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EVALUATION OF BIO-BASED FAD MATERIALS IN RELATION TO MARINE BIODEGRADABILITY CERTIFICATION STANDARDS

This document was produced by the IATTC staff in response to a FADWG-9 recommendation, endorsed by the SAC-16 that, "*The IATTC scientific staff present to the Working Group an analysis derived from the compilation and evaluation of the certification options for bio-based materials which are used in FADs, and which will ensure that the new material and the final product do not contribute to the pollution of the marine environment.* "

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SUMMARY

Fish Aggregating Devices (FADs) are central to tropical tuna purse-seine fisheries but also raise ecological concerns, particularly through stranding events and marine pollution from abandoned, lost, or otherwise discarded fishing gear (ALDFG). To address these impacts, the Inter-American Tropical Tuna Commission (IATTC) has initiated a transition toward biodegradable FADs (bio-FADs) under Resolution C-23-04. This measure phases out synthetic materials, bans netting by 2025, and aims for the exclusive use of biodegradable FADs by 2031. The goal is to ensure that materials maintain their fishing performance while degrading in an environmentally safe and non-toxic manner. This transition has led to increased exploration of both traditional natural materials—such as plant fibers, bamboo, and wood—and emerging alternatives. Some innovations focus on improving the durability of organic components through coatings, while others, particularly bioplastics, are being considered for structural elements like rafts and flotation devices. However, the growing use of bioplastics introduces challenges. Many materials may be ambiguously labeled, lack traceability, or are certified under incomplete or inconsistent standards. Without clear regulatory guidance, their adoption risks undermining environmental objectives and eroding confidence in the bio-FAD transition, as their environmental fate remains uncertain. In response, the IATTC's 2025 *ad hoc* FAD Working Group, endorsed by the SAC-16, tasked scientific staff with evaluating certification and biodegradability standards for bio-based FAD materials.

Resolution C-23-04 defines "biodegradable" materials as non-synthetic or bio-based alternatives that comply with international marine biodegradability standards and do not release harmful substances, including plastics or heavy metals resulting from biodegradation. However, the term "bioplastic" remains broad and potentially misleading. It includes materials that may be bio-based but not biodegradable, biodegradable but fossil-derived, or both. As a result, bio-origin does not guarantee environmental safety or degradation in marine conditions.

This document reviews international marine biodegradability standards and certification schemes, highlighting key limitations. Current test methods often rely on indirect indicators, lack clear pass/fail criteria, and are often unsuitable for thicker or more complex FAD materials. They also fail to capture variability in marine environments, creating uncertainty about degradation in real ocean conditions. The document clarifies key concepts—biodegradation, compostability, and biodeterioration—and raises concerns about chemical safety and traceability. Some bioplastics may contain additives or compounds with toxicity comparable to conventional plastics, and incomplete degradation may contribute to microplastic pollution, highlighting the need for transparency in material composition, certification, and performance.

The study concludes that while bioplastics and other alternatives show promise, their adoption should follow a precautionary approach. It recommends improving traceability by requiring vessel operators to report, before each trip, key details (e.g., specifications, function) on materials used in FAD construction. In addition to being used by observers during deployments, this information, once cataloged and linked to IATTC databases, should support monitoring and informed decision-making. Expanding studies and tests on marine biodegradability and materials, and continuously reviewing evolving standards is also recommended, along with providing clarity regarding Commission's degradation time and medium goals. Collaboration among stakeholders will be essential to ensure that the transition to bio-FADs effectively reduces environmental impacts while maintaining the operational needs of the fishery.

1. INTRODUCTION

The relevance of Fish Aggregating Devices (FADs) as the most effective method for catching tunas in the tropical tuna purse-seine fishery is globally acknowledged (Lennert-Cody and Hall, 1999; IATTC, 2025; Hall and Román, 2013; ISSF, 2025; Murua et al., 2023). However, this is coupled with several ecological risks, some of them specifically attributed to the FAD fate and structure, including potential issues associated to abandoned, lost or otherwise discarded fishing gear (ALDFG) (e.g., ghost fishing, stranding events) and marine debris and pollution (Franco et al., 2009; Hall and Román, 2013; Filmalter et al., 2013; Maufroy et al., 2015; Sinopoli et al., 2020; Escalle et al. 2024).

The Inter-American Tropical Tuna Commission (IATTC) has taken several key actions to address the impact of FAD structure in the eastern Pacific Ocean (EPO). One of the first steps was a series of experiments conducted by its scientific staff using biodegradable FADs (hereafter, bio-FADs; see Román et al., 2022; Román et al., 2023),which informed the development of a management plan for a bio-FAD fishery in the EPO. Based on the findings, during its 14th meeting in 2023, the IATTC Scientific Advisory Committee (SAC; see document SAC-14-16) endorsed several recommendations from the IATTC staff and the FADWG aimed at supporting a transition to a fully bio-FAD fishery, which were subsequently adopted by the IATTC through Resolution C-23-04.

Among the main provisions of this resolution are:

- The prohibition of netting in FAD construction by 2025, eliminating entanglement risks for species.
- A gradual transition toward the exclusive use of FADs made entirely with biodegradable materials in the EPO by 2031.

To minimize the potential impacts to the fishery due to this transition, Resolution C-23-04 adopted five categories of FADs, ranging from those made entirely of non-biodegradable materials (Category V —these are the conventional FADs used to date) to Category I, which consists of FADs made exclusively of biodegradable materials, including both the surface and submerged components, according to the biodegradable definition indicated in C-23-04: "*non-synthetic materials*[1] *and/or bio- based alternatives that are consistent with international standards*[2] *for materials that are biodegradable in marine environments. The components resulting from the degradation of these materials should not be damaging to the marine and coastal ecosystems or include heavy metals or plastics in their composition*". A stepwise transition to increasingly more biodegradable FADs will allow the EPO fleet to progressively move among these categories, such that:

1. In 2026, only FAD of categories I, II, III or IV shall be used;
2. in 2029, only FAD categories I or II shall be used;
3. in 2030, the IATTC shall determine whether, by 2031, only FADs of category I shall be used.

In addition to adopting the regulatory framework, the IATTC, and the broader community out there, have made substantial efforts recent years to advance the transition toward bio-FADs. These efforts include the abovementioned experimental controlled and large-scale trials with bio-FADs conducted with the purse-seine fleet in the EPO (Román et al., 2023), but also numerous global initiatives to promote the adoption of bio-FADs (Lopez et al., 2019; Moreno et al., 2020, Román et al., 2023; Zudaire et al., 2023; Murua et al., 2023; Escalle et al., 2025). In these efforts, both scientists and fishers have worked, most of the times in collaboration, to develop bio-FADs with an reasonable operational lifespan —that is, a period

[1] For example, plant-based materials such as cotton, jute, manila hemp (abaca), bamboo, natural rubber, or animal-based such as leather, wool, lard.
[2] International standards such as ASTM D6691, D7881, TUV Austria, European or any such standards approved by the Members of the IATTC.

during which they remain cohesive and effective for fishing—comparable to that of conventional FADs. This objective has led to new lines of research, including modifications to FAD designs to increase durability and decrease friction (Moreno et al., 2023), as well as investigations into new biodegradable materials. Initially, most trials testing bio-FADs focused on the use of materials of organic origin, primarily bamboo cane, balsa and paulownia woods, as well as plant-based fibers such as cotton, manila hemp, abaca, sisal, jute, fique and coconut fiber. More recently, the fishing industry, in association with different FAD/buoy manufacturers, and several Non-Governmental Organizations (NGOs) have also begun to explore the use of bioplastic materials and coatings products (e.g., animal lard, plant-based rubber, resins) to increase the duration of the organic ropes and canvas made of vegetable fibers. Additionally, experiments with bioplastic materials aiming at extending the bio-FAD's lifespan are being conducted, with floatation remaining as one of the key issues.

While bioplastics can appear as a promising option to increase bio-FAD durability, progress in their adoption can be hindered —and its "biodegradable" nature undermined, if these materials break apart in adequate chemical components and/or traceability is impeded by the lack of clear component labeling from manufacturers. This is of particular concern given that some bioplastic materials are already being used by the fishery. In addition, unverified or unsupported claims such as "biodegradable", if not properly assessed, may undermine confidence in material biodegradability from a practical and regulatory point of view. For example, scientific studies have demonstrated that some bioplastics available on the market are just as toxic as conventional plastics with regards to chemicals they contain and release (Zimmermann et al.,2020). This could represent a major problem if these materials were used in the bio-FAD manufacture, following Resolution C-23-04. In this regard, an evaluation of the different international standards for these bio-based materials is key for practical matters and transparency, while ensuring traceability and applicability of all these materials used in the EPO tuna purse-seine FAD fishery.

The use of bioplastic materials in the FAD fishery is progressively increasing, highlighting the need for appropriate assessments and establishing certification criteria and standards. In parallel, it is essential to broaden our understanding of bioplastics, particularly with respect to their chemical safety to ensure that their use is environmentally friendly and consistent with sustainability objectives of the IATTC and the adopted standards.

As a result, the SAC, during its 16th Meeting (see doc. SAC-16 Recommendations), endorsed a recommendation of the FADWG for the IATTC scientific staff to "*present to the Working Group an analysis derived from the compilation and evaluation of the certification options for bio-based materials which are used in FADs, and which will ensure that the new material and the final product do not contribute to the pollution of the marine environment*".

Certification standards for biodegradability in the marine environment represent a relatively new and rapidly evolving scientific field. Therefore, a number of key concepts and definitions must therefore be clarified before proceeding.

Addressing the SAC-16/FADWG-9 recommendation would benefit from creating and maintaining an IATTC database for cataloguing all biodegradable materials used in bio-FAD manufacture. Entries should include the material composition, the manufacturer, and any marine biodegradability certification held.

This document reviews key concepts related to biodegradability, compiles existing marine biodegradability test standards, and assesses how these apply to materials currently used in EPO bio-FAD construction, with the aim of providing the FAD Working Group with guidance on material certification.

2. BIO-BASED MATERIALS USED IN EPO FADS

The bio-FAD transition under Resolution C-23-04 involves a range of bio-based materials, each serving different structural and functional roles in FAD design. These materials can be broadly grouped into three categories: plant-based natural fibers, bioplastics, and rubber/latex coatings. This section reviews each category and its current application in EPO FAD construction.

2.1. PLANT-BASED NATURAL FIBERS

Plant-based natural fibers have been the primary materials used in bio-FAD construction to date. These lignocellulosic materials are derived from renewable plant sources and are generally accepted as inherently biodegradable in marine environments, given their organic composition and well-documented decomposition pathways.

The main plant-based fibers currently used in EPO bio-FAD construction include cotton, manila hemp (abaca), sisal, jute, fique, and coconut fiber (coir). These are used primarily for ropes, twines, and panels in both the surface (raft) and submerged structures of FADs. Bamboo cane is also widely used as a structural framing material for FAD rafts, while balsa and paulownia woods serve as flotation or structural components.

Natural fibers are generally recognized as non-toxic and environmentally benign upon degradation. Their decomposition in seawater produces organic matter that is readily assimilated by marine microorganisms without releasing hazardous by-products, heavy metals, or persistent microplastics. For these reasons, plant-based materials are broadly considered to satisfy the biodegradability requirements set out in Resolution C-23-04 without the need for formal certification under bioplastic-specific standards.

However, the main limitation of plant-based natural fibers is their relatively short operational lifespan at sea. Exposure to seawater, UV radiation, and mechanical abrasion from wave action and currents accelerates their degradation, often resulting in FAD structural failure within a few months. This has prompted the fishing industry to explore protective coatings (e.g., rubber/latex) and bioplastic-based alternatives to extend FAD durability while maintaining compliance with biodegradability requirements.

2.2. BIOPLASTICS

Rising environmental concerns and advances in biomass processing have driven global initiatives to replace fossil-based plastics with bio-based polymers[3] across multiple sectors, including construction (Mousavi et al., 2025).European Bioplastics (2022) defines a “bioplastic” as a material that is bio-based, biodegradable, or both (Figure 1). However, as noted by Zimmermann et al. (2020), the term remains ambiguous: commercial products such as starch blends are classified as bioplastics, yet the status of plant-based materials combined with synthetic components (e.g., cellulose or bamboo-based blends) is less clear. Regardless of definition, these materials are designed to serve the same functions as conventional plastics.

BIO-BASED AND FOSSIL-BASED BIOPLASTICS

The U.S. Department of Agriculture (USDA) has defined a bio-based product as “*a commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products, including renewable domestic agricultural materials (including plant, animal, and aquatic materials), forestry materials, intermediate materials, or feedstocks. Biobased products exclude motor vehicle fuels, heating oil, or electricity produced from biomass*”.

[3] A polymer is a material made of very large molecules formed by linking many small repeating units. Polymers are typically lightweight, strong and resistant to water and chemicals, for example, plastic, bioplastic, rubber, nylon.

Importantly, bio-based does not necessarily mean biodegradable. Some bio-based plastics -those produced by microorganisms, are biodegradable, such as PLA (Polylactic Acid), PBS (Polybutylene Succinate - obtained from plant resources), TPS (Thermoplastic starch), PHA (Polyhydroxyalkanoate) and its variants: PHBV (Polyhydroxybutyrate-co-valerate), PHV (Polyhydroxyvalerate) and PHB (Polyhydroxybutyrate), etc., but others are not, such as bio-based PTT (Bio-based Polytrimethylene Terephthalate), bio-based PE (Bio-based Polyethylene), bio-based PA (Polyamida), bio-based PET (Polyethylene terephthalate), etc., (Kato et al., 2023; Zimmermann et al., 2020; Barron and Sparks, 2020; Lavagnolo et al., 2024; Cheng et al., 2022; European bioplastics, 2022; Figure 1).

Most fossil-based plastics and synthetic fibers are not biodegradable, e.g., PE (Polyethylene), PET (Polyethylene terephthalate), PP (Polypropylene), PVC (Polyvinyl chloride), PMMA (Polymethyl methacrylate) etc.; however, some are biodegradable, such as some fossil-based bioplastics, e.g., PBAT (Polybutylene adipate terephthalate), or PCL (Polycaprolactone) (European bioplastics 2022; Lavagnolo et al., 2024; Cheng et al., 2022), or the bio-based PBS (Polybutylene Succinate - obtained from fossil fuels; Kato et al., 2023; Figure 1).

2.3. RUBBER AND LATEX

Rubber used to coat FAD panels and ropes is a special category of bio-based material. It is composed of polymers known as elastomers, which share some properties with plastics but are chemically distinct (Liu et al., 2025).

Natural latex is a milky white substance (sap) collected from the rubber tree (*Hevea brasiliensis*) and some other plants. It is a suspension (colloid) in which solid particles of the elastomer along with a negligible amount of non-rubber components are suspended in water (Pattanawanidchai et al., 2024). The result of precipitation or coagulation of the natural latex is the natural rubber (NR). Its primary component is the elastomer called Poly(*cis*-1,4-isoprene), a bio-based polymer (Pattanawanidchai et al., 2024; Vaysse et al., 2013; Luo et al., 2024).

NR exhibits elasticity, flexibility, durability, temperature resistance, impermeability, and is inherently biodegradable, but has limited tensile strength (Pattanawanidchai et al., 2024; Luo et al., 2024; Coran, 2013). However, through vulcanization process is when the bio-based polymer changes significantly its molecular structure, achieving strength, and increasing elasticity, consistency and flexibility (Pattanawanidchai et al., 2024; Coran, 2013). In addition to natural rubber, synthetic rubber also exists, and its mechanical strength can likewise be enhanced through vulcanization.

Although vulcanization imparts toughness and durability, it hampers recycling and significantly decelerates NR biodegradation (Shah et al., 2013; Schwab et al., 2024). Shah et al. (2013) also estimated that total microbial/fungal soil biodegradation of vulcanized NR products (e.g., surgical latex gloves) would take at least 100 years. On the other hand, rubbers (natural or synthetic) vulcanized with synthetic polymers are not biodegradable, and cannot be conventionally recycled (Rodgers and Waddell, 2005).

In addition to extremely slow or null biodegradability, it is well documented that some synthetic rubber, such as those used in tire manufacturing, can generate significant amounts of microplastic pollution. In particular, tire wear is estimated to release around 6 million tons of tire wear microplastics (TWM) into the environment, including the marine environment, in the form of micro (<5mm) or nanoparticles (<1000 nm), (Klun et al., 2023; Johannessen et al., 2022). Microplastics are problematic when ingested, affecting the species metabolism, or when accumulated in the body of an organism, affecting its vitality (Klun et al., 2023; Rios Mendoza et al., 2023; Mao et al., 2022).

3. BIODEGRADABILITY, COMPOSTABILITY, AND BIODETERIORATION

The biodegradation of plastics and bioplastics is a complex process that results in extensive reworking of the carbon-containing compounds in the plastic by living organisms (European Union, 2020). According to Lavagnolo et al. (2024), a material, such as bioplastic is defined as biodegradable "*if it can be decomposed into carbon dioxide (CO_2) under aerobic degradation or methane (CH_4) and CO_2 under anaerobic conditions, inorganic compounds and new cellular biomass, by the action of naturally-occurring microorganisms*". The biodegradation of bioplastic process occurs through two successive stages (SAPEA, 2020; Figure 2):

1. **Polymer breakdown**, where the carbon contained in the plastic's molecules is converted into smaller organic compounds that separate from the material.
2. **Microbial assimilation**, in which these small organic compounds are absorbed and metabolized by microorganisms, ultimately producing inorganic compounds (CO_2, CH_4) and new microbial biomass.

Stage 1 involves chemical reactions that occur either without living organisms (abiotic) or are driven by living organisms through enzymes, acting on the bulk plastic, breaking down its constituent polymers and releasing low molecular weight organic compounds (SAPEA, 2020). Stage 2 involves microorganisms absorbing low molecular weight organic compounds and metabolizing them to generate energy (catabolism), producing CO2 (or CO2 and CH4 under anoxic conditions) and forming new microbial biomass (anabolism). The transformation of carbon from the polymers into these gases and its incorporation into microbial biomass represent the intended endpoints of biodegradation (SAPEA, 2020). Laboratory biodegradability standards tests typically measure this process through respirometry analyses of CO_2 (and CH_4) production, which form the foundation for certification procedures (see Section 6).

Most bioplastic products biodegrade only under specific environmental conditions (European Union, 2020), and the definition of biodegradation therefore requires clarification. First, for regulatory purposes, it must be complemented by specifications on the required extent of biodegradation within a set timeframe and in the (open) environment where it is assessed, generally ranging from a few months to 2 years (Table 2, Figure 2). Second, this definition applies only to the organic components of plastic materials. If a plastic contains -entirely or in part, inorganic polymers (i.e., non–carbon-based), these inorganic components do not undergo biodegradation as defined above, requiring separate scientific and regulatory assessment. Plastics composed entirely of inorganic polymers must therefore not be labeled "biodegradable," as doing so would violate this definition (SAPEA, 2020).

3.1. COMPOSTABILITY OF BIOPLASTICS

The terms "biodegradable" and "compostable" are often confused. Compostability goes further than biodegradability: in addition to breaking down into CO_2 or CH_4, a compostable material must transform into compost—an organic amendment that improves soil quality (Lavagnolo et al., 2024; USDA).

Compostable bioplastics are engineered to biodegrade under controlled conditions, with distinct industrial and home composting categories (Ghasemlou et al., 2024; European Union, 2020). These materials must be collected and directed to appropriate composting facilities. The European standard EN 13432:2000 defines requirements for industrially compostable packaging but does not apply to home or marine composting environments.

Compostability aligns with circular economy principles, as plant based polymers (biopolymers) extracted from compost could be reused to produce new bioplastics (Figure 3). However, achieving this in the marine environment is challenging, as bioplastics—such as bioplastic floats used at FADs—would need to be recovered either at sea or after stranding on land in order to be composted.

3.2. BIODETERIORATION OF BIOPLASTICS

It is important to distinguish between biodegradation and biodeterioration. Biodeterioration refers to the broader impact of microorganisms on the physical properties of a plastic, without the chemical transformation of carbon-containing compounds that defines biodegradation. This distinction is important because it determines the applicable testing requirements and standards (European Union, 2020).

A more detailed glossary with key definitions is provided in Annex 1.

4. TEST STANDARDS ON THE BIODEGRADABILITY OF BIOPLASTICS IN THE MARINE ENVIRONMENT

A material's biodegradability is confirmed when it meets test standards established by bodies such as the International Organization for Standardization (ISO), the American Society for Testing and Materials (ASTM), and the European Committee for Standardization (CEN). Table 2 lists marine biodegradability standards compiled by IATTC staff to date. Marine biodegradability testing procedures are still considered at an early stage of development (Briassoulis et al., 2024), and no clear pass/fail criteria currently exist for ocean degradation (Lavagnolo et al., 2024). Biodegradation must be inferred from indirect indicators such as CO_2 evolution, biogas formation, oxygen consumption, and reductions in total organic carbon (TOC) or dissolved organic carbon (DOC) (Briassoulis et al., 2024; Lavagnolo et al., 2024; Filiciotto and Rothenberg, 2021).

Each method has strengths and limitations, but none can directly quantify the conversion of polymer-derived carbon into biomass carbon (Lavagnolo et al., 2024; Cheng et al., 2022; European bioplastics, 2022; upPE-T, 2025). Moreover, without specifying the timeframe or extent of decomposition under environmental or microbial influence, all plastics could be considered biodegradable -ranging from weeks to millions of years (Lavagnolo et al., 2024). Additionally, standards do not generally specify the particular type of bioplastic to be tested. Although they can provide some information about the size and shape of the test sample material, such as film, pellet, powder, monofilament etc., however, there is no standard tests for larger or thicker sampling items (e.g., bioplastic bars, >5 mm sheets). For certification of these larger or thicker bioplastics, current standards do not provide explicit guidance, which is a recognized gap in international protocols (BPC Instruments, *pers. comm*).

The wide variability of oceanographic conditions further complicates certification: many standards fail to capture the full range of environmental factors affecting degradation, so some certified bioplastics may not degrade as expected in practice. For example, the TÜV Austria OK Biodegradable MARINE certification applies only to the photic zone and does not cover the seabed or aphotic layer, where differences in temperature, salinity, light, and microbial activity can substantially alter degradation rates (Benito-Kaesbach et al., 2025).

Some vulcanized rubbers have been reported as chemically recycled and biodegradable; however, these findings remain at the experimental stage, and further research is needed to scale up production using advanced processing methods (Schwab et al., 2024). Therefore, their use in the fishery should not be considered unless reliable marine biodegradability tests are conducted.

5. CERTIFICATION BODIES ON BIODEGRADABILITY OF BIOPLASTICS IN MARINE ENVIRONMENTS

In a certification scheme, the client engages a certifier and an accredited laboratory to carry out the required tests (Figure 4). Independent facilities perform the analyses and provide results reviewed by the certifier's experts (SAPEA, 2020). Chemical characterization is provided by the client or external laboratories, and the certifier may request additional analyses. Once the review is complete, certification is granted and the corresponding label may be used. Certificates are time-limited and must be renewed after expiry or following changes in material composition (SAPEA, 2020).

Certifiers may design programs specifying what can be tested (e.g., pure polymers, products, natural materials), which methods to use, and any additional requirements (SAPEA, 2020). Criteria should ideally be transparent, although test data often remain confidential to protect proprietary formulations. Certification is a commercial service, with clients paying fees for initial certification and renewal (SAPEA, 2020).The main certification bodies operating marine biodegradability schemes for bioplastics are:

DIN CERTCO. Applies to standard biodegradation tests on basic bioplastic materials (e.g. films, non-wovens, powders; Table 2), additives, and marine-use products (e.g. fishing nets). Does not cover thicker items such as packaging or cutlery (DIN CERTCO, 2022).

Japan BioPlastics Association (JBPA). A private body promoting bio-based and biodegradable plastics and developing certification schemes, including marine biodegradability certification under the BiodegradablePla programme (JBPA, 2025).

TÜV Austria. Offers the OK Biodegradable MARINE certification (Figure 4), requiring that materials biodegrade under defined marine conditions within a set timeframe. The scheme operates in partnership with AIMPLAS (Spanish Plastics Technology Centre).

6. ASSESSMENT: MAPPING OF CURRENT EPO BIO-FAD MATERIALS AGAINST AVAILABLE CERTIFICATIONS

A central objective of this document is to assess the extent to which bio-based materials currently used in EPO FAD construction are covered by existing marine biodegradability certification schemes. The table 4 summarizes this mapping for the principal material categories and specific products known to the IATTC staff. For each material, it identifies: the relevant marine biodegradability test standard(s), the applicable certification body, whether any currently commercialised product carries that certification, and the current compliance status or gap. The information is drawn from IATTC observer data, manufacturer communications, and the scientific literature reviewed in this document. Where information is incomplete or unconfirmed, this is explicitly noted, as these gaps themselves constitute an important finding and a basis for the conclusions and recommendations in Section 9.

A comprehensive text description and assessment of material categories outlined in Table 4 is provided below:

- **Plant-based natural fibers** (cotton, abaca, sisal, jute, coir, bamboo, balsa, paulownia). FAD component: Ropes, panels, raft structure, flotation. Certification status: No bioplastic-specific certification required or available. Generally accepted as inherently biodegradable under Resolution C-23-04 definition of non-synthetic materials. No known environmental concerns from degradation by-products.
- **Natural rubber/latex coatings** (e.g., TUNACONS latex-ammonia process, SANOCEANOS elastomeric coating, TEIMSA latex-coated panels). FAD component: Protective coating for ropes and panels. Certification status: No marine biodegradability certification identified. Natural (unvulcanized) rubber is inherently biodegradable but extremely slow (estimated over 100 years for vulcanized forms). Vulcanization process and additives unknown for most manufacturers. Potential microplastic risk if synthetic rubber components are present.
- **PBS bioplastic** (e.g., Zunibal ZunFloat). FAD component: Flotation (raft buoy). Certification status: Holds JBPA Marine Biodegradability certification and ISO 14006 eco-design certification. Tested as pellet material under standard conditions. No certification for thick or structural forms as used in FAD floats. Designed as reusable (5-year cycle), biodegradation rate variable under standard environmental conditions.

- **PHA/PHB bioplastics**. FAD component: Experimental (panels, twines). Certification status: Some PHA variants have demonstrated partial or complete marine biodegradation in research settings. No FAD-specific commercial products currently certified. Promising for future FAD applications pending further testing.
- **Other bioplastics** (PLA, PBAT, PCL, starch blends). FAD component: Not widely used in EPO FADs. Certification status: Some hold industrial composting certifications (EN 13432) but limited or no marine biodegradability certification. PLA shows very slow marine degradation. PCL and PBAT show variable results depending on test conditions.

This assessment reveals several key findings. First, the most widely used bio-FAD materials in the EPO are plant-based natural fibers, which do not require bioplastic certification but are accepted under the non-synthetic materials provision of Resolution C-23-04. Second, rubber and latex coatings, despite being widely applied, lack any marine biodegradability certification, and their degradation behaviour and chemical composition remain largely undocumented. Third, among bioplastics, only PBS (as used in the Zunibal ZunFloat) holds a marine biodegradability certification, and this was obtained for pellet-form material rather than the thick structural components actually deployed at sea. Fourth, for most bioplastic polymers, existing certifications relate to industrial composting or soil biodegradation conditions that differ substantially from the marine environment. These gaps underscore the need for FAD-specific testing protocols and for greater transparency from manufacturers regarding material composition and certification status.

7. CATALOGUE SYSTEM AND DATA COLLECTION

To further advise the FAD Working Group and the Commission on certification compliance, a catalogue of bio-based materials used in bio-FAD construction should be compiled. Each entry should list the polymer structure, commercial name, manufacturer, and function within the FAD (e.g. raft, rope, twine, or panel; surface or submerged component). Where available, entries should include the applicable test standards, certification body, labelling scheme, and any other relevant information. This system could enable systematic documentation of materials used at the vessel or company level.

Where a material holds partial certification, this should be clearly indicated (e.g. by a suffix to the commercial name). For research and reporting purposes, the catalogue could be integrated into the IATTC databases (e.g., Floating-object database), using the commercial name of each component as a cross-reference key.

A practical challenge for observers is that distinguishing natural from synthetic materials in panels, ropes, or coatings becomes difficult at deployment, and especially, after extended drifting periods. The most reliable solution could be to obtain material information from the vessel/company before departure, via the Secretariat or field office. Component data recorded at deployment can then be ideally linked to subsequent encounters using the buoy serial number—including any materials added or replaced to extend the FAD's service life. Regular audits could also be organized to ensure proper material use in FAD construction, along with the provision of detailed invoices for the material purchased.

The main sources of information for building and maintaining this catalogue are:

7.1. IATTC OBSERVER FLOATING-OBJECT DATABASE

The IATTC observer programme was established in 1979 following an agreement at the Commission's 34th meeting (IATTC, 1980). Initially, data collection focused on fishery interactions with marine mammals, catches of target species, and fleet operational characteristics (Duffy et al., 2022; Joseph, 1994).

IATTC observers began collecting floating-object data in 1987. Initial records included the date and location of each set or sighting, object dimensions, percentage submerged, previous interaction history, schematic drawings, and general information on type, shape, material, and colour.

In 1997, additional fields were added: epibiota type and coverage, maximum depth, and expanded codes for object type and shape.

In 2005, major updates were introduced. Observers began recording component details, the method and equipment used to locate the object, transmission equipment capabilities, and the object's origin. Data on entangled fauna were also added. Objects were assigned a unique identifier and a consecutive encounter number, enabling tracking within trips.

In April 2019, in observance of Resolution C-17-02 on the *Conservation Measures for Tropical Tunas in the Eastern Pacific Ocean (EPO) during 2018-2020*, observers started collecting relevant information on buoys attached to FADs (e.g., identification, interactions) as well as detailed species-specific information on entangled fauna. Additionally, they collected information related to the natural or synthetic origin of different materials used in the construction of FAD floating and submerged structures. The Table 3 shows the list of these components.

7.2. INDUSTRY AND OTHER STAKEHOLDERS

The IATTC scientific staff has maintained a close collaboration with the tuna industry and a wide range of fishery stakeholders. In relation to bio-FADs, the scientific staff, together with the fleet, Tuna Conservation Group (TUNACONS), and the Association of Large Tuna Freezers (AGAC), carried out a large-scale bio-FAD experiment in the eastern Pacific Ocean (see Román et al., 2022; Román et al., 2023). In recent years, the IATTC-industry collaboration has expanded to other areas of tuna fisheries management. For example, scientific staff have participated in skipper seminars and capacity-building workshops organized by TUNACONS, the Ecuadorian Tuna Fishers Association (ATUNEC), and AGAC. Additionally, since 2024, the entire EPO tuna purse-seine fleet has been invited to participate in the IATTC's annual Online Skipper Seminar.

This cooperation has built trust and enabled shared objectives. For the purposes of this analysis, it will be important to engage the industry regarding the FADWG-9/SAC-16 request and the proposed response. A key contribution from industry will be information on the biodegradable materials used in bio-FAD construction, including the certification standards applicable to each material. This will improve the resolution of the observer floating-object database and support proper cataloguing in the FAD components inventory.

Collaboration with research organizations has also produced important results. Joint work with AZTI-Technalia and the International Seafood Sustainability Foundation (ISSF) has contributed to FAD Working Group and FADWG discussions. IATTC staff have participated in the International Workshop on bio-FADs, and further work with AZTI-Technalia has included bioplastic material testing at the IATTC-Achotines Laboratory in Panama.

7.3. MANUFACTURERS USING BIOPLASTICS AND OTHER BIODEGRADABLE MATERIALS IN FAD CONSTRUCTION

This section lists, in alphabetical order, the bio/polymer-based materials currently used by bio-FAD manufacturers in the EPO fishery, as marketed and known to IATTC staff. Inclusion does not constitute endorsement of any particular product.

SANOCEANOS. Manufactures bio-FADs using ropes and panels made from natural fibers, coated with a natural elastomeric (rubber) waterproofing material (Figure 5). The production process for the rubber coating is not documented.

TEIMSA, S.A. Produces industrial multilayer cotton panels coated with natural latex, with resistance to abrasion, corrosion, and prolonged UV exposure (Figure 6). The latex production process is not documented.

TUNACONS. Manufactures bio-FADs using ropes and panels made from natural fibers (Figure 7). Ropes and panels are soaked in a solution of latex and 2% ammonia (NH_3), used as an anticoagulant, then dried at the manufacturing facility to allow the NH_3 to evaporate and the latex to solidify into natural rubber (J. García, pers. comm.).

Zunibal Inc. Manufactures a bio-based FAD flotation component (ZunFloat), designed to be reusable (Figure 8) and to reduce costs in materials, labour, and transport; intended for recycling every five years. The ZunFloat is based on PBS (Polybutylene Succinate), a compostable and biodegradable polymer that breaks down into biomass, H_2O, and CO_2 through microbial action, typically under specific composting conditions; degradation rates under standard environmental conditions are variable (MCG; Ghasemlou et al., 2024). Standard-tested as pellet material, this polymer has a Marine Biodegradability certification issued by the Japan BioPlastics Association (JBPA; I. Zudaire, pers. comm.).

ITSASKORDA, S.L. A company developing biodegradable ropes and twines for tuna fisheries (e.g., *Natukor encerado, Tunako-Bio, Hilo Trenzado-Bio*). The ropes are manufactured using a mixture of cotton and tencel (both of natural origin and biodegradable) as raw material, and using braiding with or without crimping in the manufacturing process. The yarns are sourced from textile waste provided by local suppliers. Comparisons of twines degradation over time were conducted using a statistical modeling approach to evaluate the degradation of twines over time (Lopez et. al., 2019). Linear models were then fitted and extrapolated to estimate the point at which breaking strength reached zero, providing predicted times to failure. Results showed a minimum predicted time to failure of approximately 193 days and a maximum of about 557 days, with intermediate estimates around 417 days, reflecting substantial variability in durability among materials.

FAD manufacturers working with bioplastics should be considered key partners in the search for innovative solutions to reduce plastic pollution. In the context of marine applications, several biodegradable bioplastics have recently been developed for use in fishing gear. Among these are the bio-based Polybutylene Succinate (PBS), and the polyhydroxyalkanoates (PHAs), a group of polyesters synthesized through bacterial fermentation. Certain PHAs, such as polyhydroxybutyrate (PHB), have demonstrated partial or complete biodegradation in marine environments (Chae and Lee, 2025; Ghasemlou et al., 2024; Kim et al., 2023). Exploring the use of PHA polyesters in FAD construction (e.g., panels, twines) may therefore be worthwhile.

7.4. SURVEYS

Since September 2020, IATTC staff have conducted informal and anonymous surveys at skipper capacity-building seminars covering FAD deployments, retrievals, interactions, and fishery dynamics, among others. Including questions specifically on biodegradable materials in future surveys would be valuable, as would allow identify new producrts and capturing colloquial names used locally for bioplastics and other materials considered biodegradable for FAD construction.

8. DISCUSSION

8.1. SHOULD BIO-BASED PLASTICS BE USED IN FADS?

Using bio-based plastics in FADs may appear attractive as a way to reduce reliance on fossil-derived materials. However, the transition promoted under IATTC Resolution C-23-04 is fundamentally driven by the need to reduce environmental impacts and marine debris and pollution, meaning the decisive criterion is not whether a material is bio-based, but whether it is demonstrably environmentally safe and effectively biodegradable in marine conditions, with reliable traceability and certification.

8.2. WHY "BIO-BASED" ALONE IS NOT SUFFICIENT

Bio-based refers to feedstock origin, not environmental fate. Many bio-based plastics are chemically similar to conventional plastics and can persist in the environment for long periods. If such materials are used in FAD components that may be lost at sea, they could still contribute to long-term marine debris and microplastic generation as well as stranding impacts, undermining the environmental objectives of the bio-FAD transition.

8.3. THE KEY REQUIREMENT: VERIFIED MARINE BIODEGRADABILITY

For FAD applications, the relevant question is whether a material biodegrades under realistic ocean conditions (e.g., temperature, salinity, light availability, oxygen, microbial communities, depth compartment). The major limitations in current standards are:

- **Biodegradation is inferred from indirect proxies** (CO_2/biogas evolution, oxygen uptake, TOC/DOC reductions), and no method directly quantifies polymer carbon conversion to biomass;
- there is high **spatial and temporal variability** in ocean conditions, which many standards do not capture;
- **current test protocols can be poorly suited** to thick, complex, or multi-material components, which are common in practical FAD designs.

As a result, a material labeled "biodegradable" under some schemes may not degrade as expected in the environments where FADs drift, strand, or sink.

8.4. OPERATIONAL DURABILITY VS. ENVIRONMENTAL GOALS

Fishers require FADs to function for a meaningful operational lifespan (about 12 months, according to fishers in the EPO), and industry interest in coatings and polymer-based components is partly driven by the need to increase durability and, possibly, enable redeployment. But greater durability can conflict with the objective of minimizing harm when FADs are lost. This creates a two-fold tension:

I. longer-lasting materials may be operationally beneficial but environmentally risky if they do not truly biodegrade in the marine environment; and,

II. if biodegradation occurs mainly in soil or composting facilities, then environmental benefits depend on retrieval and controlled end-of-life management, which is not guaranteed for all FADs.

8.5. CHEMICAL SAFETY, CREDIBILITY RISKS, AND PRACTICAL MATTERS

Some "bioplastics" may contain chemicals with toxicity comparable to conventional plastics, and ambiguous labeling and weak traceability can erode industry confidence and compromise implementation in the mid to long-term. This argues for a precautionary approach: bio-based plastics should not be adopted at scale unless their chemical composition, additives, and environmental fate are transparent and independently verified.

Therefore, bio-based plastics could be appropriate in FADs only under the following conditions, such as:

1. Clear polymer identification and traceability (commercial name, manufacturer, chemical signature).

2. Independent certification relevant to marine conditions of concern (e.g., not only the photic zone).
3. Evidence that the material does not introduce hazardous additives and does not increase microplastic risk.
4. Consideration of a management approach that links materials to a catalog/database for research, monitoring and compliance.
5. When biodegradation depends on composting, a realistic plan for retrieval and transport to appropriate facilities.

9. CONCLUSIONS AND RECOMMENDATIONS

This document reviews the landscape of marine biodegradability certification standards as they apply to bio-based materials currently used in EPO bio-FAD construction, in response to the FADWG-9 and SAC-16 recommendations. The analysis covers bioplastics, rubber/latex coatings, and natural plant-based fibers. Key information and limitations of existing standards and certification schemes are identified, and an approach for cataloguing bio-FAD materials against these standards is proposed. The IATTC scientific staff recognizes that polymers used in the fabrication of bioplastics and other materials may offer a viable alternative to extend the durability of bio-FADs. At the same time, the staff is alert to the growing bio-based components market, in which various materials are increasingly advertised as biodegradable. Beyond biodegradability, chemical safety should be explicitly considered. Screening for hazardous additives, toxic monomers, or by-products, especially for materials used in FADs that are intended for large-scale deployment in the marine environment. In this respect, the staff considers necessary an inventory and catalogue of these materials based on their commercial name, chemical signature, along with any standard and certifications they might be accompanied with, so as to determine whether or not these are in compliance with marine biodegradability certification standards so that they can be accepted by the fleet and the Commission. For that, continued collaboration among all relevant stakeholders, such as the fishing industry, NGOs, manufacturers, research institutions, and certification bodies is essential. To ensure proper implementation of Resolution C-23-04 and the reliability of data collection of these materials (see Section 6 and 7), it is also important to obtain this information prior to vessel departure. Finally, expectations regarding bio-FAD lifespan may need to be aligned with environmental goals of Resolution C-23-04. Rather than seeking indefinite durability, future innovation should aim to optimize functional performance during active use while ensuring safe degradation or recovery once the FAD is no longer monitored or operational. In pursuit of these considerations, the staff's recommendations are as follows:

Apply a precautionary approach to the use of new bioplastic or coated materials in FADs, allowing their use only when there is clear evidence of environmental safety, including compliance with recognized marine biodegradability standards and certifications.

Provide guidance on environmental performance objectives for FAD materials, in particular target degradation times and the environmental medium (e.g., seawater or sediment) under which marine biodegradability standards should be assessed, and periodically review these standards as science and international regulations evolve.

Encourage studies and testing of bio-based materials for FADs, including development of marine biodegradability protocols that reflect the thickness, structural complexity, and multi-material composition of actual FAD components.

Strengthen reporting requirements by requiring vessels or companies, prior to each trip, to submit to the Secretariat or field office the commercial name, polymer composition (bio or fossil based), manufacturer, function, and any applicable biodegradability standards and certifications of materials used in bio-FAD construction, for integration into IATTC databases.

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11. TABLES

TABLE 1. FAD categories according to their degree of biodegradability, as indicated in the Resolution C-23-04.
TABLA 1. Categorías de plantados según su grado de biodegradabilidad, de acuerdo con lo establecido en la Resolución C-23-04.

Category	Definition
I	The FAD is made of fully biodegradable materials.
II	The FAD is made of fully biodegradable materials except for plastic-based flotation components (e.g., plastic buoys, foam, purse-seine corks).
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).
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.
V	The surface and subsurface parts of the FAD contain non-biodegradable materials.

TABLE 2. Current biodegradability test standards of bioplastics according to certification criteria for biodegradation in marine environments.
TABLA 2. Estándares actuales de análisis de biodegradabilidad de bioplásticos según criterios de certificación de su biodegradación en el mar.

Standard	Focus	Key method	Bioplastic test sample	Inoculum	Test duration	Incubation temp.	Validation criteria/degradation conditions	Reference
ASTM D6691	Biodegradation percentage of plastic materials and additives in a pelagic marine environment	By determining aerobic biodegradation of plastics by a defined microbial conglomerate on natural sea water inoculum	PBS (film) PCL (film) PBAT (powder) PLA (film) PHB (pellet) Cellulose (filter)	Natural seawater	~90 days	30° C	70 % or more biodegradation after 6 months for the reference material	(Lee et al., 2025) Kim et al. (2023) Hino et al. (2023) Delacuvellerie et al. (2021) Briassoulis et al. (2024)
ISO 19679	Biodegradation % of non-floating plastics when settled on sandy sediment between a seawater/sea floor interface	Determination of aerobic biodegradation tests by measuring the evolved CO_2	PBS PCL (powder) PBAT (film) PLA (powder) PHB (film) Cellulous (filter)	Natural seawater and sediment	~2 years	15-25° C	≥60% biodegradation extent for the reference material after 180 days, with CO_2 emission not exceeding 20 %	(Lee et al., 2025) Nakayama et al. (2019) Tanadchangsaeng and Pattanasupong (2022) Briassoulis et al. (2024)
ISO 23977-1	Determination of the aerobic biodegradation % of plastic materials exposed to seawater	Analysis of the evolved CO_2	Any type. Films, pellets, and smaller plastic components	Natural seawater	~2 years	15-25° C	Up to 90% of biodegradation up to 1 year, but the test could be prolongued up to 2 years, if significant biodegradation is still being observed	DIN CERTCO (2022) AROPHA 1 AROPHA 2 CERI BPC Instruments
ISO 23977-2		Measuring the oxygen demand in closed respirometer						
ISO 22404	Determination of the aerobic biodegradation % of non-floating materials when buried in marine sediment	By measuring the evolved CO_2. The standard requires that a reference material, such as cellulose, is included in the test and meets a minimum	Suitable for any bioplastic that can be formed into films or sheets	Marine sediment	~2 years	15-25° C	Test is valid if cellulose degrades ≥ 60% within 6 mo., confirming a sediment with aerobic microbial activity capable of aerobic biodegradation	CERI ISO 22404:2019(en) Briassoulis et al. (2024) BPC Instruments

EN ISO 18830	Determination of aerobic biodegradation of non-floating plastic materials in a seawater/sandy sediment interface	Method by measuring the oxygen demand in closed respirometer	Suitable for any bioplastic that can be formed into films or sheets	seawater/sandy sediment interface	~2 years	15-25° C	Up to 90% of biodegradation(total or relative to a suitable reference material) after 6 months is required in order to show intrinsic biodegradation in	Lavagnolo et al. (2024) DIN CERTCO (2022) Briassoulis et al. (2024) BPC Instruments
ISO 15314	Biodegradability for simulated environments, including marine exposure	Oxidation and photo-oxidation methods for exposing plastics in marine environments to assess durability and changes in	Any type (no info on the shape)	Natural seawater	Surface exposure and partial immersion (1 year). Complete immersion (6 mo.)	It depends on the marine exposure site	No info	Lavagnolo et al. (2024) BPC Instruments ISO 15314:2018
ASTM D7991	Aerobic biodegradation of buried plastics	This test method does not measure the amount of organic carbon that is converted into biomass, but only biodegradation that leads to mineralization (that is, the formation of CO_2)	Often used with various polymer types including bioplastics (no info on the shape)	Sandy sediment and seawater	~ 2 years	No info	No info	Lavagnolo et al. (2024) ASTM D7991 BPC Instruments
TUV Austria (OK Biodegradable MARINE)	Certification of biodegradability in marine environment (pelagic zone)	Biodegradation per ASTM D6691 / ISO 23977; disintegration per ISO 23832; plus ecotoxicity and heavy metals/fluorine testing	Plastic material (powder, film, or finished product)	Natural seawater (collected from marine environment, e.g., North Sea)	Maximum 6 months (biodegradation); 12 weeks (disintegration)	30°C	≥90% carbon-to-CO_2 conversion within 6 months; ≥90% disintegration in 12 weeks; pass ecotoxicity and heavy metals/fluorine limits	TÜV Austria OK biodegradable MARINE certification scheme (references ISO 23977, ASTM D6691, ISO 23832)

ASTM D7881 (mentioned in Resolution C-23-04)	Completely unrelated to biodegradation. A chemical analysis standard for determining impurities in purified terephthalic acid.	NA	NA	NA	NA	NA	NA	Wrongly listed in Resolution C-23-04 as one of the standard option for biodegradability.

TABLE 3. Name of the FAD components currently collected by IATTC observers.
TABLA 3. Nombre de los componentes de plantados actualmente recopilados por observadores de la CIAT.

Component name ENG	Component name SPN	Description ENG	Description SPN	Collection year
Tree	Arbol	Tree	Arbol	2005
Carcass	Animal	Dead animal	Animal muerto	
Weight	Peso	Chain / cable / rings	Cadena / cable / anillos / peso	
Cane	Caña	Cane / bamboo	Caña / bambú	
Bait	Carnada	Bait container / bait	Contenedor con carnada / carnada	
Rope	Soga	Cord / rope	Cuerda / soga	
Floats	Flotador	Floats / corks	Flotadores / corcho	
Lights	Luz	Artificial light for attracting fish	Luz artificial para atraer pescado	
Netting	Malla	Net material	Malla de red	
Sack	Saco	Sacks / bags	Sacos / bolsas	
Board	Madera	Planks / pallets / plywood	Madera / triplay / tarima / carrete	
Drum	Tambor	Metal drum / plastic drum	Tambor metálico / plástico	
Tubes	Tubo	PVC or other plastic tubes	Tubos de PVC u otro plástico	
Plastic	LonaPlas	Plastic sheeting	Lona de plástico, tela u otro	
Unk	Desc	Unknown	Desconocido	
Other	OTR	Other	Otro	
SOGA	SOGA	Rope unknown material	Soga material desconocido	2019
SOGN	SOGN	Rope natural material	Soga fibra natural	
SOGS	SOGS	Rope synthetic material	Soga fibra sintética	
LONA	LONA	Canvas unknown material	Lona material desconocido	
LONN	LONN	Canvas natural material	Lona de fibra natural	
LONS	LONS	Canvas synthetic material	Lona de fibra sintética	
RED	RED	Net webbing	Malla de red	
SACN	SACN	Sack natural material	Saco/tejido de fibra natural	
SACS	SACS	Sack synthetic material	Saco/tejido de fibra sintética	
ARBL	ARBL	Tree, any type	Árbol natural (palmera, fruta, etc.)	
MADR	MADR	Shaped wood (pallet, plywood)	Madera formada (tarima, carretes)	
BMBU	BMBU	Bamboo, cane	Bambú, caña	
BAND	BAND	Flag	Bandera	
REFL	REFL	Radar reflector	Reflector de radar	
LAMP	LAMP	Lights	Lámpara	
PLAS	PLAS	Plastic objects	Objeto de plástico	
TUPL	TUPL	Plastic tube (PVC, etc.)	Tubos plásticos (PVC, etc.)	
LLAN	LLAN	Tire	Neumáticos	
CARP	CARP	Bait in plastic drum	Carnada en tubo/tacho plástico	
CARM	CARM	Bait in metal drum	Carnada en tubo/tacho metal	
CONP	CONP	Plastic drum without bait	Contenedor plástico sin carnada	
CONM	CONM	Metal drum without bait	Contenedor metálico sin carnada	
BAMU	BAMU	Dead whale	Ballena muerta	
OAMU	OAMU	Other dead animal (not whale)	Otro animal muerto (no ballena)	
ALGA	ALGA	Seaweed	Algas marinas	
PLNG	PLNG	Longline derelict	Palangre abandonado	
EPES	EPES	Other derelict fishing gear	Otro equipo de pesca abandonado	
BOYA	BOYA	Buoy or float (not scientific buoy)	Boya o flotador (no de investigación)	
SALV	SALV	Life preserver	Anillo salvavidas	
METL	METL	Metal (chain, cable, rings, etc.)	Metales (cadena, cable, anillos, etc.)	
BOYI	BOYI	Scientific buoy (functional)	Boya de investigación funcional	
MASC	MASC	More components than space allows	Más componentes que espacios disponibles	

TABLE 4. Mapping of bio-based materials currently used in EPO bio-FAD construction against available marine biodegradability certification standards.
TABLA 4. Comparación de los materiales bio-basados que se utilizan actualmente en la construcción de bio-FAD de la OPO con las normas de certificación de biodegradabilidad marina disponibles.

FAD component / material	Material type	Applicable marine biodegradability standard(s)	Certification body	Certified product(s) in EPO use (if known)	Compliance status / gap
Rope / panel (canvas): cotton, abaca, jute, sisal, hemp, coir	Natural plant-based fiber	Inherently biodegradable; used as reference material in ASTM D6691, ISO 23977-1/2, ISO 22404	No formal marine certification required	SANOCEANOS, TEIMSA, TUNACONS (abaca, cotton); all EPO fleet bio-FAD experiments (Román et al., 2022; 2023)	COMPLIANT by nature with C-23-04 definition. Key gap: durability, not biodegradability.
Structural frame: bamboo cane, balsa, paulownia wood	Natural lignocellulosic material	Inherently biodegradable; no marine certification standard specifically applicable	No formal certification required	Widely used in IATTC bio-FAD experiments and EPO fleet	COMPLIANT by nature. No certification gap. Observer identification post-deployment may be difficult.
Rope / panel coating: natural rubber (latex)	Bio-based elastomer (Hevea brasiliensis latex)	Inherently biodegradable if unvulcanized; no standard marine test identified for vulcanized NR	No applicable marine certification scheme identified	SANOCEANOS (natural elastomeric coating); TUNACONS (latex + NH_3 process)	UNCERTAIN. Unvulcanized NR likely compliant; vulcanization significantly slows biodegradation (100+ yr). Production process not documented for current EPO products. Requires further investigation.
Flotation component: PBS (Polybutylene Succinate) — ZunFloat	Bio-based / biodegradable bioplastic	ASTM D6691, ISO 23977-1; tested as pellet	JBPA (Marine Biodegradability)	ZunFloat (Zunibal Inc.) — JBPA marine certification confirmed (as pellet, not as final product; I. Zudaire, pers. comm.)	PARTIALLY COMPLIANT. Certified at pellet scale (JBPA); no standard test exists for thick/structural PBS components. Designed mostly for reuse/recycling (5 year lifetime). ISO 14006 cited in some communications is an eco-design standard, NOT a biodegradability certification.

FAD component / material	Material type	Applicable marine biodegradability standard(s)	Certification body	Certified product(s) in EPO use (if known)	Compliance status / gap
Panel / twine / rope component: PHA polyesters (PHB, PHBV)	Bio-based / biodegradable bioplastic	ASTM D6691, ISO 23977-1; demonstrated marine biodegradation in literature (Chae and Lee, 2025)	TÜV Austria, DIN CERTCO, JBPA (depending on specific product)	Under exploration for FAD panels/twines; no EPO product currently confirmed in use	POTENTIALLY COMPLIANT but not yet confirmed in EPO use. Promising option for panels and twines; requires product-specific certification verification.
Various components: PLA (Polylactic Acid)	Bio-based bioplastic; compostable but NOT marine biodegradable	No applicable marine biodegradability standard; degrades only at high temperature in industrial compost	Not certifiable for marine biodegradability	Not confirmed in EPO FAD use; sometimes misidentified as “biodegradable” in marketing materials	NON-COMPLIANT for marine use. Should NOT be accepted as biodegradable under C-23-04 unless retrieved and composted.
Various components: bio-based PE, bio-based PET, bio-based PA (non-biodegradable bio-based plastics)	Bio-based origin but NOT biodegradable	No applicable marine biodegradability standard; chemically identical to fossil-based equivalents	Not certifiable for biodegradability	May appear in FAD components marketed as “bio-based”; EPO use unconfirmed	NON-COMPLIANT. “Bio-based” labelling does not imply biodegradability. These materials fail the C-23-04 definition and should be rejected as Category I components.

Colour coding: green = compliant with C-23-04; yellow = uncertain or partially compliant, requiring further investigation; orange = non-compliant, should not be accepted as biodegradable for Category I - IV FAD components. This table should be treated as a working document and updated as new manufacturer and certification data become available.

12. FIGURES

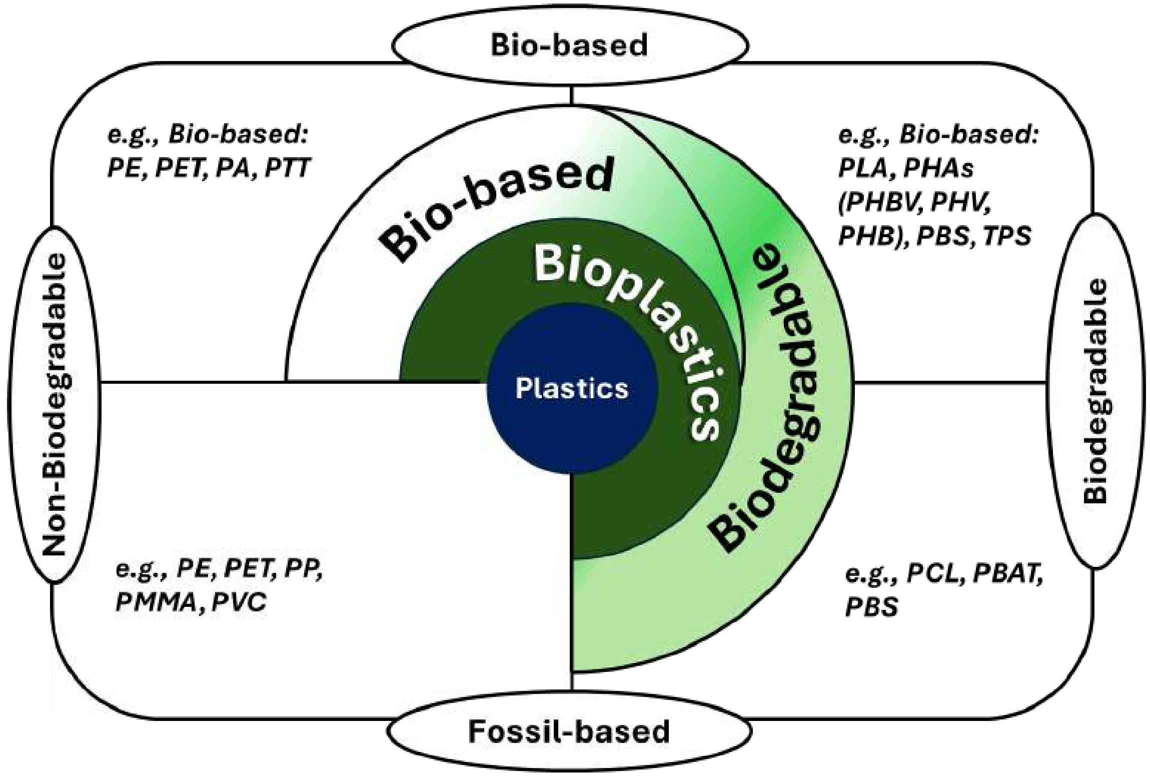

FIGURE 1. Bioplastics grouped by the origin of the source material and biodegradability (modified from Lavagnolo et al., 2024).
FIGURA 1. Bioplásticos agrupados de acuerdo con el material precursor y biodegradabilidad (modificado de Lavagnolo et al., 2024).

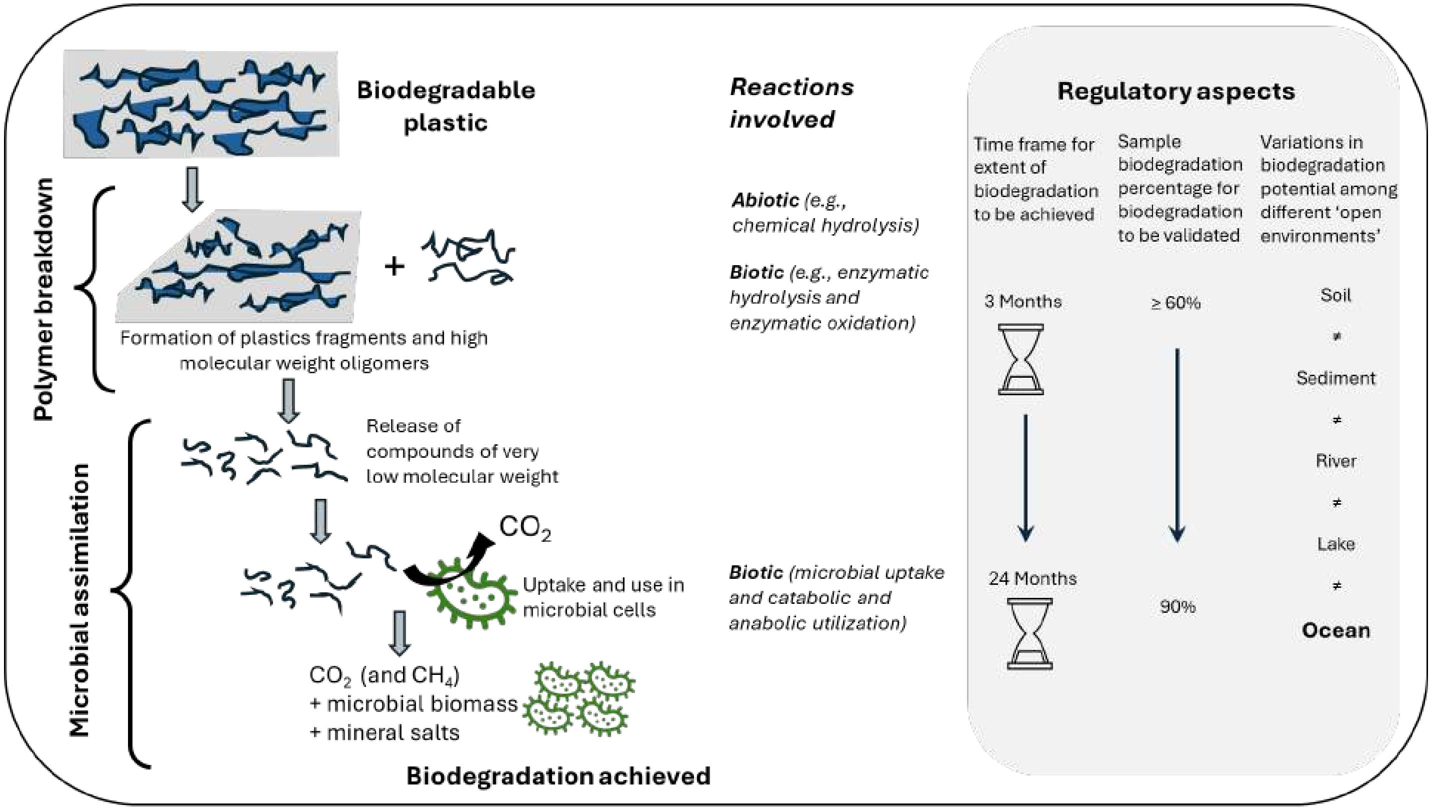

FIGURE 2. Process involved in bioplastic biodegradation, the reactions involved, and the regulatory considerations for certification criteria (modified from SAPEA, 2020).

FIGURA 2. Proceso involucrado en la biodegradación de los bioplásticos, reacciones implicadas y consideraciones normativas para los criterios de certificación (modificado de SAPEA, 2020).

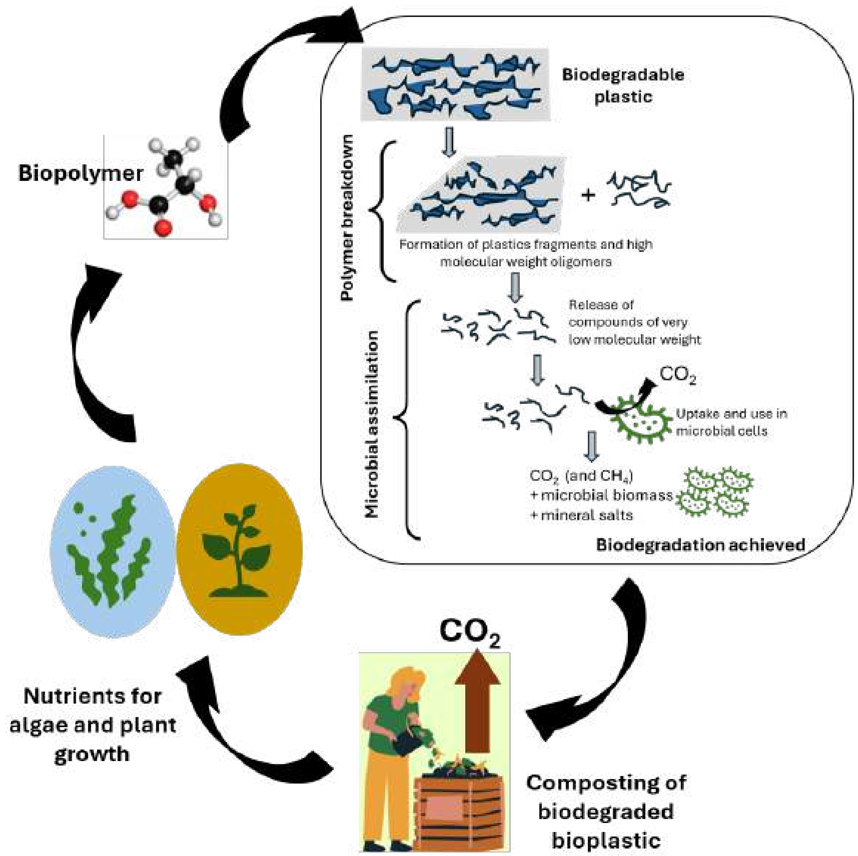

FIGURE 3. Compostability process for bioplastics as part of a closed recycling cycle (modified from SAPEA, 2020).
FIGURA 3. Proceso de compostabilidad de bioplásticos como parte de un ciclo de reciclaje cerrado (modificado de SAPEA, 2020).

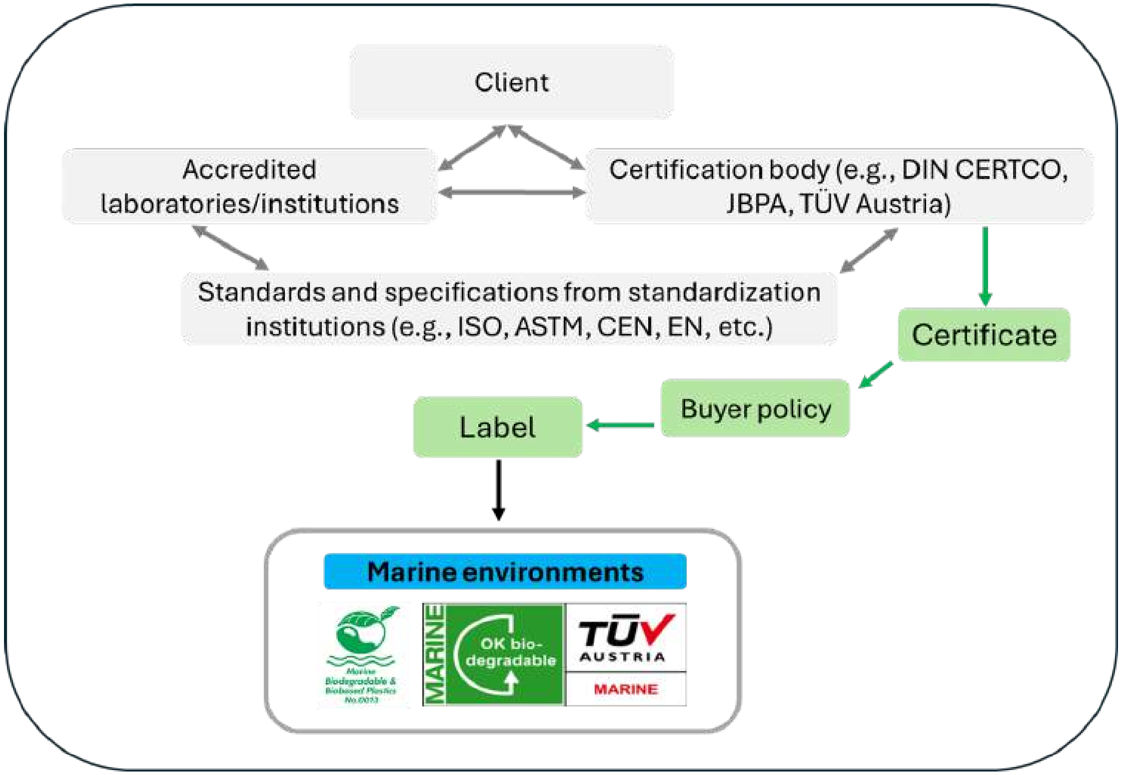

FIGURE 4. Certification procedure and examples of labels for marine environments (modified from SAPEA, 2020).
FIGURA 4. Proceso de certificación y ejemplos de etiquetado de biodegradabilidad en ambientes marinos (modificado de SAPEA, 2020).

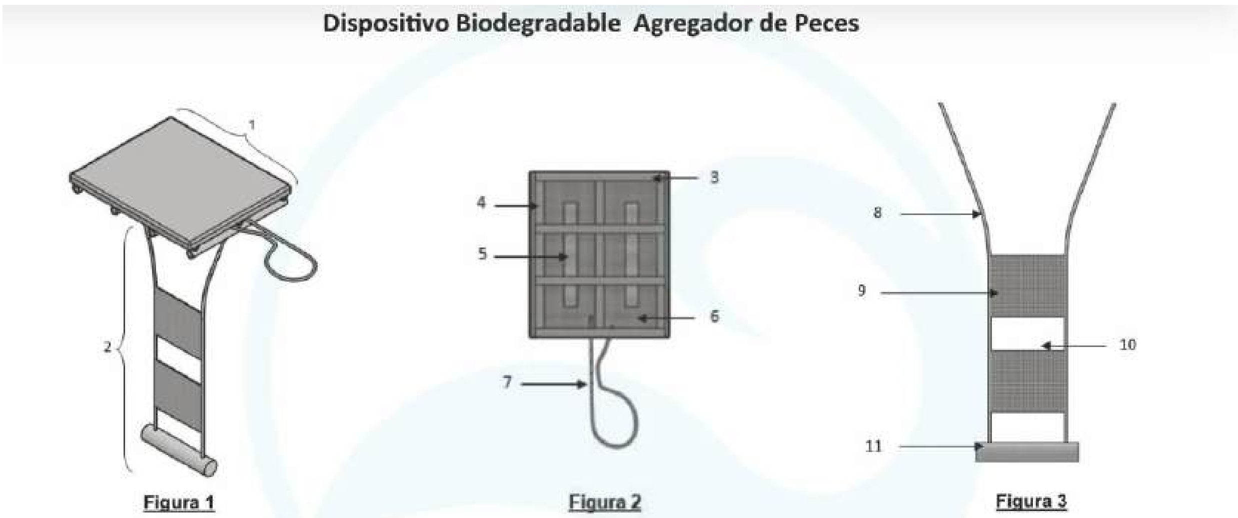

Figura 1: Dispositivo agregador de peces	
Pieza	Descripción
1	Parte flotante
2	Parte sumergible

Figura 2: Parte flotante		
Pieza	Cantidad	Descripción
3	4	Caña guadua; L: 1.5m; Ø: 0.20~0.25
4	3	Caña guadua; L: 1.8m; Ø: 0.20~0.25
5	2	Madera balsa; L: 1.10m; Ø: 0.25~0.30
6	2	Paño de fibra de abacá 2.1x1.9m
7	1	Cuerda de abacá; L: 3.5m; Ø:1"

Figura 3: Parte sumergible		
Pieza	Cantidad	Descripción
8	2	Cuerda de abacá; L: 22m; Ø: 32mm
9	2	Paño de fibra de abacá 2.5x0.7m
10	4	Caña guadua; L: 0.70m; R:0.10~0.125
11	1	Caña guadua; L: 0.7m; Ø: 0.20~0.25

FIGURE 5. Bio-FAD manufactured by SANOCEANOS (image property of SANOCEANOS).
FIGURA 5. Bio-FAD fabricado por SANOCEANOS (imagen propiedad de SANOCEANOS).

FIGURE 6. Bio-FAD manufactured by TEIMSA (image property of TEIMSA).
FIGURA 6. Bio-FAD fabricado por TEIMSA (imagen propiedad de TEIMSA).

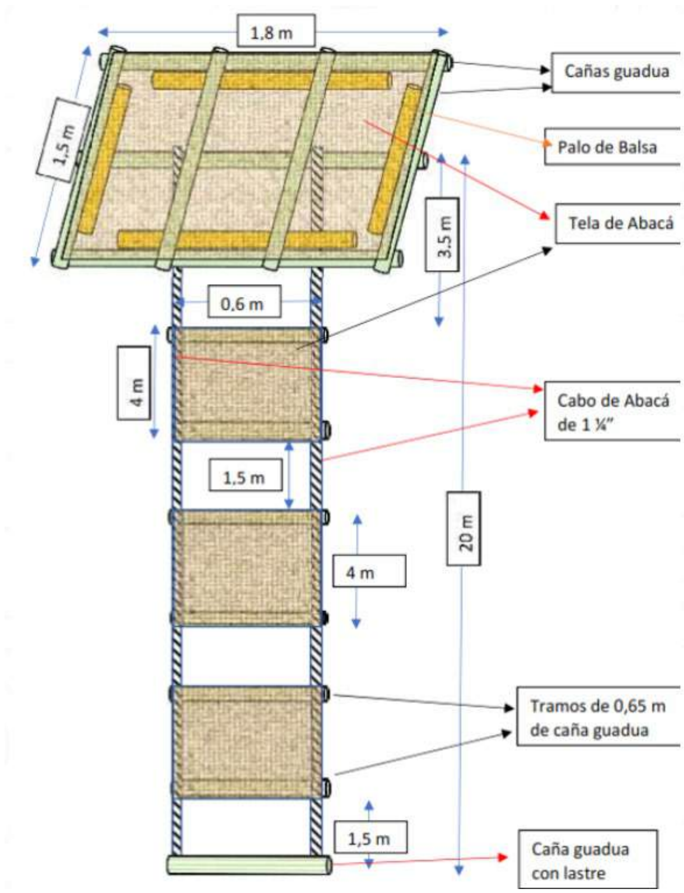

FIGURE 7. Bio-FAD manufactured by TUNACONS (image property of TUNACONS).
FIGURA 7. Bio-FAD fabricado por TUNACONS (imagen propiedad de TUNACONS).

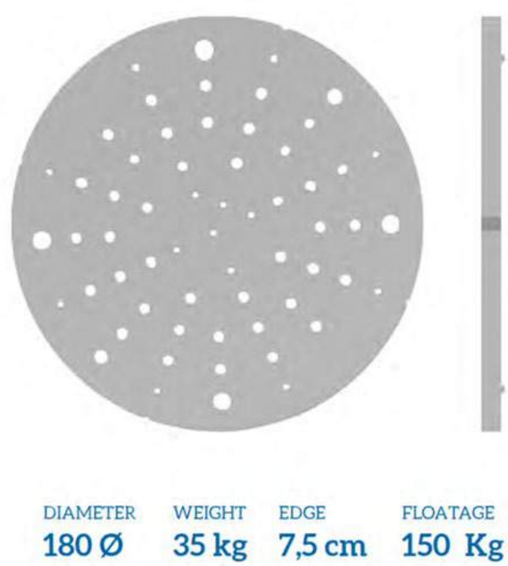

FIGURE 8. Bio-FAD manufactured by ZUNIBAL (image property of ZUNIBAL).
FIGURA 8. Bio-FAD fabricado por ZUNIBAL (imagen propiedad de ZUNIBAL).

ANNEX 1. GLOSSARY OF KEY TERMS

Polymer: A polymer is a material made of very large molecules (macromolecules) built from repeating smaller units called monomers. Polymers can be natural (e.g., cellulose, starch, natural rubber) or synthetic (e.g., polyethylene, polypropylene). Plastics—including bioplastics—are a class of polymeric materials engineered to deliver specific properties such as strength, flexibility, and durability.

BIODEGRADABLE as per C-23-04: Non-synthetic materials[4] and/or bio- based alternatives that are consistent with international standards[5] for materials that are biodegradable in marine environments. The components resulting from the degradation of these materials should not be damaging to the marine and coastal ecosystems or include heavy metals or plastics in their composition.

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

Biodegradable (ASTM D6813; European Bioplastics): A material is biodegradable if naturally occurring microorganisms can break it down and convert its carbon into CO_2 (under aerobic conditions) or CO_2 and CH_4 (under anaerobic conditions), plus inorganic compounds and new microbial biomass. In practice, biodegradability must always be defined for a specific environment (marine, soil, compost, etc.) and a specified timeframe, because the same material can behave very differently under different conditions.

Bio-based (biobased): A bio-based material is produced wholly or partly from renewable biological resources (plants, algae, microorganisms, agricultural residues, etc.). The term refers to the origin of the feedstock (where the carbon comes from), not to what happens to the material in the environment. Importantly, bio-based does not necessarily mean biodegradable. Thus there are non-biodegradable bio-based materials.

Bioplastic: “Bioplastic” is an umbrella term for plastics that are bio-based (from biological sources), biodegradable, or both. This broad definition can be misleading because it includes materials with very different environmental fates: some are bio-based but not biodegradable, others are biodegradable but fossil-based, and some have both properties. For that reason, “bioplastic” should ideally be accompanied by clear information on polymer type, additives, and relevant biodegradability standards/certifications.

Biodeterioration: Biodeterioration refers to biological damage that changes a material’s properties (e.g., loss of strength, surface erosion, fragmentation) due to microbial activity, without necessarily achieving full mineralization (conversion of polymer carbon into CO_2/CH_4 and biomass). A plastic may show biodeterioration yet still persist as fragments if true biodegradation is incomplete.

Compostable: A compostable material is a subset of biodegradable materials designed to biodegrade under composting conditions, and to produce compost that is suitable for soil application. Compostability typically requires collection and treatment in appropriate composting systems and does not imply that the material will biodegrade effectively in the ocean.

Oxo-biodegradable plastic: A conventional plastic (typically polyethylene, polypropylene, or polystyrene) that contains pro-oxidant additives designed to promote abiotic oxidative degradation when exposed to

[4] For example, plant-based materials such as cotton, jute, manila hemp (abaca), bamboo, natural rubber, or animal-based such as leather, wool, lard.
[5] International standards such as ASTM D6691, D7881, TUV Austria, European or any such standards approved by the Members of the IATTC.

heat, oxygen, and ultraviolet radiation. This process results primarily in fragmentation of the plastic into smaller pieces, including microplastics and potentially nanoplastics, rather than complete microbial mineralization. As a result, the final degradation products are persistent plastic fragments, not carbon dioxide, methane, water, or microbial biomass, and therefore oxo-biodegradable plastics do not meet true biodegradability.