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TESTING BIODEGRADABLE MATERIALS AND PROTOTYPES FOR THE TROPICAL TUNA FAD FISHERY: PROGRESS REPORT AND STAFF'S RECOMMENDATIONS

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1. SUMMARY

Purse-seine effort on the fish-aggregating device (FAD) fishery in the EPO has steadily increased since the early 1990s due to its efficiency in capturing tropical tunas that aggregate under FADs. As with most fishing methods, FADs may also have negative effects on associated species and ecosystems through entanglement of vulnerable species (e.g., sea turtles), accumulation of marine debris and pollution, and stranding events in vulnerable habitats (e.g., coastal nursery areas). To address these potential effects, the IATTC staff was required to present scientific recommendations that would help with transitioning from traditional to biodegradable FADs, which are expected to reduce those impacts. The European Union granted the IATTC funds for a two-phase project involving experiments with biodegradable non-entangling FADs in a controlled environment (Phase 1) and under real-time at-sea fishing conditions (Phase 2). During Phase 1, the selection of biodegradable materials to be used in the construction of three different prototypes for Phase 2 was determined. The work plan for Phase 2 included several activities, such as the design of prototypes for non-entangling and biodegradable materials (NEDs), the identification of collaborators and participants, the construction of the NEDs, the development and agreement of an experimental design, the monitoring and tracking of the experimental FADs, as well as the data collection and analyses. A total of 715 NEDs (114 prototype 1; 392 prototype 2; 209 prototype 3) were deployed along with their corresponding paired controls for a total of 1,420 experimental FADs. Similar values in catch per set were observed between NEDs and paired controls (NEDs = 34.0 mt/set, paired control FADs = 31.2 mt/set; Table 1). The submerged rope of prototype 1 was in poor condition, but the rest of materials appeared to be in good condition after a minimum of two months at sea. Prototype 2 was in good condition after at least two months of soak time. The NED design of prototype 3 was the least durable, and therefore some modifications were made in collaboration with the fleet to improve durability. The staff's conclusions, recommendations, future actions, and lessons learnt from positively engaging with the industry and fishers are also described.

2. INTRODUCTION

Fishers have taken advantage of the aggregative behavior of tunas around floating objects for decades (Watters 1999; Hall and Román 2013). During the 1980s, fish-aggregating devices (FADs)—artificial drifting objects constructed to attract tunas—started to be used by the tropical tuna purse-seine fleet in the eastern Pacific Ocean (EPO). In the early 1990s, the FAD fishery greatly expanded and became the most efficient way to capture tropical tunas in the region (Lennert-Cody and Hall 1999; IATTC 2019; Hall and Román 2013). As a result of the use of satellite-linked echo-sounder buoys that allow remote monitoring of their location and tuna biomass levels, FAD fishing has become a very efficient method (e.g., limited search time, low number of null sets) over recent decades (Lopez *et al.* 2014; Lopez *et al.* 2016; Cillari *et al.* 2018). FAD fishing is not specific to the EPO; currently the majority of the global commercial tuna catches are caught on FADs (ISSF, 2022).

FADs are typically constructed in two segments with one consisting of a surface part and the other of a submerged part. The surface component provides flotation to the FAD and traditionally has been built with bamboo wrapped in old recycled fishing nets; plastic floats or PVC frames have been added to increase floatability (Hall and Román 2013). The floatability component is usually constructed with dark-colored materials that prevent detection by other vessels and is expected to keep the FAD afloat typically for 6-12 months, although durability depends on the environmental conditions where the fishery is operating. While the fishing season is limited to 4-5 months in some regions (e.g., Peru) and FADs lasting up to 6 months are acceptable by the industry, fishers show preference for FADs lasting at least 9-12 months in other regions (e.g., west of 110°W).

The submerged component consists of materials that hang in the water column, and frequently include old fishing nets or other webbing materials. This part is believed to increase the attractive nature of the object and impacts drifting speeds (Minami *et al.* 2007; Satoh *et al.* 2007; Lennert-Cody *et al.* 2008; Hall and Román 2013). The depth of the submerged part seems to have increased in recent years, particularly in some areas of the EPO, where depths from 70 to 90 m have been reported (FAD-05-INF-A). Commonly, this component reaches 30-40 m in depth (Franco *et al.* 2012; Hall and Román 2013).

Because FADs are usually made of non-biodegradable materials, their use is often linked to several potential ecological impacts. First, although yet to be determined in the EPO, studies from other oceans suggest that some entanglement of sharks and sea turtles in the FAD's submerged webbing material (Franco *et al.* 2009; Hall and Román 2013; Filmalter et al. 2013). Second, the generation of marine debris and pollution through lost, abandoned or damaged FADs can produce habitat impacts through stranding events in coastal areas, including beaching (Maufroy *et al.* 2015; Sinopoli *et al*. 2019).

Fishing on FADs may also increase rates of bycatch and catches of small-sized tunas including juveniles. However, conservation measures for tropical tunas exist (e.g., Resolution C-21-04) and the staff is conducting several projects to try to reduce the impact on taxa caught as bycatch and the catch of undesirable sizes of tunas (IATTC-93-06a; SAC-13-01). These projects include, among others, experiments on the effectiveness of sorting grids (Document IATTC-94-04; Project M.1.b), and the dynamic ocean management project, which investigated near real time areas for maximizing catch of target species and minimizing catch of bycatch species (SAC-10 INF-D, Project J.2.a).

However, initiatives assessing and reducing the impacts of using non-biodegradable FADs are generally more recent, both locally and globally. For example, first attempts of producing non-entangling objects were carried out in the Indian Ocean and consisted of a submerged tubular structure made of synthetic sailcloth (Delgado de Molina *et al*. 2006). Dagorn *et al.* (2012) later suggested non-netting materials be used for the submerged part (e.g., ropes) of FAD designs or rolling the netting into sausage-like bundles, in order to reduce the risk of shark entanglement. Despite IATTC observer records indicating that shark entanglements are seldom observed in the EPO, no dedicated experiment has yet to be conducted to quantify these events. On the other hand, turtle entanglement in FADs has been frequently recorded by observers, although mortality rates are negligible and the crew is required to promptly release turtles alive when possible (see Resolutions C-03-08 and C-07-03). In 2013, t-RFMOs started testing experimental FAD designs that prevent both turtle and shark entanglements and minimize environmental impacts generated by pollutant and non-degradable debris (ICCAT-13-01; IOTC-13/08; IATTC C-13-04). Recently, several regional initiatives have been conducted, or are still in place, to test biodegradable FADs on a large scale under real-time conditions (ISSF 2020; Zudaire et al. 2021). For example, in the EPO, the Tuna Conservation Group (TUNACONS)—a consortium of Ecuadorian tuna fishing companies—developed trials with natural fibers in controlled conditions, and tested tens of these FADs under current fishing conditions (TUNACONS, 2018). Similarly, 20% (1,000 plus) of FADs deployed by the TUNACONS fleet since 2021 have voluntarily been constructed with biodegradable materials (TUNACONS-EcoFADs). An EU consortium has deployed around 1,000 FADs in the Indian Ocean, and other initiatives are in place in the Atlantic and Western and Central Pacific Oceans (Zudaire *et al*. 2018; Moreno *et al*. 2018c; ISSF 2020; Zudaire et al. 2021). In addition to these efforts, a new non-entangling, degradable, innovative, and simplistic FAD initiative aiming to extend the durability of its components by reducing the drifting speed, and by avoiding wind and wave surface dragging, has been tested with encouraging results in different oceans (Moreno *et al*. 2021).

Another objective of these initiatives is to better understand the nature and the implementation of what should be considered a biodegradable FAD, including standards for materials and construction, since the use of biodegradable materials may be subject to certain requirements and specifications (Zudaire *et al*. 2018). In this regard, Zudaire *et al*., (2021) suggested that a standardized definition of biodegradable FADs should consider, among others, the international standards, the regulatory framework, the minimum requirement conditions for materials, and whether the term biodegradable should be applied to the materials themselves or to the final product (i.e., the FAD as a whole). However, currently no harmonized definition exists among t-RFMOs, although tentative definitions have been proposed that take into account the aforementioned elements (see Zudaire *et al*. 2021 for details).

In terms of materials, bamboo has always been identified by both scientists and fishers as one of the main alternatives for an eco-friendly surface structure (Hall and Román 2013). Bamboo is abundant worldwide and non-pollutant, and its durability at sea could be enhanced through natural treatments (Razak *et al.* 2005; 2008). For the submerged FAD component, several vegetal fibers distributed worldwide have been explored and tested, either as a net-webbing substitute to avoid species' entanglement or to improve structure cohesion. The abaca fiber (*Musa textilis*) has been used for multiple purposes since the early 20th century (Saragih *et al.* 2018). In recent years, its potential as a biocomposite plastic substitute material, or interaction material in composite systems traditionally using plastic fibers, has been suggested due to its remarkably high tearing resistance (Saragih *et al*. 2018; Valášek *et al.* 2017; Karlsson 2007). The use of cotton fiber (*Gossypium spp*.) dates back centuries with multiple applications (Mwaikambo 2006). Its resistance from sea trials has been tested either alone or with other natural fibers, offering insights into its potential use in the EPO tuna purse-seine fishery (Lopez *et al*. 2019). Alternatively, bio-based biodegradable plastic materials may be an option to consider in the future, as long as they comply with regulatory marine biodegradation standards (Zudaire *et al*. 2021).

Significant efforts have been made in the EPO to reduce entanglements with FADs. These include the promising potential shown by some biodegradable and non-entangling materials and by some initiatives on testing materials of natural origin (TUNACONS, 2018, Lopez et al., 2019). However, no scientifically monitored large-scale at-sea trials with FAD designs made entirely of bamboo, cotton, abaca or other biodegradable materials have been conducted in the EPO.

In 2015, and following Resolution C-15-03, the IATTC staff was required to present recommendations on the use of biodegradable materials to mitigate the entanglement of species and reduce marine debris. Because of this, the European Union granted the IATTC with funds (Grant EU-7592) for a two-phase project involving both controlled and at-sea experiments with biodegradable non-entangling FADs. Funds for the first project (Phase 1) were granted in July 2015, and funds for the second project (Phase 2) in December 2017.

2.1. Phase 1: testing non-entangling and biodegradable materials under controlled conditions

During Phase 1, conducted in 2016-2017, scientists tested non-entangling and biodegradable materials (NEDs) and designs under controlled conditions at the IATTC Achotines laboratory in Panama in a three-replica experiment. Three NEDs prototypes were constructed, all with bamboo for the surface component. Each design used different underwater components: palm leaves (prototype 1; Figure 1-A), bamboo halves in lattice fashion (prototype 2; Figure 1-B) and cotton canvas (prototype 3; Figure 1-C). All prototypes included coconuts in two bags made of 'henequen', a vegetal fiber, to increase buoyancy. The dimensions of these prototypes were 20.4 m deep, 3.0 m long and 1.0 m wide. The NEDs were anchored approximately 0.5 miles from the shoreline and scattered about 0.1 miles apart. The level of deterioration of materials was monitored by divers every two weeks. Because of unexpected adverse sea conditions at Achotines, another three-replica experiment was deployed under calmer sea conditions. However, designs were slightly modified and consisted of 2 prototypes with the same floating component and 2 different submerged components, 1 with bamboo canes (prototype 4; Figure 1-D), and the other with cotton canvas (prototype 5; Figure 1-E). In this second trial, the number of slots in the canvas was increased from the previous prototype to avoid premature tearing (Figure 1-C). The deployment and monitoring protocols remained the same. Results showed that prototype 4 stayed afloat longer than the other prototypes (range= 46-65 days, avg= 55 days), followed by prototype 5 (range= 49-61 days, avg=

53.3 days).

Based on these results, an inter-regional workshop was organized by the IATTC, TUNACONS and the Association of Large Tuna Freezers (AGAC) in October 2017. Scientific experts from fisheries organizations in other oceans, along with regional stakeholders and fishers, gathered to discuss results of Phase 1. The potential use of new materials tested in independent experiments implemented by the fleet and other initiatives being assessed around the globe under existent fishing conditions were also discussed. The workshop participants agreed that some materials tested in Phase 1, like bamboo and cotton canvas, must be considered for experiments in real-time fishing conditions opposed to controlled conditions, but that alternative materials, like balsa wood, canvas and ropes made from abaca fibers, should also be tested to improve NED floatation and durability up to 6-12 months. As a result, a series of NED designs were developed and approved between companies and fishers participating in Phase 2 (see below for details), where the objective was to test experimental NEDs under existent fishing conditions.

2.2. Phase 2: large-scale testing of non-entangling and biodegradable prototypes under existent fishing conditions

The Phase 1 work in Panama, along with initiatives conducted in other oceans, provided background information for effective NED designs. However, obtaining durable biodegradable materials for NEDs under actual fishing conditions has been a challenge globally. To assist with these challenges, the EU provided additional funds (EU Grant 7592) to conduct a second phase focused on a large-scale test of biodegradable materials and prototypes in conjunction with the fishing fleet.

Discussions during the inter-regional workshop allowed for eventual approval of the designs for the surface and submerged components, although effective flotation and biodegradable materials that retain the non-entangling characteristics were a point of concern. Ideally, NEDs should stay afloat and remain cohesive for up to a year, but a duration of 6 months may still be useful for some fleets and areas. Besides durability, NEDs were designed in consultation with the fishing industry, to consider cost-effective materials, those with high availability, and those that are easy to manipulate onboard vessels. For large-scale implementation, NEDs should also be attractive to tunas and, if possible, have similar drifting patterns to traditional FADs.

Although Phase 1 failed to produce appropriate durability results, it provided definitive information on some materials. For example, components like palm leaves, henequen or other vegetable fibers, cloths and coconuts were eliminated due to durability, cost, and processing needs. Instead, the use of bamboo, balsa wood and cotton canvas had positive feedback and became the predominant choice of materials in Phase 2. Phase 1 also helped to prove that using biodegradable materials on FADs may work as effectively as nylon to attract tunas. Results of Phase 1 were also instrumental in promoting the use of biodegradable materials on FADs among the fishing community. Phase 2 aims to promote and facilitate conversations between scientists, the fishing industry, and other stakeholders on the suitability of using other eco-friendly materials for FAD construction. The principal motivation, workplan and experimental design, including data collection and monitoring protocols, as well as preliminary results of Phase 2 are detailed below.

3. OBJECTIVE

The objective of Phase 2 is to develop and test NEDs on a large spatial scale under current fishing conditions. The NEDs should have the following qualities:

- Durability lasting at least 6 to 12 months and degradation without harmful effects on the environment.
- Non-entangling construction characteristics achieved in Phase 1.

- Performance similar to traditional FADs with respect to the attraction and retention of tunas (i.e. fishing efficiency).

4. WORK PLAN

Phase 2 consists of the following activities:

4.1. Choosing prototype materials for testing

Although the inter-regional workshop provided solid guidelines on the use of designs and materials for the construction of NEDs, it was necessary to explore additional options for improving flotation and material durability, particularly potential treatments for bamboo and abaca/cotton canvas. A local project coordinator was hired to assure the program was functioning correctly, including dissemination of information and coordination with the scientific staff of project partners, who conducted some durability trials with materials like abaca, bamboo and balsa wood. Field visits as well as in-person interviews and online communications were conducted with the participants in the project to promote the exchange of ideas on flotation, antifouling and durability. For the latter, animal lard was chosen to be applied on the abaca ropes and canvas, although other treatments were also explored (e.g., natural rubber). Based on all previous information, as well as outputs from similar initiatives around the world (Moreno and Restrepo 2018; Moreno *et al*. 2018a,b; Zudaire *et al*. 2018), three definitive NED prototypes were chosen (Figure 2). The main natural fiber component of NED prototypes 1 and 2 consisted of abaca, whereas cotton was the main natural fiber component of prototype 3 (See Figure 2 for details on prototype dimensions and components).

4.2. Identification of companies and vessels willing to collaborate

TUNACONS and AGAC are two tuna fishing organizations that are comprised of 5 and 9 groups of companies, respectively. Vessel owners from both organizations expressed interest in participating in the experiment, resulting in 31 TUNACONS and 14 AGAC vessels. Both fishing organizations committed to the project through detailed Memorandums of Understanding (MoU's) signed in December 2018. Responsibilities for all participants, companies and fishing crews were described in these MoU's. The selection of the type of NED to be used by each vessel was determined by each company, but IATTC staff recommended a balance between prototypes for the purpose of maintaining a sound experimental design. As a result, prototypes 1 and 2 were exclusively selected by TUNACONS whereas prototype 3 was selected by AGAC.

4.3. Construction of experimental NEDs

Identification of NED constructors and material suppliers for the three prototypes (Figure 2) was key for obtaining standardized NEDs. To avoid quality and technical differences in materials, they were obtained from suppliers selected by the participating organizations (AGAC, TUNACONS) and the IATTC staff. Additionally, each NED prototype was constructed in the same place to assure standardization, as much as possible. Due to increasing costs associated with NED construction, and the desire to maximize the total number of NEDs in the experiments, the participating organizations agreed to cover half of the costs of the materials in NED's construction (see Figure 3 for details), and the totality of costs of the NEDs' associated electronic equipment (e.g., satellite-linked echo-sounder buoys and corresponding connection and data transfer fees), which covered approximately 85% of the total project costs (assuming $1,000 USD per NED buoy, and $15 USD/mo. for a 1-year transmission fee).

In an attempt to avoid deterioration of NEDs by prolonged storage time and to ensure that seasonality is a component of the experimental design, construction and delivery of NEDs was conducted quarterly. The purchasing, material acquisition, and construction strategies were negotiated and agreed upon by both fishing organizations independently, because each organization had unique logistical needs (Figure. 2).

4.4. Experimental design

The total number of prototypes per vessel, season and project was determined after reviewing the budget and by restricting external funding and effort to reasonable levels, while constructing the maximum number of NEDs that would preserve the statistical quality of the project. This was important because of the relatively low ratio of visits and sets on deployed objects by the fishery. As such, a total of 796 NEDs were targeted (199 per quarter) for the at-sea trials. The number of experimental floating objects deployed by each vessel is capacity-specific (in metric tons, mt), as follows:

1. Vessels > 1200 mt: 20 NEDs/year, 5 per quarter;
2. Vessels <=1200 and >363mt: 16 NEDs/year, 4 per quarter;
3. Vessels <=363 and >182mt: 12 NEDs/year, 3 per quarter; and,
4. Vessels <=182 mt: 4 NEDs/year, 1 per quarter.

NEDs were accompanied by deployments of 1 traditional FAD (paired control FAD) within 10-15 miles. All experimental floating objects (i.e., NEDs and traditional FADs) were deployed with satellite buoys and colored metallic tags with unique serial numbers on both the raft and the buoys (Green N-0001 to N-0796 tags for the NEDs; Red T-0001 to T-0796 for the paired control FADs). The serial numbers were provided to the observer for effective tracking and monitoring (Figure 4).

The deployment area was selected by the vessel owner or the skipper, but was always east of 130°W. The IATTC staff encouraged minimal redeployments but recognizes seasonality and the regular fishing practices of the fleet. As such, on certain occasions (e.g., after the Peru fishing season), vessels were allowed to retrieve the objects from a non-suitable fishing area and redeploy them in a more convenient location following the rules and requirement for object marking and tagging. To cover the share of experimental object deployments by vessels during a closure period, a flexible deployment policy was agreed upon by the participants. While a vessel was observing a closure, deployments could be made by other vessels within the same company as long as the deployed experimental objects, as well as their associated metallic tags and satellite buoys, belonged to the original owner (i.e., vessels observing the closure). In these cases, vessels were asked to deploy other vessels' experimental objects at the end of the trip, to reduce potential interaction time between deployments and original owners.

The number of experimental objects in the projects, as well as the rest of the experimental design, was developed by the IATTC staff with the support of workshop participants and fishing organizations.

4.5. Monitoring and tracking of experimental FADs

As mentioned above, NEDs and paired control FADs were deployed with metallic tags with unique alphanumeric codes that attach to both the floating object and the associated buoy. Guidelines and visual material (i.e., posters, Figure 11) were produced to train observers and project participants on how to properly use metallic tags and satellite buoys in each interaction, including deployments and buoy replacements. For example, the paired FAD should, whenever possible, have similar dimensions, and the satellite buoy make and model should be the same as the NED. This allows for consistency and easy comparisons. When satellite buoys are changed after an interaction with the objects, the IATTC staff requested to use, whenever possible, the same brand and model of satellite buoy. Likewise, metallic tags on the buoys and the objects should always match (i.e., any buoy replacement should be accompanied by a subsequent tag replacement).

Dedicated data collection forms (i.e., Registro de objetos flotantes complementario, ROF-C; Figure 5, see details below) and instructions were created for observers and, in situations when observer were absent, for skippers and fishing crew of TRIMARINE's fleet (NPR-TS; Figure 6a), and for any other fleet (RNC-NO;

Figure 6b). A specific email address was also created to receive the project's data and questions from participants. Stakeholders and fishing organizations also received the documentation and posters with the methodology, objectives, expectations and responsibilities of the project's participants, to familiarize themselves with the project's protocol and specific requirements. Similarly, observers were trained by the local coordinator and personnel from other regional field offices. Workshops have been regularly conducted with skippers to inform them of the project's development and to respond to any inquiry they may have regarding the functionality and preliminary results, including key concepts on the monitoring and tracking of experimental objects, preliminary catch rates and durability estimates. A dedicated database was created for the project, which is linked to the main IATTC observers' database using basic trip and detailed object information.

4.5.1. Data collection

The information on the degradation and condition of NEDs over time for both the floating and submerged components is collected on a dedicated form (ROF-C; Figure 5). The condition of each component is categorized as excellent (1); very good (2); good (3); fair (4); poor (5), and very poor (6). The observer can also record on the form when a specific component of the NED has been replaced. Each NED recorded on the ROF-C form is unique and is identified by the metallic tag and the combination of the following attributes: the trip ID number, the floating-object ID number, and the number of times the NED was encountered. These attributes are also recorded on the main flotsam observer form (i.e., Registro de objetos flotantes, ROF; Figure 7), and hence are used to link both forms in the database. The regular ROF is used to obtain specific NED data not included on the ROF-C. These data fields include date, time and the location of the NED interaction, information on NED origin (i.e., vessel-owned NED, NED from a different vessel, etc.), information on catch of target and non-target species, and information related to the satellite buoy identification code. All data are incorporated into the database once the fishing trip is completed and debriefing with the observer has been conducted.

Although infrequent, there have been situations in which the observer was not present onboard to collect the NED information. In these situations, skippers are expected to communicate and send all of the information to the IATTC scientific staff through the dedicated email address created for the project. Skippers are expected to send this information at the end of the fishing day, so that the IATTC staff can incorporate the information into the database before the trip is finished. All data are checked for potential errors using dedicated computer routines.

The information collected by observers from national observer programs has historically been submitted to the IATTC once per year, which would cause significant delays in the data collection of the project and prevent completion of analyses in a timely manner. To mitigate this delay, the local project coordinator interviews the observers of national observer programs in person or coordinates with them via email/telephone, and requests copies of the ROF and ROF-C in advance (i.e., scanned copies, pictures). This information is added to the dedicated database as soon as possible. Observers' ROF and ROF-C reports of non-participating vessels are also included in the study and improve final quantitative comparisons of experimental objects by time period and area. All of the information on the paired control FAD is recorded on the conventional flotsam form only (i.e., ROF). This information is also requested from the observers and national programs as soon as the trip is finished and accessed and validated by the project coordinator through connections to the databases.

The information on satellite buoys, including trajectories and biomass information, is also requested and currently being collected for both NEDs and control FADs (as detailed in the MoUs signed by both fishing organizations). A minimum of 1 position and biomass sample per day is requested, or as frequently as possible (i.e., depending on the make, the model and the sampling strategy originally decided by the fisher—the project aims to reduce, as much as possible, changes in the fishing strategy). The data can be directly transferred from buoy manufacturers to the IATTC staff and are stored in a local database at the La Jolla headquarters to guarantee confidentiality. These data are to be reported with a 2-3 month delay, which is a reporting strategy that has proven to be efficient for information reported under Resolutions C-17-02 and C-20-06 and other global initiatives (e.g. Zudaire et al. 2021). Unfortunately, the COVID-19 pandemic and supply chain issues (e.g., product availability) and durability issues with some materials and prototypes have delayed a fraction of the experimental deployments, and thus, satellite-buoy data have yet to be completed.

5. DATA ANALYSIS

5.1. Interactions with experimental objects

Object interactions like deployments, re-deployments, visits with no set involved (hereafter “visits”) and visits leading to a set (hereafter “sets”) were analyzed to better understand the spatial-temporal distribution and frequency of interactions on NEDs by prototype and the paired control FADs. There were a few cases where NEDs were attached to a floating object found at sea. These NEDs were excluded from the analysis.

5.2. Catch per set

Similarly, the catch per set (i.e., the amount of total tuna per set, mt) of NEDs by prototype was compared to the catch of multiple sets on FADs closely related in time and space, including paired control FADs when possible. For the time component, all sets on FADs conducted seven days before or after the NED set were included in the analysis. In terms of spatial constraints, only sets on FADs conducted within a radius of 1-degree (111 km) of the NED set were considered. Unsuccessful sets (total tuna catch = 0) were not included in the analysis. When consecutive sets were made on the same FAD over a short time period (e.g., 2 days), the total tuna catch was summed and considered to be a single set. This was done to avoid potential influence of catch per set on the object—because fishers may set a FAD multiple times in consecutive days—to make sure the whole tuna aggregation was captured. Indeed, individual tunas and aggregations are known to exhibit short residence times at FADs, which seem to happen at different rates per species (Schaefer and Fuller 2013, Travassos-Toloti *et al*. 2020; Tsukagoe 1981; Cayré 1991; Leroy *et al*. 2009; Matsumoto *et al*. 2006). For example, Schaefer and Fuller (2013) observed short residence times of bigeye tunas in the EPO (2-3 days) while other residence times lasted up to 24 days. In the Atlantic Ocean, studies that analyzed association dynamics of tunas with drifting FADs reported average continuous residence times of 9, 19 and 25 days for skipjack, yellowfin and bigeye tuna, respectively (Travassos-Toloti *et al*. 2020). Also, Baidai *et al*., (2019) estimated the residence time of a tuna aggregation around a drifting FAD to be about 6 days, using echo-sounder buoys. Therefore, the conservative measure of two days is expected to account for the variability in residence times in this study. The same methodology was applied to conduct the catch per set comparisons between paired control FADs and surrounding non-experimental objects. In addition to catch per set, the number of days between the set and deployment was also estimated and compared for both NEDs and paired control FADs.

5.3. Condition of NEDs

To assess the degradation of materials and designs of NEDs at sea, the soak time for each NED interaction (e.g. sets, visits) was estimated, and the condition values recorded by the observers for the different components of the floating and submerged parts were extracted and analyzed for each prototype. The soak time—defined as the at-sea duration of NEDs per prototype and paired control FADs between their deployment and retrieval, or last know record—was grouped into four different categories: 1-30 days; 31-60 days; 61-90, and >90 days. Condition values for each element of the NEDs were averaged for each time period. The soak time was estimated using minimum, maximum, and quantile values of 25, 50 and 75%.

The activity and catch per set analysis using 2019-2021 data included the observer data from both the IATTC and national observer programs, while the 2022 data analysis was based only on data from the IATTC observer program.

6. PRELIMINARY RESULTS

6.1. Activities and interactions with experimental objects

Deployments of experimental objects started in the 3rd quarter of 2019. As of April 1, 2022, a total of 715 NEDs (114 prototype 1; 392 prototype 2; 209 prototype 3) and 705 paired control FADs were deployed (Table 1). Prototype 2 had a broader distribution (70°W–130°W; 7°N–17°S), than the other two prototypes, and a greater number of activities near the South American continent and the Galapagos Islands (Figure 8). Prototype 3 had a large longitudinal distribution (85°W–150°W), comprised mostly of deployments between 3°N and 3°S. The bulk of activities for prototype 1 were observed between 115°W and 150°W, and between 7°N and 4°S (Figure 8).

Redeployments rarely occurred for both NEDs and paired control FADs (n=15, 2.1% and n=12, 1.7%, respectively), most of these were for prototype 2 (n=14). A total of 86 visits (prototype 1: n=5; prototype 2: n=73; prototype 3: n=8), and 56 sets (prototype 1: n=8, prototype 2: n=46, prototype 3: n=2; Table 1; Figure 8) were conducted on NEDs during this study whereas paired control FADs were visited and set 106 and 134 times, respectively (Table 1).

6.2. Catch per set

As of April 1, 2022, a total of 1,906 mt of tuna was caught in the 56 sets made on NEDs (34 mt/set), whereas a total of 4,177 mt were caught in 134 sets on the paired control FADs (31.2 mt/set; Table 1). Both types of FADs showed similar catch-per-set values to other short and long-term monitored floating objects (FAD-05-INF-A, SAC-13-06).

Only seven matching pairs of NEDs and paired control FADs deployed and set upon have been found to date (Table 2). However, only 1 matching pair (unfortunately found outside of the EPO) met the spatiotemporal criteria established. The NED catch was 15mt, and that of the paired FAD 20mt. They were set 2 days apart, and with 56.8km (about 0.5 degrees) of separation. Given data constrains, group comparisons with other objects in a specific spatial-temporal window (see data analysis section for details) were considered (Figure 9). The catch-per-set ratios of the NEDs versus the FAD ranged from 0.1 to 11.9 (25 groups, avg = 1.9; median = 0.9; Table 3). Similarly, the catch per set ratios of the paired control FADs versus the other traditional FADs ranged from 0.2 to 21.5 (36 groups, avg = 2.3; median = 0.8; Table 4).

6.3. Condition of NEDs

Table 5 summarizes the observed conditions of the components of the three NED prototypes as a function of time. Prototype 1 was observed 12 times, and the materials of both the floating and submerged components were considered to be in good to very good condition after a minimum of 2 months at sea (i.e., soak time). Prototype 2 was observed 111 times, and its components were, in general, considered to be in a very good condition for at least 2 months of soak time, and with good to fair condition until at least 3 months. In contrast, the NED design of prototype 3 had the least durability to date. This prototype was observed 9 times, and some of the of materials were deemed to be in poor condition or disappeared after 3 months of deployment. As a result, new cotton and rope materials were acquired for the third and fourth batch of prototype 3 deployments. Data for these deployments are currently being collected and will be analyzed as they become available.

It is important to note that the 'NA' code shown in table 5 represents different meanings in our analysis; either a prototype does not contain a specific material or component (e.g., the submerged canvas of prototype 1), or the NED or some of its components could not be observed (e.g., only the satellite buoy was found).

Figure 10 shows the distribution of days of the total soak time per prototype and paired control FADs, estimated as the difference between the first deployment and retrieval or last encounter. Similarly, Table 6 shows the minimum, maximum, average and the 25, 50 (median) and 75% quantiles of total soak time for experimental FADs. For NED prototype 1, the total soak time fluctuated between 33 and 139 days (>4.5 months), with an average and median of 62 and 50 days, respectively. Total soak time for prototype 2 ranged between 1 and 244 days (>8 months), with an average and median of 43.6 and 39 days, respectively, whereas prototype 3 ranged between 40 and 94 days (>3 months), with an average and median of 66.9 and 59 days, respectively. The recorded total soak time for the paired control FADs ranged between 1 and 425 days (>14 months), with an average and median of 87.4 and 68 days, respectively.

7. PROJECT FEEDBACK

Industry and fishers' engagement and feedback is key to the success of the project. Familiarization with the objectives and methodology and project dynamics is important to ensure NED designs are preserved and the proper use of tracking methods (e.g., metallic tags), among others, is well understood. As such, posters describing the project's most important functional matters have been delivered and shared with the fleet, and workshops have been organized with vessel participants and non-participants on a regular basis and will continue for the duration of the project (Figure 11). The overall response of the fleet has been positive. For example, some fishers have sent information (e.g., date, location) and pictures of NEDs they have encountered at sea, which allows for cross-checking against the observer data once the trip has completed. Additionally, the local project coordinator regularly interviews participant skippers on any matter related to the program, with particular interest on the NED prototypes used and their performance. To maintain a close and consistent relationship with the fleet, fishers from the two organizations (TUNACONS and AGAC) are also regularly given project updates through online or in-person workshops in Manta and Posorja, Ecuador. To date, all participants have provided useful feedback, proposed solutions to challenges and expressed full commitment to the project.

8. PROJECT CHALLENGES

The COVID-19 pandemic—starting in the 1st quarter of 2020—had several adverse effects on the working dynamics of this project. For example, logistical difficulties hampered the collection of new data (e.g., shortage in the number vessels and observers to go to sea), and supply chain issues delayed the construction of new NEDs (e.g., shortage and availability of materials, import and export constraints). Factories along with customs and borders have been closed and international and national shipments and travels have been restricted. These factors hindered the availability, manufacturing, shipping, and reception of material, which ultimately impacted NED construction and deployments. However, material availability has improved, and restrictions and regulations have recently been easing, which has allowed for NED construction to gradually continue.

Although, in general, NEDs have performed reasonably well, some concerns were raised by participants during the prototype testing in the 3rd and 4th quarters of 2019. To address these concerns, efforts were undertaken to improve these prototypes and accommodate fleets' concerns. For example, laboratory tests showed that the condition of the canvas and ropes of abaca fibers in prototype 2 could be improved when coated with natural products (i.e., rubber). Also, the fishing crew noted a potential weakness in the connection between the submerged component and the floating component in prototype 1. For this prototype, a slight modification was approved to reinforce the link and reduce the potential loss of the submerged component; moreover 2 small nylon ropes running independently and in parallel to each abaca braided rope were added. It was noted, the method of tying and hanging the ropes should be considered so that the performance of the abaca ropes is not compromised. Similarly, problems associated with the cotton canvas, likely due to the quality of the material used, were reported for prototype 3. The prototype 3 NEDs deployed in the 4th quarter of 2019 and 1st quarter of 2020 appeared to break apart, particularly the floating component, which increases the chances of satellite buoy detachment from the experimental object. However, the experiments conducted during Phase 1 showed that performance of the cotton canvas could be improved if the quality was preserved, and therefore participants agreed on improving both the quality and thickness of the cotton for prototype 3 NEDs for the 3rd quarter of 2021 and last batch of deployment (still pending; see "Future work"). In addition to the issue with the cotton canvas, some of the ropes used in the submerged part for prototype 3 in the 4th quarter of 2019 and 1st quarter of 2020 appeared to be failing. Therefore, material was acquired from a new supplier to replace the ropes in the submerged component of prototype 3 NEDs for deployment in the 3rd quarter of 2021. The selection of the supplier and material was based on the success of similar projects in other regions of the world where some of the participant companies had previously participated (Zudaire et al. 2021). However, the material did not perform as expected, which resulted in another modification to the NED design, aiming to extend its durability. For the last batch of deployments, the biodegradable ropes were replaced with synthetic ropes to ensure the NED's long-term cohesion and integrity. In addition to these modifications, and similar to prototype 1, minor changes to preserve the flotation and strengthen the connection between the submerged and the surface components were applied to prototype 3 (e.g., the addition of small nylon ropes to reinforce the connection between the submerged and surface components and the increase in the quantity of balsa wood used; Figure 12). At the time of this report, no data have been collected to assess any improvements in design and condition of materials in prototype 3.

9. FUTURE WORK

Although the project is near completion, approximately 70 NEDs of prototype 3 (along with their paired control FADs) have yet to be deployed. The staff is also in close contact with other voluntary and scientific programs that are deploying biodegradable FADs in the region (e.g., the TUNACONS voluntary initiative on biodegradable FADs, the ISSF jellyFAD project). Therefore, it is necessary to continue processing and analyzing the information collected by the observers and other means (e.g., from echo-sounder buoys), to better understand the at-sea performance of the different experimental objects. Moreover, given the changes in the quality of some materials and minor design modifications in these 3 NED prototypes it may be desirable to update the analyses and results on the condition of NED materials in the near future by assessing their performance separately with an increased sample size. All this information could be used to inform an effective and gradual implementation of biodegradable FADs in the region.

Although some initiatives are underway to assess the drifting and durability performance of FADs with different depth components and simpler designs (e.g., the jellyFAD, FAD-05-INF-B), large-scale at sea experiments that address this issue are still lacking in the EPO. Therefore, initiatives that consider testing simpler FAD designs and use of materials are desirable. In addition, it would be necessary to engage in participatory approaches with other fleets to promote engagement and to discover means to reduce material usage in FADs without compromising fishing performance. This could be of particular interest for those fleets that use deeper FADs and operate mostly offshore and closer to the western border of the IATTC convention area, where deeper FADs have historically been used (e.g., FAD-05-INF-C).

Given the relatively less resilient and faster degradation nature of the NED components, it is reasonable to assume that biodegradable FADs may be more sensitive to manipulation than traditional FADs (Roman et al. 2020). As a result, fishers would like to minimize unnecessary contact and rough manipulations with biodegradable FADs as much as possible to improve their functional life at sea, at least during experimental and implementation phases. However, fishers seem to be aware of these differences, which may be already affecting the FAD manipulation and fishing strategies. These assumptions, though, would need to be confirmed and validated by data (e.g., empirical information, interviews) so that the real impacts of transitioning from traditional FADs to biodegradable FADs in the various fishing strategies can be assessed holistically.

Once experimental deployments are over and all data available, the IATTC staff aims to collect and analyze trajectories and biomass records of the echo-sounder buoys, while also exploring the use of additional observer data (e.g., catch and size composition of target and non-target species) to better understand prototypes' performance and efficiency at different scales. Statistical tests and models will be conducted to analyze in more detail experimental objects' durability, condition, biomass aggregation and colonization processes, as well as trajectory and drifting patterns. Understanding all of these elements is important for the fishing industry, stakeholders, and policy makers to efficiently implement and adopt non-entangling biodegradable FADs. Therefore, analyses of these data are expected to be conducted prior to the Commission meeting in August 2022.

The IATTC scientific staff will continue coordinating with participants on NED construction, discussing and finding solutions where necessary and providing support to ensure the proper functioning of the project, as well as to support and coordinate with similar private initiatives in the EPO and globally (e.g., the jelly-FAD experience in the EPO and other oceans, the voluntary deployment of 20% biodegradable FADs for TUNACONS companies, initiatives in other t-RFMOs). As such, the staff will continue to engage in conversations with external partners in the search for improved materials and designs that will extend the durability of the NEDs at sea. Similarly, the IATTC scientific staff will maintain coordination with the national observer programs to support, to the extent possible, regional data collection programs on biodegradable FADs and to obtain information on experimental FADs in a timely manner. Finally, dissemination and information exchange workshops with fishers are expected to be held in late 2022 and early 2023. Preferably, these workshops will be held in person to improve participant engagement, but this will depend on the status of the COVID-19 pandemic.

10. CONCLUSIONS AND RECOMMENDATIONS

Preliminary results showed NEDs performed better when non- or low-processed natural materials were used. The bamboo and the balsa wood were present in all 3 prototypes, and their condition was very good every time its presence was recorded. Also, the abaca fiber used in prototypes 1 and 2—especially when coated with natural rubber—proved to be durable given its reasonable condition after at least 3 months of total soak time. These materials were relatively easy to obtain without significant logistical constraints, because they could be obtained locally. However, potential local availability and shortage constraints may need to be considered if these materials are to be used at a large scale by all fleets operating in the EPO. Given these promising results, approximately 43 vessels, under the TUNACONS FAD management plan, are voluntarily using the prototype 2 in at least 20% of their FAD deployments, and 12 additional vessels representing 2 Ecuadorian fleet companies are likely to adhere to this initiative in the near future. On the other hand, materials like cotton fibers did not achieve the expected results, particularly for those acquired for the first batch of the project. An update of the improved cotton quality is underway. It is important to note that a good quality cotton product had to be imported from overseas, which resulted in associated logistical constraints, delays and elevated costs. However, the IATTC staff believes that some of those constraints could be effectively overcome by searching for similar quality cotton materials sourced locally or by strengthening communications and purchasing commitments with certain local suppliers (e.g., suppliers with headquarters in the USA).

Hence, the IATTC staff's recommendations are as follows:

- Consider current prototypes 1 and 2 as potential examples for effective biodegradable FAD construction[3].
- Harmonize across t-RFMOs and regional biodegradable FAD initiatives, to the extent possible, the definition of biodegradable FADs, the guidelines and timeline for their construction and implementation, as well as data collection priorities.
- Consider the following definition for biodegradable FADs, simplified from Zudaire et al., (2021):

  "*A biodegradable FAD is composed of non-netting from organic materials[4] and/or bio-based alternatives certified by international standards[5] as biodegradable in marine environments[6][7]*"

- Require further trials at sea to refine important practical and technical aspects for the full implementation of biodegradable FADs (e.g., durability, designs, material availability and acquisition). Ideally, these trials should be monitored and conducted in collaboration with scientists.
- Request the results of biodegradable trials at sea be made available to the FAD WG.
- Consider a gradual/stepwise process, including a timeline for the implementation of fully biodegradable FADs based on the current state of material availability.
- Reduce, to the extent possible and within the gradual process of biodegradable FAD implementation, the amount of material (e.g., tail depth) and the non-biodegradable components of NED design and construction, provided that fishing efficiency is not compromised.
- Revise, as needed, IATTC data collection methods and tools, including fisheries observer data, for the implementation of biodegradable FADs in the EPO to be effectively monitored.

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[3] Prototype 3 results will need to be updated, and its suitability considered, once all deployments are finalized

[4] For example, plant-based materials such as cotton, jute, manila hemp (abaca), bamboo, or animal-based such as leather, wool, lard.

[5] International standards such as ASTM D6691, D7881, TUV Austria, European Standards EN 13432.

[6] The components resulting from the degradation of these materials should not be toxic for the marine and coastal ecosystems or include heavy metals in their composition.

[7] This definition does not apply to electronic buoys attached to FADs to track them.

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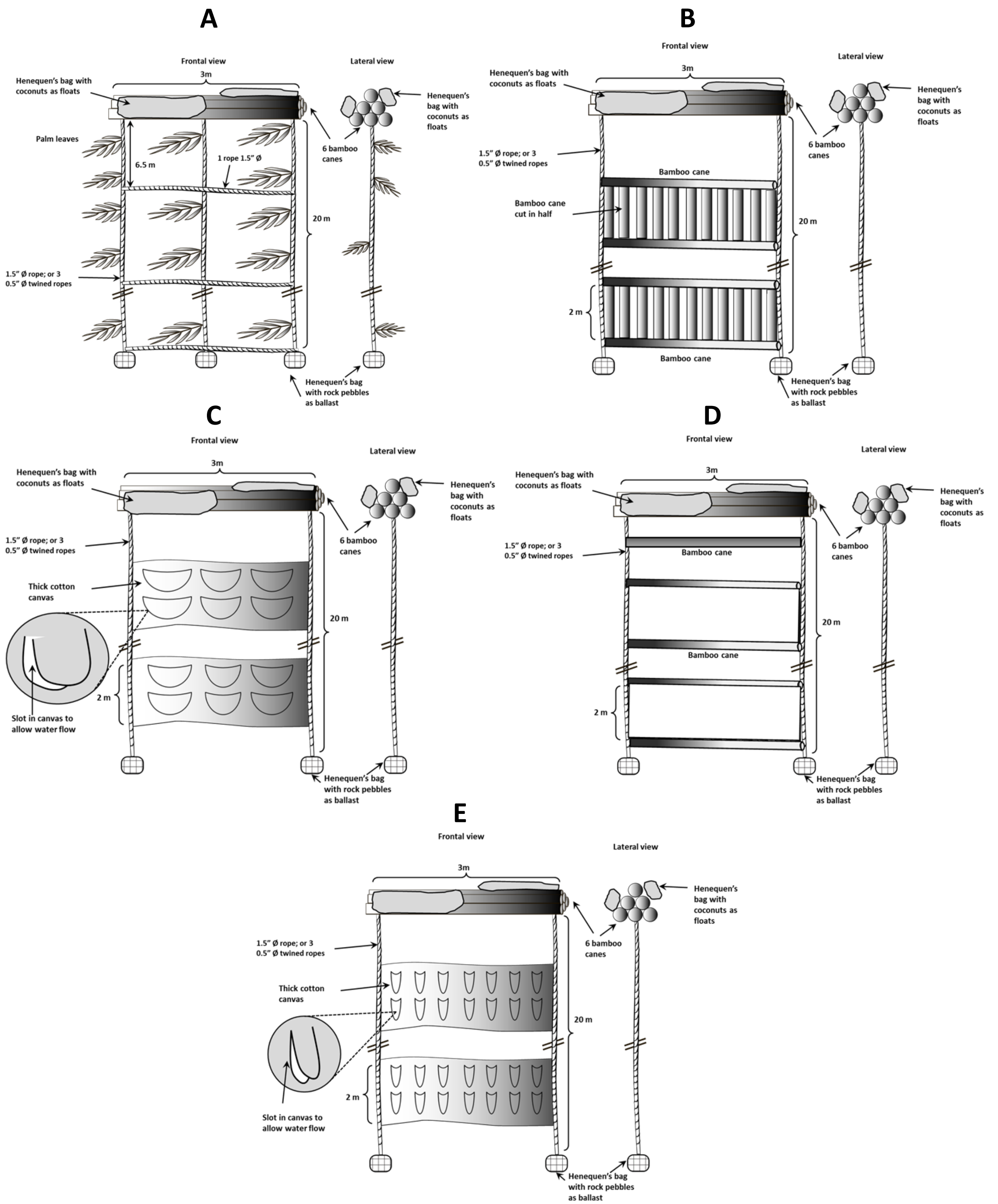


FIGURE 1. Prototypes 1(A) to 5 (E) used in Phase one (EU grant 7592).

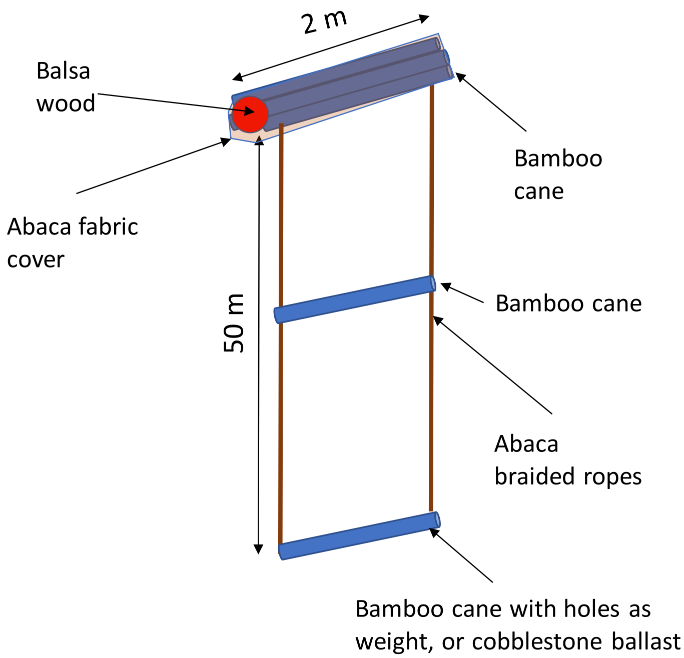


FIGURE 2a. NED prototype 1.

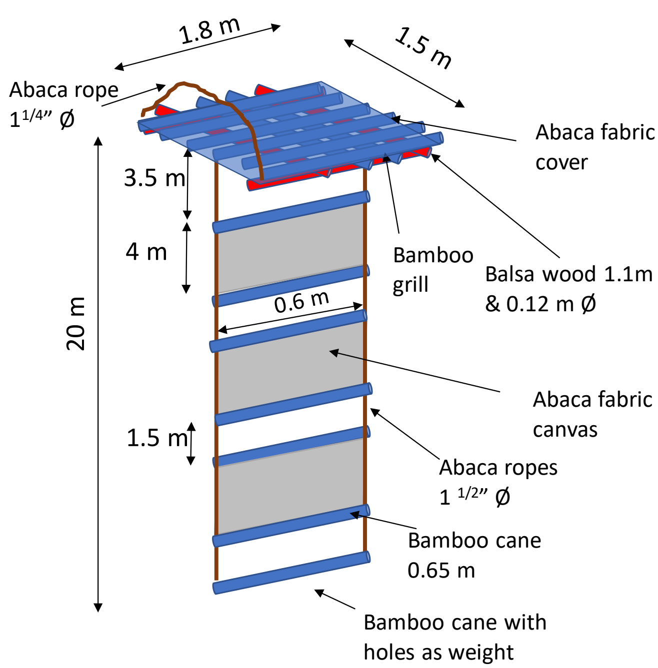


FIGURE 2b. NED prototype 2.

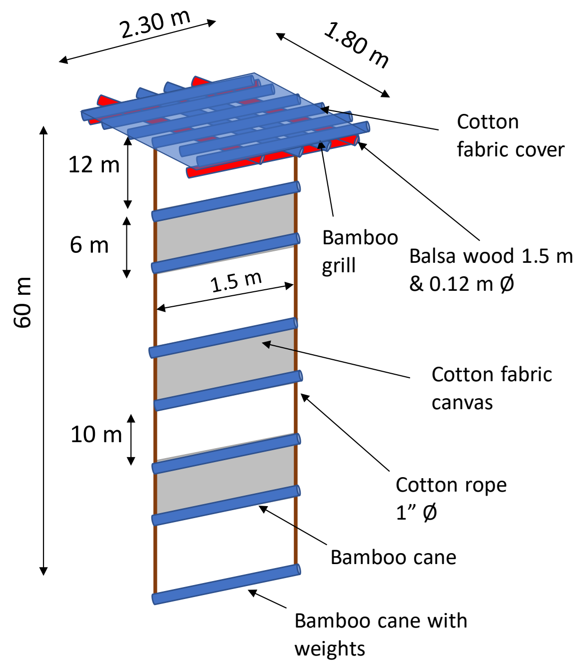


FIGURE 2c. NED prototype 3.

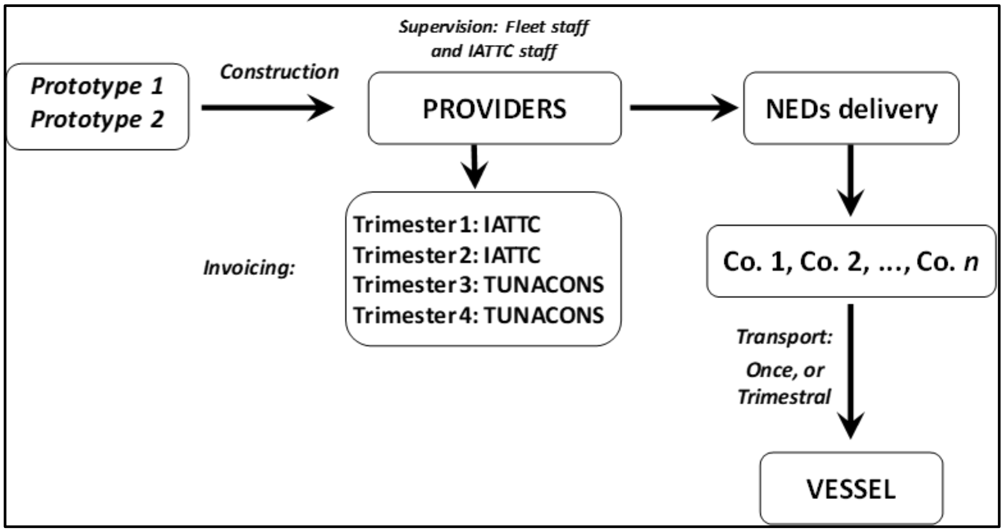


FIGURE 3a. Flowchart showing construction and payment options for NEDs used by TUNACONS.

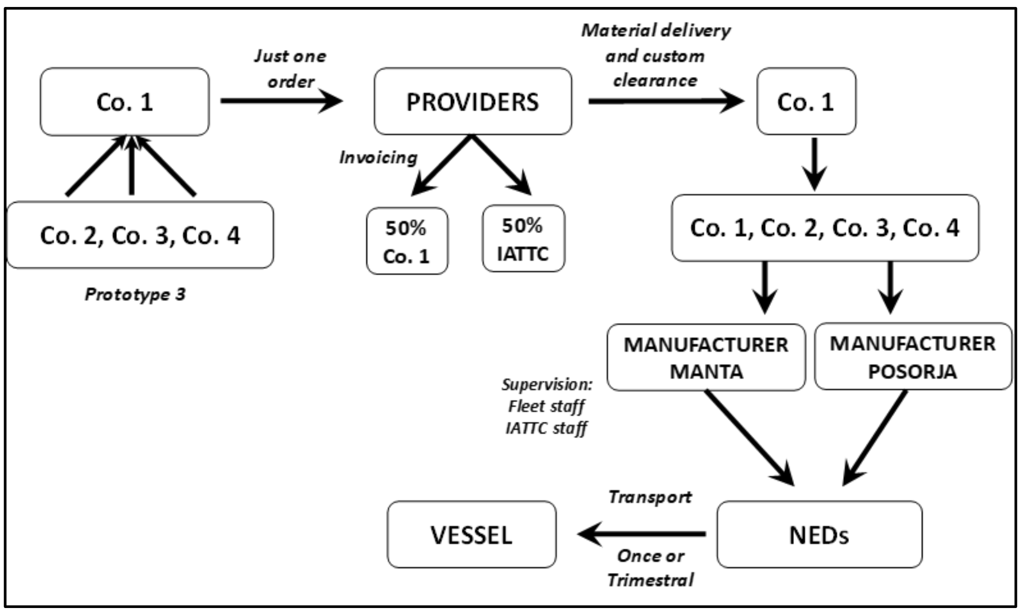


FIGURE 3b. Flowchart showing construction and payment options for NEDs used by AGAC.

FIGURE 4. Colored metallic tags placed on both the raft and the buoys of experimental FADs; NEDs (green) and paired control FADs (red).

Comisión Interamericana del Atún Tropical

REGISTRO DE OBJETOS FLOTANTES COMPLEMENTARIO (ROF-C)

Utilice este registro exclusivamente para proveer información de los NED descritos en el instructivo

No. de Crucero
1 5 0 0 0 0

No. de objeto	NE	NP	Levantado	Estructura superficial	Condición	¿Reemplazado?	Estructura bajo el agua	Condición	¿Reemplazado?
0 0 1	0 1	1	Sí [ ] No [ ]	Bambú	[1]	Sí [ ] No [X]	Lonas	[ ]	Sí [ ] No [ ]
Comentarios:				Lona envolvente	[1]	Sí [ ] No [X]	Soga principal	[1]	Sí [ ] No [X]
				Balsa	[1]	Sí [ ] No [X]	Soga de amarre	[1]	Sí [ ] No [X]
				Soga de amarre	[1]	Sí [ ] No [X]	Bambú (estructura)	[ ]	Sí [ ] No [ ]
							Bambú (lastre)	[1]	Sí [ ] No [X]

No. de objeto	NE	NP	Levantado	Estructura superficial	Condición	¿Reemplazado?	Estructura bajo el agua	Condición	¿Reemplazado?
0 0 2	0 1	3	Sí [X] No [ ]	Bambú	[2]	Sí [ ] No [X]	Lonas	[3]	Sí [ ] No [X]
Comentarios: AL SER REMOLCADO, PUDE OBSER				Lona envolvente	[3]	Sí [ ] No [X]	Soga principal	[3]	Sí [ ] No [X]
VAR LA PARTE COLGANTE DEL NED				Balsa	[2]	Sí [ ] No [X]	Soga de amarre	[3]	Sí [ ] No [X]
CERCA DE LA SUPERFICIE. NED				Soga de amarre	[3]	Sí [ ] No [X]	Bambú (estructura)	[2]	Sí [ ] No [X]
FUE LEVANTADO A LA MITAD.							Bambú (lastre)	[2]	Sí [ ] No [X]

FIGURE 5. An example of the observer complementary flotsam form (ROF-C).

Inter-American Tropical Tuna Commission

NED AND PAIRED FAD INFORMATION RECORD FOR TRIMARINE SKIPPERS (NPR-TS)

Vessel name	DATE YY MM DD	TIME	LATITUDE N/S	LONGITUDE W

A. General information. Use buoy code table below to indicate the satellite buoy manufacturer. When the buoy is replaced, use the space for Buoy 2. Use the condition codes table below to record the components condition.

Activity: Deployed ☐ Fished ☐ Visited ☐ | Was the object removed from the sea? Yes ☐ No ☐

Satellite or radio buoys

	Make / Model		Serial number		**Metallic tags**
Buoy 1				Tag 1:	
Buoy 2				Tag 2:	

Lifted: Yes [ ] No [ ]	NED floating structure (Raft)	Condition	Replaced?	NED underwater structure (Tail)	Condition	Replaced?
Prototype No.: [ ]	Bamboo	[ ]	Yes[ ] No [ ]	Canvas	[ ]	Yes[ ] No [ ]
Comments:	Canvas cover	[ ]	Yes[ ] No [ ]	Main rope	[ ]	Yes[ ] No [ ]
	Balsa wood	[ ]	Yes[ ] No [ ]	Tightening rope	[ ]	Yes[ ] No [ ]
	Tightening rope	[ ]	Yes[ ] No [ ]	Bamboo (structure)	[ ]	Yes[ ] No [ ]
				Bamboo (ballast)	[ ]	Yes[ ] No [ ]

Condition codes of degradable components

Code	Condition	Description
0	Not observed	Component is present, but its condition could not be observed (very turbid water, observed at night, etc.).
1	Excellent	New. With its natural color. No signs of damage or deterioration. Strongly attached to other components.
2	Very good	Little discoloration. No apparent signs of damage or deterioration. Firm cohesion with other components.
3	Good	Slightly worn. Few cracks/tears/discoloration. Cohesion with other components is relatively firm. Begins to show signs of weakness.
4	Fair	Evidence of wear. Several cracks/ tears. Cohesion with other components is weak. Very discolored.
5	Poor	Very deteriorated. Separated from other components. 50% has disappeared. Very discolored. Cohesion with other components is insufficient and very weak.
6	Very poor	Little evidence of its presence. More than 80% has disappeared. Very discolored. Cohesion is almost non-existent.

Buoy code table – Make and model of buoys

MARINE INSTRUMENTS (Nautical)			SATLINK		
Model	**Codes**		**Model**	**Codes**	
Unknown	MARD	100	Unknown	SATD	200
MDP	MDP	101	D+ battery	D+	201
MDS	MDS	102	D+ battery with echo-sounder	DS+	202
M2D	M2D	103	D+ solar	DL+	203
MSI	MSI	104	D+ solar with echo-sounder	DSL+	204
M3i	M3I	105	IDP solar with echo-sounder	ISL+	205
M3i+	M3I+	106	IDP solar disc with echo-sounder	ISD+	206
M4i	M4I	107	SLX solar "ECO"	SLX+	207
ZUNIBAL					
Model	**Codes**		**Model**	**Codes**	
Unknown	ZUND	300	Tunabal-e7+ (F-series)	F7+	306
Tunabal-7	T07	301	Tuna8 Explorer	T8E	307
Tunabal-e7	TE7	302	Tuna8 Xtreme	T8X	308
Tunabal-e7+	T7+	303	Tuna8 Explorer (F-series)	F8E	309
Tunabal-7 (F-series)	F07	304	Zuni with no echo-sounder	ZO7	310
Tunabal-e7 (F-series)	FE7	305	Zuni-e with no echo-sounder	ZE7	311

Buoy without make or unknown make	DESC	0
Other type of non-satellite buoy	OTRN	900
Other satellite buoy of a make not indicated above	OTRS	911

FIGURE 6a. Data collecting for skippers and fishing crew of TRIMARINE's fleet (NPR-TS).

Comisión Interamericana del Atún Tropical

REGISTRO DE NED Y PAREJAS DE CONTROL PARA BARCOS SIN OBSERVADOR (RNC-NO)

Nombre del barco	FECHA AA	FECHA MM	FECHA DD	HORA	LATITUD	N/S	LONGITUD	W

A. Información general del objeto flotante. Use la tabla de códigos de boyas (abajo) para indicar el fabricante de la boya, así como la tabla para la condición del componente. Si la boya es remplazada, use el espacio para Boya 2.

Actividad: Sembrado ☐ largado ☐ visitado ☐ **¿Subieron el objeto a bordo?** Sí ☐ No ☐

Boyas satelitales o radio boyas

	Marca / Modelo	Número de serie
Boya 1		
Boya 2		

Placas metálicas (N o T)

Marca 1:

Marca 2:

	Estructura superficial	Condición	¿Reemplazado?	Estructura bajo el agua	Condición	¿Reemplazado?
Levantado: Si [ ] No [ ]						
Prototipo No.: [ ]	Bambú	[ ]	Sí [ ] No [ ]	Lonas	[ ]	Sí [ ] No [ ]
Comentarios:	Lona envolvente	[ ]	Sí [ ] No [ ]	Soga principal	[ ]	Sí [ ] No [ ]
	Balsa	[ ]	Sí [ ] No [ ]	Soga de amarre	[ ]	Sí [ ] No [ ]
	Soga de amarre	[ ]	Sí [ ] No [ ]	Bambú (estructura)	[ ]	Sí [ ] No [ ]
				Bambú (lastre)	[ ]	Sí [ ] No [ ]

Códigos de condición de los componentes degradables

Código	Condición	Descripción
0	No observado	Componente está presente, pero no pudo observar su condición. (Agua muy turbia, observado en la noche, etc.)
1	Excelente	Nuevo. Con su color natural. Sin signos de daño o degradación. Fuertemente afianzado a los demás componentes.
2	Muy bueno	Poca decoloración. Sin signos de daños o degradación aparentes. Cohesión con los demás componentes es firme.
3	Bueno	Ligeramente desgastado. Pocas grietas/rasgaduras/decoloración. Cohesión con los demás componentes relativamente firme. Comienza a mostrar signos de debilidad.
4	Regular	Evidencia de desgaste. Varias grietas/rasgaduras. Cohesión con los demás componentes es débil. Muy decolorado.
5	Malo	Muy deteriorado. Está separado de los demás componentes. Ha desaparecido un 50%. Muy decolorado. Cohesión con los demás componentes es insuficiente y muy débil.
6	Muy malo	Con poca evidencia de su presencia. Ha desaparecido más del 80%. Muy decolorado. Cohesión casi inexistente.

Tabla de códigos de boyas – Marca y modelo de boyas

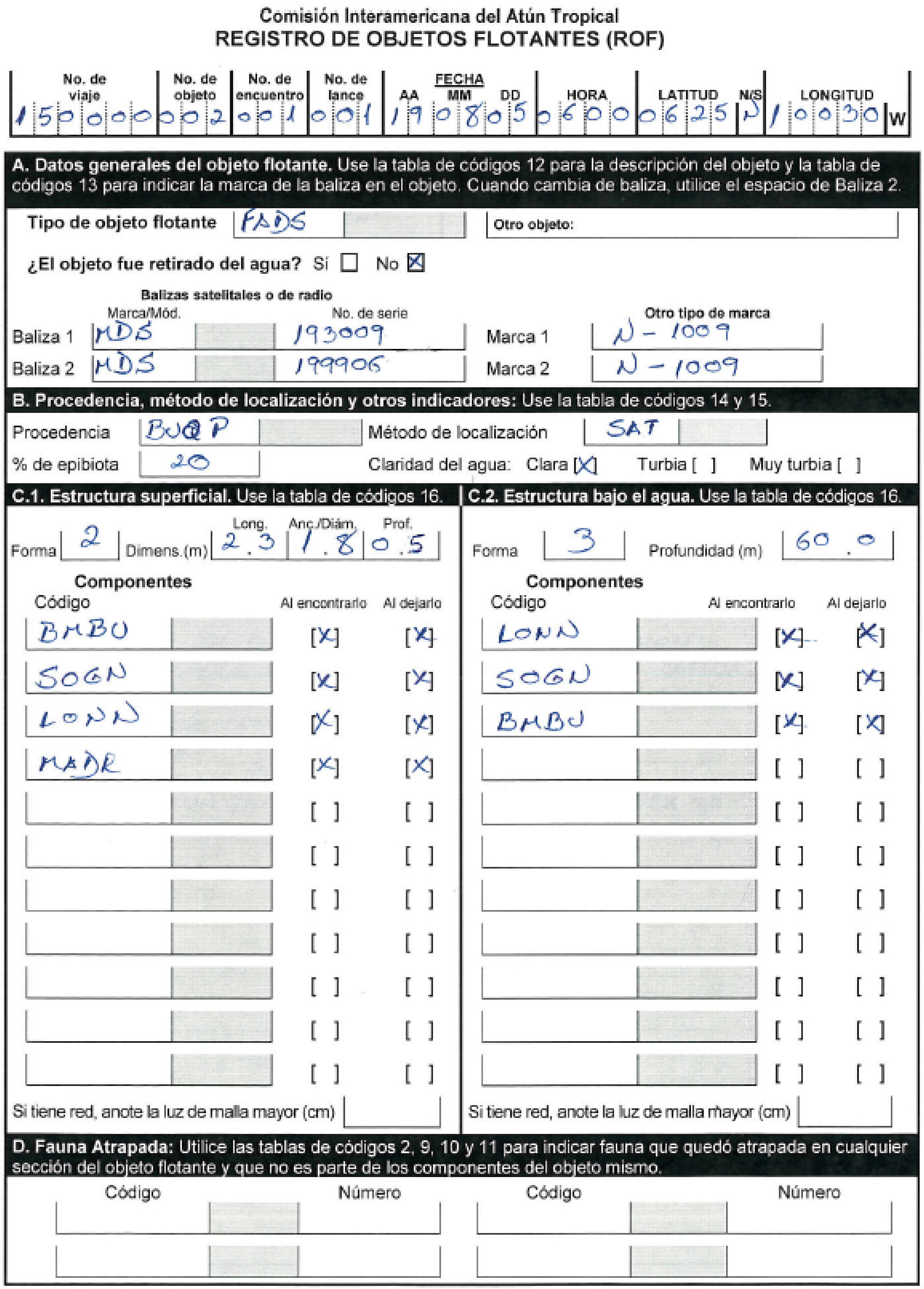
MARINE INSTRUMENTS (Nautical) Modelo	Códigos		SATLINK Modelo	Códigos	
Desconocido	MARD	100	Desconocido	SATD	200
MDP	MDP	101	D+ pila	D+	201
MDS	MDS	102	D+ pila con sonda	DS+	202
M2D	M2D	103	D+ solar	DL+	203
MSI	MSI	104	D+ solar con sonda	DSL+	204
M3i	M3I	105	IDP solar con sonda	ISL+	205
M3i+	M3I+	106	IDP solar disc. c/sonda	ISD+	206
M4i	M4I	107	SLX solar "ECO"	SLX+	207

ZUNIBAL

Modelo	Códigos		Modelo	Códigos	
Desconocido	ZUND	300	Tunabal-e7+ (F-series)	F7+	306
Tunabal-7	T07	301	Tuna8 Explorer	T8E	307
Tunabal-e7	TE7	302	Tuna8 Xtreme	T8X	308
Tunabal-e7+	T7+	303	Tuna8 Explorer (F-series)	F8E	309
Tunabal-7 (F-series)	F07	304	Zuni sin sonda	ZO7	310
Tunabal-e7 (F-series)	FE7	305	Zuni-e sin sonda	ZE7	311

Baliza sin marca o marca desconocida	DESC	0
Otro tipo de baliza no satelital	OTRN	900
Otra baliza satelital de una marca no indicada arriba	OTRS	911

FIGURE 6b. Data collection form for skippers and fishing crew (RNC-NO) on vessels other than those in TRIMARINE's fleet.



Comisión Interamericana del Atún Tropical
REGISTRO DE OBJETOS FLOTANTES (ROF)

No. de viaje	No. de objeto	No. de encuentro	No. de lance	FECHA AA	FECHA MM	FECHA DD	HORA	LATITUD	N/S	LONGITUD	
150000	002	001	001	19	08	05	0600	0625	N	10030	W

A. Datos generales del objeto flotante. Use la tabla de códigos 12 para la descripción del objeto y la tabla de códigos 13 para indicar la marca de la baliza en el objeto. Cuando cambia de baliza, utilice el espacio de Baliza 2.

Tipo de objeto flotante: FADS — Otro objeto:

¿El objeto fue retirado del agua? Sí [ ] No [X]

Balizas satelitales o de radio	Marca/Mód.	No. de serie		Otro tipo de marca
Baliza 1	MDS	193009	Marca 1	N - 1009
Baliza 2	MDS	199906	Marca 2	N - 1009

B. Procedencia, método de localización y otros indicadores: Use la tabla de códigos 14 y 15.

Procedencia: BUQP — Método de localización: SAT

% de epibiota: 20 — Claridad del agua: Clara [X] Turbia [ ] Muy turbia [ ]

C.1. Estructura superficial. Use la tabla de códigos 16.

Forma: 2 — Dimens.(m): Long. 2.3, Anc./Diám. 1.8, Prof. 0.5

Componentes

Código	Al encontrarlo	Al dejarlo
BMBU	[X]	[X]
SOGN	[X]	[X]
LONN	[X]	[X]
MADR	[X]	[X]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]

Si tiene red, anote la luz de malla mayor (cm)

C.2. Estructura bajo el agua. Use la tabla de códigos 16.

Forma: 3 — Profundidad (m): 60.0

Componentes

Código	Al encontrarlo	Al dejarlo
LONN	[X]	[X]
SOGN	[X]	[X]
BMBU	[X]	[X]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]
	[ ]	[ ]

Si tiene red, anote la luz de malla mayor (cm)

D. Fauna Atrapada: Utilice las tablas de códigos 2, 9, 10 y 11 para indicar fauna que quedó atrapada en cualquier sección del objeto flotante y que no es parte de los componentes del objeto mismo.

Código	Número	Código	Número

FIGURE 7. An example of the observer flotsam form (ROF).

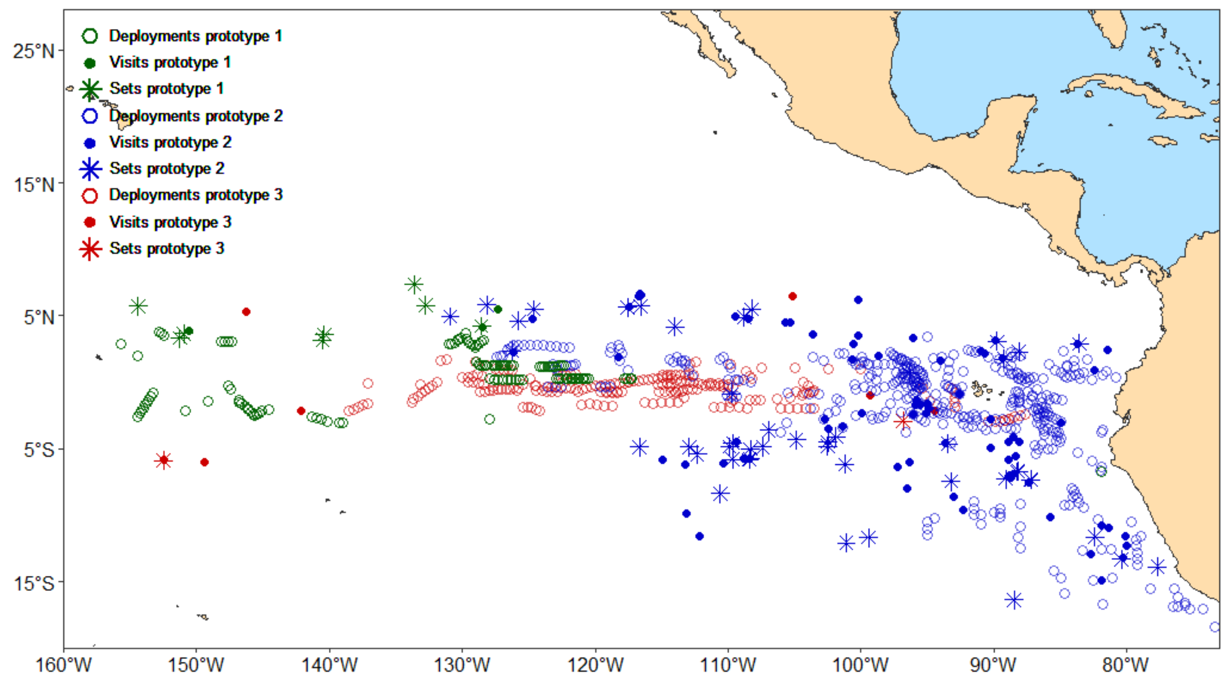


FIGURE 8. Spatial distribution of NED deployments, visits and sets from 2019–2022.

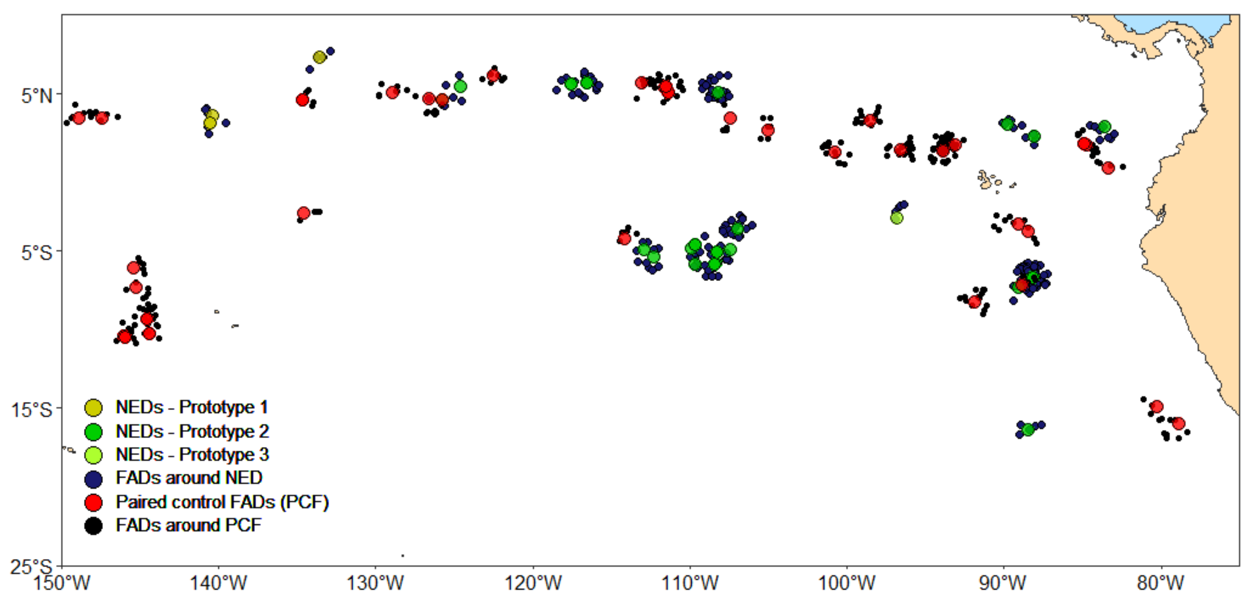


FIGURE 9. FAD sets made at a 1-degree radius and 7 days before or after a set on a NED or paired control FAD.

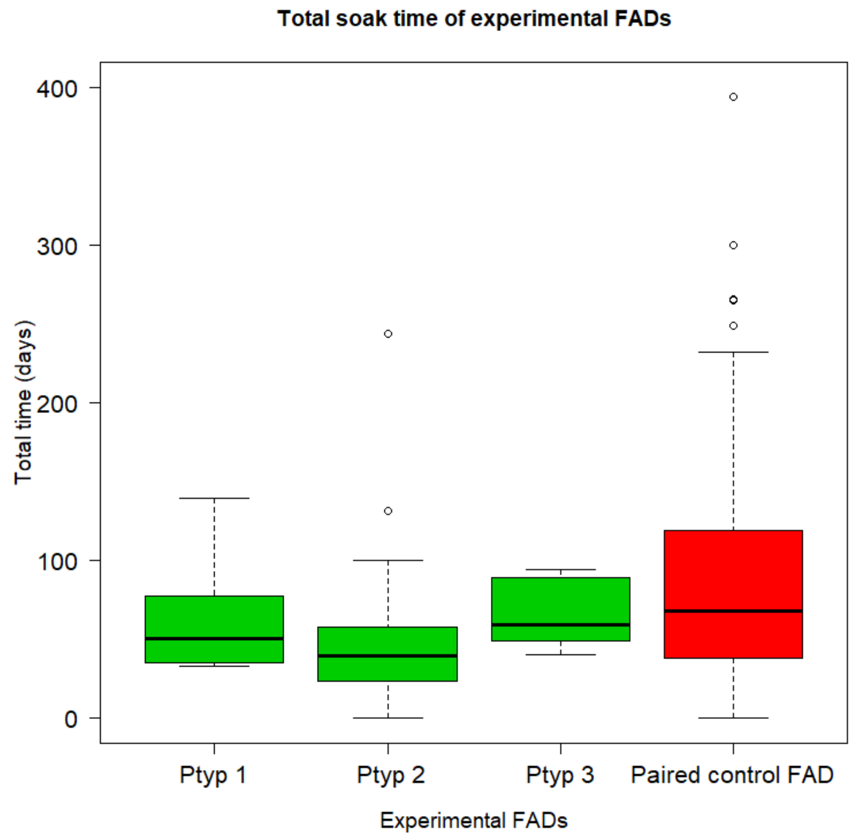


FIGURE 10. Distribution of total soak time of experimental FADs between first deployment and retrieval or last encounter. Ptyp: prototype.

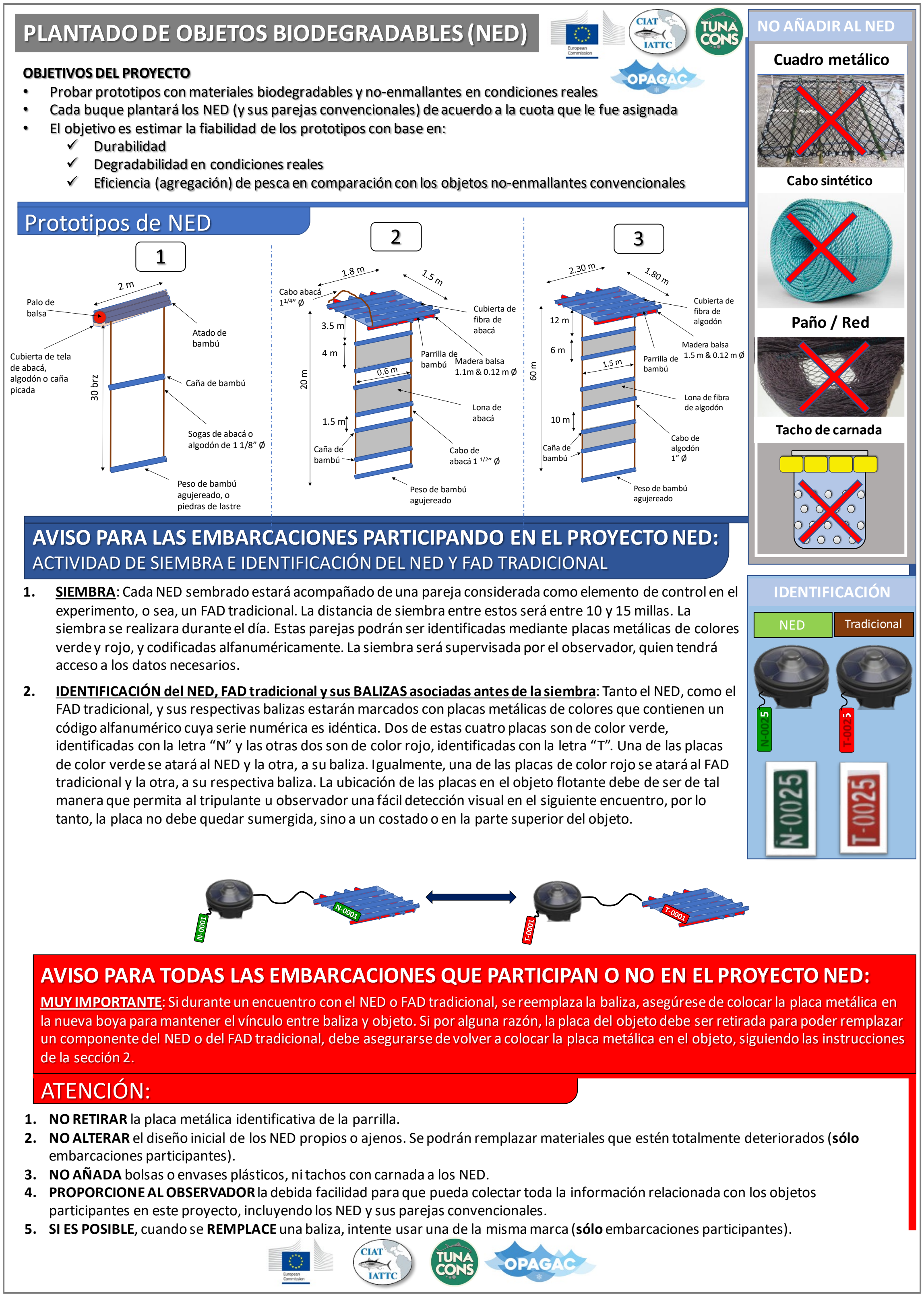


FIGURE 11. Poster for project information dissemination.

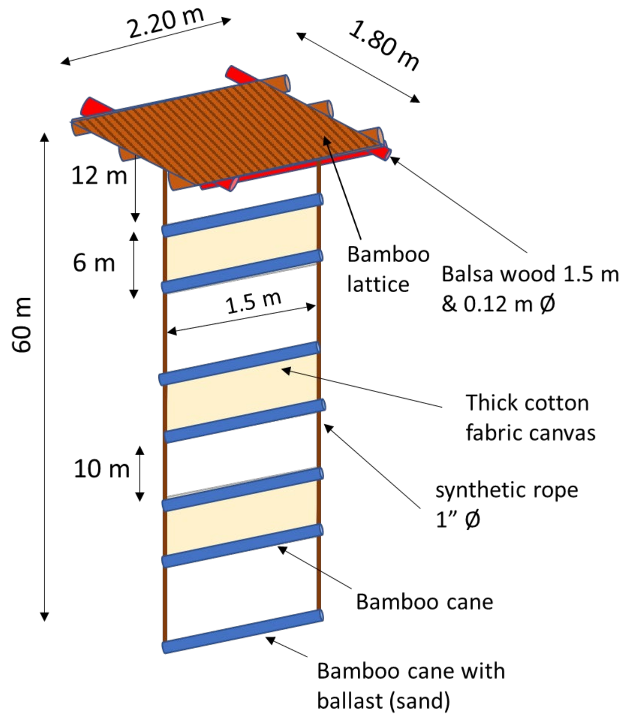


FIGURE 12. Additions and modifications to improve durability of Prototype 3. Note that synthetic rope will only be used in the last batch of deployments (still pending). Deployments of 3rd quarter of 2021 consisted of NEDs with a biodegradable cotton-based rope that was successfully used and implemented in other ocean regions by some vessels of the same fleet.

TABLE 1. Summary of NED and paired control FAD interactions.

	Deployments	Visits	Sets	Catch (mt)	Catch per set (mt)
NED – Prototype 1	114	5	8	488	61
NED – Prototype 2	392	73	46	1342	29.2
NED – Prototype 3	209	8	2	76	38
Total NEDs	715	86	56	1906	34
Paired control FAD	705	106	134	4177	31.2

TABLE 2. NEDs (N) and paired control FADs (T) that were deployed and set upon; Lon: longitude; Lat: latitude; mt: metric tons; Nm: nautical miles.

Tag Id	Deployment date	Set date	Deployment Lon	Deployment Lat	Set Lon	Set Lat	Tuna catch (mt)	Prototype	Set time apart (days)	Set distance apart (Nm)
N 1	9/18/2019	10/30/2019	-88	2	-88.13	2.28	5	2	5.0	352.7
T 1		11/4/2019	-87.85	1.93	-93.93	1.37	15			
N 2	12/3/2019	1/19/2020	-84.35	-9.22	-87.22	-7.35	50	2	90.2	86.6
T 2		4/18/2020	-84.2	-9.22	-86.97	-5.93	1			
N 3	1/10/2020	1/23/2020	-79.28	-11.87	-80.4	-13.32	0	2	21.0	190.6
T 3		2/13/2020	-79.45	-11.87	-79.28	-16.3	10			
N 4	6/12/2020	6/23/2020	-86.8	-5.38	-88.18	-6.7	55	2	18.0	76.3
T 4		7/11/2020	-86.92	-5.58	-89.08	-5.8	0			
N 5	3/13/2020	4/22/2020	-125.38	2.82	-128.18	5.82	35	2	86.9	393.9
T 5		7/18/2020	-125.63	2.83	-134.65	4.62	20			
N 6	8/1/2020	10/13/2020	-88.05	-2.02	-108.42	-5.83	207	2	9.0	166.8
T 6		10/22/2020	-88.03	-2.27	-111.2	-5.6	0			
N 7	5/13/2021	6/15/2021	-152.85	3.77	-151.27	3.32	15	1	2.0	30.7
T 7		6/17/2021	-152.93	3.8	-151.53	2.88	20			

TABLE 3. Comparisons between NEDs, and their associated tuna catch, and FADs or paired control FADs that were closely related in time and space. CPS: catch per set.

Group	Prototype	NED sets	FAD sets	Total sets	NED catch	FAD catch	Total catch	NED CPS	FAD CPS	CPS NED FADs rate	Year
1	2	1	5	6	5	8	13.0	5	1.6	3.1	2019
2	2	1	32	33	15	1239	1254	15.0	38.7	0.4	2019
3	2	1	8	9	19	353	372	19	44.1	0.4	2019
4	3	1	5	6	61	263	324	61	52.6	1.2	2019
5	1	2	6	8	1308	330	1638	654	55	11.9	2019
6	1	2	5	7	327	300	627	163.5	60	2.7	2020
7	2	2	6	8	43	619	662	21.5	103.2	0.2	2020
8	2	2	14	16	43	617	660	21.5	44.1	0.5	2020
9	2	1	5	6	70	296	366	70	59.2	1.2	2020
10	2	2	42	44	260	763.3	1023.3	130	18.2	7.2	2020
11	2	2	43	45	65	780.3	845.3	32.5	18.1	1.8	2020
12	2	1	8	9	2	43	45	2	5.4	0.4	2020
13	2	1	4	5	18	143	161	18	35.75	0.5	2020
14	2	1	8	9	14	288.01	302	14	36	0.4	2020
15	2	2	7	9	180	302	482	90	43.14	2.1	2020
16	2	2	4	6	45	62	107	22.5	15.5	1.5	2020
17	2	4	10	14	1884	642	2526	471	64.2	7.3	2020
18	2	3	11	14	212	550	762	70.7	50	1.4	2020
19	2	1	5	6	2	187	189	2	37.4	0.1	2020
20	2	1	5	6	14	223	237	14	44.6	0.3	2020
21	2	4	7	11	232	396	628	58	56.6	1	2020
22	2	1	5	6	15	193	208	15	38.6	0.4	2020
23	1	1	4	5	30	127	157	30	31.8	0.9	2021
24	2	1	6	7	5	88	93	5	14.7	0.3	2021
25	2	1	18	19	25	741	766	25	41.2	0.6	2021

TABLE 4. Comparisons between paired FADs, and their associated tuna catch, and FADs or paired control FADs that were closely related in time and space. CPS: catch per set

Group	Paired sets	FAD sets	Total sets	Paired catch	FAD catch	Total catch	Paired CPS	FAD CPS	CPS Paired FADs rate	Year
1	1	4	5	10	55	65	10	13.8	0.7	2019
2	1	29	30	15	1194	1209	15	41.2	0.4	2019
3	1	21	22	7	613.3	620.3	7	29.2	0.2	2019
4	1	13	14	10	446	456	10	34.3	0.3	2019
5	1	4	5	30	145	175	30	36.3	0.8	2019
6	1	8	9	35	255	290	35	31.9	1.1	2020
7	1	5	6	25	162.0	187.0	25	32.4	0.8	2020
8	2	5	7	524	66	590	262	13.2	19.8	2020
9	2	4	6	131	34	165	65.5	8.5	7.7	2020
10	2	10	12	76	359.5	435.5	38	36.0	1.1	2020
11	2	11	13	19	192.6	211.6	9.5	17.5	0.5	2020
12	1	4	5	5	66	71	5	16.5	0.3	2020
13	1	8	9	10	269.8	279.8	10	33.7	0.3	2020
14	1	4	5	10.14	45.2	55	10.1	11.3	0.9	2020
15	1	6	7	105	29	134	105.0	4.9	21.5	2020
16	1	7	8	43	920.6	963.6	43	131.5	0.3	2020
17	1	5	6	140	320	460	140	64.0	2.2	2020
18	1	7	8	30	233.4	263.4	30.0	33.3	0.9	2020
19	1	6	7	110	247	357	110	41.2	2.7	2020
20	1	4	5	25	128	153	25	32.0	0.8	2020
21	2	6	8	135	171.0	306.0	67.5	28.5	2.4	2020
22	2	4	6	172	534	706	86.0	133.5	0.6	2020
23	2	4	6	43	228	271	21.5	57.0	0.4	2020
24	1	12	13	4	262	266	4.0	21.8	0.2	2020
25	1	16	17	28	500	528	28.0	31.3	0.9	2020
26	1	13	14	3	196	199	3	15.1	0.2	2021
27	1	5	6	10	215	225	10	43.0	0.2	2021
28	2	10	12	84	733.0	817.0	42	73.3	0.6	2021
29	2	9	11	136	544	680	68.0	60.4	1.1	2021
30	2	22	24	84	1101	1185	42.0	50.0	0.8	2021
31	2	8	10	136	573	709	68.0	71.6	0.9	2021
32	1	4	5	18	50.0	68.0	18.0	12.5	1.4	2021
33	2	10	12	260	211	471	130.0	21.1	6.2	2021
34	2	12	14	65	331	396	32.5	27.6	1.2	2021
35	1	6	7	35	156	191	35.0	26.0	1.3	2021
36	1	9	10	34	396	430	34.0	44.0	0.8	2021

TABLE 5. Average of the NED condition based on soak time. N: number of prototypes in each category of soak time. 0: Not observed; 1: Excellent; 2: Very good; 3: Good; 4: Regular; 5: Poor, and 6: Very Poor. NA: A NED that is not composed of a specific material (e.g., the submerged canvas of prototype 1), or the NED or some of the components were lost and only the satellite buoy was found (e.g., '>90' soak time of prototype 3).

			I---------------- Floating component ----------------I				I--------------------- Submerged component ---------------------I				
Soak time (days)	Prototype	N	Bamboo	Canvas	Balsa	Tightening rope	Canvas	Main rope	Tightening rope	Bamboo	Bamboo (ballast)
1-30	1	4	1.8	1.8	1.2	1.2	NA	1.8	1.7	1.3	1.8
31-60	1	4	1.5	1.8	1.2	1.8	NA	2.5	1.5	1.3	1.5
61-90	1	3	2.9	3.8	2.1	2.2	NA	3.5	2.5	1	2.9
>90	1	1	3	3	2	1	NA	3	3	NA	3
1-30	2	63	1.6	1.9	1.6	1.8	1.8	1.9	1.9	1.6	1.6
31-60	2	34	1.9	2.1	2	2.1	2.2	2.3	2.1	2.1	2.1
61-90	2	12	2.2	3.4	2.4	2.6	3.4	3.6	3.3	3.2	3.4
>90	2	2	4.5	6	4.5	5	6	6	6	6	6
1-30	3	2	4	4.5	1.5	4.2	3	2.8	3	3	3
31-60	3	4	2.2	5.6	2.8	2.9	5.2	4.4	5.2	5.2	5.2
61-90	3	1	5	NA	1	5	3	3	3	3	3
>90	3	2	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 6. Total soak time of experimental FADs between first deployment and last removal or last encounter. N: number of NEDs or FADs; Min: minimum; Max: maximum; Q: quantile.

Experimental FAD	N	Min Soak time (days)	Max soak time (days)	Average (days)	Q (.25)	Q (.5) (median)	Q (.75)
NED - Prototype 1	12	33	139	62	35.5	50	71
NED - Prototype 2	111	1	244	43.6	23.5	39	57.5
NED - Prototype 3	9	40	94	66.9	48.5	59	89
Paired control FAD	213	1	425	87.4	38	68	119