Results of BIOFAD project: testing designs and identify options to mitigate impacts of drifting fish aggregating devices on the ecosystem

Iker Zudaire[1], Mariana Tolotti[2], Jefferson Murua[1], Manuela Capello[2], Margarita Andrés[1], Oihane Cabezas[1], Iñigo Krug[1], Maitane Grande[1], Igor Arregui[1], Jon Uranga[1], Nicolas Goñi[1], Philippe S. Sabarros[2], Jose Maria Ferarios[1], Jon Ruiz[1], Yannick Baidai[2], María Lourdes Ramos[3], Jose Carlos Báez[3], Francisco Abascal[3], Gala Moreno[4], Josu Santiago[1], Laurent Dagorn[2], Haritz Arrizabalaga[1], Hilario Murua[1,4].

[1]AZTI, Spain;
[2] IRD, MARBEC, France;
[3]Insituto Español de Oceanografía (IEO), Spain;
[4]International Seafood Sustainability Foundation (ISSF), USA.

Main author contact details: izudaire@azti.es
Phone: +34667174451

Abstract

The EU project BIOFAD was launched in August 2017. This 28-months EU project is coordinated by a Consortium comprising three European research centers: AZTI, IRD (Institut de recherche pour le développement) and IEO (Instituto Español de Oceanografía). The International Seafood Sustainability Foundation (ISSF) is also actively collaborating by providing the biodegradable materials needed to test biodegradable dFADs (drifting FADs). Following IOTC, along with other tuna RFMOs, recommendations and resolutions to promote the use of natural or biodegradable materials for dFADs, this project is seeking to develop and implement the use of dFADs with both characteristics, non-entangling and biodegradable, in the IOTC Convention Area. However, there are no technical guidelines on the type of materials and FAD designs to be used. The main objectives of the project are: (1) to test the use of specific biodegradable materials and designs for the construction of dFADs in real fishing conditions; (2) to identify options to mitigate dFADs impacts on the ecosystem; and (3) to assess the socio-economic viability of the use of biodegradable dFADs in the purse seine tropical tuna fishery. This document shows the results regarding the effectiveness of 771 BIOFADs deployed within the project, in terms of FAD lifespan, drift, materials' durability, catch and tuna aggregation in comparison to currently deployed NEFADs (non-entangling dFADs). The project BIOFAD has been supported since its inception by the whole EU purse seine tuna fishery and, more recently, with the collaboration of the Korean purse seine fleet.

"The information and views set out in this presentation are those of the author(s) and do not necessarily reflect the official opinion of EASME or of the Commission. Neither EASME, nor the Commission can guarantee the accuracy of the data included in this study. Neither EASME, nor the Commission or any person acting on their behalf may be held responsible for the use which may be made of the information contained therein."

1. Introduction

In the last decade, efforts have been focused to eliminate the entangling features of drifting Fish Aggregating Devices (FADs), as it is believed that this may affect negatively on sensitive species like turtles, sharks, and other associated non-target species. However, most of those non-entangling FADs (NEFADs) are made with synthetic and non-biodegradable materials (eg., nylon ropes and small mesh pelagic fishing nets) contributing significantly to the increase of marine litter (Dagorn et al., 2012) and other potential negative impacts for the ecosystem, such as FADs beaching (Maufroy et al., 2015, Zudaire et al., 2018a). The EU Common Fishery Policy and the Marine Strategy Framework Directive have as objective to ensure environmentally friendly fishing methods, which include the minimization of seafloor or other habitat destruction, avoid effects on other species, but also minimize the introduction of any litter into the marine environment. Along these lines, the Directorate General for Maritime Affairs and Fisheries (DG MARE) has proposed the gradual introduction of the use of biodegradable materials for FAD construction in different Tuna Regional Fisheries Management Organization (tRFMOs). The different tRFMOs have also addressed these issues through several recommendations and resolutions. For example, the Indian Ocean Tuna Commission (IOTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) have adopted the obligation to replace existing FADs with NEFADs and to undertake research on biodegradable FADs. As such, the IOTC defined procedures on a FADs management plan through the resolution 19/02, where any netting materials are eliminated for FAD construction by 1 January 2020 and it is also promoted the reduction of the amount of synthetic marine litter in line with resolution 18/04, by the use of natural or biodegradable materials for drifting FADs (Annex V; IOTC, 2019). Resolution 19/02 also fixed the start of the transition to the implementation of biodegradable FADs from 1 January 2022; data that could be revised considering the BIOFAD results. Similarly, the Inter-American Tropical Tuna Commission (IATTC) has recently stated the use of NEFADs by January 2019 and it promotes the gradual use of biodegradable materials (IATTC, 2016).

However, an effective replacement of non-biodegradable FADs by those fully/partly biodegradable still requires investigation to solve important practical/technical aspects for the operationalization of this FAD type construction, including (1) the selection of appropriate biodegradable materials taking into account their durability, (2) information on biodegradable FADs behavior regarding tuna aggregation, drifting performance, potential impacts, etc., and (3) a socio-economic study to assess cost and benefits of a phase in of biodegradable FADs by EU purse seine tropical tuna fishery. Besides, the implementation of biodegradable FADs will not be so straightforward, as these biodegradable materials following international standards are subjected to certain preconditions. Thus, more detailed definitions to be used by tRFMOs are required to provide accuracy when the term biodegradable is applied to define the materials used for FAD construction (Zudaire et al., 2018b). In line with this, the BIOFAD project developed a tentative biodegradable FAD definition and proposed different options to be implemented considering the type of materials and configurations, the environmental impacts, durability and functionality and technical feasibility (Zudaire et al., 2018b)..

The Consortium, formed by the European research centres AZTI, IRD (Institut de recherche pour le développement) and IEO (Instituto Español de Oceanografía), launched the Specific Contract Nº 07 under the Framework Contract EASME/EMFF/2016/008 provisions of Scientific Advice for Fisheries Beyond EU Waters in August 2017. The project addresses the problems associated to the current used materials and designs for FADs construction. This 28-month project aims to provide solutions that shall support the implementation of BIOFADs (i.e. non-entangling and biodegradable FAD) through the collaboration with the International Seafood Sustainability Foundation (ISSF), the EU and Korean purse seine tropical tuna fishery, Seychelles Fishing Authority (SFA) and through the consultation with IOTC. Thus, the main purpose of the project is to test the use of specific biodegradable materials and designs for the construction of BIOFADs in natural environmental conditions. The study will also provide criteria and guidelines to identify options to mitigate drifting FADs impacts on the ecosystem. It will also assess the socio-economic viability of the use of BIOFADs in the purse seine tropical tuna fishery in the Indian Ocean. Finally, it will suggest potential biodegradable materials and designs providing recommendations to foster the implementation of fully BIOFADs.

Specifically, this Specific Contract will carry out the following tasks (**Figure 1**):

- Task 1 – Revision of the state of the art regarding the use of "conventional FADs" (i.e. entangling and non-biodegradable), "NE FADs" (i.e. non-entangling and non-biodegradable) and "BIO FADs" (i.e. non-entangling and biodegradable) worldwide;
- Task 2 – Evaluating the performance (e.g. lifetime) of specific biodegradable materials and designs for the construction of FADs in natural environmental conditions;
- Task 3 – Testing, comparing and measuring the efficiency of new BIO FADs against current NE FADs to aggregate tuna and non-tuna species at sea in "real" conditions with the involvement of EU Purse Seine fishing fleet;
- Task 4 – Assessing the socio-economic impacts of BIO FADs use and phasing in the purse seiner fleet;
- Task 5 – Assessing the feasibility of using new biodegradable materials by the purse seiner fleet and recommendation of an optimum BIO FAD prototype.

The aim of this document is to present the results obtained after 14 months of the at sea trials and describe the current and future works to be conducted before the end of this project in December 2019.

2. Partners, timeline, deployment strategy and prototypes

The BIOFAD project is led by AZTI, IRD and IEO with the collaboration of the European (fleets associated to ANABAC, OPAGAC and ORTHONGEL) and Korean (Dongwon fishing company) purse seiner fleets operating in the Indian Ocean, ISSF and SFA.

The Specific Contract Nº7 started in August 2017 and lasted 28 months. The Consortium has planned a large-scale experiment with the deployment of 1000 BIOFADs in order to obtain enough data to conduct reliable scientific research. The BIOFADs are deployed, in pairs, along with currently using 1000 NEFADs for comparison purposes. The deployment of BIOFADs started in April 2018, deployments were organized by trimesters, and this activity finished in June 2019 (14 months) covering possible seasonality effects. For that, the project counts on the active collaboration of European purse seine industry with a participation of 42 purse seine and several supply vessels and afterwards two Korean purse seine vessels operating in the Indian Ocean agreed to join the project. In total, each PS vessel should deploy 24 BIOFADs (6 BIOFADs by trimester). This deployment strategy was planned by the Consortium to try to avoid the limitations previously identified in earlier small-scale trials (Moreno et al., 2017).

The methodology used for BIOFAD construction, selected biodegradable materials, prototypes design, BIOFAD deployment strategy, comparison with NEFADs, as well as BIOFAD monitoring, data collection and reporting were defined by the Consortium after being agreed with collaborators (Zudaire et al., 2017). Three prototypes (**Figure 2**) were designed by the Consortium based on designs previously identified for Indian Ocean in the ISSF Workshop held in Donostia in 2016 (Moreno et al., 2016). Fishermen's requirements and needs for FADs construction were considered for those designs covering the different drifting performance that fisherman seek with their conventional NEFADs: superficial FADs (BIOFAD prototype C), superficial FAD with medium-deep tail (BIOFAD prototypes A1 and A2), and submerged FAD high-deep tail and cage type submerged FAD (BIOFAD prototypes B1 and B2, respectively). Details regarding materials, dimensions and construction of these 3 prototypes were provided in Zudaire et al. (2017). In a recent 2nd BIOFAD Workshop held in April 2019 in Spain, some modifications in the prototypes and the configuration of their components were agreed among the Consortium and participants. Among these changes, a multilayer cotton cover and the use of metallic frame for BIOFAD's raft construction were accepted.

Traceability of BIOFADs and their pairing NEFADs during their entire lifecycle is ensured throughout an identification system and deployment strategy agreed by the Consortium and participants (Zudaire et al., 2017). All the information related to the activities (i.e., new deployment, visit, buoy exchange, set, recovery, redeployment and elimination) with experimental FADs are reported by the fleet and collected by observers onboard. All this information is reported to the Consortium using an email template and a dedicatedly designed form for skipper and observers, and so making data available to scientist quickly. Besides the activity information, these forms are also used to gather the information regarding BIOFAD and NEFAD structure status control, using simple value scale to assign the stage of degradation to each of these components (Zudaire et al., 2017).

3. Main progress and results

3.1. BIOFAD deployments, spatial distribution and drifting performance.

771 BIOFAD were deployed together with their pairing conventional NEFADs by the participating fleet. This represented 77% of the initially planned goal for BIOFAD deployments. From the total of 771 BIOFAD deployed 71% corresponded to A1 prototype, 18% to A2, 4% to B1, 2% to B2, and 5% to C1. As shown in the **Figure 3**, the deployment effort was not homogeneous through all period and during the first months few BIOFAD were deployed by the fleet for different reasons, including reparation at dry dock, stop of fishing activity due to quota limitation, or delay in the coordination of fishing companies involved in the construction of the experimental FADs. Afterwards, during the second trimester, the deployment objective increased up to 87%. In the following trimesters the effort decreased again to 65%, 47% and 50% respectively. Some vessels kept deploying BIOFADs beyond stablished period to recover accumulated delays in previous months (deployments in July and August). In **Figure 4** are shown the locations where those BIOFAD deployments occurred during the study period. The distribution of the experimental FADs deployed between April 2018 and August 2019 covered the western Indian Ocean and the deployment effort was balanced seasonally through covered trimesters.

The use of BIOFAD prototypes by the fleet was also assessed in terms of total material and synthetic material used for BIOFAD and their equivalent NEFADs construction. For that, both BIOFAD prototypes and their equivalent NEFAD were characterized, describing the type of material and dimensions for each FAD component (**Annex I**). As shown in **Table 1**, BIOFAD prototypes A1, A2 and B2, in comparison to their equivalent NEFADs, required less material (in kg) for their construction, with a reduction of 44%, 50% and 11%, respectively. In the case of BIOFAD prototypes B1 and C1, an increase in total material weight (27% and 1%, respectively) was observed in comparison with their equivalent NEFADs. However, all BIOFAD prototypes reduced the amount of synthetic materials used for their construction. Prototype A1, the most used by the fleet, required 81% less synthetic materials than its equivalent NEFADs. These results show, that BIOFAD prototypes significantly contribute to the reduction of the synthetic material in FAD construction. Consequently, this will also enable to mitigate the potential contribution of lost and abandoned FADs to marine litter, reducing also the derived impacts in the ecosystem, which is the objective promoted by IOTC resolution 18/04.

The drifting pattern of experimental FAD was assessed by pairs (BIOFAD vs NEFAD) without considering the effect of area, season of deployment or prototype at this stage of the analysis. Variability in the patterns was observed showing patterns with i) pairs following totally different drift, ii) pairs following partly similar drifts and iii) pairs following same patterns. **Figure 5** shows the results considering the distance (miles) between pairs of experimental FADs (BIOFAD vs NEFAD) after the deployment. As observed in this figure the distance between pairs can increase and decrease along their lifecycle, although overall an increase of distance between pair with days after deployment was shown.

3.2. BIOFAD efficiency: lifespan, material degradation, catch data and biomass indicator.

BIOFAD efficiency was assessed by analyzing and comparing different parameters between experimental FADs (BIOFAD vs. NEFAD): lifespan, material degradation process, catch data, tuna presence/absence and biomass indicators given by echosounder buoys.

The lifespan of experimental FADs (BIOFAD and NEFAD) was defined as the period (in days) between the day of first deployment and the day when the FAD was considered no longer active. The latter was estimated by the day when the FAD was eliminated/retrieval and/or the attached buoy was deactivated and the Consortium was no longer able to track the FAD. This information was provided by the vessel and/or buoy suppliers. The **Figure 6** shows the lifespan estimations by FAD type (BIOFAD and NEFAD) and prototype. All the prototypes, for both FAD types, showed a maximum lifespan longer than 1 year (max lifespan for a BIOFAD of 483 days and for NEFAD 493 days), except for the prototype B2 with limited number of deployments during the experiment. Highest mean lifespan values were observed in BIOFAD B1 and A1, 242 and 191 days, respectively (**Table 2**). In the case of NEFADs, prototype A1 and C1 showed the highest mean lifespan values with 209 and 182 days, respectively (**Table 2**). This analysis did not consider the degradation process of the FAD's components, so the final condition of those FADs lasting more than one year was not possible to assess. In addition, the differences of number of FADs tested by model are in some cases significant and, thus, inter model comparison should be considered with caution.

To identify the pros and cons of each biodegradable material (i.e., cotton canvas, and two type of cotton ropes), and to be compared with their synthetic equivalent, the quality status control for each component used for FAD construction was used. The crew members onboard were requested to collect this information during their activities with experimental FADs. This source of information was also used to develop the Life Cycle Analysis conducted in this project. However, a reduced number of status control reports were reported by the fleet, which could be due to the inherent fishing strategy in which in FADs visits the FADs are not commonly lifted from the water. This has limited the material degradation assessment in those months when observations were especially low. As shown in the **Figure 7** the degradation of the cotton canvas, i.e., component used to cover the raft as alternative to netting materials or synthetic raffia, started to suffer significant degradation already during the first and second month at sea. This degradation increased in the third and fourth months, when more than 50% of the observations were deemed to be in a "bad", "very bad" or "absent" states. Similar pattern was also observed in the fifth and sixth months at sea. Contrarily, the synthetic material used to cover the raft in NEFADs, showed better performance than the biodegradable component and kept in good condition until the sixth month at sea. Afterwards the observations are very low to make any conclusion.

The degradation of the cotton rope, i.e, component used in the submerged part of the FAD as main tail, was less pronounced comparing with the cotton canvas (**Figure 7**). The status control for the cotton rope was deemed to be in "very good" or "good" quality until the fourth month at sea. However, in 10-20% of the observations the "absence" of this material was reported during the first, second and third month at sea. In the fifth month the observations at this state increased up to 70%. Contrary to what was expected, the synthetic alternative used as tail in NEFADs, was also considered to be in "very bad" condition by the sixth month at sea. Similar results were observed for the looped cotton rope, i.e., component used as attractor tied to the main tail. The status control for this secondary rope was estimated to be in "very good" or "good" quality until the fifth month at sea. However, this component also showed high percentages of "absence" during the first months at sea, especially during the fifth month when values increased up to 70% of the observations.

Overall, and contrary to the perception of the cotton canvas, and according to the feedback received during the 2nd and 3rd BIOFAD Workshops, the absence of the cotton ropes from the raft of the BIOFADs have been related to failures at attachment between the tail and the raft rather than to a high degradation of the materials. If not correctly attached, these components could be lost resulting in the reported absences. Overall, the Industry had positively valued the performance of these two rope components. Although certain part of the fleet was expecting longer lifetime for those materials, other companies have already incorporated them in their current FADs construction. According to the aforementioned results and feedbacks, tested cotton ropes could be considered as a feasible solution for FAD tail, and thus, as replacement of netting materials used in the tail tied into sausage-like bundles. This result will contribute to eliminate large amount of nets for FAD construction and provides options to the industry to partly comply with Annex V requirements in the IOTC resolution 19/02.

The BIOFAD efficiency in comparison with NEFADs was further analyzed through the catch data. In total, from April 2018 to August 2019, 68 sets were associated to these experimental FADs, 36 to BIOFADs and 32 to pairing NEFADs. These is a positive result itself as the rate of fishing on BIOFAD and homologous NEFAD seems to be similar. There was not significant difference found in catches (tons of tuna by sets) between FAD types. The spatio-temporal effect was not considered at this stage of the analysis. **Table 3** shows the overall catch information by FAD type and prototype. Most of the sets were conducted in A1 prototype in both FAD type which could be due to the higher number of deployments of this prototype. Indeed, when the number of sets by each prototype was analyzed relative to the number of deployments of each prototype, differences among them were not observed. The low number of sets performed some of the prototypes does not allow to perform comparative analysis between prototypes.

Tuna Presence/Absence estimation through echo-sounder buoy data only considered one buoy model (i.e., M3i). Data filtering process followed the protocols defined in the RECOLAPE project (Baidai et al., 2018; Grande et al., 2019) in order to keep a unique working procedure between the Consortium members and to take advantage of the work being done within the Framework Contract. Tuna Presence/Absence assessment (Baidai et al., 2018) to study the colonization time and lifetime of the aggregation was conducted by pairs (BIOFAD and its pair NEFAD). **Figure 8** shows the values of first detection day between FAD type. Presence of tuna appeared to be faster in NEFAD than in BIOFAD. In terms of FAD occupation by tuna aggregation, the percentage of NEFAD occupied by tuna overcome the percentage of BIOFAD (**Figure 9)**. Finally, pairs were compared regarding the distance between both in a given time. Estimated distance differences were then grouped in determined distance ranges, such as less than 50km, 100Km, 150Km etc. being the successive ranges accumulative, i.e., the next larger distance group includes the previous ones. **Figure 10** shows higher proportion of FAD colonization at NEFADs than in the BIOFAD throughout the different range of distances between pairs.

Echo-sounder buoy data was also used to estimate the tuna biomass from acoustic energy values (Uranga et al., 2019). Acoustic data was analyzed by pairs (when acoustic data of both FADs of a pair exist) and grouped by months having as reference the deployment day. For the analysis the information derived from different buoy models was analyzed separately, i.e., data from M3i, M3i+ and ISL+ models. Biomass was estimated as the 99 percentile of daily estimation and grouped by month after deployment. Overall, very low tuna biomass estimations for both FAD types were observed in the three buoy models (**Figures 11-13).** In the M3i model analysis, higher values of biomass were observed in NEFAD than in BIOFAD during the first months after deployment. However, this pattern changed after ninth month showing higher biomass values in BIOFADs than in NEFADs (**Figure 11**). The M3i+ model did not show differences between pairs during the first months and only after fifth month at sea the values observed at BIOFADs were slightly higher than in NEFADs (**Figure 12**). The ISL+ models did not show differences between pairs through the all period analyzed (**Figure 13**).

3.3. Life-cycle analysis and socio-economic analysis

The development of life-cycle assessments (LCA) for the different FAD prototypes and the materials used for their construction, including their expected biodegrading time, and the subsequent potential negative and positive environmental impacts (e.g., carbon print, impact of chemicals used to extend FADs durability and contribution of plastic to marine littler) is still in progress. **Figure 14** shows the results of the LCA considering only the carbon print impact generated by each of the BIOFAD prototypes and their equivalent NEFADs. The simplest material configuration of BIOFAD prototypes (A1, A2, B1, B2 and C1) appeared to have less carbon footprint impact than their equivalent NEFADs prototypes. This figure also integrates carbon print variation when the effectiveness of each prototype is measured in terms of tuna biomass estimation. In this case, and as preliminary results, the prototype C1 for both type (BIOFAD and NEFAD) had the lowest carbon print impact, being the BIOFAD C1 the prototype with lowest value. This analysis did not consider the replacement rate of the materials, which is expected to be higher in BIOFAD as shown by material degradation results.

The assessment of the short and long-term socio-economic impacts of replacing NEFAD with BIOFAD is still in progress. The socio-economic analysis will also consider possible market incentives (e.g., eco-friendly labelling, etc.) to encourage the use of BIO FADs.

4. Conclusions and Recommendations

4.1. Conclusions

- The distribution of the experimental FADs deployed covered the western Indian Ocean and the deployment effort was balanced seasonally.
- BIOFAD prototypes reduce significantly the amount of synthetic material used for FAD construction.
- High variability in the drifting patterns was observed: i) pairs following totally different drift, ii) pairs following partly similar drifts and iii) pairs following same patterns.
- Except prototype B2, which was deployed in low numbers, all prototypes showed a lifespan longer than 1 year in both FAD types without considering the degradation status.
- The cotton canvas showed high degradation during the first months at sea, while cotton ropes were less degraded until fifth month.
- Few sets were observed in both FAD types, being the number of sets slightly higher in BIOFAD. No significant differences were observed in tuna catch data by FAD type.
- Tuna presence/absence data showed faster colonization and higher FAD occupation by tuna aggregation in NEFAD than in BIOFAD.
- Variability in biomass estimation by FAD type was observed in the analysis of different buoy models. Overall, NEFAD had higher values of biomass during the first month, while BIOFAD showed higher biomass values after ninth month at sea.
- Based on the data available, prototypes C1 (BIOFAD, NEFAD) seem to be the most environmentally friendly designs in terms of carbon footprint, both considering catch and biomass data.

4.2. Recommendation

- Following preliminary definition proposed in the context of this project for biodegradable FAD (Zudaire et al., 2018b), it is essential to advance towards an agreed BIOFAD definition by t-RFMOs. This will allow providing clear guidance and clarity when the term biodegradable is used to define the materials used for FAD construction.
- The definition of BIOFAD could consider, acknowledging the current state of the art for biodegradable materials and availability, different levels/categories of biodegradability of BIOFADs, similar to ISSF classification for FAD's entanglement risk (ISSF, 2019).
- An effective replacement of non-biodegradable FADs by those fully/partly biodegradable still requires investigation to solve important practical/technical aspects for the operationalization of this FAD type. Thus, further research with those natural and synthetic materials that meet the BIOFAD definition is required.
- Acknowledging the current difficulties for the implementation of fully biodegradable FADs as biodegradable materials for all FAD components are not available yet (e.g. floating parts); a stepwise process, including a timeline, towards the implementation of fully biodegradable FAD should be considered based on the current state of art of available materials. In this gradual process different options could be discussed:
- As first step, the implementation of BIOFADs could consider the use of a minimum proportion (i.e., determined by the percent of total weight or surface) of biodegradable material or the requirement of biodegradable materials for the construction of certain FAD parts (e.g., submerged part of the FAD or the material to cover the raft if needed).
- Progressively, as soon as materials are available, the % of biodegradability should be increased for the construction of other parts of the FADs targeting 100% biodegradability for the FAD as

per BIOFAD definition above. In the meantime, plastic based materials should be reduced as much as possible.

- o Gradual modification of current FAD design, in terms of reductions in the amount of material (e.g., depth of tails) and the synthetic fraction used in their construction, should be promoted at a short term while medium (long) term implementation of biodegradable NEFAD is in progress.
- o The effective development and implementation of biodegradable FAD requires the collaboration of all stakeholders, fishing industry and research centers including experts in material development.

5. References

Badaia Y, Amande M.J., Gaertner D., Dagorn L., Capello M. 2018. Recent advances on the use of supervised learning algorithms for detecting tuna aggregations under FADs from echosounder buoys data. IOTC-2018-WPTT20-25.

Dagorn L. Holland K. N. Restrepo V. Moreno G. 2013. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish and Fisheries, 14:391–415.

Grande M, Capello M, Uranga J, Baidai Y, Boyra G, Quincoces I, Orue B, Ruiz J, Zudaire I, Murua H, Depetris M, Floch L, Santiago J. 2019. From fishermen´ to scientific tools: Progress on the recovery and standardized processing of echosounder buoys data. J-T-RFMO FAD WG 2019_Grande_S:06.

Maufroy A, Chassot E, Joo R, Kaplan DM., 2015. Large-Scale Examination of Spatio-Temporal Patterns of Drifting Fish Aggregating Devices (dFADs) from Tropical Tuna Fisheries of the Indian and Atlantic Oceans. PLoS ONE 10(5): e0128023.

Moreno, G., Restrepo, V., Dagorn, L., Hall, M., Murua, J., Sancristobal, I., Grande, M., Le Couls, S. and Santiago, J. 2016. Workshop on the use of biodegradable fish aggregating devices (FADs). International Seafood Sustainability Foundation, Washington, D.C., USA.

Uranga J, Santiago J, Boyra G, Quincoces I, Grande M, Orue B, Zudaire I, Murua H. 2019. Treatment of acoustic data obtained from echosounder buoys for tuna biomass estimates. J-T-RFMO FAD WG 2019_Uranga_S:08

Zudaire, I., et al. 2017. Testing designs and identify options to mitigate impacts of drifting fads on the ecosystem. IOTC-2017-SC20-INF07

Zudaire I., Suarez M.J., Grande M., Retolaza J., Santiago J., Murua J., Tolotti M.T., Dagorn L., Ramos M.L., Baez J.C., Moreno G., Murua H. 2018a. Which is the best definition for the biodegradable FAD? IOTC-2018-WPTT20-22.

Zudaire I., Santiago J., Grande M., Murua H., Adam P.A., Nogués P., Collier T., Morgan M., Khan N., Baguette F., Moron J., Moniz I., Herrera M. 2018b. FAD Watch: a collaborative initiative to minimize the impact of FADs in coastal ecosystems. IOTC-2018-WPEB14-12.

Table 1. Data on total weight of material used for BIOFAD and equivalent NEFAD construction. Weight of biodegradable and synthetic materials used in both type FAD construction. Comparison (in percentual variation) between BIOFAD and equivalent NEFAD in terms of total and synthetic materials.

	TOTAL weight (kg)	Biodegradable Material (Kg)	Synthetic Material (Kg)	Total Weight in BIOFAD (Kg)	Total Synthetic weight in BIOFAD (kg)
A1- BIOFAD	67,6	47,1	20,5	↓ 44%	↓ 81%
NEFAD_1	121,4	12	109,4		
A2-BIOFAD	60,1	39,6	20,5	↓ 50%	↓ 81%
NEFAD_1	121,4	12	109,4		
B1-BIOFAD	79,4	48,9	30,5	↑ 27%	↓ 51%
NEFAD_2	62,6	0	62,6		
B2-BIOFAD	48,4	15,9	32,5	↓ 11%	↓ 40%
NEFAD_3	54,4	0	54,4		
C1-BIOFAD	46,4	30,9	15,5	↑ 1%	↓ 54%
NEFAD_4	45,9	12	33,9		

Table 2. Lifespan data by FAD type (BIO= BIOFAD and CON=NEFAD) and prototypes.

FAD type	Prototype	Mean (days)	Min	Max	st_dev
BIO	A1	191	1	483	145
BIO	A2	151	1	472	119
BIO	B1	242	15	432	166
BIO	B2	70	37	139	24
BIO	C1	161	3	436	146
CON	A1	209	1	493	146
CON	A2	177	5	483	132
CON	B1	180	15	432	147
CON	B2	75	22	139	31
CON	C1	182	16	448	135

Table 3. Catch data (maximum and mean in tons), number of sets, number of deployments and % of use by FAD type and prototype.

	BIOFAD	CONFAD
Max (tons)	150	225
Mean (tons)	27,96	44,2
Sets	36	32
Deployments	771	736

BIOFAD	A1	A2	B1	B2	C1
Max (tons)	150	75	0	0	0
Mean (tons)	32,21	40	0	0	0
Sets	26	5	2	0	2
Deployments	545	142	29	18	37

CONFAD	A1	A2	B1	B2	C1
Max (tons)	98	225	0	0	70
Mean (tons)	29,38	75,71	0	0	67,5
Sets	21	8	0	0	3
Deployments	497	128	43	20	42

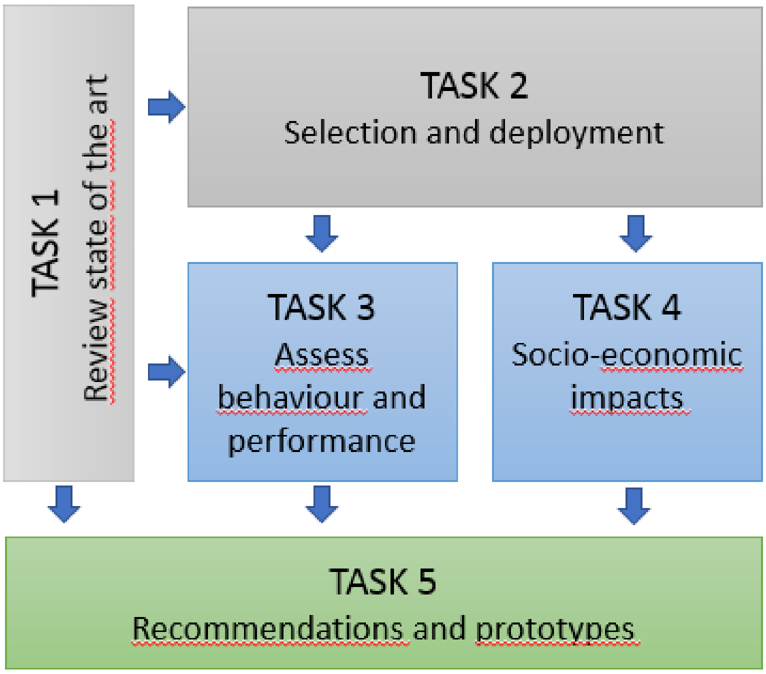

Figure 1. Flow chart of tasks of Specific Contract N0 7.

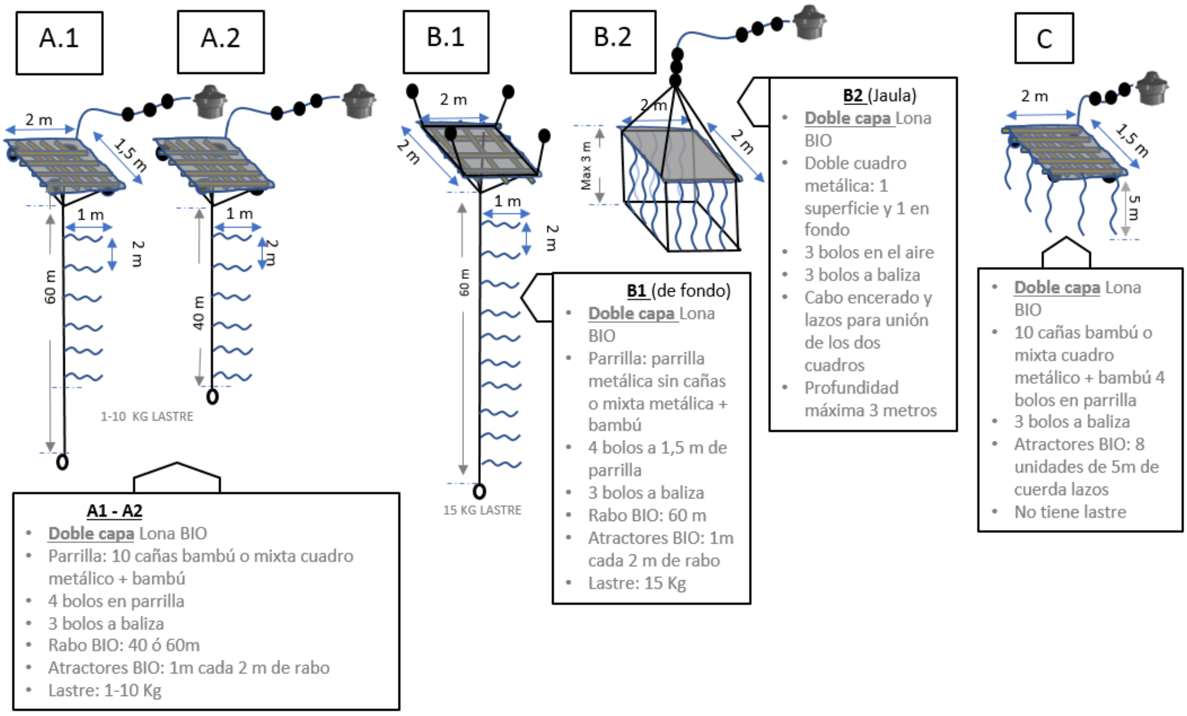

Figure 2. BIOFAD prototypes designs and the details of materials and dimensions for each of them.

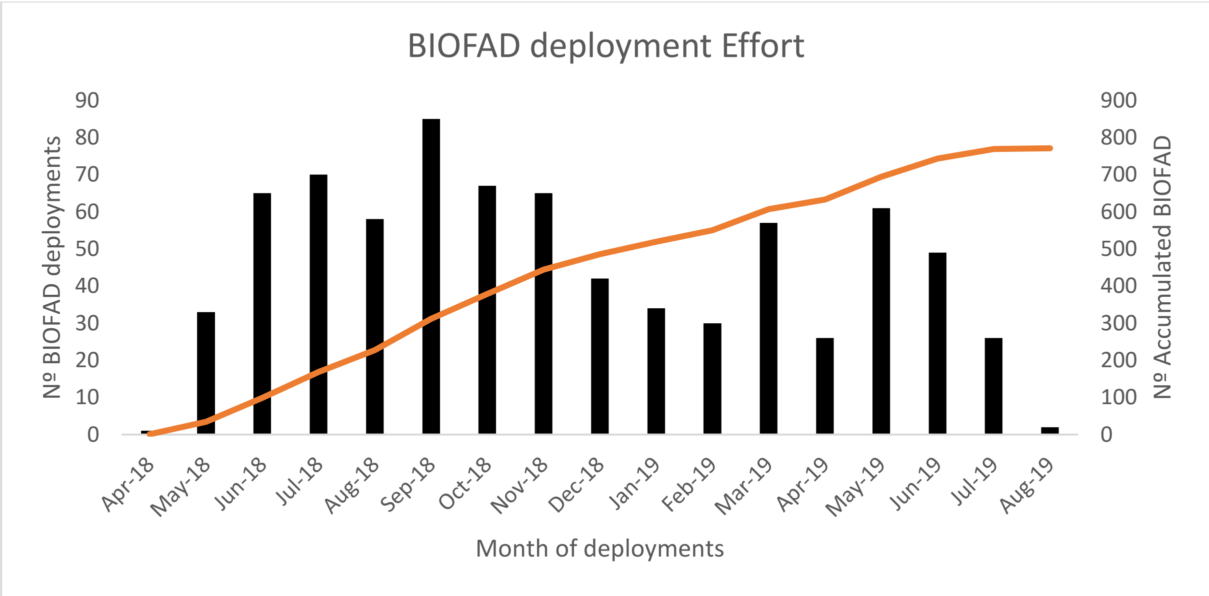

Figure 3. The number of BIOFAD deployed by month (bars) and accumulated number of deployments (red line).

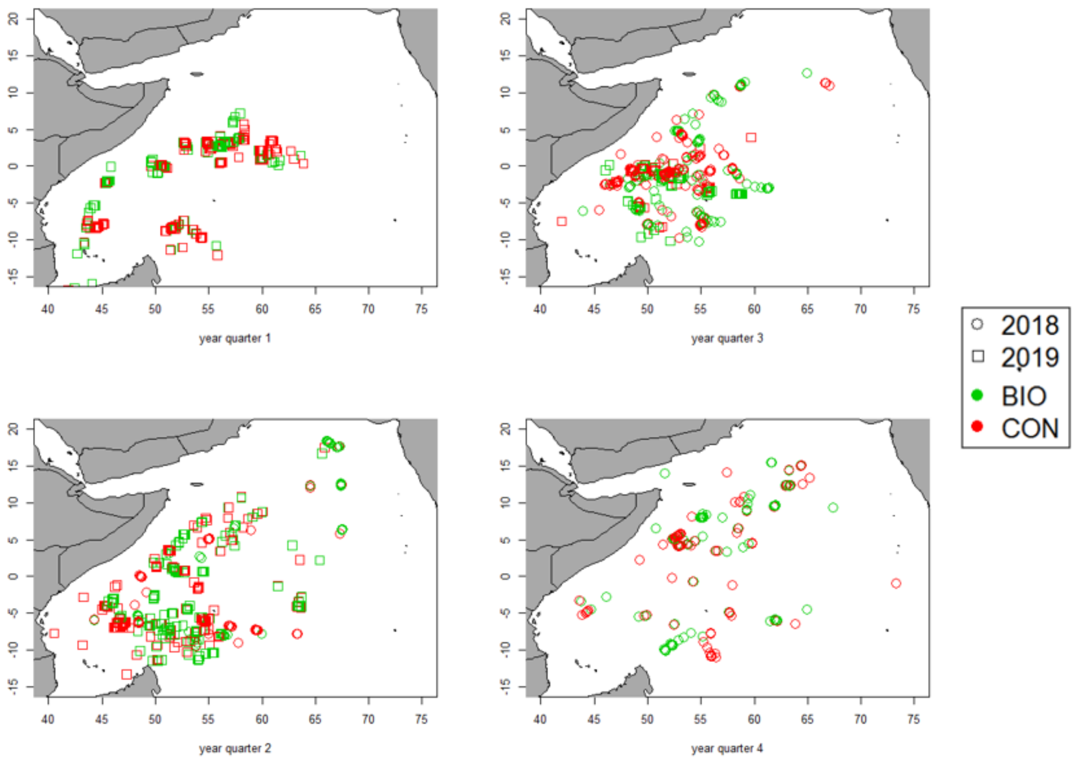

Figure 4. Representation of BIOFAD new deployments distribution through the echo-sounder buoy data provided by the EU PS fleet in the samples four trimesters.

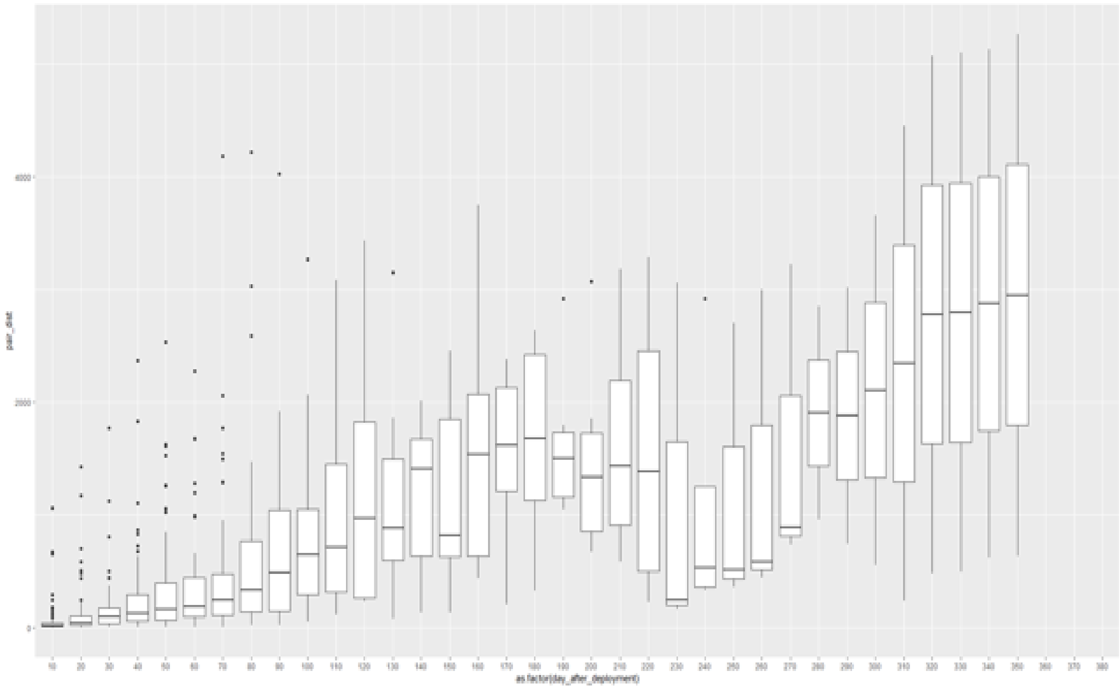

Figure 5. Distance between pairs (in miles; y-axis) relative to the time after deployment (in days; x-axis).

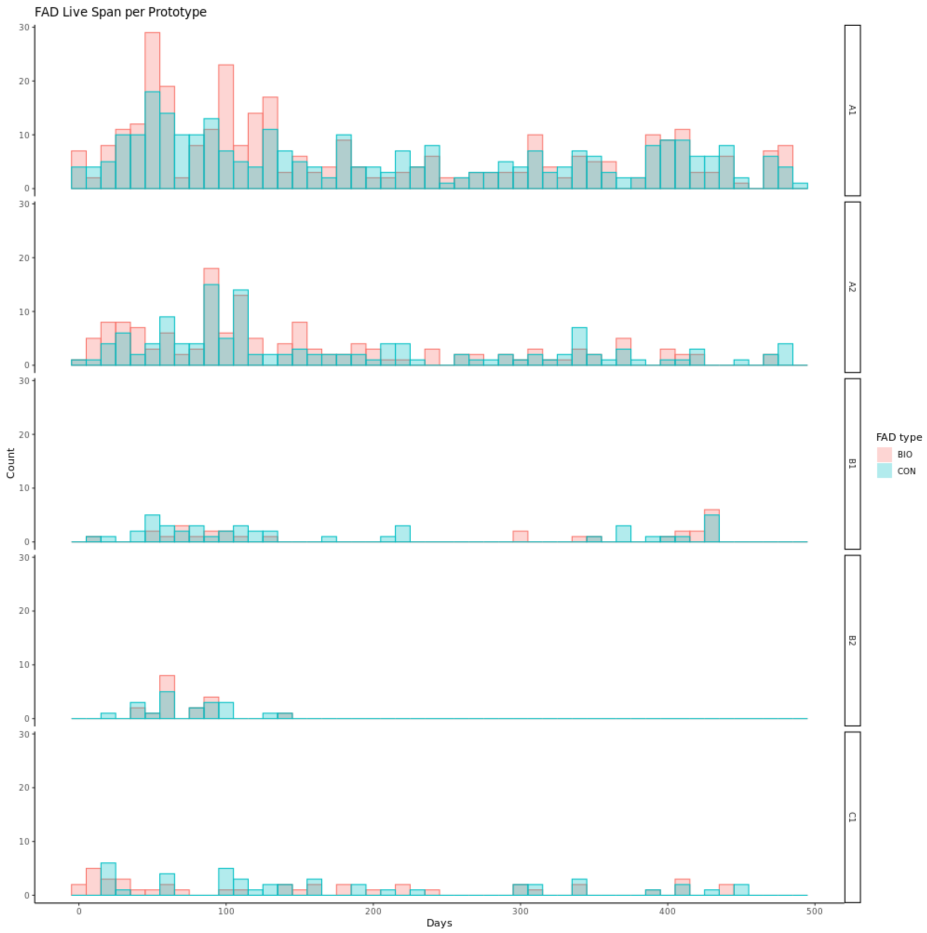

Figure 6. Lifespan results by FAD type (BIO= BIOFAD and CON=NEFAD) and prototypes.

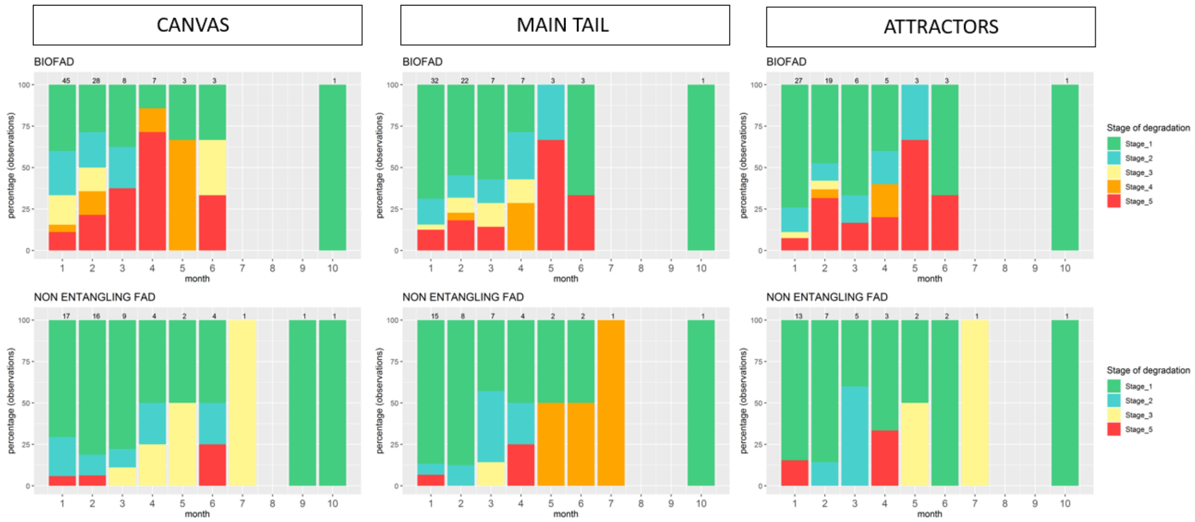

Figure 7. Status control assessment for the cotton canvas, main cotton rope and the cotton rope used as attractors for BIOFAD (upper figures) and synthetic material used as cover, tail and attractors for NEFAD (down figures). Estado_1 =Very good; Estado_2 = Good; Estado_3 = Bad; Estado_4 = Very bad; and Estado_5 = Absent.

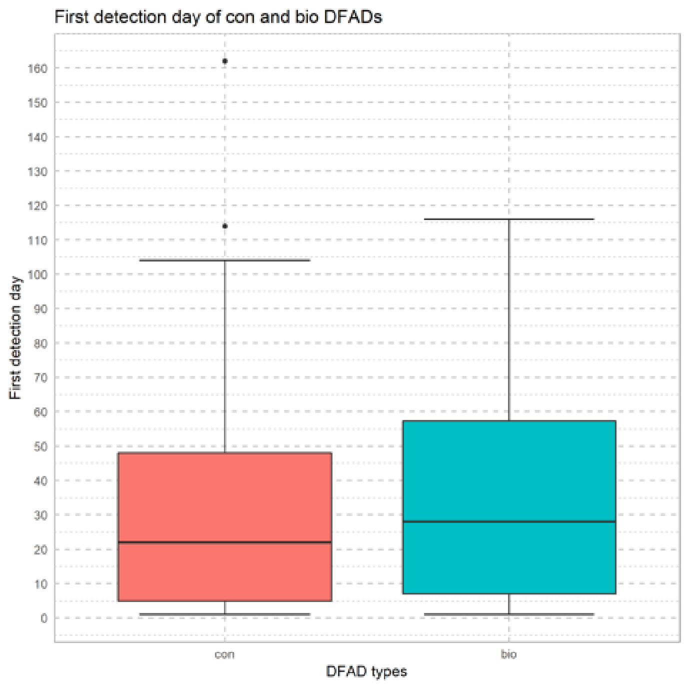

Figure 8. First day of tuna detection by type of FADs between pairs.

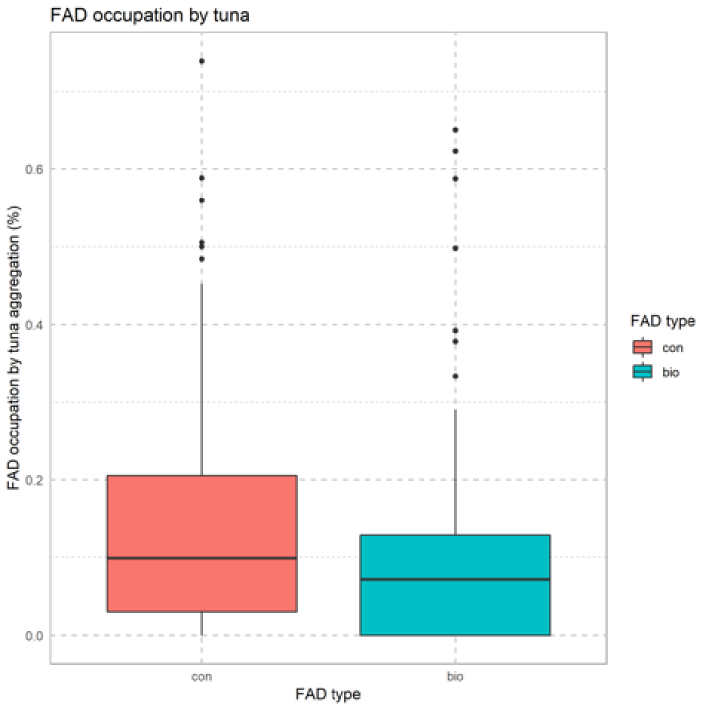

Figure 9. Proportion of FAD occupation by tuna aggregation (y-axis) by FAD type (x-axis).

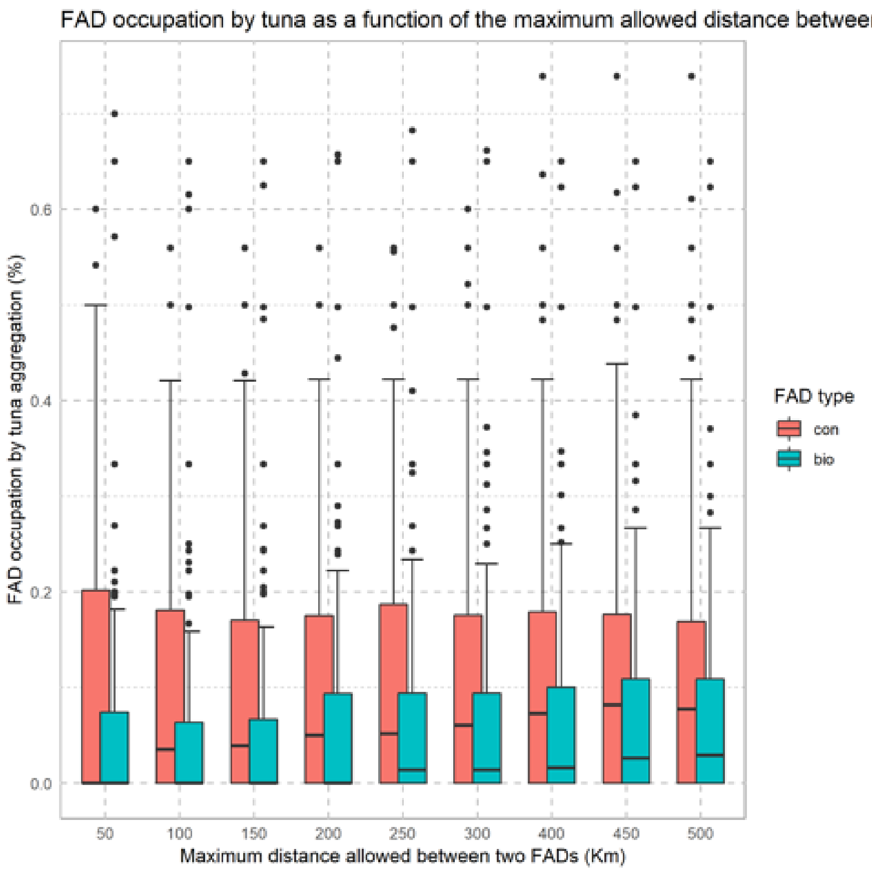

Figure 10. Proportion of FAD occupation by tuna aggregation by FAD type and by range of distance between pairs (in km).

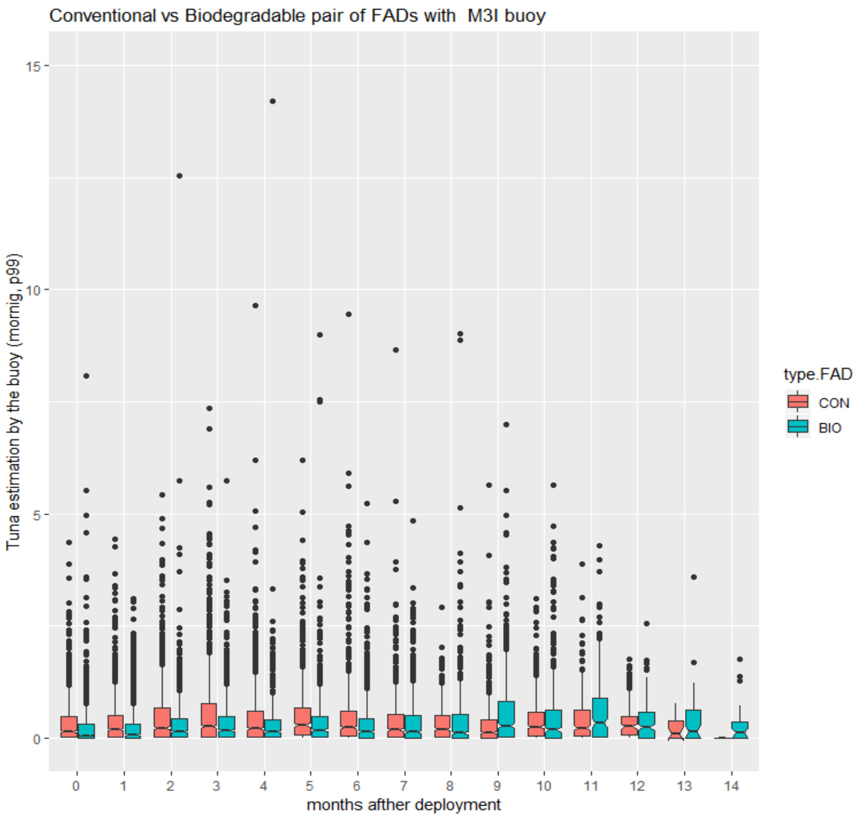

Figure 11. Tuna biomass estimation through echo-sounder data (M3i) by FAD type and by group of months since first deployment.

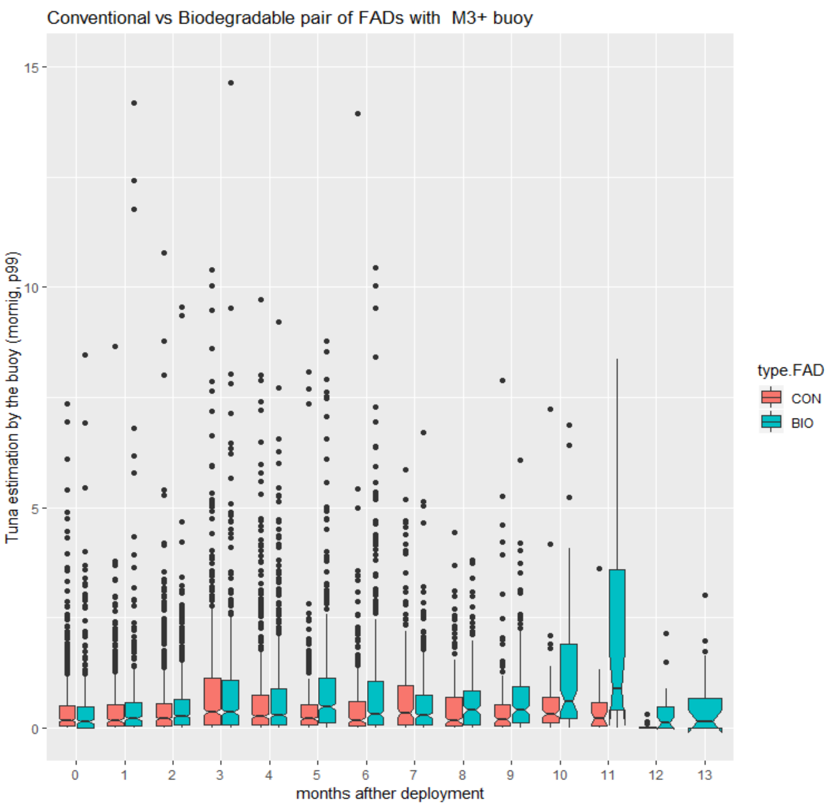

Figure 12. Tuna biomass estimation through echo-sounder data (M3i+) by FAD type and by group of months since first deployment.

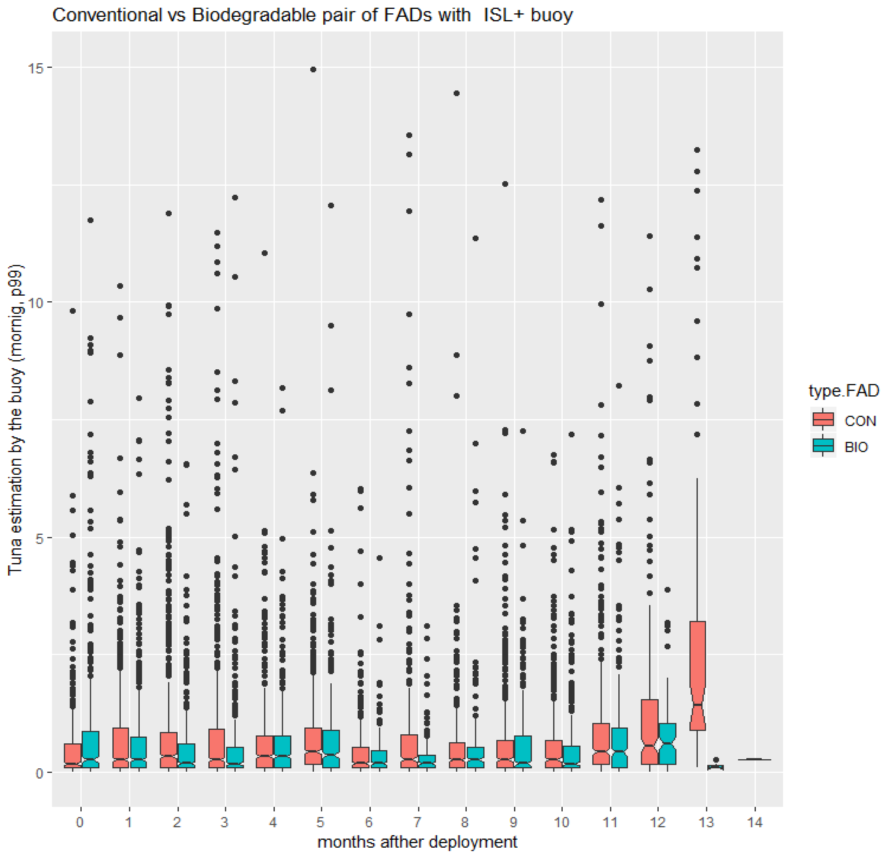

Figure 13. Tuna biomass estimation through echo-sounder data (ISL+) by FAD type and by group of months since first deployment.

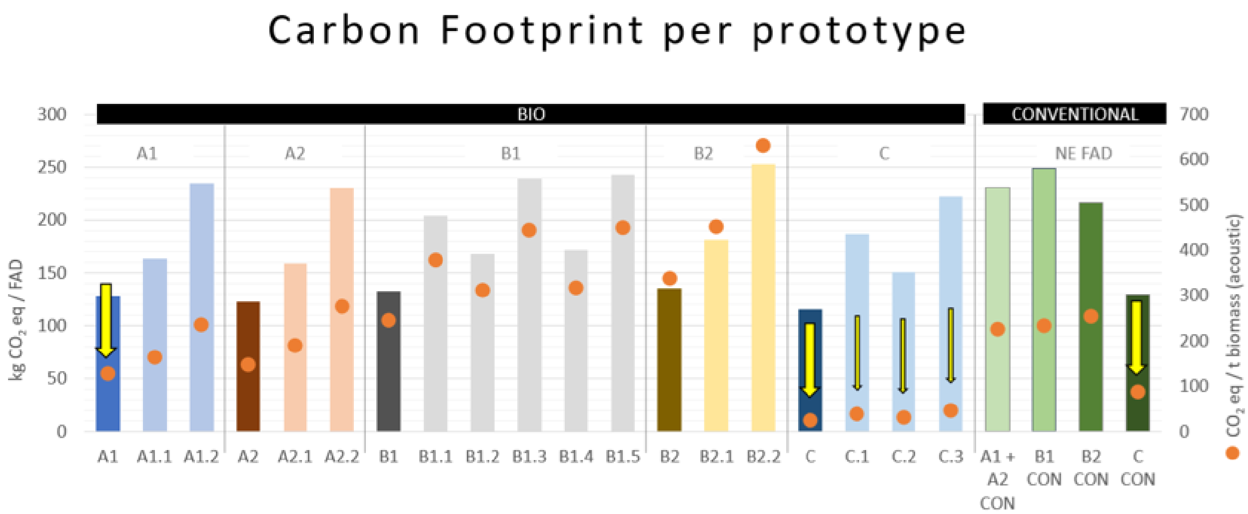

Figure 14. Carbon footprint generated by FAD type and prototype (bars). Carbon footprint generated by FAD type and prototype relative to the biomass values estimated from acoustic data (orange points). Yellow arrow shows the level of reduction in the impact of each prototype after considering the biomass estimation.

Annex I

	Comp. 1		Comp. 2		Comp. 3		Comp. 4		Comp. 5		Comp. 6	Comp. 7	GENERAL INFO			
Model	floating structure	Weight [kg]	Canvas for cover	Weight [kg]	Main ropes [m]	Weight [kg]	Rope - atractor [m]	Weight [Kg]	Floats Un.	Floats Weight [kg]	Ballast weight [kg]	Twine to tie [kg]	TOTAL weight [kg]	BIO Material Weight	Synthetic Material Weight	% Biodegradability
BIOFAD_A1	10 bamboo canes	30	Black cotton cover	2,2	Cotton 60 m	18	1 m looped cotton rope set each 2 m (30m)	4,8	4+3=7	8,9	5	0,5	69,4	55	14,4	79,3
BIOFAD_A1.2	4 bamboo canes Metallic frame	12 12,2	Doble Black cotton cover	4,4	Cotton 60 m	18	1 m looped cotton rope set each 2 m (30m)	4,8	4+3=7	8,9	5	0,5	65,8	39,2	26,6	59,6
BIOFAD_A2	10 bamboo canes	30	Black cotton cover	2,2	Cotton 40 m	12	1 m looped cotton rope set each 2 m (20m)	3,3	4+3=7	8,9	5	0,5	61,9	47,5	14,4	76,7
BIOFAD_A2.2	4 bamboo canes Metallic frame	12 12,2	Doble Black cotton cover	4,4	Cotton 40 m	12	1 m looped cotton rope set each 2 m (20m)	3,3	4+3=7	8,9	5	0,5	58,3	31,7	26,6	54,4
BIOFAD_B1	10 bamboo canes	30	Black cotton cover	2,2	Cotton 80 m	24	1 m looped cotton rope set each 2 m (40m)	6,6	4+3=7	8,9	15	0,5	87,2	62,8	24,4	72,0
BIOFAD_B1.3	4 bamboo canes Metallic frame	12 12,2	Doble Black cotton cover	4,4	Cotton 80 m	24	1 m looped cotton rope set each 2 m (40m)	6,6	4+3=7	8,9	15	0,5	83,6	47	36,6	56,2
BIOFAD_B1.5	Metallic frame	12,2	Doble Black cotton cover	4,4	Cotton 80 m	24	1 m looped cotton rope set each 2 m (40m)	6,6	4+3=7	8,9	15	0,5	71,6	35	36,6	48,9
BIOFAD_B2	6 bamboo canes (18kg) Pallet (31kg)	18 31	Black cotton cover	2,2	Cotton 80 m	24	1 m looped cotton rope set each 2 m (40m)	6,6	4+3=7	8,9	15	0,5	106,2	81,8	24,4	77,0
BIOFAD_B2.2 "Cube"	Doble Metallic frame	24,4	Doble Black cotton cover	4,4	-	0	cotton rope 4 x 3 m (12 m) Looped cotton rope 16 x 3 m (48 m)	3,6 7,9	3+3=6	7,6	0	0,5	48,4	15,9	32,5	32,9
BIOFAD_C	10 bamboo canes	30	Black cotton cover	2,2	-	0	Looped cotton rope 8 x 5 m (40 m)	6,6	4+3=7	8,9	0	0,5	48,2	38,8	9,4	80,5
BIOFAD_C.3	4 bamboo canes Metallic frame	12 12,2	Doble Black cotton cover	4,4	-	0	Looped cotton rope 8 x 5 m (40 m)	6,6	4+3=7	8,9	0	0,5	44,6	23	21,6	51,6
NE FAD _1 "conventional"	Metallic frame 4 bamboo canes	12,2 12	Synthetic black raffia Polyester net mesh size < 3 mm	2,1 2,2	80m* Twisted polyamide net and tied	54	Flags of synthetic raffia 1mx1,5m	4,5	4+3=7	8,9	25	0,5	121,4	12	109,4	9,9
NE FAD_2 "semi-surmerged"	Metallic frame	12,2	Synthetic black raffia Polyester net mesh size < 3 mm	2,1 2,2	80m* Polyethylene rope 20 mm Ø	16	Flags of synthetic raffia 1mx1,5m	4,5	6+2=8	10,1	15	0,5	62,6	0	62,6	0,0
NE FAD_3 "cube"	Doble Metallic frame	24,4	Synthetic black raffia Polyester net mesh size < 3 mm	2,1 4	No	0	Flags of synthetic raffia Polyethylene rope 16 x 3 m (48 m)	1,2 9,6	4+6=10	12,6	0	0.5	54,4	0	54,4	0,0
NE FAD_4 "superficial"	Metallic frame 4 bamboo canes	12,2 12	Synthetic black raffia Polyester net mesh size < 3 mm	2,1 2,2	No	0	8 x 5m (40m) Polyethylene rope 20 mm Ø	8	4+3=7	8,9	0	0,5	45,9	12	33,9	26,1

* Mean value estimated from data collected at FADs Logbook.

IMPORTANT: The weight of the 80 m twisted polyamide net and tied was estimated using the weight of a 23 m depth tail: total weight 15,5 kg and composed by nylon twine of 1,3 mm and 195 mm mesh size.
These materials identified as biodegradable follow the definition proposed by the Consortium for BIOFAD (Zudaire et al., 2018)