Key outcomes of the International workshop on biodegradable Fish Aggregating Devices

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SUMMARY

An international workshop on biodegradable Fish Aggregating Devices (bio-FADs) was organized by the International Seafood Sustainability Foundation (ISSF) in San Sebastián, Spain, in December 2024. The event gathered 24 participants from the fishing industry, tuna RFMOs, and scientific institutions across the three tropical oceans. The main objective was to review progress in the development, operational characteristics, and evaluation of biodegradable FADs regionally and globally, and to foster collaboration among stakeholders in anticipation of the regulatory deadlines for full transition to 100% biodegradable FADs established by most of the tuna RFMOs. The workshop featured technical presentations of six major trials conducted in the Indian, Eastern, and Western and Central Pacific oceans. Results confirmed that bio-FADs aggregate tuna at comparable rates to conventional FADs, with average catches ranging from 26 to 53 tons per set. However, major challenges remain: limited durability (3 months for some designs/prototypes), availability and costs of biodegradable materials, and logistical constraints (bio-FAD handling, deployment and storage). A minimum functional lifespan of six months at sea was identified by fishers as critical for operational viability, with some fishers suggesting that a duration of up to one year would be preferable. Group exercises with fishers and fleet managers from each ocean, and a group of scientists, revealed alignment and differences regarding the challenges ahead for bio-FAD implementation. Participants highlighted the importance of FAD traceability, standardization of data colecction, inter-fleet collaboration, and FAD construction quality control, and called for greater support through incentives and regulatory flexibility to facilitate the global transition to biodegradable FADs.

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1 INTRODUCTION

An international workshop on biodegradable FADs (bio-FADs) was organized by ISSF on the 16th and 17th of December 2024, at the San Sebastián Aquarium, Spain. The event gathered 24 participants from a broad geographic and professional spectrum, including fishers, scientists, fleet managers, and sustainability officers representing organizations from South America, Europe, Asia, and the eastern and western Pacific (see list of attendees in Appendix I). The main objective was to review the current state of development, operational characteristics, and performance of bio-FADs, and to promote dialogue and collaboration among stakeholders in tropical tuna purse seine fisheries with diverse regional experiences and operational knowledge.

This workshop built upon earlier ISSF bio-FAD initiatives started in 2016, and was convened in response to the growing need to consolidate recent progress across various fleets testing bio-FADs globally. The exchange aimed to identify common challenges and effective strategies to accelerate implementation of bio-FADs. The meeting was also timely in the context of regulatory developments by tuna Regional Fisheries Management Organizations (t-RFMOs), which have adopted measures to require the exclusive use of bio-FADs of Category I (100% biodegradables) by 2028-2031, depending on the ocean basin, as summarized in Table 1.

The conservation measures adopted by tuna RFMOs to transition to 100% biodegradable FADs follow a stepwise approach based on defined categories reflecting the degree of degradability. These range from Category V, representing traditional FADs that incorporate plastic components, to Category I, which are constructed entirely from biodegradable materials, excluding the geo-locating buoy. The starting point and the timeline for the adoption of each category vary across tuna RFMOs.

- Category I- FADs fully composed of biodegradable materials
- Category II- fully biodegradable with the exception of plastic flotation devices (foam, buoys, etc.)
- Category III- Contain synthetic, non-biodegradable materials in the raft and floatation components while the submerged components (tail) are composed of fully biodegradable materials
- Category IV- Composed of biodegradable surface components excluding floats, and a non-biodegradable tail
- Category V- composed solely of non-biodegradable materials

Table 1. Bio-FAD related conservation measures in t-RFMOs. IOTC: Indian Ocean Tuna Commission; IATTC: Inter-American Tropical Tuna Commission; ICCAT: International Commission for the Conservation of Atlantic Tuna; WCPFC: Western and Central Pacific Fisheries Commission.

RFMO	Entry into Force	Transition Approach	Deadline for Full Category I Compliance	Reference
IATTC	From 2026	Stepwise transition	By 2031*	C- 23-04
WCPFC	–	Encouraged (not mandatory)	–	CMM 2023-01
IOTC	From 2026	Stepwise transition	By 2029	Res. 24/02
ICCAT	From 2025	Stepwise transition	By 2028	Rec. 24-01

*the Commission will evaluate in 2030 whether to mandate that, by 2031, only Category I biodegradable FADs be deployed or redeployed by vessels

2 OBJECTIVES

The primary objectives of the workshop were:

- To evaluate the effectiveness and durability of biodegradable materials and bio-FAD designs tested across different oceans.
- To exchange practical experiences from fishing fleets and identify operational, logistical and economic challenges in the transition to bio-FADs.
- To discuss opportunities for improving design, implementation, and bio-FAD traceability during trials.
- To foster collaboration and discuss recommendations for faster implementation of bio-FADs and compliance with regulatory requirements.

3 WORKSHOP FORMAT

The workshop format consisted of technical presentations on the results of large-scale trials with bio-FADs, followed by focused group discussions on key topics such as bio-FAD performance, material testing and durability, and design optimization (see details of the agenda in Appendix II). The workshop began with a series of presentations providing updates on bio-FAD experiments conducted in different ocean regions and fleets: AZTI presented results from the Indian and Atlantic Oceans with the Spanish fleet; Tunacons shared findings from the eastern Pacific Ocean (EPO) with the Ecuadorian fleet; IATTC provided a regional overview of a large-scale trial involving various fleets operating in the EPO; SPC reported on trials in the Western and Central Pacific Ocean with several fleets; and ISSF presented outcomes from experiments conducted in both the eastern and western Pacific Oceans with U.S. and Spanish (Ugavi) fleets.

While not the central theme, the workshop also explored strategies to reduce FAD loss and abandonment, an issue closely linked to the broader objective of minimizing the ecological impact of lost or abandoned FADs. Discussions incorporated a broad spectrum of perspectives, ranging from technological innovation and empirical knowledge gaps to economic constraints and evolving regulatory requirements.

4 BIO-FAD TRIALS RESULTS

To set the stage for the discussions that followed, results and details of six bio-FAD trials were presented at the beginning of the workshop, highlighting ongoing efforts to test and evaluate non-entangling and biodegradable FAD designs across the three tropical oceans. Of these, four trials have already been completed or have published consolidated results, while two are still ongoing and continue to collect data as part of multi-year initiatives[1]. The trials varied in scale, number of bio-FADs deployed, and geographic context, but all contributed valuable insights into bio-FAD performance, particularly regarding durability, tuna aggregation rates, and drift behavior compared to conventional FADs (con-FADs) that were deployed and monitored together with the experimental bio-FADs (see Table 2 for details). Results from the trials show that the highest bio-FAD deployment efforts have been done in the eastern Pacific Ocean (EPO). Out of the 6 projects presented, three were conducted in the EPO, two in the WCPO and one in the Indian Ocean.

Bio-FAD visit rates and fleet involvement

The percentage of visits to deployed bio-FADs varied significantly across ocean regions and appeared to be influenced by the level of fleet involvement and/or the number of participating vessels. In the Indian Ocean, where a large-scale trial was conducted involving all purse-seine vessels operating in the western region, 160 visits were recorded for 771 deployed bio-FADs, resulting in a visit rate of approximately 20.7%. In the EPO, IATTC trials reported 86 visits to the 780 deployed bio-FADs ($\bar{x}$=11%) and the Tunacons fleet (20-25) visited 23% of their deployed bio-FADs. These rates are high compared to those observed in other trials, such as those in the Western and Central Pacific Ocean (WCPO) and in the EPO involving the Ugavi (Spanish) and US fleets, where visit rates ranged between 5% and 8%. In these latter trials, the number of vessels involved was significantly lower than in the IO and Tunacons experiments. These patterns highlight that trials with broader vessel participation enable more robust data collection, and therefore support more meaningful and reliable conclusions.

Average catch per set

The average catch per set on bio-FADs varied across regions and fleets, ranging from 26 to 53 tons, while catches on conventional FADs (con-FADs) ranged from 32 to 71 tons depending on the trial (Table 2). In the Indian Ocean, the BIOFAD project reported an average catch of 28 tons per set for bio-FADs, compared to 44 tons for con-FADs. In the Eastern Pacific Ocean (EPO), catches on bio-FADs ranged from 26 tons (Tunacons experiment), 34 tons (IATTC trials), to 40 tons (Ugavi). In the Western and Central Pacific Ocean (WCPO), the US fleet and other participating fleets, including those from Chinese Taipei, the Federated States of Micronesia, and South Korea, reported an average catch of 53 tons per set on bio-FADs, compared to 71 tons on con-FADs. It is worth noting that the average catch per set for the entire fleet operating in the Western Pacific Ocean during the trial years was 30 tons, which is lower than the average catch recorded on

[1]Detailed information on these trials can be found in the following documents: Murua et al., 2023 (Indian Ocean); Roman et al., 2023 FAD-07-02 (EPO trials); Moran et al., 2024 (Tunacons trials); Moreno et al.,2024 (Jelly-FAD, Ugavi EPO); Escalle and Moreno 2024 (Jelly-FAD US); Escalle et al., 2024 (Jelly-FAD WCPO fleets).

the tested jelly-FADs[2], with an averagae of 53 tons. These values suggest that bio-FADs can perform at levels comparable to or even exceeding those of con-FADs, depending on the design, fishing practices, and regional conditions. Overall, the results confirm that bio-FADs are capable of aggregating tuna effectively and achieving commercially viable catch rates.

Cost of bio-FADs and conventional FADs.

Cost estimates of bio-FADs and con-FADs varied considerably across trials and regions. In the Indian Ocean, the reported average cost of the most deployed bio-FAD model (excluding the geolocating buoy) was €206, while con-FADs were estimated at €116. In the EPO, depending on the bio-FAD design and whether the fleet built the FADs themselves or outsourced construction, bio-FAD costs ranged from $250 to $605. In the Western and Central Pacific Ocean, bioFAD costs were around 500-550 US$, including materials, shipment and labor/use of facilities; and 300-350US$ for materials only. These differences likely reflect variations in materials used, logistical expenses, and the scale of the trials. The cost of con-FADs also varies widely depending on the fleet. Some Asian fleets invest between $600 and $800 per FAD, whereas fleets that construct their own FADs onboard with crew involvement report costs in the range of $200–$300, again, excluding the geolocating buoy.

Bio-FAD lifetime

Bio-FAD lifetime appears to be one of the major issues related to their implementation. While some bio-FADs have demonstrated functional performance over several months, up to 11 months in the case of a jelly-FAD that was fished in good condition, other trials have reported, in general, a maximum lifespan of only 3-6 months. Fishers indicated that a minimum lifetime of six months is required for bio-FADs to be operationally viable, however some fishers suggested that a duration of up to one year would be preferable. Similar lifespan requirements among fishers from different regions were identified by Moreno et al. (2016). Determining the actual lifetime of bio-FADs remains challenging due to limited observations, inconsistent visits, and the lack of information on unmonitored or abandoned FADs. Current data rely primarily on FADs that were actively fished, providing only a partial view of their durability. There is little to no information on FADs that were deployed but never visited, or those that remained at sea after fishing events or buoy deactivation. This knowledge gap applies equally to con-FADs, prompting in 2024 an IATTC FAD working group recommendation to study their lifespan alongside of bio-FADs.

In some cases, the duration of buoy signal activity has been used as a proxy for FADs' operational longevity at sea. However, this only confirms that the buoy remained active, likely because it was still within the fishing zone and considered a potential fishing opportunity, but does not guarantee that the FAD itself remained structurally sound or functional. These uncertainties highlight the need for larger-scale trials with high vessel participation and standardized monitoring protocols to collect data on FADs lifetime.

[2] The Jelly-FAD is a novel biodegradable FAD concept designed to drift with quasi-neutral buoyancy, minimizing structural stress. It is primarily driven by slow currents at the deeper components of the device. Its movement is primarily influenced by slow currents acting on the deeper components of the device. This concept allows the FAD to perform similarly to a con-FAD, while enabling the incorporation of organic materials in its construction. See Moreno et al., 2023 for more details.

Table 2. Results of large-scale bio-FAD trials together with scientists. Bio-FAD refers to Biodegradable FADs and Con-FAD to conventional FADs;*when available, the average catch per set for the entire fleet over the trial period is provided as reference; ** Lifespan is measured as the age of the oldest set. When no set was recorded, it is based on the date of the oldest visit during which the device was found in good condition (note: other bio-FADs may have remained at sea for longer periods, but were not observed *in situ*). For trials conducted by the US fleet under WCPFC, and the other trials with the WCPO fleets, catch data were analyzed jointly; therefore, the average catch per set is identical for both trials.

Experiment / Region	Years	#vessels	Bio-FAD Design description	Cost (without geolocating buoy)	# bioFADs deployed	# visits	#sets	Average catch per set* (tons)	Max lifetime observed in good condition** (months)	Drift speed similar to con-FADs?	Reference
BIOFAD Project (Indian Ocean)	2017-2019	44 (plus supply vessels)	5 protoypes of conventional design from 5 to 60 m depth. 3 different designs, conventional FAD designs : *Raft* : metal and bamboo; *Tail* : Cotton rope *Floats* : plastic buoys; *Ballast* : iron	Bio-FAD: 206 € Con-FAD: 116 €	771	Bio-FAD: 160 (%21 of deployed FADs) Con-FAD: 123 (17% of deployed FADs)	Bio-FAD: 36 Con-FAD: 32	Bio-FAD: 28 Con-FAD: 44 IO those years: unknown	Bio-FAD: 10 Con-FAD: 10	yes	Murua et al., 2023
IATTC Trials (EPO)	2019-2023	45	3 prototypes of conventional designs from 20 to 60 m depth. 3 different designs: *Rafts* : balsa, bamboo, abacá/cotton canvas; *Tail* : abaca and cotton ropes, bamboo; *ballast:* stones, bamboo.	Bio-FAD: $337-$605 Con-FAD: unknown	780	Bio-FAD: 86 Con-FAD: 112	Bio-FAD: 57 Con-FAD: 145	Bio-FAD: 34 Con-FAD: 32 EPO that year/s: 19-29	Bio-FAD: 4 months Con-FAD: 14 months	yes	Roman et al., 2023 FAD-07-02
Tunacons (EPO)	2021-2023 (ongoing)	25-30	2 prototypes of conventional designsof 20 m depth. *Rafts* : balsa, bamboo, abacá canvas; *Tail* : abaca ropes and canvas and, bamboo; *ballast:* stones, bamboo.	Bio-FAD: - Con-FAD: -	4958	Bio-FAD: 1143 (%23 of deployed FADs) Con-FAD: -	Bio-FAD: 641 (%56 of visited bio-FADs) Con-FAD: unknown	Bio-FAD: 26 Con-FAD: unknown EPO those years: 19-29	Bio-FAD: 5 months Con-FAD: -	unknown	Moran et al.,2024
JellyFAD_Ugavi (EPO)	2021-2023	5	jelly-FAD (cube) of 50 m depth. *Raft* : sumerged with bamboo and cotton canvas; *Tail* : Bamboo, cotton canvas and rope. *Ballast* : iron, stones. *Floats* : plastic floats.	Bio-FAD: $250-$500 Con-FAD: $300	2000	Bio-FAD: 107 (%5,35 of deployed FADs) Con-FAD: 137 (%7)	Bio-FAD: 70 (%65 of visited FADs) Con-FAD: 45 (%33 of visited FADs)	Bio-FAD: 40 Con-FAD: 36 EPO those years: 19-29	Bio-FAD: 11 months Con-FAD: unknown	yes	Moreno et al.,2024 Jelly-FAD construction guide
Jelly-FAD US fleet (EPO and WCPFC)	2022-2024	16	jelly-FAD (cube) of 50 m depth. *Raft* : sumerged with bamboo and cotton canvas; *Tail* : Bamboo, cotton canvas and rope. *Ballast* : iron, stones. *Floats* : plastic floats.	Bio-FAD: $500 Con-FAD: unknown	191	Bio-FAD: 16 (%8 of deployed FADs) Con-FAD: 50 (%26)	Bio-FAD: 15 (%94 of visited FADs) Con-FAD: 50 (%100 of visited FADs)	Bio-FAD: 53 Con-FAD: 71 WCPO those years: 30	Bio-FAD: 2 months Con-FAD: 1 month	yes	Escalle and Moreno 2024
JellyFAD_FSM_Chinese Taipei, Korea (WCPFC)	2021-2024 (ongoing)	16	jelly-FAD (cube) of 50 m depth. *Raft* : sumerged with bamboo and cotton canvas; *Tail* : Bamboo, cotton canvas and rope. *Ballast* : clay, stones. *Floats* : plastic floats.	Bio-FAD: $500 Con-FAD: unknown	95	Bio-FAD: 8 (%8 of deployed FADs) Con-FAD: 0	Bio-FAD: 5 (%62 of deployed FADs) Con-FAD: 0	Bio-FAD: 53 Con-FAD: 71 WCPO those years: 30	Bio-FAD: 2 months Con-FAD: 1 month	yes	Escalle et al., 2024

Smaller trials and outreach benefits

While large-scale trials provide robust performance metrics, smaller-scale experiments involving a greater number of fleets are critical in promoting awareness and capacity building. Trials with limited numbers of bio-FADs but broader fleet participation have facilitated first-time exposure to biodegradable materials and bio-FAD construction for many fishers. These initiatives often begin with workshops that showcase findings from other regions and demonstrate construction techniques, as well as offer a space to discuss the validity and availability of biodegradable materials with fishers. Although modest in scale, these trials have proven effective in breaking down initial resistance, building trust, and generating buy-in across diverse fleets (Murua et al. 2025). This outreach-oriented approach complements large-scale efforts by ensuring that a greater number of stakeholders are included in the transition toward sustainable FAD practices.

5 RESULTS ON GROUP DISCUSSIONS

This section summarizes the main findings, lessons learned, and proposed actions arising from the group work exercises (see Appendix III for details). The activity involved organizing fishers into regional groups and having them respond to a set of ten questions related to bio-FADs. Three groups of fishers and fishing company representatives were conformed based on the ocean participants operate in. *Group 1* included fishers and fleet managers from the eastern Pacific Ocean (EPO). *Group 2* was composed exclusively of fishers from the Indian Ocean (IO). *Group 3* consisted primarily of fishers and representatives from fishing companies active in the Western and Central Pacific Ocean (WCPO). Finally, *Group 4* brought together scientists conducting bio-FAD trials across all three tropical oceans, representing institutions such as IATTC, SPC, AZTI, Tunacons, and ISSF (see Appendix IV for visual documentation).

The following summary presents the responses provided by Groups 1, 2, and 3, which were composed exclusively of fishers and fleet representatives. Their inputs have been analyzed jointly across the different ocean regions. Views from both fishers and scientists (*Group 4*) are included in the discussion section.

5.1 Design and Effectiveness

- *Group 1* (Eastern Pacific Ocean) preferred a traditional design using abaca or Manila Hemp (*Musa textilis*) and rubber-coated rope, but noted that durability is currently insufficient.
- *Group 2* (Indian Ocean) emphasized that there is no one-size-fits-all design; effectiveness depends on the ocean region and seasonality.
- Group 3 (Western and Central Pacific Ocean) presented divergent opinions: some favored the jelly-FAD for its strength and cost-effectiveness, while others advocated adapting existing conventional designs with biodegradable materials. For the Chinese Taipei fleets, following a conservative strategy was

considered more effective, focusing on the integration of biodegradable materials into current FAD designs to enable a smoother transition.

5.2 Trials Assessment

What worked well during trials:

- *Group 1* highlighted the careful material control and traceability of bio-FAD deployments, as well as incorporating captain experience.
- *Group 2* commended the tracking system used to follow both bio-FADs and their paired con-FADs, even after ownership changes.
- *Group 3* praised the strength of cotton rope in jelly-FADs used in the western Pacific, the commitment of fleets and the risk undertaken despite operational constraints, and acknowledged the overall research efforts conducted.

What went wrong during trials:

- *Group 1* cited several issues: resistance to change by fishers, lack of technical support in some regions, weak company oversight, inadequate cooperation, unreliable data from captains, and insufficient trials.
- *Group 2* maintained a constructive view, stating that every step forward was valuable.
- *Group 3* mentioned operational challenges such as bio-FAD deployments and storage being more difficult, limited tracking of deployed units, and the need for better dissemination of bio-FAD initiatives.

5.3 Key success factors

- *Group 1* underscored continuous financial support of shipowners to fishers and other institutions (NGOs, governments) to the fishing industry, durable materials (minimum lifespan of six months), and rigorous data collection and control of the trials by the fishing companies.
- *Group 2* stressed transparency, inter-stakeholder collaboration, traceability of experimental FADs, and the role and influence of regulatory bodies (t-RFMOs) and NGOs.
- *Group 3* pointed to the importance of raising awareness among fleets, the price of bio-FADs and strong fisher involvement as key enablers.

5.4 Main challenges faced and weaknesses

- *Group 1* identified material durability, inter-company collaboration, and sector-wide alignment as major challenges, along with awareness-building and funding.
- *Group 2* did not provide specific input for this question.
- *Group 3* emphasized the difficulty of making robust structures using biodegradable materials, overcoming conservative attitudes in fishers, and motivating shipowners to invest time and resources in trials.

5.5 Proposed adjustments and solutions

- *Group 1* suggested improving materials through further research, better communication within companies, more bio-FAD construction workshops, and transparency among fishers.
- *Group 2* proposed standardized protocols, closer coordination, and shared databases of experiments and lessons learned. They also requested regulatory clarity and cooperation with bio-based and organic material suppliers.
- *Group 3* advocated excluding experimental bio-FADs from active FAD limits, and promoting large-scale, externally funded projects as incentives.

5.6 Specific areas needing improvement (design, trials, etc)

- *Group* 1 emphasized the need to improve the sourcing of organic materials and the techniques for handling and deploying bio-FADs, while considering the current conventional FAD design to be adequate.
- *Group 2* stressed the need for longer bio-FAD lifespans and adaptable designs based on environmental conditions.
- *Group 3* called for improvements across the board—design, materials, handling, and recovery.

5.7 Lessons learned

- *Group 1* concluded that collaborative efforts are more effective than isolated initiatives, and that ocean-specific adaptations are necessary.
- *Group 2* noted that current durability is insufficient and has tangible operational impacts.
- *Group 3* stated that more testing is needed before drawing conclusions about the best bioFAD designs.

5.8 Recommendations to advance on the implementation of bio-FADs

- *Group 1* recommended institutional and NGOs' funding, scientific support, strong fleet commitment, and standardization of designs and materials.
- *Group 2* echoed the need for durability, but highlighted economic constraints, especially under current FAD limits. They called for t-RFMOs incentives and collaborative trials to increase statistical robustness.
- *Group 3* emphasized the need for new suppliers of organic materials, expanded training workshops, and improved information sharing among fleets.

5.9 Future outlook on transition timelines (2025/26-2028/30):

- *Group 1*: The 5-year timeline is a challenge particularly given material limitations, but acceptable if information and effort are shared across fleets, emphasizing that the deadline must be met regardless of the challenges. Incentives could facilitate the transition, such as modifying FAD limits (e.g.,

counting 3 bio-FADs as 1 con-FAD). Flexibility is important, but having a deadline is useful to accelerate progress.
- *Group 2* called for more flexibility, citing fragile financial conditions of some fishing companies and lack of incentives.
- *Group 3* expressed skepticism that the timeline allows for a sound implementation process, but acknowledged the obligation to comply with the measure.

5.10 Impact on fishing strategies

- *Group 1* foresaw no major changes to strategy but expected an increase in FAD deployments due to shorter lifespans.
- *Group 2* Proposed shared strategies among fishing fleets, such as joint-use of FAD recovery vessels to overcome the shorter lifespan of bio-FADs and increase the number of FADs in the water by retrieving those that would otherwise be lost.
- *Group 3* reported no anticipated changes in fishing strategy, apart from reducing pollution inputs to the marine environment.

6 DISCUSSION

This section summarizes the discussion of all groups, including the scientist group. The working group discussions revealed both convergence and divergence in experiences and viewpoints among fleets operating in different ocean basins. This diversity is expected, given that some fleets have already conducted extensive trials with bio-FADs, while others have yet to begin. Additionally, different ocean basins demand different FAD designs, and even within the same ocean, design requirements can vary by subregion and/or fleet. Cultural factors also play a role: certain countries and fleets are more deeply rooted in traditional practices, whereas others are more open to adopting change. Despite these regional and cultural differences, several key common issues emerged across the groups.

6.1 Technical issues

A number of technical challenges were raised during the discussions. One key issue was the need for greater clarity regarding the use of certain materials, such as metals. Some of the resolutions include footnotes referencing degradability standards as in the case of, IATTC resolution 23-04; however, these clarifications appear insufficient to clearly define what constitutes a biodegradable material and what does not. For instance, some fishers proposed the use of iron as a potential option for raft construction. While iron is a naturally occurring metallic element and its oxidation is a natural process, it is not considered organic (derived from biological sources, such as plants (e.g.,.abaca, cotton, jute, wood) or animal (e.g., wool, silk, etc)). In addition, corroded iron structures stranded on pristine beaches can cause considerable visual and potentially economic impacts, particularly in coastal areas that rely on tourism. When assessing the impacts of FADs, it is essential to consider not only their environmental effects but also their visual footprint and potential interference with other economic activities. Considering all these factors, scientists pointed out that iron does not appear to be a suitable alternative.

The impacts of bio-based materials remains unclear, as some may contain additives that could pose risks as do conventional plastics. In addition, certification schemes to assess biodegradability in marine environments are limited and normally refer to primary materials and not to final products , and many bio-based materials require specific conditions to degrade (e.g., high temperatures), which are not typically found at sea. Thus, environmental and visual impacts will occur before any degradation begins.

There was also debate around FAD design strategies. Some participants suggested that modifying conventional designs to incorporate biodegradable materials could facilitate the transition, as these would be more easily adopted by fleets. However, these designs have thus far failed to meet the six-month durability benchmark, reinforcing the need to identify stronger organic materials. One innovative approach, the jelly-FAD, introduced a paradigm shift (Moreno et al., 2023). Rather than reinforcing conventional structures, this design reduces structural stress entirely, moving away from the tension-prone configuration of traditional FADs. By minimizing mechanical stress, it expands the life range of usable organic materials, even those that are not inherently strong or durable. However, it was acknowledged that such novel designs may face initial resistance from fleets.

These differing approaches underscore that there is no one-size-fits-all solution for the development of fully biodegradable FADs. Each fleet may need to chart its own course depending on its fishing strategy and cultural context. Nevertheless, it was emphasized that fleets should be informed of the outcomes of previous trials before initiating new ones, to avoid unnecessary duplication of efforts and to build on existing knowledge.

As recommended by the 8th IATTC FAD Working Group, the IATTC staff has recently investigated different FAD lifespan dynamics in the EPO for both bio-FAD and con-FADs (IATTC, Document FAD-09-02). This study provides a description of the spatiotemporal attributes of these dynamics (e.g., deployments, sets, catches, lifespan) by FAD type (bio-FADs and con-FADs), to better understand the lifespan and anticipate the potential effects of the implementation of bio-FADs in the EPO. Based on observer data, the study found that 80% of deployed bio-FADs had lifespans of less than 50 days (measured as the number of days between deployment and the last recorded interaction in the database). Similarly, 76% of con-FADs also had lifespans below 50 days, indicating only a minor difference between the two types. Only a small proportion of both bio-FADs and con-FADs were observed with lifespans exceeding 12 months.The results of this study were not available at the time of the workshop and hence, were not discussed with the broader group.

With regard to materials, not all cotton ropes or fabrics perform equally. The issue lies not only in the type and quality of fiber used, but also in the quality of the manufacturing process. Just as some cotton T-shirts retain their shape after 40 washes while others lose consistency in the shape after only two, the performance of cotton-based materials in bio-FADs can vary significantly depending on the manufacturer. Higher quality products likely require greater initial investment, but can result in longer-lasting and more effective bio-FADs. Ultimately, each company must determine the strategy that best aligns with its operational needs and priorities.

Fishers also noted that bio-FADs are more expensive. Indeed, organic ropes and fabrics typically cost more than the synthetic alternatives currently in use (which were often recycled from fishing gear or nets). However, achieving sustainability often entails higher financial and operational costs across sectors. In the case of bio-FADs, these costs may go beyond the materials themselves and include the need for more careful handling, deployment, and onboard storage. Such additional efforts are comparable to those in other fields: for example, organic farming requires more manual labor and soil management, eco-certified tourism demands investments in water-saving technologies, waste separation, and renewable energy, and green-certified manufacturing often involves more complex sourcing, logistics, and compliance mechanisms. One potential solution for reducing the cost of bio-FADs is to promote simpler designs that require fewer materials, thereby lowering both costs and the environmental impact in case of loss or stranding. In this regard, scientists emphasized that the most suitable design would be one that minimizes environmental and visual impacts when stranded. While fishers tend to prioritize the fishing efficiency of FADs, scientists participating in the workshop highlighted that the best bio-FAD is one that both aggregates fish effectively and has the lowest environmental footprint. This contrast illustrates how different stakeholders may have fundamentally different perspectives on what constitutes a “good” bio-FAD design, emphasizing the need for collaborative approaches that balance operational needs with ecological sustainability. Scientists also introduced more forward-looking concepts, including designs for bio-FADs that could self-destruct or disintegrate before stranding, as a way to eliminate coastal impacts. Innovation is a key driver for advancing sustainable fishing, and while some of these ideas may seem like science fiction at present, keeping them in mind opens the door to future research opportunities and can inspire the development of transformative solutions as technology and materials evolve.

Scientists emphasized the importance of strict quality control in the construction of bio-FADs. Experience from trials has demonstrated that ensuring proper construction, with close attention to critical design details, is essential for performance evaluation. When bio-FADs are delivered with manufacturing defects or do not fully comply with the intended specifications, the effectiveness of the trial is compromised from the outset, potentially leading to premature failure and misleading results. It was therefore recommended that, given many bio-FADs are assembled in FAD yards, companies monitor construction quality control at the production stage to improve bio-FADs´long-term performance.

Finally, there was unanimous agreement on the importance of inter-fleet collaboration to expand the scale and representativeness of bio-FAD trials. Additionally, the need to raise awareness among fishers on the purpose and relevance of these trials, to ensure proper handling, deployment, maintenance, and reporting was highlighted.

6.2 Shared Priorities and Agreements

All three fisher groups emphasized the need to improve the durability of bio-FADs, which remains a key technical limitation undermining operational confidence. There was broad consensus on the importance of traceability during trials from both fishers and shipowners. Participants also highlighted the value of stakeholder collaboration, including hands-on workshops and guidelines for bio-FAD construction. In addition, there was a shared recognition of the need for enabling mechanisms, particularly financial incentives, to support ongoing trials and promote wider adoption. While most participants agreed that the use of bio-FADs is unlikely to significantly alter fishing strategies, the reduced lifespan of these devices may require more frequent deployments to maintain effective fishing effort. In this context, one fleet proposed the use of shared recovery vessels to retrieve bio-FADs that would otherwise be lost, helping to sustain operational FAD density at sea. In a similar line, scientists proposed incentive-based systems in which fishers could be rewarded for recovering and maintaining FADs that might otherwise be abandoned. Scientists also highlighted the relevance of incorporating circular economy principles and applying Life Cycle Analysis (LCA) to compare different bio-FAD designs and deployment strategies, thereby guiding more sustainable decision-making across the bio-FAD lifecycle.

6.3 Contrasting Perspectives

Differences across fleets also revealed contradictory positions within and between groups. For example, in the Western Pacific group, some participants described the jelly-FAD as an effective, durable, and low-cost solution that performed well during trials in fishing conditions. Yet others in the same group expressed a preference for maintaining their current traditional FAD designs and simply replacing materials with biodegradable alternatives. This reflects a broader hesitation toward adopting new FAD designs, even when viable options are available. Similarly, while several participants acknowledged the urgency of transitioning to bio-FADs and expressed support for ongoing trials, others highlighted significant operational, cultural, and economic barriers that limit their capacity to scale up these efforts. Among the key challenges mentioned was the daily pressure from shipowners on fishers to maintain catch performance, which can discourage experimentation with alternative designs perceived as less trustworthy or lacking proven effectivemess. These internal divergences suggest that adoption pathways are shaped not only by technical feasibility, but also by cultural attachment to established fishing techniques, perceived risks, shipowners´ support to fishers and varying levels of openness to new technologies. These findings suggest that the transition to bio-FADs is not solely dependent on technological readiness. A coordinated approach is needed, one that strengthens technical capacity while also addressing key human factors such as internal communication within companies, interaction between crews and management, and effective dialogue with scientists.

6.4 Human and Technical Dimensions to advance the transition.

When discussing how to accelerate the transition to bio-obiodegradable FADs, participants consistently referred to both technical and human factors as critical to success. On the technical side, the most frequently cited elements included: (1) the need for improved **materials**, particularly those offering sufficient durability (with a minimum effective lifespan of six months often mentioned); (2) the importance of robust FAD **designs** adapted to specific oceanographic conditions; (3) **traceability** systems that allow reliable monitoring of bio-FAD and con-FADs performance during trials; and (4) standardized **protocols** for experimental FAD data collection. A group also emphasized the need for better understanding of echosounder biomass estimates under experimental FADs, to compare the performance of bio-FAD and con-FADs.

On the human side, groups highlighted a range of behavioral, cultural, and organizational issues that influence the success of trials and future adoption. These included: (1) **resistance** to change among captains and fleets, particularly in regions with deeply rooted traditions; (2) the need for stronger **commitment** and engagement from both fishers and company management, including relieving the catch performance pressure frequently placed on the captains; (3) the importance of **transparency** in data reporting, especially regarding FAD tracking and performance; and (4) the role of **collaboration**, both within fleets and across companies, as a driver of progress. Several participants also mentioned the lack of internal communication within companies, such as the absence of feedback mechanisms to inform captains of trial results or what other vessels are doing. Workshops and peer-to-peer learning were seen as effective ways to bridge this gap. Participants consistently recognized the value of sharing information between fleets, ocean regions, and stakeholders. This is not only a technical requirement (e.g., for building databases or improving material testing) but also a cultural necessity for building trust, harmonizing practices, and encouraging broader participation in bio-FAD implementation.

These findings suggest that the transition to biodegradable FADs is not solely dependent on technological readiness. A coordinated approach is needed, one that strengthens technical capacity while also addressing key human factors such as internal communication within companies, interaction between crews and management, and effective dialogue with scientists. It is essential that captains understand the objectives of ongoing trials, are informed about results from other fleets, and are aware of the regulatoryframework, including bio-FAD implementation dead-lines. While technical barriers can often be addressed through innovation and research, overcoming human challenges will require sustained communication, transparency, and alignment across all levels of the operation, from the crews who build and deploy the FADs, to the captains, technical staff, and company managers, to ensure shared objectives and consistent practice.

6.5 Incentives

In general, incentives were framed by fishers as external mechanisms, with particular emphasis on the lack of incentives from t-RFMOs. The most frequently cited example was the absence of flexibility in current FAD limits, for instance, not exempting experimental bio-FADs from the active FAD count, which discourages fleets from engaging in trials that may reduce fishing opportunities.

Only scientists mentioned broader external drivers, such as market-based incentives (e.g., MSC certification), international regulations (e.g., MARPOL), pressure from coastal states affected by stranded FADs, and NGO pressures. These layered pressures were seen as complementary to t-RFMOs measures, and in some cases as more demanding than current t-RFMOs timelines.

It was also mentioned the lack of flexibility from t-RFMOs in the transition timeline to 100% bio-FADs. However, this perception contrasted by the recognition, within at least one group, that a clear and fixed deadline is also necessary to move forward. Without a deadline, there is little external pressure for fishers to take the time, risk, and financial investment required for bio-FAD trials. This apparent contradiction illustrates a familiar trade-off: while deadlines may appear rigid, they are often essential to drive commitment and concrete action. It is also worth noting that research on bio- FADs began as early as 2009, and the first formal reference within IATTC dates back to 2013, more than a decade ago. The perception of abruptness within fishing companies may stem from limited awareness of this long-standing scientific discussion, the lack of communication to fishers regarding debates within t- RFMOs, and, as mentioned earlier, the absence of a clear trigger for change. Without such a trigger, fishers may be less inclined to take early action toward improving the sustainability of their fishing practices.

Interestingly no group explicitly mentioned environmental impact reduction or the goal of minimizing plastic pollution as an intrinsic motivation or value-based incentive. In one group, when asked whether the adoption of bio-FADs would change their fishing strategy, participants replied that "*the only thing that will change is that we will stop throwing plastic into the ocean*." While this suggests an implicit awareness of environmental responsibility, such motivations were not articulated as primary drivers of change in group discussions.

However, in informal conversations, scientists have noted that many fishers do express a personal recognition of the need to preserve the ocean and reduce pollution. Still, they emphasize that change must happen collectively and fairly across fleets and regions, including other fishing gears such as driftnets, longlines etc. The principle of "same rules for everyone", a level playing field, is repeatedly cited as a prerequisite for action. This suggests that environmental values are present at the individual level but are not sufficient on their own to drive change unless reinforced by collective rules and shared obligations.

7 CONCLUSION

The workshop highlighted both the technical feasibility and socio-cultural complexity of transitioning to bio-FADs. The findings confirm that bio-FADs can match con-FADs in tuna aggregation performance, but progress is often constrained by limited durability, higher costs, and inconsistent deployment and bio-FAD monitoring practices. Importantly, the transition is not only a matter of innovation or regulation, it is a socio-cultural and organizational challenge within fishing companies. Effective implementation will require coordinated efforts that combine improved materials and designs, standardized protocols, and transparent collaboration across fleets and institutions. Incentive mechanisms and regulatory clarity will be key, but also the willingness of fishers, managers, and scientists to engage in dialogue and mutual learning. While immediate operational pressures often dominate decision-making, the long-term objective of reducing FAD-related impacts must remain central. Supporting innovation, fostering peer-to-peer knowledge sharing, and integrating both ecological and operational criteria into bio-FAD design will be essential.

Acknowledgements

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APPENDIX I. Workshop attendee list

Name	Affiliation	Position
Olivier Allot	Sapmer, France	Fisher
Louis Valentin	CFTO, France	Fisher
Damien Dugay	Sapmer, France	Fleet manager
Iñaki Munitiz	Nirsa, Ecuador	FIsher
Zigor	Nirsa, Ecuador	FIsher
Leonardo Aguirre	Nirsa, Ecuador	Fleet manager
Henry Chen	Tri Marine, Taiwan	Sustainability Officer
Warren Chen	Lung Soon Ocean Group, Taiwan	Fleet manager
Lary Acebedo	New Prosperity Fishery, Taiwan	Operation Coordinator
Joseba Blanco	Atunera Dularra, Spain	Fleet manager
Ane Iriondo	Echebastar, Spain	Sustainability Officer
Mikel Monasterio	Echebastar, Spain	Fleet manager
Slavko Mislov	Caroline Fisheries Corporation, Croatia	Fisher
Julen Gabantxo	Albacora, Spain	Fisher
Iratxe Diaz	Albacora, Spain	Sustainability Officer
Xabier Larrozea	Albacora, Spain	Fisher
Jon Lopez	IATTC, USA	Scientist
Lauriane Escalle	The Pacific Community, New Caledonia	Scientist
Jefferson Murua	AZTI, Spain	Scientist
Iker Zudaire	AZTI, Spain	Scientist
Guillermo Moran	Tunacons, Ecuador	Scientist
Marlon Roman	IATTC, USA	Scientist
Hilario Murua	ISSF, USA	Scientist
Gala Moreno	ISSF, USA	Scientist

APPENDIX II. Workshop agenda

Location: Aquarium of San Sebastian (**https://maps.app.goo.gl/9jfibjkc3ygVNC4x7**)
Dates: December 16 and 17

Monday, December 16

9:00 Start of the day

- **9:00-9:30** Welcome and introduction to the workshop
- **9:30-10:30** What makes a FAD productive?
- **10:30-12:00** Research on biodegradable FADs:
  - AZTI: Indian and Atlantic Oceans, Spanish fleet
  - Tunacons: Eastern Pacific Ocean, Ecuadorian fleet
  - IATTC: Eastern Pacific Ocean, various fleets
  - SPC: Western Pacific Ocean, various fleets
  - ISSF: Eastern and Western Pacific Oceans, US and Ugavi fleets
- **12:00-13:30** Fleet experiences with biodegradable FADs

13:30 Lunch break

- **14:30** Research on biodegradable materials (biodegradable ropes, fabrics, biodegradable flotation and biobased materials)
- **15:00** Group work: conclusions to date

17:00 End of the day

Tuesday, December 17

9:00 Start of the day

- Recap of the previous day
- **9:30-11:00** Group work: Design and testing of biodegradable FAD structures
- **11:30-13:00** Additional necessary actions: Reducing loss and abandonment
- Evaluation and closing of the meeting

13:30 Lunch
End of the workshop after lunch

APPENDIX III. Group exercise questions on bio-FADs

What conclusions can we draw so far?

Design and effectiveness:

1. Which type of BIOFAD do you consider the best, and why?

Test analysis:
2. What was done well during the tests?
3. What was done poorly during the tests?
4. What were the key factors?

Challenges and weaknesses:
5. What are the main challenges that fishers face with biodegradable FADs?

Opportunities for improvement:
6. What adjustments or changes do you propose to address the identified challenges?
7. Which specific aspects need improvement? (Design, materials, handling, implementation, etc.)

Lessons learned and proposals:
8. What key lessons have we learned from the tests carried out in different oceans?
9. What specific recommendations can you propose for improving and adopting biodegradable FADs in the future?

Future perspectives:
10. Is the timeframe proposed by the RFMOs (2030–2031) to transition towards biodegradable FADs reasonable?

11. How do you think the fishing strategy might change when using BIOFADs?

The questions raised can be addressed from various perspectives, such as technical (FAD structure, materials), logistics, responsibilities assumed by the different stakeholders, or any other approach. Each group is encouraged to analyze and discuss the questions from multiple viewpoints, taking into account both practical aspects and human/organizational dynamics, in order to propose applicable solutions and recommendations.

APPENDIX IV. Visual documentation of the workshop


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Recursos o apoyo necesario / necessary resources or support
Limits/Límites
Benefits/Beneficios
Visit/Visita
Catch/Pesca/
Captura
Other/Otro