entangling material (such as hessian or thickly woven cloth) - or be covered with netting which mesh size is below 7 cm (2.5 inches), TAILS/UNDERWATER PART All items hanging from the raft must be non-entangling. These items may be made of: - simple ropes, - or netting with a mesh size below 7 cm, - or netting with a mesh size of over 7 cm but tied into coils or "sausages", - or any other non-mesh material (such as canvas). - Submerged structures may present additional pieces and dangling attractors (e.g., palm leaves, netting panels), provided that their mesh size is below 7 cm.
ZUDAIRE ET AL., 2018	A BIOFAD will be composed of non-netting form renewable lignocellulosic materials (i.e. plant dry matter) and/or bio-based biodegradable plastic compounds, prioritizing those materials that comply with international relevant standards or certification labels for plastic compostability in marine, soil or industrial compost 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 FADs to track them.
JWGFAD-02 - MEETING REPORT	t-RFMOs should accelerate progress to reduce contributions of FADs to marine litter and mitigate negative impacts on coastal habitats and marine ecosystems, and on endangered, threatened and protected (ETP) species, such as use the of FADs without netting and those made with biodegradable materials, as well as mechanisms and incentives for recovering FADs.

2. State-of-the-art on BIOFAD model

A comprehensive review was carried out to assess the evolution of drifting Fish Aggregating Devices (dFADs) used in tuna fisheries, with a particular focus on biodegradable models and the jelly-FAD design, as well as the use of synthetic and biodegradable materials in FAD construction in general. This review draws on data from both past and ongoing biodegradable FAD trials, aiming to understand how the use of dFADs has changed over time and to identify opportunities for innovation in sustainable fishing practices. The ultimate goal was to support the eco-design of fully biodegradable dFADs that reduce the environmental impact of marine litter, especially when these devices become abandoned, lost, or discarded (ALD). By minimizing the ecological footprint of dFADs, particularly in sensitive habitats where they may strand, this work contributes to broader efforts to mitigate plastic pollution in the ocean.

To achieve this, this task encompasses two interconnected activities:

- One key component involves engaging with the purse seine freezer tuna fleet through a targeted questionnaire. Developed within the framework of the SEARCULAR project, the ISSF Skipper Workshops program and AZTI's Good Practise meeting with the industry. The questionnaire seeks to gather insights into fleet operations and FAD usage. It also explored the steps being taken to transition toward biodegradable FADs and aimed to identify materials and designs that are both effective and environmentally responsible.
- In parallel, a state-of-the-art review of biodegradable materials and dFAD designs has been conducted, focusing on recent technological advances and the availability of suitable materials across regions where tuna purse seiners operate.

2.1 Biodegradable FAD questionnaire

To better understand how each fleet operates in relation to the use of FADs. What actions are being taken for the transition towards biodegradable FADs and thus identify more sustainable materials and models that could work better, a questionnaire was developed and shared with the fleet. This was carried out within the framework of the ISSF's Skippers Workshops and taking advantage of any opportunity to meet the fleet such as AZTI's annual meetings for the monitoring of Code of Good Practices with the ANABAC and OPAGAC fleets. Participation in the questionnaire was voluntary, and no personally identifiable information was collected. All responses were processed collectively and stored securely in the AZTI and ISSF databases, with access restricted to project researchers. The data will be retained only for the duration of the SEARCULAR project and the ISSF Skipper Workshops, unless further processing is required for project-related purposes. Under no circumstances will the data be shared with third parties.

Questions were designed as multiple responses questionnaire to gather detailed insights into the technical design, material composition, operational performance, maintenance practices of conventional and biodegradable FADs, FAD use impacts and management options. With this aim the analysis of the responses to the questionnaire was divided in 4 parts:

- **Part I and II** focus on exploring the types of structures used (surface and submerged), the materials selected for each component (raft, covering, tail, flotation), the amount of flotation and ballast added, the overall dry weight of the FAD, and the percentage of plastic materials used, providing a measure of environmental sustainability. It also assesses whether fleets adapt their designs based on oceanic regions for conventional and biodegradable FADs.

- **Part III** focuses on the use of FADs, investigates whether fleets repair damaged FADs, where FADs are constructed, their typical lifespan within the fishing zone, and the main causes of FAD loss, including potential environmental impacts.
- Part IV aims to map current practices, focusing on the industry's perspectives regarding the advantages and disadvantages of the FADs currently in use, as well as potential measures to minimize their negative impacts. The objective is to identify areas for improvement and to support the transition toward more sustainable and biodegradable FAD designs.

The questionnaire was translated into both Spanish and English, with the aim of broadening its reach (Figure 3 and Annex 1).

Figure 3. QR Code for Spanish and English version of the questionnaire

The questionnaire gathered responses from a diverse group of professionals involved in the use and management of FADs, with participants located primarily in Spanish coastal towns such as Bermeo, Vigo, and A Coruña, as well as international fishing hubs like Manta in Ecuador (Figure 4). The data collection was most active during October and November 2024, with the highest number of responses recorded on October 22 and November 19.

A total of 70 responders participated in the questionnaire, who held a variety of roles within the fishing industry, predominantly captains, deck bosses, and skippers, though office managers, inspectors, and other crew members were also represented (Figure 5). The diversity of titles reflects a mix of operational and administrative perspectives.

Most participants work directly onboard fishing vessels, accounting for approximately 70% of the sample, while the remaining 30% operate from shore-based offices (Figure 6). Company affiliations were coded, with entities labelled as "n3," "n9," and "n5" being the most frequently mentioned, suggesting a concentration of responses from specific fleets or organizations.

In terms of operational areas, most of the participants currently work in the Indian Ocean, followed by the Pacific and Atlantic Oceans (Figure 7). A smaller group operates in the eastern Pacific or across multiple oceanic regions. Experience levels in the current ocean vary widely, ranging from 1 to 25 years, with an average of approximately 8.7 years, indicating a mix of seasoned professionals and newer entrants. Many respondents also reported having worked in other oceans, most commonly the Atlantic and Indian, or the Pacific and Atlantic, reflecting a high degree of mobility and adaptability.

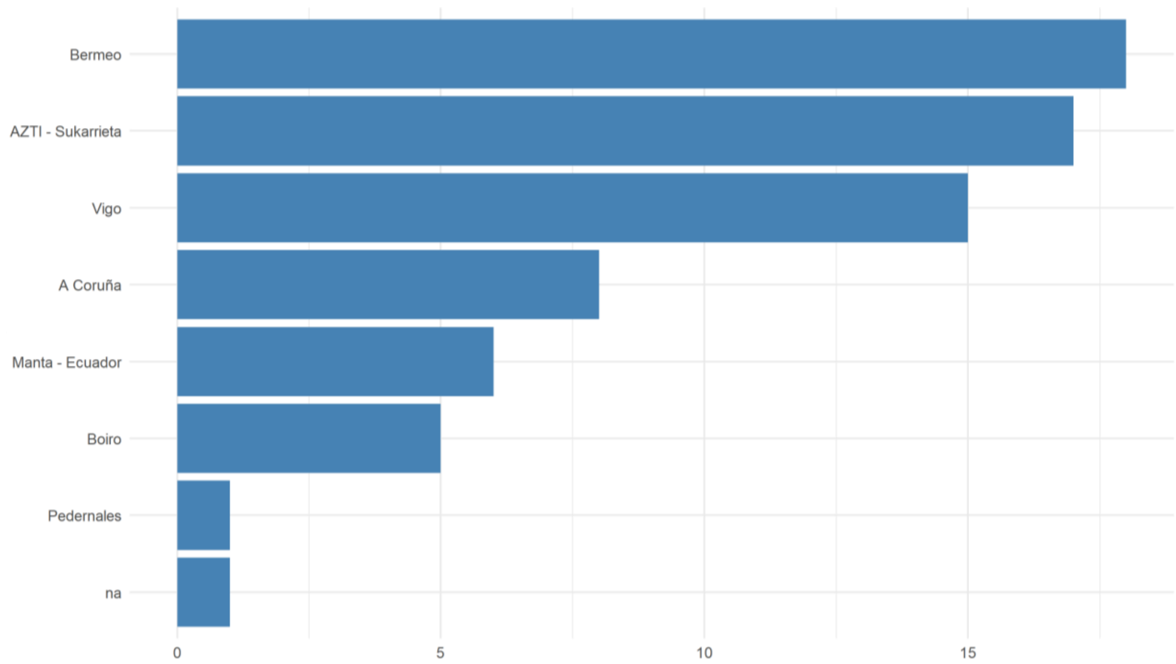


Figure 4. Main locations of professionals involved in the use and management of FADs, in terms of frequency of answer

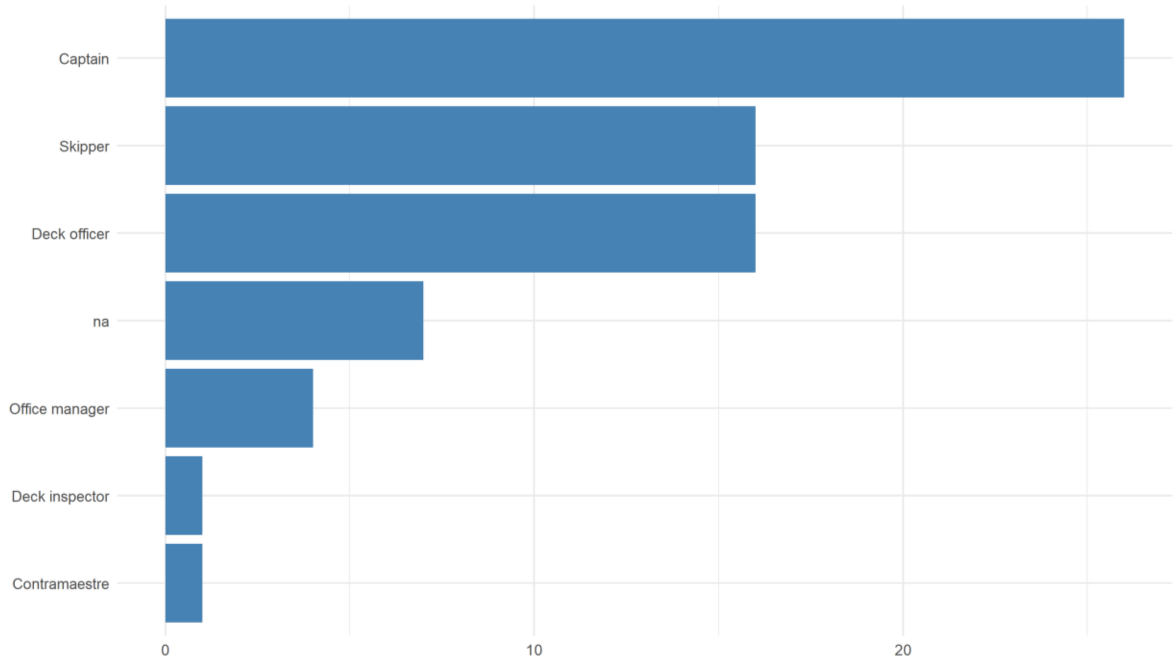


Figure 5. Qualification or occupations of responders, in terms of frequency of answer

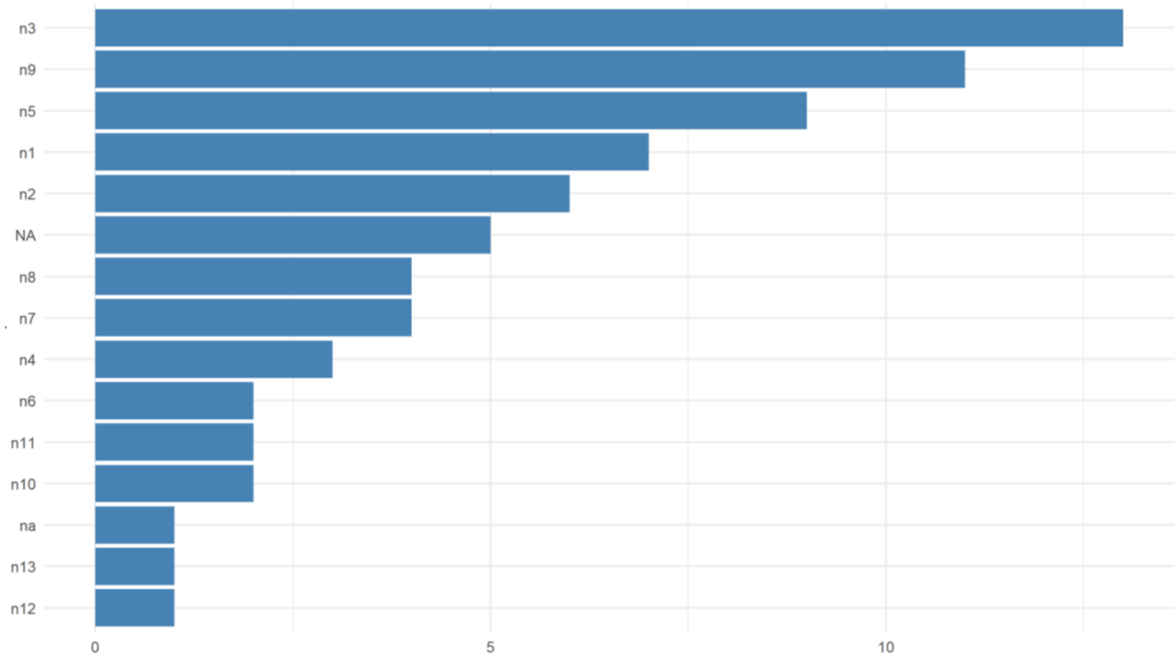


Figure 6. Company Affiliation of Responders, in terms of frequency of answer. Companies are coded "n".

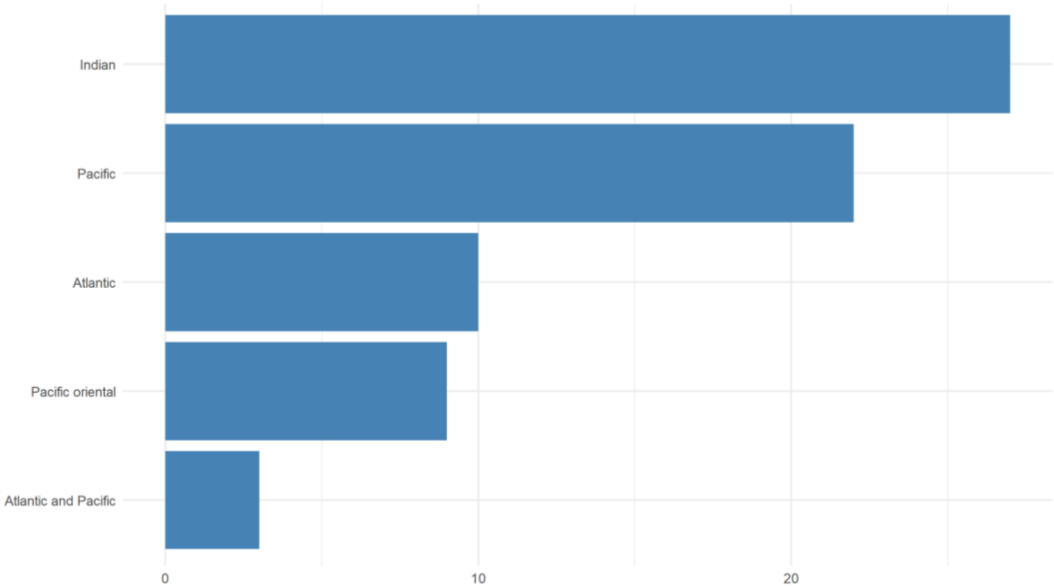


Figure 7. Area or Ocean of operation, in terms of frequency

Finally, when asked about their total experience in purse seine fishing, participants reported a broad range of years, with some having over three decades of experience (Figure 8). This highlights the depth of expertise within the group and provides a strong foundation for evaluating practices and perspectives related to FAD usage.

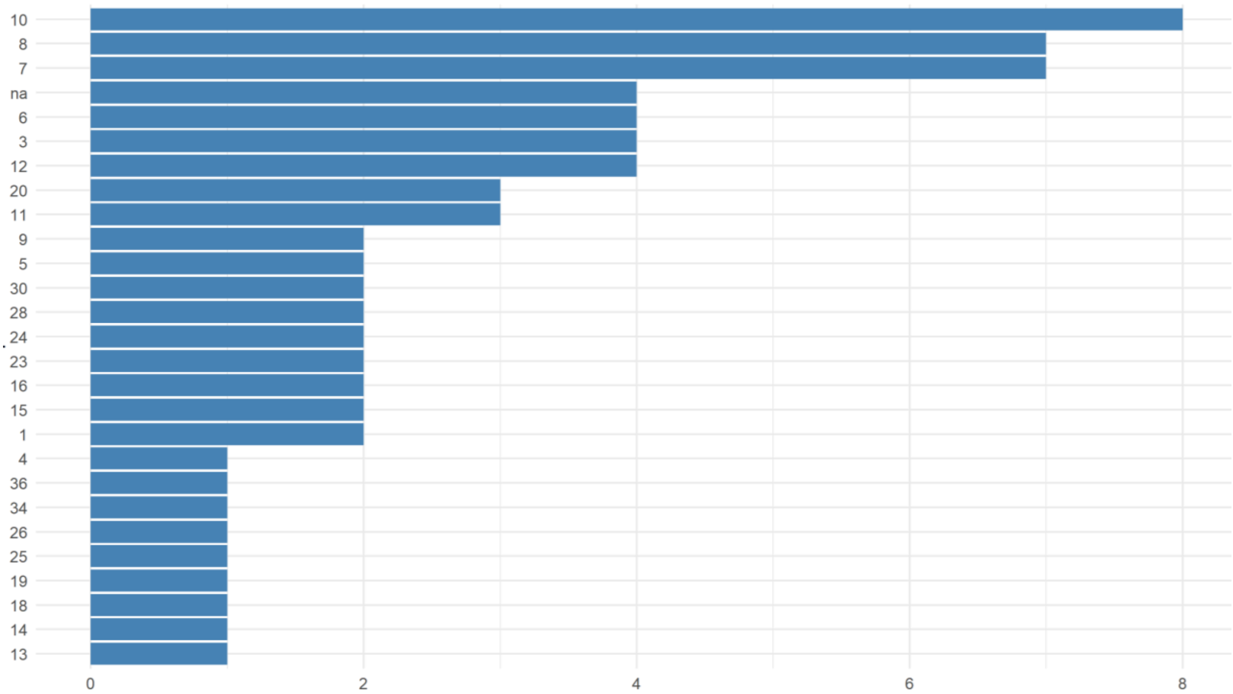


Figure 8. Years of experience in purse seine fisheries among responders, in terms of frequency

Part I – Conventional FAD designs and construction materials.

Question #10 asked participants about the type of raft they use in FAD construction. A total of 99 responses were recorded (Figure 9). The most common response was "Rectangular", selected by 69 participants, representing 69.70% of the total. This indicates a strong preference for rectangular raft designs across oceans, likely due to their practicality, availability, or effectiveness in the field. The second most frequent response was "Circular", with 18 responses (18.18%), followed by "Burrito" with 10 responses (10.10%). These alternatives may reflect adaptations to specific operational needs or regional practices. Only 2 participants selected "Octogonal", representing 2.02% of the total, suggesting limited experimentation with more complex raft shapes, which is mainly used in the Atlantic Ocean. The dominance of the rectangular raft design suggests it is either the most functional or the most standardized across fleets. Fishers use bamboo canes to construct these rafts, with the rectangular shape being the easiest structure to build with the canes. Other shapes, such as octagonal designs, are made using stainless steel. The presence of alternative designs highlights ongoing innovation and customization in FAD construction across oceans and also highlights how dynamic is this fishery in relation to the use of FADs.

Question #11 asked participants about the type of tail or submerged part used in FAD construction. A total of 95 responses were recorded (Figure 10). The most common response was "Pacific-style windows", selected by 42 participants, representing 44.21% of the total. This suggests a strong preference for this design, especially in the Pacific Ocean, likely due to its proven effectiveness in aggregating fish and drifting pattern for the current in the region. The second most frequent response was "Rope", with 27 responses (28.42%), followed by "Cage" with 19 responses (20.00%) indicating that simpler rope-based designs are also widely used depending on the ocean, these are the two main tail designs used in the Indian Ocean. Less common responses included "Atlantic-style tie" with 6 responses (6.32%) and "jelly-FAD" with 1 response (1.05%). The presence of multiple responses reflects adaptation to specific operational needs, but also indicates experimentation with alternative configurations. It suggests the mobility of skippers between oceans and highlights that some operators tailor their submerged structures to particular environmental conditions, fishing strategies, or material availability.

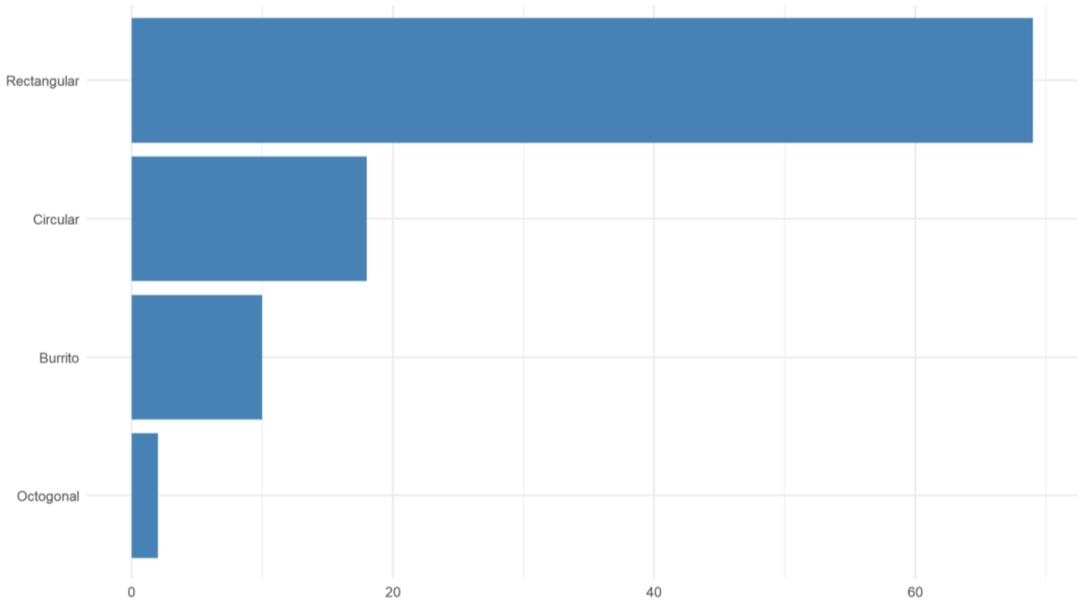


Figure 9. Type of raft used in the FADs, in terms of frequency

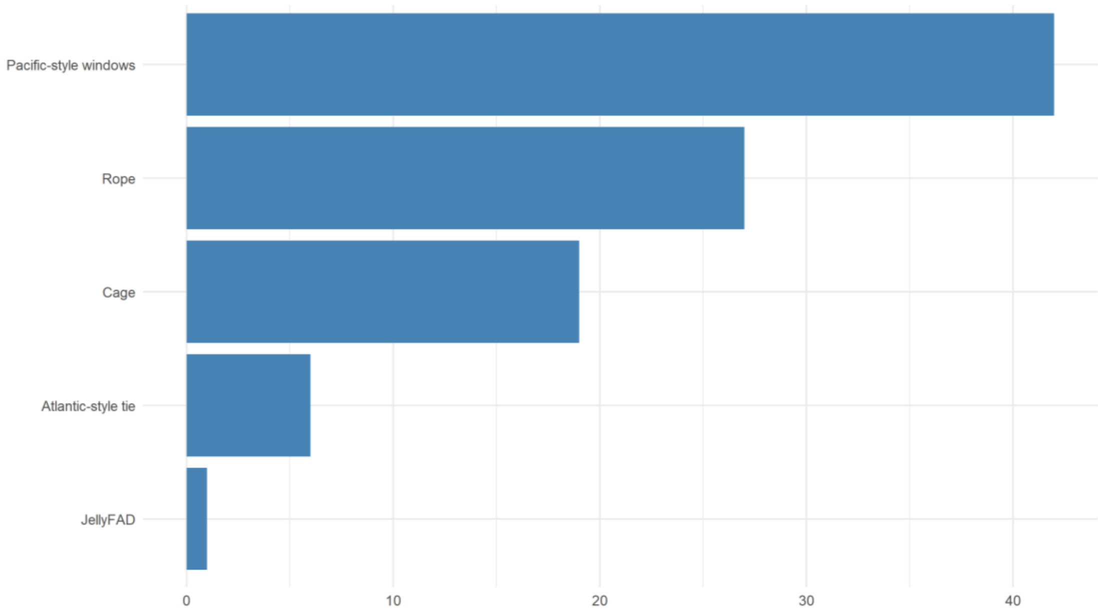


Figure 10. Type of tail or submerged part mostly used in FADs, in terms of frequency

Question #12 asked participants whether they use different types of FADs. A total of 93 responses were recorded (Figure 11). The most common response was "No, I use a single design throughout the year.", selected by 32 participants, representing 34.41% of the total. This indicates a significant portion of the fleet prefers a standardized FAD design, likely for consistency, simplicity, logistical reasons, or proved effectiveness in aggregating fish. The second most frequent response was "Yes, depending on the material available on board." with 28 responses (30.11%), followed by "Yes, depending on the currents in the area." with 18 responses (19.35%). Other responses included "Others" with 11 responses (11.83%), and two unique responses: "Area and currents at the time of deployment." – 1 response (1.08%); and "Yes, depending on the type of tuna found in the area." – 1 response (1.08%).

These answers indicate that a substantial number of participants do adapt their FAD designs based on situational factors such as material availability or oceanographic conditions depending on the ocean. The results also reflect a balance between standardization and adaptability, which is also ocean dependent. While many operators stick to a single design (normally in the Pacific and Atlantic oceans), a considerable group modifies their FADs depending on environmental or logistical variables (mainly in the Indian Ocean), highlighting the diversity of practices across fleets and regions.

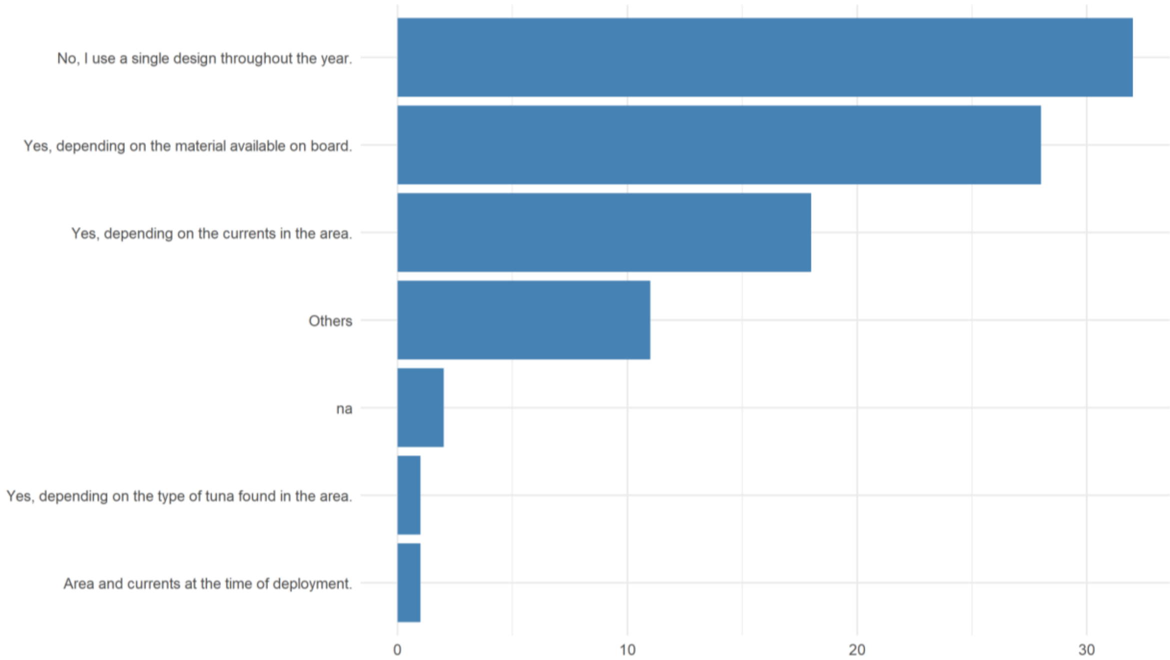


Figure 11. Usage of different type of FADs by responders, in terms of frequency

Question #14 asked participants about the materials used for the RAFT in FAD construction. A total of 132 responses were recorded (Figure 12). The most common response was "Bamboo", selected by 52 participants, representing 39.39% of the total. This suggests a strong preference for this material, likely due to its availability, durability, environmental benefits, structural properties, and/or cost-effectiveness. The second most frequent response was "Metal", with 33 responses (25.00%), followed by "Plastic" with 22 responses (16.67%) indicating that some fleets combine traditional and industrial materials. Other materials mentioned included: "Bio-based plastic" – 13 responses (9.85%); "Wood" – 11 responses (8.33%); "Others" – 1 response (0.76%).

The results show a clear preference for bamboo, likely due to its sustainability and performance. However, the diversity of material combinations highlights the variability in construction practices across fleets, influenced by factors such as material availability, durability requirements, and environmental considerations. The use of synthetic materials in raft construction highlights the need for a more robust materials for this part of the FADs to ensure the durability during its life spam.

Question #15 asked participants about the materials used to cover the FAD raft. A total of 86 responses were recorded (Figure 13). The most common response was "Synthetic canvas, no mesh", selected by 41 participants, representing 47.67% of the total. This suggests a strong preference for synthetic canvas, likely due to its durability, availability, or cost-effectiveness. The second most frequent response was "I don't cover the raft with anything", with 15 responses (17.44%), indicating that a notable portion of participants opt for uncovered rafts, possibly to reduce costs or simplify construction. Other materials mentioned included: "Biodegradable canvas, no mesh (OTHERS)" – 11 responses (12.79%); "Biodegradable canvas, no mesh (COTTON)" – 9 responses (10.47%); "Synthetic net (open net with SMALL mesh)" – 2 responses (2.33%); "Biodegradable canvas, no mesh (ABACA)" – 1 response (1.16%); "Biodegradable canvas, no mesh (SISAL)" – 1 response (1.16%) and "N/A" – 6 responses (6.98%).

Synthetic materials dominate across oceans, however, there is a clear trend toward experimentation with biodegradable options. The presence of uncovered raft also reflects a minimalist approach adopted by some fleets, possibly aligned with environmental or regulatory considerations (for example, prohibition of use of net in FAD construction).

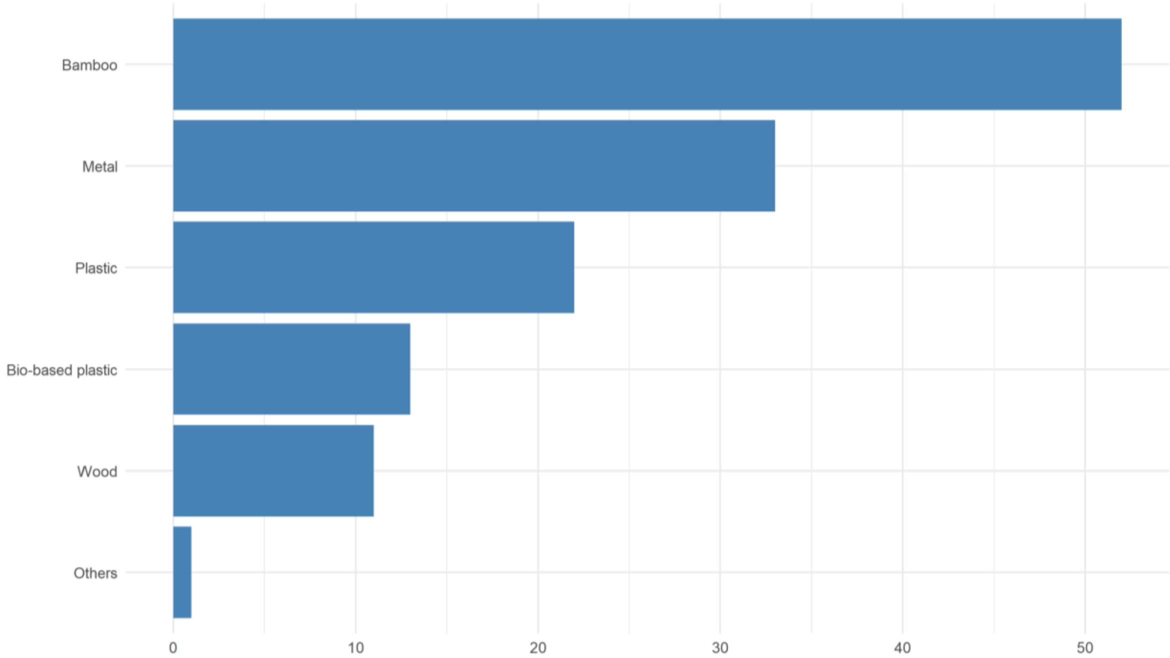


Figure 12. Materials used for the raft, in terms of frequency

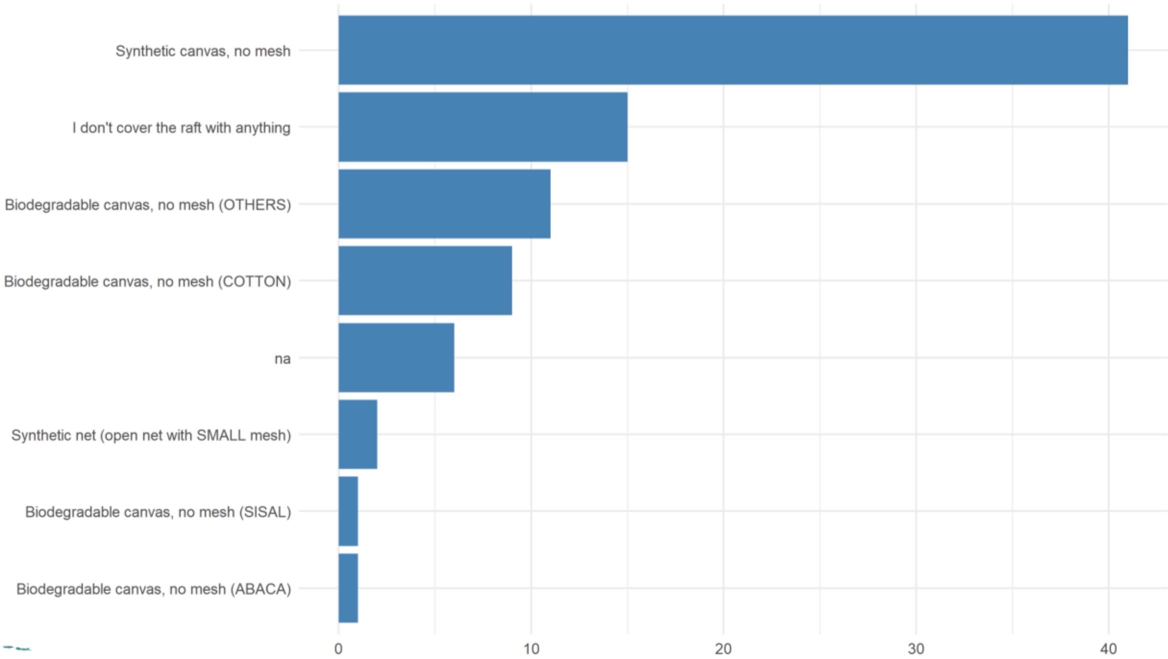


Figure 13. Materials used to cover the FAD raft, in terms of frequency

Question #16 asked participants about the materials used for the TAIL in FAD construction. A total of 130 responses were recorded (Figure 14). The most common response was "Synthetic ropes", selected by 44 participants, representing 33.85% of the total. This indicates a strong preference for synthetic ropes, likely due to their strength, availability, resistance to marine conditions, and ease of handling, besides the economic reasons. The second most frequent response was "Synthetic canvases", with 23 responses (17.69%), followed by "Biodegradable ropes (COTTON)" with 17 responses (13.08%). Other materials mentioned included were "Biodegradable canvases (COTTON)" – 13 responses (10.00%); "Biodegradable ropes (OTHERS)" – 11 responses (8.46%); "Biodegradable canvases (OTHERS)" – 6 responses (4.62%); "Synthetic net (open net with SMALL mesh)" – 4 responses (3.08%); "Biodegradable ropes (SISAL)" – 4 responses (3.08%); "Synthetic net (net tied in “SAUSAGES”)" – 2 responses (1.54%); "Synthetic net (open net with LARGE mesh)" – 2 responses (1.54%); "N/A" – 2 responses (1.54%); "Biodegradable ropes (ABACA)" – 1 response (0.77%); "Biodegradable canvases (SISAL)" – 1 response (0.77%).

The dominance of synthetic materials suggests they remain the standard across fleets, while the presence of biodegradable alternatives. These combinations indicate that some fleets are integrating biodegradable materials alongside synthetics, possibly as part of a transition toward more sustainable practices. While synthetic ropes remain the most commonly used material for the submerged tail of FADs, the presence of biodegradable options—especially cotton—reflects growing awareness and experimentation with environmentally friendly alternatives. The wide variety of combinations also highlights the adaptability of fleets to available materials and operational needs.

Question #17 asked participants about the materials used for FLOATATION in FAD construction. A total of 106 responses were recorded (Figure 15). "Plastic floats or buoys" was selected by 37 participants, representing 34.91% of the total. As second option "Net corks" (plastic corks recycled form purse seine nets) was selected by 25 participants (23.58%). The rest of the options appeared less significant with "Wood (balsa or other types)" selected by 16 participants (15.09%); "PVC tubes" 14 participants (13.21%); "Others" was selected by 9 participants (8.49%); "N/A" was selected by 3 participants (2.83%); and "Plastic bottles/containers" and "Foam tubes" were each selected by 1 participant (0.94%). The results show a diverse use of materials for floatation in FAD construction. While synthetic options like plastic floats and PVC tubes dominate, likely due to their durability, availability, and cost-effectiveness, there is also evidence that organic materials such as balsa wood are increasingly being used. This suggests again a growing awareness of environmental impacts and a shift toward sustainable practices, also driven by the current biodegradable FAD implementation regulation framework across oceans. The use of biodegradable or low-impact alternatives, though still limited, reflects ongoing experimentation and adaptation within fleets. The balance between functionality and sustainability is a key theme, indicating that while fleets are open to innovation, practical constraints continue to shape material choices specially for floatation elements.

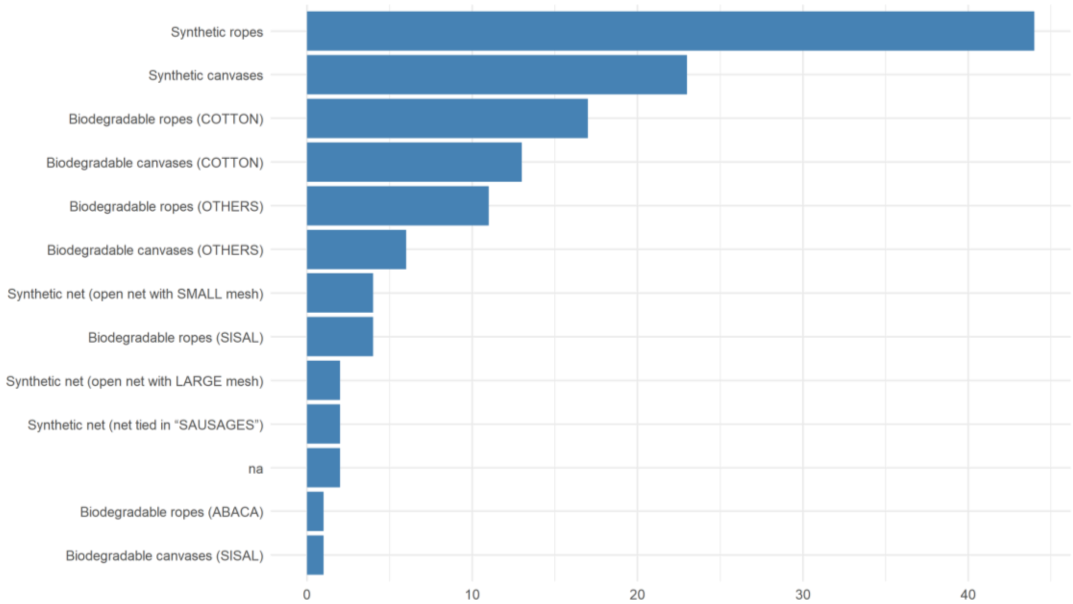


Figure 14. Materials used for the tail, in terms of frequency

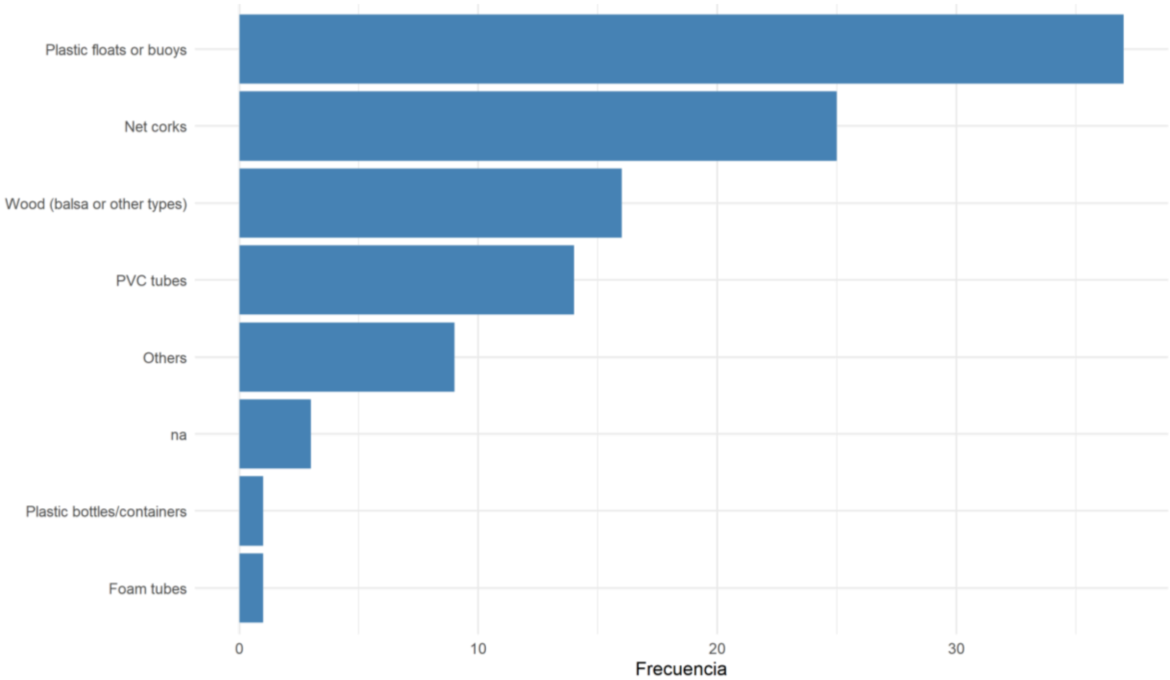


Figure 15. Materials used for the floatation, in terms of frequency

Question #18 explored the amount of flotation material added to the surface component of the FADs. A total of 32 responses were recorded. The responses were highly varied, with no single dominant answer. The most frequent values, each selected by 2 participants (6.25%). The data shows a concentration of responses around moderate flotation levels (10 – 30 L), with some fleets opting for significantly more. This likely reflects operational needs such as visibility, buoyancy requirements, or durability, besides the need to adapt the buoyancy to the diversity of FAD designs used by the fleet across oceans. The lack of standardized units also suggests a need for clearer guidelines when estimating needed floatation related to the FAD design, ballast weight, etc.

Question #19 asked participants about the type of material used as ballast in FAD construction. A total of 74 responses were recorded (Figure 16). The most common response was "Drawstring", selected by 67 participants, representing 90.54% of the total. This suggests a strong preference for this material, likely due to its effectiveness, simplicity, or widespread availability on board. Other materials mentioned included: "Chain" – 3 responses (4.05%); and "Stones" – 1 response (1.35%). The overwhelming preference for drawstring as ballast material indicates a high level of standardization across fleets. This is driven by its cost-effectiveness (discarded material on board), ease of use, and proven performance in maintaining FAD stability. The use of natural materials like stones and recycled or repurposed items such as chains or plastic containers suggests a mix of traditional and innovative approaches. This variation highlights the importance of context-specific solutions and the potential for standardizing best practices in the future.

Question #20 asked participants about the amount of weight added as ballast to the tail of FADs. The responses show a wide range of values, reflecting different design strategies and operational needs. The most frequently reported weight was 10 kg, followed by 20 kg, 30 kg, and 50 kg. These values suggest that most fleets aim for moderate ballast to ensure the FAD remains submerged and stable, without adding excessive weight that could complicate deployment or recovery, cause the FAD to sink or compromise the integrity of the entire structure. Some responses included higher weights such as 70 kg, 80 kg, and even 100 kg, indicating more robust or heavily weighted designs, possibly for deeper deployment or stronger current conditions (for example in the Atlantic and Pacific oceans). Similar to the flotation, standardizing ballast recommendations could help improve FAD performance and reduce environmental risks.

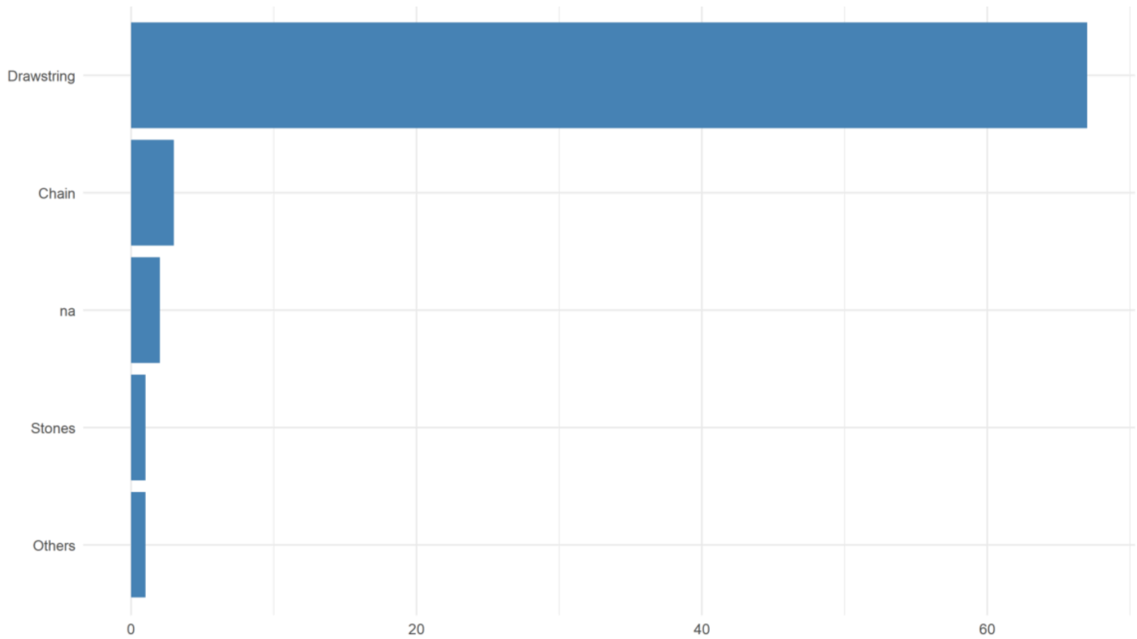


Figure 16. Materials used as ballast, in terms of frequency

Question #21 asked participants to estimate the approximate dry weight of a FAD, excluding the buoy or echo sounder. The responses show a wide range of values, reflecting the diversity in FAD construction materials and designs. The data suggests that while many FADs fall within the 200–500 kg range, there is no standard weight across fleets. This diversity may reflect different operational needs, material availability, design preferences across oceans as well as possible biases in how weight is measured or assessed. Establishing guidelines or best practices for FAD weight could help improve deployment efficiency and environmental performance, specifically to properly adapt quantities for floatation and ballast weights.

Question #22 asked participants to estimate the percentage of plastic materials (excluding the buoy or echosounder) used in the construction of their FADs. The responses reveal a wide range of plastic usage, reflecting varying levels of integration of synthetic components, as already shown in previous questions (Figure 17). The most frequently reported values were between 5% and 30%, suggesting efforts to reduce plastic content. However, values of 50% and 100%, indicate that some fleets still rely heavily on plastic-based materials. This distribution highlights the coexistence of conventional and more sustainable FAD construction practices across fleets. The data suggests a growing awareness of plastic reduction, with a significant number of respondents reporting low plastic usage. However, the presence of high-percentage responses (up to 100%) indicates that full transition to low-plastic or biodegradable FADs is still in progress.

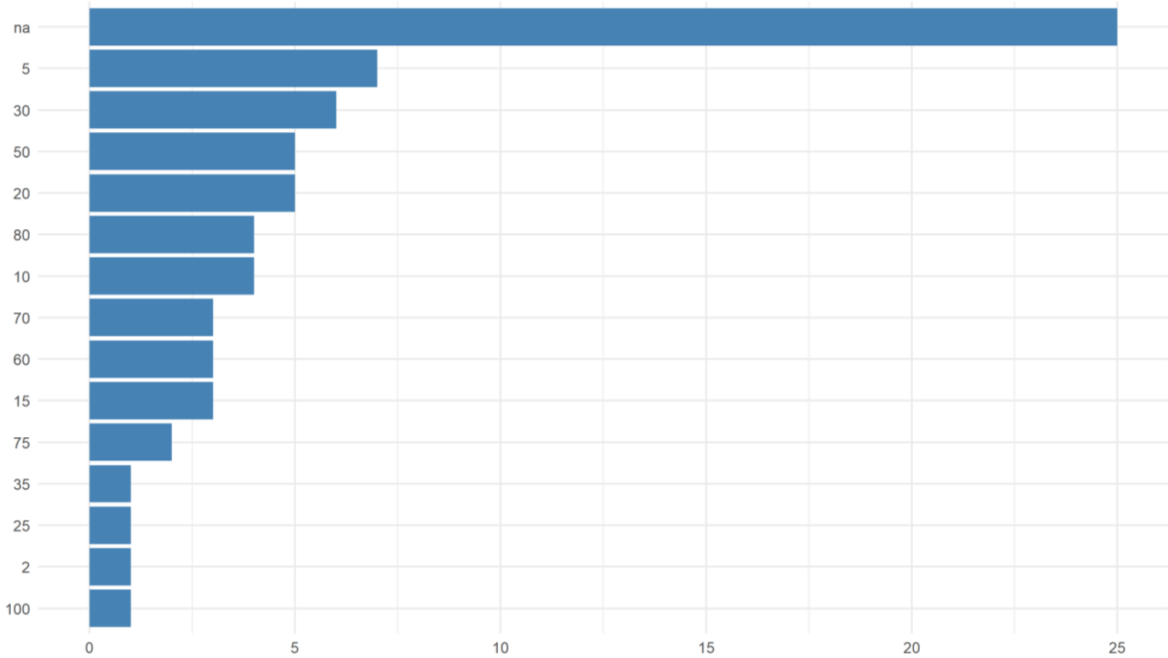


Figure 17. Percentage of the plastic materials used in the FADs, in terms of frequency

Part II – Biodegradable FAD designs and construction materials.

Question #28 asked participants to estimate the number of biodegradable FADs they have deployed. A total of 71 responses were recorded (Figure 18). The most common response was "na", selected by 28 participants, representing 39.44% of the total. Question #28 reveal a wide range of deployment levels for biodegradable FADs, indicating non-uniform adoption across fleets, but mainly indicates that many participants either have not deployed biodegradable FADs or do not track the number deployed. Among those who do report deployments, the numbers vary significantly—from single digits to hundreds or even thousands—reflecting differences in Fleet size, Access to biodegradable materials, company commitment to sustainability practices and/or operational regions and practices. This diversity highlights both progress and challenges in scaling up biodegradable FAD usage, and points to the need for standardized reporting and support mechanisms to encourage broader adoption.

In the same line Question #29 asked participants approximately how many biodegradable FADs they have deployed or found. A total of 71 responses were recorded. The most common response was "na", selected by 37 participants, representing 52.11% of the total. Again, this likely reflects either non-deployment, lack of tracking, or uncertainty in reporting. The high number of "na" responses suggests that many participants either have not engaged with biodegradable FADs or do not systematically record their deployment. Among those who do report numbers, the figures range from single units to dozens, indicating differences in fleet size and operational scope, varying levels of commitment to sustainability, and/or early-stage experimentation versus scaled-up implementation. This diversity underscores the need for supportive policies to encourage broader and more consistent use of biodegradable FADs.

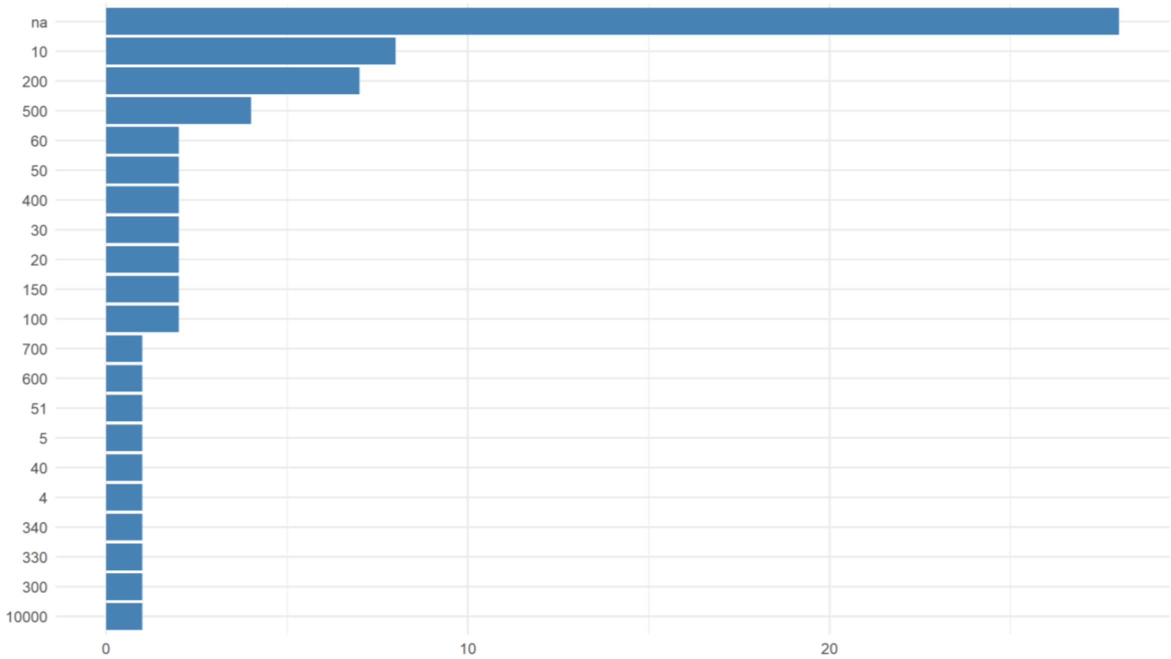


Figure 18. Number of biodegradable FADs deployed by responder, in terms of frequency

Question #35 asked participants about the biodegradable raft designs used in FADs. A total of 84 responses were recorded (Figure 19). "Rectangular" option was selected by 55 participants, representing 65.48% of the total, followed by "Circular" which was selected by 16 participants (19.05%) and "Burrito" selected by 3 participants (3.57%). "N/A" was selected by 10 participants (11.90%). The responses indicate a strong preference for rectangular designs, which account for nearly two-thirds of all responses. This dominance suggests that fleets prioritize familiarity, structural stability, and ease of construction when transitioning to biodegradable materials. The presence of circular and burrito designs, though less common, reflects ongoing experimentation and adaptation to specific operational needs or environmental conditions across oceans. The N/A responses highlight that some participants may not yet use biodegradable rafts or lack standardized designs. Overall, the data suggests that while innovation is occurring, the industry is leaning toward incremental changes that maintain proven design principles while incorporating sustainable materials.

Question #33 asked participants about the biodegradable tail designs used in FADs. A total of 99 responses were recorded (Figure 20). "Pacific-style windows" was main option selected by 29 participants, representing 29.29% of the total. Followed by "Rope" which was selected by 26 participants (26.26%). "JellyFAD" and "Cage" were each selected by 14 participants (14.14%), "Atlantic-style tie" was selected by 5 participants (5.05%) and "Others" was selected by 2 participants (2.02%). "N/A" was selected by 9 participants (9.09%).

The responses reveal a diverse range of biodegradable tail designs, indicating active experimentation and adaptation across fleets and oceans. Observed results followed the pattern observed in conventional FAD designs (Question #16), showing industry replicates conventional designs when moving towards biodegradable FADs, likely due to their proven effectiveness, ease of construction, or material availability. The presence of designs like JellyFAD, with notable adoption, reflects innovation and regional customization. Meanwhile, the smaller share of Atlantic-style tie and Others points ocean-based specification and less representativeness of participants operating in the Atlantic Ocean. Overall, the data suggests that fleets are exploring sustainable solutions while balancing performance and practicality, contributing to the evolution of biodegradable FAD technology.

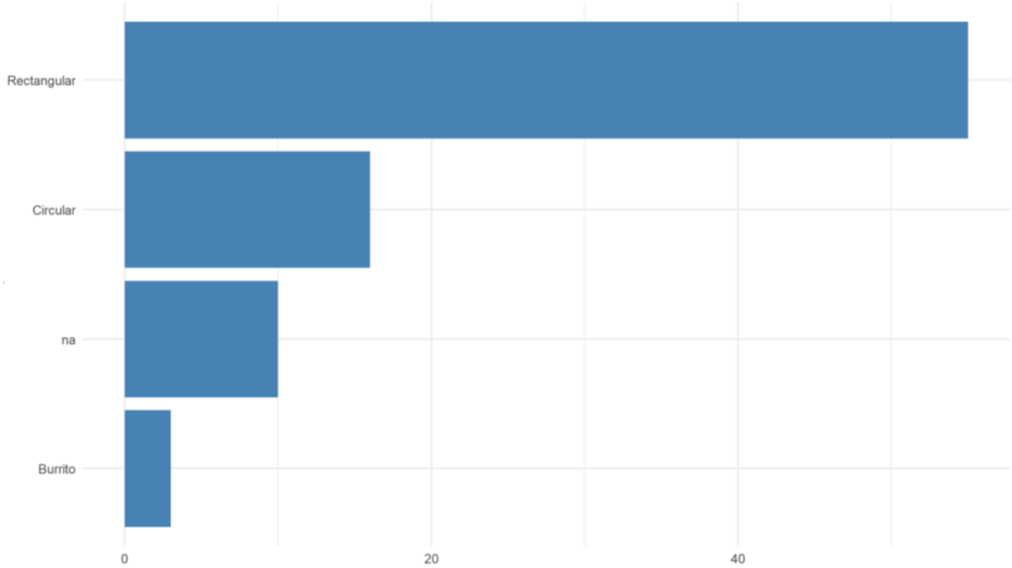


Figure 19. Type of biodegradable raft design, in terms of frequency

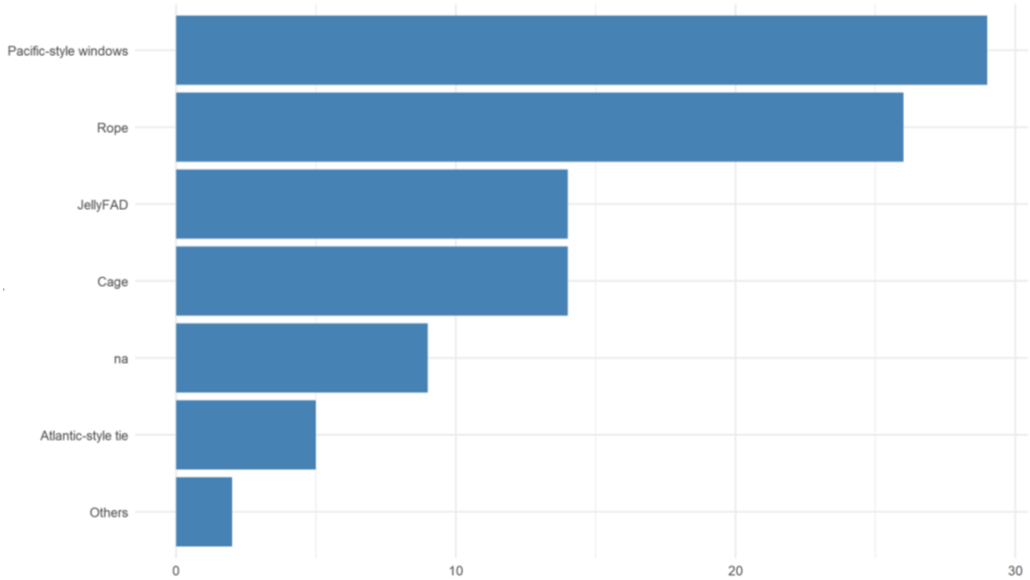


Figure 20. Type of biodegradable tail design used, in terms of frequency

Question #31 asked participants about the type of biodegradable material they have tested for the RAFT in FAD construction. A total of 117 responses were recorded (Figure 21). "Bamboo" was selected by 64 participants, representing 54.70% of the total, followed by "Balsa wood" which was selected by 24 participants (20.51%). Other options were "Bio-based" selected by 16 participants (13.68%), "Other woods" selected by 7 participants (5.98%), "Others" selected by 1 participant (0.85%) and "N/A" selected by 5 participants (4.27%).

The results show a clear preference for bamboo, which accounts for more than half of all responses. This dominance suggests that fleets prioritize materials that are abundant, cost-effective, and environmentally friendly. The significant share of balsa wood and bio-based materials indicates ongoing experimentation with alternative biodegradable options. The presence of other woods and miscellaneous materials reflects innovation and adaptation to local availability and operational requirements. Overall, the data highlights a strong commitment to sustainability, especially at those FADs' elements where the transition to biodegradable materials can be easier, with fleets actively exploring different biodegradable solutions while maintaining practical considerations such as durability and ease of construction.

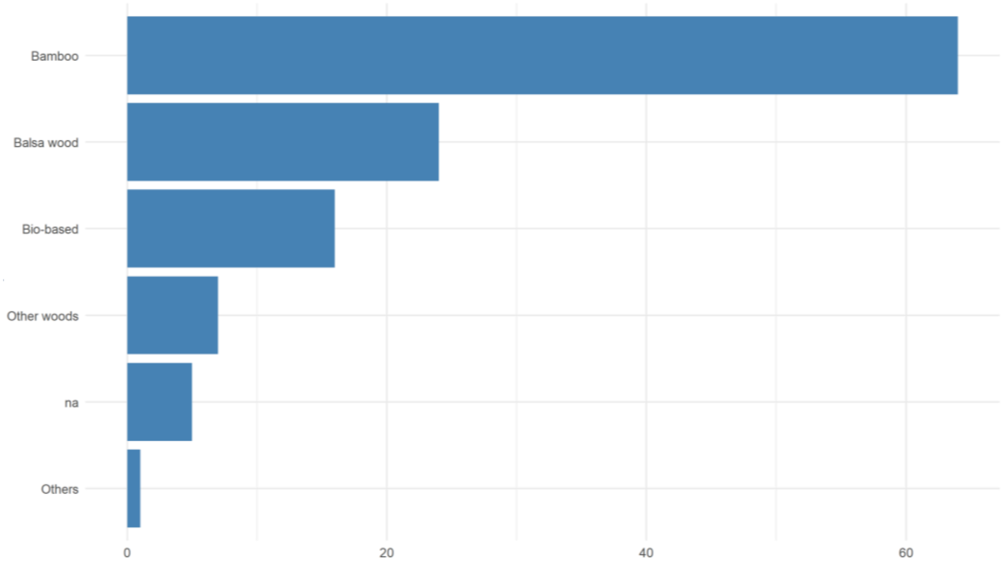


Figure 21. Type of biodegradable material used for the rafts, in terms of frequency

Question #30 asked participants about the type of biodegradable material they have tested for the TAIL in FAD construction. A total of 115 responses were recorded (Figure 22). "Plant-based ropes (COTTON)" was selected by 37 participants, representing 32.17% of the total. "Plant-based canvases (COTTON)" – was selected by 17 participants as second main option (14.78%), followed by "Plant-based ropes (OTHERS)" – selected by 13 participants (11.30%). The rest of the options obtained less that 10% of respondents: "N/A" and "Bio-based plastic ropes" – each with 10 participants (8.70%), "Plant-based ropes (HEMP)" – 8 participants (6.96%), "Others" – 7 participants (6.09%), "Plant-based ropes (ABACA)" – 5 participants (4.35%), "Plant-based canvases (OTHERS)" – 4 participants (3.48%), "Plant-based canvases (HEMP)" – 3 participants (2.61%), and "Plant-based canvases (ABACA)" – 1 participant (0.87%).

The results indicate a strong focus on plant-based materials, particularly cotton ropes and canvas, which dominate the responses. This suggests that fleets prioritize readily available, biodegradable options that balance durability and environmental performance. The presence of bio-based plastics and hemp-based materials reflects ongoing innovation and experimentation to identify alternatives that meet operational requirements. The diversity of responses highlights adaptation across fleets, with some materials gaining traction due to performance advantages or sustainability goals. Overall, the data points to a progressive shift toward eco-friendly solutions, though standardization remains limited, indicating room for further research and industry alignment.

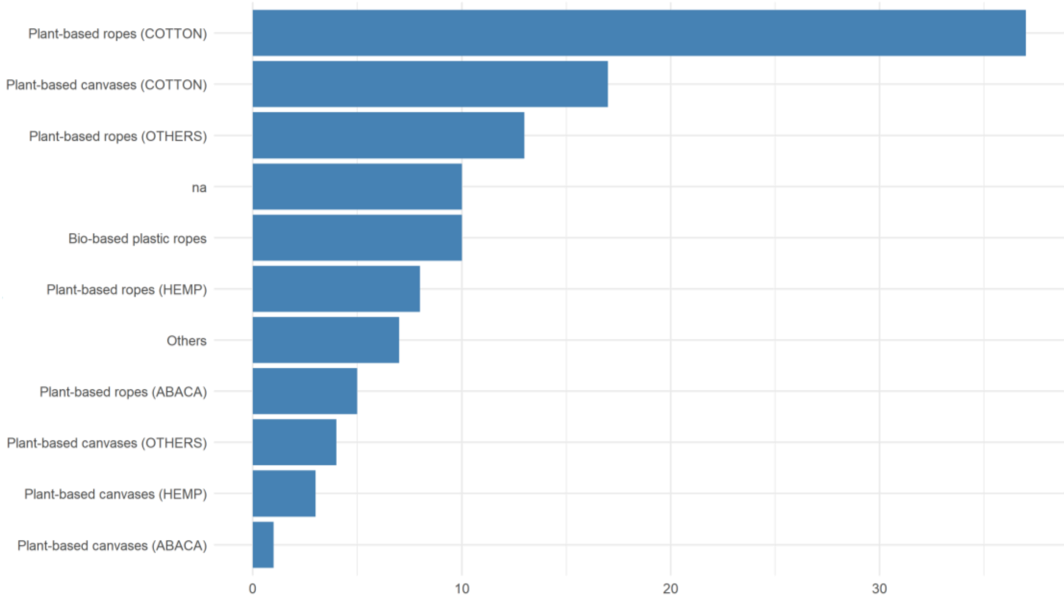


Figure 22. Type of biodegradable material used for the tail, in terms of frequency

Question #32 asked participants about the type of biodegradable material they have tested for FLOATATION in FAD construction. A total of 100 responses were recorded (Figure 23). "Bamboo" was selected by 46 participants, representing 46.00% of the total and "Balsa wood" – 23 participants (23.00%). Other selected options were "Bio-based" – 13 participants (13.00%), "N/A" – 12 participants (12.00%), "Other woods" – 5 participants (5.00%), "Others" – 1 participant (1.00%).

The results indicate a strong preference for bamboo and balsa wood, which together account for nearly 70% of responses. These materials are likely favoured for their natural buoyancy, availability, environmental benefits and cost-benefit. The presence of bio-based materials and other woods reflects ongoing experimentation to identify alternatives that meet both operational and sustainability goals. The N/A responses suggest that some fleets have not yet tested biodegradable floatation materials, highlighting an opportunity for broader adoption and the difficulties the industry is facing to find a feasible biodegradable solution for this element of the FAD. Overall, the data points to a positive trend toward eco-friendly floatation solutions, with fleets actively seeking to reduce plastic use while maintaining functional performance.

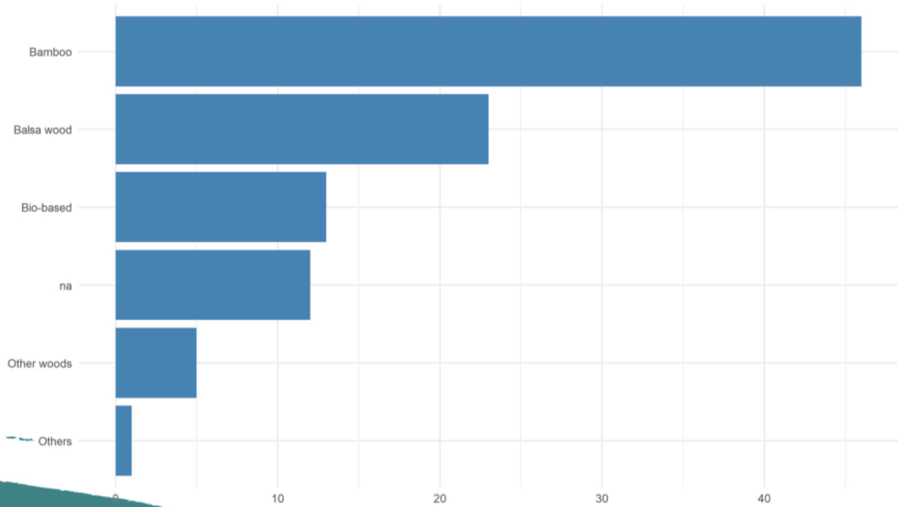


Figure 23. Type of biodegradable material used for floatation, in terms of frequency

Part III –FAD use and dynamic.

Question #23 asked participants whether they repair conventional FADs that are found in poor condition. The responses indicate a clear trend with option "Yes" selected by 45 participants, representing 63.38% of the total and option "No" selected by 26 participants, representing 36.62% (Figure 24). This suggests that a majority of respondents are actively engaging in maintenance practices to extend the life of conventional FADs, potentially reducing waste and environmental impact. The fact that nearly two-thirds of respondents report repairing conventional FADs reflects a proactive approach to resource use and sustainability. This behaviour may contribute to reducing the number of FADs lost or abandoned at sea, and could be encouraged further through training or incentives.

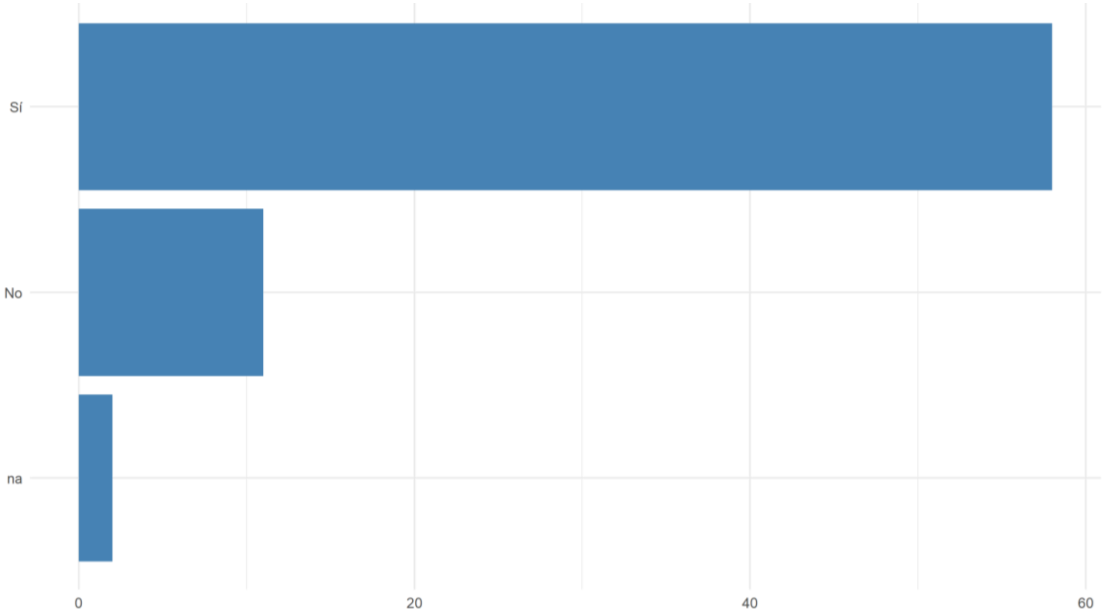


Figure 24. Reparation practice amongst the responders, in terms of frequency. Yes - they repair the recovered FADs, No - they don't, na - don't know.

Question #24 asked participants to estimate the average lifespan (in months) of a conventional synthetic FAD in the fishing zone (Figure 25). The responses show a wide range of durability expectations. The most frequently reported lifespans were: 12 months (13 responses), 10 months (9 responses), 6 months (7 responses), 9 months (6 responses). Other values ranged from 1 to 80 months, indicating significant variability in how long FADs are expected to remain functional, likely influenced by ocean conditions, materials used, and maintenance practices. The data suggests that most fleets expect conventional FADs to last between 6 and 12 months, with some reporting much longer durations. This variation may reflect differences in construction quality, deployment environments, or fleet-specific practices. Understanding these patterns can help inform design improvements and sustainability strategies, especially to understand fleet expectation with biodegradable FADs.

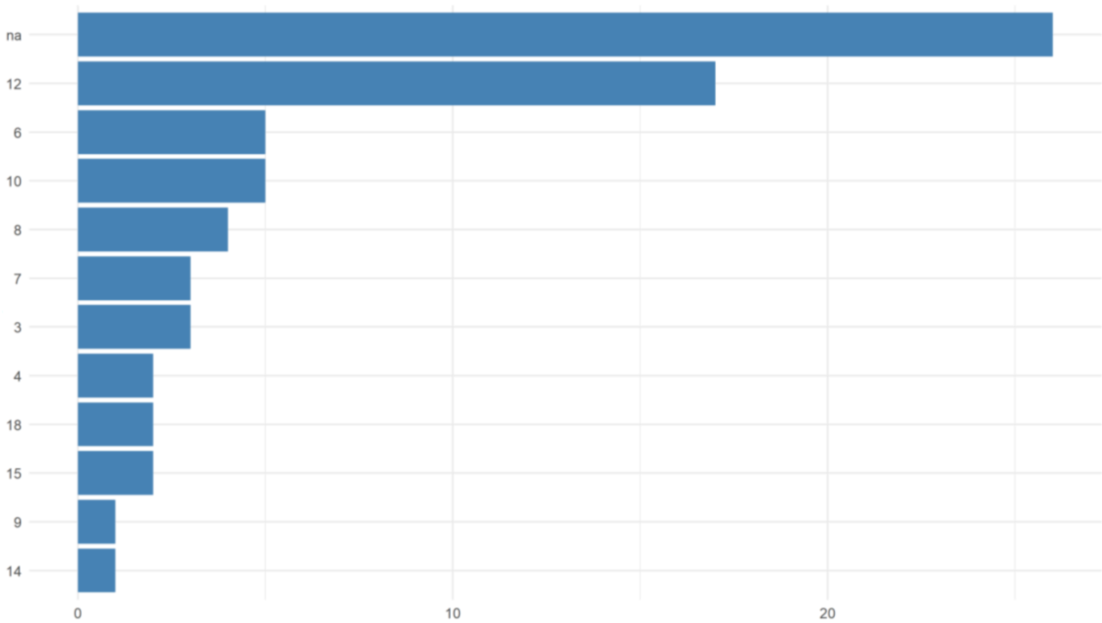


Figure 25. Average lifespan of a conventional FAD that is located within the fishing area (in years, Y-axis), in terms of frequency

Question #25 asked participants about where the FADs are built. A total of 102 responses were recorded (Figure 26). "On board" was selected by 45 participants, representing 44.12% of the total, followed by "At port (my company)" – 44 participants (43.14%). The responses show a strong preference for constructing FADs either onboard or at the fleet's own port facilities, accounting for nearly 90% of all responses. This indicates that fleets value direct control, customization, and immediate access to materials and labour. The smaller share of FADs built by external companies (5.88%) or imported (4.90%) suggests that while outsourcing exists, it is less common, possibly due to cost, logistics, or quality assurance concerns. Overall, the data reflects a trend toward in-house or onboard construction, offering fleets flexibility and efficiency in managing their FAD operations.

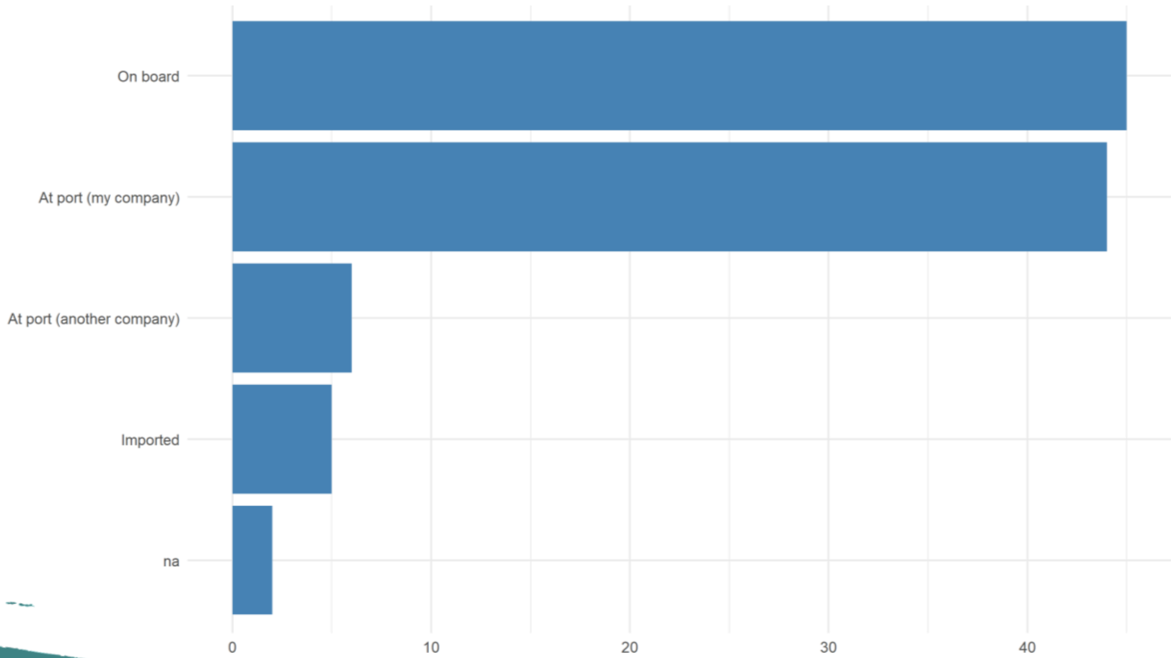


Figure 26. FAD construction locations, in terms of frequency

Question #42 asked participants about the average percentage of FADs lost. A total of 71 responses were recorded (Figure 27). The most common response was "0%", selected by 23 participants, representing 32.39% of the total. The next main options were "30%" – 14 participants (19.72%) and "40%" – 11 participants (15.49%), followed by "20%" – 7 participants (9.86%), "80%" – 6 participants (8.45%), "50%" – 4 participants (5.63%), "100%" – 3 participants (4.23%), and "10%", "60%", and "70%" – each selected by 1 participant (1.41%). The responses to Question #42 reveal a wide range of FAD loss rates, with "0%" being the most frequently reported, which is not adjusted to the reality (Maufroy et al., 2017, Inzilem et al., 2022). This suggests that the question was not correctly written or undestood by the participants. The presence of higher percentages, up to 100%, indicates that significant loss is a reality for many fleets. The data underscores the need for targeted strategies to reduce FAD loss, such as improved materials, better deployment planning, and enhanced recovery protocols, to support sustainability and reduce marine litter.

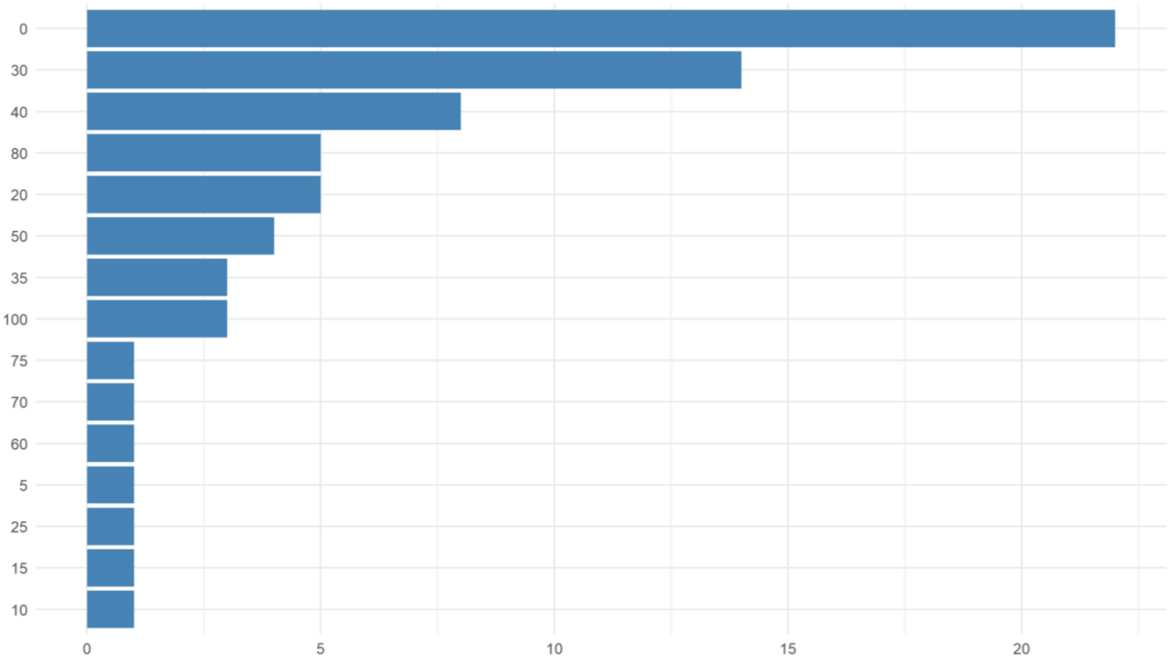


Figure 27. Average percentage of FADs lost (Y-axis), in terms of frequency

Question #49 asked participants about the reason why FADs are lost. The most frequently cited reason for FAD loss was theft, mentioned in nearly 40% of all cases (53 out of 134 total mentions) (Figure 28). This indicates that unauthorized appropriation of FADs is a widespread and systemic issue across fleets, more common on small ocean like Indian Ocean, where a reduced operation area increase the probability of encounter other vessels' FADs. The second most common reason, accounting for approximately 27% of mentions (36 responses), was specific area and season. This refers to environmental and seasonal conditions, such as strong currents and storms, that increase the likelihood of FADs being lost or drifting beyond reach.

FAD limit was the third most cited reason, with about 13% of mentions (17 responses). This suggests that regulatory restrictions on the number of FADs allowed per vessel may lead to intentional abandonment or non-retrieval of excess devices. Rough sea conditions were mentioned in around 9% of responses (12 mentions), highlighting the role of natural oceanic forces in the loss of FADs. Fisherman's behaviour was cited in nearly 7% of cases (9 mentions), as the reason contributing to FAD loss. A small number of responses were categorized as N/A (5 mentions, about 4%) or others (2 mentions, about 1.5%), indicating either unclear answers or less common causes.

The data reveals that both human factors and environmental conditions are key drivers of FAD loss. Theft stands out as the most pressing issue, suggesting a need for better monitoring, ownership tracking, and possibly cooperative agreements between fleets to reduce conflict and unauthorized use. The high number of mentions related to seasonal and geographic conditions underscores the importance of adapting deployment strategies to local oceanographic realities. This could include using predictive tools or seasonal planning to minimize risk. The mention of FAD limits as a cause of loss suggests that current regulations, while aiming to reduce environmental impact, may inadvertently encourage abandonment. This highlights the need for policy refinement. Finally, the role of fisherman behaviour and rough seas points to the value of training, awareness, and improved FAD design to withstand harsh conditions and reduce unintentional loss. Addressing these issues through policy adjustments, improved tracking, and education could significantly reduce FAD loss and its environmental impact.

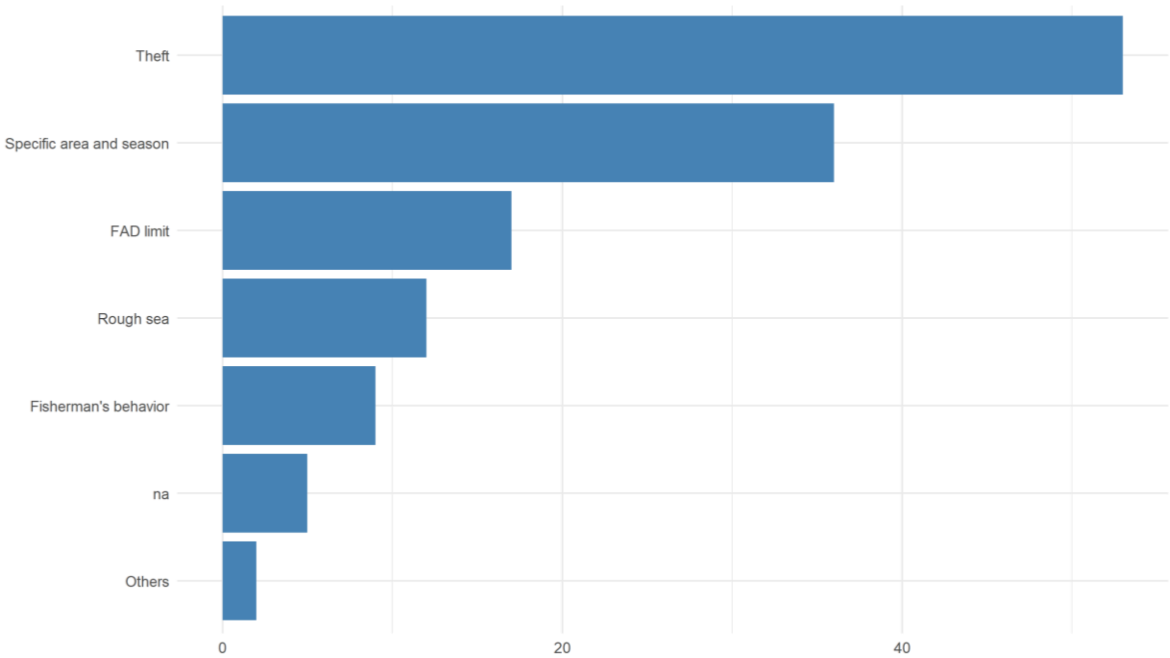


Figure 28. Reasons for losing a FAD, in terms of frequency

Question #46 asked participants about the percentage of FADs recovered. A total of 71 responses were recorded (Figure 29). "11–30%" – selected by 22 participants, representing 30.99% of the total, followed by "0–10%" – 19 participants (26.76%), "Unknown" – 18 participants (25.35%), "51–70%" – 6 participants (8.45%), "31–50%" – 4 participants (5.63%), and "71–90%" – 2 participants (2.82%). The data reveals a wide range of FAD recovery rates among participants. The most common recovery bracket is 11–30%, followed closely by 0–10%, indicating that low recovery rates are prevalent across fleets. A significant portion of responses were marked as "Unknown", suggesting that many fleets do not track recovery rates systematically, which could hinder sustainability efforts. Only a small number of participants reported moderate to high recovery rates, pointing to operational or logistical challenges in retrieving FADs. Improving FAD recovery is essential for reducing marine litter and promoting responsible fishing practices.

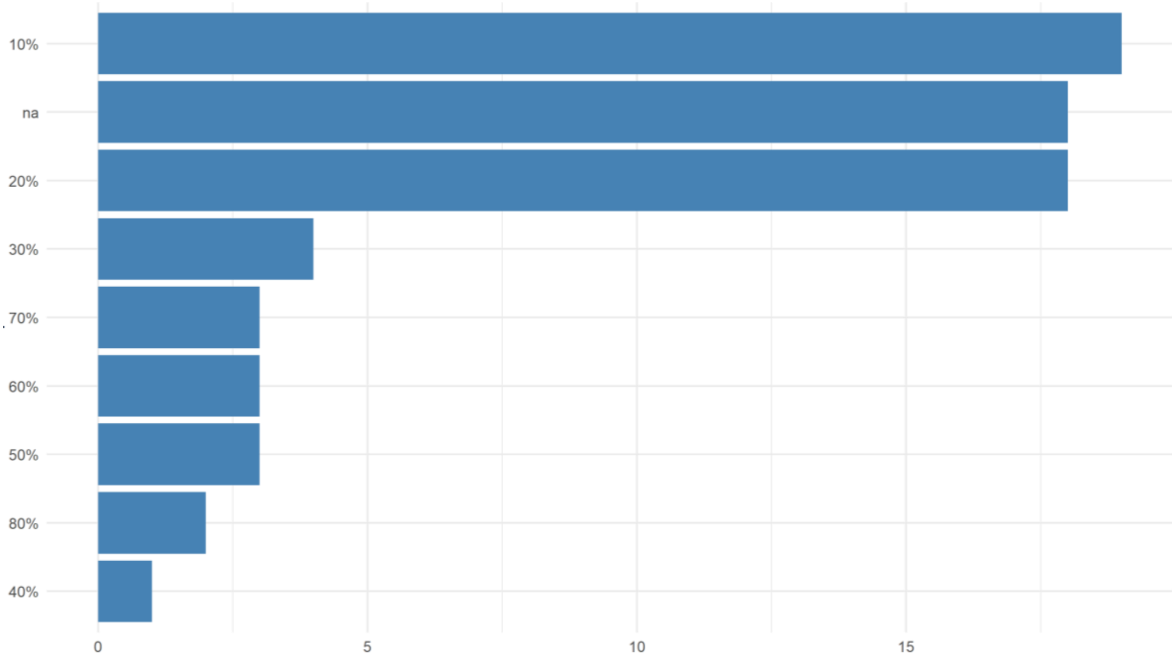


Figure 29. Percentage of FADs recovered, in terms of frequency

Question #47 asked participants about the percentage of recovered FADs that are brought to port. A total of 30 responses were recorded (Figure 30). "0–10%" – selected as main option by 18 participants (60.00%), followed by "11–30%" – 9 participants (30.00%), "31–50%", "51–70%", and "71–90%" – each selected by 1 participant (3.33%) and "91–100%" – option was not selected by any participants (0.00%). The data reveals that the majority of fleets recover only a small portion (0–10%) of their FADs to port. This suggests that most recovered FADs are not returned to land, potentially due to logistical challenges, cost, or lack of infrastructure. However, the presence of responses in higher recovery brackets indicates that some fleets have more robust systems for bringing FADs back to port. These practices may be driven by company policies, environmental commitments, or regional regulations. Increasing the percentage of FADs brought to port could significantly contribute to reducing marine litter and enhancing sustainability in tuna fisheries.

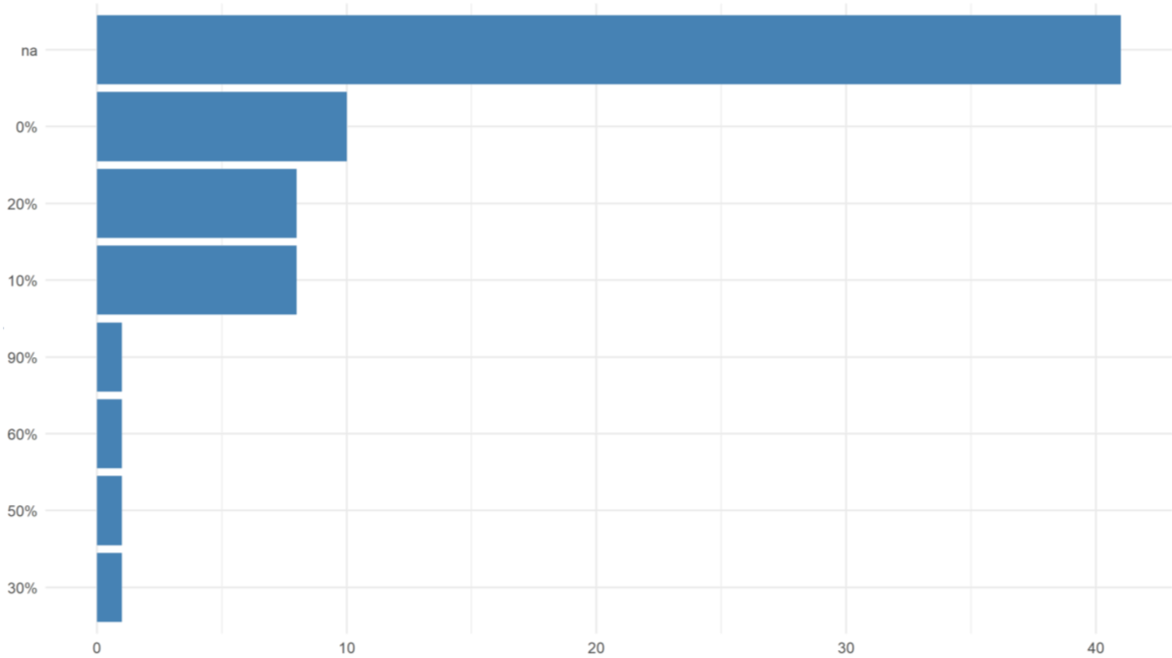


Figure 30. Percentage of recovered FADs that are brought to port, in terms of frequency

Part IV – Current practices, environmental impacts and use management.

Question #39 asked participants about the positive aspect of the FAD used (Figure 31). The most frequently mentioned positive aspect was "low environmental impact", cited in 36 responses, which represents 29.03% of all mentions. This shows a strong preference among respondents for FADs that minimize ecological harm, likely reflecting growing awareness of sustainability issues in tuna fisheries. "Sustainable materials" followed closely, with 27 mentions (21.77%), indicating that the choice of biodegradable or eco-friendly components is seen as a major benefit. "Performance" was cited 18 times (14.52%), suggesting that operational effectiveness, such as attracting fish or withstanding ocean conditions, is a key factor in FAD selection. "Long lifespan" appeared in 17 responses (13.71%), showing that durability and reliability are valued traits, likely linked to cost savings and reduced maintenance. A smaller number of responses included "low interaction with other species" (7 mentions, 5.65%), which may reflect efforts to reduce bycatch or unintended ecological effects. "Good value for money" was mentioned 6 times (4.84%), pointing to economic efficiency as another important consideration. Some responses were marked as "na" (9 mentions, 7.26%) or "others" (4 mentions, 3.23%), indicating either unclear answers or less common benefits.

The data reveals that respondents prioritize environmental sustainability, material choice, and operational performance when evaluating the FADs they use most. The prominence of “low environmental impact” and “sustainable materials” suggests that ecological concerns are increasingly influencing decision-making in FAD design and deployment. At the same time, practical aspects like performance, durability, and cost-effectiveness remain essential, reflecting the balance fleets must strike between environmental responsibility and operational efficiency. These insights point to a shift in industry values, where sustainability and functionality are no longer competing priorities but complementary goals.

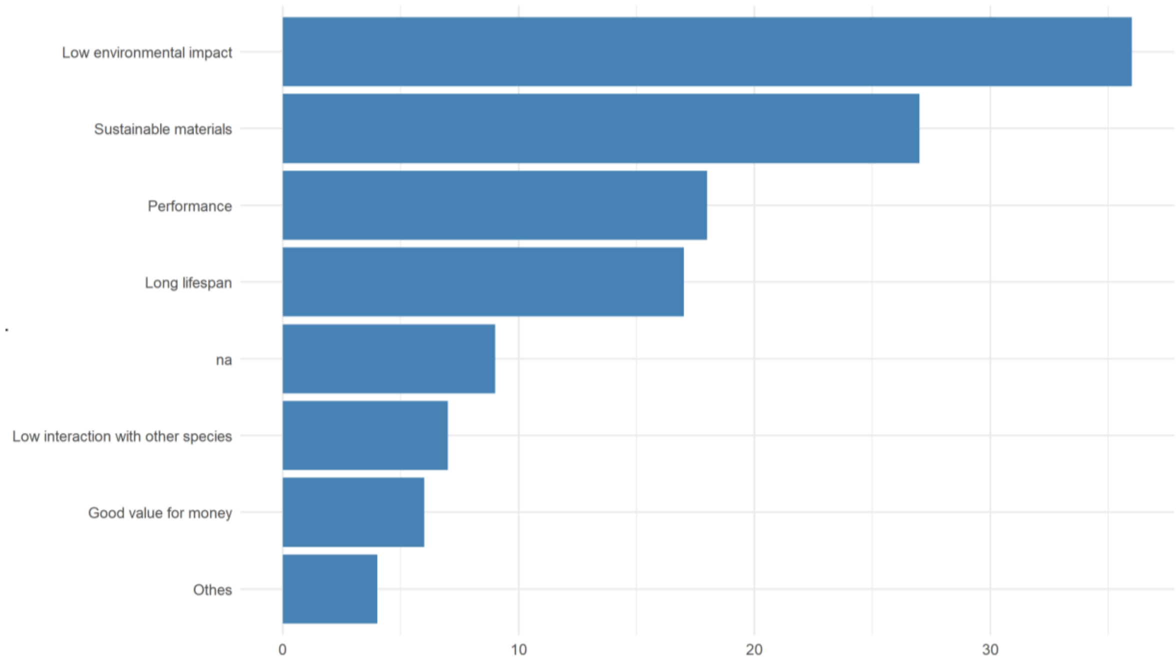


Figure 31. Positive features of the FADs in use, in terms of frequency

Question #40 asked participants about the negative aspects of the FAD type they use most (Figure 32). A total of 108 responses were recorded. The most frequently mentioned negative aspect was "short lifespan", cited 38 times, which represents 33.63% of all mentions. This indicates widespread concern about the durability of FADs, suggesting that many do not last long enough to be cost-effective. "Expensive" and "low performance" were each mentioned 17 times (15.04%), highlighting two major operational challenges: high costs and limited effectiveness in attracting or retaining target species. "Marine litter generation" appeared in 8 responses (7.08%), pointing to the environmental consequences of FADs that are lost or abandoned at sea. Three aspects, "environmental impacts (e.g.", "corals)", and "others", were each mentioned 5 times (4.42%), suggesting additional concerns about ecological damage and unspecified drawbacks. A notable portion of responses (18 mentions, 15.93%) were marked as "na", indicating either no perceived negative aspects or unclear answers.

The most frequently cited negative aspect was short lifespan, indicating that many fleets face challenges with the durability and longevity of their FADs. This could lead to increased costs, frequent replacements, and greater environmental impact. Responses such as expensive and low performance suggest that some FAD designs may not meet operational expectations or offer good value for money. These concerns may be linked to material choices, design limitations, or deployment conditions. Mentions of marine litter generation and environmental impacts highlight growing awareness of the ecological footprint of FADs, particularly in sensitive marine habitats. Overall, the data reflects a need for improved FAD designs that balance cost, performance, and sustainability, and for industry-wide efforts to address environmental concerns.

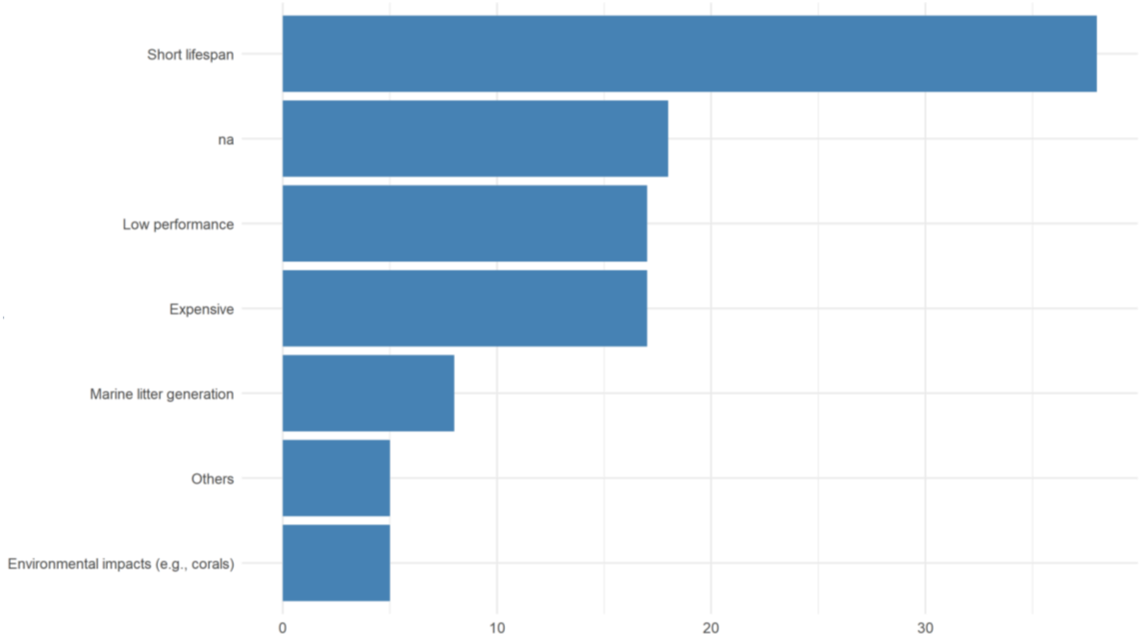


Figure 32. Negative aspects of the FAD in use, in terms of frequency

Question #44 asked participants about the impact of lost or abandoned FAD on the environment (Figure 33). The most frequently mentioned impact was the contribution to marine litter and plastics in the open ocean, cited in 36 responses, which represents 19.35% of all mentions. This highlights a major environmental concern, as lost FADs often drift for long periods, breaking down into microplastics and affecting marine ecosystems far from their origin. Closely following, contribution to marine litter and plastics in coastal areas was mentioned in 33 responses (17.74%), indicating that FADs also accumulate near shorelines, potentially harming sensitive habitats and local communities. Bad image for the fishery was cited in 32 responses (17.20%), reflecting reputational risks for the tuna industry. This suggests that stakeholders are aware of the growing scrutiny from regulators, NGOs, and consumers regarding sustainable fishing practices. Damage to coral reefs and coastal areas was mentioned in 30 responses (16.13%), pointing to the physical destruction caused when FADs run aground or entangle with reef structures. Harms the eco-certification process appeared in 28 responses (15.05%), showing that FAD loss can jeopardize compliance with sustainability standards, which are increasingly important for market access and brand value. Negative effects on tuna populations were noted in 20 responses (10.75%), suggesting concerns about ecological impacts such as increased juvenile bycatch. A small number of responses (7, or 3.76%) were marked as not applicable or unclear. The data reveals a strong awareness among respondents of the environmental, reputational, and regulatory consequences of lost or abandoned FADs. The top concerns—marine litter, habitat damage, and negative public perception—underscore the urgency of improving FAD management practices. The fact that eco-certification and tuna population impacts are also prominent suggests that fishers and companies are increasingly mindful of long-term sustainability and compliance pressures.

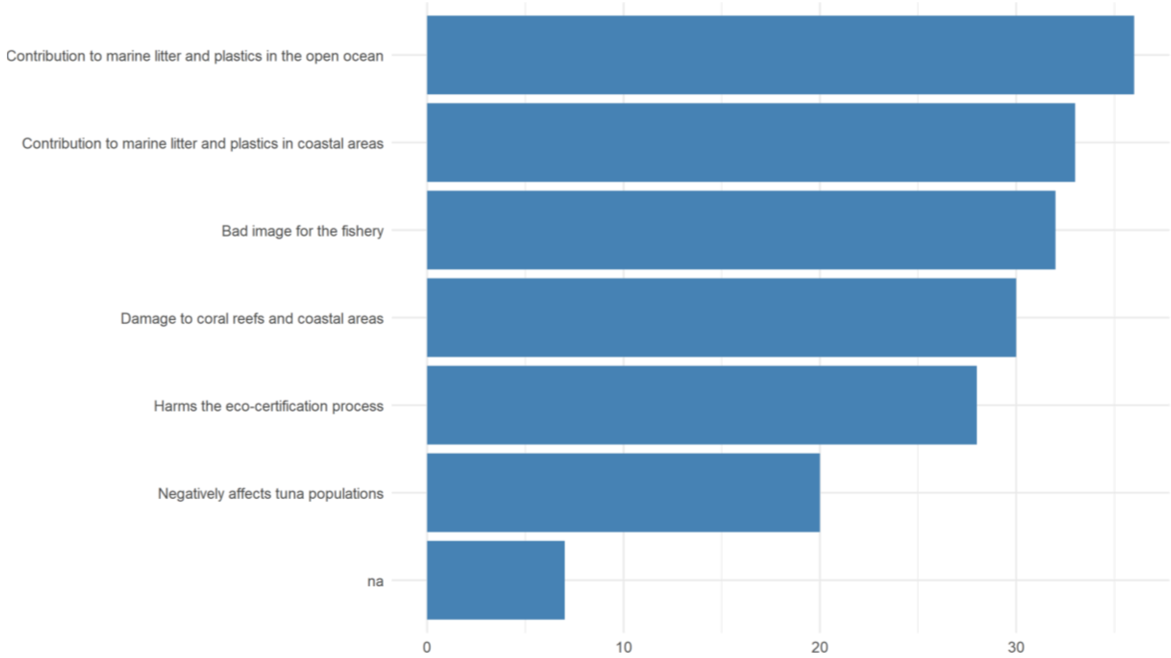


Figure 33. Potential impact of lost or abandoned FAD on the environment, in terms of frequency

Question #45 asked participants about the management options to minimize lost FAD impacts (Figure 34). The most frequently suggested management option was "Retrieve FADs at sea", mentioned in 36 responses, which accounts for 21.43% of all answers. This reflects a strong preference for proactive recovery efforts to prevent FADs from becoming marine debris. Close behind, "Switch to biodegradable FADs" was cited in 35 responses (20.83%), indicating widespread support for reducing the environmental footprint of FADs through the use of materials that degrade naturally over time. "Transfer ownership of FADs to other companies in the fleet" was mentioned in 24 responses (14.29%). This suggests a collaborative approach where responsibility for FADs can be shared or reassigned, potentially improving tracking and retrieval. "Retrieval of FADs from land" appeared in 23 responses (13.69%), highlighting the importance of collecting FADs that wash ashore or are recovered by coastal communities. Two options were tied at 10.71% each (18 responses): "Limit the number of FADs", which aligns with regulatory strategies to reduce overall FAD use and "Prevent loss at sea", which implies better deployment practices, tracking, and maintenance. A small number of responses were marked as not applicable (5.95%) or others (2.38%), indicating either unclear answers or less common suggestions.

The responses show a clear emphasis on practical and preventive measures to mitigate the environmental impact of lost FADs. The top two strategies, retrieving FADs at sea and using biodegradable materials, reflect a dual focus on active recovery and design innovation.
The mention of ownership transfer and land-based retrieval suggests that fishers recognize the value of shared responsibility and community involvement in managing FADs throughout their lifecycle. Meanwhile, support for limiting FAD numbers and preventing loss at sea points to the need for stronger operational controls and regulatory frameworks. Overall, the data indicates a growing awareness of the issue and a willingness among stakeholders to adopt diverse strategies, technological, regulatory, and cooperative, to reduce the ecological footprint of FADs. Overall, the data highlights a multi-pronged strategy combining material innovation, fleet coordination, and operational improvements to address the issue of lost FADs.

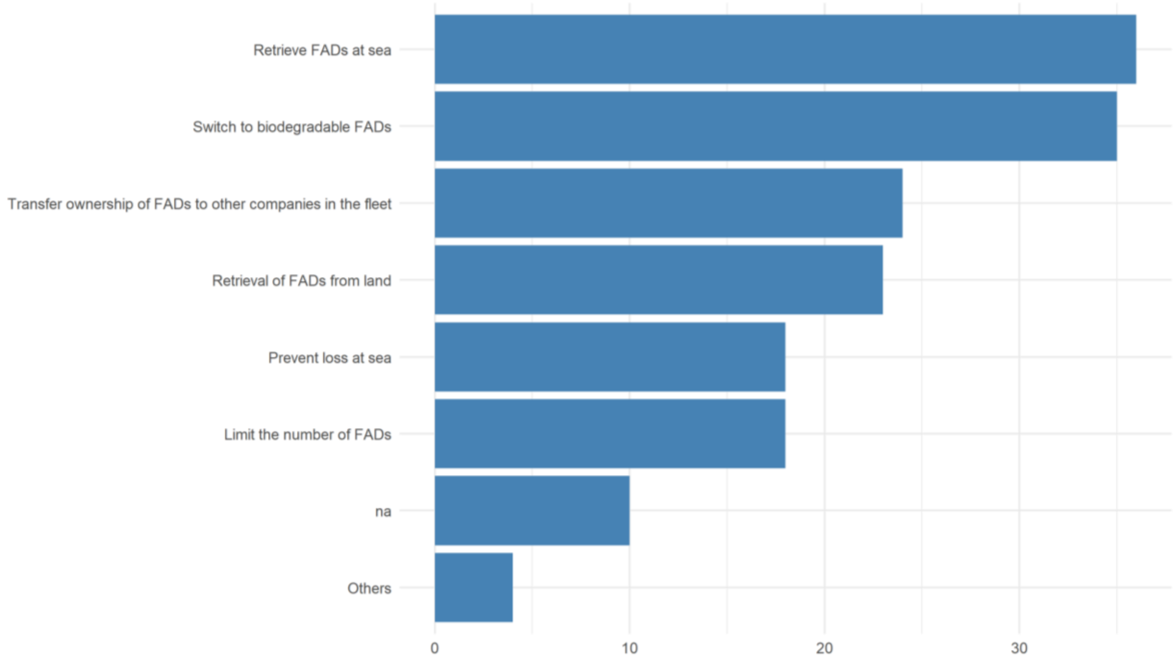


Figure 34. Management options to reduce the impact of lost FADs, in terms of frequency

2.2 Scientific biodegradable FAD trials

In recent decades, scientists have been testing natural materials and prototypes for biodegradable FADs. This approach is considered to have the lowest environmental impact, as it addresses two major issues simultaneously: ghost fishing and marine pollution. Importantly, the focus is on natural materials, excluding biodegradable materials of artificial origin (e.g., oxo-biodegradable plastics that degrade rapidly through oxidative chemical reactions). Although these synthetic biodegradable materials break down, they can still negatively affect marine ecosystems by entering the food chain.

Preventing FADs from sinking or beaching is logistically and economically unfeasible, given the vast areas involved and the difficulty of retrieving FADs that drift toward coastal zones. Therefore, the most viable solution is to design biodegradable FADs that disintegrate quickly in the ocean after their operational life ends. However, to date, few commercial fleet is known to use significant proportion of biodegradable FADs in regular fishing operations. Most FADs are still constructed using highly durable synthetic materials such as nylon nets, plastic ropes and canvas, PVC, EVA floats, metal rafts and weights. The only natural biodegradable components commonly used are bamboo rafts and, in some cases, coconut or nipa palm leaves as attractors in the FAD appendage. In some cases, organic-origin materials like cotton and abaca ropes are being incorporated into regular FAD designs.

Depending on the ocean and fleet, fishers estimate the functional lifespan of their FADs to be between 6 and 12 months (Murua et al., 2018), with only a few lasting beyond a year. In some regions, due to FAD theft or exchange, skippers may lose their FADs much sooner (e.g., in less than 3 months), although they may also gain FADs taken from other vessels.

As with non-entangling FAD trials, at the beginning of at-sea testing of biodegradable FADs were limited in scale and showed slow progress. For example, small-scale trials using bamboo rafts and sisal or jute ropes were conducted in the Indian and Atlantic Oceans (Franco et al., 2009, 2012). Due to high loss rates to other vessels, few experimental biodegradable FADs were recovered, preventing statistically significant results (Figure 35). Nevertheless, pilot trials indicated similar tuna catch yields between traditional and biodegradable FADs. The lifespan of biodegradable FADs ranged from 0 days (possibly stolen) to 227 days, with tuna colonization occurring between 1 and 54 days (Franco et al., 2012). During these studies, a scientist was present during the deployment of the biodegradable FADs but not afterward. Monitoring relied on fishers from the few participating vessels. Today, with observers (human or electronic) onboard all vessels, tracking the fate of these FADs is more feasible, although challenging. Anecdotal reports suggest that the sisal tails of some FADs may have been consumed by bycatch species such as triggerfish or rainbow runners, though no concrete evidence supports this theory.

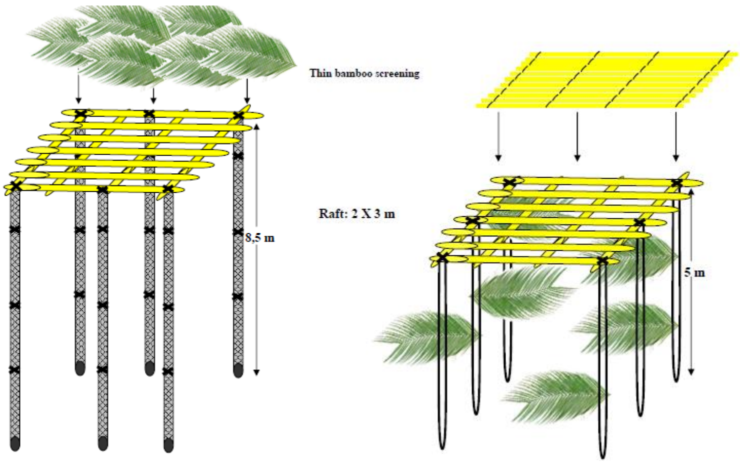


Figure 35. Initial ecological FAD prototype tested in the Indian and Atlantic oceans (Franco et al., 2009; 2012)

The Inter-American Tropical Tuna Commission (IATTC) conducted controlled trials of biodegradable FADs in Achotines Bay, Panama. Three designs were tested, all featuring a floating structure made of bamboo canes and coconut shells, with tails made of agave rope combined with (a) bamboo frames, (b) high-resistance cotton canvas, or (c) a hybrid of both. These were anchored FADs (aFADs), not drifting ones (dFADs). Due to strong swells during the experiment, the floating structures suffered significant damage, and the trials ended within three months (Marlon et al., 2022)).

Some biodegradable FAD trials have been initiated by the private sector, with companies testing them during commercial fishing operations. For instance, French vessels experimented with coconut fiber ropes and canvas for the FAD tail, but faced issues with rapid disintegration and weight gain (pers. comm. ORTHONGEL manager M. Goujon). Albacora tested six biodegradable FADs using bamboo and balsa wood for the raft and high-resistance cotton panels for the appendage. These FADs remained operational for six months, although the canvas showed significant degradation (pers. comm. fleet manager F. Velastegui). Calvo sponsored a study to evaluate the best biodegradable twine materials, cotton, sisal, and hemp, and their structural configurations (twisted, braided, bulked) for use in FAD appendages. Over five months in a controlled marine environment, twisted cotton ropes retained a breaking strength of over 1000 kgf (Lopez et al., 2019). Moreno et al. (2018) conducted a year-long trial in the Maldives, finding that mixed cotton and sisal ropes were the most durable, retaining one-third of their strength after 12 months. Other materials also tested in small-scale experiments included agave (*Furcraea mercadilla*) and abacá (*Musa textilis*) (Tunacons, 2017). Agave canvas and ropes degraded quickly, while abacá, known for its water-resistant properties, showed greater promise (Garcia et al., 2024). Bamboo-derived textile fabric is another promising material yet to be tested.

Regarding flotation materials, bamboo and balsa wood have been the main biodegradable options. Bamboo canes are widely used across three of the four oceans to construct rafts, but typically in combination with synthetic flotation aids (e.g., net corks, PVC pipes). Over time, bamboo absorbs water, gains weight, and loses buoyancy, increasing the risk of FADs sinking. Balsa wood (*Ochroma pyramidale*), one of the lightest and most buoyant woods, has shown promise in recent trials by Albacora and Tunacons in the Eastern Pacific. It is abundant and inexpensive in Ecuador, though availability and cost may vary in other regions such as the Indian Ocean or Western Pacific islands. Trials with other locally available water-resistant woods may be necessary. Additionally, natural biodegradable resins or waterproof coatings on wooden floats have been tested to help extend buoyancy.

The largest at-sea biodegradable FAD trial before 2017 was conducted in the Indian Ocean by Spanish fleet vessels under INPESCA. In this pilot study, 85 biodegradable dFADs with cotton rope tails and rafts incorporating net corks are being evaluated (Moreno et al., 2018b). The trial revealed several challenges inherent to conducting experiments under commercial fishing conditions: One major issue is the frequent exchange of dFAD ownership among vessels. As fishers routinely appropriate any productive dFAD they encounter, maintaining traceability becomes difficult. To ensure reliable data on lifespan, degradation levels, and catch performance, a significant portion of the regional fleet must participate in the trials. Otherwise, continuous changes in ownership will compromise the integrity of the data. Results from the Moreno et al. (2018b) trials indicated similar catch rates between synthetic NEFADs and biodegradable NEFADs, and lifespans of up to six months for some biodegradable dFADs.

Since 2017, several large-scale trials have been conducted to test biodegradable FADs across the world's oceans (Table 4), marking a significant shift from small, localized experiments to coordinated international efforts. Projects like BIOFAD led by AZTI in the Indian Ocean, NEFAD under IATTC in the Eastern Pacific, ECOFAD by TUNACONS, JellyFADs led by ISSF and SPC, and FADBIO by AZTI and OPAGAC in the Atlantic have collectively deployed thousands of biodegradable FADs using natural materials such as bamboo, cotton, abacá, balsa wood, and marine biodegradable polymers. These trials have demonstrated that biodegradable FADs can match conventional ones in terms of tuna aggregation and catch performance, with lifespans ranging from several weeks to over 11 months.

However, scaling up these initiatives has revealed several challenges. One major issue is traceability, as FADs frequently change ownership among vessels, complicating data collection on degradation, lifespan, and catch rates. Additionally, material durability, buoyancy, and visibility remain technical hurdles, especially in rough sea conditions. Despite these obstacles, the benefits of transitioning to biodegradable FADs are clear: reduced marine pollution, minimized ghost fishing, and alignment with sustainability goals set by RFMOs and industry stakeholders.

Moving from small-scale trials to large-scale implementation, and ultimately to global adoption, requires coordinated efforts across fleets, regions, and regulatory bodies. It also demands innovation in material science, standardized monitoring protocols, and incentives for fleets to adopt eco-friendly designs. The success of these pioneering projects provides a strong foundation for broader deployment, signaling a promising future for sustainable tuna fisheries worldwide

2.2.1 Details of biodegradable FAD trials

EU Project BIOFAD Project – Indian Ocean (2017–2019) (Source: Murua et al., 2023)

- **Region**: Indian Ocean
- **Period**: 2018–2019
- **Biodegradable FADs Deployed**: 771
- **Design**: Prototypes A1, A2, B1, B2, C1 (Figure 36)
- **Materials**: Cotton (ropes and canvas), bamboo
- **Results**:
  - Maximum lifespan: 483 days.
  - Cotton canvas degraded quickly; cotton rope was more resilient.
  - Fishing performance comparable to conventional FADs.
  - Key outputs:
    - Tuna aggregation and catch rates comparable to conventional FADs
    - Significant reduction in synthetic material use
    - Demonstrated feasibility of biodegradable FADs under commercial fishing conditions

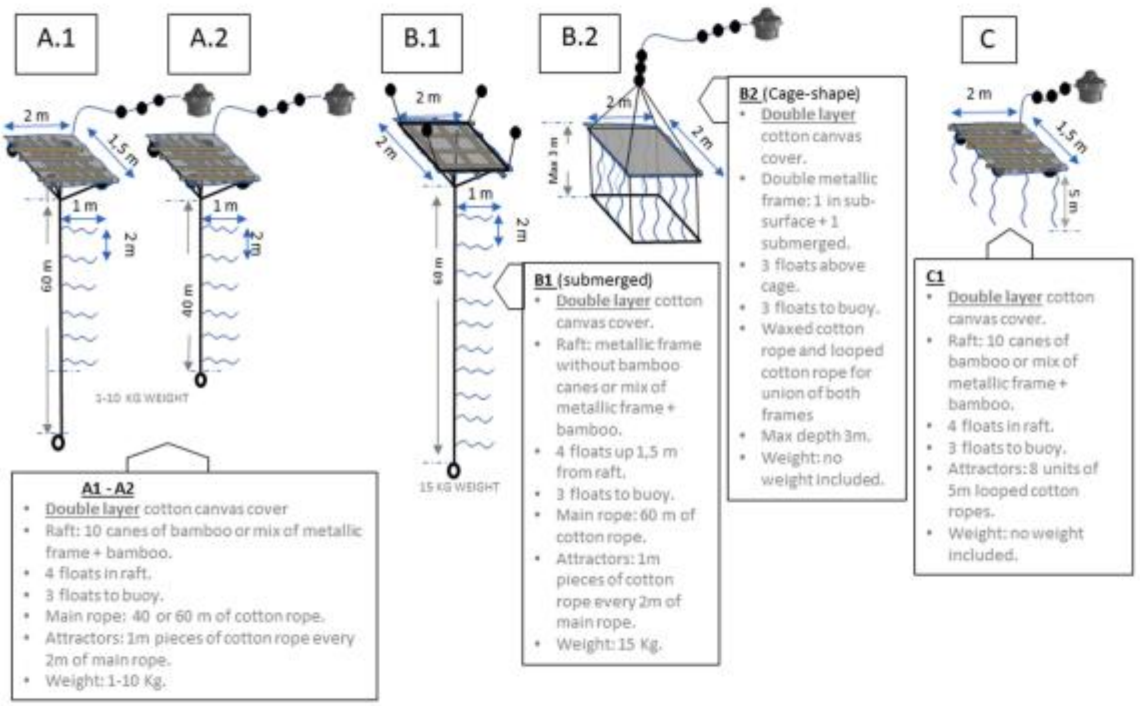


Figure 36. BIOFAD models of BIOFAD project

CIAT/IATTC – NED FADs Project (Roman et al., 2022; Ovando et al., 2025)

- **Region**: Eastern Pacific Ocean
- **Year**: 2023
- **FADs Deployed**: 780 biodegradable NEDs + 764 control FADs
- **Materials**: Cotton canvas, natural fiber ropes
- **Design**: Non-entangling and degradable (NED) prototypes (Figure 37)
- **Estimated Degradation**: ~4 months (average)
- **Objective**: Evaluate performance, drift, and biomass aggregation of biodegradable FADs compared to conventional ones.

CIAT/IATTC: launched a large-scale experiment in 2023 in the Eastern Pacific Ocean, deploying 780 biodegradable FADs alongside 764 conventional control units. The biodegradable prototypes, known as NEDs (Non-Entangling and Degradable), were made from cotton canvas and natural fiber ropes. These materials had an average degradation time of around 4 months. The study focused on comparing drift patterns, biomass aggregation, and durability between biodegradable and traditional FADs.

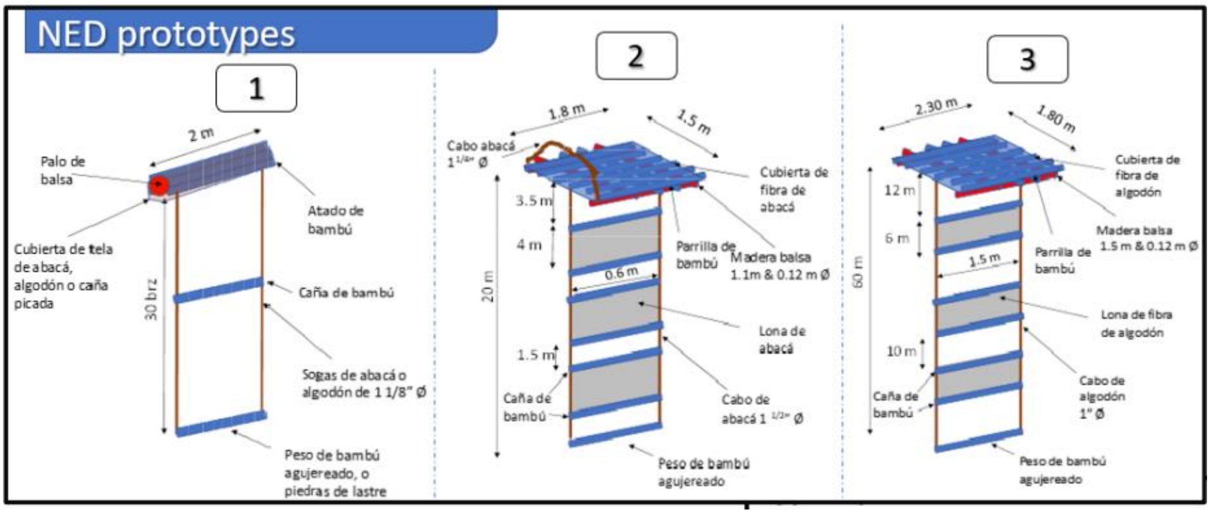


Figure 37. BIOFAD models of NED FADs project

TUNACONS – ECOfads Program (Source: Garcia et al., 2025)

- **Region**: Eastern Pacific Ocean
- **Years**: 2021–2025
- **FADs Deployed**: Over 5,000
- **Materials**: Abacá, guadua, balsa wood, organic rubber, cabuya, jute
- **Design**: ECOfads, 100% biodegradable and non-entangling (Figure 38)
- **Estimated Degradation**:
  - Jute: ~30 days
  - Cabuya: ~40 days
  - Wood and fiber components: 3–5 months
- **Objective**: Promote sustainable tuna fishing practices and reduce plastic pollution in tropical tuna fisheries.

TUNACONS, operating in the Eastern Pacific Ocean from 2021 to 2025, developed and deployed over 5,000 ECOfads made entirely from biodegradable materials. These included abacá, guadua, balsa wood, organic rubber, cabuya, and jute. The degradation time varied by material: jute degraded in approximately 30 days, cabuya in 40 days, and wood-based components in 3 to 5 months. The initiative aimed to support sustainable tuna fishing and reduce plastic pollution in tropical fisheries.

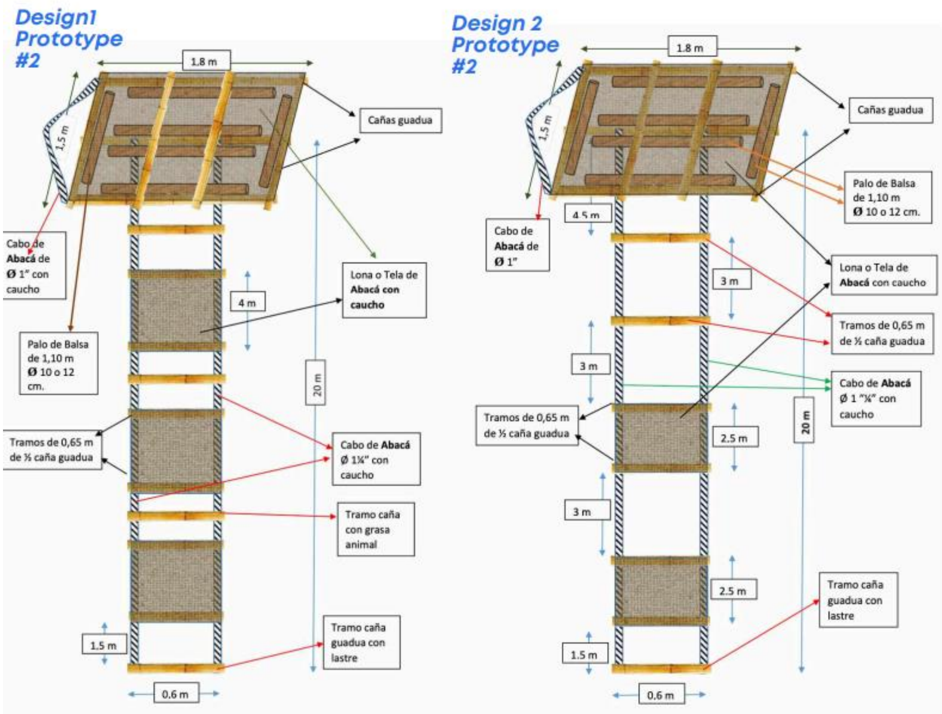
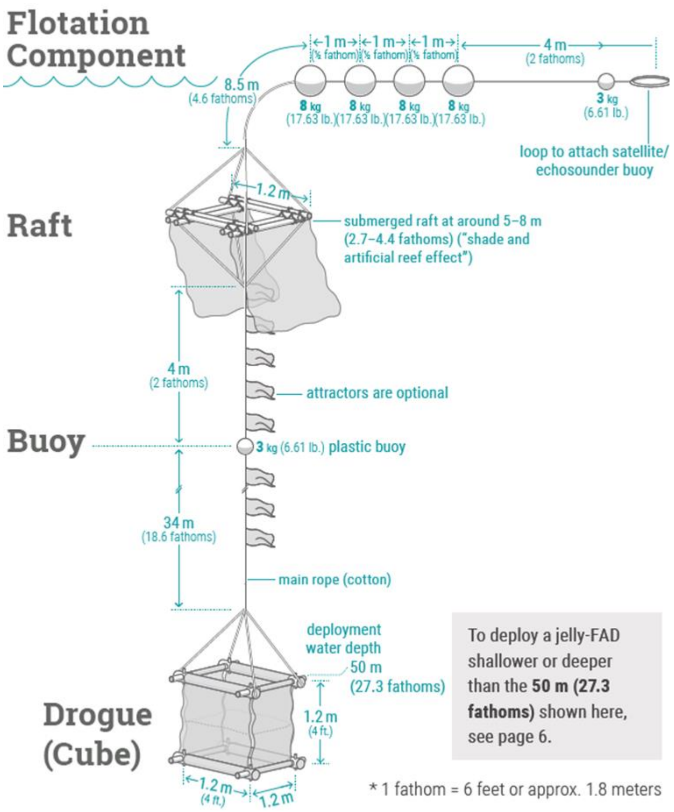


Figure 38. BIOFAD models of ECOfads program

ISSF – Jelly-FAD development and Trials (Moreno et al., 2023)

- **Region:** Western and Central Pacific Ocean & Atlantic Ocean
- **Years:** 2020–2025
- **FADs Deployed:**
    - UGAVI: >2000 JellyFADs deployed (36 monitored in trials)
    - PEVASA: 78 JellyFADs deployed
    - GHANA fleets: 127 JellyFADs deployed (Types A and B)
    - CFC: 96 JellyFADs deployed (Types A and B)
- **Materials:** Bamboo (structural frame), cotton canvas and ropes, jute, clay, Lyocell (30%) for enhanced biodegradability.
- **Design:** Modular JellyFAD configurations (cubic and cylindrical), adapted to regional conditions (Figure 39).
- **Estimated Degradation:** Average lifespan ranged from 155 to 215 days, with some units exceeding 300 days of buoy transmission.

ISSF conducted trials with Jelly-FADs in the Eastern, Western and Central Pacific Ocean and Atlantic Ocean from 2020 to 2025 (). ISSF trials with multiple fleets have demonstrated the operational feasibility of JellyFAD prototypes and strong engagement from the industry. These devices, constructed primarily from bamboo for structural integrity and cotton-based components for flexibility, have shown adequate durability under commercial fishing conditions, with bamboo elements maintaining functionality for extended periods and cotton degrading progressively as intended. Published results indicate that JellyFADs can sustain tuna aggregation effectively, with catch performance comparable to conventional FADs in several trials. While variability exists across regions and designs, the evidence supports JellyFAD as a promising biodegradable alternative that reduces the risk of marine litter and ghost fishing without compromising fishing efficiency.



39. BIOFAD models of JellyFAD trials by ISSF

SPC (Pacific Community) – Jelly-FAD Trials (Escalle et al., 2025)

- **Region**: Western and Central Pacific Ocean
- **Year**: 2022–2025
- **FADs Deployed**: 296 deployed (500 constructed)
- **Materials**: Bamboo, cotton canvas and rope, Lyocell (30%), jute, clay.
- **Design**: Cubic and cylindrical JellyFADs (Figure 40)
- **Estimated Degradation**: 269 days. 50% still transmitting after 300 days.
- **Objective**: Reduce environmental impact and ghost fishing by testing fully biodegradable components.

SPC (Pacific Community) conducted trials with Jelly-FADs in the Western and Central Pacific Ocean in 2023. These FADs were constructed using bamboo, cotton, jute, sand, and clay, designed to mimic jellyfish with neutral buoyancy. Out of 100 units built, 8 were initially deployed. The estimated degradation time for these materials ranged between 9 and 12 months. The goal was to reduce ghost fishing and marine litter while maintaining aggregation efficiency.

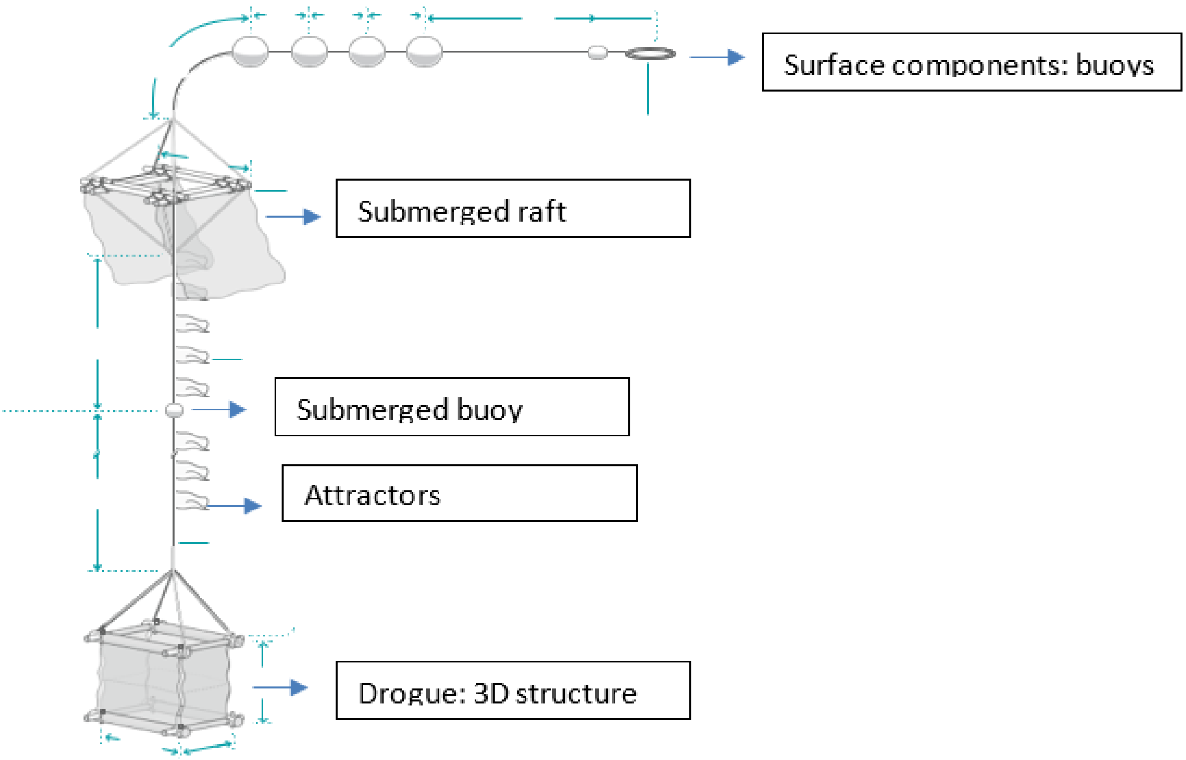


Figure 40. BIOFAD models of JellyFAD trials by SPC

OPAGAC & AZTI – Bio-FAD Initiative

- **Regions**: Indian, Atlantic, and Pacific Oceans
- **Years**: 2016–2023
- **FADs Deployed**: ~1,000
- **Materials**: Wood, bamboo, cotton, jute
- **Design**: Bio-FADs adapted to industrial tuna fleets (Figure 41)
- **Estimated Degradation**: ~18 months
- **Objective**: Lead global R&D in biodegradable FADs and reduce marine litter from industrial tuna fishing.

OPAGAC, in collaboration with AZTI and ISSF, has been testing Bio-FADs since 2016 across the Indian, Atlantic, and Pacific Oceans. These devices incorporated wood, bamboo, cotton, and jute, with an estimated degradation time of up to 18 months. Approximately 1,000 units have been deployed. The project aimed to lead global research and development efforts in biodegradable FADs for industrial tuna fleets.

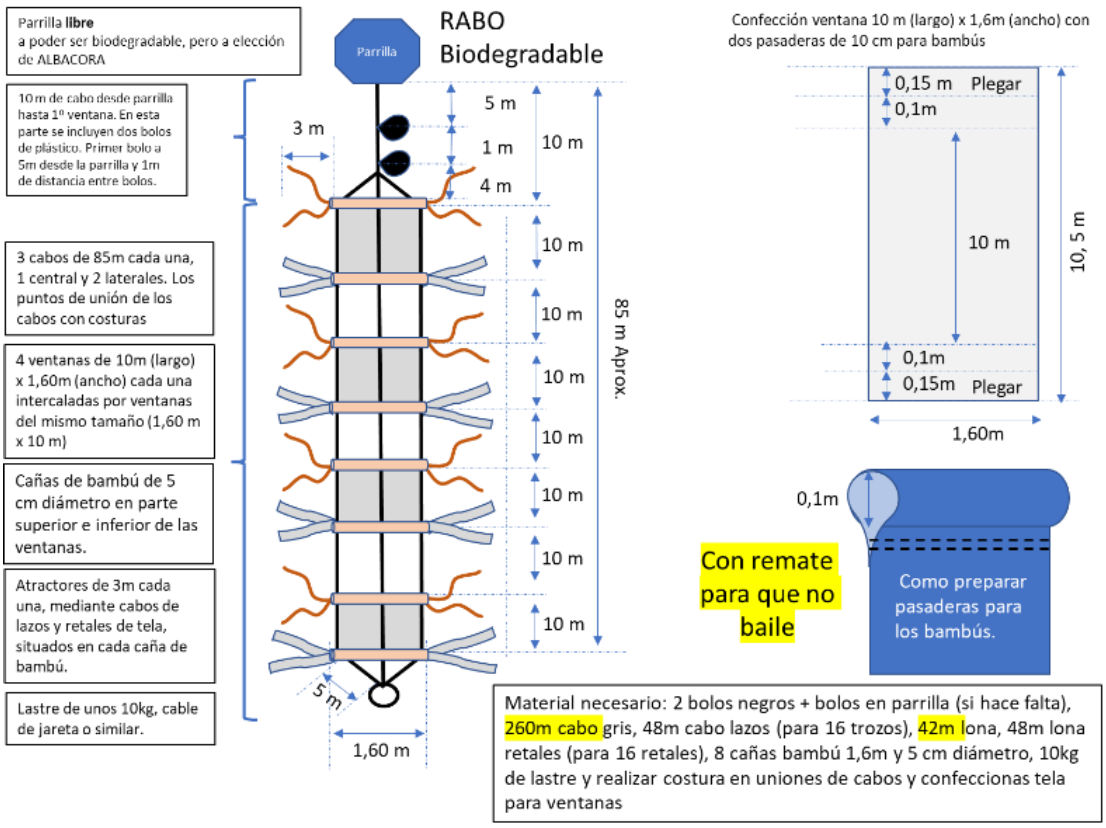


Figure 41. BIOFAD models of Bio-FAD initiative

Zunibal – Industrial Compostable FADs (Zudaire et al., 2024)

- **Regions**: Atlantic and Indian Oceans
- **Years**: 2024–2025
- **FADs Deployed**: 210
- **Materials**: PBS (Polybutylene succinate) derived from sugarcane, cassava, and corn
- **Design**: Industrial FADs certified under ISO 19679 for marine biodegradability (Figure 42)
- **Estimated Degradation**: ~12 months
- **Objective**: Develop scalable, certified biodegradable FADs for commercial use.

Zunibal, together with AZTI, developed industrially compostable FADs using PBS (polybutylene succinate), a polymer derived from sugarcane, cassava, and corn. These FADs were certified under ISO 19679 for marine biodegradability and have been deployed in the Atlantic and Indian Oceans since 2024. A total of 210 units were deployed, with an expected degradation time of around 12 months. The objective was to create scalable, certified biodegradable FADs suitable for commercial fishing operations.

Figure 42. BIOFAD models of industrial compostable FADs by Zunibal

Table 4. Summary of projects that have works with BIOFADs

Project	Region	Number of Biodegradable FADs Deployed	Designs Tested	Materials Used	Results: Lifespan and Material Condition
ECOFADs – TUNACONS	Eastern Pacific	Over 2,000 (2021–2023)	Prototype #2	Abaca (ropes and textile), bamboo, balsa wood, sand, natural latex	Average lifespan: 90 days in good condition, up to 120 days in regular condition. 48% rated as 'very good'. Abaca showed good resistance, especially with latex treatment.
JellyFAD – Ugavi Fleet	Eastern Pacific	95 JellyFADs (out of 2,000 total)	Cubic JellyFAD (Cat II and IV)	Bamboo, cotton canvas, cotton/polyethylene rope, recycled cork, plastic buoys	Maximum lifespan: 335 days. 11% successfully redeployed. Better performance with cotton rope.
JellyFAD – WCPFC Projects 110 & 110a	Western & Central Pacific	296 deployed (500 built)	Cubic and cylindrical JellyFADs	Bamboo, cotton canvas and rope, Lyocell (30%), jute	Average lifespan: 269 days. 50% still transmitting after 300 days. Lyocell rope showed high resistance (5,500 kgf).
BIOFAD – Indian Ocean	Indian Ocean	771 BIOFADs	Prototypes A1, A2, B1, B2, C1	Cotton (ropes and canvas), bamboo	Maximum lifespan: 483 days. Cotton canvas degraded quickly; cotton rope more resistant.
JellyFAD – Atlantic	Atlantic Ocean	188 JellyFADs	Revised JellyFAD	Cotton (ropes and canvas), bamboo, cork	Average lifespan: 96 days. Maximum: 340 days. High degradation observed from first month.
Atlantic – Traditional Model	Atlantic Ocean	25 biodegradable FADs	Atlantic-type model	Cotton, bamboo, canvas	Average lifespan: 66 days. Maximum: 124 days. High degradation in submerged components.
ZUNFLOAT BIO	Atlantic and Indian Ocean	210 deployed platforms	---	PBS (bio-based material)	Under research
NEDs (IATTC)	Eastern Pacific Ocean	780 biodegradable NEDs	Three types of window-shaped FAD	Cotton canvas, natural fiber ropes	These materials had an average degradation time of around 4 months. The study focused on comparing drift patterns, biomass aggregation, and durability between biodegradable and traditional FADs.

2.2.2 Feedback from Task 3.1

Tables 5-9 synthesize the results obtained in task 3.2 from large-scale trials conducted across the Indian, Atlantic, and Pacific Oceans, comparing biodegradable prototypes, such as Model A1 and JellyFAD variants, with conventional FADs. These findings highlight the technical feasibility, environmental benefits, and remaining challenges associated with transitioning toward fully biodegradable FAD solutions.

Table 5. Summary of the outputs from drift behaviour assessment. Comparison between biodegradable and conventional FADs.

DRIFT BEHAVIOR:	
BIOFAD	Model A1 recorded a mean drift speed of 0.91 knots (range: 0.01–4.00 knots) across 144 observations, confirming stable performance under operational conditions. JellyFAD prototypes achieved even lower drift speed differences, with a weighted mean of 0.61 knots (range: 0.01–9.90 knots), making them highly suitable for tuna aggregation and minimizing beaching risk.
Conventional FAD	Conventional designs showed similar drift characteristics, averaging 0.81 knots (range: 0.01–11.9 knots). No systematic difference was observed between biodegradable and conventional categories, indicating that material composition does not compromise drift performance.
OPTIMUM PROTOTYPE	JellyFAD stands out as the best-performing design for drift behaviour, combining low drift speed variability with operational stability across multiple ocean basins.

Table 6. Summary of the outputs from catch performance assessment. Comparison between biodegradable and conventional FADs.

CATCH PERFORMANCE:	
BIOFAD	Model A1 achieved an average catch of 32.3 kg per set (max 150 kg), while A2 reached 61.0 kg (max 75 kg). JellyFAD prototypes demonstrated competitive results: SPC trials reported a mean of 47.9 kg per set and a maximum of 185 kg, confirming their ability to sustain aggregation and deliver efficient catches.
Conventional FAD	Conventional counterparts showed slightly higher averages in some cases, such as A2 (96.7 kg per set, max 225 kg). However, JellyFAD performance was comparable and, in some trials, exceeded conventional designs.
OPTIMUM PROTOTYPE	JellyFAD offers the most balanced performance, achieving high catches in diverse oceanic conditions while maintaining biodegradable integrity.

Table 7. Summary of the outputs from lifespan assessment. Comparison between biodegradable and conventional FADs.

LIFESPAN:	
BIOFAD	Model A1 recorded a mean lifespan of 102 days (max 612 days), reflecting early-generation design limitations. JellyFAD prototypes significantly outperformed this, with an average of 215 days and a maximum of 717 days, confirming their suitability for extended deployments.
Conventional FAD	Conventional designs averaged 188 days, with a maximum of 717 days, slightly below the best-performing JellyFAD prototypes.
OPTIMUM PROTOTYPE	JellyFAD is the clear leader in lifespan, combining extended durability with environmental benefits, making it the most viable candidate for large-scale adoption.

Table 8. Summary of the outputs from tuna aggregation assessment. Comparison between biodegradable and conventional FADs.

TUNA AGGREGATION:	
BIOFAD	Mean biomass around BIOFADs was 11.6 tonnes, with extreme aggregation events reaching 466 tonnes. Colonization occurred earlier compared to conventional FADs, with biomass peaks within two months post-deployment.
Conventional FAD	Conventional designs showed slightly higher mean biomass (15.1 tonnes) and q90 values (99.2 tonnes), but aggregation dynamics were slower, with peaks occurring after 100 days.
OPTIMUM PROTOTYPE	JellyFAD demonstrates faster aggregation and sustained performance, making it operationally competitive despite marginal differences in peak biomass.

Table 9. Summary of the outputs from material degradation assessment. Comparison between biodegradable and conventional FADs.

MATERIAL DEGRADATION:	
BIOFAD	Bamboo-based structures (raft and drag frames) maintained GOOD condition for extended periods, confirming high resilience. Model A1 showed strong structural integrity in bamboo components but cotton-based elements degraded rapidly. Tail ropes exhibited BAD and NEEDS REPAIR states within the first year, while canvases (raft and drag) became ABSENT from month 3 onward. JellyFAD variants followed similar patterns, with bamboo performing well and cotton canvases failing early.
Conventional FAD	Plastic-based components in conventional FADs remain intact for years, contributing to persistent marine litter.
OPTIMUM PROTOTYPE	JellyFAD, with modular bamboo structure and optimized cotton use, represents the best-performing biodegradable design. Future improvements should focus on replacing cotton canvases with more durable biodegradable alternatives.

3. Searching of suitable materials

3.1 Field trip

As part of ongoing efforts to promote more sustainable fishing practices using FADs, a state-of-the-art review of biodegradable FAD materials and designs has been conducted, focused on recent technological advances and innovation in biodegradable materials. Suitable materials for BIOFAD construction have been defined, and their availability has been assessed across several regions where tuna purse seiners operate.

This sub-task focuses on identifying suppliers for biodegradable materials and FAD construction for the construction of new BIOFAD designs. To ensure a steady supply of these materials for the fleet operating across the three oceans, an assessment of potential suppliers in Asia, South America, and Europe has been conducted. This task provides a list of biodegradable material manufacturers and distributors including contact details and website for further information on the supplier from key regions such as China, Taiwan, the Philippines, Ecuador, Colombia, Spain, and American Samoa (Table 10).

The materials offered range from natural fibre ropes (sisal, jute, fique, and cotton) to balsa wood, cotton and manila hemp canvas, as well as fully assembled biodegradable FADs (examples provided in Figure 43 and Table 11). By making this essential information accessible, SEARCULAR aims to support scientists working on BIOFAD trials and assist fishing companies in transitioning to biodegradable materials for FAD construction. This initiative contributes to reducing the environmental impact of purse seine fishing and promotes the adoption of more sustainable solutions within the fishing industry. Images of products shared by certain companies are included, while product information for other companies can be found on their respective websites.

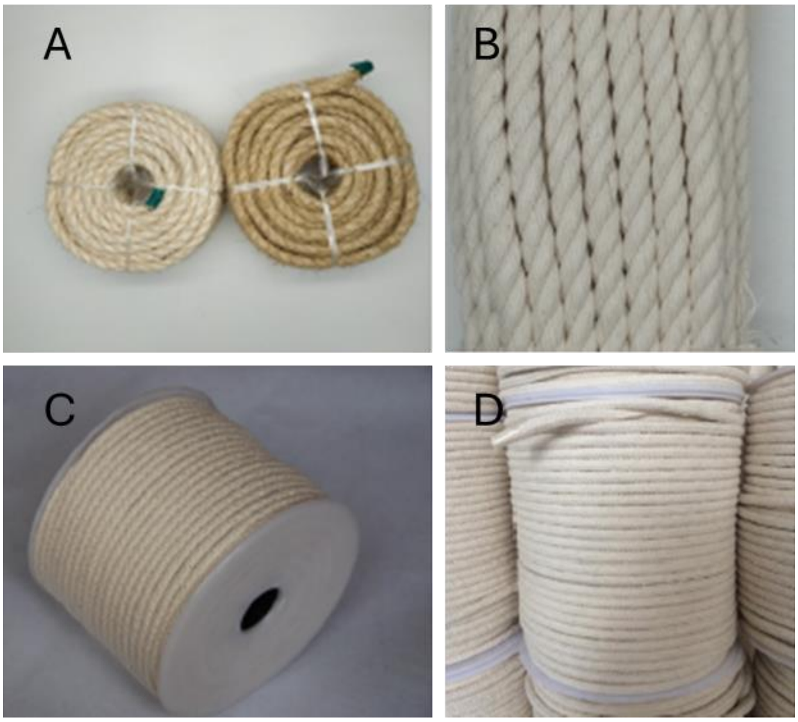
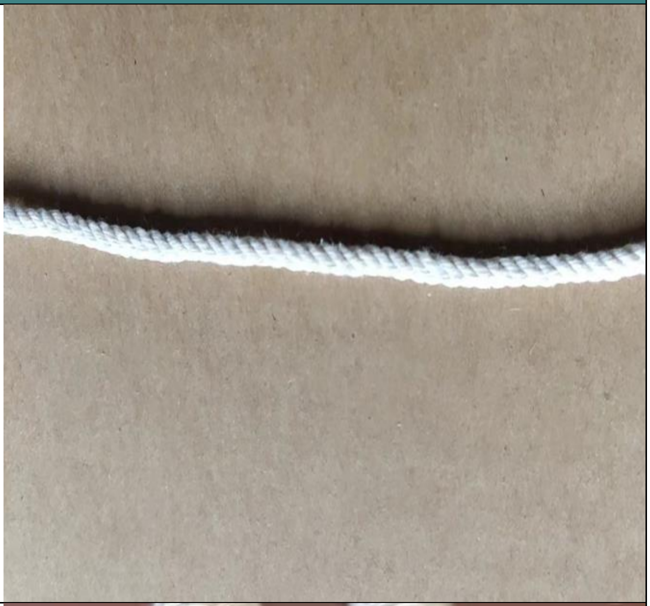
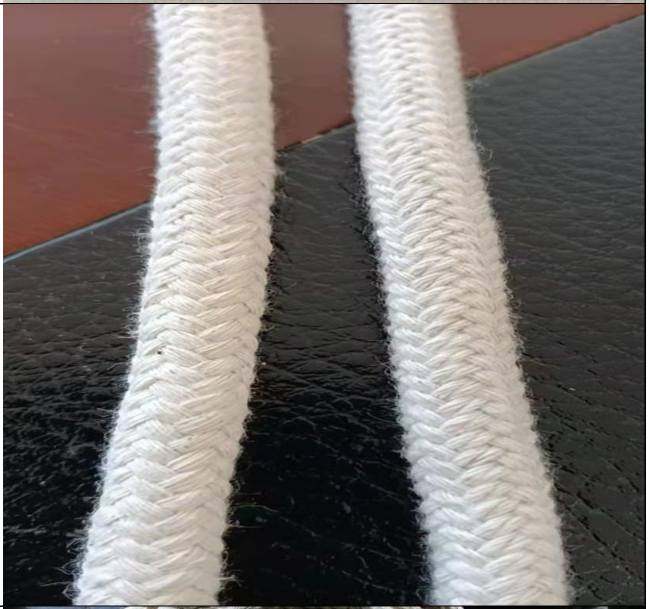


Figure 43. Examples of the materials made with organic fibres in China. A) Sisal and jute twisted ropes, B) Twisted cotton rope, and C-D) Braided cotton ropes.

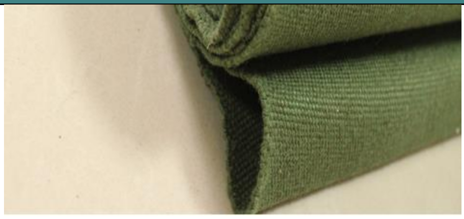
Table 10. Details from manufacturers

Country	Company name	Products	Contact name	email	Website	Phone
Shandong, China	Shandong Baron New Materials Co.Ltd	Ropes (Sisal, jute and cotton twisted and braided ropes)	Linda Hu	ropemaker@sdbaron.cn	www.baronrope.com www.sdbaron.cn	+86 538 6132138 +18653860609
Shandong, China	Shandong Haoyuntong Netting Technology Co., Ltd	Ropes and canvas	Cheng	c-zhou@shou.edu.cn	-	-
Zhengzhou Henan, China	Zhengzhou Zhongyuan Defense Materials Co., Ltd.,	Producer of raw quemical and organic materials	Cheng	c-zhou@shou.edu.cn	-	-
Manila, Phllipines	Nettex/Fortune Net	Ropes	Mel Morales	melmorales_728@yahoo.com export_fntgrp@yahoo.com	-	+63287125362 | +63287119238
PingTung, Taiwan	Ching Fa Fishing implements Factory CO., LTD	Ropes	Mr. Yang Hsu	export7@chingfa.com.tw	www.chingfa.com.tw	+886 8 833 1100
Guayaquil, Ecuador	BALSASUD S.A.	Balsa wood	Giancarlo Del Cioppo	gdc@corelitecomposites.com	www.corelitecomposites.com	+593 4 2380265 / +593 4 2881477; planta +593 4 2267007 / 2267008.
Sto Domingo de los Tsáchilas, Ecuador	BALCOMAD S.A.	Balsa wood	-	info@balcomad.com.ec	https://balcomad.com.ec/	+593 (02) 362-1887
Guayaquil, Ecuador	Tunacons	FAD manufacturers	Jazmín Bastidas	jbastidas@tunacons.org	https://www.tunacons.org/ecofads-orders/	+593998374057
Manta, Ecuador	Pronaval	FAD manufacturer and Ropes supplier	Iñaki Ostiz	iostiz@pronaval.es	www.pronaval.es	+593 97 929 7831/+34 686 224 668
Medellin, Colombia	Grupo Excala	Fique Ropes and canvas	-	info@grupoexcala.com	https://grupoexcala.com	+57(604)365 8888
Markina, Spain	Itsaskorda, S.L.	Organic Ropes	Jose Mari	itsaskorda@itsaskorda.es	https://www.itsaskorda.es	+34 94 6169408
A Pobra do Caramiñal, Spain	America Aparejos	FAD manufacturer	América	america@lopezvilar.es	https://lopezvilar.es	+34981870758
American Samoa, U.S.	Purse seine Samoa	FAD manufacturer	Frank Barron	franklbarron@gmail.com		+1(684)258 4067
Japan	Nichimo	Bio-based Rope and canvas	Akito Ishida	akito_ishida@nichimo.co.jp	https://www.nichimo.co.jp/english/	+03-3458-4020/ Mobile 070-4487-7758
Valencia, Spain	iPawlonia	Pawlonia wood	Jol Del Hierro	Joldhg@gmail.com	-	+34 693 62 69 26

Table 11. Details of materials made with natural fibres – Products from Shandong Haoyuntong Nettling Technology Co., Ltd

Type of materi al	Diame-ter	Structural property	Brea-king strengt h	Photo
twisted cotton rope	20 mm	Z-twisted cotton rope with 4 strands, but without core; naturel color-white	1400 kgf	
braided cotton rope	20 mm	braided strands; naturel color-white	1400 kgf	
twisted sisal rope	20 mm	Z-twisted sisal rope with 3 strands, without core; color-brown	to be mea-sured	

Type of material	Diameter	Structural property	Breaking strength	Photo
Other type of natural ropes with breaking strength around 1050 kgf	16 mm	Z-twisted cotton rope with 3 strands		
	10 mm	Z-twisted cotton rope with 3 strands		
	16 mm	Z-twisted sisal rope with 3 strands		

Type of material	Diameter	Structural property	Breaking strength	Photo
Cotton canvas		300-400 grams per square meter (GSM); color-green	/	 
mussel rope		There are a large number of used mussel farming ropes near the coast of China. They can be found everywhere onshore		

3.2 New material testing

As part of the SEARCULAR project's commitment to advancing the eco-design of BIOFADs (biodegradable FADs), a key objective has been the identification and validation of new, sustainable materials capable of replacing conventional plastic and metallic components. Particular emphasis has been placed on sourcing organic alternatives for two critical FAD elements: the flotation system and the structural frame, which are traditionally composed of synthetic polymers and metal, respectively. These components are among the most persistent contributors to marine litter when FADs are lost or abandoned at sea.

In this context, laboratory studies conducted by the International Seafood Sustainability Foundation (ISSF) (Figure 44) have yielded promising results for the use of Paulownia wood as a potential substitute for plastic-based flotation elements. Paulownia demonstrated excellent hydrophobic properties, with minimal seawater absorption, which translates into stable buoyancy over time. Specifically, the buoyancy of Paulownia saturated in seawater was measured at 0.84 kg of lift per kilogram of dry weight (Table 9), indicating its suitability for maintaining the necessary flotation performance in marine environments.

For this research, eight Paulownia wood logs were used. The eight logs were tested in a seawater tank in the facilities of the Instituto de Ciencias del Mar in Barcelona, Spain. They were submerged in the seawater tank using a 4.3 kg iron chain, in January 29, 2024. The aim was to track the weight variation of Paulownia logs over an 80-day period. These logs gradually absorbed seawater, leading to alterations in density and buoyancy. After 80 days submerged in seawater, the weight of the wood piece was 1.6 kg. This indicates that buoyancy only decreased by 0.8 kg, leaving a residual buoyancy for a 3.2 kg log at 2.7 kg. In Table 12, assuming buoyancy is associated with weight, we can infer:

- 1 kg of dry Paulownia wood floats 1.1 kg
- 1 kg of Paulownia wood saturated in water floats 0.84 kg

Figure 44. Evaluation of the buoyancy of Paulownia wood in the laboratory. Testing period of 80 days.

These findings suggest that Paulownia wood has minimal absorption of seawater, resulting in minimal variation in flotation. This observation positions Paulownia wood as a promising alternative to the current plastic buoys utilized in tuna fishery. However, it is crucial to conduct a thorough assessment of buoyancy requirements tailored to specific FAD designs and weights to ensure optimal performance of the FAD over the course of a year. Drawing from the results of this experiment, we suggest considering the buoyancy of Paulownia as 0.84 kg per kilogram of dry weight. Finally, further research is needed to determine whether cultivating and harvesting Paulownia wood is sustainable. This is crucial because large quantities will be required to supply the numerous fleets fishing with FADs.

Table 12. Evaluation of the buoyancy of Paulownia wood in the laboratory. Testing period of 80 days.

Id	Dry Weight (kg)	Initial Buoyancy (kg)	Final Buoyancy (kg)
1	3.2	3.5	2.7
2	3.3	3.6	2.8
3	2.8	3.1	2.4
4	2.5	2.7	2.1
5	2.4	2.6	2.0
6	2.3	2.5	1.9
7	3.2	3.5	2.7
8	3.5	3.8	2.9

Despite these encouraging results, the long-term sustainability of sourcing Paulownia wood, particularly regarding the ecological impact of cultivating and harvesting, requires further investigation. Comprehensive assessments of supply chain sustainability, growth rates, and regional availability are essential before Paulownia can be fully endorsed as a viable and scalable alternative to plastic flotation components in BIOFAD construction.

3.3 Feedback from Task 3.3 (semi-controlled sea test)

As part of the SEARCULAR project's eco-design process, semi-controlled field trials were conducted in the Mediterranean Sea to evaluate the performance of new biodegradable materials and structural configurations for BIOFADs. These trials were essential for identifying the strengths and limitations of different materials and design elements under real marine conditions, thereby informing the refinement of final prototype models for large-scale deployment.

The initial testing phase involved the deployment of 22 BIOFADs on April 13, 2024. These devices were based on an evolved version of the JellyFAD model, maintaining conventional dimensions but incorporating two key innovations: the use of Paulownia wood as a flotation material in two units, and the integration of 12 mm diameter braided cotton ropes as the main tail component. The FADs were deployed primarily in the western Mediterranean (Figure 45), where they remained at sea for periods ranging from 1.6 to 4 months.

Figure 45. FAD inspection in the Mediterranean testing. Left - Retrieving the FAD to inspect the main rope. Found in perfect condition both at the surface and at the deepest section of the FAD; middle - [illegible] floats found in perfect condition for the two jelly-FADs visited with this type of floatation, right - [illegible] perfect condition for the three jelly-FADs visited (photos credit: ISSF by Gala Moreno):

Preliminary observations revealed significant limitations in the mechanical performance of the 12 mm cotton ropes. Several units exhibited breakage in the upper sections of the tail, likely due to material fatigue and exposure to dynamic surface conditions (Figure 46). These findings highlighted the need for further testing with alternative rope diameters or constructions to ensure structural integrity over time. A more comprehensive analysis of this first phase will be conducted upon completion of the second testing phase.

The second phase of testing commenced on June 2, 2025, with the deployment of 10 additional JellyFADs featuring cylindrical drogues. These represented a lighter, more streamlined alternative to the cubic JellyFADs tested previously. The second phase aimed to assess the performance of different flotation materials and attachment methods, as well as the influence of deployment depth on FAD stability and durability.

Key variables tested included:

- **Flotation materials:** Five FADs were equipped with Paulownia wood floats, while the remaining five used bio-based plastic floats. Two attachment methods were evaluated: (i) floats connected to the main rope via a secondary line, and (ii) floats directly affixed to the main rope.
- **Deployment depth:** Devices were deployed at two depths—5 meters and 50 meters—to assess the impact of hydrodynamic forces on structural performance.
- **Main rope specification:** All units were constructed using 20 mm twisted cotton rope, which had previously demonstrated superior durability in marine environments compared to thinner alternatives.

A monitoring visit conducted between August 10–12, 2025—approximately 2.5 months post-deployment—revealed that most FADs remained structurally intact. Drogues were in excellent condition, and mooring systems were functioning as intended. However, specific observations provided critical insights:

- **Plastic floats:** Both attachment methods performed reliably, with no float failures. However, adjustments were recommended to optimize buoy distribution. It was observed that positioning the first float 0.5 meters below the GPS buoy helped prevent sagging of the main rope, whereas a 3-meter spacing led to rope submersion and buoy tilt.
- **Paulownia floats:** Units with floats attached via a secondary rope exhibited signs of abrasion and partial breakage within 2.5 months, resulting in progressive float loss (Figure 47). These findings suggest that while Paulownia offers promising buoyancy characteristics, its mechanical resilience and attachment methods require further optimization.

The second visit is planned for December 2025, following six months of prototype deployment. All FAD components will be re-inspected to evaluate their condition and determine any necessary repairs or design improvements.

These semi-controlled trials have been instrumental in identifying both the potential and limitations of candidate materials and configurations. The insights gained are being directly applied to refine the final BIOFAD designs, ensuring they meet the dual objectives of environmental sustainability and operational performance in real fishing conditions.

Figure 46. Breakages of 12mm cotton ropes

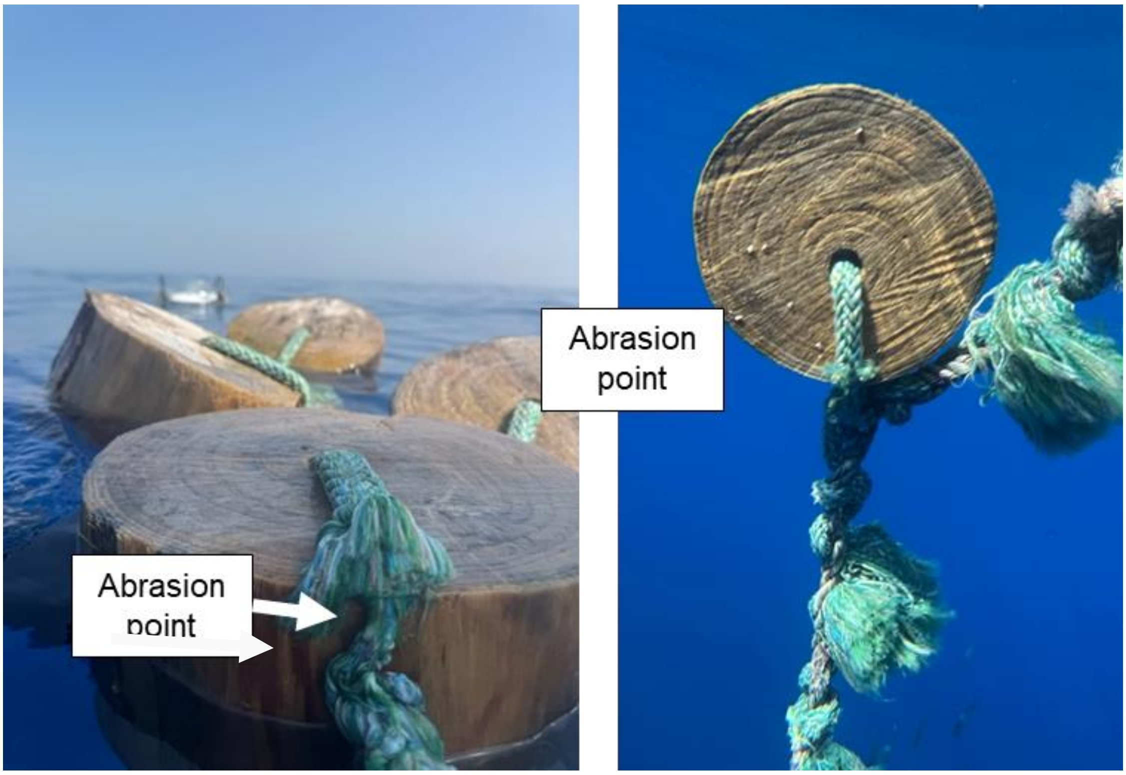


Figure 47. Paulownia wood floats attached with a secondary rope exhibited abrasion and showed a high risk of detachment. (photos credit: ISSF by Gala Moreno):

4. Life Cycle Assessment

As part of the SEARCULAR project's eco-design strategy for BIOFADs, a preliminary cradle-to-gate Life Cycle Assessment (LCA) was conducted to evaluate the environmental impact of key materials used in FAD construction. The goal was to guide material selection based on carbon footprint data, ensuring that the final BIOFAD models minimize greenhouse gas (GHG) emissions while maintaining operational viability. The scope of this preliminary LCA includes the production and transport of dFAD materials to the port in Spain at "cradle-to-gate" level. That means the system boundary starts at the raw material acquisition (in the case of fossil-based materials) or raw material production (in the case of biobased materials), material processing, and distribution. Capital goods, buildings, and infrastructure, as well as R&D activities are excluded from the scope. A full cradle-to-grave LCA (including the use and end-of-life stages) will be conducted after the sea tests including the impacts of marine litter. For this preliminary LCA, the impacts are assessed per kg of material. This neglects differences in density and quantity needed per FAD model, as well as the end-of-life treatment. Besides, this does not entirely address the function of the FADs since it does not consider the lifespan and fish aggregation effectiveness of the FADs composed of the materials. Therefore, when corresponding information is available, we will calculate the full LCA with an adapted functional unit.

The LCA focuses on an assembly of the materials in Spain. Data is based on the year 2025 and represents industrial production of the materials. The FADs are assumed to be (semi-)manually assembled on board of the vessels employing the FADs. The materials analysed in the LCA correspond to those used in the construction of the traditional JellyFAD model, which served as the baseline reference for the development of the final eco-designed BIOFAD prototypes. This approach ensures that environmental improvements are assessed relative to an operationally validated design, allowing for meaningful comparisons and targeted substitutions of high-impact components. The LCA focused on the four primary components of the FAD structure: flotation elements, ropes, structural frames, and canvas coverings. The ecoinvent 3.11 database was primarily used as the data source, but data from the Sphera MLC database and data from reviewed papers were also used.

The carbon footprint of each material was assessed per kilogram of product, considering production, processing, and transport to Spain. The ISO standards 14040 and 14044 provide a comprehensive framework of relevant environmental impact categories for conducting LCAs. For this preliminary LCA, we focused on the impact category climate change (carbon footprint, CF) which uses characterization factors of the 6^{th} assessment method of the Intergovernmental Panel on Climate Change (IPCC) following ISO 14067 (DIN EN ISO 14067:2018. Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification (ISO 14067:2018)). This impact category considers the potential climate change impact of each GHG emitted and removed by the product system, which is calculated by multiplying the mass of GHG released or removed by the 100-year GWP given by the IPCC in units of "kg CO2e per kg emission". The method covers fossil GHG emissions, biogenic GHG emissions, GHG emissions in the stratosphere, CO_2 uptake, and GHG emissions by land use and land use change. The climate change score is the sum of these calculated impacts. The 100-year GWPs are listed in Annex A to ISO 14067:2018. By differentiating between the categories mentioned, the climate advantage of biogenic raw materials is also taken into account in the cradle-to-gate assessment.

For cotton, we calculated a best-case and a worst-case scenario using different origins of production of the cotton since this has a great influence on the climate change impacts of cotton products. The world's largest cotton producers are India, China, and the US, which show significant differences in greenhouse gas emissions.

The results of the preliminary cradle-to-gate LCA are summarized below:

Floatation elements (buoys):

- **Virgin HDPE:**
  Estimated CF: **3.41 kg CO_2-eq./kg**
  Includes HDPE granulate production and blow moulding (global average data), as well as transport to Spain.
- **Virgin EVA:**
  Estimated CF: **3.33 kg CO_2-eq./kg**
  While the idea was to use recycled EVA, no information was available regarding the recycling of EVA. Therefore, if recycled EVA is used in the final BIOFAD models, corresponding information by the supplier is needed.
- **Paulownia wood:**
  Estimated CF: **-2.67 kg CO_2-eq./kg.**
  This estimate represents the global average for softwood production, harvesting, and transport to Spain, as well as thermal treatment of wood waste during processing. When more detailed information becomes available, we will investigate local production to avoid transport. Paulownia wood offers a net-negative carbon footprint due to its carbon sequestration properties, making it a highly favorable material for the floation. Note that, as the preliminary LCA only considers the cradle-to-gate system, all uptake of CO_2 during wood growth is considered but any release of CO_2 from the wood at the end of life caused by degradation is not covered. However, this will be considered in the full cradle-to-grave LCA at the end of the project.

As can be seen, the plastic materials, while durable, are associated with a higher CF per kg than the Paulownia wood. Strategies for a more sustainable FAD design would be to reduce the plastic mass needed by (partly) replacing it by less impactful materials, such as Paulownia wood.

Tail (ropes):

- **Virgin PE:**
  Estimated CF: **5.07 kg CO_2-eq./kg**
  Includes LDPE granulate production, extrusion into filament, and braiding into rope (global average data), as well as transport to Spain.
- **Cotton:**
  Estimated CF: **1.75–6.02 kg CO_2-eq./kg**, depending on country of origin
  Includes cotton yarn production and braiding, as well as transport to Spain.

While biodegradable, cotton ropes showed variable performance in field trials and require regional sourcing to reduce environmental impact. We are now investigating the use of abaca and sisal as alternative options.

Frame & cage:

- **Steel:**
  Estimated CF: **2.84 kg CO_2-eq/kg**
- **Bamboo:**
  Estimated CF: **−0.8 kg CO_2-eq./kg**
  Includes bamboo cultivation, processing in China, and maritime transport to Spain. Bamboo offers a net-negative carbon footprint due to its carbon sequestration properties, making it a highly favourable material for the structural components.

Furthermore, the project is exploring the use of **pine wood cultivated in Spain** as an alternative to bamboo and other imported materials for the structural frame of the FAD. Pine offers several advantages, including local availability, reduced transport emissions, and compatibility with existing construction techniques. Its inclusion in prototype development allows for comparative assessment of mechanical performance, durability, and environmental impact relative to other organic materials.

Canvas:

- **Virgin LDPE:**
  Estimated CF: **3.6 kg CO_2-eq./kg**
  Includes LDPE granulate production and extrusion into film (global average data), as well as transport to Spain.
- **Cotton:**
  Estimated carbon footprint: **3.22–7.43 kg CO_2-eq./kg**, depending on country of origin

Includes yarn production and weaving. Cotton canvas is widely used but presents a relatively high impact depending on the country of cotton production, reinforcing the need to explore alternative natural fibres such as abaca or sisal.

4.1 Material selection strategy

Research shows that the attractiveness of FADs is largely based on (i) their trajectory (slow drifting), and (ii) their shading / sheltering effect that attracts non-tuna fish to start colonizing the FADs. In the past, the former has been pursued by augmenting the devices' size, especially the underwater appendage (Moreno et al., 2023), thus also increasing the amount of materials littered to the ocean when the FAD is lost / abandoned or strand in more shallow water. The aim of the eco-design of the BIOFADs was to achieve a similar trajectory and sheltering effect as conventional FADs, thus maintaining the fish aggregation effectiveness, while reducing environmental impacts. The selection of materials for the BIOFAD prototypes was guided by the preliminary LCA results, prioritizing components with lower CFs. Table 13 shows a breakdown of each JellyFAD component and its preferred materials, with justification based on LCA findings:

Table 13. Materials used in the JellyFAD model by component

Component	Preferred Material(s)	LCA-Based Justification
Flotation	Paulownia wood / Bio-based buoys	Compared to conventional HDPE buoys (3.41 kg CO_2-eq./kg), Paulownia offers low water absorption, stable buoyancy, and significantly lower impact. Bio-based buoys further reduce fossil resource use and end-of-life pollution.
Frame & Cage	Bamboo / Paulownia / Spanish pine wood	Although traditional JellyFAD uses bamboo, common use for cage is galvanized iron, which has a high carbon footprint and no biodegradability. Due to their carbon uptake, woods cause net-negative emissions (Bamboo: −0.8 kg CO_2-eq./kg) at the gate. Additionally, Paulownia and pine offer local sourcing and reduced transport-related impacts.
Tail / Rope	Cotton (low-impact origin) / Abaca	The conventional JellyFAD uses cotton ropes, which are biodegradable. Compared to synthetic ropes (e.g., polyethylene or polypropylene), which have high fossil-based emissions and persist in marine environments, cotton and abaca present lower impact and better end-of-life behaviour.

Canvas Cover	Cotton / Abaca / Sisal	Cotton canvas, while used in JellyFAD, has a relatively high footprint (up to 7.43 kg CO_2-eq/kg). However, it remains preferable to synthetic fabrics due to biodegradability. Abaca and sisal offer promising alternatives with potentially lower impacts depending on sourcing and processing.
Ballast	Discarded steel cables / Clay / Gravel	Conventional FADs often use metal chains or discarded *jaretas*, which are heavy, non-biodegradable, and difficult to recover. Clay and gravel are inert, locally available, and offer a low-impact alternative for anchoring without contributing to marine debris.

5 Co-creation with stakeholders (Workshops)

As part of the SEARCULAR project, a series of four co-creation workshops were conducted in collaboration with the tropical tuna purse seine fleet to guide the eco-design of BIOFADs. These workshops were a central component of the participatory design process, ensuring that the final FAD models were both environmentally sustainable and operationally viable. The co-creation process was informed by the outcomes of preceding subtasks whose inputs provided a robust scientific and technical foundation for the collaborative design phase.

The first two workshops brought together representatives from the two participating tuna fishing companies. These initial sessions focused on defining three distinct biodegradable FAD models, taking into account the operational requirements of the fleet and the environmental performance of proposed materials. The discussions emphasized the need for designs that balance functionality, durability, and ecological impact. The final two workshops were dedicated to refining the initial designs and selecting the most suitable materials for each FAD component. This phase also integrated insights gained from prototype testing under semi-controlled conditions in the Mediterranean Sea, allowing for evidence-based adjustments to improve performance and sustainability. Throughout the workshops, each structural element of the FAD was considered in detail—including the flotation system, surface and subsurface components, submerged appendages, and ballast.

Overall, involving the industry early and continuously throughout the development process and specially through these co-creative workshops has helped align the product with the users' expectations, reduced the design errors and improved usability and social and ecological sustainability. Scientific method brings in knowledge and rigor, users contribute with practical creativity, ensuring that the final BIOFAD models were optimized for both ecological compatibility and practical deployment in real fishing operations.

5.2.1 1st BIOFAD Workshop.

The first co-creation workshop was held on December 9, 2024, at the EKOETXEA Urdaibai facilities. The session brought together representatives from ECHEBASTAR, researchers from the SEARCULAR consortium (AZTI), and the subcontracted partner ISSF (Figure 48).

The workshop focused on several key topics:

- An overview of the SEARCULAR project was presented, with particular emphasis on the objectives and specific goals of Work Package 3 (WP3), which focuses on the eco-design of biodegradable FADs (BIOFADs).
- A retrospective analysis of previous experiences was conducted to identify existing biodegradable materials and design alternatives for each component of a FAD. This included a review of configurations used in earlier BIOFAD trials and highlighted the elements that still lack viable biodegradable substitutes—such as flotation devices, ballast systems, and metallic structures.
- Results from prior studies involving the JellyFAD prototype were shared, including technical considerations such as buoyancy, drag coefficients, material tension, and stress factors, all of which are critical to the design and performance of FADs.
- Three BIOFAD models were proposed for testing during the project: two based on existing designs already used by the participating company, adapted to incorporate fully biodegradable materials; and a third, innovative circular model—JellyFAD (Figure 49).
- The third model was evaluated in terms of performance, cost, handling, biodegradability, durability, and environmental impact.
- Finally, a detailed work plan for 2025 was established. This plan includes testing the proposed models under semi-controlled conditions, with the aim of progressing to the next phase involving full-scale construction, deployment, and performance evaluation in real-world conditions in the Indian Ocean.

Figure 48. Workshop for the co-design of BIOFADs.

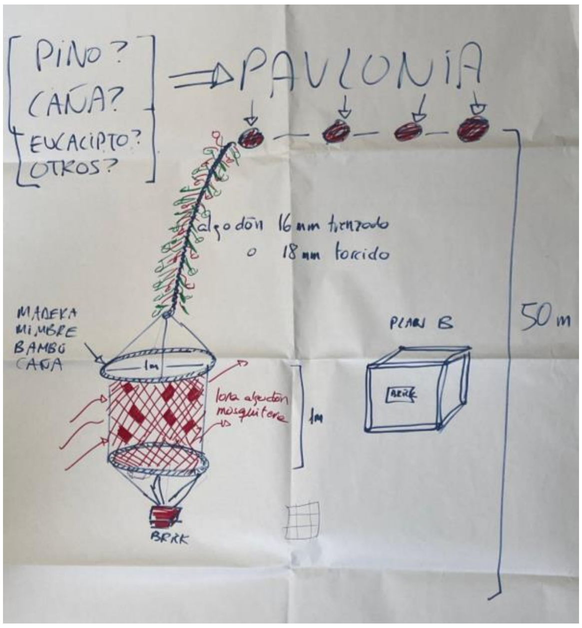


Figure 49. Example of the co-designed FAD

5.2.2 2nd BIOFAD Workshop.

The second co-creation workshop took place on March 25 at AZTI's facilities in Sukarrieta. The session was attended by nine participants, including scientists from AZTI and the International Seafood Sustainability Foundation (ISSF), as well as representatives from the two participating freezer purse seine tuna companies, ECHEBASTAR and ALBACORA, both operating in the Indian Ocean (Figure 50).

The workshop addressed the following key topics:

- A recap of the SEARCULAR project's objectives and the specific aims of Work Package 3 (WP3), focused on the eco-design of biodegradable FADs (BIOFADs).
- A comparative discussion on various flotation materials, including paulownia wood, balsa wood, and bio-based floats, evaluating their functional properties and suitability for FAD construction.
- A detailed review of the three BIOFAD models selected for testing during the project (Figure 51):
- **Model 1** (final version shown in Figure 55): Maintained its original design.
    - ECHEBASTAR: 40 units using ECH grid.
    - ALBACORA: 20 units using Sinerxia grid.
    - Flotation configuration: 25% synthetic floats, 50% mixed, and 25% paulownia wood.
- **Model 2** (final version shown in Figure 56):
    - Altitude: Proposed increase to 2 meters of rope length.
    - Participants noted that while increased exposure to wave action may cause more wear, greater surface presence improves visibility and handling.
    - Reference was made to conventional non-biodegradable FADs, which typically feature a 2-meter-high cage.
    - Cage dimensions : 1.5 m × 1.5 m × 2 m.

    - Flotation configuration: 25% synthetic floats, 50% mixed, and 25% paulownia wood.
    - Canvas: Used in 100% of the units.
    - Joints: Tied connections were preferred for better adaptability to the cane's thickness.
- **Model 3** (final version shown in Figure 57):
    - Shape: Cylindrical.
    - Dimensions: Diameter 1.5 m, height 2 m, submerged depth 2 m.
    - Flotation configuration: 50% synthetic floats and 50% paulownia wood.

- The workshop concluded with the definition of a work plan for 2025. The plan includes testing the three BIOFAD models under semi-controlled conditions, with the objective of advancing to the next phase: full-scale construction, deployment, and performance evaluation in real fishing conditions in the Indian Ocean.

Figure 50. 2nd workshop on experimental BIODAD design.

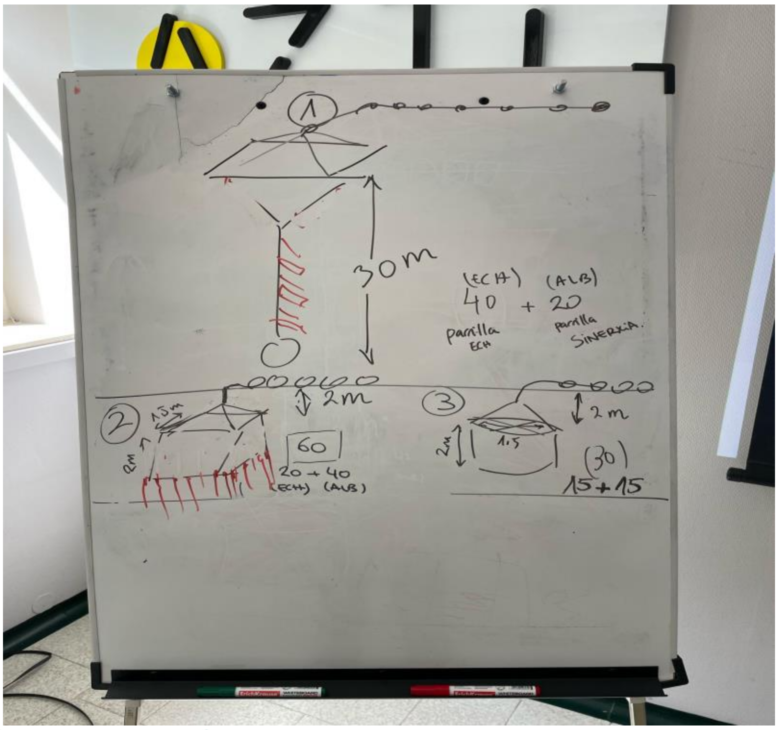


Figure 51. New experimental BIOFAD models

5.2.3 3rd BIOFAD Workshop.

The third co-creation workshop was held on March 3, 2025, in Galicia, with the participation of the same stakeholders involved in the previous session. Attendees included scientists from AZTI and ISSF, as well as representatives from the tuna purse seine companies ANONIMO_1 and ANONIMO_2, both active in the Indian Ocean.

The main objective of this one-day workshop was to visit a specialized FAD construction company and transition from conceptual design to the physical construction of the first prototypes for the three selected BIOFAD models. The session marked a critical step in the eco-design process, enabling the practical validation of design concepts and material choices.

The workshop focused primarily on the construction of **Model 3**, the most experimental of the three designs. Participants worked collaboratively to address technical challenges related to the cylindrical shape of the FAD, including:

- Identifying suitable materials and techniques to achieve the desired cylindrical form.
- Developing effective methods for connecting the cylindrical raft to the main tail structure.
- Adjusting flotation components to ensure proper buoyancy and stability.
- Calculating and integrating the appropriate ballast weight to maintain vertical positioning in the water column.

This hands-on session provided valuable insights into the practical feasibility of the proposed designs and informed further refinements to the construction approach (Figure 52). The outcomes of this workshop will directly support the next phases of prototype testing under semi-controlled conditions and eventual deployment in the Indian Ocean.

Figure 52. Hands-on session for the co-creation of Model 3

5.2.4 4th BIOFAD Workshop.

The fourth co-creation workshop took place over two days, October 14 and 15, 2025, in Galicia. As with previous sessions, the workshop brought together scientists from AZTI and ISSF, along with representatives from the tuna purse seine companies ANONIMO_1 and ANONIMO_2.

The primary objective of this workshop was to meet with the company responsible for constructing the BIOFADs for real-sea trials and to monitor the progress of prototype fabrication. The workshop served as a critical checkpoint to validate the construction process and to refine the designs based on feedback and modifications agreed upon with the fishing companies (examples are shown in Figure 53).

Key activities and outcomes included:

- **Design Adjustments:** The team reviewed and implemented several design modifications to the three BIOFAD models. For Model 1, changes were made to the grill component, selecting a more suitable material based on operational feedback. For Model 2, the cube structure was revised, incorporating paulownia and pine wood as alternatives to bamboo canes, aiming to improve structural integrity and material availability.
- **Component Integration:** Particular attention was given to the connections between different FAD elements. The team evaluated and refined the methods for joining components such as knots, fabrics, and ballast systems. These adjustments were informed by observations from previous prototype tests conducted under semi-controlled conditions in the Mediterranean Sea.
- **Final Optimization:** The workshop provided an opportunity to ensure that all three BIOFAD models were optimized for durability, functionality, and environmental performance before their deployment in real fishing conditions in the Indian Ocean.

This hands-on session marked the final step in the co-creation process, ensuring that the BIOFAD designs were fully aligned with both ecological objectives and the practical requirements of the fishing industry.

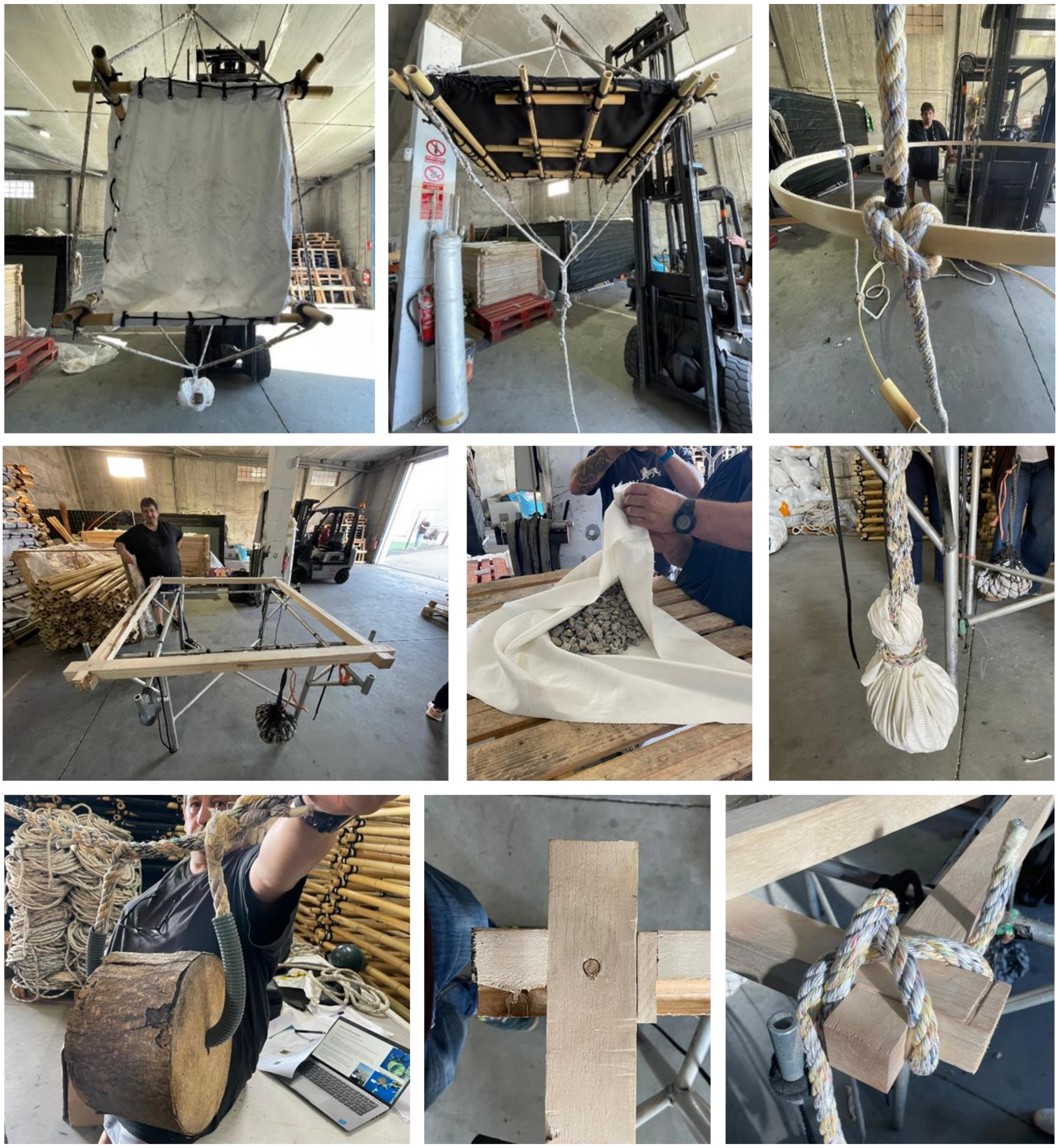


Figure 53. Outcomes of fourth co-creation workshop

6. Eco-designed BIOFAD models

Based on the results presented in this report, the BIOFADs have been eco-designed to minimize the negative environmental impacts, including effects of marine litter once these dFADs are no longer in use. The eco-design of the BIOFAD involves eliminating the use of netting and utilizing only biobased, biodegradable organic materials that degrade as quickly as possible after the end of their effective lifetime for fishing. Additionally, our efforts have focused on developing designs that replace most of the plastic elements for FAD construction with materials of organic origin, which take up CO_2 during growth. The design of the new eco-designed BIOFADs, made from organic and/or bio-based materials, also focused on simplifying the structure and reducing the size of the dFADs so that they can be built with less material, while trying to maximize their lifetime at sea.

This task first required seeking the commitment and participation of the freezer purse seine tuna fleet, both to design the new BIOFADs and to subsequently test them in real conditions (Task 3.3). This search has been a complex task partly due to the initial reluctance of the fleet to test a 'conventional' JellyFAD model and the situation the fleet is facing in the Atlantic Ocean, whereas significant number of vessels left to move to other oceans, mainly the Indian Ocean. Finally, the tuna companies ECHEBASTAR and ALBACORA agreed to participate in the project. Their commitment has been essential in the design of the new BIOFAD models, which will be tested in the Indian Ocean and not in the Atlantic as initially planned.

The SEARCULAR project followed a structured eco-design process to develop environmentally sustainable biodegradable FADs. The workflow began with a comprehensive analysis of previous scientific biodegradable trials data analysis to assess BIOFADs efficiency, followed by a questionnaire targeting the fishing industry to gather insights on current FAD practices and challenges. This was followed by a state-of-the-art review of past and ongoing biodegradable FAD trials across different oceans to identify best practices and knowledge gaps regarding the use of materials and designs (See Deliverable 3.1). Based on these findings, the team conducted a targeted search for new biodegradable materials, which were then subjected to laboratory and field testing to assess their performance and environmental compatibility. A Life Cycle Analysis (LCA) was carried out to evaluate the environmental footprint of the materials throughout their lifecycle. Finally, a co-creation process involving industry stakeholders was implemented through workshops. This collaborative phase ensured that the final BIOFAD designs were both operationally viable and aligned with sustainability goals.

Following the co-creation process with the tuna fishing industry, three eco-designed BIOFAD models were defined that meet operational and sustainability criteria:

- The first model is a deep-tail BIOFAD, closely resembling the A1 prototype of the Indian Ocean BIOFAD project, optimized for slow drift and tuna aggregation.
- The second is a cage-type BIOFAD, inspired by shallow JellyFAD designs, featuring a cube structure constructed from three types of wood (bamboo, paulownia, and pine) selected for their buoyancy and biodegradability.
- The third model is an experimental cylindrical JellyFAD, designed to reduce structural stress and facilitate handling, while maintaining quasi-neutral buoyancy and minimizing synthetic components.

6.1 Model 1.

The first BIOFAD model 1 (Figure *55*). represents a traditional deep-tail BIOFAD design commonly used in the Indian Ocean. It is the simplest of the three eco-designed models, particularly in terms of its submerged structure. The underwater section consists of a single cotton rope and a gravel ballast, minimizing complexity and material use. The surface component is composed of a bamboo raft covered with cotton canvas, providing a biodegradable and functional platform. Flotation elements, as in Models 2 and 3, are made from paulownia wood and/or bio-based plastic floats, eliminating conventional synthetic buoyancy materials. This model prioritizes simplicity and minimalism, both in the types and quantities of materials used. It has been previously tested by fishing fleets in its synthetic format and further validated in a quasi-biodegradable configuration during the BIOFAD project in the Indian Ocean. Its proven operational viability and reduced environmental footprint make it a strong candidate for wide-scale adoption in sustainable tuna fisheries.

6.2 Model 2.

The second BIOFAD model (Figure *56*) is a simplified, shallower JellyFAD designed to optimize material use and improve sustainability. Unlike the conventional JellyFAD, this version eliminates the superficial raft and significantly reduces the depth of the cube structure. Flotation is achieved using paulownia wood and/or bio-based plastic floats, replacing traditional synthetic buoyancy elements. The cube is constructed from bamboo, paulownia, or pine—materials selected to enhance sourcing sustainability and reduce reliance on bamboo imports from China. Reducing the overall dimensions of the FAD not only simplifies its construction and handling but also significantly lowers the volume of materials required, contributing to cost efficiency and operational practicality. Most importantly, the elimination of plastic flotation components directly supports efforts to reduce marine litter, particularly persistent plastic pollution, which poses long-term threats to marine ecosystems. Despite its reduced size and simplified architecture, the model maintains a drag coefficient comparable to the original JellyFAD, ensuring effective drifting behavior for tuna aggregation. This redesign achieves key eco-design objectives: minimizing synthetic material use, reducing environmental footprint, and streamlining deployment and retrieval operations without compromising functional performance.

6.3 Model 3.

The cylindric JellyFAD 2.0 or Model 3 (Figure 57) represents a significant improvement over the JellyFAD 1.0, offering a lighter and more sustainable alternative for biodegradable drifting FADs. The previous version utilized thicker bamboo poles and ropes, making it heavier and bulkier. In contrast, cylindric Jelly-FAD 2.0 features lighter components, including paulownia wood and/or bio-based plastic floats for flotation, making it an entirely organic and a lighter option. The reduced overall mass of the jelly-FAD reduces the need for floatation. The lighter structure also facilitates deployment and retrieval while minimizing its environmental impact and reduces costs of FAD transportation.

One of the most notable changes in cylindric Jelly-FAD 2.0 is the shift from a square to a cylindrical drag design. The cylindrical shape provides several advantages:

- Higher Drag Coefficient (Figure *54*): A short cylinder has a higher drag coefficient compared to a cube of the same dimensions, improving stability and retention in the fishing area.
- Reduced Risk of Entanglement: The absence of corners minimizes the risk of the FAD getting caught in the purse seine net during retrieval operations, making the lifting manoeuvre smoother and safer.
- Improved Deployment and Retrieval: The cylindrical design is easier to handle and transport, avoiding sharp edges.

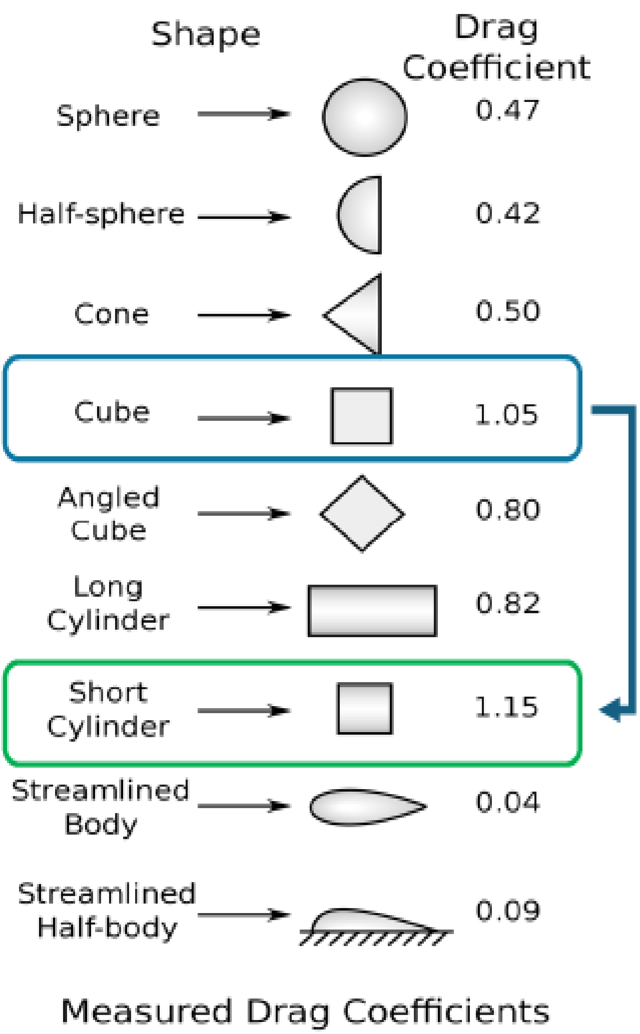


Figure 54. Drag coefficients for different shapes

Diagram for Model 1

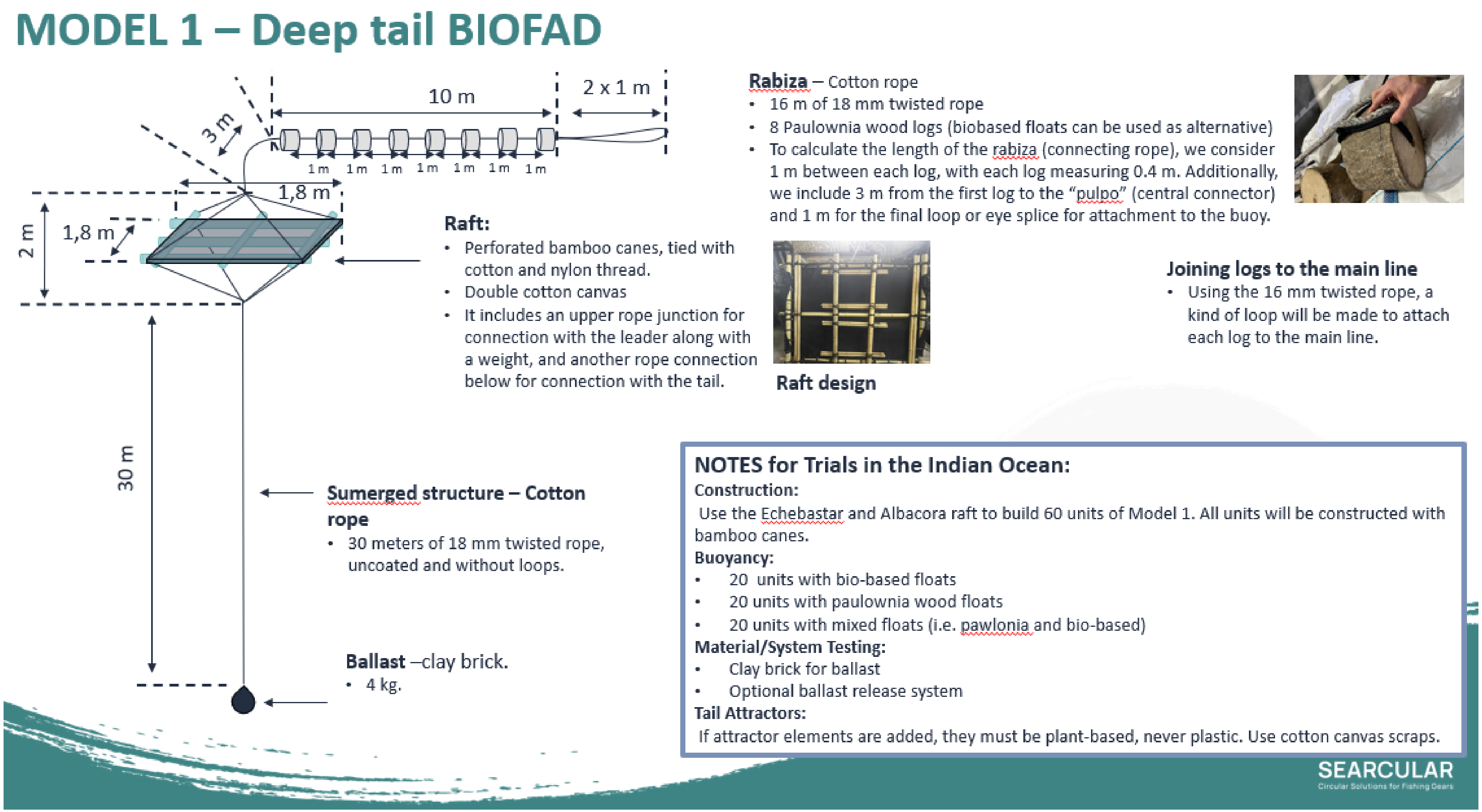
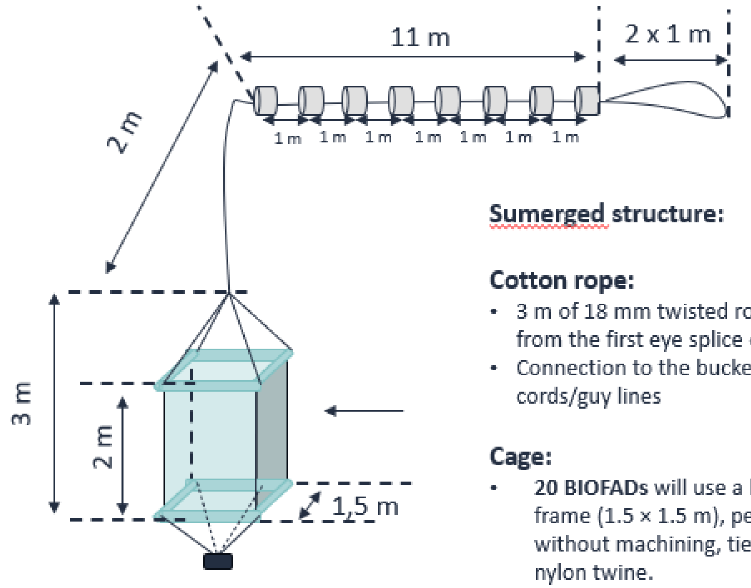


Figure 55. SEARCULAR's BIOFAD Model 1 – deep tail

Diagram for Model 2

MODEL 2 – Cage



Rabiza – Cotton rope
- 16 m of 18 mm twisted rope
- 8 Paulownia wood logs (biobased floats can be used as alternative)
- To calculate the length of the rabiza (connecting rope), we consider 1 m between each log, with each log measuring 0.4 m. Additionally, we include 3 m from the first log to the "pulpo" (central connector) and 1 m for the final loop or eye splice for attachment to the buoy.

Sumerged structure:

Cotton rope:
- 3 m of 18 mm twisted rope (Itsaskorda) from the first eye splice of the rabiza.
- Connection to the bucket using bungee cords/guy lines

Cage:
- **20 BIOFADs** will use a bamboo cane frame (1.5 × 1.5 m), perforated, joined without machining, tied with cotton and nylon twine.
- **40 BIOFADs** will use a Paulownia wood frame (upper square: 1.7 × 1.7 m) and a pine wood frame (lower square: 1.7 × 1.7 m), joined without machining, tied with cotton and nylon twine.
- **Double cotton canvas (IRC)**, each fabric side measuring 1.8 × 1.8 m, left loose.

Ballast – Clay/Mud
2 × 4 kg – Attached hanging from the lower frame of the cage

Joining logs to the main line
- Using the 16 mm twisted rope, a kind of loop will be made to attach each log to the main line.

NOTES for the Tests in the Indian Ocean:
- Construction of 60 units of Model 2.
  - 20 units of the Echebastar type.
  - 40 units of the Albacora type, with an upper frame made of Paulownia wood and a lower frame made of pine wood.
- IRC cotton fabric will be used for the cage construction, and all joints will be without machining.

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Figure 56. SEARCULAR's BIOFAD Model 2 - Cage type

Diagram for Model 3

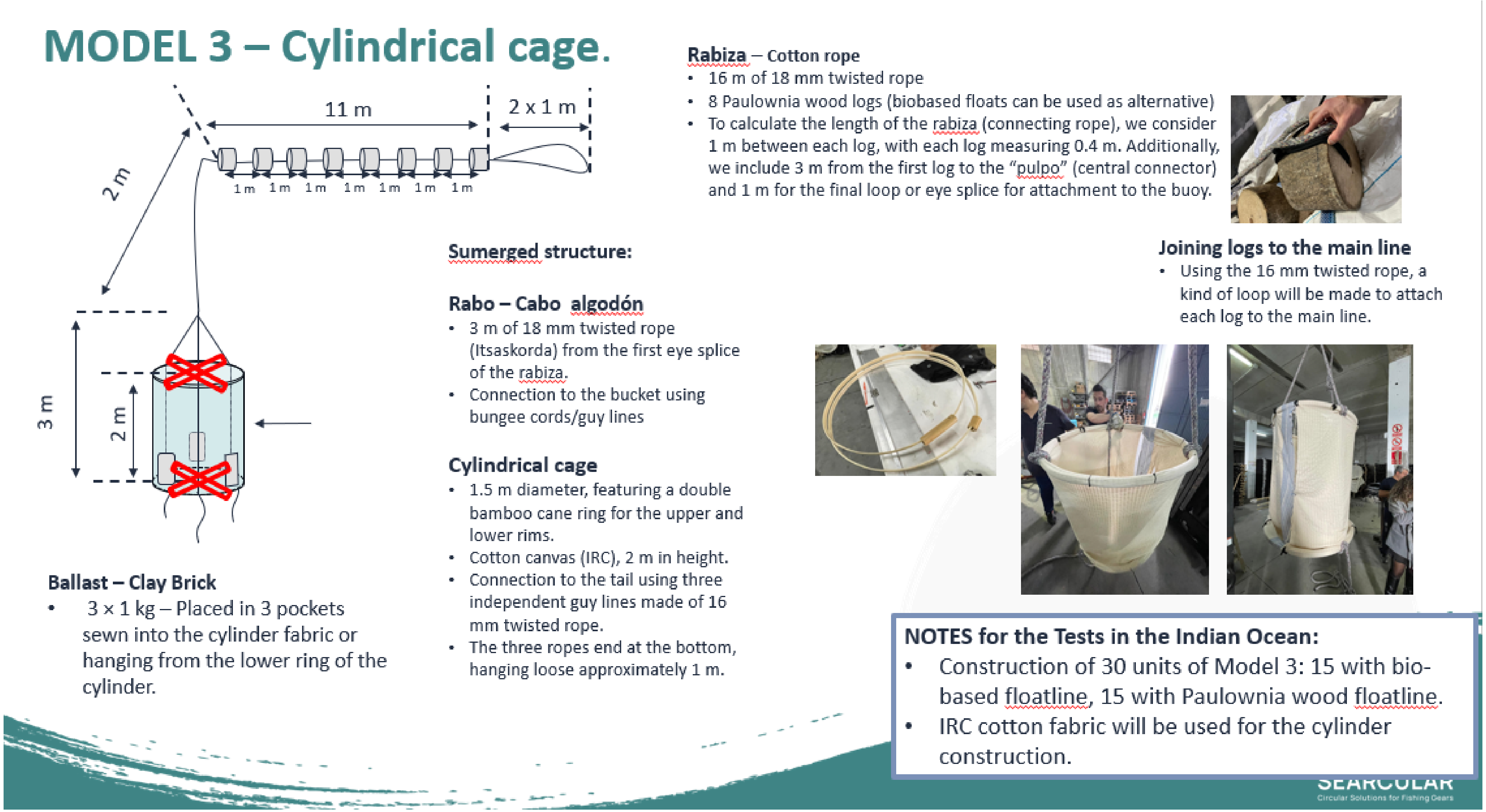


Figure 57. SEARCULAR's BIOFAD Model 3 – the JellyFAD 2.0

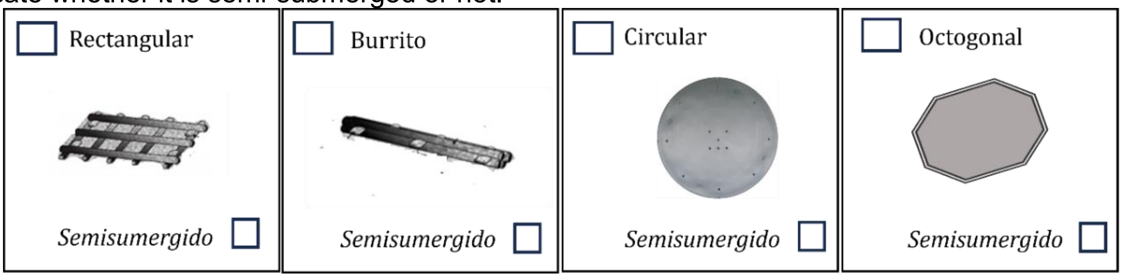
ANNEX 1 - QUESTIONNAIRE

MATERIALS AND STRUCTURES of CONVENTIONAL FAD*

*CONVENTIONAL refers to the type of FAD you currently use in your fishing operations.

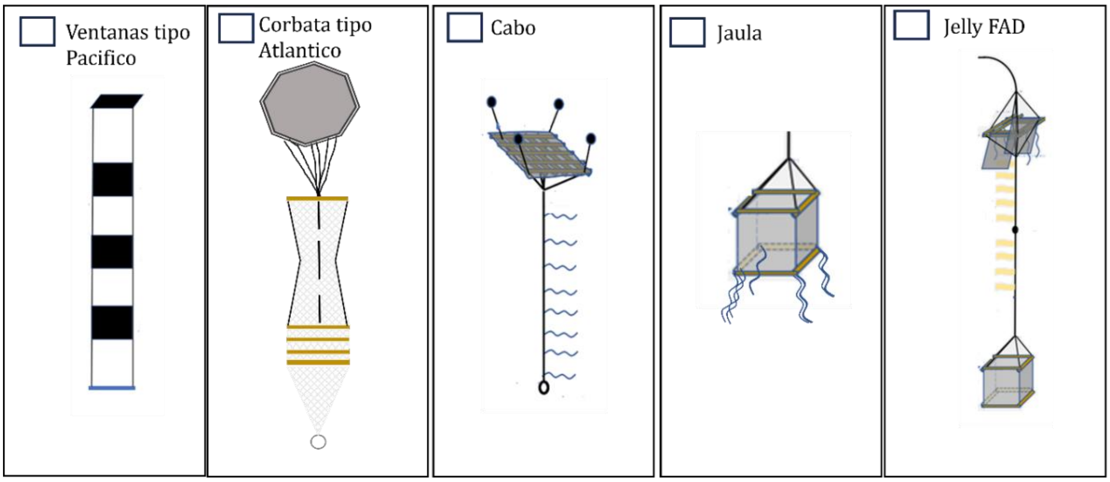
1) Structure Design –

a) Raft: Please select one or multiple types of raft design that you use in the ocean you operate in. Indicate whether it is semi-submerged or not.



☐ Rectangular ☐ Burrito ☐ Circular ☐ Octagonal
☐ Semi-submerged

b) Tail or submerged part: Please select one or multiple types of tail design that you use in the ocean you operate in.



☐ Pacific-style “Windows” ☐ Atlantic-style “Tie” ☐ Rope ☐ Cage ☐ Jelly FAD

c) Do you use different types of FAD (for example: structure type, depth of the submerged part, materials, etc.) in different areas of the ocean you operate in? (You can select more than one option):
☐ No, I use a single design throughout the year
☐ Yes, depending on the material available on board
☐ Yes, depending on the currents in the area
☐ Yes, depending on the type of tuna found in the area

☐ Others

d) What is the depth (in meters) reached by the tail or hanging submerged part in the FADs you use (1 fathom equals 1.8 m)? If you use more than one type of FAD with different depths, select the percentage of use for each type (the sum of the percentages must be 100%, for example: 20-39 m (40%) and 40-59 m (60%)). If you only use one type, select 100% for that type.

☐ 0-19 m (0-10 fathoms): ….%
☐ 20-39 m (11-21 fathoms) : ….%
☐ 40-59 m (22-32 fathoms) : ….%
☐ 60-79 m (33-43 fathoms) : ….%
☐ 80-99 m (44-54 fathoms) : ….%
☐ more than 100 m (more than 54 fathoms) : ….%

2) What materials are used in the construction of the raft (upper structure)? Check multiple options if applicable.

☐ Bamboo
☐ Woods
☐ Metal
☐ Plastic
☐ Biobased plastic (e.g. Zunibal biodegradable rafts)
☐ Others (specify)

3) What materials do you use to cover the raft of the FADs you usually use in daily fishing operations? Check multiple options if applicable.

☐ Synthetic canvas, without mesh

☐ Biodegradable canvas, without mesh (cotton)
☐ Biodegradable canvas, without mesh (MANILA HEMP)
☐ Biodegradable canvas, without mesh (sisal)
☐ Biodegradable canvas, without mesh (others - specify below)

☐ Synthetic net (open mesh LARGE net)

☐ I do not cover the raft with anything

4) What type of materials are used in the construction of the tail of the FADs you usually use in daily fishing operations? Check multiple options if applicable.

☐ Synthetic ropes
☐ Synthetic canvas
☐ Synthetic net (LARGE open mesh net)
☐ Synthetic net (SMALL open mesh net)
☐ Synthetic net (net tied in "sausages")
☐ Biodegradable ropes (COTTON)
☐ Biodegradable ropes (MANILA HEMP)
☐ Biodegradable ropes (SISAL)
☐ Biodegradable ropes (OTHERS - SPECIFY BELOW)

☐ Biodegradable canvas (COTTON)
☐ Biodegradable canvas (MANILA HEMP)
☐ Biodegradable canvas (SISAL)
☐ Biodegradable canvas (OTHERS - SPECIFY BELOW)

5) What materials do you use for the flotation of the raft of the FADs you usually use in daily fishing operations? Check multiple options if applicable.

☐ Net corks
☐ Plastic buoys
☐ Plastic bottles/containers
☐ PVC pipes
☐ Foam tubes
☐ Wood (balsa or others)
☐ Others

6) How much flotation do you add on the surface? (For example: 4 net corks of 7 litres or kilograms each, giving a total of approximately 28 kg or litres of flotation).

7) What type of material is used as ballast in the FADs? Check multiple options if applicable.

☐ Cable
☐ Ring bolts
☐ Chain
☐ Stones
☐ Sand
☐ Mud
☐ Cement
☐ Others

8)How much weight do you add as ballast to the tail?

(include number in kilograms)

9) Approximately, how much does a dry FAD weigh (excluding the buoy or echo-sounder)?
(include number in kilograms)

10) What is the % of plastic materials (including net) that you use to build your FADs (excluding the buoy or echo-sounder)?

11) Do you repair conventional FADs that you find in poor condition?

☐ Yes
☐ No

12) On average, how long does a conventional synthetic FAD last in the fishing area? Indicate the average time (in months) for the ocean where you operate.

----------- months

139 Where are the FADs you use built?

☐ Onboard
☐ In my company's port
☐ In another company's port
☐ Imported

14) What is the price of a conventional FAD? Indicate the currency in the next question.

Currency (€ / $)

TESTS WITH BIODEGRADABLE FADS MATERIALS AND DESIGNS 28.

15) Approximately, how many biodegradable FADs have you deployed to date?

16) Approximately, how many biodegradable FADs have you visited or encountered at sea to date?

17) What type of biodegradable materials have you tested in the tail? (Check multiple options if applicable).

a) Plant origin ropes:
☐ Plant origin ropes (COTTON)
☐ Plant origin ropes (HEMP)
☐ Plant origin ropes (MANILA HEMP)
☐ Plant origin ropes (OTHERS - SPECIFY BELOW)

b) Plastic ropes, but of Plant origin (biobased plastics, for example: plastics from Plant origin, potato starch, etc.)

c) Plant origin canvas:
☐ Plant origin canvas (COTTON)
☐ Plant origin canvas (HEMP)
☐ Plant origin canvas (MANILA HEMP)
☐ Plant origin canvas (OTHERS - SPECIFY BELOW)

d) Others

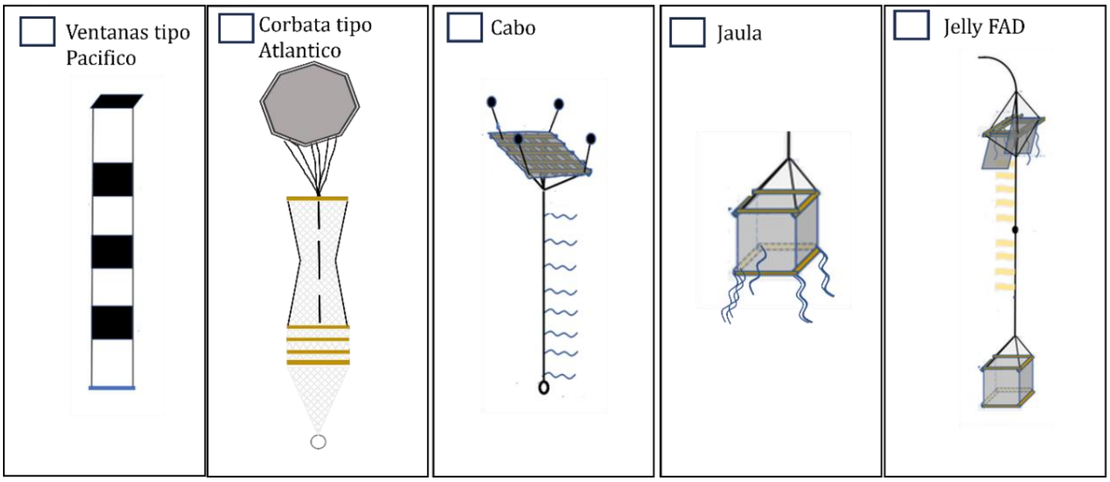
18) What type of biodegradable material have you tested to build the raft structure? (Check multiple options if applicable).

☐ Bamboo
☐ Balsa wood
☐ Other woods
☐ Biobased (for example, plastics of Plant origin, potato starch, etc.)

19) What type of biodegradable material have you tested for flotation? (Check multiple options if applicable).

☐ Bamboo
☐ Balsa wood
☐ Other woods
☐ Biobased (for example, plastics of Plant origin, potato starch, etc.)

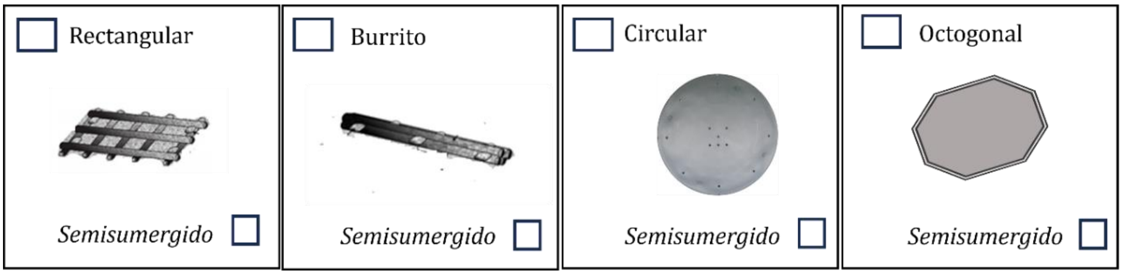
20) What biodegradable tail design have you tried? (If you have selected 'Other', please draw it).



☐ Pacific-style “Windows” ☐ Atlantic-style “Tie” ☐ Rope ☐ Cage ☐ Jelly FAD ☐ Other

Note: To attach a file, click on the cloud icon in the upper right corner. If you prefer to draw it, please be aware that you can use the available tools: undo, redo, choose colour, free drawing, add text, add circle, add rectangle, add arrow, move, and delete all.

21) What biodegradable raft design have you tried? (If you have selected 'Other', please draw it.)



☐ Semi-submerged ☐ Rectangular ☐ Burrito ☐ Circular ☐ Octagonal ☐ Other

Note: To attach a file, click on the cloud icon in the upper right corner. If you prefer to draw it, please note that you can use the available tools: undo, redo, choose colour, free drawing, add text, add circle, add rectangle, add arrow, move, and delete all.

22) What is the price of the biodegradable FAD? (Indicate the currency in the following question.)

Currency (€ / $)

23) Considering the type of FAD that you use the most, please, select its key highlights:

☐ Good value
☐ Longlife
☐ Performance
☐ Low environmental impact
☐ Sustainable materials
☐ Low interaction with other species
☐ Others

24) Considering the type of FAD that you use the most, please, select its key highlights:

☐ Expensive
☐ Short-life
☐ Low performance
☐ Impacts in the environment (e.g., corals)
☐ Generation of marine litter
☐ interaction with other species (bycatch)
☐ Others

25) What do you believe is the main difficulty in switching to biodegradable FADs? If there are multiple, rank the options in order of importance from 1 very important to 4 less important. (If multiple, rank them in order of importance from 1 very important to 4 less important)

☐ Higher cost of biodegradable FADs
☐ Biodegradable FADs do not attract tuna as much as conventional ones
☐ Biodegradable FADs do not last long enough
☐ Biodegradable materials are difficult to find

LOSS OF FADs and REUSE

26) On average per fishing campaign, what is the percentage of FADs that you lose? Indicate the total percentage of lost FADs (stolen + sunk + drifted out of fishing area, etc.) with respect to the total used per campaign. Of those lost FADs, indicate the percentage by loss category (on average per campaign). The sum of percentages in this section (24b) must be 100%.

a) of the total number of FADs deployed per season, ...% are lost.
b) of the total number of FADs lost …% are Stolen, …% are Sunk, …% are buoy malfunction, …% are drifted out of the fishing area (including stranded and those drifting out of the fishing area in this group)

27) Choose the main three impacts created by the FAD structure when it is lost or abandoned? (list in order of importance from 1 to 6).

☐ Contribution to marine litter and plastics in the open ocean
☐ Contribution to marine litter and plastics in coastal areas
☐ Damage to coral reefs and coastal areas
☐ Negatively affects tuna populations
☐ Negative image/advertising for the fishery
☐ Harms the eco-certification process.

28) Choose the main three management options you think are best to reduce the impact of lost FADs? (indicate in order of importance):

☐ Switch to biodegradable FADs
☐ Shore-based FAD retrieval
☐ Sea-based FAD retrieval Limit the number of FADs
☐ Transfer FAD ownership to other fleet companies
☐ At sea, avoid loss more (increased monitoring, retrieval when visiting, etc.)
☐ Others (describe)

29) What percentage of your FADs do you retrieve?

a) ….% of FADs are retrieved
b) Of those retrieved, …% are taken to port
c) Of those retrieved, …% are redeployed

30) In your opinion, is there any reason why more FADs are lost? You can select multiple options if required.

☐ Specific zone and time
☐ Fisher behaviour
☐ Buoy malfunction
☐ FAD limits
☐ Theft
☐ Bad weather
☐ Others (specify if this option is selected)

ANNEX 2 – Field trips searching biodegradable materials

Visual Documentation of Field Trips in Search of Biodegradable Materials

1. Field trip to Colombia (October 2024 and September 2025)

1.1. Fique (*Furcraea andina) to make organic ropes and canvas*

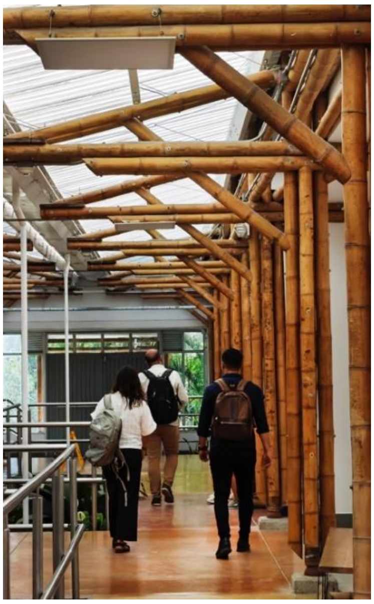
Fique fiber:

Process to manufacture ropes and canvas:

1.2 Guadua (*Guadua angustifolia) to make the Fas and bio-based products from Guadua*

Guadua forest in Pereira:

University of Pereira guadua constructions:



Bio-based materials from Guadua developed at the University of Pereira:

2. Field trip to China (March 2025)

Synthetic and bio-based plastic manufacturers:

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