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TESTING BIODEGRADABLE MATERIALS AND PROTOTYPES FOR THE TROPICAL TUNA FISHERY ON FADs

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1. SUMMARY

The purse-seine FAD fishery is currently the most important way to capture tropical tunas in the EPO. FADs are a very efficient way of fishing; yet, as most fishing methods, they may also have negative effects on species and ecosystems, such as entanglement of sensitive species, contribution to marine debris and pollution or stranding events in vulnerable habitats. To address these potential effects, the IATTC staff was required to present recommendations based on science that would help in 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 both a controlled (phase 1) and real-fishing conditions (phase 2). Phase 1 provided information on the selection of biodegradable materials to be used in the construction of three different prototypes in phase 2. Phase 2's work plan included several activities, including the design of prototypes (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

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FADs, as well as the data collection and analysis. 379 NEDs (56 prototype 1; 255 prototype 2; 68 prototype 3) have been deployed. Similar values in catch per set (NEDs = 27.7 t/set, paired control FADs = 26 t/set; Table 1) were observed. Prototype 2 showed a very good condition with two months of soak time. Prototype 1 showed a poor condition in the submerged rope, but the rest of materials appeared in good condition after two months at sea. Prototype 3 was the NED design with the least durability observed. The future actions, challenges and solutions of the project as well as ways to engage with the industry and fishers to obtain feedback and guarantee the correct functioning of the project are described as well.

2. INTRODUCTION

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

FADs are typically constructed in two parts; a surface and a submerged part. The surface component provides the flotation to the FAD, and traditionally has been built of bamboo wrapped in old recycled fishing nets, with the addition of plastic floats or PVC frames to increase floatability (Hall and Román 2013). The surface component is usually constructed with dark colored materials that prevent detection by other vessels, and is expected to keep the FAD afloat for several months; usually 6-12 months, although it is dependent on the area. In some regions the fishing season is limited to 4-5 months (e.g. Peru) and FADs lasting 6 months will suffice, whereas in other regions (around 110W), many fishers would prefer FADs that last 12 months or more.

The submerged components are materials that hang in the water column, and frequently include old fishing nets or other webbing material. The underwater part is believed to increase the attraction power of the object and impact drifting speeds (Minami *et al.* 2007; Satoh *et al.* 2007; Lennert-Cody *et al.* 2008; Hall and Román 2013). This component can be very deep, and seems to be increasing in more recent years, particularly in some areas of the EPO, reaching from 70 to 90 meters (FAD-05-INF-A) (most commonly 30-40 meters (Franco *et al.* 2012; Hall and Román 2013)).

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

FADs may also have additional negative impacts on the ecosystem, such as producing higher rates of bycatch and catches of juveniles of some tuna species. However, conservation measures for tropical tunas exist (e.g. Resolution C-17-02) and the staff is conducting several projects to try to reduce the impact in this area (SSP-Staff activities report). Examples are the experiments on the effectiveness of sorting grids (Document IATTC-94-04; Project M.1.b), and the dynamic ocean management project (SAC-10 INF, Project J.2.a).

However, initiatives assessing and reducing the impacts of using non-biodegradable FADs are more recent in general, both locally and globally. For example, first attempts of producing non-entangling objects happened in the Indian Ocean and consisted in a submerged tubular structure made of synthetic sailcloth (Delgado de Molina *et al*. 2006). Later in 2012, Dagorn *et al.* suggested FAD designs using non-netting materials for the submerged part (e.g. ropes), or by rolling the netting into sausage-like bundles, in order to reduce shark entanglement. Despite IATTC observers' records which indicate shark entanglements seldom occur in the EPO, no specific experiment has been conducted to date to quantify these events. On the other hand, turtle entanglement in FADs have been frequently recorded by observers, although mortality rates are negligible and the crew is required to release them alive when possible (see Resolution C-03-08 and C-07-03). In 2013, RFMOs started to test experimental FAD designs that prevent both turtle and shark entanglements, as well as minimize environmental impacts generated by pollutant and non-degradable debris (ICCAT-13-01; IOTC-13/08; IATTC C-13-04). Very recently, several regional initiatives have been conducted, or are still in place, to test biodegradable FADs at large scale and regular working conditions (ISSF 2020). For example, in the EPO, TUNACONS developed trials with natural fibers in controlled conditions, and tested 66 FADs in real-fishing conditions (TUNACONS, 2018). An EU consortium has deployed around 1000 FADs in the Indian Ocean, and other initiatives are in place in the Atlantic, Western and Central Pacific Oceans (Zudaire *et al*. 2018; Moreno *et al*. 2018c; ISSF 2020).

In terms of materials, bamboo has always been identified as one of the main alternatives for an eco-friendly surface structure, as it is preferred by the fishermen (Hall and Román 2013). It's abundant worldwide and non-pollutant, and its durability at sea could be enhanced through natural treatments (Razak *et al.* 2005; 2008). As for the submerged component, several vegetal fibers distributed world-wide 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. 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). Notwithstanding the efforts to release animals entangled in FADs, or the promising potential shown by some degradable and non-entangling materials, Although some important initiatives on testing with natural materials started being conducted in the EPO (TUNACONS, 2018); however, no large-scale trials with FAD designs entirely using bamboo, cotton, abaca or other degradable materials to prevent entanglement and generation of marine debris have been conducted up to date in the EPO.

In 2015, and following Resolution C-15-03, the IATTC staff was required to present, no later than July 2019, 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 experiments with biodegradable non-entangling FADs. Funds for the first project (Phase 1) were granted on July 2015, and funds for the second project (Phase 2) on December 2017.

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

Phase 1, conducted in 2016-2017, tested non-entangling and biodegradable materials (NEDs) and designs under controlled conditions at the Achotines laboratory in Panama in a three-replica experiment. Three NEDs prototypes were constructed, all of them using 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 depth=20.4m x length=3.0m x width=1.0 m. 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. The unexpected adverse sea conditions in Achotines led us to conduct an additional test in a calmer sea mode, where another three-replica experiment was deployed. However, designs were slightly modified: two prototypes with the same floating component and two different submerged components were used, one 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 compared with the previous prototype to avoid early tearing (Figure 1-C). The deployment and monitoring protocols remained the same. Results showed that prototype 4 had the maximum time observed afloat (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 and the Tuna Conservation Group (TUNACONS) in October 2017, with the participation of fisheries organizations from other oceans, other stakeholders and fishers to discuss results of Phase 1 and the potential use of new materials tested in independent experiments carried out by the fleet and other initiatives around the globe to be tested in real-fishing conditions. The participants of the workshop agreed that some materials tested in Phase 1, like bamboo and cotton canvas must be considered for real-condition experiments, 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 to 12 months. As a result, a series of NED designs were developed and agreed between companies and fishers participating in Phase 2 (see below for details), where experimental NEDs were to be tested in real-fishing conditions.

2.2. Phase 2: large-scale testing of non-entangling and degradable prototypes in real fishing conditions

The Phase 1 work in Panama, along with other initiatives conducted in other oceans, provided several lessons for effective NED designs, and were well received by fishers and stakeholders. However, progress on obtaining proper biodegradable materials for NEDs in real fishing conditions has been slower and a global issue. For that reason, additional funds were received from the EU (EU Grant 7592) to conduct a second phase focused on a large-scale test of degradable materials and prototypes in conjunction with the fleet.

The designs for the surface and submerged components were agreed upon after some discussion, with development of effective flotation being one of the critical points along with use of biodegradable materials that retain the non-entangling characteristics. Ideally, NEDs should stay afloat and robust up to a year, but a duration of 6 months may still be useful for some fleets and areas. Besides durability, NEDs were designed considering certain criteria to increase acceptance by the industry, such as only using materials of reasonable cost, high availability in the market, and easy to manipulate on board. To be implemented at a large scale, NEDs should also be attractive for tunas and have, if possible, similar drifting patterns as traditional FADs.

Although Phase 1 failed to produce appropriate durability results, it provided information on different materials. As a result, 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 become the predominant choice in Phase 2. Phase 1 also helped eliminate the idea among fishers that nylon is the best and only choice for FADs to attract tunas. Fishers seem to have slowly become more open to trying alternative materials and designs. Phase 2 aims to facilitate and make this conversation possible, empirically proving the suitability of using other eco-friendlier 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. OBJECTIVES

The objective of phase 2 is to develop and test at large scale and under real fishing conditions:

- NEDs with a useful life of at least 6 to 12 months that will degrade without being harmful to the environment.
- Maintenance of the 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. Definition of prototypes for testing

Although the inter-regional workshop provided solid guidelines on the use of designs and materials for NEDs construction, additional options had to be explored to improve flotation and material preservation, particularly potential treatments for bamboo and abaca/cotton canvas. A local project coordinator-technician was hired to assure the correct functioning of the program, including information sharing 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 personal interviews and other forms of communication were conducted with the actors involved in the project to promote the exchange of ideas on flotation and antifouling. 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 the previous information, as well as outputs from other similar initiatives around the world (Moreno and Restrepo 2018; Moreno *et al*. 2018a,b; Zudaire *et al*. 2018) three definitive NED prototypes were chosen for testing (Figure 2). NED prototypes 1 and 2 have abaca as the main natural fiber component, whereas prototype 3 has cotton as the main natural fiber component (See Figure 2 for details on prototypes dimensions and components).

4.2. Identification of companies and vessels willing to collaborate

TUNACONS and the Association of Large Tuna Freezers (AGAC) are two tuna fishing organizations that are comprised of five and nine groups of companies, respectively. Vessels from both groups (TUNACONS, 31; AGAC, 14) expressed interest in participating in the experiment. Both fishing organizations have clearly committed to the project through detailed MoU's signed on December 2018 where responsibilities for all participants, including the 45 participating vessels, companies and fishing crews were described. The selection of the type of NED to be used by each vessel was left to each company, but balance between prototypes was recommended by the IATTC staff to maintain a good experimental design. As such, and responding to the higher number of vessels in each fishing organization, prototype 1 and 2 were exclusively selected by TUNACONS whereas prototype 3 was selected by AGAC.

4.3. Construction of experimental floating objects

Identification of NED constructors and suppliers of materials for the three prototypes (Figure 2) is key for obtaining standardized NED units. To avoid quality and technical property differences of materials, they were obtained from suppliers selected by the participating organizations (AGAC, TUNACONS), before approval by the IATTC staff. Similarly, NEDs are being constructed in a unique place per prototype to assure, as much as possible, the standardization of the experimental objects. In order to adjust with the budget while maximizing the total number of samples, the participating organizations agreed to cover half of the costs of the materials for the NEDs (see Figure 3 for details) and the totality of the paired traditional control FADs and the electronic equipment associated to them (e.g. satellite-linked echo-sounder buoys and the associated connection and data transfer fees), which covers approximately 85% of this cost (assuming $1,000 USD per NED buoy, and $15 USD/mo. for 1-year transmission fee). To avoid deterioration of NEDs by prolonged time storage, construction and delivery will be conducted quarterly. The purchasing, material acquisition and experimental object construction strategies were negotiated and agreed to by both fishing organizations independently, each with specific needs and requirements due to logistic differences (Figure. 2).

4.4. Experimental design

The determination of the total number of prototypes per vessel, season and total for the project was a result of optimizing the budget to restrict external funding and effort to reasonable levels while constructing the maximum number of experimental objects that would preserve the statistical needs of the project, particularly considering 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), as follows:

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

NEDs will be accompanied by deployments of one traditional control FAD within 10-15 miles. All experimental floating objects will be deployed with satellite buoys and colored metallic tags with specific serial numbers in both the raft and the buoys (Green N-0001 to N-0796 tags for the NEDs; Red T-0001 to T-0796 for the traditional FADs), and the codes provided to the observer for tracking and monitoring.

The area of deployment will be selected by the vessel owner or the skipper, always east of 130°W. The IATTC staff encourages minimal experimental object redeployments but is aware of seasonality and the regular fishing practices of the fleet. As such, in certain occasions (e.g. Peru season, experimental objects leaving the fishing ground), vessels would be allowed to retrieve the object 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 to with participants. While a vessel is observing a closure, its deployments may be made by other vessels of the same company, as long as the deployed experimental floating objects, as well as their associated metallic tags and satellite buoys, belong 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 the time of potential interaction 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 or plates with specific alphanumeric codes that attach to both the floating object and the associated buoy. Guidelines and visual material were produced to show observers and project participants 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 satellite buoy make and model as the NED, for consistency and to allow easy comparisons. When satellite buoys are changed after an interaction with the objects, the staff requested to use, whenever possible, the same brand and model of satellite buoy. Likewise, metallic tags in the buoys and the object should always match, meaning that any buoy replacement should be accompanied by a subsequent tag replacement.

Dedicated data collection forms (ROF-C; Figure 4, see details below) and instructions were created for observers and, in the cases of observer absence, for skippers and fishing crew (NPR-TS; Figure 5). A specific email address was also created to receive the project's data collection and questions from participants. Stakeholders and fishing organizations also received the documentation and visual material with the methodology, objectives, expectations and responsibilities of the participants of the project, so that they could become familiar and involved with the protocol and project's needs. Similarly, observers were trained by the local coordinator and other field offices personnel. Workshops are regularly conducted with skippers to inform them on the development of the project and to respond to any inquiry they may have regarding the functioning of the project, including key concepts on the monitoring and tracking of experimental objects. 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 elements over time for both the floating and submerged structure of the NED is collected on a dedicated form (ROF-C; Figure 4). 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 note in the form when a specific component of the NED has been replaced. Each NED recorded in the ROF-C form is unique through the combination of the following attributes: the ID number of the trip, the ID number of the floating object, and the number of the interaction upon the object. This set of attributes is also recorded in the main flotsam observer form (ROF; Figure 6), and hence it's used to link both forms in the database. The regular ROF is used to obtain specific NED data not included in the ROF-C, for example: date, time and the location of the NED interaction (i.e. deployments, visits, sets, removals, etc.), information on NED origin (i.e. vessel-owned NED, NED from a different vessel, etc.), information of target and non-target species catch, and information related to the satellite buoy identification code. All of the data is incorporated into the database once the fishing trip is finished and the debriefing with the observer conducted.

Although infrequent, in cases where the observer was not present on board to collect the NED information, 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. This information should be sent 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 is checked for potential errors with dedicated routines.

The information collected by observers from national observer programs has historically been submitted to the IATTC once a year, which would cause significant delays in the data collection of the project and prevent complete 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 (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 will improve final quantitative comparisons of experimental objects by period and area. All of the information on the paired control FAD is recorded on the conventional flotsam form only (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 collected in the project for both the NEDs and control FADs (as detailed in the agreements signed with both fishing organizations on this matter). 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 will be stored in a local database in 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 Resolution C-17-02, for example.

5. DATA ANALYSIS

5.1. Activities on experimental objects

Object interactions like deployments, re-deployments, the visits with no set involved (hereafter named "visits") and the visits leading to a set (hereafter named "sets") were analyzed to better understand the spatial distribution and frequency of interactions on NEDs by prototype and the paired control FADs.

5.2. Catch per set

Similarly, the catch per set (amount of total tuna per set, in metric tons; t) of NEDs by prototype was compared with 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 considered for analysis. In terms of spatial constraints, only sets on FADs conducted within a radius of 1-degree 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, the total tuna catch was summed up and considered as a single set/catch, so as not to affect the catch per set of the object. Sometimes, fishers set multiple times on a FAD, even in consecutive days, to make sure the whole tuna aggregation is captured. Tuna aggregations are known to exhibit short periods of residence times, which happen at different frequencies and time of day 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 periods of residence of bigeye tunas in the EPO (2-3 days) with previous events lasting up to 24 days. In the Atlantic Ocean, studies analyzing tuna association dynamics 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 at about 6 days using echo-sounder buoys. To account for the variability in residence times, in this study, and as a conservative measure, the catch was added up and considered as a single set/catch for sets on the same FAD no more than two days apart. The same methodology was applied to conduct the catch per set comparisons between paired control FADs and surrounding FADs. Besides catch per set, the number of days between set and deployment was also 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 (i.e. sets, visits) was estimated, and the condition values recorded by the observers for the different components of the floating and submerged parts extracted and analyzed for each prototype. Because most of NED interactions in our database happened in a range of 1-90 days, the soak time was grouped into three different categories: 1-30 days; 31-60 days; and 60-90 days. Condition values for each element of the NED were averaged for each period of time. Minimum, average and maximum recorded soak times per prototype were also estimated.

As a general observation, activity and catch per set analysis of 2019 data include the observer data from both the IATTC and national observer programs, while analysis of 2020 data are 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 third quarter of 2019. By 25 May 2020, a total of 379 NEDs (56 prototype 1; 255 prototype 2; 68 prototype 3) and 373 paired control FADs were deployed (Table 1). Prototype 2 showed a broader distribution in the EPO (75°W-130°W in longitude; 7°N-17°S in latitude), with a greater number of activities near the American continent and Galapagos Islands (Figure 7). NED prototype 3 showed an extensive distribution too, but only in longitudes east of 90°W, whereas NED prototype 1 showed a more restricted distribution both in longitude and latitude, also in the western part of the EPO (118°W-133°W longitude; 0°-6°N latitude; Figure 7).

Redeployments seem to happen rarely (2% of the deployments for NEDs, 7 cases; >1% for paired control FADs; 3 cases), most of them being prototype 2 (6 cases). A total of 49 visits (prototype 1 = 1; prototype 2 = 43; prototype 3 = 5), and 21 sets (prototype 1 = 1, prototype 2 = 19, prototype 3 = 1; Table 1; Figure 7) were conducted on NEDs in the study period whereas paired control FADs were visited and set 53 and 36 times, respectively (Table 1).

6.2. Catch per set

A total of 582 t of tuna was caught in the 21 sets made on NEDs (27.7 t/set), whereas a total of 936 t were caught in 36 sets on the paired control FADs (26 t/set; Table 1). Both showed values similar to traditional object catch-per-set (FAD-05-INF-A).

Only one matching pair of NED and paired control FAD was set upon, although they were not closely related in terms of time and space to allow direct comparisons (Figure 8). As such, group comparisons with other objects in a specific spatial-temporal window were considered (see data analysis section for details) (Figure 9). The catch per set ratios of the NEDs versus the FAD ranged from 0.4 to 3.9 (7 groups, avg = 1.9; median = 1.2; Table 2). Similarly, the catch per set ratios of the paired control FADs versus the FAD ranged from 0.1 to 21.5 (12 groups, avg = 2.7; median = 0.7; Table 3).

6.3. Condition of NEDs

Table 4 summarizes the condition of the components of the three NED prototypes with respect to the different time periods considered. Prototype 1 was only observed twice. Aside from the poor condition in the submerged main rope, the rest of the materials seem to be in very good condition after two months at sea. Prototype 2 was observed 59 times, and its components showed, in general, a very good condition with two months of soak time. Prototype 3, alternately, was the NED design with the least durability so far. The majority of materials were in very poor condition or disappeared within two months of deployment.

Point to note, the 'NA' code represents different meanings; either a prototype 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 just the satellite buoy was found (e.g. prototype 3, and the '>60' soak time period for prototype 2).

Regarding time at sea, Table 5 shows the minimum, maximum and average time at sea for the experimental FADs that were set upon. For NED prototype 1, the soak time fluctuated between 36 and 62 days, with an average of 49 days . Prototype 2 records ranged between 6 and 92 days, with an average of 35.6 days, and for prototype 3 it was between 16 and 94 days, with an average of 51 days adrift after deployment. The soak time values for the paired control FADs ranged between 1 and 243 days, with an average of 57.7 days.

7. DISSEMINATION-FEEDBACK OF THE PROJECT

Industry and fishers' engagement and feedback is key for the success of the project. Familiarization with the objectives and methodology of the project and its dynamics is important to ensure NED designs are preserved and the proper use of metallic tags, among others, well understood. As such, visual materials (i.e. posters) describing the most important functional matters of the project are delivered and shared with vessel participants and non-participants (Figure 10). In this regard, the response of the fleet has been positive. For example, some fishers send the date, location and pictures of NEDs they have encountered, which allows to cross-check the observer data once the trip is finished. 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. With the intent to maintain a close and constant relationship with the fleet, fishers from the two organizations are also regularly given project updates through workshops in Manta and Posorja, Ecuador. To date, all the actors provided useful feedback and expressed a full commitment to the project.

8. CHALLENGES ENCOUNTERED IN THE PROJECT

The pandemic situation which broke out during the first quarter of 2020 adversely affected the work dynamic of this project. For example, collecting new data has been more difficult due to logistic concerns, as has been the acquisition of material to construct new NEDs. Customs and borders have been closed and international and national shipments and travels have been restricted. This caused delays in the manufacturing, shipping and reception of material, and ultimately on NED construction and deployments. However, restrictions and regulations seem to be relaxing, and NED construction has been gradually reactivated.

Although, in general, NEDs of prototype 2 have performed reasonably well, some concerns were raised by participants during the testing of the other prototypes in the first quarter. For example, the fishing crew noted a potential weak connection between the submerged component and the floating component in Prototype 1. In this case, a slight modification was agreed upon to reduce the potential loss of the submerged component, with the addition of two nylon ropes running independently and in parallel to each abaca braided rope. The tying and hanging should, however, be made in a way that will not compromise the performance of the abaca ropes. Similarly, Prototype 3 reported problems associated with the cotton canvas, likely due to the poor quality of the material used. Prototype 3 NEDs deployed in the first quarter seem to break apart, particularly the floating component, which increases the chances of satellite buoy disconnection from the object. Based on the experiments conducted during phase 1 of the project, where the cotton canvas lasted at sea an average of 53.3 days in reasonable conditions, the IATTC staff recommended and agreed with the participants to increase the quality and thickness of the cotton for future NEDs. Additional small modifications that preserve flotation and strengthen the connection between the submerged and the surface components could be applied to Prototype 3 without significantly altering its design (e.g. treatment of cotton with natural products, the addition of small synthetic ropes to ensure cohesion in specific parts, increase in the amount of balsa wood). The staff is already discussing alternative options with some participants to potentially replace/modify Prototype 3 significantly in the future in case the proposed changes also fail.

9. FUTURE WORK

The IATTC scientific staff will continue coordinating with participants on NED construction, discussing and finding solutions where necessary and providing the necessary support to ensure the proper functioning of the project. As such, and as mentioned above, the staff will continue in the search for improved materials and designs which will extend the durability of the NEDs at sea, in general, but especially for the cotton material. Similarly, dissemination and information exchange workshops with fishers are expected to be held in 2020 and 2021, if allowed with the Covid-19 situation. Finally, the IATTC scientific staff will maintain coordination with the national observer programs to obtain the information on the experimental FADs in a timely manner.

The IATTC staff also aims to collect and analyze trajectories and biomass records of the echo-sounder buoys for the SAC in 2021, while exploring the use of additional observer data (e.g. catches of target and non-target species caught in association with NEDs and regular FADs within specific spatio-temporal windows) to better understand prototypes' performance and efficiency. Statistical tests and models will be conducted to analyze in a more detailed way experimental objects' durability, condition, biomass aggregation and colonization processes, as well as trajectory and drifting patterns. Understanding all of these elements is key for a more efficient implementation and adoption of non-entangling degradable FADs by fishing the industry, stakeholders, and policy makers.

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1 Tables

	Deployed	Visits	Sets	Catch (t)	Catch per set (t)
NED – Prototype 1	56	1	1	43	43
NED – Prototype 2	255	43	19	478	25.2
NED – Prototype 3	68	5	1	61	61
Total NEDs	379	49	21	582	27.7
Paired control FAD	373	53	36	936	26

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

Group	Prototype (group)	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	3	2	5	178	95	273	59.3	47.5	1.2	2019
3	2	1	32	33	15	1239	1254	15	38.7	0.4	2019
4	2	1	8	9	19	353	372	19	44.1	0.4	2019
5	3	1	5	6	61	263	324	61	52.6	1.2	2019
6	2	1	2	3	53	27	80	53	13.5	3.9	2020
7	2	1	3	4	70	76	146	70	25.3	2.8	2020

Table 2. Comparisons of NEDs with tuna catch from FADs or paired control FADs closely related in time and space.

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	3	4	20	70	90	20	23.3	0.9	2019
5	1	13	14	10	446	456	10	34.3	0.3	2019
6	1	3	4	83	41	124	83	13.7	6.1	2019
7	1	4	5	10	60	70	10	15	0.7	2019
8	1	2	3	4	106	110	4	53	0.1	2020
9	1	4	5	30	145	175	30	36.3	0.8	2020
10	1	3	4	10.1	42.2	52.4	10.1	14.1	0.7	2020
11	1	6	7	105	29.3	134.3	105	4.9	21.5	2020
12	1	2	3	29	87	116	29	43.5	0.7	2020
13	3	2	5	241	87	328	80.3	43.5	1.8	2020

Table 3. Comparisons of paired FADs with tuna catch from FADs or paired control FADs closely related in time and space.

Soak time (days)	Prototype	N	Floating component: Bamboo	Floating component: Canvas	Floating component: Balsa	Floating component: Tightening rope	Submerged component: Canvas	Submerged component: Main rope	Submerged component: Tightening rope	Submerged component: Bamboo	Submerged component: Bamboo (ballast)
1-30	1	No data	No data	No data	No data	No data	NA	No data	No data	No data	No data
31-60	1	1	1	2	1	2	NA	1	2	1	0
>60	1	1	1	2	1	2	NA	5	2	1	1
1-30	2	24	1.6	1.7	1.6	1.7	1.5	1.6	1.7	1.4	1.4
31-60	2	29	2.1	2.2	2.2	2.2	2.6	2.8	2.5	2.6	2.4
>60	2	6	2.3	3.3	2.3	2.5	2	1.5	1.5	2	3
1-30	3	1	3	3	2	3	NA	NA	NA	NA	NA
31-60	3	4	2.2	6	2.8	3	6	5	6	6	6
>60	3	1	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4. Condition of the NED according to soak time. 0: No 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. the prototype 3, and the '>60' soak time period in prototype 2).

Experimental FAD	N	Min soak time (days)	Max soak time (days)	Average (days)
NED-Prototype 1	2	36	62	49
NED-Prototype 2	59	6	92	35.6
NED-Prototype 3	6	16	94	51
Paired control FAD	78	1	243	57.7

Table 5. Experimental FADs soak time between first deployment and set.

2 Figures

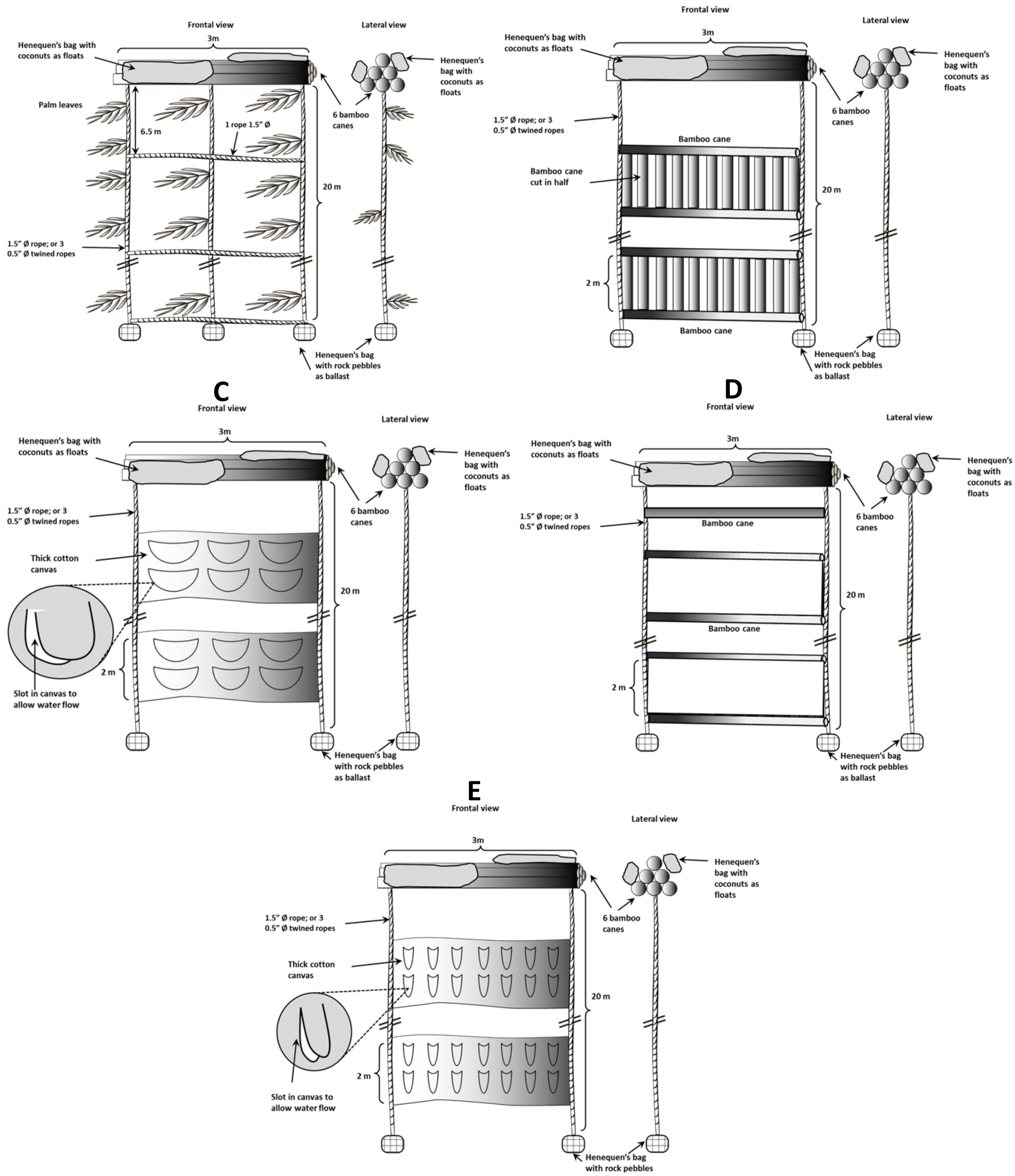


Figure 1: Prototypes 1(A) to 5 (E) used for phase one (EU grant 7592).

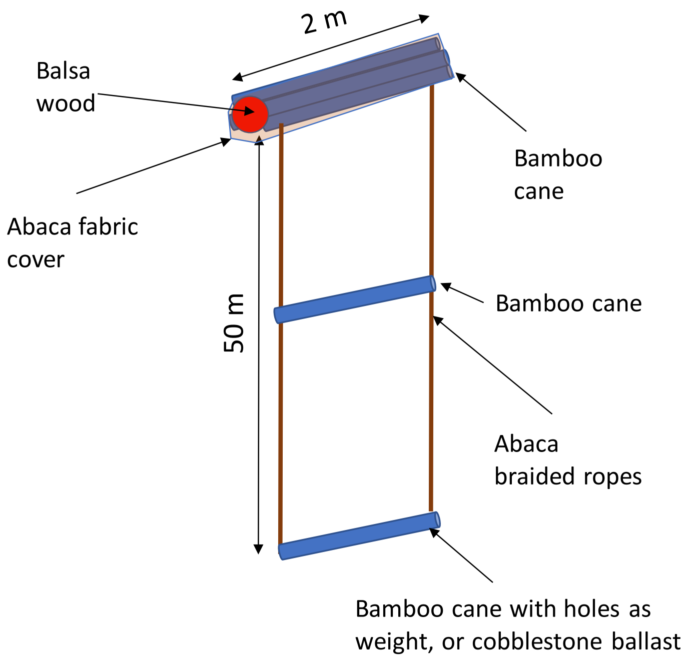


Figure 2a. NED prototype 1.

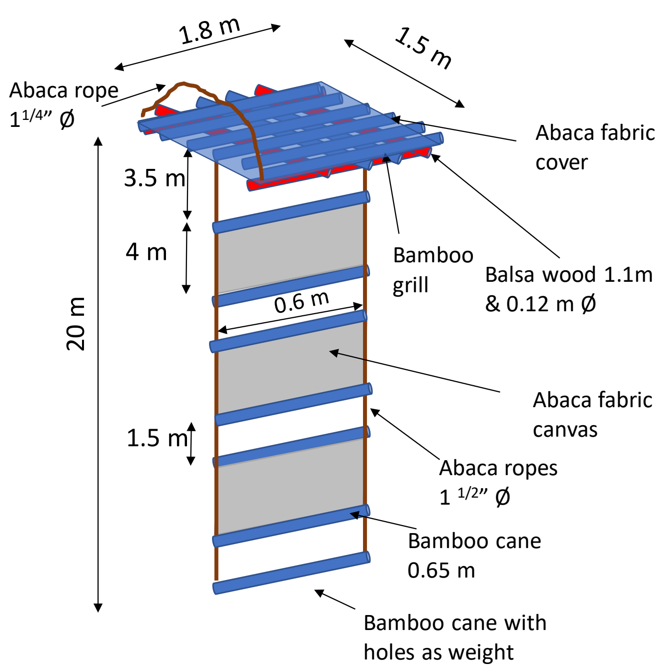


Figure 2b. NED prototype 2.

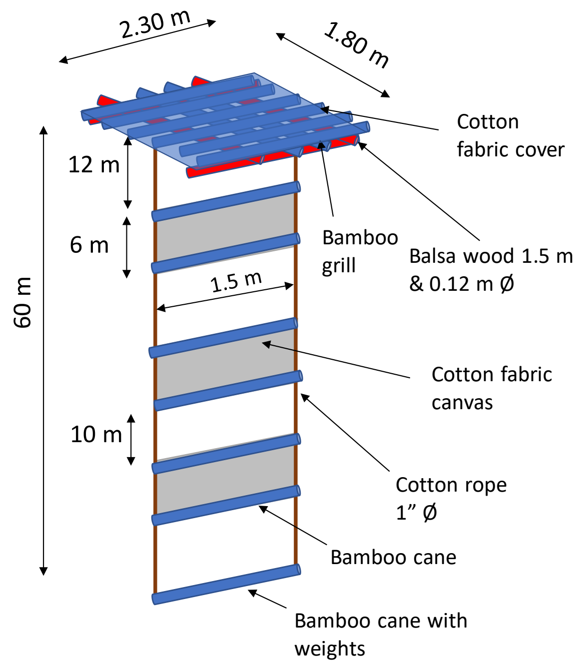


Figure 2c. NED prototype 3.

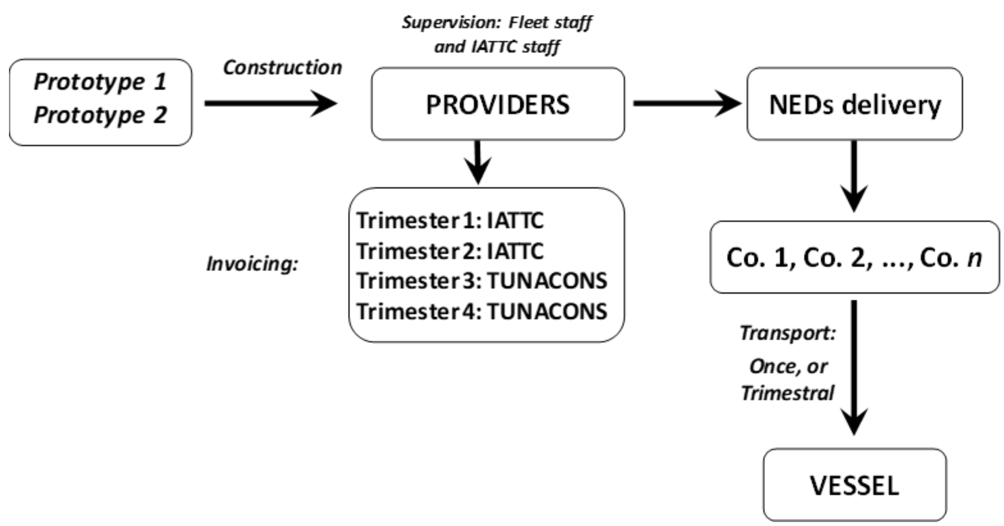


Figure 3a. Construction and payment options map of NEDs used by TUNACONS.

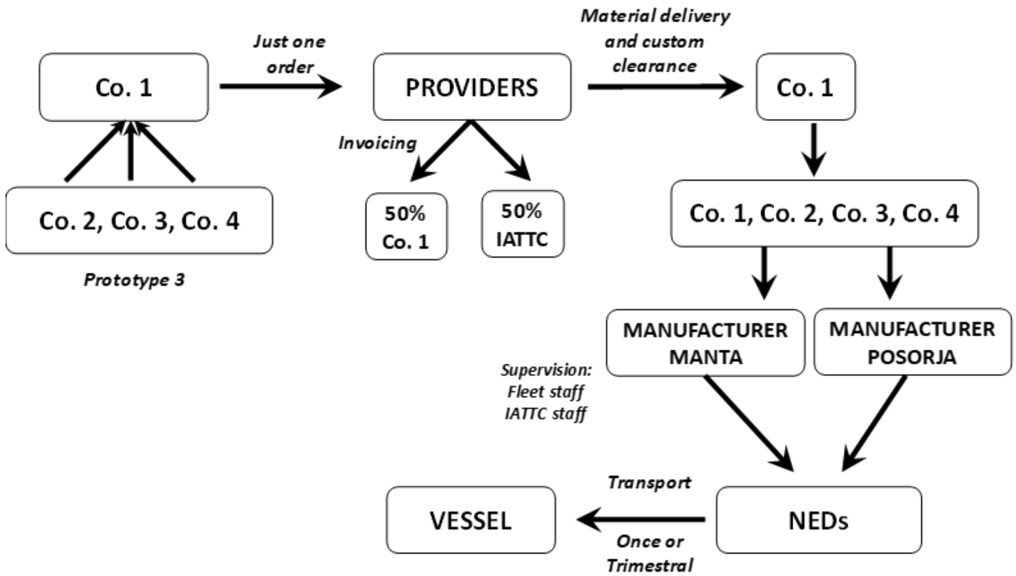


Figure 3b. Construction and payment options map of NEDs used by AGAC.

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 4. 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:	

	NED floating structure (Raft)	Condition	Replaced?	NED underwater structure (Tail)	Condition	Replaced?
Lifted: Yes [ ] No [ ]						
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.

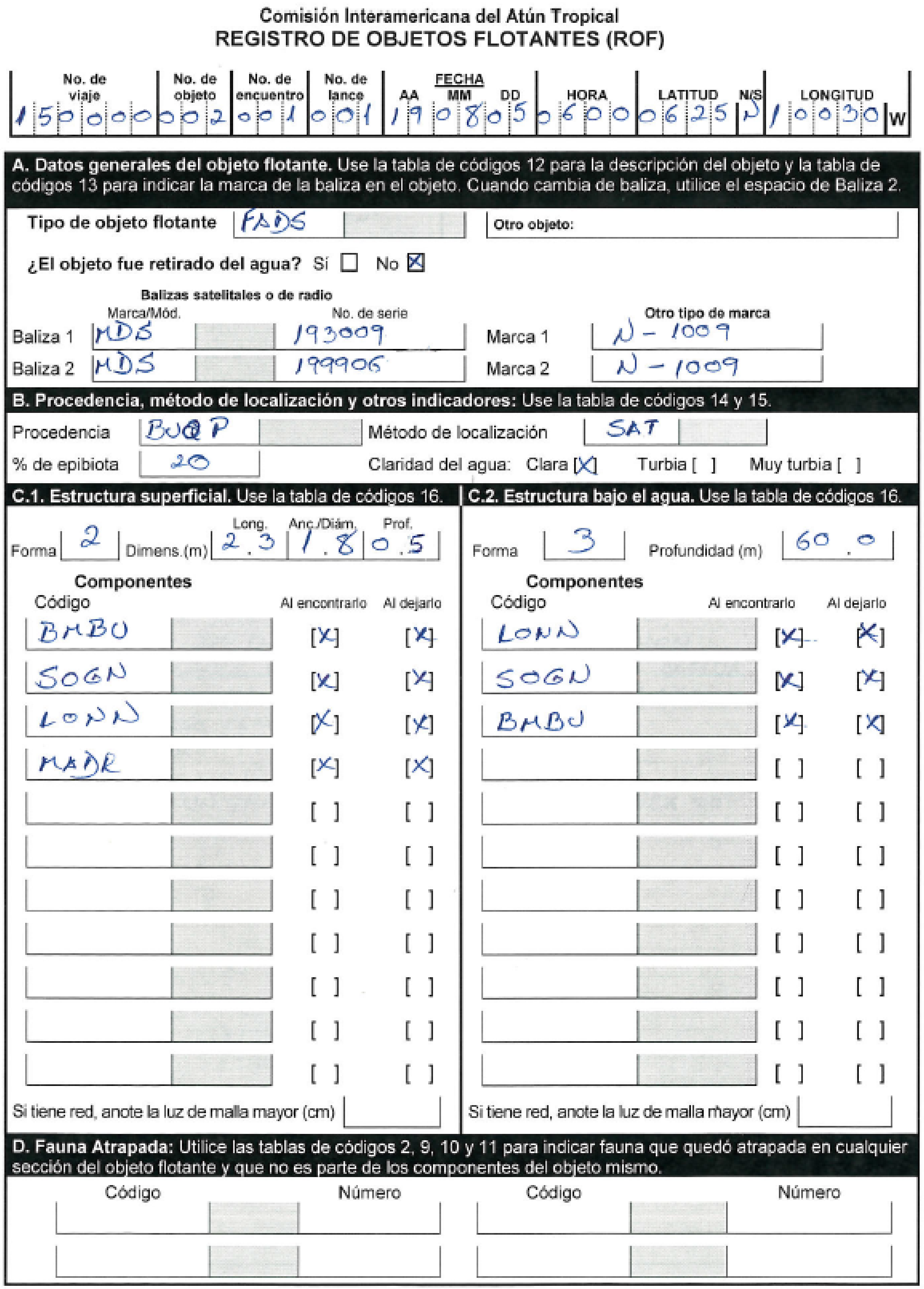
Buoy code table – Make and model of buoys

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 5. Data collecting for skippers and fishing crew (NPR-TS).



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 6. Observer flotsam form (ROF).

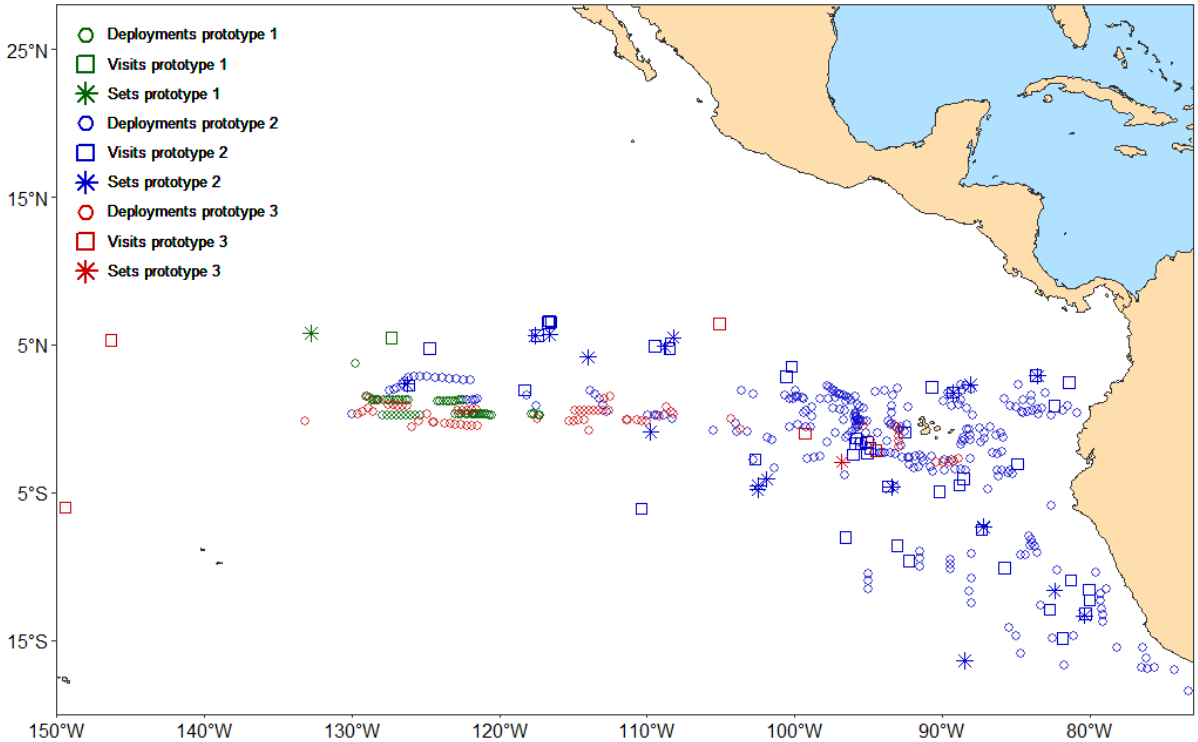


Figure 7. Spatial distribution of NED deployments, visits and sets.

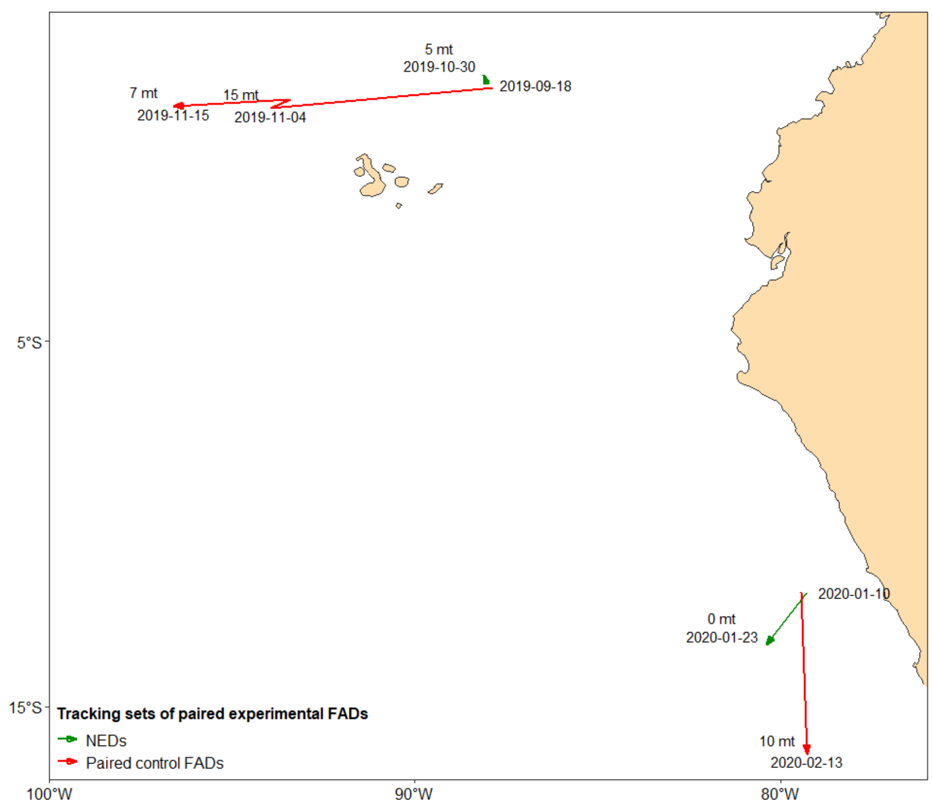


Figure 8. Tracking of sets made on experimental FADs with the same numeric code.

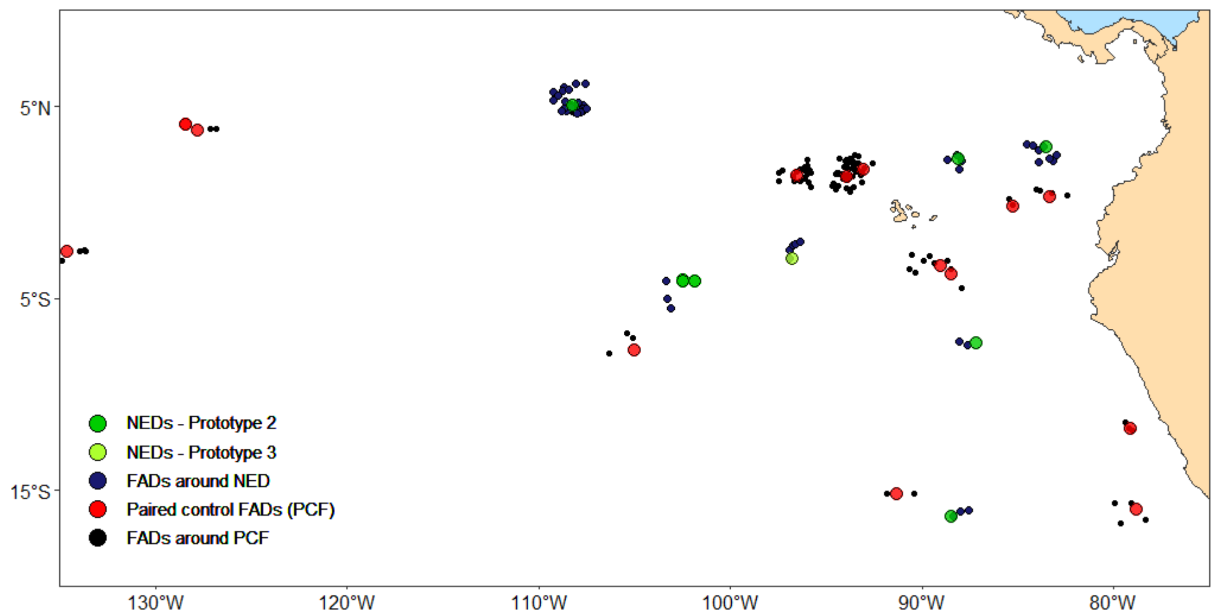


Figure 9. FAD sets made at 1-degree ratio and 7 days before or after a set on a NED or paired control FAD.

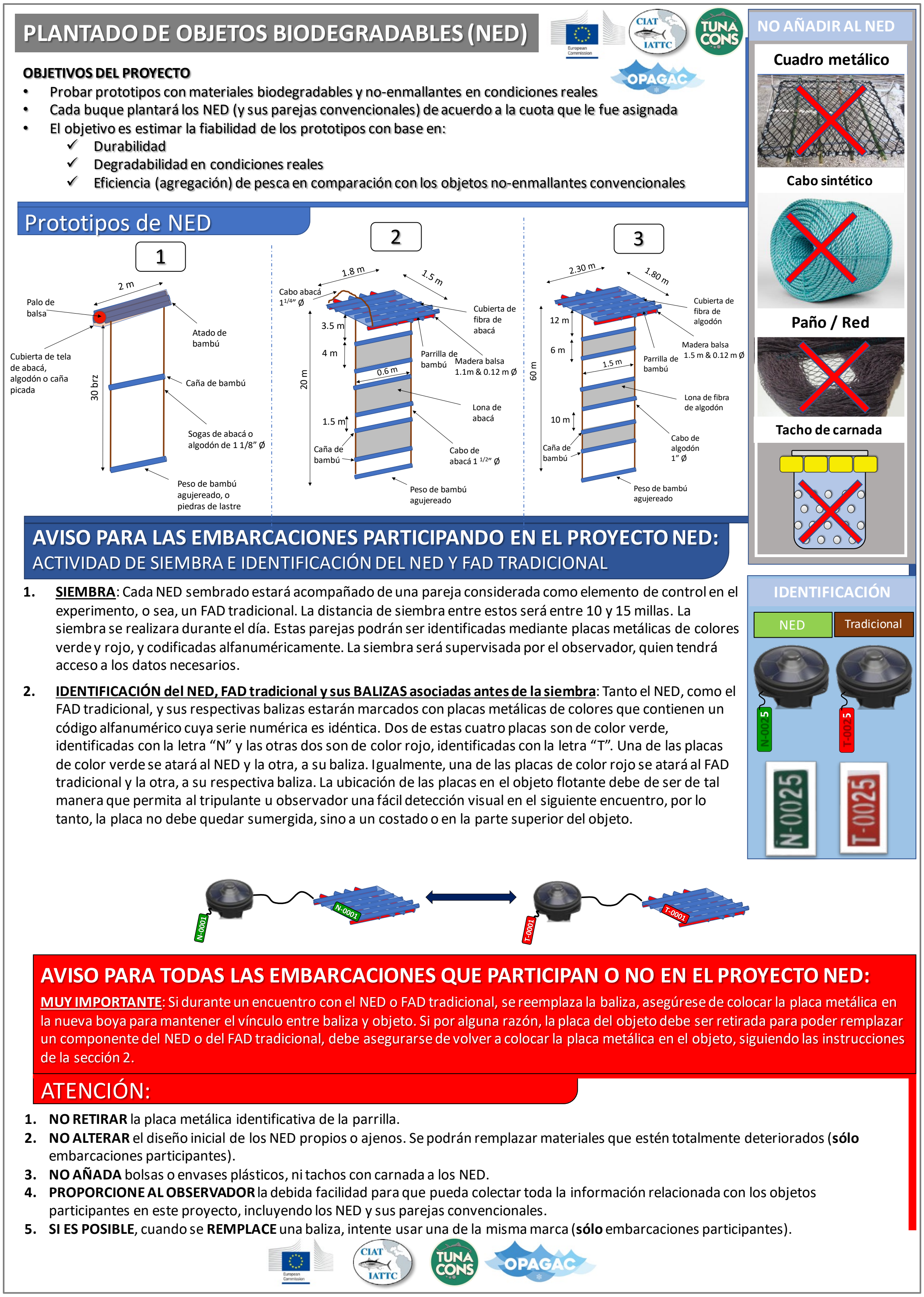


Figure 10. Poster for project information dissemination.