SEARCULAR Project: Developing New Bio-FAD Designs.

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Abstract

The widespread use of drifting Fish Aggregating Devices (dFADs) in tropical tuna fisheries has increased fishing efficiency but also generated significant marine litter due to persistent plastic materials used in dFAD construction. The SEARCULAR project aims to develop and validate biodegradable dFADs (bio-FADs) as a sustainable alternative to conventional dFADs, which are made primarily of plastic. This study combines the analysis of a global dataset build on scientific research and industry-based surveys (>1,800 deployments), and the identification of alternative materials to support the eco-design of bio-FADs. Three prototype models were co-developed by researchers, NGO and the industry stakeholders through participatory workshops and refined through semi-controlled trials, identifying key challenges related to material durability and structural performance. Large-scale field testing starting in June 2026, and involving 150 BIOFAD deployments, will provide a further assessment of their operational performance under real fishing conditions. These results support the transition towards bio-FADs while maintaining fishing efficiency.

1. Introduction

The use of drifting Fish Aggregating Devices (dFADs) in tropical tuna fisheries has increased significantly since the 1980s (Gershman et al., 2015). The advances in dFAD-related technology and other fishing equipment have progressively improved dFAD-fishing efficiency (Lopez et al. 2014; Wain et al., 2021). However, dFAD structure, materials and designs have remained quite rudimentary and virtually the same since the beginning of their use (Moreno et al. 2023). Traditionally, dFADs have been constructed using heavy end-of-life (EOL) polyamide (PA) purse-seine netting, other plastic components (e.g., ropes, canvas, bait buckets, subsurface attractors, coloured plastic ribbons, and worn salt sacks), flotation materials such as bamboo and net corks, and metal wires or rings used as ballast among others (Escalle et al. 2023; ISSF, 2019; Murua et al.,2017). The persistence of petroleum-based plastic materials has contributed to the growing environmental impacts associated with dFADs, particularly in relation to marine litter. A substantial proportion of deployed dFADs are eventually lost, abandoned, or discarded (Escalle et al., 2019; Gilman et al., 2021; Syversen et al., 2022), reaching up to 40% of deployments in the Atlantic and Indian Oceans in the case of the French fleet alone (Imzilen et al., 2022). These dFADs may subsequently strand in vulnerable habitats, including coral reefs (MacMillan et al., 2022; Uyarra et al., 2023).

In response, tropical Regional Fisheries Management Organizations (tRFMOs), including the Indian Ocean Tuna Commission (IOTC), have adopted several measures aimed at mitigating these impacts. Such measures include limits on the number of daily active dFADs monitored by each vessel, prohibitions on the use of netting in dFAD construction, and the establishment of fixed implementation timelines for bio-FADs (Zudaire et al 2023). Implementation schedules for bio-FADs are stepwise and ocean-specific. The categories are defined according to the biodegradable components of the dFAD and are harmonized across tuna RFMOs (Table 1).

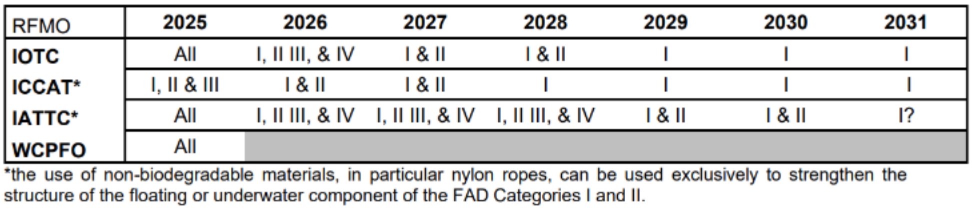
Table 1. Description of biodegradable dFAD categories based on the biodegradable components of the dFAD.

.Category	Description
Category I	The FAD is made of fully biodegradable materials.
Category II	The FAD is made of fully biodegradable materials except for plastic-based flotation components (e.g., plastic buoys, foam, purse-seine corks).

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

Global implementation should be completed within a maximum period of seven years, following ocean-specific timelines, except for theWestern and Central Pacific Fisheries Commission (WCPFC) in which the transition to bio-FADs is still not required (Table 2). In the Indian Ocean, dFADs are expected to be biodegradable, with the exception of flotation components, by 2027, and to become fully biodegradable by 2029.

Table 2. Stepwise implementation framework for biodegradable dFADs across ocean basins



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

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

In parallel, over the last decade, numerous project initiatives have focused on the development and testing of bio-FADs, bringing together scientists with expertise in dFADs and the fishing sector. These collaborative efforts have aimed to improve the design, performance, and practical implementation of bio-FADs, combining scientific knowledge with fishers' operational experience (Moreno et al., 2018, 2020, 2025; Murua et al., 2023a; H. Murua et al., 2023b; Roman et al., 2022).

Despite the transition of dFADs towards biodegradable models and the increasing use of biodegradable materials in their construction (e.g., jute, abaca, sisal, bamboo canes, and cotton), the problem of marine litter remains unresolved. In this context, circular economy approaches, including the development of alternative designs and the use of organic materials, are being promoted as part of the solution. These materials degrade more rapidly in the environment than plastic and are free from toxins and heavy metals, thereby substantially reducing the long-term accumulation of dFAD components in sensitive areas after they are lost (Moreno et al.,2018; 2019). However, biodegradable materials are particularly vulnerable to the structural stress experienced by dFADs while adrift in the open ocean, under real sea conditions, which can substantially shorten their operational lifespan (Moreno et al., 2023). This limitation highlights the importance of advancing toward innovative dFAD design solutions specifically aimed at reducing mechanical stress on the structure, thereby improving durability and functional performance at sea. In this regard, particular attention should be given to dFAD designs that optimize weight and buoyancy requirements while minimizing tension on key structural components. Further emphasis should also be placed on developing neutrally buoyant designs that reduce drag forces and vertical strain within the water column, as demonstrated by the Jelly-FAD concept (Moreno et al., 2023).

Such improvements are critical for increasing the operational viability of bio-FADs while maintaining their environmental advantages over conventional devices.

In this context, SEARCULAR proposes an eco-designed bio-FAD solution. This design aims to:

(i) minimize the use of plastic in its construction by replacing it with plant-based fibres;
(ii) reduce the overall size of the dFAD in order to decrease material use;

(iii) promote faster degradation than conventional plastic-based dFADs once their functional fishing lifespan has ended; and
(iv) eliminate the use of netting in its construction.

This document describes the actions undertaken to co-create and test new BIOFAD designs for application in the Indian Ocean.

2. Compilation and assessment of available information

2.1. Analysis of available bio-FAD data

A comprehensive compilation and integration of available bio-FAD datasets was conducted to assess their performance under operational fishing conditions. This effort brought together data from major scientific and industry-led initiatives across the Indian, Atlantic, and Pacific Oceans, including large-scale projects such as IOTC BioFAD EU-Project, International Seafood Sustainability Foundation (ISSF) trials with Jelly-FAD concept and designs, bio-FAD trials by The Pacific Community (SPC) and ISSF, and AZTI–OPAGAC experiments. The resulting database represents the most extensive global dataset currently available on bio-FAD deployments, incorporating a wide range of prototype designs, environmental conditions, and fishing practices, with 1,836 recorded bio-FAD deployments that were tracked across three ocean basins (See Annex I).

Two primary data sources were compiled to enable a multidimensional evaluation of bio-FAD performance. First, echo-sounder buoy data provided continuous high-resolution information on dFAD position, drift dynamics, and acoustic estimates of tuna biomass. Second, operational fishing data collected by purse seine fleets documented interactions with dFADs, including deployment, visits, fishing sets, retrievals, and detailed assessments of material condition and degradation. The combination of these datasets allows for a joint analysis of physical, biological, and operational processes driving dFAD performance.

To ensure data consistency and comparability across projects, a rigorous data processing workflow was applied. This included standardization of variables, validation of records, and merging of operational and acoustic datasets using unique buoy identifiers. Filtering procedures were implemented to retain only valid trajectories associated to each deployment, remove anomalous buoy behaviour, and restrict acoustic analyses to appropriate depth layers and time windows representative of tuna aggregation (Orue et al., 2019; Uranga et al 2019). These steps ensured the quality and robustness of the integrated dataset for subsequent analyses.

The harmonized database was then used to evaluatebio-FAD performance through a comparative framework against conventional dFADs, focusing on key metrics such as drift behaviour, tuna aggregation, catch efficiency, dFAD lifespan, and material degradation. This global-scale synthesis provides a unique opportunity to assess the effectiveness of biodegradable designs across regions and operational contexts and constitutes a critical foundation for the eco-design and optimization of next-generation of bio-FAD prototypes.

2.2. Industry-based questionnaire survey

The industry-based questionnaire survey was conducted to characterize current dFAD practices within the tropical tuna purse seine fleet and to support the transition towards biodegradable designs. The survey targeted key stakeholders, including skippers and crew members, and was implemented through ISSF Skippers Workshops and AZTI industry meetings. A total of 70 voluntary and anonymous responses were collected, providing a representative overview of operational practices across fleets and regions.

The questionnaire gathered standardized information on dFAD design, materials, operational use, and management. The analysis was structured into four main components:

(i) conventional dFAD designs and materials;
(ii) bio-FAD designs and tested materials;

(iii) dFAD use and dynamics, including lifespan and loss; and
(iv) stakeholder perceptions of performance, impacts, and management options.

The survey provided a comprehensive overview of industry practices and highlighted key patterns across fleets. Results indicated a high degree of standardization in conventional dFAD designs, with widespread use of rectangular raft structures and synthetic materials, particularly in submerged components and flotation components. While the adoption of fully biodegradable dFADs remains limited and heterogeneous, the responses revealed an increasing integration of plant-based materials, such as bamboo, cotton, and wood, particularly in structural components where replacing plastic is more feasible.

Importantly, the findings also identified major constraints for the implementation of bio-FADs. These include the reduced durability of biodegradable materials, the lack of reliable alternatives for key components such as flotation components, and cost-related considerations. At the same time, stakeholders recognized the environmental benefits of biodegradable designs, with reduced marine litter and lower ecological impact being among the most valued attributes.

Overall, the questionnaire results provided critical industry-driven insights that informed the subsequent eco-design process within the SEARCULAR project. By integrating operational knowledge with scientific and technical analyses, this approach ensured that the development of bio-FAD prototypes was aligned with both environmental objectives and the practical requirements of the fishing sector.

2.3. Identification of alternative materials

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

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

The identified materials range from natural fibre ropes (sisal, jute, fique, and cotton) to balsa wood, cotton and manila hemp canvas, as well as fully assembled bio-FADs (examples provided in Figure 1). By making this essential information accessible, SEARCULAR aims to support scientists working on bio-FAD trials and assist fishing companies in transitioning to biodegradable materials for dFAD construction. This initiative contributes to reducing the environmental impact of purse seine fishing and promotes the adoption of more sustainable solutions within the fishing industry. Images of products shared by certain companies are included, while product information for other companies can be found on their respective websites.

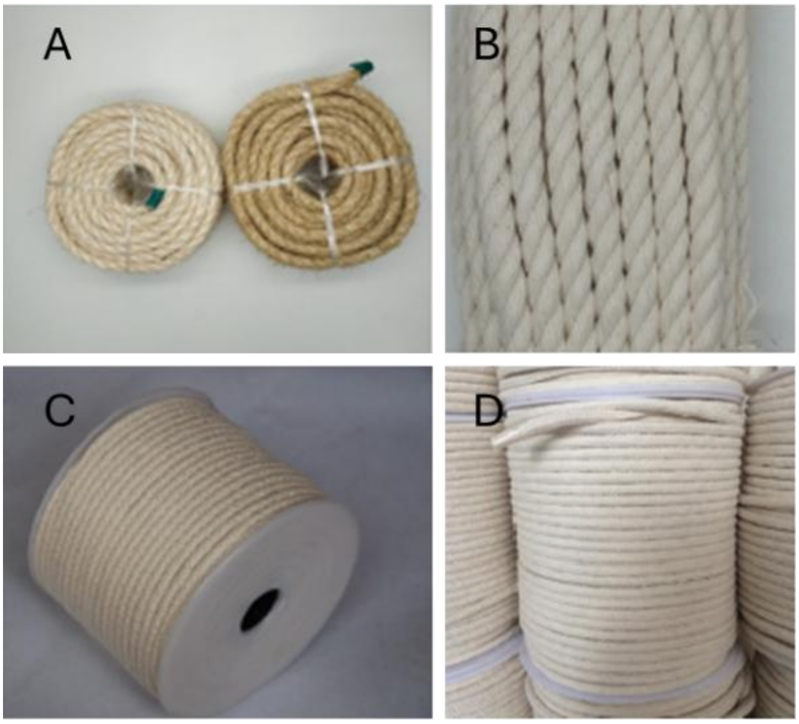


Figure 1. Examples of the materials made with organic fibres in China. A) Sisal and jute twisted ropes, B) Twisted cotton rope, and C-D) Braided cotton ropes.

2.4. Preliminary testing of candidate materials

To advancing the eco-design of bio-FADs, a key objective was the identification and validation of new, sustainable materials capable of replacing conventional plastic and metallic components of conventional dFADs. Particular emphasis was placed on sourcing organic alternatives for two critical dFAD elements: the flotation components and the structural frame, which are traditionally composed of synthetic polymers floats and galvanized metallic frame, respectively. These components are among the most persistent contributors to marine litter when dFADs are lost or abandoned at sea.

Following successful laboratory-case studies conducted by ISSF (Figure 2) on the use of Paulownia wood as a potential substitute for plastic-based flotation elements. Paulownia was found to exhibit, in the laboratory test, excellent hydrophobic properties, with minimal seawater absorption, which translates into stable buoyancy over time. Specifically, the buoyancy of Paulownia saturated in seawater was measured at 0.84 kg of lift per kilogram of dry weight (Table 3), indicating its suitability for maintaining the necessary flotation performance in marine environments.

For this research, eight Paulownia wood logs were used. The eight logs were tested in a seawater tank in the facilities of the Institut de Ciències del Mar in Barcelona, Spain. They were submerged in the seawater tank using a 4.3 kg iron chain, in January 29, 2024. The aim was to track the weight variation of Paulownia logs over an 80-day period. These logs gradually absorbed seawater, leading to alterations in density and buoyancy. After 80 days submerged in seawater, the weight of the wood piece was 1.6 kg. This indicates that buoyancy only decreased by 0.8 kg, leaving a residual buoyancy for a 3.2 kg log at 2.7 kg. Assuming buoyancy is associated with weight, we can infer (as shown in Table 3):

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

Figure 2. Evaluation of the buoyancy of Paulownia wood in the laboratory. Testing period of 80 days.

These laboratory-scale findings suggest that Paulownia wood has minimal absorption of seawater, resulting in minimal variation in flotation. This observation positions Paulownia wood as a promising alternative to the current plastic buoys utilized in tuna fishery. However, it is crucial to conduct a thorough assessment of buoyancy requirements tailored to specific dFAD designs and weights to ensure optimal performance of the dFAD over the course of a year. Drawing from the results of this experiment, we suggest considering the buoyancy of Paulownia as 0.84 kg per kilogram of dry weight. Finally, further research is needed to determine whether this characteristic is maintained at real condition sea test. Despite these encouraging results, the long-term sustainability of sourcing Paulownia wood, particularly regarding the ecological impact of cultivating and harvesting, requires further investigation. This is crucial because large quantities will be required to supply the numerous fleets fishing with dFADs.

Table 3. Evaluation of the buoyancy of Paulownia wood in the laboratory. Testing period of 80 days.

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

3. Eco-design of SEARCULAR BIOFAD models

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

The first two workshops brought together representatives from the two participating tuna fishing companies (Figure 3). These initial sessions focused on defining three distinct biodegradable dFAD models, taking into account the operational requirements of the fleet and the environmental performance of proposed materials. The discussions emphasized the need for designs that balance functionality, durability, and ecological impact. Cost-effective aspects were also considered. The final two workshops were dedicated to refining the initial designs and selecting the most suitable materials for each bio-FAD component. This phase also integrated insights gained from prototype testing under semi-controlled conditions in the Mediterranean Sea (see section 4.1), allowing for evidence-based adjustments to improve performance and sustainability. Throughout the workshops, each structural element of the bio-FAD was considered in detail, including the flotation system, surface and subsurface components, submerged appendages, and ballast.

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

The workshops focused on several key topics:

- An overview of the SEARCULAR project was presented, with particular emphasis on the objectives and specific goals of Work Package 3 (WP3), which focuses on the eco-design of bio-FADs.
- A review of previous experiences was conducted to identify existing biodegradable materials and design alternatives for each component of a dFAD. This included a review of configurations used in earlier bio-FAD trials and highlighted the elements that still lack viable biodegradable substitutes—such as flotation devices, ballast systems, and metallic structures.
- Results from prior studies involving the Jelly-FAD prototype were shared, including technical considerations such as buoyancy, drag coefficients, material tension, and stress factors, all of which are critical to the design and performance of dFADs.
- Three bio-FAD models were proposed for testing during the project: two based on existing designs already used by the participating company, adapted to incorporate fully biodegradable materials; and a third, innovative cylindric model (Figure 4).
- A comparative discussion on various flotation materials, including paulownia wood, balsa wood, and bio-based floats, evaluating their functional properties and suitability for dFAD construction.
- Specialized dFAD construction company was visited twice to follow the transition from conceptual design to the physical construction of the first prototypes for the three selected bio-FAD models. This hands-on session provided valuable insights into the practical feasibility of the proposed designs and informed further refinements to the construction approach (Figure 4).
- Finally, a detailed work plan for 2025-2026 was established. This plan includes testing the proposed models under semi-controlled conditions in the Mediterranean Sea, with the aim of progressing to the next phase involving full-scale construction, deployment, and performance evaluation in real-world conditions in the Indian Ocean.

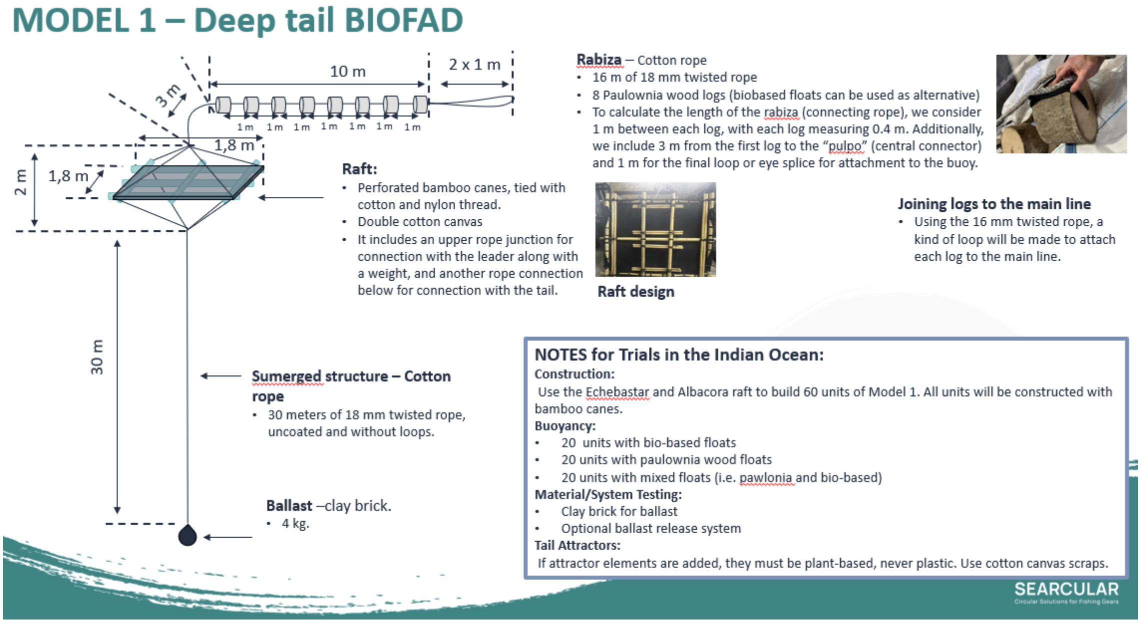
Figure 3. Workshops with the fishing fleets to define bio-FAD models and materials

Figure 4. Hands-on workshop with FAD manufacturers and fishing fleets to construct first bio-FAD prototypes.

The models proposed are the following:

Model 1. Deep tail bio-FAD

The bio-FAD model 1 (Figure 5) represents a traditional deep-tail dFAD design commonly used in the Indian Ocean. It is the simplest of the three eco-designed models, particularly in terms of its submerged structure. The underwater section consists of a single cotton rope and a gravel ballast, minimizing complexity and material use. Surface component is composed of a bamboo raft covered with cotton canvas, providing a biodegradable and functional platform. Flotation elements, as in Models 2 and 3, are made from paulownia wood and/or bio-based marine biodegradable plastic floats, eliminating conventional synthetic buoyancy materials. This model prioritizes simplicity, both in the types and quantities of materials used. It has been previously tested by fishing fleets in its synthetic format and further validated in a quasi-biodegradable configuration during the BioFAD project in the Indian Ocean. Its proven operational viability and reduced environmental footprint make it a strong candidate for wide-scale adoption in sustainable tuna fisheries.



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

Raft:
- Perforated bamboo canes, tied with cotton and nylon thread.
- Double cotton canvas
- It includes an upper rope junction for connection with the leader along with a weight, and another rope connection below for connection with the tail.

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

Sumerged structure – Cotton rope
- 30 meters of 18 mm twisted rope, uncoated and without loops.

Ballast –clay brick.
- 4 kg.

NOTES for Trials in the Indian Ocean:

Construction:

Use the Echebastar and Albacora raft to build 60 units of Model 1. All units will be constructed with bamboo canes.

Buoyancy:
- 20 units with bio-based floats
- 20 units with paulownia wood floats
- 20 units with mixed floats (i.e. pawlonia and bio-based)

Material/System Testing:
- Clay brick for ballast
- Optional ballast release system

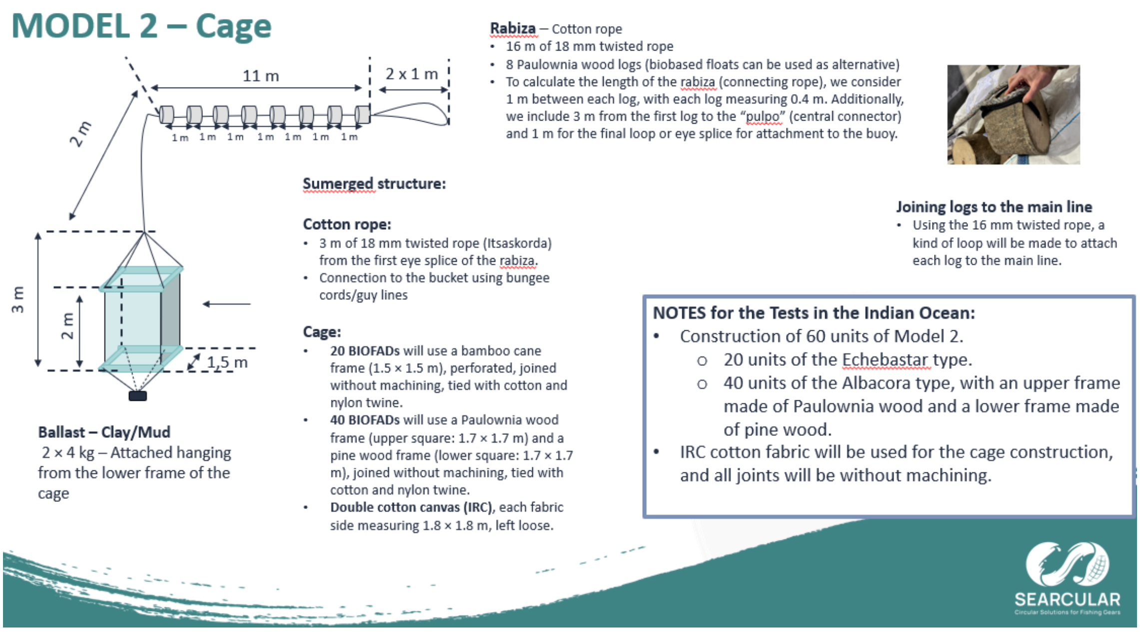
Tail Attractors:

If attractor elements are added, they must be plant-based, never plastic. Use cotton canvas scraps.

Figure 5. Bio-FAD Model 1 description including dimension and elements for its construction.

Model 2. Cage type bio-FAD

The bio-FAD model 2 (Figure 6) is a simplified, shallower Jelly-FAD designed to optimize material use and improve sustainability. Unlike the conventional Jelly-FAD, this version eliminates the superficial raft and significantly reduces the depth of the cube structure. Flotation is achieved using paulownia wood and/or bio-based marine biodegradable plastic floats, replacing traditional synthetic buoyancy elements. The cube is constructed from bamboo, paulownia, or pine—materials selected to enhance sourcing sustainability and reduce reliance on bamboo imports from China. Reducing the overall dimensions of the dFAD not only simplifies its construction and handling but also significantly lowers the volume of materials required, contributing to cost efficiency and operational practicality. Most importantly, the elimination of plastic flotation components directly supports efforts to reduce marine litter, particularly persistent plastic pollution, which poses long-term threats to marine ecosystems. Despite its reduced size and simplified architecture, the model maintains a drag coefficient comparable to the original Jelly-FAD, ensuring effective drifting behavior for tuna aggregation. This redesign achieves key eco-design objectives: minimizing synthetic material use, reducing environmental footprint, and streamlining deployment and retrieval operations without compromising functional performance.



MODEL 2 – Cage

Rabiza – Cotton rope

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

Joining logs to the main line

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

Sumerged structure:

Cotton rope:

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

Cage:

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

Ballast – Clay/Mud

2 × 4 kg – Attached hanging from the lower frame of the cage

NOTES for the Tests in the Indian Ocean:

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

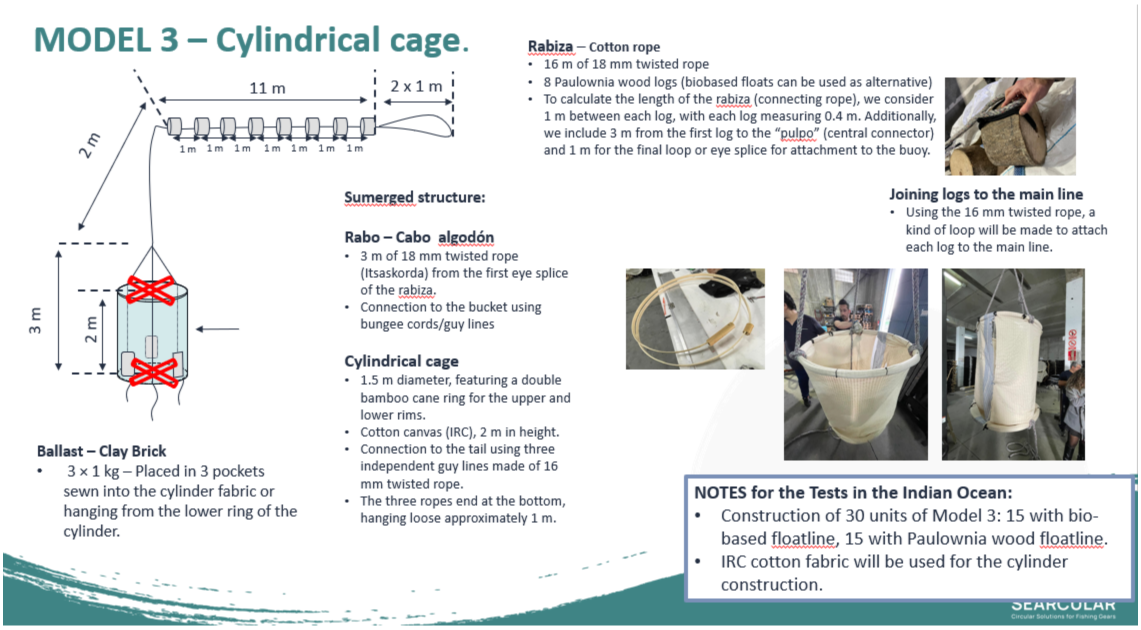
Figure 6. Bio-FAD Model 2 description including dimension and elements for its construction.

Model 3. Cylindric cage bio-FAD

The bio-FAD Model 3 (Figure 7) represents a significant improvement over the cage, offering a lighter and more sustainable alternative for bio-FADs. The previous version utilized thicker bamboo poles and ropes, making it heavier and bulkier. In contrast, cylindric cage features lighter components, including paulownia wood and/or bio-based plastic floats for flotation, making it an entirely organic and a lighter option. The reduced overall mass of the structure reduces the need for flotation. The lighter structure also facilitates deployment and retrieval while minimizing its environmental impact and reduces costs of dFAD transportation.

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

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



MODEL 3 – Cylindrical cage.

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

Sumerged structure:

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

Cylindrical cage
- 1.5 m diameter, featuring a double bamboo cane ring for the upper and lower rims.
- Cotton canvas (IRC), 2 m in height.
- Connection to the tail using three independent guy lines made of 16 mm twisted rope.
- The three ropes end at the bottom, hanging loose approximately 1 m.

Ballast – Clay Brick
- 3 x 1 kg – Placed in 3 pockets sewn into the cylinder fabric or hanging from the lower ring of the cylinder.

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

NOTES for the Tests in the Indian Ocean:
- Construction of 30 units of Model 3: 15 with bio-based floatline, 15 with Paulownia wood floatline.
- IRC cotton fabric will be used for the cylinder construction.

Figure 7. Bio-FAD Model 3 description including dimension and elements for its construction.

4. Testing of SEARCULAR bio-FAD models

4.1. Semi-controlled trials

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

The initial testing phase involved the deployment of 22 bio-FADs on April 13, 2024. These devices were based on an evolved version of the Jelly-FAD model (Moreno et al., 2023), maintaining conventional dimensions but incorporating two key innovations: the use of Paulownia wood as a flotation material in two units, and the integration of 12 mm diameter braided cotton ropes as the main tail component. The bio-FADs were deployed primarily in the western Mediterranean (Figure 8**¡Error! No se encuentra el origen de la referencia.**), where they remained at sea for periods ranging from 1.6 to 4 months.

Figure 8. Bio-FAD inspection in the Mediterranean testing. Left - Retrieving the bio-FAD to inspect the main rope. Found in perfect condition both at the surface and at the deepest section of the dFAD; middle – Attachments for the plastic floats found in perfect condition for the two Jelly-FADs

visited with this type of floatation, right - Drogue found in perfect condition for the three Jelly-FADs visited (photo credit: ISSF by Gala Moreno).

Preliminary observations revealed significant limitations in the mechanical performance of the 12 mm cotton ropes. Several units exhibited breakage in the upper sections of the tail, likely due to material fatigue and exposure to dynamic surface conditions (Figure 9). These findings highlighted the need for further testing with alternative rope diameters or constructions to ensure structural integrity over time. A more comprehensive analysis of this first phase will be conducted upon completion of the second testing phase.

The second phase of testing commenced on June 2, 2025, with the deployment of 10 additional cylindric cage (Model 3). These represented a lighter, more streamlined alternative to the traditional cubic Jelly-FADs tested previously. The second phase aimed to assess the performance of different flotation materials and attachment methods, as well as the influence of dFAD deployment depth on its stability and durability.

Key variables tested included:

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

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

- Plastic floats: Both attachment methods performed reliably, with no float failures. However, adjustments were recommended to optimize buoy distribution. It was observed that positioning the first float 0.5 meters below the GPS buoy helped prevent sagging of the main rope, whereas a 3-meter spacing led to rope submersion and buoy tilt.
- Paulownia floats: Units with floats attached via a secondary rope exhibited signs of abrasion and partial breakage within 2.5 months, resulting in progressive float loss (Figure 10). These findings suggest that while Paulownia offers promising buoyancy characteristics, its mechanical resilience and attachment methods require further optimization.

Figure 9. Breakages of 12mm cotton ropes

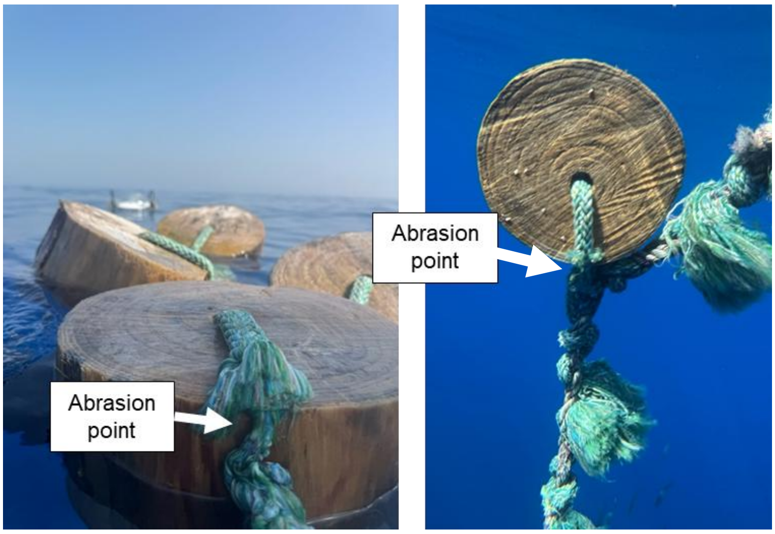


Figure 10. Paulownia wood floats attached with a secondary rope exhibited abrasion and showed a high risk of detachment. (photos credit: ISSF by Gala Moreno):

The second visit was conducted in December 2025, following six months after cylindric bio-FAD deployment. One dFAD was visited and all its components were inspected to evaluate their condition and determine any necessary repairs or design improvements.

The results after six months at sea were very positive. The main cotton rope supporting the entire structure was found to be in perfect condition (Figure 11). The cotton rope used for the flotation component and geolocating buoy attachement was found in perfect condition (Figure 12). The drogue frame, consisting of bamboo rings, was also in excellent condition, including the cotton rope used to secure the rings. The cotton fabric used in the drogue was not torn, although one section had become detached (Figure 13). Overall, there were no clear signs of significant degradation after six months at sea.

This is likely because the drogue is deployed at depth, where exposure to light and biofouling is minimal (i.e. 50 meters depth) and, therefore, degradation is also reduced. In addition, the Jelly-FAD concept, in which the structure is designed to avoid bearing significant tension, helped prevent damage to its components.

One improvement would be to sew the fabric of the drogue more securely to better close the circumference and prevent it from becoming detached. Overall, the cylindric bio-FAD showed full functionality and structural performance after six months at sea. The next inspection is planned for June 2026, when the structure will be assessed after 12 months in the water.

Figure 11. Main rope cotton rope found in perfect condition after 6 months at sea (photo credit: Joaquín Salvador):

Figure 12. Cotton rope used for the flotation component and geolocating buoy attachement found in perfect condition (photo credit: Joaquín Salvador)

Figure 13. The drogue of the jelly-FAD after 6 months (photo credit : Joaquín Slavador)

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

5. Future actions and next steps

The next phase of the SEARCULAR project will focus on the large-scale validation of bio-FAD prototypes under real fishing conditions. Starting in June 2026, a total of 150 bio-FAD units, along with its conventional dFAD pair, will be deployed across the main fishing regions, enabling a comprehensive assessment of key performance indicators, including drift behaviour, tuna aggregation, catch efficiency, lifespan, and material degradation. This large-scale experimental setup will provide robust comparative evidence across the three prototype models and under different environmental and operational conditions.

To ensure the traceability of bio-FADs throughout their operational life cycle during the project, each unit will be identified through a specific marking system, distinct from the FAD official number or code given by IOTC for FAD registry. This identification system will facilitate bio-FAD monitoring during the deployment, fishing operations, and eventual recovery phases. To this end, two green physical marks bearing the same unique identifier will be installed: one on the satellite buoy and another directly on the bio-FAD structure itself (Figure 14). This will be an alphanumeric FAD coding system that follows this structure, first “SEA” (project name SEARCULAR) and a serial number starting from 001 to 200. These identifiers will be linked to an internal record documenting, the technical characteristics of the unit, the materials used, the deployment date, as well as any relevant incidents recorded during its service life. Whenever any activity involving the buoy or the FAD is carried out, fishers will report the details of the activity and the condition of the bio-FAD, if inspected. If the buoy is replaced, the green tag will be transferred from the old buoy to the new one to ensure traceability of the bio-FAD through its complete operational lifetime. This approach will improve individual device tracking, strengthen the consistency of data collected with each unit, and support the technical assessment of their performance under real operating conditions along the entire lifespan.

Figure 14. Alphanumeric coding and physical marking system for bio-FAD traceability.

Building on findings from previous phases, particular attention will be given to improving the durability of critical components and optimizing material selection and structural configurations. The results obtained will support the refinement of bio-FAD designs and contribute to the development of practical recommendations for the fishing industry and management bodies, facilitating the transition towards fully biodegradable dFADs and reducing the environmental impact of tropical tuna fisheries.

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Annex I

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

Annex II

Country	**Company name**	**Products**	**Contact name**	**email**	**Website**	**Phone**
Shandong, China	Shandong Baron New Materials Co.Ltd	Ropes (Sisal, jute and cotton twisted and braided ropes)	Linda Hu	ropemaker@sdbaron.cn	www.baronrope.com www.sdbaron.cn	+86 538 6132138 +18653860609
Shandong, China	Shandong Haoyuntong Netting Technology Co., Ltd	Ropes and canvas	Cheng	c-zhou@shou.edu.cn	-	-
Zhengzhou Henan, China	Zhengzhou Zhongyuan Defense Materials Co., Ltd.,	Producer of raw quemical and organic materials	Cheng	c-zhou@shou.edu.cn	-	-
Manila, Phllipines	Nettex/Fortune Net	Ropes	Mel Morales	melmorales_728@yahoo.com export_fntgrp@yahoo.com	-	+63287125362 | +63287119238
PingTung, Taiwan	Ching Fa Fishing implements Factory CO., LTD	Ropes	Mr. Yang Hsu	export7@chingfa.com.tw	www.chingfa.com.tw	+886 8 833 1100
Guayaquil, Ecuador	BALSASUD S.A.	Balsa wood	Giancarlo Del Cioppo	gdc@corelitecomposites.com	www.corelitecomposites.com	+593 4 2380265 / +593 4 2881477; planta +593 4 2267007 / 2267008.
Sto Domingo de los Tsáchilas, Ecuador	BALCOMAD S.A.	Balsa wood	-	info@balcomad.com.ec	https://balcomad.com.ec/	+593 (02) 362-1887

Guayaquil, Ecuador	Tunacons	FAD manufacturers	Jazmín Bastidas	jbastidas@tunacons.org	https://www.tunacons.org/ecofads-orders/	+593998374057
Manta, Ecuador	Pronaval	FAD manufacturer and Ropes supplier	Iñaki Ostiz	iostiz@pronaval.es	www.pronaval.es	+593 97 929 7831/+34 686 224 668
Medellin, Colombia	Grupo Excala	Fique Ropes and canvas	-	info@grupoexcala.com	https://grupoexcala.com	+57(604)365 8888
Markina, Spain	Itsaskorda, S.L.	Organic Ropes	Jose Mari	itsaskorda@itsaskorda.es	https://www.itsaskorda.es	+34 94 6169408
A Pobra do Caramiñal, Spain	America Aparejos	FAD manufacturer	América	america@lopezvilar.es	https://lopezvilar.es	+34981870758
American Samoa, U.S.	Purse seine Samoa	FAD manufacturer	Frank Barron	franklbarron@gmail.com		+1(684)258 4067
Japan	Nichimo	Bio-based Rope and canvas	Akito Ishida	akito_ishida@nichimo.co.jp	https://www.nichimo.co.jp/english/	+03-3458-4020/ Mobile 070-4487-7758
Valencia, Spain	iPawlonia	Pawlonia wood	Jol Del Hierro	Joldhg@gmail.com	-	+34 693 62 69 26

Table 1. Details of materials made with natural fibres – Products from Shandong Haoyuntong Nettling Technology Co., Ltd

Type of material	Diame-ter	Structural property	Brea-king strength	Photo
twisted cotton rope	20 mm	Z-twisted cotton rope with 4 strands, but without core; naturel color-white	1400 kgf	
braided cotton rope	20 mm	braided strands; naturel color-white	1400 kgf	
twisted sisal rope	20 mm	Z-twisted sisal rope with 3 strands, without core; color-brown	to be measured	

Other type of natural ropes with breaking strength around 1050 kgf	16 mm	Z-twisted cotton rope with 3 strands		
	10 mm	Z-twisted cotton rope with 3 strands		
	16 mm	Z-twisted sisal rope with 3 strands		

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