Preliminary assessment of the behaviour of drifting FADs during stranding events and costs of a recovery vessel at sea

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EXECUTIVE SUMMARY

Each year, drifting Fish Aggregating Devices (dFADs) used by purse-seine tuna fleets are lost or abandoned at sea, and some of them strand in coastal areas. We present, for the first time, experiments that simulate the stranding of different dFAD types characteristic of the Indian, Atlantic and Pacific Oceans in a non-sensitive coastal site, to better understand the mechanisms of interaction of their structures with the seabed. The submerged part of the dFADs, especially the ballast at the lower end, generated impacts on the bottom even when the materials were biodegradable. This information is important to improve dFAD designs if the goal is to minimize their physical impact on sensitive habitats such as coral reefs. We also examine the potential operating costs of an at sea FAD retrieval programme to reduce the number of dFADs reaching the coast, which could complement existing land-based FAD recovery efforts.

1. INTRODUCTION

Fish Aggregating Devices (FADs) are routinely used by tropical purse-seine tuna fleets to improve fishing opportunities (Wang et al., 2020; Castresana et al., 2025). However, their loss or abandonment can produce ecological impacts, including marine litter, damage to sensitive habitats such as coral reefs, and socioeconomic conflicts in coastal areas (e.g., tourism) (Balderson and Martin, 2015; Schiller et al., 2025). Both the tuna purse-seine industry and scientists and managers have identified this impact and begun to implement corrective measures. For example, regulations aimed at limiting the negative impacts of dFADs include limits on the number of active dFAD buoys per vessel, temporary closures/seasonal bans on fishing on dFADs, bans/limits on auxiliary support vessels, and timelines for transitioning to fully biodegradable dFADs (Pons et al., 2023; Zudaire et al., 2023).

A further step in this direction is the support by tuna Regional Fisheries Management Organizations (RFMOs) for member States to initiate voluntary FAD recovery programmes through cooperative initiatives among fishing vessels operating in their areas, or vessels implementing projects to recover such dFADs (Herrera et al., 2021; Murua et al., 2025). The aim of these collection programmes is not to restrict normal fishing operations (e.g., forcing tuna vessels to travel long distances to retrieve their own dFADs) nor to increase fishing efficiency (e.g., vessels doing dFAD maintenance for fishing fleets), but rather to encourage the collection of drifting dFADs for transport to port for recycling or final disposal. In addition, the IATTC is the first RFMO to require dFAD owners to keep the GPS of satellite buoys active once they leave certain fishing areas (south of 10°S and west of 100°W), without those buoys counting toward the daily limit of active buoys per vessel, in order to know the position of the dFADs and facilitate collection by FAD recovery programmes (Res. C-25-07). With real-time positions of these dFADs outside fishing areas, they would no longer be considered lost or abandoned objects, because they continue to be monitored by RFMOs and collaborating FAD recovery programmes. Reporting of information associated with dFAD recovery activities is also established through inclusion in databases or specific forms, for purely scientific purposes.

FAD retrieval programmes are emerging as a key tool to mitigate the negative impacts of FAD structures, either by intercepting them before they reach the coast, removing them once beached, or even recovering them at sea. If the different retrieval options were to be prioritized, at sea retrieval would be the preferred option because, at that stage, the dFAD structure, having not interacted with the seabed or sunk, has minimal impact. Despite this, all existing retrieval programmes in the Pacific currently operate from land and none operate at sea (Moreno et al., 2024). In the Indian Ocean, an industry-led initiative carried out an at sea collection for one company's dFADs by a support vessel with positive results (i.e., 128 dFADs in 51 days) (Alkorriz et al., 2025). An at sea FAD retrieval programme is considered to require greater investment (e.g., larger vessels and higher fuel consumption); however, with detailed planning based on dFAD drift patterns, its efficiency in terms of dFADs recovered per year could be high. Such effectiveness would be affected by multiple parameters, such as the ocean areas to be covered by the retrieval vessel(s), or the number of companies collaborating by providing dFAD position data. It would be useful to estimate the associated costs and investigate which zones and seasons would be optimal for implementation by ocean basin, in order to evaluate feasibility should funding become available.

The second-best option would be retrieval by an on-land program prior to stranding. However, many of these programmes have a limited operating range, with small vessels constraining their travel capability, onboard space and capacity to lift large dFADs. Having multiple recovery programmes in coastal areas, both on the mainland and across island groups, would be desirable. Finally, retrieval once dFADs have already stranded implies that the physical impact on the coastal seabed has already occurred, or that multiple impacts may have occurred in the case of re-stranding (Mourot et al., 2025). There is, however, very little information available on this latter scenario because, when a stranded dFAD is recovered (MacMillan et al., 2022), it is difficult to determine whether it previously stranded elsewhere. For example, if a raft (i.e., the surface part of the dFAD) is found on a reef, one may assume that the tail (i.e., the submerged part of the dFAD) may have previously impacted a deeper area (e.g., 50–60 m), becoming lodged and eventually due to currents and wave action the floating part detached. However, because there are no real-time studies of dFAD stranding (land-based programmes usually attempt to recover dFADs immediately after they are located), the contact dynamics of the different dFAD structural types with the seabed remain unknown (Uyarra et al., 2025). With the aim of developing dFAD designs that minimize their impact and facilitate retrieval, this study seeks to characterize dFAD–seabed interactions and their implications for retrieval.

2. METHODS

2.1. STRANDING OF dFADs NEARSHORE

This study investigated the interaction of three dFAD types with the seabed in experiments conducted on rocky bottoms along the Cantabrian coast (Spain). Below, we describe the working areas and the characteristics of each dFAD type, as well as the modifications made to adapt them to depths that were safe for divers. The three prototypes represent the most characteristic dFAD models in the Indian Ocean (Cage and Raft) and in the Atlantic and Pacific Oceans (Sails). The three prototypes were built mainly with biodegradable materials (except for the surface floats and the metal frames), given that the Indian Ocean, Atlantic and Eastern Pacific RFMOs currently have implementation timelines for fully biodegradable dFADs for 2028–2030. Therefore, it made more sense to learn how these biodegradable materials behave, rather than the synthetic materials that are being phased out.

2.1.1. STUDY AREA

To assess how the different dFAD types interact with the seabed, Pasaia Bay in the Basque Country (43° 19′ 30″ N latitude and 1° 55′ 00″ W longitude) was selected as the test area. The following factors were considered when choosing the location:

- Flat but irregular bottoms and sloping bottoms with algal and macro-invertebrate cover, similar in structure to bottoms that dFADs commonly interact with in tropical waters (e.g., coral reefs). The authors of this study have this knowledge, as they have worked on previous dFAD drift studies in the Indian Ocean.

- Proximity to AZTI’s facilities to (i) transport the dFADs using the organization’s own vessel, and (ii) return to shore easily if additional equipment was needed.
- A sheltered area to ensure that the work could be carried out on the planned dates, since these innovative tasks require diving and the Cantabrian Sea is exposed to demanding and rapidly changing ocean-meteorological conditions.

Within Pasaia Bay, the most suitable area to conduct the experiment was selected, considering exposure to oceanographic conditions and the intrusive nature of the experiment, since it could cause real damage to the environment; the experiment and the chosen area sought to minimize such impacts. To that end, the area marked with the red arrow (Figure 1) was selected: a sheltered zone that shows signs of degradation but still has the presence of algae and macro-invertebrates.

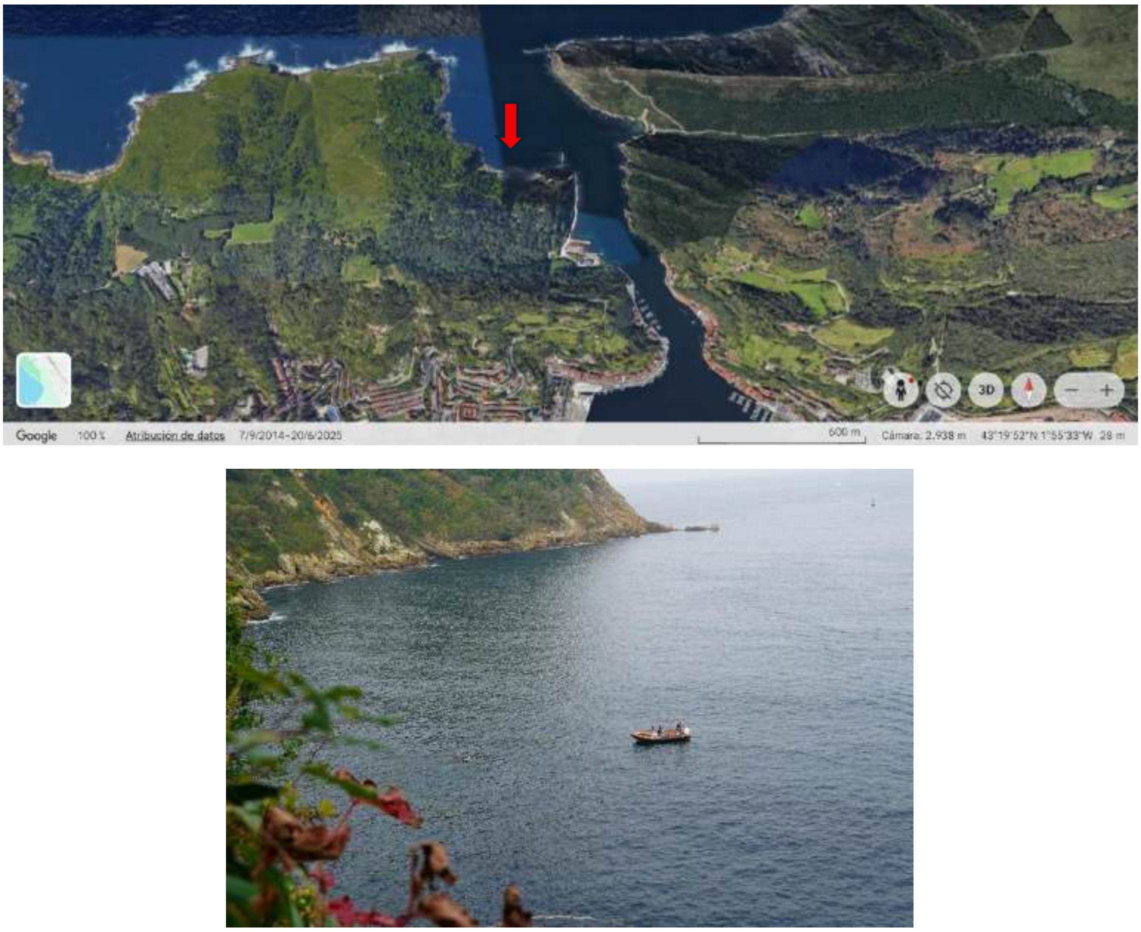

Figure 1. Map of Pasaia Bay showing (with an arrow) the dFAD stranding experiment area (the outer face of the Puntal of Pasaia San Pedro) (top) and a panoramic view (bottom).

The seabed structure in this area included an almost flat but irregular zone at a depth of 7–12 m, resembling a “bank reef”, and a zone with a constant slope resembling a “slope reef”. Due to this relatively shallow depth, the deeper dFAD types such as the “Raft” and “Sails” models—which normally extend to 30–50 m—had to be modified by shortening the tail, thereby enabling the experiment to be conducted to study how different parts of the dFAD impact the seabed.

2.1.2. TYPES OF dFADs

2.1.2.1. Cage-type dFAD

The cage-type dFAD is so named because it consists of a semi-submerged cube with four or five canvas walls that form a cell- or cage-like structure (Figure 2).

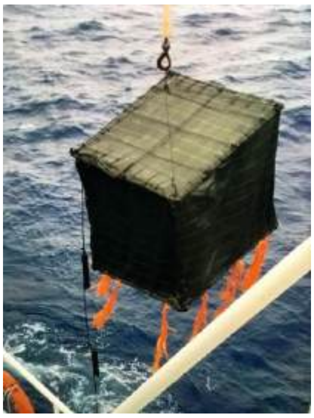

Figure 2 – Cage-type dFAD being deployed in the Indian Ocean (left) and a schematic drawing of a Cage-type dFAD (right).

The cage consists of two metal frames that give it its cubic structure. The metal frames are connected to each other by ropes/lines, and the sides and top of the cube are covered with canvas, here cotton. The cube is suspended from a drop line connected to the satellite buoy, also using a cotton rope (brand Itsaskorda), with 5–7 surface floats that provide buoyancy. In some cases, attractors are added to the cube (frayed ropes and pieces of coloured sackcloth or fabric). In this case, attractors were not added because they are not an essential part of the object and this device was to be used for stranding experiments rather than to attract tuna (Figure 3).

Figure 3 – Cage-type dFAD hoisted onto the vessel for experimental trials.

The material specifications for the “Cage” model were as follows:

- Cotton cord, 10 mm diameter
- Twisted un-waxed cotton rope, 18 mm diameter
- 100% cotton canvas, 5 m of 1.80 × 1.0 m
- Galvanized iron metal frame
- Nylon reinforcement at the corners
- 5 floats with two lugs/eyes

Considering the drop line and the cube structure, the total depth of the dFAD is relatively shallow, extending about 5–10 m below the sea surface.

2.1.2.2. Raft-type dFAD

The other dFAD type used in the Indian Ocean is the raft model, also known as “kite” or “deep” type. These dFADs reach greater depths than cage-type dFADs, typically extending 30–50 m, with the lowest point being the ballast or weight. Current raft models are also semi-submerged, with a drop line fitted with synthetic floats that prevent it from sinking, and a raft—typically made of bamboo or wood—with an extra float at each corner to provide buoyancy (Figure 4).

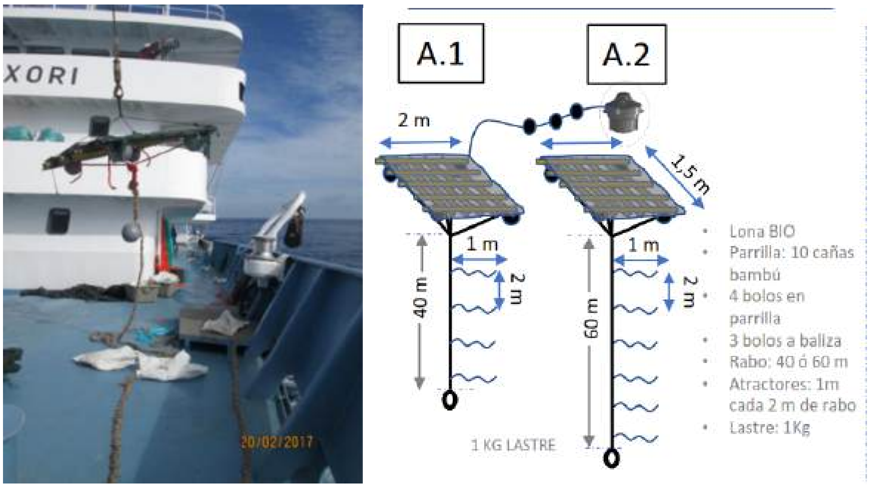

Figure 4 – Raft-type dFAD in the Indian Ocean (left) and schematic drawings of raft-type dFAD models of different depths (right).

Figure 5 – Typical ballast on a raft-type dFAD, consisting of a metal purse-seine wire ring covered with synthetic canvas.

A synthetic or cotton line (as in this experiment) hangs from the raft and extends down to a maximum of 50 m, ending with a weight—typically a ring made out of a piece of purse-seine cable or a metal chain—which keeps the structure vertical in the water. In this experiment, a concrete brick was used as a biodegradable alternative weight (Figure 6).

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Figure 6 – Raft-type dFAD with a concrete block ballast.

Construction materials for the “Raft” model:

- Cotton cord, 10 mm diameter
- Twisted un-waxed cotton rope, 18 mm diameter
- 100% cotton canvas, 1 m of 1.80 × 1.80 m
- Bamboo canes, 5–7 cm diameter
- Nylon thread reinforcement at the corners
- Weight: 10 kg concrete brick
- 6 floats with lugs/eyes

Due to the shallow depth of the experimental area, the submerged length was shortened by tying off part of the rope that forms the tail (Figure 7). In this way, we avoided the dFAD touching the bottom immediately upon deployment.

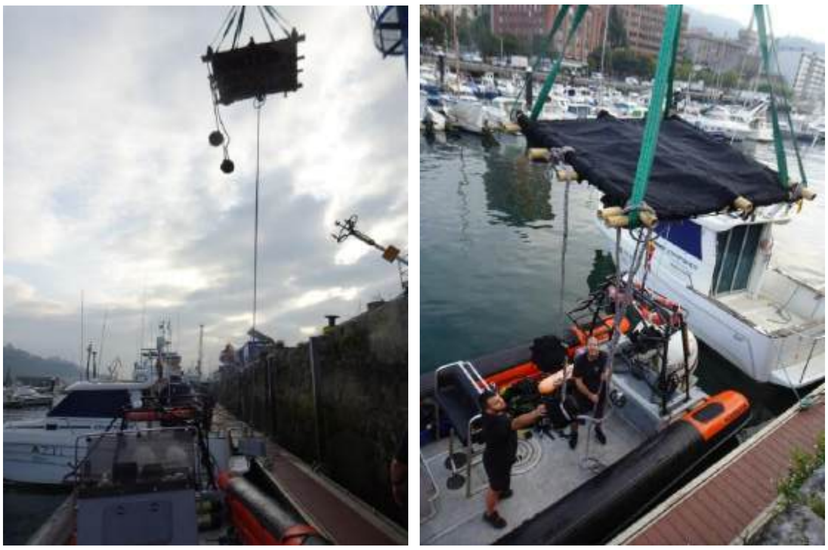

Figure 7 – Experimental raft-type dFAD with a shortened cotton-rope tail.

2.1.2.3. Sails-type dFAD

The “sails” model is named after its configuration, consisting of a dFAD with three canvas panels or “windows” located along the tail, which provide resistance to currents and thereby slow the object’s drift. At the surface, the dFAD has a bamboo raft and floats (e.g., net corks, PVC tubes or buoys), which are in turn covered by a canvas or bamboo strips (see Figure 8).

Figure 8 – Sails-type dFAD characteristic of the Eastern Pacific with a bamboo frame raft and extra PVC flotation (left) and a three-sail tail in the net yard of the port of Manta (Ecuador) (right).

In the experiment, a raft with bamboo flotation and pieces of paulownia wood (known for its high buoyancy) was used, covered by a black cotton canvas to make the dFAD more biodegradable (Figure 9). Cotton was used both for the tail lines that hold the sails and for the sail canvases. For the ballast, a bamboo cane at the end of the tail was filled with gravel to add weight, as a substitute for the metal chain or a purse-seine cable ring.

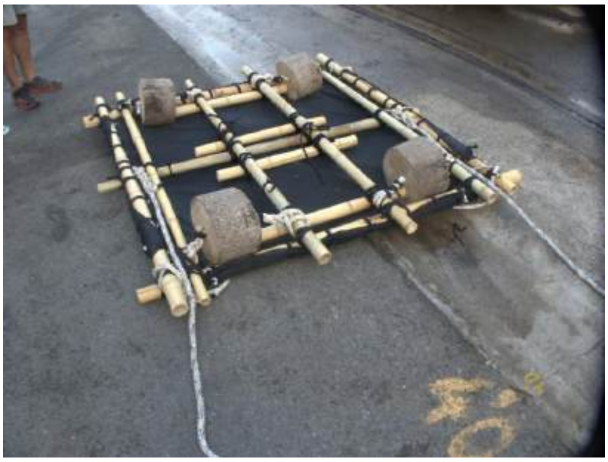

Figure 9 – Raft of the Sails-type dFAD with a bamboo and paulownia-wood structure for flotation.

Construction materials for the Sails-type dFAD model:

- Bamboo, 5–7 cm diameter
- 100% cotton raft fabric, 1.80 × 1.80 m
- Cotton cord, 10 mm
- 10 mm BIO rope
- 16 mm BIO rope
- 4 pieces of paulownia wood
- 3 sails made of 100% cotton fabric, 5.00 × 1.80 m
- Bamboo, 5–7 cm diameter
- Cotton cord, 10 mm
- 18 mm BIO rope
- Gravel for weight (4 kg)

Again, due to depth limitations in the experimental area, the dFAD tail was shortened, leaving only one sail/panel made of cotton (Figure 10).

Figure 10 – Original experimental Sails-type dFAD (left) and modified model (right).

Figure 11 – Loading the modified experimental Sails-type dFAD onto the vessel.

2.1.3. EXPERIMENTAL STRANDING PROTOCOL

To optimize resources, we simulated drift to examine how the dFAD interacts with the seabed. This drift was initially planned to be carried out using a motor vessel towing the dFAD; however, it ultimately had to be performed by a diver pulling from the surface in order to better control the drift and its speed.

During the drift process, there was one diver on deck, three divers in the water, and one surface diver. The three divers in the water were responsible for scientific monitoring, assessing the impacts generated by the dFAD on the seabed.

The divers' roles were defined as follows:

- *Water Diver 1*: Responsible for recording *in situ* the number of contacts between the dFAD and the seabed, which parts make contact, and the type of contact. Drift guide, in direct communication with the Surface Diver.
- *Water Diver 2*: Responsible for recording the monitoring with a GoPro camera.
- *Water Diver 3*: Responsible for freeing knots and snags that may form between the dFAD and the seabed, and for recording with another GoPro.
- *Surface Diver*: Responsible for guiding the dFAD in the direction indicated by Water Diver 1.
- *Deck diver*: Diver on *stand-by* in case any need arises.

For each dFAD type, the following simulations were planned:

- *Simulation 1 – Natural drift*: Each dFAD was allowed to drift freely for 10 min from the point at which the deepest part of the dFAD made contact with the bottom.
- *Simulation 2 – Snagged*: For the Cage- and Raft-type dFADs, the dFADs were kept snagged on the bottom and assessed for at least five minutes, both in terms of observed behaviour (number of contacts and affected area) and the time needed to achieve release.
- *Simulation 3 – Forced drift*: Drift of each dFAD was forced from the surface for a minimum of 5 minutes, following a trajectory in which the deepest part of the dFAD could make contact with the bottom.
- *Simulation 4 – Forced drift upslope*: Drift of each dFAD was forced from the area where the dFAD makes first contact with the bottom and guided towards shallower zones, to evaluate how seabed interaction changes as the dFAD approaches shallower water. This simulation lasted 5 minutes, and it was not possible to reach 0 m depth due to wave conditions.

Figure 12 – Simulation of natural drift of a dFAD over the seabed.

Figure 13 – Simulation of forced drift of a dFAD by divers over the seabed.

In addition to the divers’ recordings, GoPro underwater cameras were attached to the dFADs to obtain images from other perspectives and to record the process continuously.

For the experiment, the following data sheet was developed to collect information systematically (Table 1) for subsequent analysis.

Table 1 – Data sheet for the dFAD stranding experiment.

DRIFT No.:	**Date:**	**Observers:**
Depth:	**Start time:**	**End time:**
Contact part	**Contact type**	**Number of contacts**
Raft / Cage	Collision	
	Abrasion	
	Snagging	
Tail	Collision	
	Abrasion	
	Snagging	
Ballast	Collision	
	Abrasion	
	Snagging	

2.2. COSTS OF IMPLEMENTING OFFSHORE RETRIEVAL PROGRAMMES

A second questionnaire was prepared to examine the costs associated with a potential offshore dFAD retrieval programme (Annex I). The questionnaire was distributed among several tuna companies, as there is currently no operational programme of this type; however, a support vessel used for deploying and retrieving dFADs could serve as a reference for these estimates. To simplify the scenario, the questionnaire asked respondents to calculate the costs of a retrieval vessel operating in a specific offshore area. The first part of the questionnaire asked about the costs of purchasing or chartering a vessel capable of operating offshore and the equipment needed onboard. It also requested estimation of wage costs for a crew on that vessel.

3. RESULTS

3.1 COASTAL STRANDING EXPERIMENTS

The results presented below are, on the one hand, descriptive—based on observations made by the team of scientific divers—and, on the other hand, based on quantification of impacts using *in situ* observations and video recordings.

Video recordings and photographs from the divers' cameras were used, as well as footage from the camera mounted on the tail of the Cage-type dFAD, approximately 3.5 m above the ballast. Footage from the cameras on the Cage-type and Sails-type dFADs could not be used because the fabrics on their tails made it difficult to observe interactions with the seabed. Scientific monitoring was carried out by the three divers in the water, who assessed the effects of the dFAD on the seabed (see Figure 14).

Figure 14. Divers monitoring interactions between Sails-, Raft- and Cage-type dFADs and the seabed.

3.1.1. DESCRIPTION OF STRANDING OBSERVATIONS

Before presenting the quantification of interactions and damage caused by the different dFADs, we provide a descriptive account of the observations made.

3.1.1.1. *Cage-type dFAD*

It was observed that the first interactions between the seabed and the dFAD occurred at 5 m depth. During Simulation 1 (Natural), the dFAD moved very slowly with wave action, making contact with the seabed via the lower part of the cage (the lower metal frame of the cube, approximately 1.8 × 1.8 m) (Figure 15).

An additional natural drift simulation was conducted by leaving the dFAD resting on the seabed at 4 m depth. It was observed that wave action gently rocked the cage, which slowly generated abrasion on the seabed due to contact with the lower metal frame. After five minutes of observation, a stronger wave provided enough energy for the dFAD to leave the area where it was settled and moved it to become settled again at a nearby point. Overall, very slow movement was observed: the dFAD first generated abrasion at the point where it was settled and then made a small "hop", becoming stranded again and repeating the abrasion process.

Figure 15. Observations and monitoring of interactions between the Cage-type dFAD and the seabed.

An additional simulation was conducted by placing the dFAD on a rock covered with anemones. It was observed that, in addition to abrasion caused by the structure itself on the anemones, the movement of the dFAD caused the lower metal frame of the cage to break and detach several anemones from the substrate (Figure 16).

Figure 16. Anemone snagging (indicated with a yellow arrow) on the lower part of the cage at the moment it detaches from the bottom and a new stranding begins.

The simulations showed that the lower metal frame of the Cage-type dFAD, covered with fabric, was the main element responsible for abrasion and collision with the seabed. Its rigid structure caused impacts and abrasion when striking the bottom.

3.1.1.2 Raft-type dFAD

In general, during the simulations carried out with the Raft-type dFAD (Figure 17), it was observed that the ballast, in this case a concrete brick, was the main element interacting with the seabed, causing collisions and damage (Figure 18). This was observed both during natural drift, where the ballast was seen to rise and fall over the seabed, causing damage on adjacent rocks, and during drift in motion, where the ballast collided with each rock in its trajectory, causing damage to the bottom. During natural drift, while the ballast remained at the limit of contact with the seabed, the observed damage was minimal (something that would likely be different on coral bottoms given their fragility). The dFAD rose and fell gently (which likely varies with wave energy), and the ballast did the same. However, once the ballast moved to a point where it became settled, the damage became much more visible, especially when the ballast became trapped between rocks. Note that the ballast normally used is usually a metal purse-seine wire ring or iron chains. Therefore, the impact with non-biodegradable weight elements would also have been highly forceful.

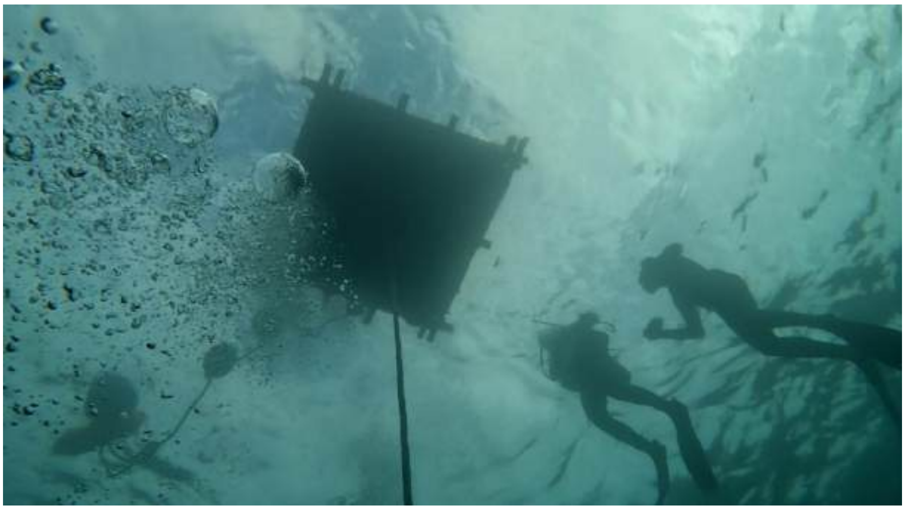

Figure 17. Perspective of the Raft-type dFAD taken from below.

Figure 18. Interaction of the brick ballast and line of the Raft-type dFAD with the seabed.

We assessed whether the brick ballast could fracture naturally but concluded that a very strong impact would be required. Therefore, the ballast was removed to observe tail behaviour, and it was observed that the submerged rope remained anchored (it did not float up towards the surface during drift). Thus, a tail snag between rocks was simulated, which required one minute to be released naturally. When force was applied to the knot attaching the ballast after it became trapped between rocks, no release was observed during the observation period.

3.1.1.3. Sails-type dFAD

Adjustments were made to the dFAD for this experiment. The bamboo in the dFAD tail, having not been previously submerged and not being water-saturated, had excessive buoyancy that prevented the sails from anchoring. In addition, the bamboo acting as ballast, having been filled with stones and sealed, also retained air inside, increasing its buoyancy and causing it to remain at the surface. To force anchoring, holes were drilled in the bamboo acting as ballast, allowing air to escape and water to enter; additionally, lead weights were added inside. It is important to consider these modifications to understand the dFAD's behaviour in the water (Figure 19).

Figure 19. Deployment of the Sails-type dFAD, photographed from the seabed looking up towards the surface.

In this case, although the three drifts were carried out as planned, it should be noted that drift in motion was complicated because, when forced, the sails changed angle and behaved in a way that would not be natural. In both static and moving conditions, the main contact with the seabed occurred via the weighted bamboo, and the impacts were not significant (Figure 20). This may have been due to the relatively high buoyancy of the bamboo at that time, or because the seabed tested were very hard and therefore no relevant damage could be observed. During drift towards shallower water, it was observed that, in addition to the anchoring bamboo, the sails were the elements with greatest contact with the seabed (Figure 20). Wave action caused the sails or windows to rise and fall over rocks, producing abrasion—here affecting algae and invertebrates—leaving the rock surface free of organisms in the sail-contact area.

Figure 20. Interaction of the bamboo and sail fabric of the Sails-type dFAD with the seabed.

3.1.2. QUANTITATIVE ASSESSMENT OF dFAD–SEABED INTERACTIONS AND IMPACTS

This section refers to interactions between the different dFADs and the seabed. Note that these interactions are determined by wave height and period, as well as current speed/intensity and winds. Because observations were made on different days under different ocean-meteorological conditions, results should be treated with caution; the type of damage and the part of the dFAD interacting with the seabed are more informative than contact frequency and damaged area. Since the seabed in this study are harder than what would be expected from shallow tropical coral species, collisions and abrasion that produced marks on rocks and detachment of living organisms (algae and anemones) in our experiments may cause scarring and breakage in a coral environment.

3.1.2.1. *Natural drift*

As described in the previous section, this drift was carried out by positioning the dFAD so that its lower part (lower square of the cage, brick ballast, or gravel-filled bamboo) was at the limit of contact with the seabed, so that wave action would have the potential to raise and lower it over the bottom.

As shown in Table 2, it was the lower part of the dFAD that interacted with the seabed, causing a similar number of collisions in the Cage-type and Raft-type dFADs, and fewer in the Sails-type dFAD. Abrasion was higher in the Cage-type dFAD, although it should be considered that this interaction started at a shallower depth (around 5 m) than for the other two dFADs.

Table 2. Summary of interactions of the three dFAD types during a natural drift at the boundary zone, where the lower part of the dFAD touches the seabed but the device remains buoyant.

DRIFT 1 NATURAL	**Contact type**	**Cage-type dFAD**	**Raft-type dFAD**	**Sails-type dFAD**
Depth		**5m**	**7m**	**12m**
Contact part		**# contacts/min**	**# contacts/min**	**# contacts/min**
Upper grid / Cage	Collision	0	0	0
	Abrasion	0	0	0
	Snagging	0	0	0
Fabric / tail / sails	Collision	0	0	0
	Abrasion	2,14	0	0
	Snagging	0	0	0
Lower grid / ballast	Collision	3,71	4	1
	Abrasion	60 (continuous)	2,4	3
	Snagging	0	0,1	0

3.1.2.2. *Drift 2 – Ballast snagged*

This type of drift was only carried out with the Cage-type and Raft-type dFADs, as it was not possible to perform it with the Sails-type dFAD due to the high positive buoyancy of the bamboo. If the bamboo had been underwater for more than two weeks (the time needed for water saturation to fill its pores), it would have lost that buoyancy and would have behaved more like a typical ballast.

In this experiment, continuous contact of the lower part of the Cage-type dFAD with the seabed was observed (Table 3), and wave motion generated abrasion of the bottom (in this case on algae and anemones). Likewise, during the natural release of the dFAD from the stranding area, the lower square caused several anemones to detach. In the Raft-type dFAD, the brick ballast produced substantial abrasion and a high number of collisions, causing abrasion and detachment of organisms. On coral bottoms, this simulation would likely have caused severe breakage and scarring.

Table 3. Summary of interactions of the Cage-type and Raft-type dFADs while snagged on the seabed.

DRIFT 2 **SNAGGED**	**Contact type**	**Cage-type dFAD**	**Raft-type dFAD**
Depth		**5m**	**7m**
Contact part		**# contacts/min**	**# contacts/min**
Upper grid / cage	Collision	0	0
	Abrasion	0	0
	Snagging	0	0
Fabric / tail / sails	Collision	0	0
	Collision	1,12	0
	Abrasion	0	0
Lower grid / ballast	Collision	4	6,1
	Abrasion	60 (continuous)	9,5
	Snagging	0,25	0

In addition, the Cage-type dFAD caused an estimated damaged area of 1,135 cm^2 (33.7 cm × 33.7 cm) during the 5 minutes of observation, i.e., almost 15 cm × 15 cm of damaged area per minute. The observation was stopped after 5 minutes because that was the time it took for the dFAD to leave the zone where it had become stranded (Figure 21).

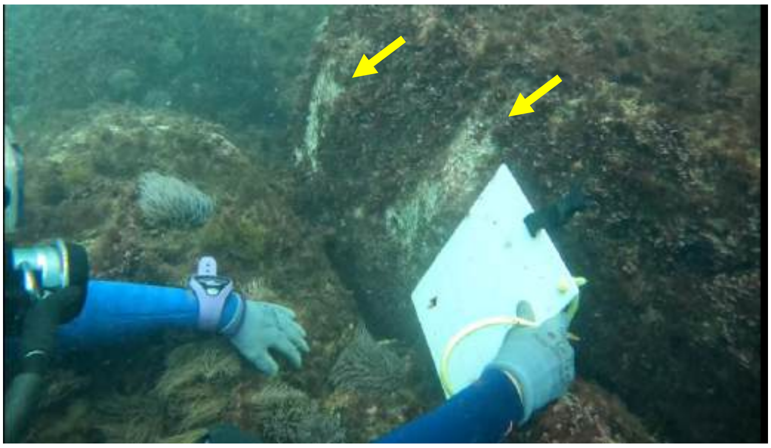

Figure 21. Abrasion damage (indicated with yellow arrows) caused by the lower part of the Cage-type dFAD in contact with the seabed.

For the Raft-type dFAD with brick ballast, an estimated damaged area of 978 cm^2 (31.3 cm × 31.3 cm) was quantified during the 10 minutes of observation, i.e., almost 10 cm × 10 cm of damaged area per minute (Figure 22). During the full observation period, the ballast did not release due to the hardness of the rocks between which it was snagged. However, considering the tension generated by wave action on the ballast through the rope/line, it is reasonable to imagine that, if this had been a coral bottom, the corals would very likely have broken.

Figure 22. Example of abrasion caused by ballast rubbing on the seabed and damage caused by ballast collision with the seabed.

Based on these observations—and being cautious with the results, as they come from a single dive—it is considered that the damage caused during a stranding event is greater for a Cage-type dFAD than for a Raft-type dFAD. However, as noted above, the depth reached by each dFAD determines the area in which a dFAD can become stranded. In this regard, the Raft-type dFAD has the potential to become stranded from greater depths, and therefore to undergo a higher number of re-strandings.

For the Cage-type dFAD, re-stranding was observed 5 minutes after the start of observation.

3.1.2.3. *Forced drift*

This drift was forced from the surface, and the dFAD was moved over a flat (although rough) seabed. Table 4 shows the results of the observations.

Table 4. Summary of interactions of the three dFAD types during a forced drift in motion over an irregular seabed of constant depth.

DERIVA 3 IN MOTION	Contact type	Cage-type dFAD	Raft-type dFAD	Sails-type dFAD
Depth		**5m**	**7m**	**12m**
Contact part		**# contacts/min**	**# contacts/min**	**# contacts/min**
Upper grid / cage	Collision	0	0	0
	Abrasion	0	0	0
	Snagging	0	0	0
Fabric / tail / sails	Collision	0	0	0
	Abrasion	0,2	0	0
	Snagging	0	0	0
Lower grid / ballast	Collision	2,4	3,2	1,6
	Abrasion	0	0	1,4
	Snagging	0	0	0,2

During the drift in motion, it was observed that collisions were greater in number and intensity for the Raft-type dFAD, despite the Cage-type and Sails-type dFADs having a larger contact surface. This was due to the hardness and weight of the ballast used in the Raft-type dFAD (concrete block), as well as its angular shape, which, upon contacting the seabed, directly produced visible signs of damage.

We assessed the damage caused by the Raft-type dFAD and estimated it as 48 cm × 48 cm over 10 minutes, i.e., approximately 15.3 cm × 15.3 cm per minute. It is important to consider that the drift was forced, and therefore the number of impacts—and thus the damaged area—was likely greater than what would naturally have occurred. However, it should also be considered that, in a natural setting, a dFAD has much more time (hours to months) to interact with a coral seabed.

3.1.2.4. *Forced drift upslope*

The following results refer to observations made when dFADs were forced to drift towards shallower waters (Table 5).

Table 5. Summary of interactions of the three dFAD types during a forced drift in motion over an irregular upslope seabed in shallow waters.

DRIFT 3 **IN MOTION**	**Contact type**	**Cage-type dFAD**	**Raft-type dFAD**	**Sails-type dFAD**
Depth		**5m → 3m**	**7m → 5m**	**12m → 9m**
Contact part		**# contacts/min**	**# contacts/min**	**# contacts/min**
Upper grid / cage	Collision	0	0	0
	Abrasion	0	0	0
	Snagging	0	0	0
Fabric / tail / sails	Collision	0	0	0
	Abrasion	60	Not quantified	60
	Snagging	0	0	0
Lower grid / ballast	Collision	0	8	0
	Abrasion	60	60	Not quantified
	Snagging	0	0	0

From these observations, it is worth highlighting that continuous abrasion of some part of the dFAD occurred in all cases. For the Cage-type dFAD, the lower square was observed to be the main part rubbing on the seabed. For the Raft-type dFAD, abrasion occurred mainly due to the ballast and the line; however, the latter was not recorded and therefore the affected area could not be quantified. Finally, it is noteworthy that for the Sails-type dFAD, during upslope drift, the sails caused the greatest damage. The large surface area of the sails caused algae to detach from the seabed because of abrasion.

3.1.3. MANOEUVRABILITY OF dFADs

Below is a summary referring to different aspects that determined the manoeuvrability of the different dFADs during transport, deployment and retrieval (Figure 23; Table 6).

Figure 23. Deployment manoeuvre of the Cage-type dFAD and retrieval manoeuvre of the Sails-type dFAD.

In general, the dimensions and structural complexity of the dFAD determine how easy it is to handle and stow, with the Cage-type and Raft-type dFADs being easier to handle. It should be recalled that, for the Raft-type and Sails-type dFADs, the dimensions of the experimental prototypes were reduced from their typical size (30–50 m) to smaller ones (10–15 m) due to the depth of the experimental area.

Table 6. Aspects related to handling of dFADs during transport, deployment and retrieval. Green highlights positive aspects, yellow neutral aspects, and red negative aspects for each dFAD (regardless of whether the value is low, medium or high).

Phase	Assessed element	Cage	Raft	Sails
Transport	Difficulty transporting from shore to vessel	Low	Low	High
	Space required (bulkiness)	Low	Low	High
	Robustness	High	Medium	Medium
Deployment	Difficulty manoeuvring during deployment	Low	Low	High
Retrieval	Difficulty manoeuvring during retrieval	Low	Low	High

For the Raft-type dFAD, only the length of the cotton line was reduced, which does not result in such a significant change in the weight of the object (**Table 7**).

Table 7. Weights of the original experimental dFADs and after depth-reduction modifications.

dFAD type	Cage (kg)	Raft (kg)	Sails (kg)
Original	66	60	106
Modified	-	54	73

However, for the Sails-type dFAD, two of the three "windows" of the device were removed for the experiment, which reduced the tested prototype's weight by 33 kg. Its deployment—and especially its retrieval—would have been more complicated if its original size and weight had been maintained.

3.1.4. OPTIONS TO MINIMIZE dFAD ARRIVALS TO COASTS

3.1.4.1. AT SEA RETRIEVAL PROGRAMMES

All dFAD retrieval programmes currently operate from land (e.g., FADWatch in the Indian Ocean or programmes in the Galápagos, Palmyra and Tahiti in the Pacific Ocean), except for one initiative carried out in the Indian Ocean. These land-based programmes have a range of logistical needs and costs for their establishment and long-term maintenance, estimates of which were presented at the 9th Meeting of the FAD Working Group in May 2025 (https://www.iattc.org/GetAttachment/7de72ee9-65ea-4626-9bce-0dec7dea4e1a/FAD-09-RD-E_Evaluating-needs-for-the-set-up-and-maintenance-of-land-based-FAD-retrieval-programs.pdf). Despite the great effort and investment of time and money made by these land-based retrieval programmes, in some cases the number of dFADs recovered annually is low (e.g., < 50 dFADs/year). This may be because the programmes cover relatively small coastal areas (e.g., small islands) or have limited resources to cover longer stretches of coastline. To examine alternatives that could result in a higher number of dFADs recovered, surveys were conducted with fleet managers and vessel owners of European tuna companies to estimate the costs of an offshore retrieval programme operated by a vessel.

Programmes for dFAD retrieval, like any waste-management system, aim primarily to deliver environmental benefits rather than economic profitability. Nevertheless, this section presents a simulation designed to estimate how many dFADs—together with their associated satellite buoys—would need to be recovered for resale so that implementing the programme would not represent an additional cost for the funding entities.

The simulation considers an annual offshore retrieval programme with at-sea collection operations conducted by an auxiliary vessel (support vessel). An initial investment is assumed for the support vessel and communications equipment. The investment in the support vessel is estimated at USD 1,170,000, with a useful life of 20 years and a residual value of USD 117,000. For communications equipment, a useful life of 10 years is assumed. Revenues and costs are detailed in Table 8. Total operating costs would currently be USD 1,535,000 to 1,677,000 per year, including fuel, salaries, insurance, maintenance, etc., depending on whether it operates continuously for 200 or 250 days per year. To finance this operation the analysis is based on the premise that satellite buoys from recovered dFADs can be sold back to the original owner at a reduced price (e.g., less than half the price of a new buoy). Under these conditions, the number of satellite buoys in functional condition that would need to be recovered to balance programme costs is between 4,100 and 5,250 units per year, depending on the unit resale price of the satellite buoys, which ranges between USD 292 and USD 409 per buoy (with the price of a new buoy being around USD 800–1,000). Total operating costs are currently USD 1.5 million, including fuel, salaries, insurance, maintenance, etc. In a scenario where there is an annual limit on satellite buoy purchases, as in the Indian Ocean (Rec. 24/02, 400 buoys per year), it may be of interest to vessel owners to recover lost buoys. It is important to note that this estimate does not include the costs associated with satellite transmission of buoy positions for dFADs outside the fishing area, which is needed to know their real-time position so that the retrieval vessel can locate them.

This simulation considers a single offshore retrieval vessel, which could have the capacity to store 200–300 dFAD units per trip and is assumed to operate 200–250 days per year, with fuel costs for a vessel that is constantly sailing. The number of buoys that would need to be collected by the vessel to achieve a zero-cost scenario is high, and it would be necessary to assess how many dFADs it could potentially collect by optimizing trajectories in areas of loss/deactivation and if all fleets in that RFMO participated in the initiative. This type of vessel would be more efficient in oceans with a high concentration of abandoned dFADs in specific areas and seasons. Even if the estimated number of dFADs for a zero-cost scenario were not reached, buoy resale could partially fund the initiative, and the remaining budget could be financed by different actors such as CPCs, industry or NGOs. In addition, other possibilities exist, such as having the support vessels that already operate—where allowed—serve as retrieval vessels during certain periods.

Table 8 - Simulation of an offshore dFAD retrieval programme in which revenues equal costs.

Total revenue	**MIN (USD)**	**MAX (USD)**	**UNITS**
	1.535.796	**1.677.219**	USD/año
Revenue per satellite buoy	292	409	USD/satellite buoy
Number of satellite buoys recovered	5.245	4.092	Number
Operating costs			
Operating days	200	250	Days
Fuel costs	2.693	2.693	USD/day
Vessel maintenance	234.240	234.240	USD/year
Permits and fees	70.272	70.272	USD/year
Land rent (warehouse)	1.756	1.756	USD/month
Number of people	8	8	Crew
Wage costs	417.649	417.649	USD/ year
Insurance costs	167.059	167.059	USD/ year
Total operating costs	**1.406.892**	**1.541.580**	USD/ year
Other costs (5%)	70.344	77.079	USD/ year
Annual depreciation	58.560	58.560	USD/ year
Total annual costs	**1.535.796**	**1.677.219**	**USD/** year

4. DISCUSSION

This work helps to advance knowledge about the effects of dFAD strandings on seabeds and to identify solutions to potential negative impacts of their structures, either through improvements in dFAD designs or by providing information to promote at sea retrieval programmes. Although the initial intention of the study was to examine *in situ* dFADs stranded in coastal areas of tropical oceans such as the Indian (e.g., Seychelles Islands) or Pacific (e.g., Galápagos Islands), this approach was ultimately discarded because permits for an intentional dFAD stranding study in sensitive ecosystems would be very difficult to obtain.

Conducting a one-off dFAD sampling campaign in a stranding hotspot would not ensure the ability to examine how the objects behave when they reach coral reefs. For example, in a previous project assessing impacts on reefs, despite deploying vessels and researchers from AZTI and FADWATCH in Seychelles to understand the damage caused when dFADs reach the reef, only a limited number of objects were found and these were already grounded, so the mechanism of coral abrasion could not be observed directly (Uyarra et al., 2025). For this reason, we chose to conduct a stranding experiment along the Basque coast on non-sensitive rocky bottoms with different dFAD types, monitoring impacts on the seabed in real time.

This is the first stranding experiment carried out globally, providing valuable information on interactions of different dFAD types used across all oceans (Pacific, Indian and Atlantic). As this is a simulated stranding experiment with a very limited number of replicates, we acknowledge that no definitive conclusions can be drawn without increasing the experimental sample size. However, this first study identified important aspects related both to manoeuvrability and to the interactions and impacts of the different dFAD components. In general, less bulky and less complex dFADs such as Cage and Raft types are easier to handle and therefore more suitable for collection by small recovery vessels, and they are also potentially more cost-effective due to the lower amount of material used. Likewise, all dFADs examined have the potential to impact the seabed; the depth reached by each dFAD is a key factor, so the Cage model would have a smaller potential impact area because it will only contact the bottom when very close to the coast. Nevertheless, the surface area, shape and material of the lower elements of the submerged part largely determine impact, with those having greater surface area, angularity and weight responsible for more severe damage. We also observed re-stranding of the Cage model and consider the potential for re-stranding for the other two dFADs; again, the depth reached by the dFAD determines the area that may be damaged initially. For example, with the brick ballast on the Raft-type dFAD, if it had become trapped in less hard/resistant bottom habitats such as corals, it would very likely have caused breakage, releasing the dFAD, as a high degree of tension was observed in the tail, generated by snagging and wave energy. Once the line is released from the bottom, it could snag again elsewhere or even result in the upper grid/raft impacting the seabed in very shallow areas. Although no re-stranding was observed for the Raft-type dFAD during the 10 minutes of observation, it is reasonable to think that, during a stranding event on more fragile coral bottoms, the tension caused by the rope line would lead to coral breakage, release of the dFAD, and a possible subsequent re-stranding. It is important to note that the bioFADs used in these tests were new (i.e., they had not been soaking in seawater for weeks or months), and therefore their structural integrity and resistance were not compromised. If these biodegradable materials had undergone prior degradation in seawater, their behaviour and potential impact upon contact with the seabed might have differed. For instance, older dFADs may reach the coastline with parts of their structure already missing.

The size, weight and shape of the ballast are decisive in the seafloor type of damage caused and the extent. Over-ballasting (comparison of the concrete block *versus* bamboo), pronounced edges and corners (e.g., the concrete block used; bamboo at corners), and large surfaces (e.g., the lower grid of the cage) are responsible for significant damage and therefore must be considered in dFAD design to reduce impacts. An important lesson from this work is confirmation that biodegradable ballasts such as gravel-filled bamboo or concrete blocks, due to their hardness, can cause significant damage to the seabed. One recommendation arising from this knowledge is to reconsider ballast types that remain biodegradable but minimize physical impacts, with less bulky and less rigid designs. For example, some ballast ideas that could be promoted include ballasts made of small biodegradable bags (cotton, jute, hemp) filled with sand/clay or gravel, so that after the first impact the bag would tear and its contents would disperse. Another option is to make the biodegradable tail lines thinner at the final section that holds the ballast (e.g., going from 20 mm diameter to 5–10 mm). In this way, the tension exerted by the ballast when contacting the seabed would break the connection between the rope and the ballast, and the ballast would detach. Although the ballast would remain on the reef, the problem of repeated impacts from this part of the dFAD due to re-stranding would be avoided, and if biodegradable it would decompose over time.

One aspect that remains pending to review in this real-time stranding study is what happens when submerged elements such as the tail break and detach, leaving only the raft/grid drifting and potentially stranding as well. Because the experiments were conducted with new biodegradable dFAD models, they had not been in the water long enough to deteriorate and detach parts such as the tail from the floating raft. To examine the impact of rafts or floating parts (such as a tether with floats) on the seabed, the devices would need to be dragged over bottoms shallower than 5 m. Although not presented in the Results section, a test was carried out at the end of the project with the Sails model raft to check whether placing it on a shallow rocky area would cause damage. In this pilot experience, it was confirmed that bamboo canes and paulownia log sections, despite being biodegradable materials, due to their hardness and large surface area (raft 1.8 × 1.8 m), left clear marks on the examined rocky bottom. It can be hypothesized that if a dFAD raft (without the tail) maintains buoyancy, it could pass over a coral reef if the reef is not very shallow (e.g., >5 m depth) and reach the lagoon or beach without impacting the reef. However, if the reef is very shallow—nearly exposed during low tides—or if the raft has lost buoyancy and is semi-submerged, there is a risk of stranding on the bottom and causing damage. Therefore, in the future it would also be necessary to seek dFAD raft designs that are less bulky and made of less rigid materials, such as “burrito” type rafts that have only one line of flotation.

Another point in this study was identifying the main difficulties of land-based retrieval programmes using small vessels to recover dFADs, with the weight and size of some structures being a determining factor. For example, Sails-type dFADs—which prevail in three of the four oceans (Western Pacific, Eastern Pacific and Atlantic)—have tails longer than 60 m and can reach 300 kg when covered with biofouling such as barnacles. If at sea retrieval programmes existed with large vessels (e.g., >18 m length overall) equipped with hydraulic cranes, the process of lifting the dFAD out of the water and storing it onboard would not be excessively complicated. However, in land-based programmes where small vessels are used (e.g., zodiacs or small motorboats) and there are few people onboard (1–4), manual extraction becomes difficult. Previous surveys of land-based programmes showed that none had auxiliary crane equipment onboard to assist with lifting, and in many cases the dFAD is left grounded because it cannot be removed by hand, or only the surface part (raft) of lower weight is extracted and the tail is left in the water (Murua et al., 2025). Less bulky dFAD designs such as the Cage model or biodegradable dFADs such as the JellyFAD (Moreno et al., 2023), especially the newer, lighter prototypes with circular bamboo rings, use less material, which not only reduces unit cost and storage space onboard, but also facilitates extraction for land-based recovery programmes.

Although very valuable information has been collected, it would be interesting in the future to expand sampling with a larger number of dFADs of each model, over seabeds with different topographies and under diverse oceanographic conditions (e.g., spring and neap tides, swell versus calm sea, etc.). That said, for diver safety reasons our experiments were conducted in a sheltered area and on days with low wave energy. One way to monitor dFAD behaviour under more extreme conditions would be to install underwater cameras on their structures. As this was our first experiment, we obtained mixed results by placing GoPro cameras tied to different parts of the objects: good videos in the case of the Raft-type dFAD, but less useful footage for the Cage-type and Sails-type dFADs because the cotton canvas on their tails partially obstructed the recorded images. This is a point to improve in future stranding trials.

A critical conclusion of this study is that, to minimize physical impacts on sensitive coastal ecosystems, transitioning to biodegradable dFADs is not sufficient. As shown here, physical structures made of natural materials can still cause damage to coral reefs. Therefore, prevention systems to reduce loss and abandonment of dFADs and retrieval programmes, both land-based and at sea, should be supported. This is why it is important to characterize different types of retrieval programmes to understand their benefits and needs. Land-based or nearshore recovery programmes can operate under different strategies (e.g., collection by fishers, by scientific divers, etc.). Although the number of land-based dFAD retrieval programmes is currently limited, more initiatives of this type are expected to be established in the future, since RFMOs and other management bodies have expressed support for such impact-reduction activities. In addition, some purse-seine companies certified or in the process of certification by MSC must comply with conditions under Principle 2 related to mitigation of impacts on marine habitats, and these programmes contribute to that objective.

This work attempted to estimate the costs of operating an at sea dFAD retrieval programme (i.e., vessels that recover abandoned dFADs in open ocean waters), which would be compatible with land-based programmes in high-stranding areas given the large number of dFADs abandoned or lost annually across all oceans. Today there is no operational at sea programme, but a suitable proxy to estimate the cost of such an initiative is the expenses associated with a support or auxiliary vessel, which, due to its size, has operational autonomy and can transport a significant number of dFADs (e.g., >300 dFADs). Using information provided in company surveys, a theoretical annual cost was calculated for operating a support-type vessel dedicated to offshore dFAD retrieval with an onshore storage area, estimated at approximately USD 1.53 to 1.67 million per year. Although this may seem high, if dFADs are recovered and associated functional satellite echo-sounder buoys are resold at a reduced price, the programme could be self-financing if approximately 4,500 buoys were recovered annually. The resale of other reusable dFAD materials (e.g., bamboo, floats, etc.) was not considered here. Even if that number of dFADs were not recovered, retrieval programmes should be understood, like any waste-management system, as aiming primarily to generate environmental benefits rather than economic profitability. In this context, for initiatives to reduce environmental impacts there is the concept of Extended Producer Responsibility. In the case of lost or abandoned dFADs, responsibility for recovery would not only lie with tuna fishing companies, but also with suppliers of dFADs and their components (e.g., satellite buoys, construction materials). There would also be shared responsibility with RFMOs and public administrations (e.g., flags that authorize dFAD use) and potentially other actors such as waste-management companies, environmental NGOs, and even canneries and supermarkets that profit from selling tuna products caught using dFADs. It should be noted that, if regulations required each vessel to retrieve all dFADs it deploys, it would be completely unfeasible for large-scale purse-seine tuna vessels to recover at sea all dFADs they deactivate, due to the wide dispersion of dFADs and the disruption caused by having to focus effort on retrieval rather than fishing. The economic costs if a purse-seine vessel had to travel for days to recover dFADs outside fishing areas would be prohibitive. However, combining mitigation approaches, such as using biodegradable dFADs and implementing retrieval programmes both on land and at sea, may be the solution to the problem of impacts from abandoned and lost dFADs.

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ANNEX I – SURVEY ON COSTS OF AT SEA dFAD RETRIEVAL PROGRAMMES

This survey aims to collect information on the costs associated with implementing and operating an at sea dFAD (FAD) retrieval programme, in order to better inform other stakeholders or managers who may be considering establishing dFAD retrieval initiatives.

As a first scenario, we assume there is only one retrieval vessel operating in a specific at sea region where object losses typically occur (i.e., not covering all areas of an ocean), and that all costs are borne by a single entity (i.e., without co-financing). This retrieval programme would be different from those operating from land with small boats very close to islands or the mainland.

If you identify any cost that is not covered in the survey, please note it along with its description and cost in the blank spaces of the tables provided. If some costs do not apply, simply write "NA" (not applicable). If you consider that the programme should operate differently or wish to describe certain aspects in more detail, please let us know in the comments section at the end of the survey.

COSTS TO SET UP AN AT SEA dFAD RETRIEVAL PROGRAMME:

Materials:

Description	**Cost (USD)**
Purchase of retrieval vessel	
Annual charter cost of retrieval vessel (if not owned)	
Vessel equipment (radio, GPS, sonars, etc.)	
Communications equipment (mobile phones, computers)	

PERSONNEL:

Description	**Cost (USD/year)**	**Number of people**
Captain salary		
Crew salary		
Personal insurance costs		
Travel costs (crew changes, etc.)		

VARIABLE COSTS:

Description	**Number of dFADs**
Estimate the average number of dFADs that would be recovered per year	

Description	**Cost (USD/ year)**
Satellite buoy data costs	
Fuel per day	
Rent of onshore storage or recycling area	
Vessel maintenance	
Port mooring fee	
Return shipping of satellite buoys to their owners	
Outsourcing of different services (describe type)	
Permits/fees (describe type)	

REVENUES

Description	Income (USD/ Year)
Resale of recovered buoys	
Fleet donations (describe type)	
Funding from governments, RFMOs or other organizations	

COMMENTS: