Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem

European Maritime and Fisheries Fund (EMFF)

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Provision of Scientific Advice for Fisheries Beyond EU Waters

Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem

Final Report

Executive Agency for Small and Medium-sized Enterprises (EASME)
European Maritime and Fisheries Fund (EMFF)
EASME/EMFF/2016/008 Provision of Scientific Advice for fisheries beyond EU Waters
"Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem"
2020

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2. EXECUTIVE SUMMARY.

2.1. Executive summary.

This report refers to the Framework Contract EASME/EMFF/2016/008 and, specifically, to Specific Contract Nº7 EASME/EMFF/2017/1.3.2.6 "Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem". The main objective of the project is to test the use of specific biodegradable materials and designs for the construction of non-entangling and biodegradable fish aggregating devices (BIOFADs) in at sea natural environmental conditions. This study aims to provide criteria and guidelines to identify options to mitigate drifting FADs impacts on the ecosystem (e.g., marine litter, FAD beaching and ghost fishing). It also assesses the efficiency of BIOFAD and the socio-economic viability of phasing out of non-entangling FADs (NEFAD) by BIOFADs in the purse seine tropical tuna fishery in the Indian Ocean. Finally, it suggests potential biodegradable materials and designs providing recommendations to promote the implementation of fully non-entangling and biodegradable FADs.

The project has been involved in several developments and aims:

- To design BIOFAD prototypes using biodegradable materials for their construction and to test them at a large-scale at sea in trials in the Indian Ocean,
- To assess the efficiency of BIOFADs in terms of catch, presence and aggregation of tuna; and to estimate the impacts generated by FADs in the ecosystem,
- To assess socio-economic impacts associated with the use of BIOFADs in the tuna purse seine fishery in the Indian Ocean.

The objective of this final report is to explain the work undertaken, giving details of the implementation and results of the specific tasks. The final section in each task report also lists recommendations for future work to improve the implementation of BIOFAD in the Indian Ocean.

To this end the following tasks were proposed and have been developed:

Task 1 reviewed the state of the art regarding the use, development and worldwide impacts of conventional FADs (i.e., entangling and non-biodegradable), NEFADs (i.e., non-entangling and non-biodegradable) and BIOFADs (i.e., non-entangling and biodegradable). This was done by discussing past and on-going initiatives from the Atlantic, Indian and Pacific Oceans. FADs generated impacts such as higher bycatch than in free school sets, ecological trap, ghost fishing and marine pollution were also considered in the review. In addition, FAD types according to entanglement risks and use in each ocean were described. Finally, a summary including previous and current trials regarding biodegradable materials and NEFADs conducted worldwide was provided.

Task 2 carried out the selection of materials and designs for BIOFAD construction based on previous experiences and by conducting different participatory approach workshops with all stakeholders before and during the BIOFAD deployment period. In total three main BIOFAD workshops were conducted: *1st BIOFAD WS* to define the prototypes and materials to be tested and to define the experimental protocols (e.g. BIOFAD construction, deployment strategy, data collection/reporting) to be applied during the project. *2nd and 3rd BIOFAD WS* to provide project progress information to all stakeholders and obtain feedback from involved fleet participants. In addition, other workshops and meetings were organized in order to strengthen the engagement of the fleet with the objectives of the project and defined protocols.

The assessment of the advantages and disadvantaged of different biodegradable materials and designs was considered, by characterizing tested BIOFAD prototypes in terms of used materials and quantity. The total amount of material used in FAD construction and its biodegradable and synthetic fractions were also assessed, focusing as well in the plastic fraction of both FAD types (i.e., BIOFAD and NEFAD). The degradation of tested materials (cotton canvas and two types of cotton ropes) were also assessed to identify pros and cons of each of these materials. The results showed a relatively good performance of cotton ropes while the cotton canvas did not meet the expected performance.

Further alternative materials were also tested as potential options for future sustainable FAD constructions. For this, a screening of functionality of biobased, biodegradables and recycled (from marine litter) material candidates was conducted.

For the first-time a tentative BIOFAD definition was provided. To establish a potential definition for BIOFADs, besides regulation issues, the type of materials and configuration, the environmental impacts, the durability and functionality and technical feasibility were considered. The definition was developed and based on material specifications (e.g., *lignocellulosic materials and/or bio-based biodegradable plastic compounds*) rather than the final product (e.g., floats or the FADs themselves).

A large-scale at-sea BIOFAD deployment strategy was defined in order to obtain required data to perform a robust analysis (i.e., initial goal of 1000 BIOFADs deployment). The best deployment strategy for BIOFADs also accounted for potential seasonality effects. Finally, 771 BIOFADs were deployed during the project covering the all fishery operational areas of the tropical tuna PS fleet in the Western Indian Ocean throughout the year.

Task 3 evaluated BIOFADs behavior and performance in comparison to currently used NEFADs. This aassessment and comparison of the behavior and performance of NEFADs and BIOFADs considered: (i) tuna catches, (ii) presence/absence of tuna to estimate first detection values of tuna and ratios of FAD occupation, and (iii) tuna aggregation biomass indices to estimate daily aggregation, biomass estimation regarding the time spent at sea and the distance between pairs of BIOFADs and NEFADs. Tuna was first detected at around

35 days in both FAD types, and only the analysis at prototype level showed some larger differences between FAD types but without a clear pattern between them. Ratios of FAD occupation by tuna were higher in NEFADs than in BIOFADs. Overall, tuna biomass estimation did not show remarkable differences between the two FAD types, neither in daily aggregations nor in biomass estimation regarding months at sea and distance between pairs.

The lifespan of BIOFADs and NEFADs was also assessed by the period (in days) between the day of first deployment and the day when the FAD was considered no longer active. 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 a NEFAD of 493 days).

In addition, the assessment also included a validation procedure for the collected data and a life-cycle assessment of different designs to identify the best performing designs. Impacts in terms of carbon footprint and marine aquatic ecotoxicity were assessed for tested BIOFAD and NEFAD prototypes. This was applied to study the impact generated by the construction of individual prototypes. Impacts were also assessed considering different functional units (e.g., tons of tuna catch) and the replacement rate of materials used in FAD construction was also taken into account in the analysis. The C BIOFAD prototypes performed the best in terms of lowest carbon footprint and followed by the B1 BIOFADs. The results indicated that, as one would expect, the more material used in a FAD the higher its environmental impact score. The option of doubling material use (i.e. double canvas or double metallic frame) to expand the life span of FADs consequently increased the environmental impact of FADs for both carbon footprint and marine ecotoxicity significantly.

Task 4 assessed the socio-economic impacts of replacing NEFADs with BIOFADs. Assessment of the socio-economic impacts of BIOFADs use and their phasing-in included an analysis of the possible costs and profits of the replacement process in the EU fleet. This analysis considered the implementation of these new BIOFADs in the tuna purse seine fishery in the short- and long-term. For that several scenarios were tested depending on the fish price premium and catchability. Regarding catchability, the price premium range considered went from 0% to 10%, as a premium of 10% is enough to estimate how much does the price need to be increased to offset additional costs of using BIOFADs. The maximum drop in revenues for replacing NEFADs by BIOFADs was 12%, when there was no price premium and the catchability of BIOFADs was much lower than for NEFADs. But if a price premium of 10% took place and the catchability of BIOFADs equalled that of NEFADs, the revenues could increase by 10%. Furthermore, potential market incentives (e.g., eco-friendly labelling, etc.) encouraging the use of BIOFADs was also considered when projections of new scenarios were conducted. The potential job creation linked to the production of BIOFADs was also explored. On average labor costs due component replacements increased from 24% to 34% when using BIOFADs and therefore, employment levels would also increase.

Task 5 aimed to make recommendations to construct the most efficient BIOFAD prototypes. The feasibility of using new biodegradable materials by the European fleet was assessed analyzing the different outcomes produced in previous tasks (Task 2-4) to recommend several optimum BIOFAD prototypes. Each of the parameters assessed during the project were analyzed separately to provide guidance in the definition of the optimum BIOFAD prototype and advance towards the full implementation of non-entangling and biodegradable FADs in the Indian Ocean.

2.2. Resumen Ejecutivo.

Este informe hace referencia al Contrato Marco EASME/EMFF/2016/008, concretamente, al Contrato Específico Nº 7 EASME/EMFF/2017/1.3.2.6 "Testing designs and identify options to mitigate impacts of drifting FADs on the ecosystem". El objetivo principal del proyecto es testar el uso de materiales biodegradables y diseños específicos en la construcción de los dispositivos concentradores de peces no enmallantes y biodegradables (BIOFAD) en condiciones ambientales reales en el mar. Este estudio pretende proporcionar criterios y directrices para identificar opciones para mitigar los impactos de los dispositivos concentradores de peces (DCP) de deriva en el ecosistema (ej., desechos marinos, varamientos de DCP y pesca fantasma). Asimismo, se evalúa la eficiencia de los BIOFAD y la viabilidad socioeconómica del proceso de eliminación gradual de los DCP no enmallantes (NEFAD) por los BIOFAD en uso por la flota de cerco de atuneros tropicales que operan en el Océano Índico. Por último, se sugieren materiales biodegradables y diseños potenciales, y se formulan recomendaciones para promover la implantación de los DCP totalmente no enmallantes y biodegradables.

El proyecto ha estado involucrado en diversos desarrollos y objetivos:

- Diseñar prototipos de BIOFAD utilizando materiales biodegradables para su construcción y testarlos en pruebas a gran escala en el Océano Índico,
- Evaluar la eficiencia de los BIOFAD en términos de captura, presencia y agregación de atún; y estimar los impactos generados por los DCP en el ecosistema,
- Evaluar los efectos socioeconómicos asociados al uso de los BIOFAD en la industria de cerco de atuneros tropicales en el Océano Índico.

El objetivo de este Informe Final es explicar la labor realizada, dando detalles de la implementación y los resultados de las tareas específicas. Se ha incluido una sección final en cada tarea incluye también un listado con las recomendaciones para futuros trabajos destinado a mejorar la implementación de los BIOFADs en el Océano Índico.

Con este fin se proponen y se desarrollan las siguientes tareas:

La **Tarea 1** examinó el estado del arte con relación al uso, el desarrollo y los impactos generados por los DCP convencionales (es decir, enmallantes y no biodegradables), los NEFAD (es decir, no enmallantes y no biodegradables) y los BIOFAD (es decir, no enmallantes y biodegradables) a nivel mundial. Para ello, se revisaron iniciativas previas y en curso en los océanos Atlántico, Índico y Pacífico. El análisis tuvo en consideración los impactos de los DCPs, como es una mayor captura incidental que en los lances a banco libre, la trampa ecológica, la pesca fantasma y la contaminación marina. Asimismo, se describieron los tipos de DCPs según los riesgos de enmallamiento y su uso en cada océano. Por último, se presentó un resumen incluyendo las investigaciones previas y actuales relativas a los materiales biodegradables y los NEFADs realizados en todo el mundo.

La **Tarea 2** llevó a cabo la selección del material y los diseños para la construcción de los BIOFAD teniendo como referencia las experiencias previas y mediante la realización de diferentes talleres con un enfoque participativo con todas las partes interesadas antes y durante el período de plantado de los BIOFADs. En total se realizaron tres talleres principales de BIOFAD: el *1º taller de BIOFAD*, tuvo como objetivo definir los prototipos y los materiales a ser testados y establecer los protocolos experimentales (ej., la construcción del BIOFAD, la estrategia de plantado, la recogida y envío de datos) a ser implementados durante el proyecto. El *2º* y *3º taller de BIOFAD* tuvieron como objetivo proporcionar, a todas las partes implicadas, la información adquirida durante el proyecto y obtener la valoración de la evolución del proyecto directamente de la flota involucrada. Asimismo, se organizaron otros talleres prácticos y reuniones para reforzar el compromiso de la flota con los objetivos del proyecto y los protocolos definidos.

Se evaluaron las ventajas y desventajas de los diferentes materiales y diseños biodegradables, mediante la caracterización de los prototipos de BIOFAD testados en cuanto a los materiales y cantidades utilizadas. Asimismo se evaluó la cantidad total de material utilizada en la construcción de los DCP y las fracciones biodegradables y sintéticas de los mismos, centrándose también en la fracción plástica de ambos tipos de DCP (es decir, BIOFAD y NEFAD). En línea con esto, se evaluó la degradación de los materiales testados (la lona de algodón y los dos tipos de cabos de algodón) para identificar las ventajas y desventajas de cada uno de estos materiales. Los resultados mostraron un rendimiento relativamente bueno de los cabos de algodón, mientras que la lona de algodón no alcanzó el rendimiento esperado por la flota.

Complementariamente, se ensayaron otros materiales alternativos como posibles opciones para futuras construcciones sostenibles de los DCP. Para ello, se llevó a cabo una revisión de la funcionalidad de diversos materiales candidatos como los materiales biobased, biodegradables y reciclados (procedentes de desechos marinos).

Por primera vez, se proporcionó una definición provisional de BIOFAD. Para poder establecer esta definición potencial de BIOFAD, además de las cuestiones de regulación, se consideraron el tipo de materiales y su configuración, los impactos ambientales generados, la durabilidad y la funcionalidad, así como la viabilidad técnica. La definición de BIOFAD se elaboró y se basó en las especificaciones de los materiales (ej., materiales lignocelulósicos y/o compuestos plásticos biodegradables de base biológica) en lugar del producto final (ej., flotadores o el propio DCP en sí).

Se definió una estrategia de plantado de los BIOFAD a gran escala en el mar con el fin de obtener los datos necesarios para realizar un análisis sólido (el objetivo inicial de plantado fue de 1000 BIOFAD). La estrategia de plantado de BIOFAD más adecuada también tuvo en cuenta el posible efecto estacional. Finalmente, durante el proyecto se plantaron 771 BIOFAD, cubriendo, a lo largo de todo un año, las zonas del Océano Índico occidental donde opera la flota de cerco de atuneros tropicales.

La **Tarea 3** evaluó el comportamiento y el rendimiento de los BIOFAD en comparación con los NEFAD actualmente utilizados por la flota de cerco atunera. Para esta evaluación y comparación del comportamiento y el rendimiento de los BIOFAD y NEFAD se tuvo en cuenta: (i) las capturas de atún, (ii) la presencia/ausencia de atún para estimar los valores de primera detección de atún y los porcentajes de ocupación de los DCP, y (iii) los índices de agregación de biomasa de atún para estimar la agregación diaria, estimación de biomasa relativa al tiempo de permanencia en el mar y la distancia entre parejas de BIOFAD y NEFAD. El atún fue detectado por primera vez aproximadamente a los 35 días en ambos tipos de DCPs, y sólo el análisis a nivel de prototipo mostró algunas diferencias mayores entre los tipos de DCPs, sin que se observara un patrón claro entre ellos. Los índices de ocupación de DCPs fueron mayores en los NEFAD que en los BIOFAD. En general, la estimación de la biomasa de atún no mostró diferencias notables entre los dos tipos de DCPs en las agregaciones diarias, en las estimaciones de la biomasa respecto al tiempo de permanencia en el mar, ni tampoco respecto a las distancias entre parejas de DCPs.

La vida útil de los BIOFAD y los NEFAD se evaluó con relación al período (en días) entre el primer día de plantado y el día en el que el DCP se consideró no activo. Todos los prototipos, para ambos tipos de DCP, mostraron una vida útil máxima superior a 1 año (vida útil máxima para un BIOFAD de 483 días y para un NEFAD de 493 días).

Asimismo, la evaluación incluyó un procedimiento para la validación de los datos recogidos y una evaluación del ciclo de vida de los diferentes diseños con el fin de identificar los diseños con mejor rendimiento. Se evaluaron los impactos en términos de huella de carbono y ecotoxicidad acuática marina para cada prototipo testado de BIOFAD y NEFAD. Esto se aplicó con el fin de estudiar el impacto generado por la construcción de cada prototipo. Los impactos también se evaluaron considerando diferentes unidades funcionales (ej., toneladas de captura de atún). En el análisis también se consideró la tasa de sustitución de los materiales utilizados en la construcción de los DCP. Los prototipos C

BIOFAD obtuvieron los mejores resultados en cuanto a la menor huella de carbono generada, seguidos por los BIOFAD B1. Los resultados indicaron que, como era de esperar, a mayor uso de material en la construcción de un DCP, mayor era su puntuación de impacto ambiental. La opción de duplicar el uso de material (es decir, doble lona o doble marco metálico), permitido por el Consorcio con el objetivo de alargar la vida útil de los DCPs, aumentó en consecuencia, de manera significativa, el impacto ambiental de estos, tanto en lo que respecta a la huella de carbono como a la ecotoxicidad marina.

La **Tarea 4** evaluó los impactos socioeconómicos de la sustitución de los NEFAD por los BIOFAD. La evaluación de los impactos socioeconómicos de la introducción gradual incluyó un análisis de los posibles costes y beneficios del proceso de sustitución en la flota de cerco de atuneros tropicales de la UE. En este análisis se consideró la aplicación de esos nuevos BIOFAD a corto y largo plazo. Para ello se proyectaron varios escenarios en función de la prima del precio del pescado y la capturabilidad del tipo DCP. En cuanto a la capturabilidad, el rango de prima de precio considerado fue de 0% a 10%, ya que una prima del 10% es suficiente para estimar cuánto debe aumentarse el precio para compensar los costos adicionales del uso de los BIOFAD. La máxima caída de los ingresos por la sustitución de NEFAD por BIOFAD fue del 12%, cuando no había prima de precio y la capturabilidad de los BIOFAD era mucho menor que la de los NEFAD. En el caso de que hubiese una prima de precio del 10% y la capturabilidad de los BIOFAD fuera igual a la de los NEFAD, los ingresos podían aumentar un 10%. Asimismo, los posibles incentivos de mercado (ej., el etiquetado ecológico, etc.) que fomentan el uso de los BIOFAD también se tuvieron en cuenta cuando se realizaron las proyecciones de los nuevos escenarios. De la misma manera se exploró el potencial de creación de empleo vinculado a la producción de BIOFAD. En promedio, los costos laborales derivados de la sustitución de componentes aumentaron del 24% al 34% cuando se utilizaron BIOFAD y, en ese caso, los niveles de empleo también aumentarían.

La **Tarea 5** tenía como objetivo hacer recomendaciones para la construcción de los prototipos de BIOFAD más eficientes. La viabilidad de utilizar nuevos materiales biodegradables por la flota europea fue evaluada analizando los diferentes resultados obtenidos en las tareas previas (Tarea 2-4) para recomendar varios prototipos óptimos de BIOFAD. Cada uno de los parámetros evaluados durante el proyecto se analizó independientemente para orientar en la definición del prototipo óptimo de BIOFAD y avanzar hacia la plena implantación de los DCP no enmallantes y biodegradables en el Océano Índico.

2.3. Résumé Executif.

Le présent rapport se réfère au contrat-cadre EASME/EMFF/2016/008 et, plus précisément, au contrat spécifique n°7 EASME/EMFF/2017/1.3.2.6 "Tester les plans et identifier les possibilités pour atténuer les impacts des DCP dérivants sur l'écosystème". L'objectif principal du projet est de tester l'utilisation de matériaux et de conceptions biodégradables spécifiques pour la construction de dispositifs de concentration de poissons biodégradables et non maillants (BIOFAD) dans des conditions environnementales naturelles en mer. Cette étude vise à fournir des critères et des lignes directrices pour identifier les options permettant d'atténuer les impacts des DCP dérivants sur l'écosystème (par exemple, la pollution marine, l'échouage des DCP et la pêche fantôme). Elle évalue également l'efficacité des BIOFAD et la viabilité socio-économique du remplacement progressif des DCP non maillants (NEFAD) par les BIOFAD dans la pêche aux thons tropicaux à la senne coulissante dans l'océan Indien. Enfin, elle suggère des matériaux et des conceptions biodégradables potentielles et formule des recommandations pour promouvoir la mise en œuvre de DCP totalement non maillants et biodégradables.

Le projet a été impliqué dans plusieurs développements et objectifs :

- Concevoir des prototypes de BIOFAD en utilisant des matériaux biodégradables pour leur construction et les tester à grande échelle en mer lors d'essais dans l'océan Indien,
- Évaluer l'efficacité des DCP en termes de capture, de présence et d'agrégation de thon ; et estimer les impacts générés par les DCP dans l'écosystème,
- Évaluer les impacts socio-économiques liés à l'utilisation des DCP dans la pêche au thon à la senne coulissante dans l'océan Indien.

L'objectif de ce rapport final est d'expliquer le travail entrepris, en donnant des détails sur la mise en œuvre et les résultats des tâches spécifiques. La dernière section de chaque rapport de tâche énumère également des recommandations pour les travaux futurs visant à améliorer la mise en œuvre des DCP dans l'océan Indien.

À cette fin, les tâches suivantes ont été proposées et développées :

La **Tâche 1** a examiné l'état de l'art concernant l'utilisation, le développement et les impacts mondiaux des DCP conventionnels (c'est-à-dire maillants et non biodégradables), des NEFAD (c'est-à-dire non maillants et non biodégradables) et des BIOFAD (c'est-à-dire non maillants et biodégradables). Pour ce faire, les initiatives passées et en cours dans les océans Atlantique, Indien et Pacifique ont été examinées. Les impacts générés par les DCP tels que prises accessoires plus importantes que dans les bancs libres, piège écologique, pêche fantôme et pollution marine ont également été pris en compte dans l'examen. En outre, ont été décrits les types de DCP en fonction des risques de maillage et de leur utilisation dans chaque océan. Enfin, nous incluons un résumé comprenant les essais antérieurs et actuels concernant les matériaux biodégradables et les DCP réalisés dans le monde.

La **Tâche 2** a permis de sélectionner les matériaux et les conceptions pour la construction de BIOFAD sur la base des expériences précédentes et en organisant différents ateliers participatifs avec toutes les parties prenantes avant et pendant la période de déploiement des BIOFAD. Au total, trois ateliers BIOFAD principaux ont été organisés : le *premier atelier BIOFAD* pour définir les prototypes et les matériaux à tester et pour définir les protocoles expérimentaux (par exemple, la construction de BIOFAD, la stratégie de déploiement, la collecte de données/les rapports) à appliquer pendant le projet. Les *2ème et 3ème ateliers BIOFAD* pour fournir des informations sur l'avancement du projet à toutes les parties prenantes et obtenir un retour d'information de la part des participants de la flotte concernée. En outre, d'autres ateliers et réunions ont été organisés pour renforcer l'engagement de la flotte par rapport aux objectifs du projet et aux protocoles définis.

L'évaluation des avantages et des inconvénients des différents matériaux et conceptions biodégradables a été prise en compte, en caractérisant les prototypes BIOFAD testés en termes de matériaux utilisés et de quantité. La quantité totale de matériaux utilisés dans la construction des DCP et ses composants biodégradables et synthétiques a également été évaluée, en se concentrant également sur la fraction plastique des deux types de DCP (c'est-à-dire BIOFAD et NEFAD). La dégradation des matériaux testés (toile de coton et deux types de cordes de coton) a également été évaluée afin d'identifier les avantages et les inconvénients de chacun de ces matériaux. Les résultats ont montré une performance relativement bonne des cordes de coton alors que la toile de coton n'a pas atteint la performance attendue.

D'autres matériaux alternatifs ont également été testés en tant qu'options potentielles pour les futures constructions durables de DFA. Pour ce faire, un examen de la fonctionnalité des matériaux candidats biologiques, biodégradables et recyclés (à partir de déchets marins) a été effectué.

Pour la première fois, une définition provisoire du BIOFAD a été fournie. Pour établir une définition potentielle des BIOFAD, outre les questions de réglementation, le type de matériaux et la configuration, les impacts environnementaux, la durabilité et la fonctionnalité ainsi que la faisabilité technique ont été pris en compte. La définition a été élaborée et basée sur les spécifications des matériaux (par exemple, les matériaux lignocellulosiques et/ou les composés plastiques biodégradables d'origine biologique) plutôt que sur le produit final (par exemple, les flotteurs ou les DCP eux-mêmes).

Une stratégie de déploiement de BIOFAD en mer à grande échelle a été définie afin d'obtenir les données nécessaires pour effectuer une analyse robuste (c'est-à-dire l'objectif initial de déploiement de 1000 BIOFAD). La meilleure stratégie de déploiement des BIOFAD a également pris en compte les effets potentiels de la saisonnalité. Enfin, 771 BIOFAD ont été déployés au cours du projet, couvrant toutes les zones opérationnelles de pêche de la flotte PS de thons tropicaux dans l'océan Indien occidental tout au long de l'année.

La **Tâche 3** a évalué le comportement et les performances des BIOFAD par rapport aux NEFAD actuellement utilisés. Cette évaluation et cette comparaison du comportement et de la performance des NEFAD et des BIOFAD a pris en compte : (i) les captures de thon, (ii) la présence/absence de thon pour estimer les valeurs de première détection de thon et les ratios d'occupation des DCP, et (iii) les indices de biomasse d'agrégation de thon pour estimer l'agrégation quotidienne, l'estimation de la biomasse concernant le temps passé en mer et la distance entre les paires de NEFAD et BIOFAD. Le thon a été détecté pour la première fois à environ 35 jours dans les deux types de DCP, et seule l'analyse au niveau du prototype a montré des différences plus importantes entre les types de DCP, mais sans qu'il y ait un schéma clair entre eux. Les ratios d'occupation des DCP par les thons étaient plus élevés dans les NEFAD que dans les BIOFAD. Dans l'ensemble, l'estimation de la biomasse des thons n'a pas montré de différences remarquables entre les deux types de DCP, ni pour les agrégations quotidiennes ni pour l'estimation de la biomasse concernant les mois en mer et la distance entre les paires.

La durée de vie des BIOFAD et des NEFAD a également été évaluée en fonction de la période (en jours) entre le jour du premier déploiement et le jour où le DCP est considéré comme n'étant plus actif. Tous les prototypes, pour les deux types de DCP, ont montré une durée de vie maximale supérieure à 1 an (durée de vie maximale pour un BIOFAD de 483 jours et pour un NEFAD de 493 jours).

En outre, l'évaluation comprenait également une procédure de validation des données collectées et une évaluation du cycle de vie des différents modèles afin d'identifier les plus performants. Les impacts en termes d'empreinte carbone et d'écotoxicité aquatique marine ont été évalués pour les prototypes de BIOFAD et NEFAD testés. Cette méthode a été appliquée pour étudier l'impact généré par la construction des prototypes individuels. Les impacts ont également été évalués en tenant compte de différentes unités fonctionnelles (par exemple, les tonnes de thon capturé) et le taux de remplacement des matériaux utilisés dans la construction des DCP a également été pris en compte dans l'analyse. Les prototypes C de BIOFAD ont obtenu les meilleurs résultats en termes de faible empreinte carbone, suivis par les BIOFAD B1. Les résultats ont indiqué que, comme on pouvait s'y attendre, plus le nombre de matériaux utilisés dans un DCP est élevé, plus son impact sur l'environnement est important. L'option consistant à doubler l'utilisation de matériaux (c'est-à-dire une double toile ou un double cadre métallique) pour prolonger la durée de vie des DCP a donc augmenté de manière significative l'impact environnemental des DCP, tant en termes d'empreinte carbone que d'écotoxicité marine.

La **Tâche 4** a permis d'évaluer les impacts socio-économiques du remplacement des NEFAD par des BIOFAD. L'évaluation des impacts socio-économiques de l'utilisation des BIOFAD et de leur mise en place progressive comprenait une analyse des coûts et des bénéfices possibles du processus de remplacement dans la flotte de l'UE. Cette analyse a porté sur la mise en œuvre de ces nouveaux BIOFAD dans la pêche au thon à la senne coulissante à court et à long terme. Pour cela, plusieurs scénarios ont été testés en fonction de la majoration de prix du poisson et de la capturabilité. En ce qui concerne la capturabilité, la fourchette de majoration de prix considérée variait de 0 à 10 %, une prime de 10 % étant suffisante pour estimer de combien le prix doit être augmenté pour compenser les coûts supplémentaires liés à l'utilisation des BIOFAD. La baisse maximale des recettes pour le remplacement des NEFAD par des BIOFAD était de 12 %, lorsqu'il n'y avait pas de majoration de prix et que la capturabilité des BIOFAD était beaucoup plus faible que celle des NEFAD. Mais si une majoration de prix de 10 % était appliquée et que la capacité de capture des BIOFAD était égale à celle des NEFAD, les recettes pourraient alors augmenter de 10 %. En outre, les incitations potentielles du marché (par exemple un label écologique, etc.) encourageant l'utilisation des BIOFAD ont également été prises en compte lors des projections de nouveaux scénarios. La création potentielle d'emplois liée à la production de BIOFAD a également été étudiée. En moyenne, les coûts de main-d'œuvre dus au remplacement des composants sont passés de 24 % à 34 % lors de l'utilisation des BIOFAD et, par conséquent, les niveaux d'emploi augmenteraient également.

La **Tâche 5** visait à faire des recommandations pour construire les prototypes de BIOFAD les plus efficaces. La faisabilité de l'utilisation de nouveaux matériaux biodégradables par la flotte européenne a été évaluée en analysant les différents résultats obtenus lors des tâches précédentes (tâche 2-4) afin de recommander plusieurs prototypes BIOFAD optimaux. Chacun des paramètres évalués au cours du projet a été analysé séparément afin de fournir des orientations pour la définition du prototype BIOFAD optimal et de progresser vers la mise en œuvre complète de DCP non maillants et biodégradables dans l'océan Indien.

3. INTRODUCTION.

3.1. General introduction to the specific contract.

EASME commissioned the AZTI led consortium (AZTI, AGROCAMPUS, CEFAS, IEO, IPMA, IMARES, IRD, MRAG) to fulfil the request under the Framework Contract EASME/EMFF/2016/008 on the "*Provision of scientific advice for fisheries beyond EU waters*". The present Final report refers to the Specific Contract (SC) Nº 7 within this framework.

The purpose of this specific contract was to provide the Directorate-General for Maritime Affairs and Fisheries (DG MARE) with a technical and scientific analysis on FADs, specifically:

i) to test the use of specific biodegradable materials and designs for the construction of drifting FADs in natural environmental conditions.

ii) to identify options to mitigate drifting FADs impacts on the ecosystem, and

iii) to assess the socio-economic viability of the use of BIOFADs (i.e. non-entangling and biodegradable) in the tropical tuna purse seine fishery.

These aims were achieved through five specific objectives:

1) Revising the state of the art of the use of "conventional FADs" (i.e. entangling and non-biodegradable), "NEFADs" (i.e. non-entangling and non-biodegradable) and "BIOFADs" (i.e. non-entangling and biodegradable) worldwide.
2) Evaluating the performance (e.g., lifetime) of specific biodegradable materials and designs of FADs in natural environmental conditions to address the concerns of tuna regional fisheries management organizations (tRFMO) concerns such as marine littering and other impacts on habitat.
3) Testing, comparing and measuring the efficiency of new BIOFADs against existing non-entangling and non-biodegradable FADs to aggregate tuna and non-tuna species in the natural environment with the involvement of the EU purse seine fishing fleet.
4) Assessing the socio-economic impacts of BIOFAD use and their phasing-in.
5) Assessing the feasibility of using new biodegradable materials by the European fleet and providing recommendations for optimal BIOFAD prototypes.

The starting point for the development of this study was based on the outputs of previous initiatives (e.g., ECOFAD project, EU FP7 MADE project, BIOFAD Calvo, etc.) and current ones being undertaken, for example, by the Inter-American Tropical Tuna Commission (IATTC) (e.g., twin BIOFAD project with EU funding), the International Seafood Sustainability Foundation (ISSF) (e.g., biodegradable FAD trials with INPESCA), or by the tuna fishing industry (e.g., voluntary initiatives by different companies trying out new biodegradable prototypes in the Atlantic, Pacific and Indian Oceans).

To this end the following tasks were proposed and have been developed:

- **Task 1. Review the state of the art of FAD use, development, and impacts:** State of the art regarding the use, development and worldwide impacts of conventional FADs (i.e., entangling and non-biodegradable), NEFADs (i.e., non-entangling and non-biodegradable) and BIOFADs (i.e., non-entangling and biodegradable), through discussing on-going initiatives from the Atlantic, Indian and Pacific Ocean. This review will also include information on the data available to assess the adverse impacts of FADs in marine ecosystem and to manage them in terms of use and impacts (e.g., degradation) by tRFMOs.

- **Task 2. Selection of materials and designs, and deployment strategy:** Assessment of the advantages and disadvantages of different biodegradable materials and designs, and the selection of materials and definition of prototypes to be used in the experiments at sea (i.e., deployment of 1000 BIOFADs). Identification of the best deployment strategy for BIOFADs and NEFADs to account for potential seasonality effects was also considered.

- **Task 3. Assessment of BIOFAD behavior and performance in comparison to NEFADs:** This comparison was done in relation to each FAD type species' aggregation efficiency and species composition. The assessment also included a validation procedure for the collected data and a life-cycle assessment of different designs to identify the best performing ones.

- **Task 4. Assessment of socio-economic impacts of replacing NEFADs with BIOFADs:** Assessment of the socio-economic impacts of BIOFAD use and their phasing-in. It included an analysis of the possible changes in costs and profits of replacing NEFADs by BIOFADs in the EU fleet and an assessment of socio-economic impacts considering the implementation of these new BIOFADs in the tuna purse seine fishery in a short- and long-term. Furthermore, potential market incentives (e.g., eco-friendly labelling, etc.) to encourage the use of BIOFADs and the potential job creation linked to BIOFADs production were explored.

- **Task 5. Recommendations and BIOFAD prototypes**: The feasibility of using new biodegradable materials by the European fleet was assessed to recommend several BIOFAD prototypes.

3.2. Geographical scope of the study.

The geographical scope of the study was the Indian Ocean. This study, which adopted the objectives of the Common Fisheries Policy (CFP) and Marine Strategy Framework Directive (MSFD, DIRECTIVE 2008/56/EC) and shared the agreement of the European Commission (EC) and different tRFMOs. The project was focused on addressing the effect that an extensive use of synthetic-material FADs can generate in terms of marine pollution, ghost fishing and other adverse impacts to vulnerable coastal habitats and marine species. Thus, this study covered the drifting FADs in areas of purse seine tropical tuna fisheries under the purview of IOTC (Indian Ocean Tuna Commission).

Data and information were gathered, compiled and analyzed, covering the three major segments of the EU fleet (ANABAC, OPAGAC and ORTHONGEL). This study also considered the results obtained by previous and ongoing initiatives such as the ECOFAD project (Goujon et al., 2012), EU FP7 MADE project, BIOFAD Calvo (Lopez et al., 2016), interviews with skippers, and the ISSF Bycatch Project, which included a specific workshop on the use of biodegradable FADs (Moreno et al. 2016). In addition, several designs for biodegradable FADs tested by the industry (e.g., PEVASA, INPESCA, ALBACORA), IATTC twin project (with EU funding) and by ISSF were considered. The databases of tRFMOs, the Data Collection Framework, national FAD plans and any other relevant sources were consulted when available to gather required information. Publications and information available from the Food and Agriculture Organization of the United Nations (FAO), tRFMOs and other relevant publications were also utilized as reference for i) different methodological approaches applied to the investigation of the biodegradable materials and FADs designs; ii) to assess adverse impacts to marine ecosystems; as well as iii) to assess the socio-economic viability of the use of BIOFADs in the tropical tuna purse seine fishery in the Indian Ocean.

The work was conducted by several partners from the consortium (AZTI, IEO and IRD), and in close collaboration with the three major segments of the EU fleet (ANABAC, OPAGAC and ORTHONGEL) and with ISSF.

3.3. Objective and structure of the report.

The objective of this Final report is to explain the work undertaken, giving details of the implementation and results of the specific tasks. The final section in each report task also lists recommendations for the future work to improve the implementation of non-entangling biodegradable FADs by the tropical tuna purse seine fleet in the Indian Ocean. Moreover, this report describes the difficulties encountered so far, and the ways used by the consortium to address them. The Final Report section reflects the structure of the tasks, from Task 1 to Task 5.

4. OBJECTIVES, METHODS, PROGRESS AND MAIN RESULTS BY TASK.

4.1. TASK 1 - REVIEW THE STATE OF THE ART REGARDING FADS USE, DEVELOPMENT AND IMPACTS WORLDWIDE.

4.1.1. OBJECTIVES.

The objective of this task was to compile information on the state of the art regarding the use, development and worldwide impacts of conventional FADs (i.e., entangling and non-biodegradable), NEFADs (i.e., non-entangling and non-biodegradable) and BIOFADs (i.e., non-entangling and biodegradable), by analyzing relevant past and on-going FAD initiatives from the Atlantic, Indian and Pacific Oceans. This review also summarizes the data available on FAD-derived adverse marine impacts and proposes methodological approaches to assess and manage them (e.g., degradation) by tRFMOs.

4.1.2. METHODOLOGY.

This was mainly a desk-based task, revising and summarizing data already compiled and new available information by region/ocean. A literature review was performed using scientific peer-reviewed papers and documents from tRFMOs, as well as reports and documents from ISSF and other international bodies (e.g., FAO, NGOs). This task compiled the knowledge acquired from previous projects like ECOFAD (Goujon et al., 2012), EU FP7 MADE, BIOFAD Calvo (Lopez et al., 2016), from interviews with skippers (e.g. Murua et al., 2018), the industry's previous experience (e.g., PEVASA, INPESCA, ALBACORA), the ISSF Bycatch Project including workshop reports on the use of biodegradable FADs (Moreno et al. 2016), and current initiatives testing and exploring biodegradable materials and FAD designs in the Atlantic, Indian and Pacific regions. This revision evaluated the rationale and the outputs of these previous trials and, if feasible, conducted quantitative and qualitative data analyses when possible.

This task involved a thorough review of the state of the art regarding the use of three main types of FADs: "Conventional FADs", "NEFADs" and "BIOFADs". The revision considered previously conducted works and whether they provided knowledge improvements in terms of:

1) BIOFAD materials and designs and, if available, their behavior and performance in comparison to conventional FADs and NEFADs, and

2) measurements and management solutions to mitigate the impacts of the three types of FADs and implementation of BIOFADs in the areas of competence of tRFMOs.

The review also involved consultations through several means (i.e. e-mail, telephone interviews, small group in-person workshops) with experts in the topic of FADs and tRFMOs, including skippers and stakeholders, to better understand the challenges associated with FAD design and deployment strategies, data collection, assessment methods and implementation of management measures.

4.1.3. MAIN RESULTS.

This subsection shows the review of the state of the art regarding FADs use, development and impacts worldwide. It gives an overview of the development of the tropical tuna purse seine fishery and fishing technology (e.g., use of FADs). Besides, FADs associated impacts (e.g., higher bycatch relative to target species than in free school sets, ecological trap, ghost fishing and marine pollution) are also analyzed. In addition, FAD types according to entanglement risks and use in each ocean are described. Finally, we provide a summary of the trials regarding biodegradable materials and NEFADs conducted worldwide.

Today most tropical tuna catches worldwide derive from FAD sets by purse seiners (PS). Several impacts have been associated with FADs including bycatch of vulnerable species, ecological trap, ghost fishing and marine pollution. These problems are often associated with the type and configuration of materials used to construct the FAD structure, particularly surplus synthetic purse seine netting. To address these issues, scientists and industry have been working on alternatives like non-entangling FADs (NEFADs) and the use of natural biodegradable materials for FAD construction that quickly break down after the working lifetime of these floating objects. There have been various pilot projects examining biodegradable NEFAD options in the last decade, but these have been few and small in scale. This document discusses some of the latest advances in biodegradable NEFADs and future perspectives.

4.1.3.1. Development of the tropical tuna PS fishery and fishing technology.

Up until the 1970s the principal extractive gears used for catching tropical tunas had been pole and line and longline (Miyake et al., 2010). Both of these methods use hooks to catch tuna individually, with pole and line catching mainly surface-dwelling skipjack tuna (*Katsuwonis pelamis*) and longline targeting adult yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) found at greater depths. However, in the late 1950s successful tropical tuna purse seining emerged after the fishing technology of nylon nets and use of power blocks of Northern European fisheries catching temperate bluefin tuna was transferred to this fishery. Tropical tuna purse seining evolved initially in the Pacific Ocean, but thereafter spread to the Atlantic and Indian Oceans. Purse seine fishing gear could take advantage of the schooling behavior of tunas, which tend to aggregate in large groups for feeding and mating. Due to the high efficiency afforded by the large purse nets (1,500-2,000 m length) enabling encirclement of great schools of tuna in a single shooting or set with up to 400 tons, this fishing mode became increasingly popular. Especially after the 1980's, with the introduction of FADs providing large access to skipjack stocks, purse seine catches rapidly reached 3 million tons or 70% of global tuna catches (Miyake et al, 2010).

There are three types of fishing sets depending on the kind of association shown by tuna. The first is free school tuna, where larger adult individuals roaming in groups for food are caught. These schools are located by using helicopters or high-power binoculars that identify foaming in the sea surface caused by fast swimming tuna surfacing to catch their prey. These sets provide high-quality tuna but are more difficult to catch due to the effort in locating the schools and the fast escape response of these adult fish (e.g., higher incidence of null or failed sets) (Hall and Roman, 2013). Another type of sets are dolphin sets, which is a quite specific case as it only occurs regularly in a very restricted zone in the Eastern Pacific Ocean. In the Pacific waters of Central America adult yellowfin tuna schools associate with pods of dolphins and purse seiners target these schools. Specialized skipper training and fishing operations are in place (e.g., backdown procedure) to prevent dolphin mortality in these sets (Hall, 1998). The third type of set, and the one of most interest for this review, is the floating object set. These are sets on natural or artificial floating objects around which tunas and several other oceanic species aggregate.

Many fish species, including tunas, show a tendency to aggregate around objects floating in the sea (Castro et al., 2002). Among the most accepted theory is the "indicator log hypothesis" which states that tunas and other fish evolved to group under floating logs as often these originated from nutrient-rich coastal river run-offs or accumulate in strong convergence areas; thus, acting as markers or indicators for the presence of food-abundant productive currents in the middle of the oligotrophic open ocean (Hall, 1992). Another hypothesis is the "meeting point" theory, stating that in a barren empty environment like the open ocean, floating objects provide a reference point for tuna, especially younger individuals, to meet and form bigger schools which can provide benefits in terms of defense against predators and reproductive potential (Dagorn and Freon, 1999). Indeed, these theories are non-exclusive and could help explaining the behavioral attraction of tunas and other species to floating objects.

Fishers quickly realized that drifting logs and other natural (e.g., seaweed pats, dead whale carcasses) or artificial (e.g., marine debris) floating objects could concentrate tuna, and often made sets on them. Sets on floating objects maximize catchability as tunas show a weaker escape response and most sets are successful (Gaertner et al., 2015). In the early days of the purse seine fishery, fishers randomly looked out for natural floating objects like tree trunks and branches, sometimes visiting floating object rich zones (e.g., river deltas like the Gulf of Guinea, Costa Rica Dome or the Mozambique Channel during the rainy season) to increase their rate of floating object encounters, but still the fishery mainly focused on free school sets.

The first break-through in floating object fishing strategy was the development of radio-buoy technology in the mid 1980's, which enabled tracking and locating a floating object in a restricted area (e.g., < 500 km), by tethering a buoy to a drifting log (Gaertner and Pallares, 2002). This largely expanded the use of FADs, the term referring to any man-made artificial floating objects or modified natural floating object deployed by fishers to attract tuna. Initially several logs tied together, or large logs with greater tuna attraction potential, were selected and followed with the buoys; but soon after fishers started adding artificial elements to the logs to increase tuna attraction. For example, by tying surplus purse seine net underneath to provide an underwater structure for fish to shelter, or cork line buoys to add floatability to waterlogged objects (Itano et al., 2004). Perhaps the first accounts of fully man-made drifting FADs (e.g., not just modifying a log found at sea) come from the Japanese fleet in the Western and Central Pacific, using one or several bamboo canes as floatation and open panels of old purse seine net hanging underneath (Watanabe, 1983). Similarly, in the late 1980s Spanish fishers in the Eastern Atlantic had started using rafts constructed with a basic frame made from bamboo and net corks for floatation. The raft was wrapped around in large black-colored mesh from purse seine netting (13-21-cm mesh) to provide structural strength and reduce visibility to other vessels. The submerged appendage consisted of old purse seine netting hanging loosely underneath. Similarly constructed drifting FADs (dFADs) were still being used until recent times by many fleets (except for current longer tails). At the same time, in the Eastern Pacific fishers were experimenting with FADs built in the same fashion. Prior to the dolphin-safe problematic in the late 1980's and early 1990's much of the Eastern Pacific tuna fishery had focused on dolphin sets, but after this, many boats moved to FAD-fishing as an alternative (Hall, 1998).

In the 1990s satellite position transmitting buoys with GPS technology were incorporated into FAD buoys (Itano, 2003). This revolutionized tuna fisheries, as now fishers could not only easily monitor at any distance and time of the day the location of all their FADs, but also received key information such as FAD trajectory, drifting speed, water temperature, etc. Fishers were able to travel directly to check the FADs they thought would be productive, or plan trips to areas where more of their FADs were located. By the late 1990's in most oceans annual FAD sets had superseded free school sets, expanding the fishing grounds and becoming the principal mode of tuna fishing, especially for skipjack (Fonteneau et al., 2013). In the early 2000's another technological advance, the incorporation of echo-sounders into the GPS buoys, further improved FAD-fishing efficiency by providing fishers with remote real-time information on the estimated biomass of tuna under each FAD (Lopez et al., 2014). This way fishers could know how much fish was under each dFAD and visit dFADs with the largest tuna aggregation while avoid trips to inspect empty FADs. Meanwhile, to maximize fishing time of the purse seiners, specialized supply-vessels were increasingly used to cope with FAD-related tasks such as dFAD deployments, checks, repairs, and acquiring or removing competitor's floating objects (Arrizabalaga et al., 2001).

Despite relevant advances by purse seiners in FAD-related technology such as echo-sounder buoys, and other fishing equipment (e.g., sonars, bird radars, sounders, engine power, etc.) (Itano et al., 2004), FAD structure, materials and designs had remained quite rudimentary and virtually the same since their discovery. In most oceans dFADs are characterized by the prevailing heavy use of nylon purse seine netting and floating materials like bamboo and net corks (ISSF, 2017).

4.1.3.2. FAD associated impacts.

As with any other fishing gear, there are several ecological impacts linked to the utilization of dFADs. Most of these potential negative effects have been enhanced by the intensive large-scale use of dFADs across all oceans in the last decade (Fonteneau et al., 2013).

4.1.3.2.1. Higher bycatch rates in FAD sets than in free school sets.

Free school sets are usually composed of just one species of adult target tuna (either skipjack, yellowfin or bigeye) and virtually no other bycatch. On average non-target tuna bycatch is only 0.43% of the catches (retained plus discarded) of skipjack, yellowfin and bigeye combined in free school sets (Justel-Rubio and Restrepo, 2017), which makes it one of the most selective forms of fishing anywhere. A typical FAD-set would be composed in its majority of target tuna species, mostly being adult and juvenile skipjack, and a lower proportion of juvenile yellowfin and bigeye tuna (Fonteneau et al., 2013). Floating objects sets, both natural logs and FADs, are characterized by having not only target tuna species but a mixture of other bycatch species, which can make on average 2.24% of the catches (retained plus discarded) of skipjack, yellowfin and bigeye combined (Justel-Rubio and Restrepo, 2017). Most FAD-associated bycatch comes from small pelagic tuna species of the *Auxis* group (e.g., frigate and bullet tuna) or the *Euthynnus* group (e.g., Pacific black skipjack, little tunny), making 0.80 % of the catch, but other bony fish species such as dolphinfish (*Choryphaena hippurus*), triggerfish (*Balistes spp*.), or rainbow runner (*Elagatis bipinnulata*) commonly appear too. These small pelagic tunas and pelagic bony fishes are highly productive species and their bycatch is not considered to be a threat to their oceanic stocks (Dagorn et al. 2012). Also, in smaller numbers, megafauna such as marlins, turtles or sharks can be found (Taquet et al., 2007; Lezama-Ochoa et al., 2015). These species are of greater concern due to their vulnerable population status in many oceans (Myers et al., 2007; Lewison et al., 2004). Note that all fishing gears have collateral accidental catches and that compared to other tuna fishing gears such as longline or gillnets, the percentage of bycatch in FAD-fishing is at least an order of magnitude lower (Kelleher, 2005). Nevertheless, due to the very high catches of tunas (e.g., > 4 million tons per year; FAO, 2016), the cumulative effect of bycatch could still be significant (Ruiz et al., 2018).

4.1.3.2.2. Small bigeye and yellowfin tunas.

An important impact related to FADs identified by scientists and fishery managers is the high-level of small sized (e.g. 2-5 kg) juvenile bigeye and yellowfin tunas caught in FADs. Some of the stocks of these larger tuna species, which take longer to mature and reproduce (e.g. 2-3 years), are under increasing pressure and have reached an overfished status in some regions (ISSF, 2016). As a precautionary or corrective response, tRFMOs have adopted several restrictive measures including FAD-related area closures in all oceans and, in more recent years, limits on the number of active FADs deployed per vessel in all oceans (e.g., Indian Ocean[1] 300 active FADs; Western and Central Pacific Ocean[2] and Atlantic Ocean[3] 350 active FADs and East Pacific Ocean[4] from 70 to 450 active FADs depending on the PS class). In addition, trials with short-tailed FADs have been tested to see if they attract less bigeye tuna, as these species tend to move slightly deeper in the water column compared to skipjack. However, these experimental short-tail FADs have not yielded lower catches of bigeye tunas compared to long-tailed FADs (Restrepo et al., 2016).

4.1.3.2.3. Ecological trap hypothesis.

As stated before, tunas, especially juvenile individuals, show a behavioral tendency to associate under floating objects (Castro et al., 2002). The evolution of this behavioral mechanism should, in theory, confer tunas a selective advantage, whether location of richer food areas, greater mating opportunities or increased protection from predators. Natural floating objects (e.g. logs, seaweed pats, etc.) have always existed, but their number is often limited to specific areas and seasons. Tunas can associate with a floating object from hours to several weeks (Dagorn et al., 2007). Some scientists hypothesize that the massive deployment of dFADs, which now greatly outnumbers natural logs, may keep or "trap" tunas in dFAD abundant zones, altering their normal migratory patterns (Marsac et al., 2000; Hallier and Gaertner, 2008; Wang et al., 2016). In theory, because at present dFADs are present in large numbers in most oceanic areas (Dagorn et al., 2013) including both plankton-rich and -poor ones, some tunas may stay longer than normal in low-quality habitats (e.g., low productive areas) due to their attraction to dFADs. While some studies have found tunas in higher dFADs density areas to have lower body condition factor (Hallier and Gaertner, 2008; Wang et al., 2017), which is used as an indicator measure of health status related to body energy storage, other studies have not found this relationship (Restrepo et al., 2016). Thus, it remains uncertain if the ecological trap theory is correct and further work needs to be conducted (Dagorn et al., 2012; Anonymous, 2014).

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[1] Resolution 19/02 for IOTC
[2] Recommendation 19/02 for ICCAT
[3] Resolution 17/02 for IATTC
[4] Resolution 18/01 for WCPFC

4.1.3.2.4. FAD ghost fishing

Traditionally, the principal material in dFADs construction has been surplus large mesh tuna purse seine netting, both to cover the raft and to create the submerged tail structure. Although dFADs are monitored remotely by GPS echo-sounder buoys, when dFADs are deployed they can go unchecked for weeks to months, operating like an abandoned, lost or otherwise discarded fishing gear (ALDFG) (Gilman et al., 2012). Only the dFADs with a strong fish-aggregation signal from the echo-sounder buoy will be revisited after. During this time, the wide mesh net of conventional dFADs can act as a trap that ghost fishes aggregated species. As reviewed by Stelfox et al. (2016) currently there are large knowledge gaps related to ghost fishing impacts related to dFADs.

Primarily two animal groups are known to entangle in dFADs, namely turtles and sharks. Turtles tend to get ensnared in the netting on top of the raft or in the net folds near the raft surface, when trying to climb on to the raft surface to rest. Because of this their entanglement is easier to detect visually, and fishers will rapidly release trapped turtles if they encounter them. Based on observer data, turtle entanglement in conventional dFADs is relatively low and most individuals are released alive. For example, in 2008 in the Indian Ocean (prior to non-entangling dFADs) about 250 turtles were found entangled in dFADs and over 80% of them were successfully released alive (Bourjea et al., 2014). Similar low turtle entanglement numbers have been obtained in other oceans, even when higher-risk large mesh dFADs were the norm (Hall and Roman, 2013).

Meanwhile, shark entanglement was previously thought to be a very occasional form of accidental mortality as not many events were observed. However, a study by Filmalter et al. (2013), using diver surveys and electronic tagging, estimated that shark entanglements caused five to ten times more deaths than the purse seine fishing operation itself in the Indian Ocean. This unexpected result raised the alarm of scientist and fishing industry and accelerated the move away from entangling FADs. At the time most dFADs in that ocean where built with loosely hanging open panels of very large mesh size (e.g., 7-9 inches). This study also reported that most shark entanglements go unrecorded not only because entanglement occurs several meters below the sea surface, but also because, on average, the body of the dead shark would only last one or two days entangled before falling off to the sea bottom (Filmalter et al., 2013). For dFADs in open pelagic waters almost exclusively two species of sharks are found. The principal species is the oceanic silky shark (*Carcharhinus falciformis*), making up 75-90% individuals by number, and to a much lower extent the white tip shark (*Carcharhinus longimanus*) (Hall and Roman, 2013). Most of the dFAD associated silky sharks are juveniles (Taquet et al., 2007) and probably their small size facilitated their entanglement in large mesh netting. In addition, these sharks are obligate ram ventilators, which means that if they stop moving, they will rapidly suffocate. So unlike turtles, which can survive for an extended period entangled until they are found and rescued, there is zero survival of entangled sharks. To solve the problem of ghost fishing by dFADs, fishers and scientists from several oceans have developed dFADs with entangling-preventive designs (see section on low entanglement risk FADs and non-entangling FADs).

4.1.3.2.5. Marine pollution.

Currently, the exact number of dFADs utilized by purse seiners, but also other gears such as pole and line, is unknown. Some estimate FADs deployed per year globally at 90,000-120,000 FADs (Scott and Lopez, 2014; Gersham et al., 2015). Meanwhile, the recent trend for most fleets has been towards a rapid increase in dFAD numbers (Maufroy et al., 2017). Most dFADs eventually end up sinking to the seabed or reaching coastal ecosystems such as beaches (i.e., beaching), coral reefs or mangroves. The rate of dFADs beaching in the Indian Ocean has been estimated at 10% of the total number of FADs deployed in the period between 2007 and 2011 by French fleet (Maufroy et al., 2015). The problem is that because dFADs are constructed with highly durable materials such as netting made from nylon, net corks from Ethylene Vinyl Acetate (EVA), or pipes from polyvinyl chloride (PVC), most of these materials accumulate year after year in sensible marine and coastal ecosystems because they are not easily degraded. In addition, other non-degradable dFAD materials, such as metallic framed rafts with plastic containers for floatation, have been introduced in the Indian and Atlantic Oceans in the last five years (ISSF, 2014). Furthermore, even when these materials eventually degrade after many years, the particles into which they breakdown will continue to be harmful to the marine environment. For example, by producing micro- and nano-plastic particles that enter the food chain of marine fauna (Li et al., 2016). Furthermore, FAD fishing nets entangled in highly productive environments like coral reefs have probably greater chances of causing entanglement to animals due to the high-density of species inhabiting this zone.

4.1.3.3. Types of dFADs according to entanglement risk and use in each ocean.

4.1.3.3.1. High entanglement risk FADs (HERFADS).

Conventional dFADs made from wide mesh net covering the floating part of the object and open panels (e.g. spread out net, not tied into bundles) of netting in the underwater structure were the most common type since the start of dFADs in the 1980's. These kind of dFADs have been categorized by scientists as high entanglement risk FADs (HERFADs), as they are the ones with the greatest potential to ghost fish bycatch species (ISSF, 2012; 2015; 2019). This kind of large mesh design was the one used in the Indian Ocean at the time that the study by Filmalter et al. (2013) discovered massive ghost fishing of sharks. Similar HERFAD designs were being used in most man-made floating objects across oceans up to 2013.

At present, fleets in the Indian, Atlantic, and Eastern Pacific Ocean have totally replaced or are in the process of phasing-out HERFADs. Only in the Western and Central Pacific

Ocean most operating fleets kept their traditional HERFADs. The most common type of dFAD in this region is what some call the "Korean-type FAD", used by most of the Asian fleets (e.g. Taiwan, China, South Korea, Philippines, etc.) and composing the largest proportion of purse seiners in this fishery. The float is made from a line of 6-7 net-corks, which can have a bamboo cane or a rope crossing through the middle to hold them together. The corks are then tightly wrapped in dark wide mesh (4-5 inch) purse seine netting to make them less visible and add structural strength to the floating structure. Some fishers call this type of float the "burrito". Although the burrito includes wide-mesh net, because the structure is so narrow, turtles rarely try to climb up on them to rest and their entanglement rate is extremely low (Pilling et al., 2017).

The submerged part of these HERFADs in the Western and Central Pacific consist of 40-80 m of open panel purse seine net (4-5- inch mesh), which have bamboo canes crossing at 10 m intervals to add weight to the appendage and keep the net stretched and vertical in the water column. A metallic chain or piece of net cable is often added at the end of the dFAD's tail as a weight, again to maintain the net tensed in the water column, almost acting as an underwater anchor to slow down drift. Often some panels of green-colored trawling net are inserted, and multiple colored strips are added, as some fishers think that these colors attract fish attention. Thus, these dFADs in addition to have high entanglement risk, are virtually made entirely from non-biodegradable materials if we except the bamboo canes. To date, the four main tRFMOs the Western and Central Pacific Fisheries Commission (WCPFC), the International Commission for the Conservation of Atlantic Tuna (ICCAT), the Interamerican Tropical Tuna Commission (IATTC) and the IOTC are promoting/encouraging the use of biodegradable FADs in their FAD conservation measures and the non-entangling nature of FADs is also included in all tRFMOs FADs related measures.

4.1.3.3.2. Low entanglement risk FADs (LERFADS).

Several groups of scientists had been working since the mid 2000's in the Atlantic and Indian Oceans developing dFAD prototypes that minimize turtle and shark entanglement. These trials were characterized by small sample numbers of alternative floating objects (e.g., < 50 dFADs per experiment) (Delgado de Molina et al., 2007; Franco et al., 2009). Because dFAD theft is so prevalent in these "smaller" oceans (e.g., over 50% of dFADs can be lost to other boats in a single trip; ISSF, 2014), and others end up beaching (e.g., 10-15% dFADs beach; Maufroy et al., 2015), sink or simply drift too far away of the fishing and go uninspected; very few experimental dFADs were recovered and results could not be compared statistically.

The big push in alternative FAD designs came when European tropical tuna purse seine fishers and scientists cooperated in larger scale anti-entanglement FAD trials between 2010 and 2013 with the involvement of the whole European fleets. For example, the French fleet in the Indian Ocean tested over 800 alternative dFADs, providing solid results and making skippers more used to working with this kind of floating objects in the water (Goujon et al., 2012). Prior scientists-fisher's collaborations in the tuna purse seine fisheries had also yielded positive results, such as the development of dolphin-safe fishing gear (e.g., Medina panel) and novel fishing operations (e.g., backdown procedure) (Bratten and Hall, 1997). Several factors facilitated this active FAD bycatch mitigation collaboration. One was the increased awareness by fishers of the scale of the entanglement problem through FAD bycatch-mitigation skipper workshops (Murua et al., 2014). Another was that tropical tRFMOs had been adopting measures in the last five years supporting the shift away from HERFADs (Murua et al., 2016), providing a major incentive for the rapid advances in non-entangling FADs (NEFADs) implementation in their Convention areas.

Most entanglement-minimizing designs tested in the trials, and later adopted in commercial fishing operations, still maintained some kind of netting. Fishers have always used this material but this time it was either tied in bundles or "sausages" to prevent open wide mesh being exposed or employed open net of very small mesh (e.g. < 2.5 inches) coming from small pelagic fishing nets. These kinds of dFADs with netting that try to minimize entanglement were categorized by ISSF as low entanglement risk FADs (LERFADs) as accidental ensnarement is still possible if the "sausage" tied netting becomes loosened or small-mesh starts to breakdown into larger holes overtime (ISSF, 2015). Note, however, that tRFMOs (and other management bodies) are considering LERFADs in the same category as non-entangling FADs (NEFADs), because observer data appear to indicate that entanglements in LERFADs are exceptionally rare (Lopez et al., 2017).

Purse seine fleets operating in the Indian and Atlantic Oceans have fully substituted HERFADs, most having done it voluntarily well before their respective recommendation's deadlines (e.g. Code of Good Practices by Spanish fleet; Goñi et al., 2015). In the Eastern Pacific Ocean most skippers have recently informed they have replaced them, but some still have to make the change before the 2019 resolution deadline (Murua et al., 2016).

The most common type of LERFAD in the Atlantic Ocean are "Korean-style" deep open net panels of small mesh sizes (e.g. < 7 cm). Apparently, the tied netting bundle model did not work well in this ocean as it drifted too fast (ISSF, 2014). Due to the strong westward superficial currents in the Eastern Atlantic, fishers prefer the open panel type as it acts as an underwater anchor slowing down drift to facilitate fish aggregation. It also prevents excessive drift to keep the dFADs in the areas for which they hold fishing licenses and retain them close to the African continent where the most productive fishing grounds are.

In the Eastern Pacific remaining HERFADs in use and popularly used LERFADs also consist of an open panel netting, and of large and small mesh respectively. Again, fishers want to slow down the drift of the dFAD in the equatorial line, dominated by strong westerly currents, so that fish can follow the dFAD and to prevent it entering the neighboring WCPFC area (Hall and Roman, 2013). In terms of marine waste, HERFADs and LERFADs could be considered equals, as both use similar raft materials and important quantities of synthetic netting.

4.1.3.3.3. Non-entangling FADs (NEFADS).

NEFADs (Figure 4.1.3.3.3.1.) are those FADs which use no netting or other potentially entangling materials in their construction (ISSF, 2015; ISSF, 2019). Unlike beaching HERFADs or LERFADs, even when lost or abandoned, NEFADs should not entail a ghost fishing threat (Balderson and Martin, 2015). Most of the NEFADs floating structure keep the raft uncovered (e.g., not wrapped in netting) or lay on a black canvas cover to reduce their visibility. Up to now, the most common form of underwater structure in NEFADs have been tails made from one or several nylon ropes, with a weight (e.g. chain or net cable) at the end to keep it vertical in the water column. Sometimes palm leaves or color strips can be added to increase attraction. According to some fishers these NEFADs seem to work well (e.g., aggregate tuna, follow the desired drift trajectory) in the Indian Ocean (ISSF, 2014). Comparisons between HERFADs and NEFADs in the Indian Ocean reveal that both dFAD types yield similar target tuna catches (Hernández-García et al., 2014). Overall, moderate current speeds in the Indian Ocean possibly facilitate the success of simple rope prototypes, without the need for a sail or anchor effect. For oceans like the Atlantic requiring an underwater sail, the use of non-entangling fabric canvas panels instead of net panels has been suggested (Moreno et al., 2016b). However, an issue with the canvas panels is that they must offer prolonged resistance to sea-conditions and could also increase FAD costs.

In addition to dFADs, which are the dominant kind of FAD worldwide, there are certain regions in the Western Pacific such as Indonesia, Philippines or Papua New Guinea which use anchored FADs (aFADs). The aFADs are stationary, held to the seabed by a long anchoring rope with heavy concrete blocks at the bottom, and are categorized as NEFADs. Both the floating structure, traditionally built with bamboo but now mostly made of encased foam blocks, and the underwater appendage, consisting of a rope with palm leave attractors, lack any kind of netting in the construction (Widodo et al., 2016). No ghost fishing reported incidents of marine fauna in aFADs could be found in the literature.

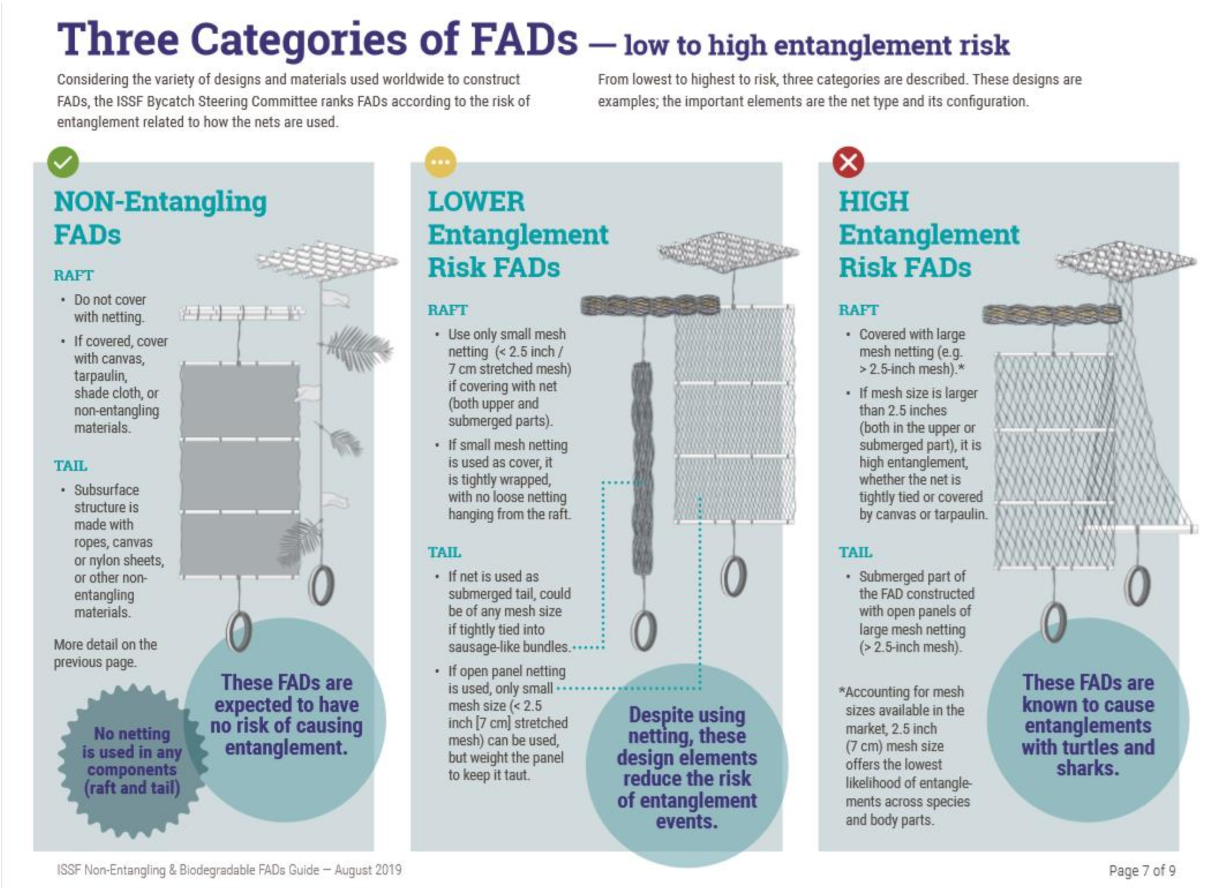


Figure 4.1.3.3.3.1. Diagram of different types of FADs regarding entanglement risk based on ISSF guide for non-entangling and biodegradable FADs (ISSF 2019).

4.1.3.4. Trials and current knowledge on biodegradable NEFADs.

In the last decade, scientists have been testing suitable natural materials and prototypes for biodegradable NEFADs. This solution is thought to provide the lowest impact of FADs on the marine ecosystem, as it solves two problems at once: ghost fishing and marine pollution. It is worth noting that the focus is on natural materials, not including other biodegradable materials of artificial origin (e.g., oxo-biodegradable plastics that breakdown quickly by oxidative chemical reagents). Non-natural biodegradable materials continue to impact marine ecosystems by entering the food chain as they breakdown.

Preventing FADs from sinking or beaching is logistically and economically unfeasible due to the great difficulty involved in trying to collect a large number of FADs getting closer to the coast in such a vast area. For this reason, building biodegradable FADs which will rapidly disintegrate in the ocean after their working life is expired is the most viable option. However, and to our knowledge, no fleet is currently using fully biodegradable FADs in their daily commercial fishing. In fact, except for some specific cases, FADs are mostly constructed out of highly durable synthetic materials such as nylon nets, PVC and EVA floatation or metal rafts and weights. The only natural biodegradable materials used regularly are bamboo rafts and, in some cases, coconut or nipa palm leaves as attractors and recently biodegradable twins are being used in the FAD's appendage.

Depending on ocean and fleet, fishers consider that their FADs have a functional life of 6-12 months (Murua et al., 2017), with few FADs working for over a year. In fact, because of FAD exchange or theft, in some regions skippers will lose their FADs much faster (e.g., < 3 months) to other vessels (but also will gain FADs taken from others).

As with NEFAD trials, at sea tests with biodegradable FADs have been very limited in scale and resulted in a slow rate of improvement. For example, small plantations of experimental biodegradable FADs were tested in the Indian and Atlantic Oceans, with bamboo rafts and sisal and jute ropes (Franco et al., 2009, 2012). However, due to the high loss rate of FADs to other vessels, few experimental dFADs were recovered and prevented obtaining statistically significant results. In spite of this, the pilot trials indicated similar tuna catch yield trends between traditional and biodegradable dFADs, with a lifetime range from the biodegradable FADs from 0 (possibly stolen by other vessel) to 227 days, and a tuna colonization time ranging from 1 to 54 days (Franco et al., 2012). At sea biodegradable dFAD inspection reports relied on fishers from the one or few vessels participating in the project. Nowadays, all vessels carry observers onboard (person or electronic) and it would have been easier to trace the fate of some of these dFADs. Based on anecdotal accounts by skippers, the sisal tail in some of the dFADs might have been eaten away by aggregated bycatch fish species (e.g., triggerfish, rainbow runner), but no concrete evidence was gathered to support this theory. The IATTC conducted a set of biodegradable FAD tests in a controlled environment in a bay in Achotines (Panama). Three biodegradable FAD designs were trialed, with a common floating structure made of bamboo canes and coconut shells and a tail either made with agave ropes with (a) bamboo frames, (b) high-resistance cotton canvas, or (c) a combination of both, inserted in between. These FADs were anchored (aFADs), instead of dFADs, and due to strong swells at the time of the experiment the floating objects suffered considerable damage finalizing the experiments after less than three months from the start (pers. comm. M. Hall).

Some biodegradable FAD trials have originated from the private sector, with individual companies testing them at sea during commercial fishing operations. For instance, French vessels have experimented with ropes and canvas made from coconut fibre to construct the dFAD's tail, but rapid disintegration and weight gain was an issue (pers. comm. ORTHONGEL manager M. Goujon). Companies like Albacora reported testing 6 biodegradable dFADs using bamboo and balsa wood for the raft and an appendage made from high-resistance cotton panels. These dFADs were still operational after 6 months, but the canvas showed considerable degradation (pers. comm. fleet manager F. Velastegui). Other companies like Calvo, sponsored a study to evaluate best biodegradable twine materials such as cotton, sisal, and hemp and their structural configuration (e.g., twisted, braided and bulked) for use in FAD appendages. This experiment examined the resistance of these materials over five months in a controlled sea environment and showed twisted cotton ropes as the best option as they retained a breaking strength of over 1000 kgf (Lopez et al., 2016). In Maldives biodegradable twines were also tested under controlled conditions by ISSF in collaboration with the Marine Research Centre in the Maldives and FAO Common Oceans Tuna project (Moreno et al., 2019). Three types of biodegradable ropes in oceanic and shallow waters were tested following their evolution and fate over one year at sea: twisted 100 % cotton rope; twisted 50% cotton and 50% sisal rope; and cotton, sisal and linen rope with loops (Moreno et al., 2019). Given the results obtained, mixed cotton and sisal ropes were the strongest, retaining one third of their strength after 12 months. However, given the degradation time, costs and other criteria 100% cotton rope was identified as the most appropriate to be tested at FADs in real fishing conditions (Moreno et al., 2019). Other natural biodegradable materials that have been recently tested at small-scale experiments to make ropes and canvas are agave (*Furcraea mercadilla*) and abaca (*Muxa textilis*) (Tunacons, 2017). The agave canvas use to cover the raft and submerged ropes rapidly degraded in a few weeks/months, while abaca holds more promise since it has water-resistant properties (pers. comm. Captain Luis García). Other materials options which have not yet been tested and may be good candidates include bamboo-derived textile fabric.

Regarding biodegradable materials for floatation bamboo and balsa wood are at present the already checked options. Bamboo canes were already used in three out of four oceans to construct the raft, but always in conjunction with other synthetic durable floatation aids (e.g., net corks, PVC pipes). This is because bamboo overtime absorbs water, gains weight and loses floatability, which increases the risk of the dFAD sinking. Balsa (*Ochroma pyramidale*) is known as one of the most light and buoyant woods. Recent experiments by the companies Albacora and Tunacons in the Eastern Pacific seem to indicate balsa is a durable alternative for biodegradable floatation. This type of wood is very abundant and cheap in Ecuador, but availability and price might be less favorable in other regions like small islands of the Indian Ocean or the Western Pacific. Trials with other more abundant water-resistant woods for floatation in each region might be required. Natural biodegradable resins or impermeant coats over wooden floats may also help buoyancy duration.

In addition to the two principal factors for biodegradable FAD adoption (i.e., similar tuna aggregate capacity and lifetime to conventional FADs) other variables need to be considered including price per FAD unit, large supply of materials, visibility in the water, adequate drift speed and trajectory, size for storage space on board, etc. Discussion with fishing masters from several oceans indicate that the price range of biodegradable and synthetic material FADs (between 150-250 €) would be similar (Moreno et al., 2016b).

Note that the most expensive part of a dFAD is its associated echo-sounder buoy, costing ten times the price of the building materials. Regarding dFAD visibility to other vessels, biodegradable materials should be preferably dark, either natural color, tainted or painted. Skippers also point out that the dFADs raft should not "stick out" to much from the water surface, so they are better hidden. Adequate floatation balance is also important as it ensures the dFAD does not sink in rough weather or as it gains weight by biofouling. Given that, perhaps except for balsa wood, no natural floatation materials have been yet identified to maintain the same buoyancy overtime. For now, some artificial floatations (e.g., net corks, PVC) are being permitted in experimental trials with biodegradable dFADs to prevent sinking. This is the case in the largest at-sea biodegradable trials conducted to date. This was carried out in the Indian Ocean by boats of INPESCA (Spanish fleet), where 85 biodegradable dFADs with cotton rope tails (but rafts with net corks) are being examined (Moreno et al., 2017b). It has highlighted several key potential difficulties associated with experiments under fishing working conditions. In the Indian Ocean, as in the rest of oceans, dFADs very regularly change hands as fishers appropriate and set on any productive dFAD they encounter. To obtain good levels of biodegradable dFAD traceability, if not all, a large part of the fleets operating in a region must be involved. Otherwise, continuous swap of dFAD ownerships will lead to loss of relevant data on the lifetime, level of degradation, or total catches with biodegradable dFADs. Early indications from Moreno et al. (2017b) trials seem to provide promising results such as equal catches between synthetic NEFADs and biodegradable NEFADs, or life-times of up to 6 months of some biodegradable dFADs.

Conservation and Management Measures in place for FAD construction

Considering potential impacts on the pelagic and coastal habitats and sensitive species interacting with the purse seine fishery, IOTC Resolution 19/02 states that the FAD must be constructed of non-mesh material since 1st of January of 2020. In addition, it encourages the use of biodegradable FADs in FAD construction from 1 January 2022. In the Atlantic Ocean, ICCAT Recommendation 19-02, has adopted bycatch mitigation measures for the use of non-entangling FADs and use of more sustainable materials. The designs of non-entangling raft and subsurface structures were set to reduce the entanglement of sharks, sea turtles or any other species. In this ocean the definition of the entangling material does not include any reference to the presence of meshed materials or mesh size as has been included in other measures as described in this section. In addition, to diminish the amount of synthetic marine debris, CPCs should "*endeavor that as of January 2021 all FADs deployed are non-entangling, and constructed from biodegradable materials, including non-plastics, with the exception of materials used in the construction of FAD tracking buoys*".

In the case of the Pacific, both in the IATTC and in the WCPFC, if open mesh is used the mesh size is restricted to 7 cm and if it is above 7 cm it must always be well rolled in coils to minimize the entangling potential and meet with RFMO requirements, both in the submerged and floating part. In the IATTC area, all FADs must meet the criteria established as of January 1, 2019 (C-19-01) and the use of biodegradable FADs should be promoted, while in the WCPFC reference is made to January 1, 2020 (CMM-2018-01).

4.2. TASK 2 - SELECTION OF FAD MATERIALS AND DESIGNS, AND DEPLOYMENT STRATEGY.

4.2.1. OBJECTIVES.

The objective was to assess the advantages and disadvantaged of different biodegradable materials and designs previously identified, to select the materials to be used in the *in-situ* experimentation. We also identified the best deployment strategy for NEFADs and BIOFADs to account for potential seasonality effects for the Indian Ocean.

To accomplish this, Task 2 was divided in the following sub-tasks:

- Sub-task 2.1 – Identify different BIOFADs designs and biodegradable materials to be tested.
- Sub-task 2.2 – Identify the pros and cons of each design and material, and justify the selection made.
- Sub-task 2.3 – Deploy a statistically significant number of BIOFADs and NEFADs throughout the year, to account for potential seasonality effects, in the Indian Ocean.

4.2.2. METHODOLOGY.

We evaluated the performance of specific biodegradable materials and designs for the construction of FADs to be deployed in natural environmental conditions to address RFMOs' concerns.

The work was subdivided in three sub-tasks (described below) and was mainly field work, although some desk-based work was also conducted. Information to define biodegradable materials and prototypes was obtained from reports and outputs from workshops. Consultations by e-mail, telephone interviews and in-person meetings with fishery experts, tuna associations and companies have been conducted when required to better understand what the challenges in prototypes designs, materials and deployment strategies were. Whenever feasible, quantitative analyses of the results were also performed.

4.2.2.1. <u>Sub-task 2.1 – Identify different BIOFADs designs and biodegradable materials to be tested.</u>

Information collected in Task 1 and outputs from the ISSF workshop on biodegradable FADs, where consensus on the designs of different BIOFADs prototypes was reached for the 3 main oceans (Atlantic, Indian and Pacific Oceans) (3-4 November 2016 in San Sebastian; Moreno et al., 2016), have been used as reference points. Moreover, due to the urgency to select BIOFAD materials and designs at the beginning of the project, a 2-day workshop was conducted on 17-18 July 2017 in Sukarrieta (Spain) at AZTI’s headquarters involving scientist of the Consortium (AZTI and IRD), skippers from the three tuna associations (ANABAC, OPAGAC and ORTHONGEL), and ISSF. During this workshop, the following points were agreed:

- BIOFAD designs and biodegradable materials to be tested in the project
- Deployment strategy for BIOFAD and paired NEFADs
- BIOFAD and NEFADs identification methods to ensure FAD traceability
- Data collection/reporting procedures
- Logistics for material shipment and purchase
- BIOFAD construction methods

The outputs of this workshop are described in section 4.2.3.1.1

Efforts were also made to contact material suppliers to assess the origin materials and whether they could source them from countries where the purse seiners are based (e.g., Seychelles).

Further assessments for the identification of novel biodegradable materials with potential for the project were conducted. This work was subcontracted to GAIKER research center (estimated cost 15,000 €). The main objective of GAIKER was to test the functionality of biologically-based, biodegradable and recyclable (from marine waste) material candidates, for the construction of the FAD flotation components. This subcontracting started in January 2018 and finalized in June 2018. The research company elaborated a final report providing a selection of the best materials and best process for manufacturing prototypes, a degradability evaluation and a preliminary comparison. The analysis was carried out to:

- Select materials.
- Prepare samples for testing manufacturing of FAD flotation components.
- Test thermomechanical and physical properties of the materials (i.e., density, flexural resistance, compression resistance, impact resistance, hardness, water adsorption, abrasion resistance and HDT)
- Test material ageing (i.e., 2 months to 1-year checks)
- Assess mechanical properties after ageing.

4.2.2.2. Sub-task 2.2 – Identify the pros and cons of each design and material, and justify the selection made.

Published literature, outputs from previous international workshops and initiatives on this topic were reviewed, and interviews with skippers and twine dealers were also conducted. The objective being to determine the pros and cons of each design and material and to justify the best ones to be used in the project. Similarly, the workshop carried out at the very beginning of the project (17-18 July 2017) provided preliminary information on the advantages and disadvantages of each material and design considered in both this study and in previous worldwide initiatives. Unifying efforts through discussions with all the actors involved in the FAD fishery was key to identify advantages and disadvantages of the material(s) and design(s) adopted for the large-scale deployment. Therefore, stakeholder active engagement was also promoted throughout the deployment of experimental BIOFADs, as well as during project progress evaluation workshops and meetings.

One-to-one meetings with each fishing company were conducted even before starting with BIOFADs deployments, in order to seek agreement regarding BIOFADs prototypes, materials and deployment strategy among all participants. These meetings focused on discussing the points agreed in the workshop (see section 3.2.3.1) and providing clear information about the experimental procedures to all the captains and skippers from the EU PS fleet, as well as crew from supply vessels.

4.2.2.3. Sub-task 2.3 – Deploy a statistically significant number of BIOFADs and NEFADs throughout the year, in order to account for potential seasonality effects, in the Indian Ocean.

An effective FAD deployment strategy was adopted taking into consideration the EU fleet's FAD fishing strategy and its dynamics in the Indian Ocean. Such strategy was based on fisheries data (e.g., fishing logbooks, observer data, and FAD logbooks) and information arising from direct interaction with fishers (e.g., interviews and workshops). A total of 1,000 BIOFAD deployments was planned, sharing the deployment effort among the 42 participating PS from the three EU fleet owner organizations (ANABAC, OPAGAC and ORTHONGEL) operating in the Indian Ocean. Each vessel had to deploy 24 BIOFADs between April/May 2018 and April/May 2019 (6 BIOFADs per vessel and trimester, preferably). Deployment was planned to be conducted during the four trimesters of the fishery (Mar-May, Jun-Aug, Sept-Nov, Dec-Feb, Mar-May). This resulted approximately in 250 FADs deployed each season. It was expected that these BIOFAD prototypes could last in functioning state for 1 year, the time period fishermen thought a FAD should work at sea.

The sustained implication of the vessels throughout the whole project was sought to ensure the correct development of the project. Assistance for vessels to correctly share deployment effort data was also provided. BIOFADs and NEFADs were deployed in pairs (i.e., 1:1 ratio) to allow FAD material degradation, tuna/non-tuna species aggregation efficiency, and trajectory characteristics comparisons. Experimental NEFADs had a similar design (e.g., length of hanging ropes) to its paired BIOFAD but was made from the materials currently used for standard NEFADs by the fishing industry (i.e., non-entangling and non-biodegradable constructed with synthetic plastic-based materials such as netting). All FADs deployed by the project (both NEFADs and BIOFADs) were marked with unique identifier codes inscribed in metallic plates, each one tied to a FAD's echo-sounder buoy. The unique number plate was then linked to the unique echo-sounder buoy ID code to ensure traceability. In the case of BIOFADs they were double tagged, with the FAD's raft also being marked with an extra plate having the same ID number as that used for the buoy. Replacing the buoy originally attached to an experimental FAD was not recommended as it complicates tracking individual FADs over its lifetime. However, if this happened due to the experimental FAD changing hands (i.e., the FAD being appropriated by another vessel that attaches its own tracking buoy), all these buoy changes had to be recorded accordingly in a specifically designed monitoring form. During the 1st BIOFAD workshop it was agreed that the BIOFADs and their paired NEFADs would be deployed 2 miles apart to avoid any undesirable interactions between them that could affect normal FAD fishing (e.g., deployed FADs becoming accidentally entangled). However, this distance was close enough to allow BIOFAD and NEFAD drift and efficiency comparisons. Buoy information with a small-time delay was made available by fleet owner organizations to the Consortium members under agreed confidentiality rules.

Permanent AZTI and IRD offices in Seychelles supported the coordination of materials supply/delivery to the fleet and the construction of selected BIOFAD designs. These offices have also been involved in providing and recovering digital data (e.g., pictures) and other required material for data collection and analysis.

4.2.3. MAIN RESULTS.

4.2.3.1. Sub-task 2.1 - Identify different BIOFADs designs and biodegradable materials to be tested.

4.2.3.1.1. BIOFAD workshops and meetings.

1st BIOFAD workshop

The 1st BIOFADs workshop was held at AZTI in Sukarrieta (17-18 July 2017). Three main topics were discussed between consortium members (AZTI, IRD, IEO) and collaborators from the fishing industry (ANABAC, OPAGAC and ORTHONGEL) and ISSF:

- Materials and prototypes for BIOFAD construction.
- Identification and deployment strategy for BIOFADs and paired conventional NEFADs.
- Data collection and reporting data procedures.

This first workshop addressed technical aspects to define the designs and protocols to be used during the BIOFAD project regarding prototypes and the material for their construction. The different procedures for identification of BIOFADs and NEFADs, deployment strategy, data collection and reporting were also discussed in order to adapt them to current operational procedures onboard vessels during regular commercial fishing trips.

Thus, the outcomes from the 1st BIOFAD workshop were used to complete and define sub-task 2.1. The following three subsections describe in more detail the reached outcomes:

Materials and prototypes for BIOFADs construction

The selection of the biodegradable materials to be utilized for the construction of BIOFADs was made based on the outputs provided by previous studies, examining the feasibility of different natural plant fibres for biodegradable drifting FAD construction at offshore aquaculture facilities and in several small trials at sea (Lopez et al., 2016; Moreno et al., 2017a; 2017b; Tunacons, 2017). Several plant fibres such as cotton, sisal, hemp and linen have been analysed for the construction of ropes, and parameters like potential biodegradation, resistance, reproducibility, and availability in the market were assessed (Lopez et al., 2016). Previously, some small-scale trials have been conducted by purse seine companies, ISSF and research institutes to test some of these plant fibres in biodegradable FAD construction under real sea conditions in the Atlantic (Franco et al., 2009;2012), Indian (Moreno et al., 2016; 2019) and Pacific Oceans (pers. comm. fleet manager F. Velastegui; pers. comm. M. Hall). Although some of these studies did not end with a clear recommendation of a particular biodegradable material, others have shown cotton ropes as one of the best options yet found, as they retained a breaking strength of over 1000 kgf after 6 months (Lopez et al., 2016). Based on those results, the Consortium members together with ISSF decided to use 100% cotton as the principal biodegradable material for both twined rope and canvas cover.

Several types of cotton ropes with different structural configurations were presented to the industry in the 1st BIOFAD workshop for selection. Finally, two types of 100% biodegradable ropes were selected: i) wax covered twisted cotton rope and ii) twisted looped cotton rope. The rope (i) was used for the larger subsurface structure hanging part (i.e., main rope) and looped rope (ii) as short-length attractors attached at intervals to the main rope. In the case of rope (i), the rope was covered by a non-hazardous palm oil derived wax (EC 1999/45/EEC). This wax product has a melting point interval between 48 – 59 ºC and it is non-soluble in water below 70ºC. In the case of looped rope (ii) no wax product was applied. The selected FAD's raft cover/canvas was also totally biodegradable made with 100% cotton. Bamboo canes and wood were also selected as raft materials for the construction of BIOFAD rafts. Initially, the option of metal frames for FAD raft construction was rejected during the 1st BIOFAD workshop as it was not clear whether metal qualified as a biodegradable material.

The design and selection of the prototypes agreed in 1st BIOFAD workshop were based on the outputs of the ISSF workshop held in Donostia (Spain) in 2016 where several biodegradable prototypes intended for the Indian Ocean were designed (Moreno et al., 2016). Figure 4.2.3.1.1.1. shows the three final experimental prototypes selected in the BIOFAD project. These designs included all the details in terms of dimensions and materials defined during this initial workshop. These prototypes were designed to cover the different drifting performance requirements that fishers seek in their conventional NEFADs to track different currents: semi-superficial FADs (prototypes A1 and A2), deep FADs (B1 and B2), and superficial FADs (prototype C):

- **Prototypes A1 and A2** covered medium depth strata. The difference between prototype A1 and A2 corresponded to the depth reached by the FAD's main rope (i.e., prototype A1 with a 60 m and prototype A2 with 40 m rope). Prototype A1 was a design very similar to the conventional NEFAD model currently used by most of the French PS industry in the Indian Ocean. Prototype A2 was designed to adapt A1 to the Spanish PS industry requirements regarding floatability and durability of the FAD.
- **Prototype B1 and B2** covered a higher depth stratum. These were sub-superficial designs, meaning the FAD's raft was submerged 1.5 m below the sea surface to make it less visible to other vessels. Prototype B2 aimed to replace the metallic frame currently used in the constructions of conventional NEFADs by using a wooden pallet. During the 1st BIOFAD workshop fishers showed some doubts about the use of a wooden pallet in the construction of the raft, due to concerns with floatability and durability. In order to clarify these uncertainties about wooden pallets, a small test with a prototype B2 was conducted in a controlled environment* to assess its feasibility as a replacement for the metallic frame. An alternative prototype B1 was also proposed with a raft built with only bamboo canes.

***NOTE:** *A test with a prototype B2 to assess the use of wooden pallets in the construction of FAD rafts was carried out in September 2017. A prototype B2 was built and deployed in the port of Mutriku (Basque Country, Spain) using AZTI's aquaculture facilities. Monthly monitoring was carried out and the evolution of the structure in terms of durability and floatability was controlled in each visit to ensure this prototype provided a sub-superficial raft structure, as wanted by fishers. The prototype maintained good structural integrity after one year and the wooden raft sunk just enough below the sea surface, reaching desired sub-superficial characteristics to make it less visible, two months after deployment.*

- **Prototype C** covered the need for shallow FADs tracking superficial strata. This prototype was similar to those shallower early day FADs when they commenced utilizing artificial floating objects for tuna fishing in the Indian Ocean. This prototype was designed to be deployed when monsoon effects were less damaging on the FAD structure.

One of the initially set goals for the 1st BIOFAD workshop was to design 100% biodegradable prototypes. However, scientists and industry participants did not identify feasible biodegradable replacements for some of the components of the FAD such as the floats and weights. Thus, all prototypes used in addition to biodegradable floatation (e.g., bamboo) some non-biodegradable float and weight elements. In line with the original goal, and in order to find more sustainable candidate materials to replace synthetic floats in the near future, the project subcontracted GAIKER research institute to test the functionality of biologically-based, biodegradable and recyclable (from marine litter) material candidates for the construction of the flotation components of FADs. Information about the laboratory results in this activity is given below (see section 4.2.3.1.2). The rest of the materials used for the construction of the raft (e.g., 100% cotton covers and bamboo canes) were natural origin biodegradable materials. Similarly, the tail hanging part of the BIOFAD was also biodegradable (100% cotton twisted rope and 100% cotton twisted looped ropes) except for the metal weight.

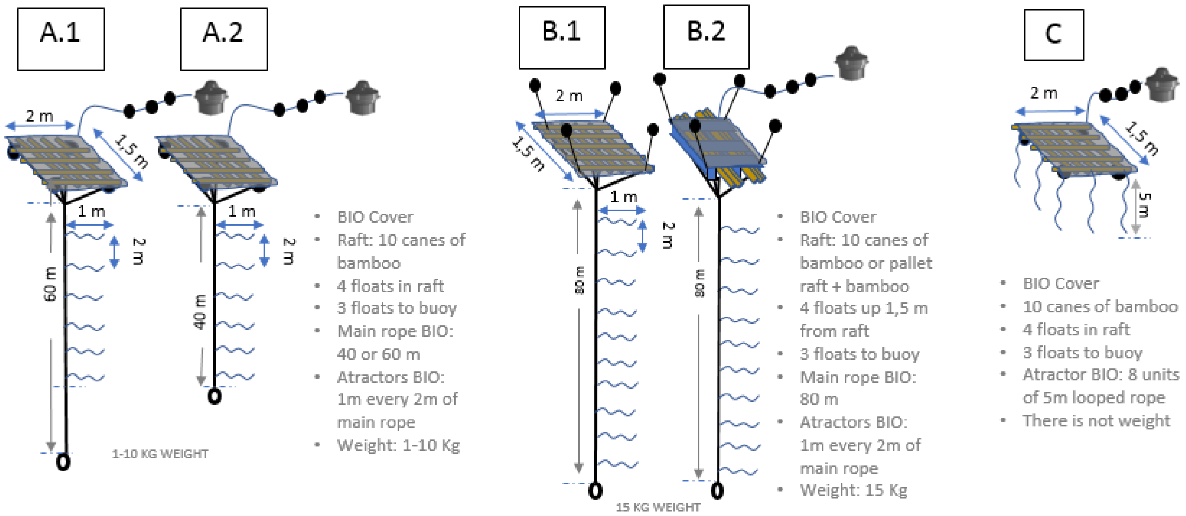


Figure 4.2.3.1.1.1. Prototypes designed during the 1st BIOFAD workshop. Details of materials and dimensions are given for each prototype.

During the 1st BIOFAD workshop, agreement was reached to conduct a complementary short workshop on the 12th of April at Seychelles Fishing Authority (SFA) in Mahé (Seychelles) (see section 4.2.3.3.). The objective of this additional workshop was to guide and oversee the construction of the experimental prototypes at the beginning of the project by visiting the main facilities where they were being built at port.

Identification and deployment strategy for BIOFADs and paired conventional NEFADs

During the 1st BIOFAD workshop, the procedure to identify individual BIOFADs and NEFADs was defined/agreed between all participants. The following points were found to be very important for the correct functioning of the trials:

- BIOFADs need to be identified at all times to ensure their traceability.
- Each BIOFAD should be identified with a unique ID number (e.g., from BIO-0001 to BIO-1000).
- This ID number should always be related to the same BIOFAD during the whole project period.
- BIOFAD ID numbers should be visible by using an ID plate attached to both the FAD structure (e.g., raft) and to the echo-sounder buoy tethered to the BIOFADs raft (Figure 4.2.3.1.1.2).
- The ID plate attached to the raft should never be removed from it. Only if the part of the raft structure where the plate is attached is replaced, in which case the ID plate will be removed and attached again to the newly replaced part. The operator performing the replacement will ensure that the ID plate is again attached correctly to the new part of the FAD before deploying it again.
- During the life period of BIOFADs every time there is a buoy replacement, the ID number plate from the buoy will be changed from the "old" buoy to the newly attached buoy.
- BIOFADs are identified by two ID plates with the same number, one attached to the raft and the other attached to associated buoy. If the number of these two plates at BIOFADs are different it will mean that an error has occurred when manipulating those BIOFAD plates and that the traceability is not ensured.

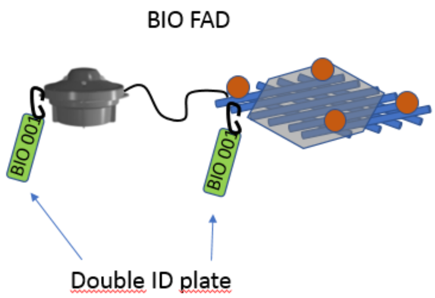


Figure 4.2.3.1.1.2. Procedure to attach the BIOFAD ID number plate to the BIOFAD raft and to the echo-sounder buoy attached to the BIOFAD.

The following BIOFAD and NEFAD deployment strategy was agreed between all participants. In total, 42 PS vessels (from ANABAC, OPAGAC and ORTHONGEL) were identified as suitable to participate in the Indian Ocean project. The project had an initial objective deployment of 1000 BIOFADs, which equated to 2 BIOFAD deployments per month and vessel (6 BIOFADs quarterly per vessel). A priory was that designed BIOFAD prototypes lasted long enough in working order, which was considered to be a period of approximately one year.

A deployment of a fixed number of BIOFADs per prototype option and vessel was not planned. Some fishing companies selected one or more prototypes to be used during the whole project, for example, the French fleet through ORTHONGEL decided to deploy only prototype A1 (very similar to their currently used NEFAD design). For the Spanish fleet some vessels informed that they would deploy and use the different designed prototypes, depending on the specific needs per season/area and the services provided by each of the prototypes, while others chose from the start the prototypes they would use for the whole experimental period. For example, vessels for the company PEVASA selected A1 and A2.

In order to carry out the comparison between BIOFADs and NEFADs in terms of tuna and non-tuna species aggregation, structure durability and degradation rate, and FAD performance (e.g., drift), the following procedure was defined (Figure 4.2.3.1.1.3):

- Every time there is a BIOFAD deployment, it will be accompanied by a NEFAD deployment.
- The BIOFAD and NEFAD deployed in pairs will be of similar prototypes (i.e., same design and dimensions, but different materials).
- The echo-sounder buoy attached to a BIOFAD and its NEFAD pair will be of the same brand and model.
- The distance between the deployment of a BIOFAD and its NEFAD pair will be approximately 2 miles.

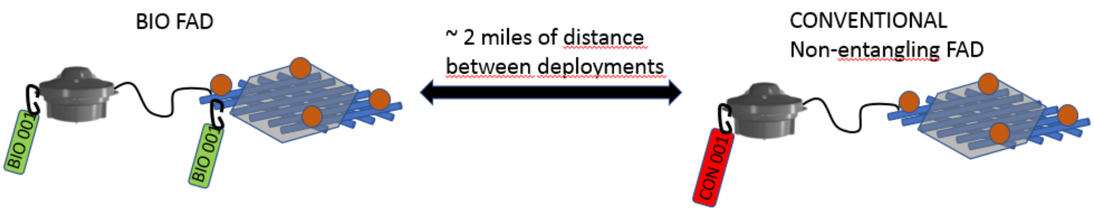


Figure 4.2.3.1.1.3 Deployment strategy for the BIOFAD and its NEFAD experimental pair.

The identification of the experimental control NEFADs, was conducted following the points described:

- The experimental NEFAD needs to be identified at every moment to ensure its traceability like it happens with BIOFADs.
- Each control NEFAD should be identified with a unique ID number (e.g., from CON-0001 to CON-1000). The CON-number will correspond with the BIO-number of the BIOFAD deployed in the pair (e.g. CON-001 and BIO-001).

- This ID number should always be related to the same NEFAD during the whole project duration.
- The NEFAD ID number will be visible by an ID plate attached only to the echo-sounder buoy.
- During the life period of the experimental NEFAD every time there is a buoy replacement, the ID number plate from the buoy will be changed from the "old" buoy to the newly attached buoy.

Data collection and reporting of data procedures.

During the 1st BIOFAD workshop, the procedure for data collection was defined and agreed between all participants. The following points were identified as very important for the correct functioning of the project.

Each time there was an encounter with a BIOFAD and/or with its paired NEFAD, the following information would always be collected:

- ID number of BIOFAD or NEFAD as shown in the ID plate.
- Codification number of the echo-sounder buoy attached to the BIOFAD or paired NEFAD.
- Status control information (e.g., degradation condition) of the BIOFAD or paired NEFAD found.

Every time there was a change of echo-sounder buoy in a BIOFAD or paired NEFAD, fishers should record and report the new echo-sounder buoy codification number to follow up the traceability and buoy data (e.g., position, biomass, etc.) of the FAD. The operator changing the echo-sounder buoy must have ensured that the ID plate was changed from the "old buoy" to the "new" one now being attached to the FAD. Different options to ensure correct data collection were proposed such as: recording of the ID number by writing it down during the buoy change operation from the speedboat, or by informing with the speedboat radio to the captain in the bridge, or by using cameras to record the ID numbers shown in the plate attached to the buoy.

During the 1st BIOFAD workshop, the agreed procedure for BIOFAD and NEFAD structure status control data collection was the following:

- Every time the net is set on a BIOFAD or its paired NEFAD, PS are suggested that when possible, they should lift the experimental FAD out of the water to help better assess the status of the different components, especially the tail or subsurface structure.
- The control of the structure will be done by both the observer onboard and the skipper/captain responsible of completing this task. When there is no person observer onboard, the crew will complete this task.
- All parts of the FAD structure described in Table 4.2.3.1.1.1 will be checked. A scale from 1 to 5 will be applied to value the overall status condition of the FADs (1 = Very good, not damaged; 2 = Good, a bit damaged; 3 = Bad, quite damaged; 4 = Very bad, close to sinking; 5 = component missing; Blank = unknown information).

- When possible, pictures of the parts of the FAD structure assessed should be taken.
- Every time there is a replacement of any part of the BIOFAD or paired NEFAD, it should be reported in the table (Table 4.2.3.1.3.1).
- In the case of BIOFADs, any damaged parts susceptible of replacement should be replaced with biodegradable materials, similar to the materials used when first constructed.
- The operator will have the option to add any other relevant observation to further describe the state of the structure (e.g. degradation % of each part).

Table 4.2.3.1.1.1. Table to collect required information to assess the status of the BIOFAD and NEFAD structure included in an email template provided to the fishing fleet.

Control de estado BIOFAD y CONFAD						REPARACION	
Floating parts	1	2	3	4	5	SI	NO
Bamboo canes							
Pallet/Metallic frame							
Floats							
Cover/canvas							
Parte sumergida	1	2	3	4	5		
Main rope							
Attractor (looped rope)							
Weight							

1	Very good, not damaged	**5**	Component missing
2	Good, a bit damaged	**Blank**	Unknown state
3	Bad, quite damaged		
4	Very bad, close to sinking		

Vessel name

Date / Hour:

Activity (add a X in the correct cell)

New deployment	Visit/buoy transfer	Set	Retrieval	Redeployment	Removal

Prototype (add a X in the correct cell)

A1	A2	B1	B2	C

BIOFAD or CONFAD Code:
BIO or CONFAD ownership (Yes/No):
Echo-sounder buoy Code:
NEW Echo-sounder buoy Code:
Lift up (Yes/No):

During the first workshop, the following points were considered important in the agreed procedure for data reporting:

- An email address was created for scientific coordinators to receive all the reports sent by the PS fleet and also to clarify any doubts regarding the topics above described.
- An email template was developed where all required experimental FAD status information could be easily described (Table 4.2.3.1.1.1.) and sent in an easy and fast manner to the scientists in charge of receiving this information.
- If required, vessels had further support from consortium members based permanently in the Seychelles port.

During the 1st BIOFAD workshop, the procedure for echo-sounder buoy data reporting was discussed and agreements were reached. The following points were highlighted for the correct functioning of the project:

- All the information obtained from the echo-sounder buoys attached to the BIOFADs should be provided for analysis.
- All the information obtained from the echo-sounder buoys attached to the NEFAD deployed in pairs with the BIOFADs should also be provided.
- Most participants did not consider necessary to provide echo-sounder buoy information in real time. Thus, it was agreed that PS companies would provide echo-sounder buoy information for BIOFADs and paired NEFADs following the same procedure for reporting buoy information in other ongoing projects (e.g., FAD limit verification projects).

Biodegradable material acquisition and delivery

The biodegradable material (i.e., two types of cotton ropes and a cotton cover) acquisition/purchase for the project was organized by the ISSF through the FAO Common Oceans Project (estimated budget of approximately 260K €). In this regard, FAO published an invitation to bid (2017/CSAPF/FIDFD/100116) for the selection of suppliers on 2 October 2017 and kept the tender open for candidates until 16 October 2017. The selection process and the required administrative process for material purchase was organized by FAO staff. Resolution of the bid and hence awarded suppliers were officially informed by FAO on January 2018. All purchased material arrived to Seychelles in two batches. The first batch corresponding to two containers with the total amount of the biodegradable ropes and ¼ of the biodegradable covers, which arrived to the Seychelles port on 25 March 2018. The second batch corresponding to one container with the remaining ¾ of the biodegradable cotton covers arrived to the Seychelles port on 4 April 2018. FAO through the IOTC Secretariat contributed with the administrative process related to customs clearance. For the delivery of the material once at port to each fishing company the Consortium counted with the support of the Seychelles Fishing Authority and the fishing companies themselves. All biodegradable materials were delivered to the vessels by 16 April 2018. For the rest of experimental FAD materials, fishing industry provided bamboo canes, floats, metallic rings or chains as weight for the construction and echo-sounder buoys for the monitoring of BIOFADs.

2nd and 3rd BIOFAD workshops.

The 2nd BIOFAD workshop was held at Torre Madariaga (Spain) during 4-5 April 2019 and the 3rd BIOFAD workshop was held in Pasaia (Spain) on 24 September 2019. The main objective of these workshops was to discuss the progress of the project, collate at sea obtained results and get feedback from the fleets regarding the performance of the material and prototypes from the fishers' points of view.

The 2nd BIOFAD workshop was also organized as a tool for focusing on corrective measures and plan the last deployment period trying to rectify identified delays in the BIOFAD deployment schedule. During this 2nd workshop the Consortium made efforts to engage vessels in increasing the number of BIOFAD pairs to be deployed per month from two to three pairs. The Consortium took advantage of the workshop to inform industry about the deployment efforts completed until that date and to highlight the necessity to increase the number of deployments for those vessels trailing behind the programed objective. During the 2nd BIOFAD workshop, the PS industry participants raised some concerns about the cotton canvas used to cover the BIOFAD rafts. According to the opinion of some of the PS company representatives, and the preliminary results obtained by the Consortium and by ORTHONGEL (visual observation) from the tested prototype at Concarneau (Brittany, France), the cotton canvas showed fast degradation in the first months after deployments.

This degradation was faster than anticipated and apparently would not meet the needs of industry. In this line, part of the fleet representatives also indicated having perceived skipper disappointment with this material due to its quick deterioration. According to skippers, the limited lifespan s of the cotton covers conditioned the normal BIOFAD deployment activity, as vessels were less likely to deploy FADs which were not working as expected. Also, the dark canvas covering the raft has the function of making it less visible to other vessels. Fishers were less inclined to deploy FADs knowing that they would quickly become more visible once the cotton canvas degraded and therefore likely to be appropriated by others. In contrast, most of the PS companies highlighted their acceptance of the cotton ropes and the ropes used as attractors as valid materials for FAD construction.

In the 2nd BIOFAD workshop, part of the EU fleet also expressed discouragement with some of the prototypes selected which, according to them, were outdated since the start of the project. Note that in some oceans, particularly the Indian Ocean, the fishery is very dynamic and preferred skippers' FAD designs can change very rapidly, even within a short period of months. In line with this idea, the overall perception of the companies presented in the workshop was the need, in this project and future initiatives, for more room for flexibility to choose and develop their own prototypes, to adapt the trials to the current state of evolution of the fishery and not to be so rigid with the prototype designs permitted during the project period. The Consortium proposed different solutions in order to solve identified problems and to renew the interest of the fleet in collaborating with the experiment. On one side, prototypes accepted during the 1st BIOFAD workshop were modified and a new design of "cage-shape FAD" prototype, in line with the "latest FAD trend" in the Indian Ocean, was accepted (Figure 4.2.3.1.1.4.). In terms of materials, double layering of the cotton canvas was accepted to increase raft cover lifespan with this material. The metallic frame was also accepted by the Consortium to be used during the last trimester deployments in order to allow the fleet to construct biodegradable "cage-shape FADs" and also to strengthen the raft structure of the FAD.

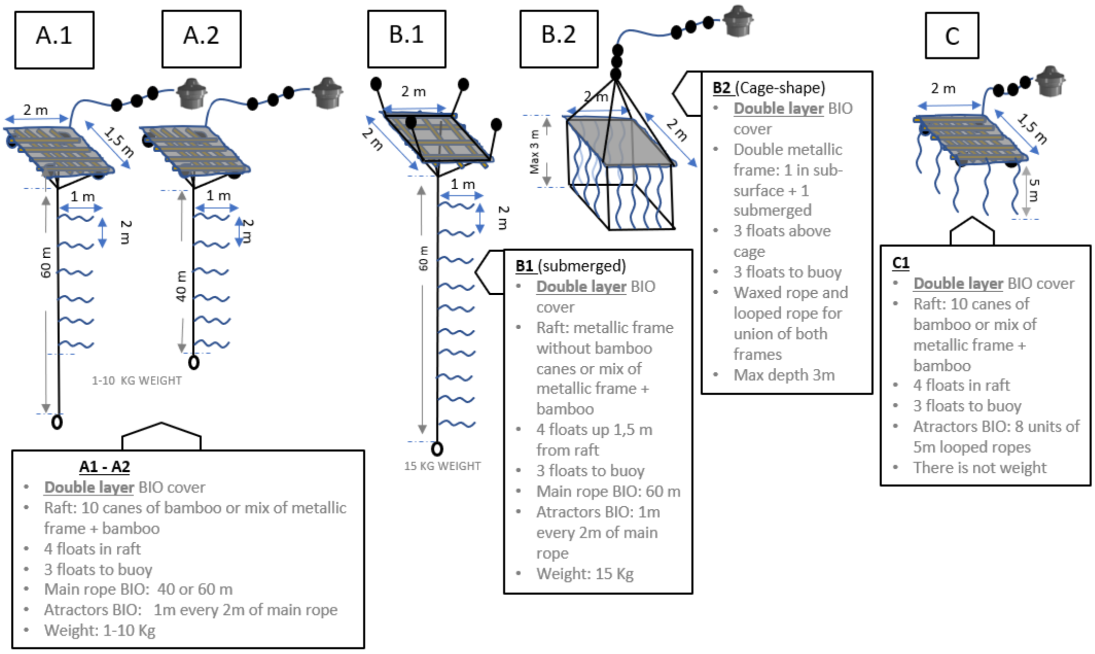


Figure 4.2.3.1.1.4. Poster detailing the deployment and monitoring of BIOFADs.

In the 3rd BIOFAD workshop, similarly to the 2nd BIOFAD workshop, the main objective was to present the latest update of project results to the fleet members and collect feedback from them. In this 3rd workshop the Consortium also aimed to discuss the strengths and weaknesses of BIOFAD's defined protocols to learn lessons for future projects. The Consortium and the industry sector highlighted the need to continue working on the search for suitable materials by looking to new alternatives. It was also noted that further research is needed to increase the durability of existing materials and to find biodegradable solutions for all parts of the FAD, including floatability elements. Although natural materials are recommended, other reformulated materials such as bio-based and biodegradable synthetic materials could also be explored.

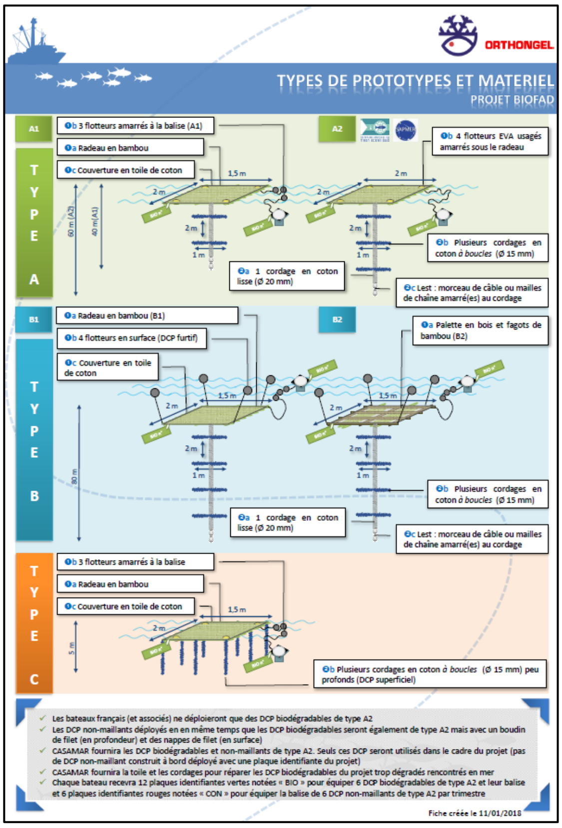
***NOTE**: The Outputs from the two workshops presented in this section are only the main discussion and conclusions. A more detailed description of outputs was provided in the Workshop Minutes. Besides, comments on the results of the workshop, specially feedback received from the fleet, were included in more detail throughout that document.*

Additional BIOFAD workshops and meetings with Industry

Following the 1st BIOFAD workshop's agreements, the Consortium organized two additional workshops in Sukarrieta (Spain) and Concarneau (France) to work with fishing companies in the construction of selected prototypes. Additionally, several meetings and conference calls with fishing companies and tuna fishing associations (ANABAC, OPAGAC, and ORTHONGEL) to explain the outputs and agreements reached in the 1st BIOFAD workshop were conducted to strengthen the message especially for PS crew not attending the workshop but who would be involved in the experimental FAD deployments. Moreover, these meetings were used to define the best strategy to disseminate the project information within the French and Spanish fleet and to encourage their participation once BIOFAD deployments started. In-person meetings were the main channel of communication between AZTI and Spanish companies, while video conference calls were established between IRD and the French industry due to the greater geographic distance between them. Both communication methods provided a good platform for fast exchange of information, discussion and feedback. The most relevant points discussed during these meetings and related activities are summarized below.

Dissemination of the project:

AZTI (for the Spanish fleet) and ORTHONGEL and IRD (for French companies) created a set of posters to be distributed among participating fishing companies for display in the purse seine vessels as a reference guide during the period of deployments. The posters describe the deployment procedure for BIOFADs and NEFADs in detail as well as the monitoring protocol to be followed (Figure 4.2.3.1.1.5.). In addition, other materials like Power Point presentations and explanatory emails were sent to the associations and companies with the same objective.



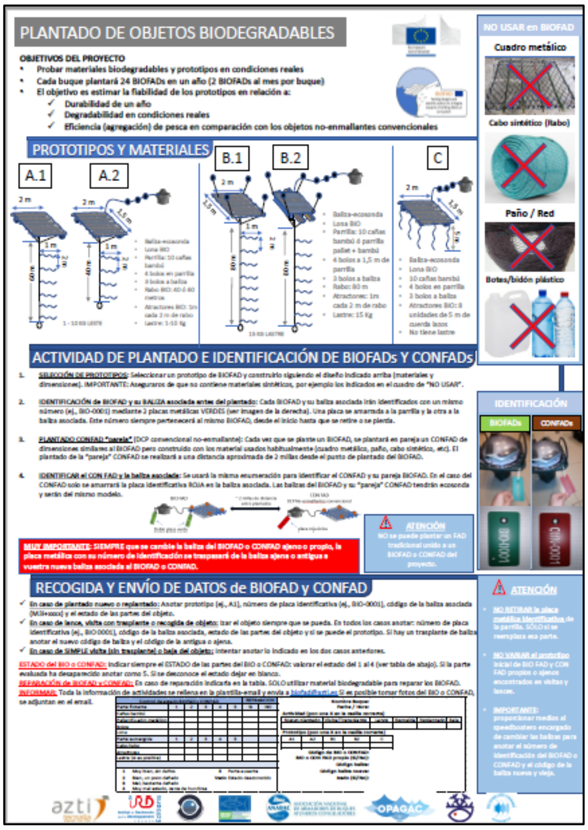


Figure 4.2.3.1.1.5. Posters created by ORTHONGEL (left) and Consortium (right) intended for onboard crew and detailing the deployment and monitoring of BIOFADs. These informative documents were developed and provided to the fishing industry to support vessel crew in the correct functioning of the project.

Addressing concerns and ensuring participation:

The Consortium organized two additional workshops, one at AZTI (Sukarrieta, Spain, December 2017) and another at CFTO (Concarneau, France, January 2018) to work with fishing companies in the construction of BIOFAD prototypes. These workshops aimed to address industry' concerns about the designs and to ensure high levels of commitment with the project. During these workshops French and Spanish fishing companies provided some feedback with regards to the prototypes. The French fleet also raised some questions about the best ways of sewing and fixing the biodegradable cotton cover to the raft and attaching the biodegradable ropes. The floatability aspect of the BIOFAD was also reported as a concern for both fleets. With the materials available, representatives of the fishing companies were able to build different BIOFAD prototypes (Figures 4.2.3.1.1.6. and 4.2.3.1.1.7.). This exercise allowed them to identify essential tools needed to aid the construction process, especially regarding the sewing of the cover.

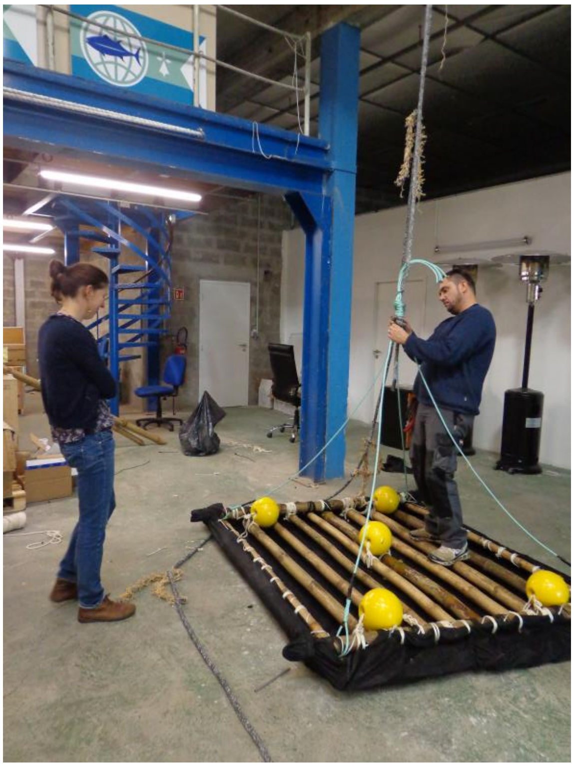


Figure 4.2.3.1.1.6. First BIOFAD prototype (type A) built by ORTHONGEL and CFTO (Concarneau, France).

Figure 4.2.3.1.1.7. Representatives from different fishing companies from ANABAC and OPAGAC building BIOFAD prototype B2 at AZTI (Sukarrieta, Spain).

Some of these BIOFAD preliminary "on land" constructions were further tested by the Consortium and industry. For example, as mentioned previously (section 4.2.3.1.1) the Consortium tested a BIOFAD B2 prototype anchored in the port of Mutriku (Spain) and monitored for 1 year (deployment September 2017). Another prototype was built and monitored by the French fleet under controlled aquatic conditions. In this case the prototype was anchored at the port of Concarneau (France). ORTHONGEL organized further activities to build BIOFAD prototypes so before the deployments at sea start. The idea behind all these activities was to define an efficient construction protocol beforehand and to ensure a quality standardization of these construction practices. ORTHONGEL together with French skippers and with CASAMAR (company in charge of the construction of FADs for ORTHOGEL) also conducted a trial (29 November-1 December 2017) for the construction of BIOFADs at the Seychelles port with the objective of testing a sample of the cotton cover for the BIOFAD raft. Other objectives of this test were to define some construction procedures for FAD building (e.g., distance between secondary ropes and amount of weight to be used).

Finally, a third additional workshop was held at the Seychelles Fishing Authority premises (Mahé, Seychelles, 12 April 2018) which was attended by almost all EU PS companies involved in the project. The deployment period was officially started with this workshop, at which the outputs and agreements reached in the 1st BIOFAD workshop were explained to strengthen the message among PS crew attending. Consortium members also took advantage of this visit to Seychelles to coordinate the delivery of biodegradable materials to the fishing companies, to communicate with Consortium staff based in Seychelles, and visit PS vessels present at the port in order to streamline the deployment process.

4.2.3.1.2. Screening for functionality biobased, biodegradable and recycled (from marine litter) material candidates, for the construction of FAD structural elements.

In parallel to the deployment of BIOFADs and the assessment of data collected from them, research testing the functionality of biologically-based, biodegradable and recycled (from marine waste) material candidates for the construction of the flotation components of FADs was subcontracted to GAIKER. In this subsection a summary of work carried out by GAIKER including the most relevant information is presented. More details about tested materials, used methods and results obtained in the screening study are provided in the final version of the document prepared by GAIKER (submitted together with this report), which was firstly submitted in the first version of the Second Interim Report in APPENDIX II, and later submitted as a separate document in the first version of the Third Interim Report.

Two main objectives of the screening study were:

- To propose new biodegradable candidate materials for the structural parts of the FAD (i.e., raft) with improved functionality and
- To use laboratory scale samples (i.e., small size specimens) to tests and select the best candidate materials, before moving forward to the construction and testing of prototypes in real conditions.

To achieve the above described objectives the following sub-objectives were planned:

i) to determine the performance (mechanical and physical properties) and durability of a range of pre-selected natural (plant origin), biodegradable and recycled materials to marine ageing in laboratory conditions.

ii) to quantify the effect of specific treatments (coating and thermal) applied to the natural materials in order to improve their durability.

Two types of materials were pre-selected to conduct the screening:

- Natural materials. In this category, the following options were considered:
    - Radiata pine
    - Bamboo
    - Cork composites

- Biodegradable or recycled thermoplastic materials, which are synthetic materials with biodegradable material certification for packaging applications or recycling plastics from circular economy.
    - Blend of Polylactic acid (PLA)/ Polyhydroxyalkanoates (PHA) in ratio (1:1)
    - Recycled Polyamide from fishing nets

The preparation of the test specimens for the different material categories considered above was different for both the natural and the thermoplastic materials. In the former case (pine, bamboo and cork), the test specimens were obtained by cutting pieces at the required geometry, but in the latter case the material was received in pellet form. Afterwards, pellets were extruded to obtain a blend, and injection moulding used to obtain the standard test specimens with the called “dog bone” shape.

Material categories, finally tested in the screening also included those natural materials with thermal and coating treatments**:**

- Radiata pine
- Thermally treated Radiata pine
- Bamboo semi-cane (Bamboo samples were cut longitudinally to be comparable with coated samples)
- Cork composite
- PLA/PHA (50:50)
- Recycled polyamide (PA)
- Radiata pine + coating
- Bamboo semi-cane + coating
- Cork composite + coating

Regarding the testing method to determine materials’ performances, it is important to explain that they were defined according to the type of properties tested and considering not only the durability of the material in marine conditions, but also other aspects related to their floatability when submerged in marine water. So, two main groups of properties were covered:

i) Mechanical properties. These were related to functionality/durability of the material as part of the FAD structure:
    a. Resistance and tensile modulus,
    b. Resistance and flexural modulus,
    c. Charpy impact (with or without notch, depending on material)
    d. Compression resistance.

ii) Physical properties. These were assessed as they may induce changes in the floatability:
    e. Density variation

f. Water absorption variation

The standard method selected to evaluate the properties above mentioned considered the following aspects:

- Availability of the material dimensions for testing
- Limit of resistance of the materials
- Checking out whether the load cells of the equipment available at GAIKER facilities were valid for testing the samples.

The assessment of the above-mentioned properties was conducted based on international standard methods:

- Density, according to UNE EN ISO 1183
- Water absorption according to an internal procedure
- Tensile properties (Tensile strength and modulus) according to UNE EN ISO 527. This standard was only considered for the thermoplastic materials.
- Compression resistance according to UNE EN ISO 826
- Flexural properties (Resistance and modulus) according to UNE EN ISO 178 (in the case of the natural materials, the applied UNE EN ISO 14125 required specimens with other dimensions)
- Charpy Impact according to UNE EN ISO 179 was used only for thermoplastic materials.

To reproduce marine ageing effects on materials' properties, plastic containers with marine water were prepared to carry out the immersion of the prepared test specimens. These containers were placed at the roof of GAIKER facilities during the study period. The containers were checked on a daily basis to assess samples and guarantee a homogeneous contact of samples with water and external environmental conditions. As these containers were kept on the roof with no lid, they were not protected from rain, so that they were under controlled laboratory conditions for monitoring, but somewhat subject to external environmental conditions like they would in real at sea situations, and thus samples were also subjected to variations in sun radiation, rain and temperature.

The total duration of the experiments was planned for a period of 130 days (see note below). This testing period for the different materials was planned with several control steps integrated: 0 (reference) and 45 days, 90 days and 130 days after immersion in simulated laboratory ageing conditions. The evolution in properties was described considering the average results of the specimens tested in every monitored interval (5 refence specimens at initial tests, 2 specimens at mechanical tests and 3 specimens at physical tests) at 45, 90 and 130 days. From a logistic point view, to avoid overlapping sampling times of a large number of samples, these were immersed into the containers on two different dates. In addition, all the different property controls were performed during the week after the removal from water. Consequently, during this week of assessment, samples were kept under preconditioning conditions (23ºC and 50%RH) while mechanical tests were finalized according to the standards.

During the screening, any remarkable change of test specimens was visually assessed to ensure there were no alterations in sample floatability. The following categories were observed in order to score the materials expected to float:

i) Samples/specimens that maintained floatability during the whole testing period (130 days):
   - All specimens of coated radiata pine
   - Specimens of bamboo cane with coating (those prepared for water absorption tests)
   - All specimens of cork and cork with coating

ii) Samples that maintained floatability up to 90 days:
   - All specimens of natural radiata pine
   - All the specimens of coated bamboo cane

iii) Samples that maintained floatability up to 45 days:
   - All the specimens for different materials with the exception of thermoplastics (biodegradable and recyclable) that had densities higher than 1.1 g/cc in both cases

The main conclusions obtained from test trials are detailed below for each material:

Radiata Pine.

In the case of radiata pine, as shown in the results for density evolution and water gained, only the coated samples achieved a density below 1 g/cc at the end of the 130 days period. The coating seems to be effective in terms of avoiding variation in density for this material (45-90 days density was almost the same).

According to the results radiata pine is an example of a material that shows a decrease of mechanical properties (of around 35%) after 45 days submerged in marine water. However, the mechanical properties were maintained in the same range, from the first control (45 days) to the final monitoring period (130 days).

In the case of thermally treated radiata pine, theory says that treatment of wood in an autoclave could result in changes of colour, decrease in mechanical properties but also reduce in the hygroscopic behaviour of the wood. Nevertheless, the results of the screening study showed that at the end of the study period (130 days), the increase in the density of this material was higher than in the natural and coated pine states. In addition, the absorption of water shown by this material showed high values in comparison with the rest of the samples. For these reasons, based on the conclusions of the study thermally treated wood would be discarded as a valid candidate.

Bamboo cane

This material is currently used in FAD structures, with relative success in the Indian, Atlantic and Pacific Oceans. This is a sustainable solution considering that bamboo is a local native wood in those geographical areas. However, its sustainability requires also that this renewable resource is managed responsively.

The tests showed that the applied coating system was not probably the best option for the bamboo canes, as some blistering patches were observed starting to appear during the period between 90-130 days. This means there was certain degree of incompatibility due to the swelling effect produced by the water.

Considering the effects recorded for floatability properties of materials (density and water absorption), lower levels on water absorption and density variations were observed for the coated bamboo canes. Nevertheless, at 130 days of testing, the floating capacity of these coated samples was partially compromised. In fact, both materials (coated and uncoated), showed a progressive increase in density and water absorption values, being more significant in the case of the uncoated bamboo cane.

Regarding the rest of properties, the effect of coating was more remarkable when applied to "thin" bamboo cane samples rather than "thick" canes. An analysis was done to assess the improvement percentage by comparing the overall variation in properties at initial values and values after 130 days. A decrease in the physical properties for both types of materials (coated and uncoated samples) was observed, while a positive trend in the mechanical properties of coated bamboo was observed.

Some other interesting aspects observed with the bamboo canes were:

- Within 45-90 days in marine water, changes in colour and formation of a tacky maroon coloured layer caused by fouling on the surface was observed. This effect was also partially observed in coated canes.
- From 90 days onwards, in the coated bamboo canes, formation of a blistering surface in the interface between the cane and the coating was observed. This was interpreted as a loss of adhesion caused by the swelling of the materials or problems related to the application of the coating (i.e., insufficient pre-drying of the cane substrate before coating application)

Cork composites.

Significant differences in terms of density and water absorption were observed when examining evolution of this material over the 130 days.

In both properties (density and water gained), observed variation in the uncoated specimens could be defined as "a progressive increase along the period of ageing", while in the case of coated cork samples, this variation was less acute. The difference at the end of the 130 days was about 0.25 g/cc between the two samples.

For uncoated cork, it would be necessary to extend the screening time to test whether the material could achieve a final density value that could compromise its floatability. However, the density values of this natural material were clearly below the limit of 1.1 g/cc, while water gained showed a maintained profile along the time frame monitored. Water absorption behaviour was also significantly different, however in both cases, the water gained value had a constant trend.

Regarding the rest of properties, variations were similar along different controls performed, being slightly smaller for coated cork with the exception of impact behaviour. However, differences were not significant between coated and uncoated samples.

The analysis of the improvement percentage of the final properties at the end of the study between the coated and uncoated cork samples, showed a positive ratio for flexural properties (improvement of 23-44%), while similar compression behaviour was observed for both samples.

Results for the coating treatment for cork showed it is effective for stabilizing water absorption capacity and density, but not so significant for maintaining mechanical properties.

Blend of Polylactic acid (PLA)/ Polyhydroxyalkanoates (PHA) (1:1).

Variations were not significant during the period of ageing with respect to the initial or reference property values. Property profile variations showed values in the range of 1-3%. The behaviour of the material was very stable, probably due to the stability of PLA in mechanical properties. It would be interesting to try out an increased ratio of PHA in future tests.

Recycled Polyamide from marine nets.

Water absorption behaviour was significant for a thermoplastic material, with sustained values of 6-7 % for water gained in the 3 controls (similar at 130 days compared to 45 days). Similarly, results for density assessment were also steady throughout controls with values around 1.14 g/cc.

However, ageing affected water absorption capacity of this material, producing changes in mechanical properties as water acted as plasticizing agent (i.e., a plasticizer is a substance, sometimes included in plastics formulations, to modify the physical properties like plasticity or viscosity or the impact resistance) for the polyamides. This was the main cause for the variation of properties, with a reduction in all mechanical properties related to material toughness and rigidity by at least 50%. At the same time, increased flexibility produced impact resistance increases of up to 230%. This means that the material was becoming more elastic, but at the same time, the breakage force was lower. In addition, the reduction of the rest of mechanical properties was progressive and continuous during the ageing process.

It is important to note that all the conclusions obtained from the study are affected in some way by the limitations of the screening in terms of time (130 days) and number of tested specimens. This also applies to the ageing method used in this study, as it did not consider other mechanical risks potentially found during real testing conditions in oceans. Thus, extrapolation of these results to real life behaviour in tropical ocean conditions should be done with caution.

However, besides the above mentioned limitations, this study provided a method to distinguish trends of the tested materials and preliminarily identify best performing materials, or effectiveness of treatments like protective coatings to improve the performance of materials.

In addition, due to the limited number of replicates tested in each control (n=2) compared with the specimens tested to establish the initial specifications (n=5), percentages of improvement of at least 30-40% can be considered as an indication of variation in a specific property. This means these results can be useful if they are considered for comparison purposes between proposed selections, but with limited application to their behaviour as part of a real FAD, where the structural design of the components will be very relevant.

NOTE: The testing period was set based on operational requirements and the activity progress schedule planned in the Inception Report, which strongly conditioned the duration of the testing period to fulfil with Consortium's commitments related to the reporting schedule (the testing period was agreed between AZTI and GAIKER).

4.2.3.1.3. Establishing a definition for biodegradable FADs

In collaboration with GAIKER, the Consortium tried to establish a definition for BIOFADs (biodegradable and non-entangling FADs). The aim of this sub-task was not only to propose a first tentative definition for BIOFADs but to also foster the discussion to address minimum standards (e.g., materials, derived-components and environmental considerations) when the term biodegradable is applied to define the materials utilized for BIOFAD construction. To advance towards an agreed BIOFAD definition by tRFMOs, it would be desirable to review present definitions in the Joint tRFMO FAD Technical Working Groups. This would allow opening the discussion between stakeholders and providing clear guidance and clarity when the term biodegradable is used to define the materials used for FAD construction.

The term "biodegradable" is applied to materials or substances that are subject to a chemical process in which microorganisms in the environment (sea, soil, etc.) convert the original materials into natural substances such as water, carbon dioxide, and compost. The process of biodegradation depends on the surrounding environmental conditions (e.g., location or composition of the media, humidity and temperature), the type of material and on its application (i.e., thickness) (https://www.european-bioplastics.org/).

Organic materials, in the process of their degradation on land, completely disappear as they are part of the food source for soil organisms, however, this process may not occur in the same manner in marine environments. To claim that a material is biodegradable in marine conditions (or other environments) it is necessary to account for the time frame required to consider it as "biodegradable". This time frame is generally defined according to specific standards addressing the process of biodegradation of materials.

In this section, we will take plastics as an example, as they are the materials for which standards are best defined, both in terms of definitions of testing methods and certification scales. There are various international standards for certification of compostable (organically recycled) plastics in industrial composting plants and other natural environments (i.e., soil or marine):

Some examples of industrial composting standards:

- EN 13432:2000 Plastics for packaging
- EN 14995:2006 Plastics in general
- ISO 18606 Plastic for packaging
- ISO 17088 Plastics in general
- ASTM D 6400 (USA standard for plastics compostable in industrial or municipal facilities)
- AS 4736 "Australian Standards, for "Biodegradable plastics suitable for Composting and other microbial treatments".

There is also the possibility for "biodegradable in soil" (i.e., EN 17033) or "marine" (i.e., ASTM D6691, ASTM D7081) certification, depending on the testing conditions. These are the requirements that need to be validated under European standards (i.e., EN 13432 or EN 14995):

- **Chemical test:** Disclosure of all constituents, i.e., threshold values for heavy metals that need to be assessed.
- **Biodegradability in controlled composting conditions (oxygen consumption and production of CO_2):** Proof provision that at least 90 percent of the organic material is converted into CO_2 within 6 months.
- **Disintegration:** After 3 months composting and subsequent filtering through a 2 mm sieve, no more than 10 percent residue may remain, as compared to the original mass.
- **Practical test of compostability in a semi-industrial (or industrial) composting facility:** No negative influence on the composting process is permitted.
- **Ecotoxicity test:** Examination of the effect of resultant compost on plant growth (agronomic test).

Despite the above mentioned and considering that ASTM D7081 has been withdrawn (without replacement for the moment), there is no accepted standard for biodegradation of plastics in marine environments which can provide useful pass/fail criteria. However, there are companies such as Tuv Austria (former VinÇootte) that offer a certification scheme based on ASTM D7081, which requires a biodegradation of at least 90% of the material over a period of 6 months. In addition, currently withdrawn ASTM 7081 stated that the materials also required to pass the ASTM D6400 compostability standard.

The present absence of a clear regulatory framework defining the standards and test methods for biodegradable materials in marine environments prevents a clear definition for the type of materials that could be permitted in BIOFAD construction.

Besides regulatory issues regarding FADs, an important question is if the term "biodegradable" should then be applied to the materials themselves or to the final product (i.e., FAD) that is composed of various parts. In the latter case, each part may have different functionality/duration (e.g., time frame), shape (e.g., thickness) and associated detrimental environmental impacts, as the FAD can degrade as whole or in separate parts (e.g., when the tail of a FAD becomes detached and sinks).

To establish the potential definition for BIOFADs, the following points have been considered:

- **Type of materials and configuration:** use of naturally occurring materials (e.g., bamboo, cotton, or plant fibres), or in their absence, prioritizing bio-based/biodegradable compounds which comply with international standards. In any case, materials meeting previous requirements must be always non-entangling following ISSF criteria for non-entangling FADs (NEFADs) (ISSF, 2019).

- **The environmental impacts:** cumulative impacts by plastics or other synthetic materials from FADs (e.g., long-term accumulation in marine environments), as well as the high number of whole FADs lost should be considered to assess real impacts.
- **Durability and functionality:** a time frame for biodegradability should be determined, accounting for fishing industry functional requirements to achieve a sufficient working lifetime of a FAD (estimated at one year). FAD material disintegration velocity should be compatible with the requirements of compostable regulations described according to specified standards.
- **Technical implementation feasibility:** for different FAD parts to be replaced by biodegradable alternatives (depends on the material but also on the physical characteristics of the material used, such as its thickness).

The following is the first tentative BIOFAD definition taking into consideration the above-mentioned requirements. This definition has been developed and based on material specification (e.g., lignocellulosic materials and/or bio-based biodegradable plastic compounds) rather than the final product (e.g., floats or the FAD itself):

A BIOFAD is composed of non-netting renewable lignocellulosic materials (i.e. plant dry matter) and/or bio-based biodegradable plastic compounds, prioritizing those materials that comply with international relevant standards or certification labels for plastic compostability in marine, soil or industrial compost environments. Sustainable harvest of the materials used should be guaranteed. In addition, the substances resulting from the degradation of these materials should not be toxic for the marine ecosystems or include heavy metals in their composition. This definition does not apply to electronic buoys attached to FADs to track them.

Acknowledging the current state of the art for available biodegradable materials and the difficulties inherent to the implementation of this definition for FADs, a scale with different levels or categories of biodegradability for BIOFADs could be created. Similar approaches for FAD entanglement risk categories, such as ISSF's classification guidelines (ISSF, 2019) have proven successful. Fleets should work towards targeting 100% biodegradable FADs based on the present definition. This biodegradable FAD classification may be presented in a stepwise manner, including a timeline or planned deadline adapted to fulfil particular objectives stated in RFMOs' resolutions. For example, in IOTC Resolution 19/02 it is noted that "…*CPCs shall encourage their flag vessels to use biodegradable FADs… with a view to transitioning to the use of biodegradable FADs… by their flag vessel from 1 January 2022*". Thus, we expect that the proposed process by IOTC including a deadline, which is set in the near future, may contribute to speed up an effective use of partly or fully biodegradable FADs, as more companies prepare in anticipation for the forthcoming regulatory ban of non-biodegradable FADs. At present, implementation of 100% biodegradable FADs still requires investigation to solve important practical/technical aspects for the operationalization of this FAD type and scientists and industry are progressing step by step, as it happens in most new research processes

In this gradual process three different options have been discussed by the Consortium for BIOFAD categorization:

- **Option 1.** BIOFADs categories could be defined based on requirements of using biodegradable materials for the construction of certain FAD parts. For example, considering separately the biodegradability of materials used in the construction of the raft and the tail.
- **Option 2.** BIOFAD categories could be defined based on requirements to use a minimum percentage or proportion of biodegradable materials in their construction. For example, using a scale that considers different proportions of biodegradable materials in a FAD relative to the FAD's total weight (in kg) or surface (in m^2).
- **Option 3.** BIOFAD categories could take the form of a hierarchical scheme based on Life Cycle Analysis (LCA) results for types of materials used in FAD constructions. This selection could be defined according to functionality criteria providing technical solutions for the different parts such as tail structure, floating elements, etc. and prioritizing the materials according to:
    - Certified as Biodegradable in the marine environment or compostable.
    - Bio-based or obtained from natural resources but also recycled in a circular economy frame ("from marine water to marine application").
    - Materials reducing carbon footprint (from marine waste).

Onboard verification of FAD construction materials for the correct implementation of the above proposed options is key to assess industry compliance. However, option 2 and 3 imply several technical difficulties in this regard. Besides, development and application of FAD categorizations for these two options (e.g., hierarchy scheme, weight/surface thresholds, etc.) will not be straightforward when defining thresholds. Thus, the Consortium proposes Option 1 as the most feasible one for implementation by industry in the short- and medium-term. We propose three possible categories of BIOFADs within **Option 1** according to the degree of biodegradability of FAD parts. BIOFAD classification based on Option 1 could help move forward the stepwise process towards the implementation of fully biodegradable FADs:

- Category I. This category corresponds to 100% biodegradable FADs. This means all parts (i.e., raft and tail) of a FAD are built with biodegradable materials. Used materials should fulfil proposed BIOFAD definition.
- Category II. This category corresponds to FADs using biodegradable materials for whole FAD except for the floating component (i.e., plastic floats). This means that all parts (i.e., raft and tail) of a FAD are built with

biodegradable materials fulfilling the proposed definition for BIOFAD but have additional non-biodegradable floatation elements.

- Category III. This category corresponds to FADs using only biodegradable materials in the construction of the tail but non-biodegradable materials in the raft (e.g., synthetic raffia, metallic frame, plastic floats). This means all underwater hanging parts (i.e., tail) of a FAD are built with biodegradable materials fulfilling the proposed BIOFAD definition.
- Category IV. This category corresponds to FADs with all parts (i.e. raft and tail) only built partly or with no biodegradable materials.

Progressively, as soon as new kinds of biodegradable materials become available, the proposed categories of biodegradability should be adapted and refined for the construction of other FADs parts (e.g., tracking buoys) targeting 100% biodegradability as per the BIOFAD definition above. In the meantime, the term bio-based could also be considered as biodegradable when applied to all FAD parts. This term would also include bio-based plastics, if these are finally allowed and meet with BIOFAD definition requirements agreed by stakeholders. It was highlighted by the Consortium that further research with those natural and alternative materials that meet the BIOFAD definition is still required.

4.2.3.2. Sub-task 2.2 - Identify the pros and cons of each design and material, and justify the selection made

The selection and design of the BIOFAD prototypes were made based on the results provided in previous studies examining different plant fibre materials (Lopez et al., 2016), trials with experimental prototypes (Moreno et al., 2019) and the output of international biodegradable FADs workshops (Moreno et al., 2016b). This information was collated to steer the 1st BIOFAD workshop, where the final material and prototypes were selected by participants.

All selected BIOFAD prototypes were evaluated and the pros and cons of each design and material used in their construction assessed. Construction materials for each BIOFAD prototype were characterized qualitatively (i.e., specification of the material) and quantitatively (i.e., weight in Kg or length in m of material used for each construction) (Appendix II, Table 4.2.3.2.1). Four additional non-biodegradable and non-entangling FADs (NEFADs) used by EU PS in the Indian Ocean were considered in the qualitative and quantitative analysis. This allowed comparisons between selected BIOFAD prototypes and conventional NEFADs at the time used by PS in the Indian Ocean. As agreed during the 2nd BIOFAD workshop, newly proposed prototypes (i.e., cage-shape FAD) and the inclusion of the double layer of cotton canvas and the metal frame for BIOFAD construction (for more details see 2nd BIOFAD WS Minutes) were also considered in the analysis. This increased the number of combinations for each of the initially defined BIOFAD prototypes from 5 to 19 available options (Appendix II, Table 4.2.3.2.1).

Table 4.2.3.2.1 (Appendix II) shows the FAD characterization results (BIOFAD and NEFAD with the description of each component and the % of biodegradability for each prototype (i.e., ratio between the weight of biodegradable materials and the total weight of all materials used). Information about the specification of materials was obtained through conversations with EU PS fleet members and direct weight and length measurements from built prototypes at the laboratory and fishing port. The measurements describing the experimental paired NEFAD prototype components are approximations as high variability may exist in each components' length and weight. To better represent the variability in NEFAD construction and characterize each component (i.e., type of materials and dimensions), whenever possible further measurements were collected to best represent each of these parts. As mentioned above, this analysis considered those designs defined in the 1st BIOFAD workshop plus the new designs and modifications accepted in the 2nd BIOFAD workshop. According to the fishing industry some of the prototypes defined in the 1st BIOFAD workshop (July 2017) were no longer used by them or have evolved since the start of the project. This fishery is known for rapid adoption of new FAD design trends over very short time periods (i.e., months) (Murua et al., 2017). In line with this, in the 2nd BIOFAD workshop, industry members conveyed the necessity of more flexibility to adapt selected prototypes to their requirements.

For BIOFAD and NEFAD characterization each component was identified and whenever possible their technical specifications provided:

- Floating part:
  - Floats (In Appendix II Table 4.2.3.2.5.)
  - Cotton cover (In Appendix II Table 4.2.3.2.2.)
  - Bamboo (In Appendix II Table 4.2.3.2.6.)
  - Wooden pallet (No specification provided)
  - Synthetic twine (No specification provided)
  - Metal frame (in progress)
- Hanging part:
  - Twisted cotton main rope (In Appendix II Table 4.2.3.2.3.)
  - Twisted looped cotton rope (In Appendix II Table 4.2.3.2.4.)
  - Weight (No specification provided)
  - Metal frame

Based on the results observed in Table 4.2.3.2.1 (Appendix II) 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 significantly reduced the amount of synthetic materials used in their construction. Prototype A1, the most used in trials, required 81% less synthetic material than its equivalent paired NEFAD. These results show how BIOFAD prototypes, even when allowing plastic floats, significantly contribute to the reduction of synthetic materials in FADs (Table 4.2.3.2.7.). Consequently, markedly mitigating the potential contribution of lost and abandoned FADs to marine pollution and its derived impacts on the ecosystem, which is the objective promoted by IOTC resolution 18/04.

Table 4.2.3.2.7. Data on total weight of material used for BIOFAD and equivalent NEFAD construction. Weight of biodegradable and synthetic materials used in the construction of both FAD types. 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		

To further evaluate the advantages and disadvantages of each material, and to justify the final selection, the quality status of each BIOFAD component was estimated based on data provided by vessels interacting with FADs. Component quality assessment was required every time a vessel interacted with an experimental FAD. At each interaction, whenever possible, all parts of the FAD structure should be checked. A scale from 1 to 5 was developed to value the overall status of the FADs (1 = Very good, not damaged; 2 = Good, a bit damaged; 3 = Bad, quite damaged; 4 = Very bad, close to sinking; 5 = component missing; Blank = unknown information). However, as explained in section 4.2.4., there was an important lack of these assessments in terms of both quantity and quality, especially for those experimental FADs with more than 6 months at sea after deployment. This significantly affected the reliability of the material degradation analysis for those months when observations were especially low. Nevertheless, the degradation of the three biodegradable materials (i.e., cotton canvas, and two types of cotton ropes) was assessed and discussed in the following paragraphs.

As shown in Figure 4.2.3.2.1, the integrity of the cotton canvas (i.e., component used to cover the raft as alternative to netting materials or synthetic raffia), started to show significant degradation already by the first and second month at sea. This degradation increased in the third and fourth months, when more than 50% of the observations were reported to be in a "bad", "very bad" or "absent" states. A similar pattern was also observed in the fifth and sixth months at sea. Meanwhile, the synthetic materials covering the raft in paired NEFADs, showed better performance than the biodegradable component and kept in good condition until the sixth month at sea. Afterwards observations were too low to make any statistically sound comparison. These results are in line with the perception conveyed by industry during the 2nd and 3rd BIOFAD workshops. Their perception and acceptance of the cotton canvas was not positive as they observed high degradation from the first month at sea after deployment.

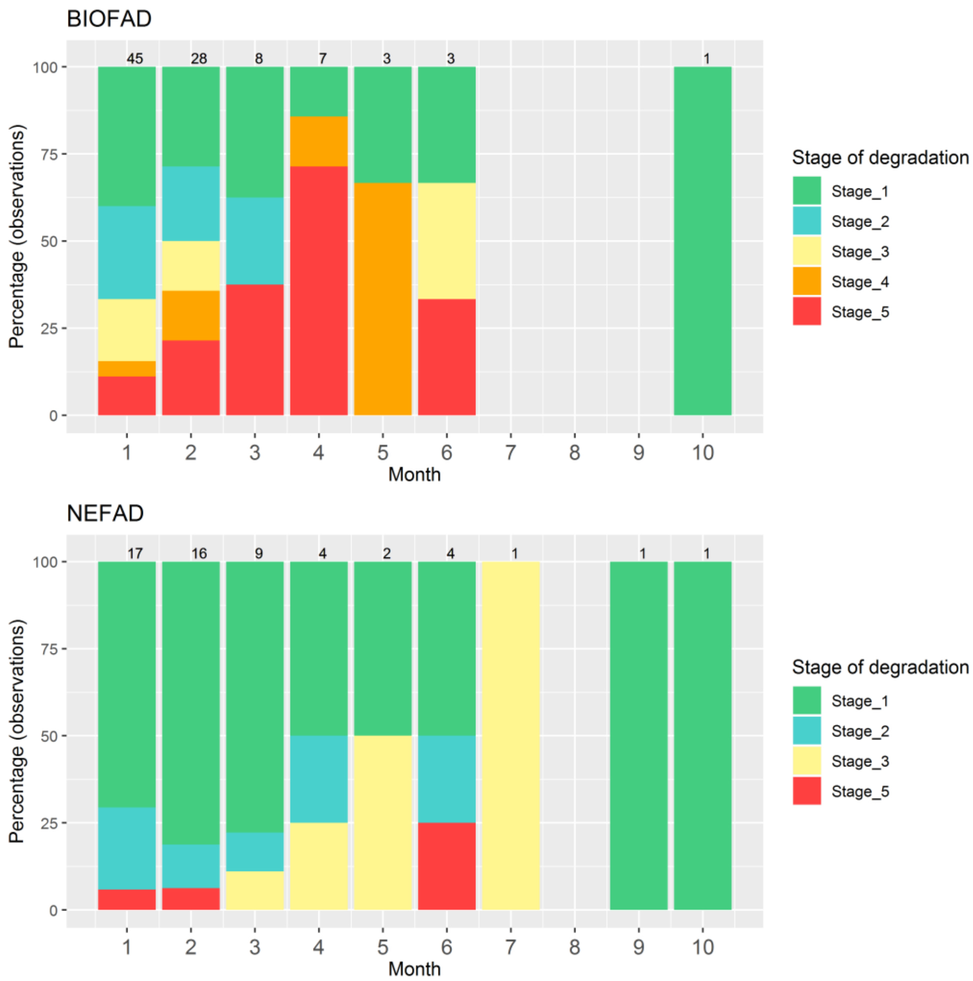


Figure 4.2.3.2.1. Status control assessment for the cotton canvas for BIOFAD and synthetic material for NEFAD. Stage_1 =Very good; Stage_2 = Good; Stage_3 = Bad; Stage_4 = Very bad; and Stage_5 = Absent.

The degradation of the cotton rope (i.e., component used in the submerged part of the FAD as main tail material) was less pronounced comparing with the cotton canvas (Figures 4.2.3.2.2.). The status control for the cotton rope was reported to be in "very good" or "good" quality until the fourth month at sea. However, in 10-20% of the observations of this material it was reported as absent during the first, second and third months at sea. In the fifth month the "absence" observations 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) (Figure 4.2.3.2.3.). 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.

According to feedback during the 2nd and 3rd BIOFAD workshops and unlike the general perception with the cotton canvas, the absence of the BIOFAD cotton rope tails were related to deficient attachment between the raft and tail union point, rather than to a high degradation of this material. If not correctly attached (e.g., the tail rope knots tying to the raft becoming loose) the whole tail structure could be lost resulting in the reported absences. An indication of this happening was that in many instances the whole BIOFAD's tail structure had disappeared, where not even small sections of rope remained hanging. Future trials should ensure prevention of weak connection points between FAD parts. Overall, industry positively valued the performance of these two rope components. Although part of the fleet was expecting longer lifetime from them, other companies have already incorporated them into their FADs used in everyday commercial fishing operations. According to the aforementioned results and feedback, tested cotton ropes could be considered as a feasible solution for FAD tails, and thus, as replacement for synthetic netting materials used in tails tied into coils or "sausages". This result will contribute to eliminate large amounts of synthetic net in FAD constructions and provide options for fleets to partly comply with Annex V requirements in IOTC´s resolution 19/02.

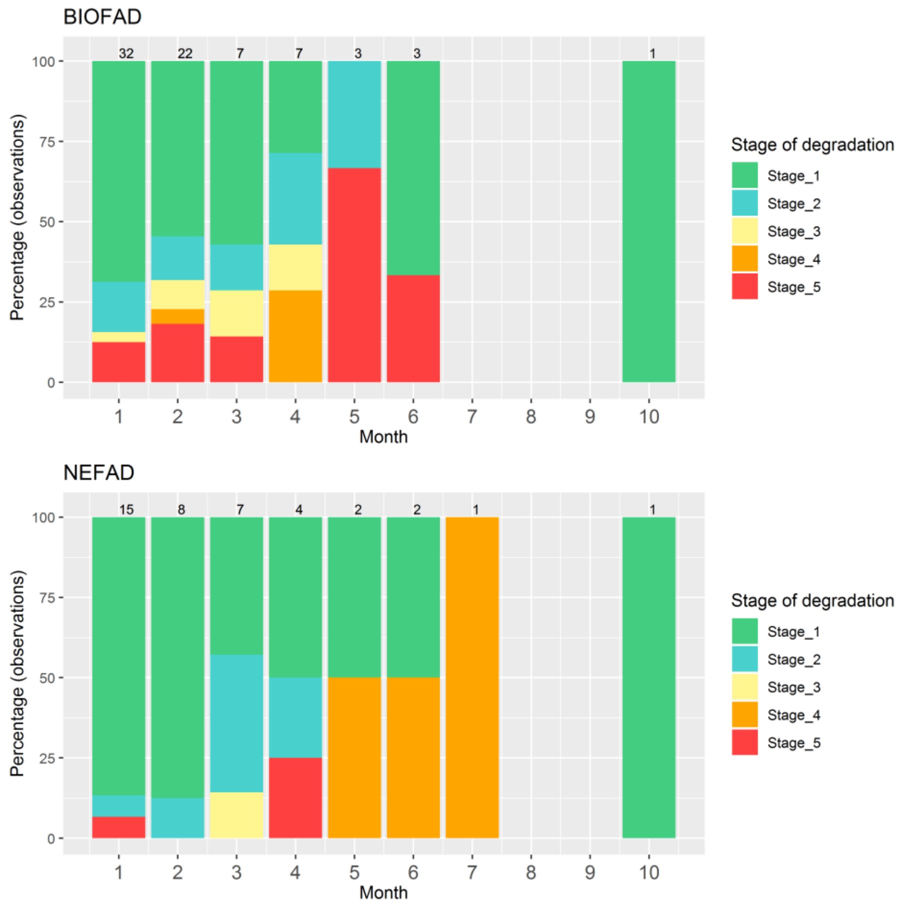


Figure 4.2.3.2.2. Status control assessment for the main cotton rope for BIOFAD and synthetic material used as tail for NEFAD. Stage_1 =Very good; Stage_2 = Good; Stage_3 = Bad; Stage_4 = Very bad; and Stage_5 = Absent.

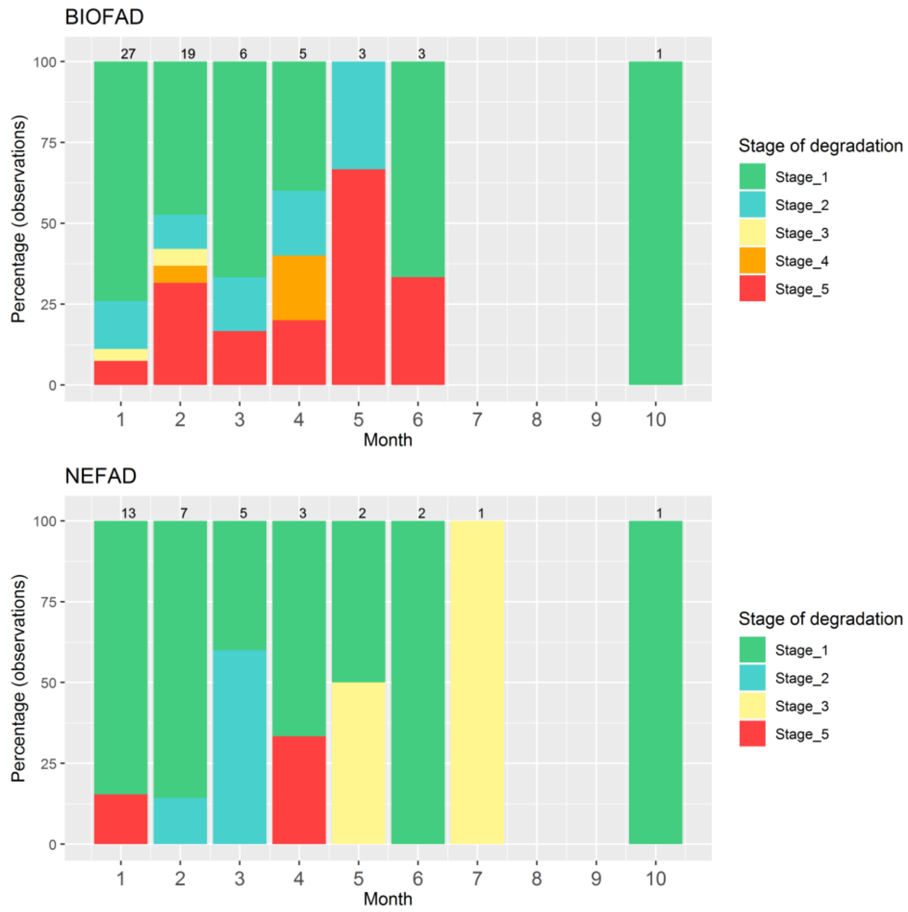


Figure 4.2.3.2.3. Status control assessment for the cotton rope used as attractors for BIOFAD and synthetic material used as attractors for NEFAD. Stage_1 =Very good; Stage_2 = Good; Stage_3 = Bad; Stage_4 = Very bad; and Stage_5 = Absent.

4.2.3.3. Sub-task 2.3 - Deploy a statistically significant number of BIOFADs and NEFADs throughout the year, to account for potential seasonality effects, in the Indian Ocean

The final number of BIOFAD deployments (Figure 4.2.3.3.1.) was affected significantly by the initial delays to the start of the deployment period (see section 4.2.4.). This process was also affected by other circumstances related to vessels' working operations such as reparations at dry docks, cease of fishing activity due to yellowfin tuna quota limitation, or delays in the coordination of fishing companies involved in the BIOFAD construction. The experiment's deployment period officially started with the BIOFAD workshop held in Mahé (12 April 2018, Seychelles), at Seychelles Fishing Authorities facilities, and attended by almost all EU PS companies involved in the project. During that workshop the outputs and agreements reached in the 1st BIOFAD workshop were explained to strengthen the message among the PS crew. Consortium members also took advantage of the visit to Seychelles to coordinate the delivery of biodegradable materials to fishing companies, communicate with Consortium staff based in Seychelles, and visit PS vessels at port to help with deployment process issues.

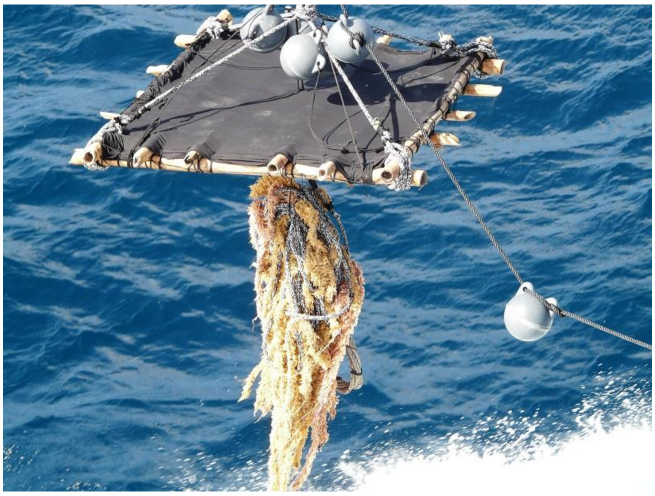


Figure 4.2.3.3.1. BIOFAD prototype A1 deployment by the EU PS fleet.

The first BIOFAD was deployed by EU vessels on April 2018. Finally, 771 BIOFADs were deployed by the EU and Korean fleet during the project trials, together with their paired conventional NEFADs, thus totaling 1,542 experimental FADs. This number represents 77% of the initially planned objective for the 14-month deployment period (April 2018 -June 2019). As shown in Figure 4.2.3.3.2., few BIOFAD deployments were carried out during the first months, mainly due to the reasons previously described. For the second trimester, deployments increased up to 87% of the planned objective for that period. However, BIOFAD deployments decreased again during the third and fourth trimesters, 65% and 32% respectively, which was directly related to vessels stopping all fishing activity due to reaching their yellowfin tuna quotas by November and December. Despite these unforeseen limitations, overall, not taking into account the kind of BIOFAD prototype, a balanced effort in BIOFAD deployments was observed among trimesters. In terms of deployment of different BIOFAD prototypes, there was no balanced deployment effort neither in number nor seasonally; from the total of 771 BIOFAD deployed 71% corresponded to prototype A1, 18% to A2, 4% to B1, 2% to B2 and 5% to C1.

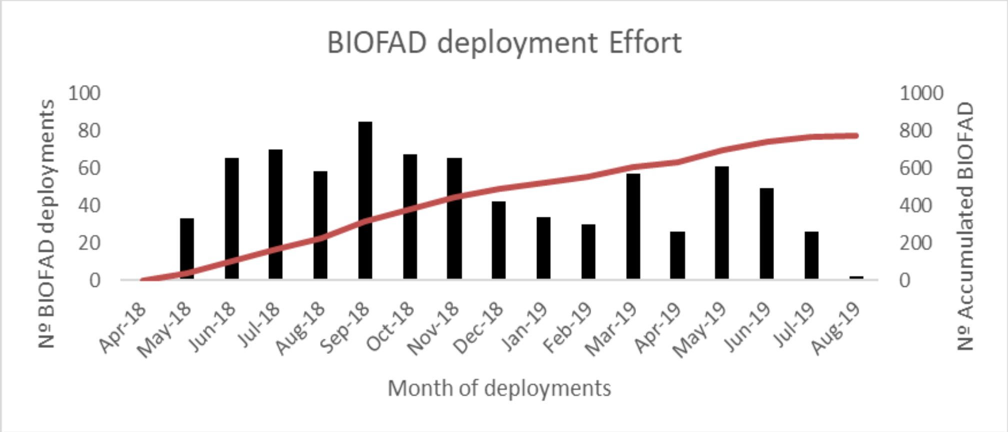


Figure 4.2.3.3.2. The number of BIOFAD deployments (black bars) and accumulated numbers (red line) by the EU PS fleet by month.

Although the deployment process was initially designed to be carried out by all PS vessels associated with the main three EU tuna associations (ANABAC, OPAGAC and ORTHONGEL), the Korean PS company DONGWON showed interest in participating in the project. Korean participation was initially planned to be limited to data collection in order to maintain traceability of deployed BIOFADs. However, the Consortium was able to provide the two Korean PS vessels in this ocean with biodegradable material and allowed them to construct and deploy 12 BIOFADs each. This enabled the Consortium to involve in the project all PS fleets operating in the Western Indian Ocean. All these companies were instructed to follow the same protocols for BIOFAD construction, deployment, data collection and data reporting.

To rectify identified delays in BIOFAD deployments, the Consortium asked vessels to increase the number of BIOFAD deployments from two to three units per month. Furthermore, during the 2nd BIOFAD workshop, the Consortium took the opportunity to show industry the deployments executed until then and highlight the necessity for those vessels below the marked objective to increase efforts (i.e., the number of deployments per month). Since the beginning of the project (August 2017), multiple in-person meetings and conference calls have been conducted between Consortium members and PS companies and associations. All of them provided a good platform for rapid exchange of information, constructive discussion and useful feedback. Support informative material was prepared by AZTI (for the Spanish/Basque and Korean fleets) and IRD-ORTHONGEL (for French companies) as guidelines for PS crew doing the deployments (Figure 4.2.3.1.1.5.) to clarify any doubts regarding the details of important experimental procedures. As described in section 4.2.3.1.1, the 2nd BIOFAD workshop was mainly organized to discuss progress on the deployments, collate preliminary results and obtain feedback from the fleets regarding material and prototype performances from the skippers' perspectives. This 2nd BIOFAD workshop was also organized as a platform for corrective measures to focus and plan the last deployment period.

BIOFAD deployments conducted between April 2018 and July 2019 were well distributed throughout the whole Western Indian Ocean tuna fishery grounds, covering the principal PS fleet operating areas (Figure 4.2.3.3.3.). These deployments were also well distributed spatially by trimester (Figure 4.2.3.3.4.).

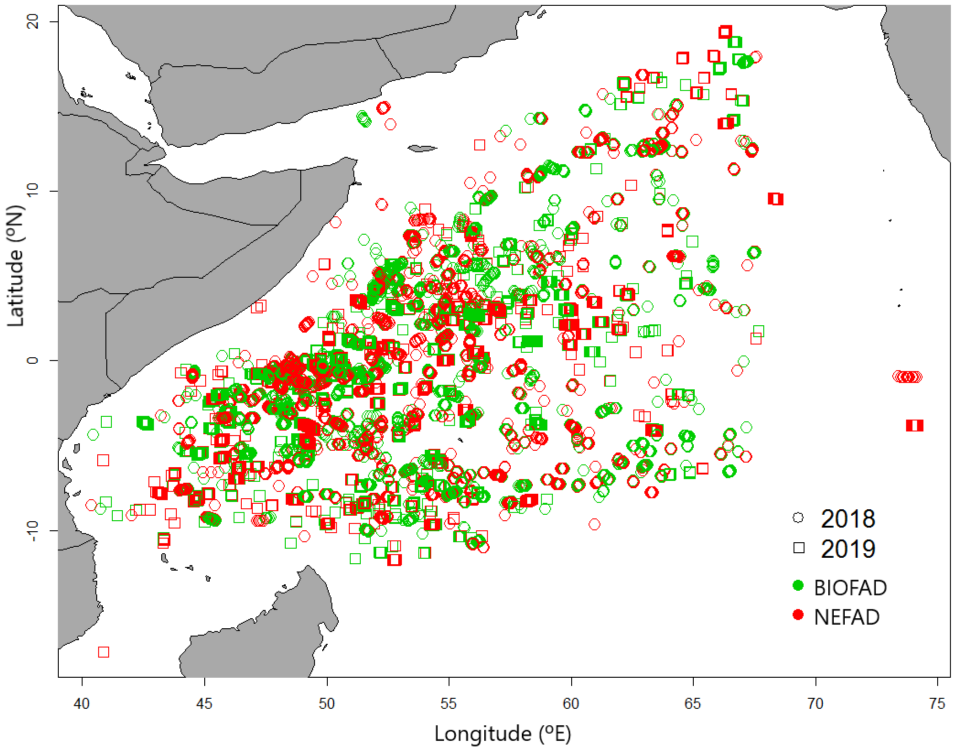


Figure 4.2.3.3.3. Spatial distribution of all BIOFAD deployments during 2018 and 2019 by PS fleets operating in the Western Indian Ocean.

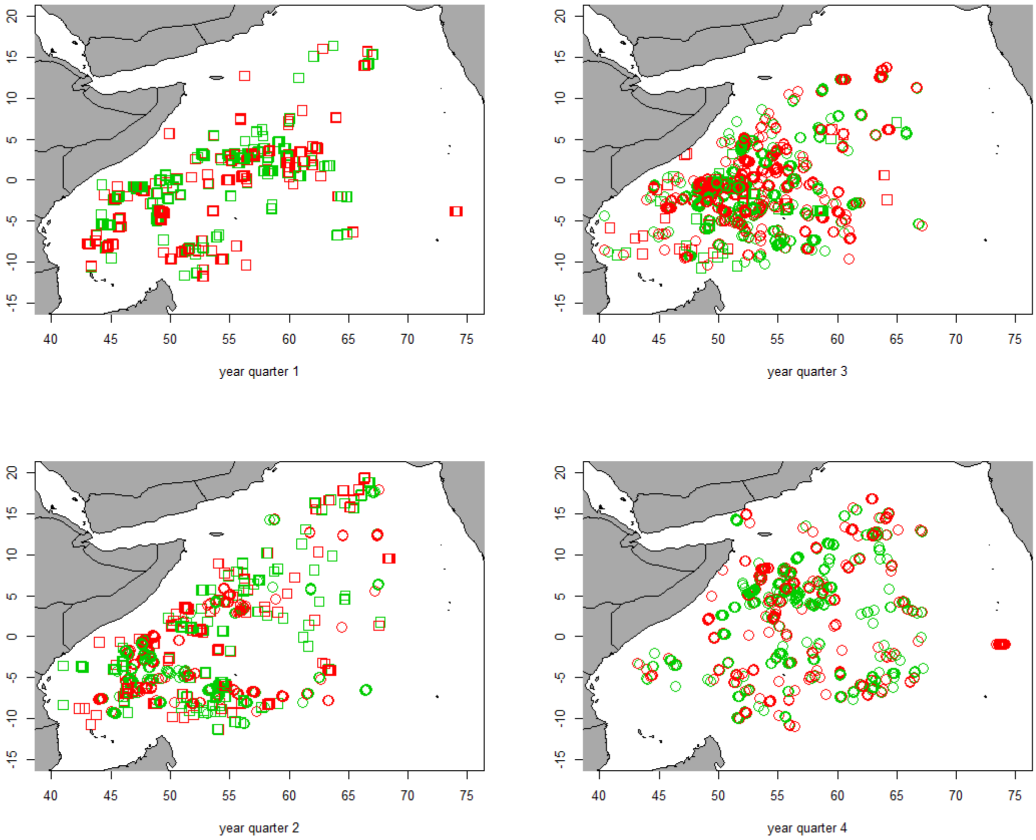


Figure 4.2.3.3.4. Spatial distribution of BIOFAD deployments by quarter during 2018 and 2019 by PS fleets operating in the Western Indian Ocean.

4.2.4. DIFFICULTIES AND RECOMMENDATION FOR FUTURE WORKS

Difficulties:

Delays in material purchase and delivery:

The BIOFAD deployment process suffered significant delays on the initially agreed planning period. This task was hindered by the process or model of acquisition and provision of biodegradable materials to provide the tuna purse seine fleets for BIOFAD construction. While acquisition/purchase of biodegradable materials for the SC07 was organized by the ISSF, the funding was provided by the Food and Agriculture Organization of the United Nations (FAO). In that regard, FAO published an invitation to bid (2017/CSAPF/FIDFD/100116) for the selection of suppliers on 2 October 2017 and kept the tender open for candidates until 16 October 2017. FAO was actively encouraged by AZTI (as coordinator of FWC and SC07) and ISSF to complete this selection process as soon as possible to avoid delays to the project. However, the rigorous administrative burdens inherent to FAO's selection process and a reorganization of the people in charge of the tender during the selection process, prevented a rapid resolution of the bid. Consequently, selected suppliers of materials were officially informed by FAO on January

2018. This delay derived subsequently in a modification of the action plan. Finally, all manufactured biodegradable materials arrived to Seychelles in two batches: First batch corresponding to two containers with the total amount of biodegradable cotton ropes and ¼ of the biodegradable cotton covers, which arrived to the Seychelles port on 25 March 2018; and a second batch corresponding to one container with the remaining ¾ of the biodegradable covers which arrived on 4 April 2018. The delivery of the material to each fishing company finished by 16 April 2018. The Consortium had originally planned to construct and deploy the BIOFADs starting on January 2018 as noted in the kick-off Meeting Minutes and Inception Report. However, due to the important delay in the material supplier selection process, the start of deployments was re-scheduled to April-May 2018. Consequently, this had a cascading effect on the rest of the activities requiring data derived from BIOFAD and NEFAD deployments/experiments. Other issues encountered during the project by the Consortium were the extended periods at dry docks of vessels, the cessation of fishing activity by most vessels towards the end of the year due to reaching quota limitations, and poor involvement by some skippers with the BIOFAD deployments. The unforeseen issues mentioned above, proved to be an impediment for reaching the 1000 BIOFAD deployment objective.

High degradation of biodegradable material and discouragement of the fleet:

Early on in the project the tuna PS fleet raised some concerns about the biodegradable cotton covers used in rafts for BIOFAD prototypes. According to the opinion of many fishers, later corroborated by the Consortium´s observations of the material degradation assessments, the cotton canvas degraded faster than expected and did not meet industry's expectations. Besides the poor performance of this component as noted during the 2nd BIOFAD workshop, the EU fleet also expressed disappointment with some of the prototypes, which according to them, were "out-of-date" by the start of the deployments. Fishers and industry asked for more flexibility during experimental trials. The Consortium proposed different solutions in order to solve identified problems and to recover the interest of the participating fleet.

Lack of biodegradable material degradation assessment:

From the start of BIOFAD deployments and posterior activities with them, the Consortium identified a poor provision of biodegradable components assessment reports provided by the fleet. This information was important to assess the degradation stage of materials over the FAD's lifetime and to quantify the replacement rate of each of the components. The small amounts of this information, in terms of quantity and quality, hindered also the LCA analysis. Nevertheless, the Consortium was able to provide a partial assessment of the degradation of the three biodegradable materials (i.e., cotton canvas, and two type of cotton ropes) based on the assessment reports that were completed. Scientific coordinators tried to emphasize to the fleet at meetings and workshops the importance of this data to properly assess the effectiveness of tested materials and prototypes. .

Recommendation for future work:

- Foresee and plan for possible delays in material purchase and delivery. To speed up the administrative work anticipate if possible associated requirements and tasks in this regard.
- Include an interim reflection period to assess the selected material performance and defined protocols. This will require flexibility in material selection and preparation of alternative options if the performance of one or more selected materials is below expectations. This adaptable approach can be applied to the definition of prototypes as well.
- Program for a large enough fixed number of control material degradation samples to obtain a minimum number of samples to ensure reliability of the study.

4.3. TASK 3 – ASSESS BIOFAD BEHAVIOUR AND PERFORMANCE IN COMPARISON TO NEFAD.

4.3.1. OBJECTIVES

The objective was to assess and compare the behaviour and performance of NEFADs and BIOFADs in relation to their aggregation efficiency and aggregation species composition. This was mainly a desk-based work, although field work was also carried out for the collection of required data onboard the vessels. A validation procedure for the collected data was performed and a life-cycle assessment (LCA) was conducted to identify the best performing designs.

To accomplish this, Task 3 was divided in the following sub-tasks:

- Sub-task 3.1 - Assess the efficiency of BIOFADs to aggregate tuna and non-tuna species through FAD trajectories, echo-sounder buoy information, and observer data.
- Sub-task 3.2- Validate results and collect detailed information on species composition in FADs through observer data
- Sub-task 3.3- Develop LCA for the different FAD designs and materials, including their expected biodegrading time and the subsequent potential negative and positive environmental effects (e.g., carbon print, impact of chemicals used to extend FAD durability, etc.).
- Sub-task 3.4- Identify best performing designs.

4.3.2. METHODOLOGY.

Echo-sounder buoy information and data collected at sea by crew and observers were assessed to test, compare and measure the tuna and no-tuna species aggregation efficiency of BIOFADs in relation to current NEFADs in the Indian Ocean EU purse seine fleet.

4.3.2.1. Sub-task 3.1 - Assess the efficiency of BIOFADs to aggregate tuna and non-tuna species through FAD trajectories, echo-sounder buoy information, and observer data

As mentioned previously, BIOFADs and equivalent synthetic NEFADs, both equipped with the same echo-sounder buoys, were deployed together in pairs. Attaching echo-sounder buoys to FADs is standard in tuna purse seiner fleet operations to monitor and control their floating objects for biomass aggregation, location and trajectory parameters. Echo-sounder buoys generate daily data (e.g., position, speed and drift of buoys), but when this was not available (e.g., errors in recorded data or missing records) an interpolation of missing data was proposed to fill the gaps. FAD trajectories, in conjunction with biomass aggregation, was compared between the two FAD types to evaluate their performance (i.e., functionality of FADs for the fleet in terms of catches). Thus, to allow robust comparison of FAD efficiency and features, vessels deployed both types of FADs with echo-sounder buoys of similar characteristics (brand and model: Satlink, Marine Instruments, Zunibal, Thalos, etc.). The information collected (from all experimental FADs deployed, approx. 24 BIOFADs and 24 NEFADs per vessel, including replacements) was made accessible to EU scientists under confidentiality rules discussed at the beginning of the project.

To ensure data tracking, both BIOFADs and their paired NEFADs were marked with unique FAD identifier codes. During the fishing operations, if a buoy was replaced because the FAD had changed hands (i.e. it is "transferred" to another vessel), ideally, the replacement of the buoy by the new FAD owner should be using the same buoy type (i.e., model and brand). This buoy transplantation should be recorded and monitored using a special form, designed for the project to gather information on the FAD's characteristics and fate. The information regarding buoy code and type, prototype selected, degradation level of materials and parts, activity on the FAD, etc. was collected by crew members and observers. Once the data was collected and sent back to the research institute coordinators, a comparative analysis was conducted following methodologies and statistical approaches that consider catch (e.g., logbooks, port sampling), observer and echo-sounder buoy data. Efficiency was measured through indicators such as maximum tuna and non-tuna aggregated biomass and average amounts, time evolution, and species ratios. Spatio-temporal patterns were also considered when possible for the comparison of the indicators, in order to assess possible effects of season and area on experimental FAD efficiency.

4.3.2.2. Sub-task 3.2- Validate results and collect detailed information on species composition in FADs through observer data

As mentioned above, a new form was developed to specifically collect and monitor BIOFAD information for this project, including a field where observer information and fleet activity could be linked. This information was used to validate the efficiency of BIOFADs in aggregating target and non-target species, and to better understand their species composition.

In theory, BIOFADs should reduce impacts on some non-target species and coastal habitats compared to conventional high risk and lower risk entanglement FADs because non-entangling materials are used, and thus are expected to cause no accidental meshing of shark or turtles. Similarly, BIOFADs would be expected to have similar catch rates of target species (e.g., skipjack, yellowfin and bigeye tunas) as paired synthetic NEFADs of similar design. The data and results obtained in this task allowed conducting follow-up analysis (e.g., LCA) and validate the behavior and performance of BIOFADs.

4.3.2.3. *Sub-task 3.3- Develop life-cycle assessments for the different FAD designs and materials, including their expected biodegrading time and the subsequent potential negative and positive environmental effects (e.g., carbon print, impact of chemicals used to extend FADs durability, etc.)*

Data collected was used to assess the potential environmental effects of different experimental FAD designs and the materials used in their making. For that purpose, a LCA study of the selected FAD designs and materials was conducted using SimaPro 8. This is a software with a wide range of background data-related databases and impact assessment methods, crucial to conduct life cycle models in a systematic and transparent manner. These models are based on raw material and energy flows also known as "life cycle inventory" in the LCA methodology. Results aimed to show which of the FAD designs are the most and least environmentally friendly (i.e., in terms of carbon footprint, impact of chemicals used) in the short-, medium- and long-term. The results were based on the type and quantity of materials and energy used during the different life cycle stages (from primary material extraction, and fabrication, distribution, use and end of life of the product) of each FAD prototype. Besides, the ageing time of materials was used to estimate the amount of waste produced by the usage of FADs and released into the ocean. This can happen when FADs or part of them remain in the ocean once their productive life has come to an end, either by intentional abandonment or because they have been lost at sea. Either way they become marine litter and produce environmental impacts. During the project, this aspect was assessed using the information of quality control (e.g., degradation level of materials) of BIOFADs and NEFADs collected by skippers/crew and observers onboard. Likewise, results highlighted which materials, processes or assemblies exerted the greatest environmental impact and therefore require most attention if aiming for an eco-friendly design. The most representative impact categories, which are used to transform the material and energy flow, were defined during the project. These impact categories were selected to present the results, such as the carbon footprint and the different functional units for environmental impact per ton.

Any LCA study requires a large amount of data to do a comprehensive analysis. Two datasets were requested for defining the material and energy flow of the target FADs. The first was requested to ship owners, and included information on the type and usage of consumables (including fuel) employed for deployment of each FAD type, biodegrading time of different materials, and the aggregation efficiency of catch associated to the FADs. The second dataset included information provided by the FAD manufacturers on the type and amount of materials (including chemicals) and energy used, and the waste produced from the manufacturing process.

Finally, if feasible, the potential negative environmental effect generated in the region of origin of the raw materials (e.g., bamboo) supplied for the construction of BIOFADs was proposed to be assessed using information collected by contacting local research centers and based on scientific studies analyzing this specific issue (e.g., possible deforestation problems due to the use of bamboo in the construction of FADs).

4.3.2.4. Sub-task 3.4- Identify best performing designs

A list of designs and materials with good performance were identified. Ranks based on different criteria were developed to define the overall performance capability. Results were used and discussed in a final workshop (3rd BIOFAD workshop) that included the participation of all partners as well as EASME/DG MARE, and which formed the basis to reach agreement on final designs and level of adoption and acceptance with stakeholders and fishing crew.

4.3.3. MAIN RESULTS.

4.3.3.1. Sub-task 3.1 - Assess the efficiency of BIOFADs to aggregate tuna and non-tuna species through FAD trajectories, echo-sounder buoy information, and observer data

All the information regarding BIOFAD and paired NEFAD activity (e.g., new deployments, buoy exchanges, visits, sets, etc.) was collected by fishers and observers. Despite the electronic monitoring systems (EMS) being valued as an option in case of human observer absence in a vessel, this option was finally rejected as a data source due to uncertainties on their capability to record all the required information fields. The vessels used a specific form developed for the BIOFAD project to provide information on the activities with experimental FADs. In general, few problems were encountered when receiving activity data from them. For example, some identified errors included incorrect buoy numbers, not transferring ID plates during buoy transfers, erroneous constructions of BIOFADs. Similarly, observers from AZTI, IRD, IEO, SFA, CSP and TAAF on-board vessels also collected activity data using the observer BIOFAD form. This enabled linking information with logbook, Form D and OBSERVE databases when required. Additionally, catch data was requested from the fishing companies for sets identified in the BIOFAD forms provided by vessels. In parallel, this catch information was also received through available logbooks. Finally, agreements were signed with all tuna fishing associations or fishing companies to obtain access and analyse echo-sounder buoy data. Once having the companies´ approval, the Consortium contacted directly with buoy suppliers for the provision of information during the project period.

The goal for this sub-task was to perform a comparative analysis between BIOFADs and their NEFAD counterparts following methodologies and statistical approaches that considered catch data (e.g., logbooks, port sampling), observer data and echo-sounder buoy data. For that, the assessment of experimental FAD efficiencies was measured through indicators such as maximum and average amounts of tuna and non-tuna aggregated biomass, aggregation evolution (e.g., colonization time, lifetime of the aggregation), and ratios of tuna occupancy. Despite some difficulties with the database to properly assess the influence of spatio-temporal patterns (i.e., non-balanced data samples between prototypes, high variability in deployment period and area), this factor was still considered when suitable. These were the main research lines defined to assess efficiency:

- Tuna presence/absence analysis to estimate colonization time through echo-sounder buoy data.
    - Assessment of aggregation dynamics.
- Estimation of tuna biomass through the acoustic energy from buoys associated to experimental FADs.
    - Assessment of tuna aggregation dynamics.
    - Spatio-temporal influence.
- Catch data analysis from the experimental FADs.
    - Comparison by FAD type.
- Experimental FADs drift comparison.
    - Comparison by pairs (BIOFAD and its NEFAD).

To achieve these sub-task goals, the Consortium attended the RECOLAPE Workshop (MARE/2016/22 "Strengthening regional cooperation in the area of fisheries data collection" Appendix III "Biological data collection for fisheries on highly migratory species") held at AZTI (Pasaia, Spain) on January 2019 and the BIOFAD data preparatory workshop held at AZTI (Pasaia, Spain) on April 2019, to define the main research lines and work with preliminary results, respectively. Additionally, during these workshops, a working platform was created to facilitate work distribution between Consortium members and to allow a joint database to carry out analysis work coordinately. In line with this, data table format standardization was also agreed and conducted to facilitate data merging processes.

During this analysis descriptive statistics were mainly used to describe the results. Further statistical tests (e.g., analysis of variance (ANOVA) or Kruskal-Wallis tests) were only used in certain cases. Most of the time, the deployment strategy, which is highly correlated with the fishing strategy, did not allow obtention of an homogeneously stratified sampling. Thus, several factors potentially affecting the differences between categories or groups (e.g., prototype, area of deployment, time of deployment, etc.) could not be accounted for.

Tuna Presence/Absence.

Tuna presence/absence analysis through echo-sounder buoy data, was conducted considering only data corresponding to one buoy brand (i.e., Marine Instruments). Data filtering and indicator estimation processes followed the protocols defined in the RECOLAPE project for working procedure uniformity between Consortium members and to make the most of the work being done within the Framework Contract (Baidai et al., 2018; Grande et al., 2019).

Tuna presence/absence analysis to study the colonization time and lifetime of the aggregation was conducted by pairs (i.e., BIOFAD and its paired NEFAD). Available database information after filtering was limited to 202 comparable pairs (A2=123; A1=62; B1=7 and C1=10). The pairs were compared regarding the distance between both at a given time. Estimated distance differences were then grouped in predetermined distance ranges, such us less than 50km, 100Km, 150Km, etc. being the successive ranges accumulative, i.e., the next larger distance group includes the previous ones.

First day of tuna detection.

In general, similar patterns of first tuna detection were observed in both FAD types (BIOFAD and NEFAD) (Figure 4.3.3.1.1). No statistically significant differences were found between both FAD types (Kruskal-Wallis chi-squared = 0.14349, df = 1, p-value = 0.7048). More variability was observed when this indicator was assessed by FAD type and deployed prototypes (Figure 4.3.3.1.2). However, when statistical tests were applied to observed differences between prototypes (only A1 and A2 were considered for the test) no statistically significant differences were found between FAD type and prototypes (prototype A1: Kruskal-Wallis chi-squared = 0.23799, df = 1, p-value = 0.6257; prototype A2: Kruskal-Wallis chi-squared = 0.073504, df = 1, p-value = 0.7863). First tuna detection was also considered according to the distance between pairs and the results showed a faster presence of tuna (in days) in NEFAD than BIOFADs. This pattern was kept throughout the different range of distances between pairs (Figure 4.3.3.1.3).

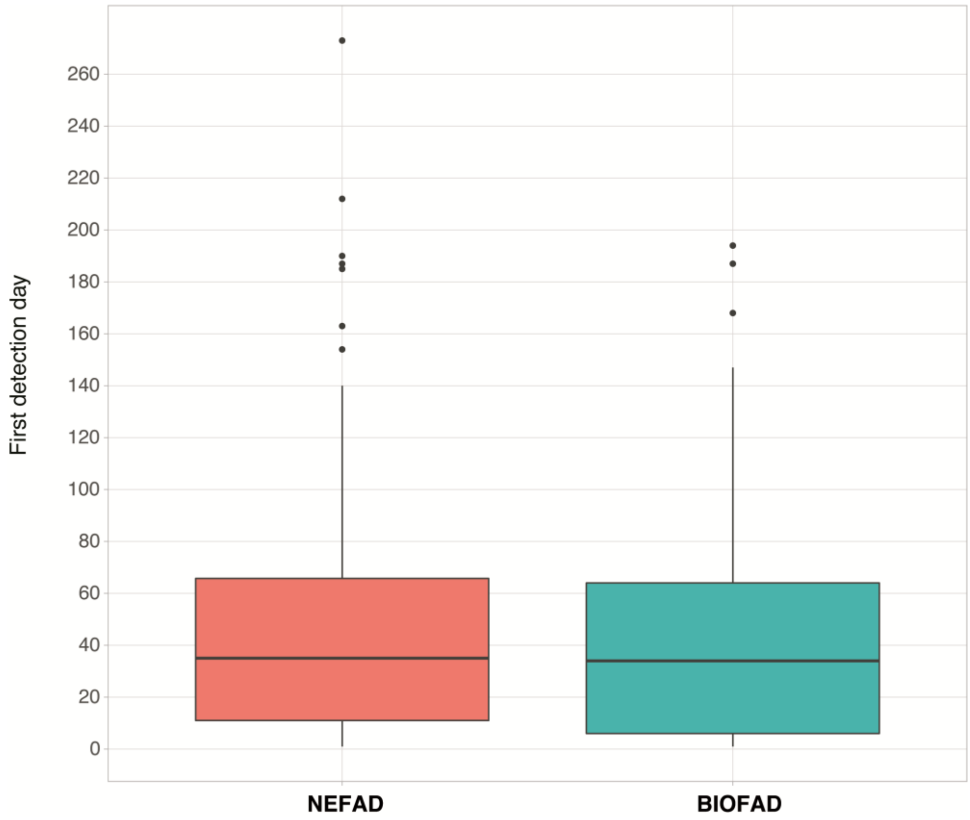


Figure 4.3.3.1.1. First day of tuna detection by type of FADs (combined data).

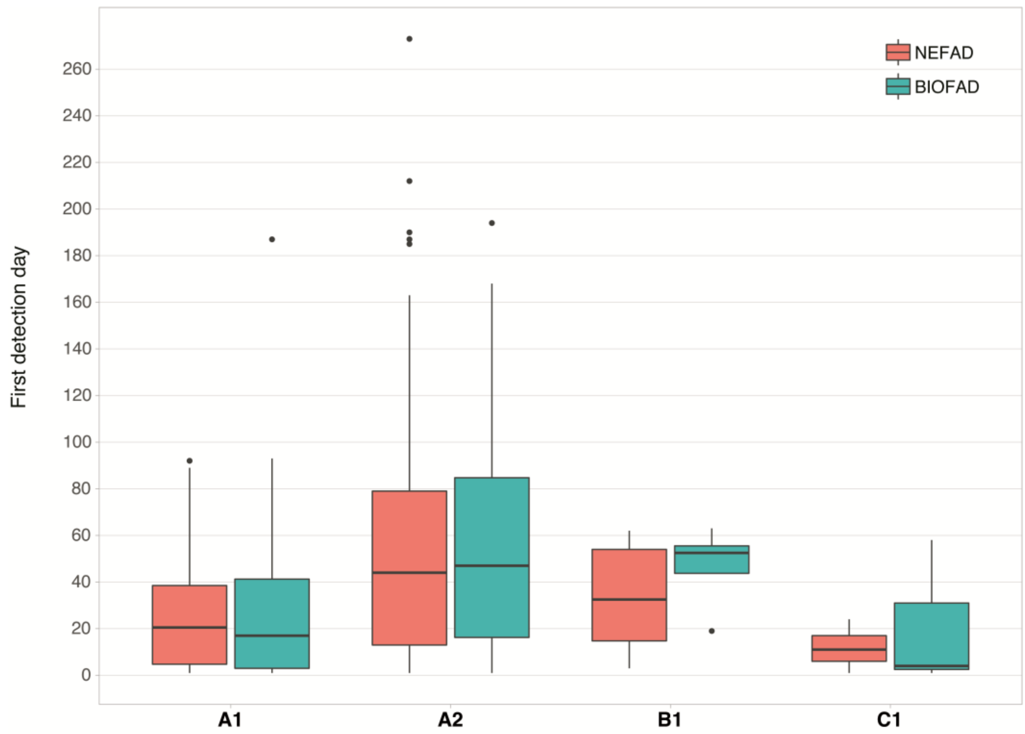


Figure 4.3.3.1.2. First day of tuna detection by type of FADs and prototypes.

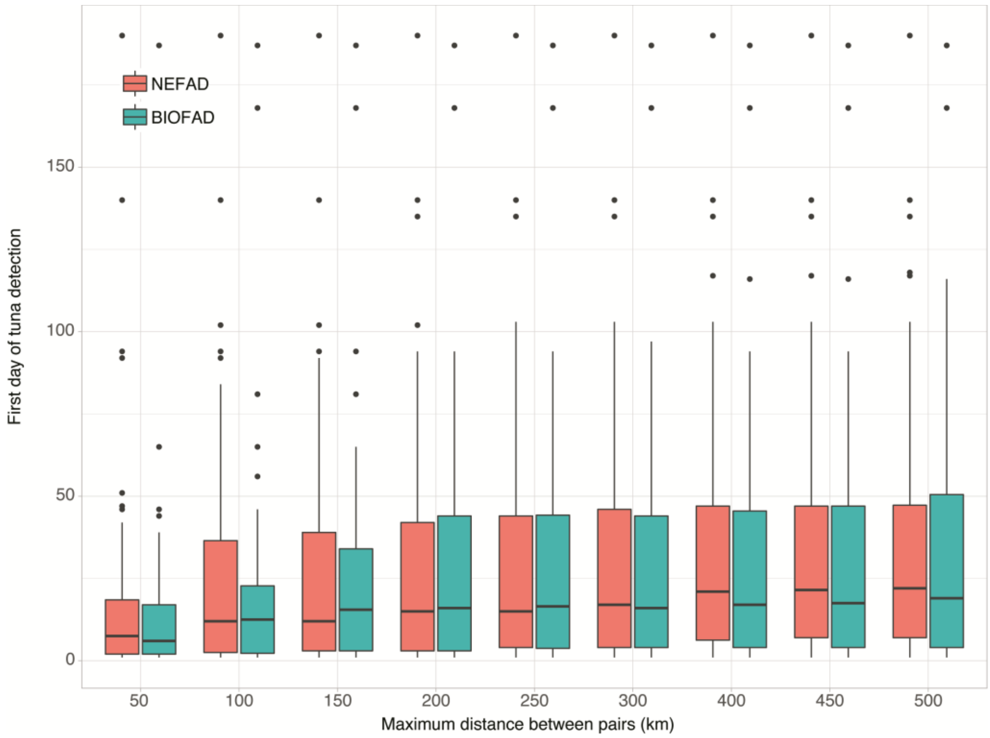


Figure 4.3.3.1.3. First day of tuna detection by type of FADs and by range of distance between pairs.

Proportion of FAD occupation by tuna.

Similarly, the comparative assessment of the proportion of FAD occupation by tuna was analysed by FAD type, prototype and distance between pairs. Results described higher occupation ratio of NEFADs than BIOFADs throughout the different range of distances between pairs (Figure 4.3.3.1.4.). This result is consistent with previously shown results on the first day of tuna detection according to the distance between pairs.

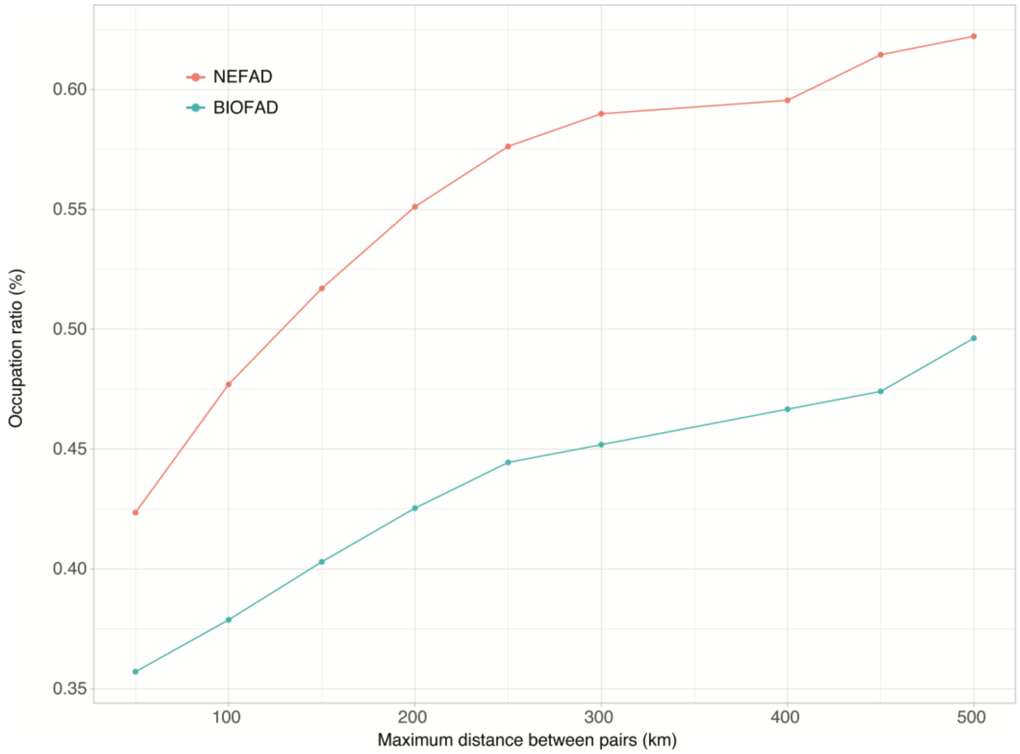


Figure 4.3.3.1.4. Proportion of tuna occupation (y-axis) by FAD type and by range of maximum allowed distance between two FAD pairs in Km (x-axis).

Presence/absence data was also analysed to estimate the proportion of FAD occupation by tuna aggregation, considering only the FAD type. Similar to previous results, NEFADs showed higher proportions of FAD occupation, being this difference statistically significant (Kruskal-Wallis chi-squared = 6.5734, df = 1, p-value = 0.01035) (Figure 4.3.3.1.5.). Differences were also observed when FAD occupation was assessed by FAD type according to deployed prototypes. In this case, prototype A2 and B1 NEFADs showed higher occupancy values than BIOFAD counterparts, but not for prototypes A1 and C1 where similar patterns were observed between the two FAD types (Figure 4.3.3.1.6). However, the statistical test applied to prototype A1 and A2showed no significant differences between FAD type and prototypes (prototype A1: Kruskal-Wallis chi-squared = 3.5805, df = 1, p-value = 0.05846; prototype A2: Kruskal-Wallis chi-squared = 0.47523, df = 1, p-value = 0.4906). Prototypes B and C had unbalanced sample sizes and were not considered for this analysis.

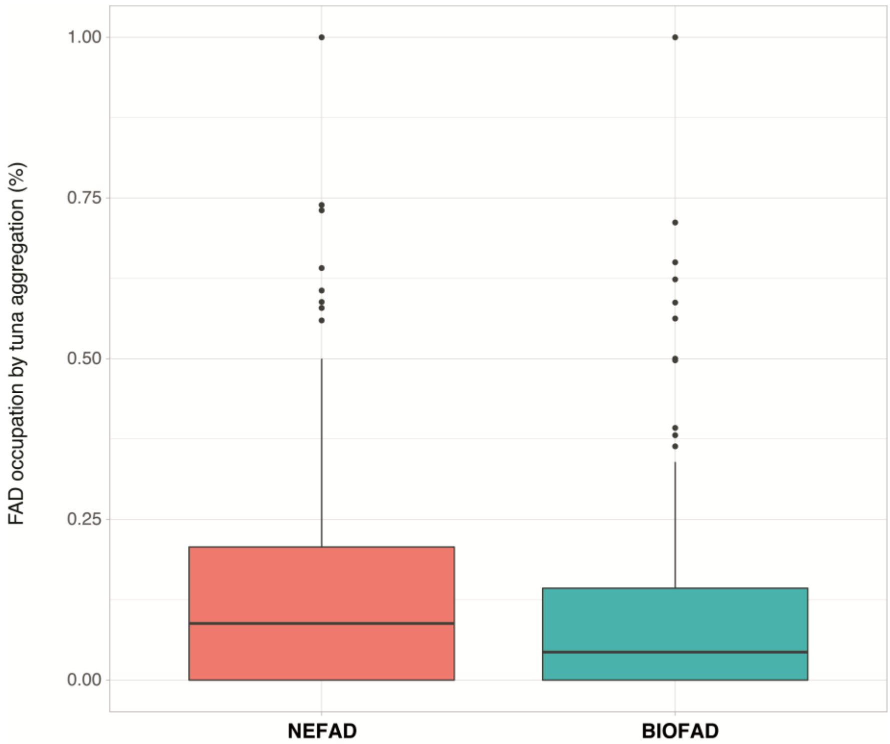


Figure 4.3.3.1.5. Proportion of FAD occupation by tuna aggregation by FAD type (combined data).

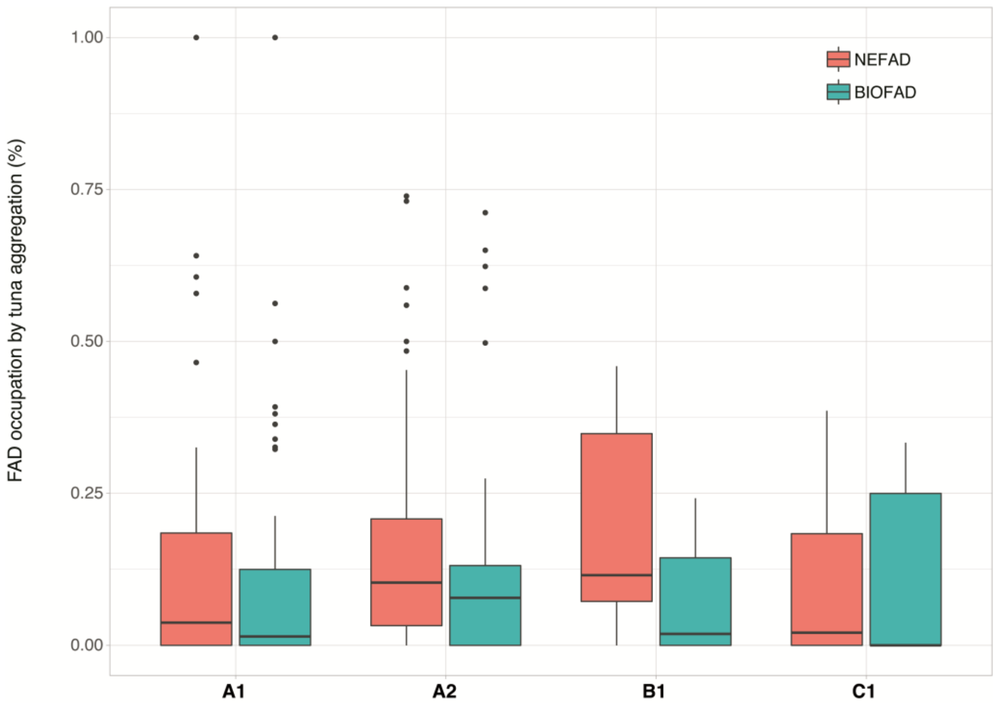


Figure 4.3.3.1.6. Proportion of FAD occupation by tuna aggregation by FAD type and prototypes.

In Figure 4.3.3.1.7 higher proportions of FAD occupation by tuna in NEFADs than in BIOFADs were observed as the distance between pairs increased. The proportion tended to increase when the distance between pairs was higher than 150 Km.

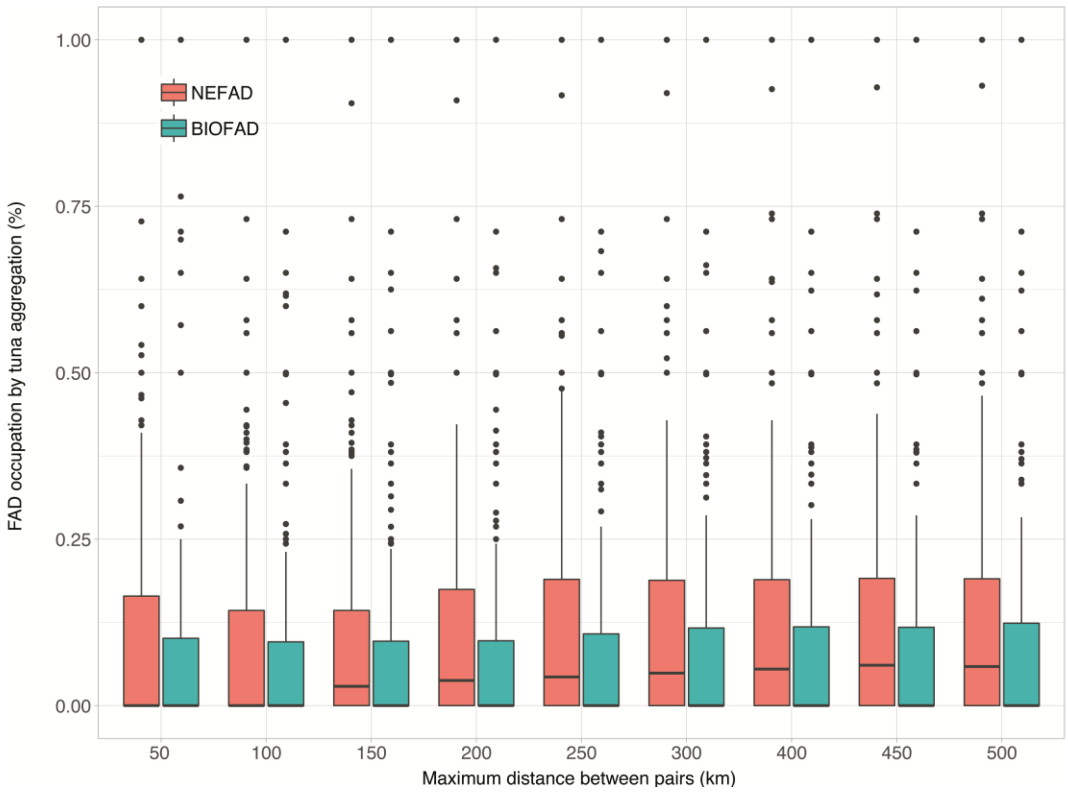


Figure 4.3.3.1.7. Proportion of FAD occupation by tuna aggregation by FAD type and by distance range (km) between pairs.

Binary choice analysis was conducted to illustrate the competition between the two types of FADs by calculating the % of time only one type of FAD had tuna presence, the % of time both types had tuna presence and the % of time none of the types had presence of tuna. For this comparison only those FADs with at least 30 days at sea after deployment and a maximum distance of 500Km between pairs was considered. Figure 4.3.3.1.8 shows that in 53% of the cases, both pairs had tuna presence; in 13% of pairs both, BIOFADs and NEFADs, showed no presence of tuna; in 21% of the cases NEFADs had presence of tuna while its BIOFAD pair did not and; in 13% the opposite pattern was observed.

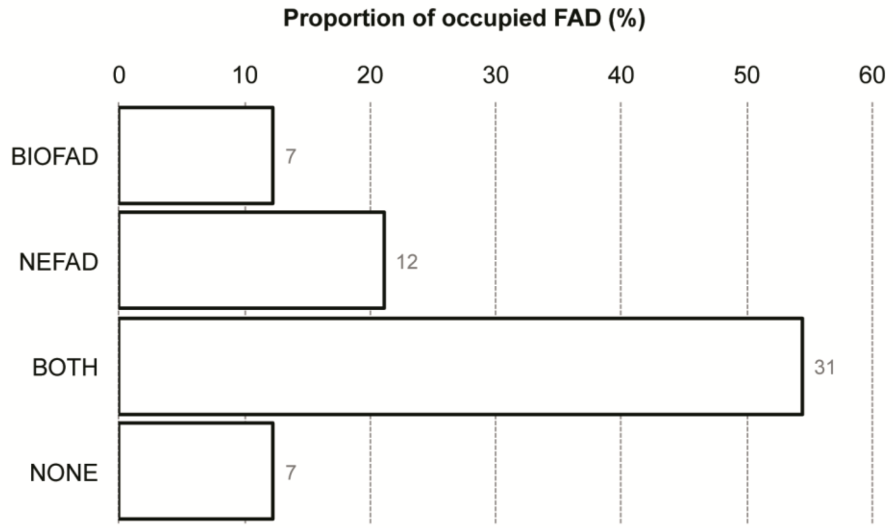


Figure 4.3.3.1.8. Proportion of FAD occupation by tuna aggregation using binary choice by FAD type between pairs.

Biomass aggregation estimation

Echo-sounder buoy data was also assessed as an index of tuna biomass aggregation estimated from acoustic energy values (Grande et al., 2019). Echo-sounder buoy data was analysed to estimate (i) daily tuna biomass aggregation, (ii) tuna biomass aggregation in “virgin segments”, and (iii) tuna biomass aggregation by FAD type and prototypes considering distance and time at sea between pairs. The spatio-temporal effect was also considered by analysing tuna biomass aggregation by quarters of FAD deployment.

Daily aggregation of tuna biomass

Daily tuna aggregation was conducted considering only data corresponding to one buoy model and brand (i.e., Marine Instruments M3i buoy model) to avoid bias in biomass estimations between brands and models. Data corresponding to the first 40 days after deployment was assessed to compare differences in the aggregation patterns between the two FAD types. As shown in the Figure 4.3.3.1.9, overall, very low biomass value estimations were obtained for both FAD types during the first 40 days at sea. Furthermore, large variability was observed in the biomass estimation and biomass estimation corresponding to daily values of the quantile 90 (black line in the figure 4.3.3.1.9), which showed a constant development of this index without clear differences between two FAD types.

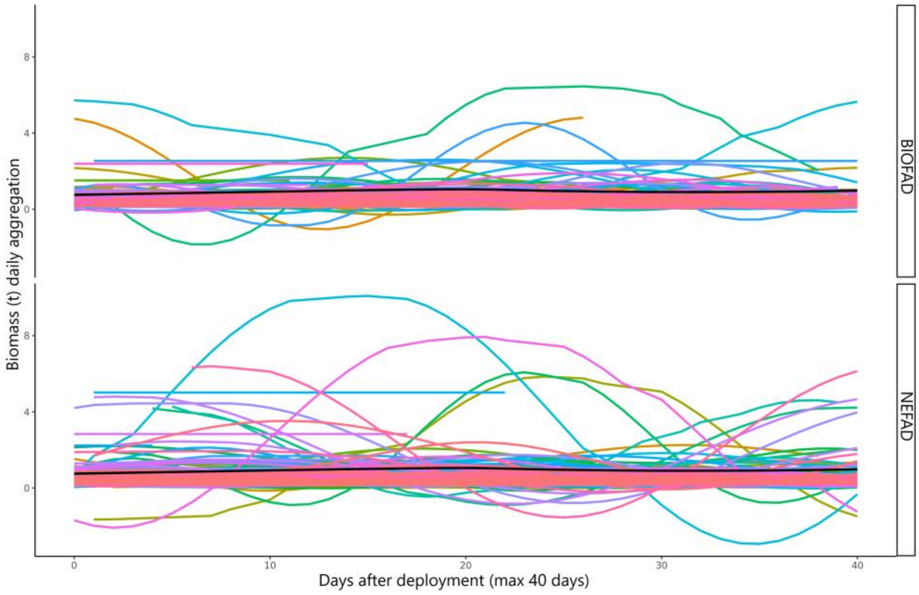


Figure 4.3.3.1.9. Daily aggregation of tuna biomass by FAD type. This figure only represents data corresponding to M3i model echo-sounder buoys. Coloured lines represent estimation of daily tuna aggregation for each analyzed buoy. Black line represents the estimation of biomass corresponding to daily value of the quantile 90.

Aggregation of tuna biomass at "virgin segments"

Tuna aggregation patterns by FAD types was further analysed by estimating biomass at "virgin segments" (Santiago et al., 2019). The objective of this method was to consider acoustic records more likely associated to FAD trajectory, termed "virgin segments", and make these segments' acoustic data comparable between all analyzed FADs. A virgin segment is defined as the segment of a FAD trajectory that represents a new deployment which has been potentially colonized by tuna and not already fished (Santiago et al., 2019). Orue et al. (2019) concluded that tuna seemed to arrive at FADs on average after 13.5±8.4 days and, thus, we considered as virgin segments (i.e., when tuna has aggregated to FAD) those segments of trajectories from 20-35 days at sea. This analysis was also conducted considering only data corresponding to one buoy model and brand (i.e., Marine Instruments M3i buoy model).

Estimation of biomass at virgin segments was performed based on the area and quarter at which a FAD was deployed. For that a combined variable including a spatial grid of 10ºx10º and quarter was created. Figure 4.3.3.1.10. shows higher mean biomass estimations at virgin segments in those FADs deployed during the first quarter of the year. This pattern was observed in most of the areas defined by a 10ºx10º grid in the Indian Ocean, except for the northwestern Indian Ocean region. Pairs of FADs deployed during the first quarter showed large variability between FAD types, but without a clear dominance of one FAD type over the other. Apart from the first quarter deployments, those pairs of FADs deployed in the 2nd, 3rd, and 4th quarters did not show clear differences in tuna aggregation at virgin segments between FAD types. Only in region 3110050 NEFADs showed higher mean biomass estimations than BIOFADs in the four quarters analyzed (Figure 4.3.3.1.10.).

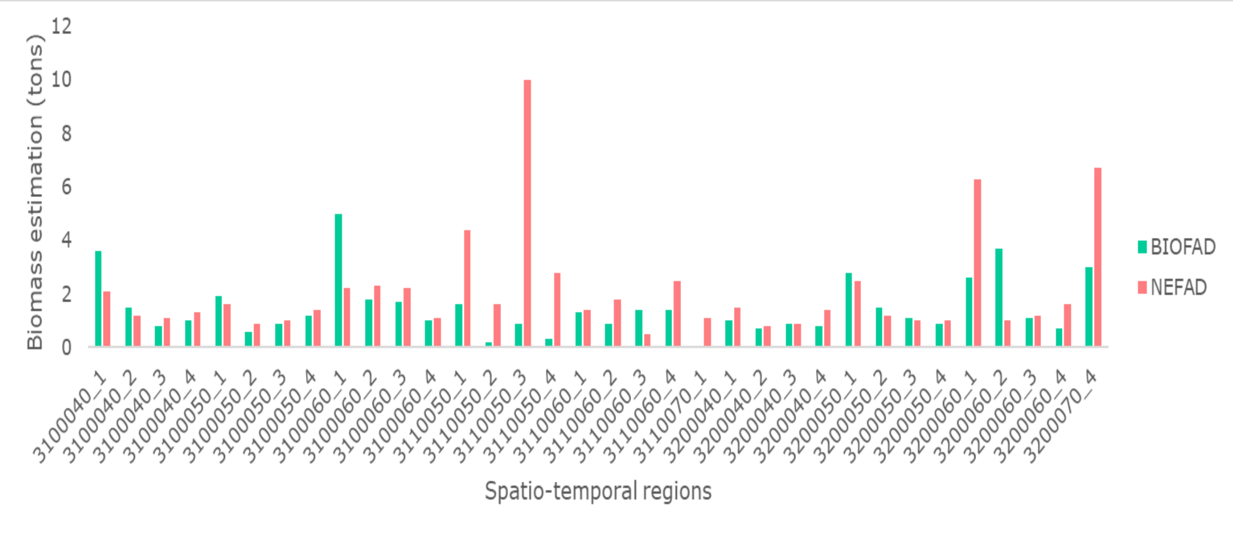


Figure 4.3.3.1.10. Biomass estimation of tuna aggregation at virgin segments by FAD type and grouped by spatio-temporal variable. This figure only represents data corresponding to M3i model echo-sounder buoys.

Table 4.3.3.1.1. Biomass estimation tuna aggregation at virgin segments by FAD type and grouped by spatio temporal variable. This figure only represents data corresponding to M3i model echo-sounder buoys.

	BIOFAD		NEFAD	
Spatio-Temporal factor	*n*	Biomass (t)	*n*	Biomass (t)
3100040_1	3	3.6	3	2.1
3100040_2	9	1.5	11	1.2
3100040_3	12	0.8	18	1.1
3100040_4	11	1	7	1.3
3100050_1	32	1.9	35	1.6
3100050_2	16	0.6	11	0.9
3100050_3	42	0.9	54	1
3100050_4	25	1.2	28	1.4
3100060_1	10	5	6	2.2
3100060_2	12	1.8	9	2.3
3100060_3	9	1.7	13	2.2
3100060_4	21	1	17	1.1
3110050_1	3	1.6	3	4.4
3110050_2	1	0.2	2	1.6
3110050_3	3	0.9	4	10
3110050_4	10	0.3	8	2.8
3110060_1	5	1.3	4	1.4

3110060_2	14	0.9	13	1.8
3110060_3	4	1.4	3	0.5
3110060_4	13	1.4	12	2.5
3110070_1	0	-	1	1.1
3200040_1	8	1	7	1.5
3200040_2	39	0.7	34	0.8
3200040_3	36	0.9	40	0.9
3200040_4	15	0.8	16	1.4
3200050_1	3	2.8	3	2.5
3200050_2	30	1.5	25	1.2
3200050_3	26	1.1	34	1
3200050_4	22	0.9	23	1
3200060_1	8	2.6	7	6.3
3200060_2	6	3.7	2	1
3200060_3	4	1.1	10	1.2
3200060_4	8	0.7	4	1.6
3200070_4	3	3	2	6.7
TOTAL	463	1.3	469	1.5

Estimation of tuna biomass

Echo-sounder buoy data was also used to estimate the tuna biomass from acoustic energy values (Uranga et al., 2019). Acoustic data was analysed by pairs (when acoustic data of both paired FADs existed) and grouped by months having as a reference the deployment day and by distance between pairs. These two analyses were also conducted considering the quarter at which a FAD was deployed in order to assess temporal effect on biomass estimation. For the analysis the information derived from different buoy models was analysed separately; only the three most frequently used buoy models in the project were included in this document (i.e., data from M3i, M3i+ and ISL+ models). Biomass was estimated as the 99 percentile of daily estimation. Only those samples obtained around sunrise, between 4 a.m. and 8 a.m., were considered for the analysis. These samples are supposed to capture echo-sounder biomass signals that better represent fish abundance under the FADs, as this is the time of the day when tunas are observed to be more closely aggregated under FADs (Brill et al., 1999; Josse et al., 1998; Moreno et al, 2007).

Overall, very low tuna biomass estimations for both FAD types were observed in the three buoy models (Figure 4.3.3.1.11.; Appendix III Figures 4.3.3.1.20-4.3.3.1.21.). In the three buoy models (M3i, M3i+, ISL+), biomass estimation resulted in slightly constant values during the first months after deployment for both FAD types. Afterwards, in months five and six biomass values showed more variability between pairs, and different patterns were observed depending on the buoy model and brand. For example, M3i and ISL+ showed higher values in NEFADs, while with M3i+ the pattern was not clear, showing higher values in BIOFADs and NEFADs depending on the month. These results are in line with the outcome of previous presence/absence analysis.

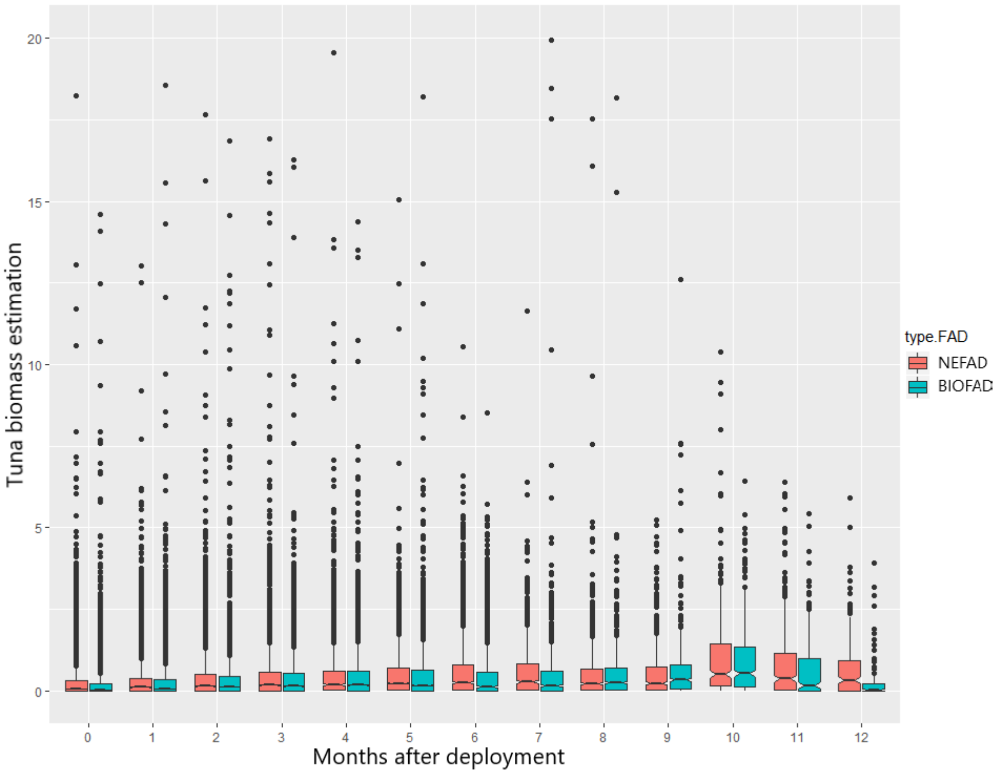


Figure 4.3.3.1.11. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by month since first deployment. Biomass estimation was done using acoustic energy from M3i buoy model.

Tuna biomass estimation considering the months after deployment was also assessed seasonally. For this, the quarter at which FADs were deployed was considered when conducting the paired FAD analysis. Like in previous results, tuna biomass estimation resulted fairly constant during the first months after deployment for both FAD types. Afterwards, in months five and six biomass values started showing more variability between pairs, and again different patterns were observed depending on the buoy model and brand (Figure 4.3.3.1.12.; Appendix III Figure 4.3.3.1.22.). Generally, tuna biomass estimation values were higher in NEFADs than in BIOFADs, and these differences increased as period of FADs at sea increased (Figure 4.3.3.1.12.; Appendix III Figure 4.3.3.1.22.). According to these results it is likely that the period at which FADs were deployed did not have a significant effect in the difference between FAD types. Among quarters, only those FADs deployed in quarter 2 showed slightly higher mean tuna biomass value estimations for both FAD types.

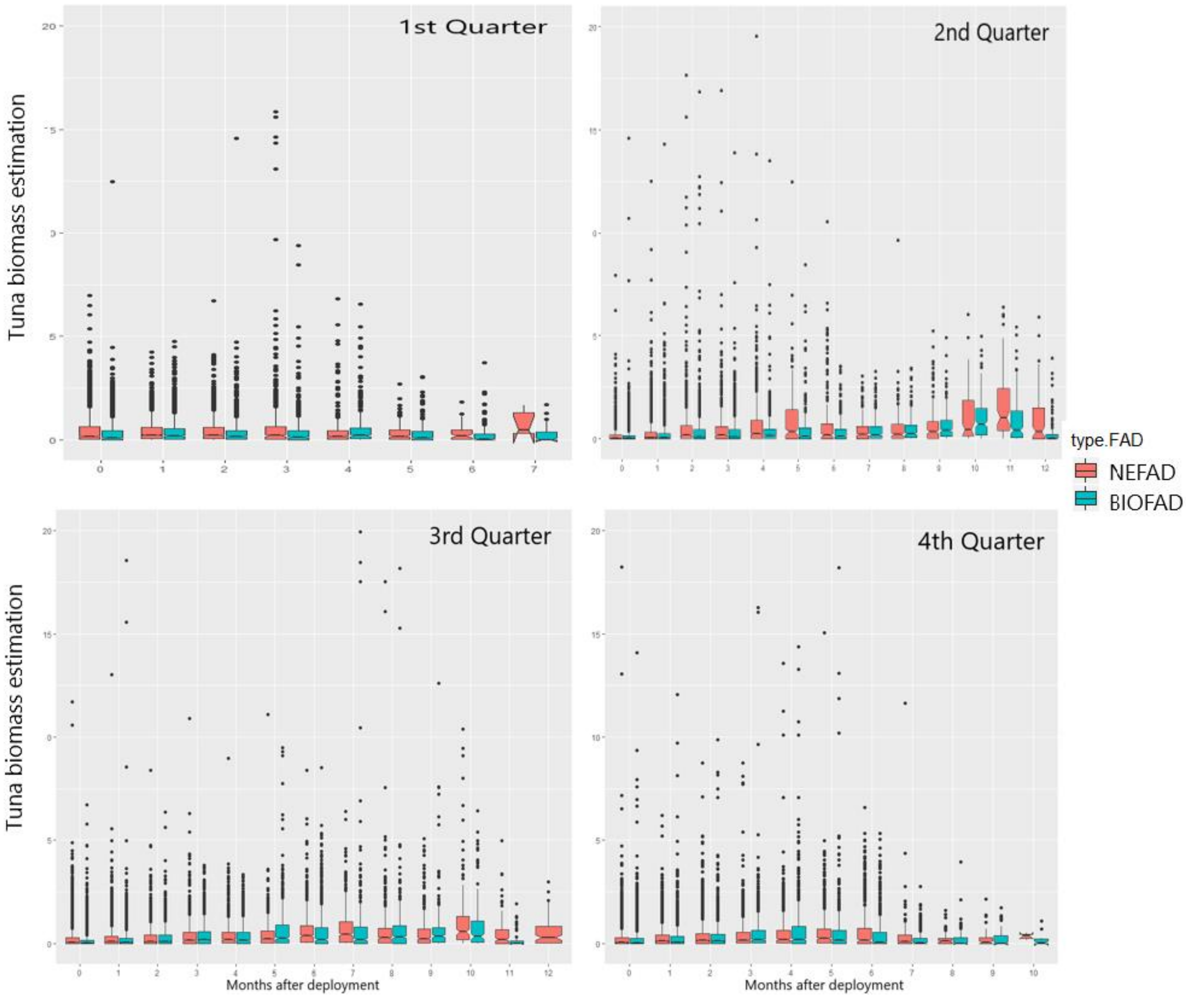


Figure 4.3.3.1.12. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by months since first deployment. Biomass estimation was done using acoustic energy from M3i buoy model. Data was grouped by deployment quarter to assess seasonal effect on tuna aggregation.

Tuna biomass estimation was also analysed grouped by distance between pairs. In the three buoy models (M3i, M3i+, ISL+), tuna biomass estimations were low and differences between pairs were fairly constant when distance between them was lower than ~2000 km (Figure 4.3.3.1.13; Appendix III Figures 4.3.3.1.23-4.3.3.1.24.). Over this distance, biomass values showed more variability between pairs, and different patterns were observed depending on the buoy model and brand. For example, M3i and M3i+ models showed higher values in BIOFADs than in NEFADs, while with model ISL+ the pattern was not clear as the distance between pairs increased. The number of observations for pairs having large distances between them decreased as the distance increased. This may limit the interpretation of the results, however, according to Figure 4.3.3.1.13., as pair distances increased themselves the tuna aggregation values obtained for BIOFADs were higher. While this can be a bias caused by the low number of observations, it could also be affected by those BIOFADs being located in a more productive area than their NEFAD pairs.

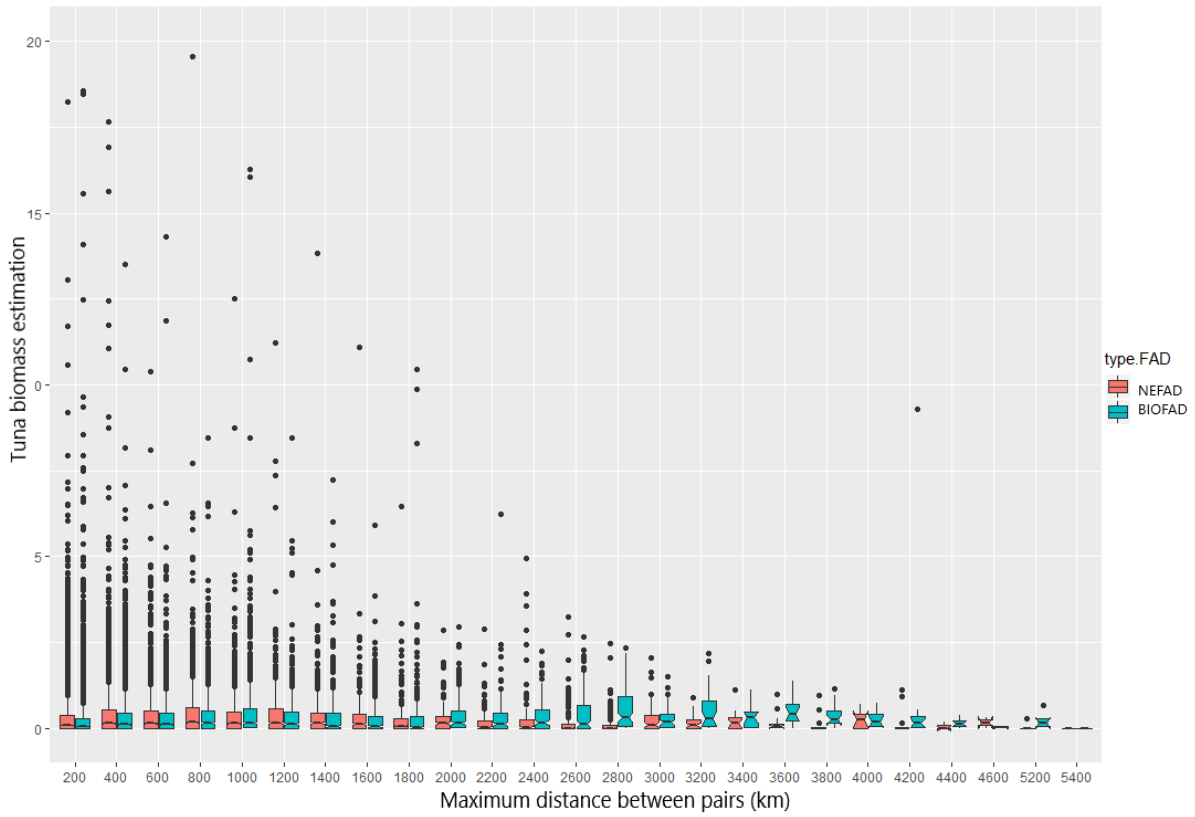


Figure 4.3.3.1.13. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by distance between pairs. Biomass estimation was done using acoustic energy from M3i buoy model.

Tuna biomass estimation grouped by distance between pairs was also examined seasonally. The FAD deployment quarter was considered to conduct the FAD paired analysis. Like in the previous analysis, tuna biomass estimations by FAD type resulted in larger differences as distance between pairs increased. However, the three buoy models (M3i, M3i+, ISL+) did not show a clear pattern and the interpretation of the results was not evident. It could be noted that as distance between pairs increased, FADs could be affected by different conditions present in the area, leading to different tuna biomass aggregations shown by FAD types (Figure 4.3.3.1.14.; Appendix III Figures 4.3.3.1.25).

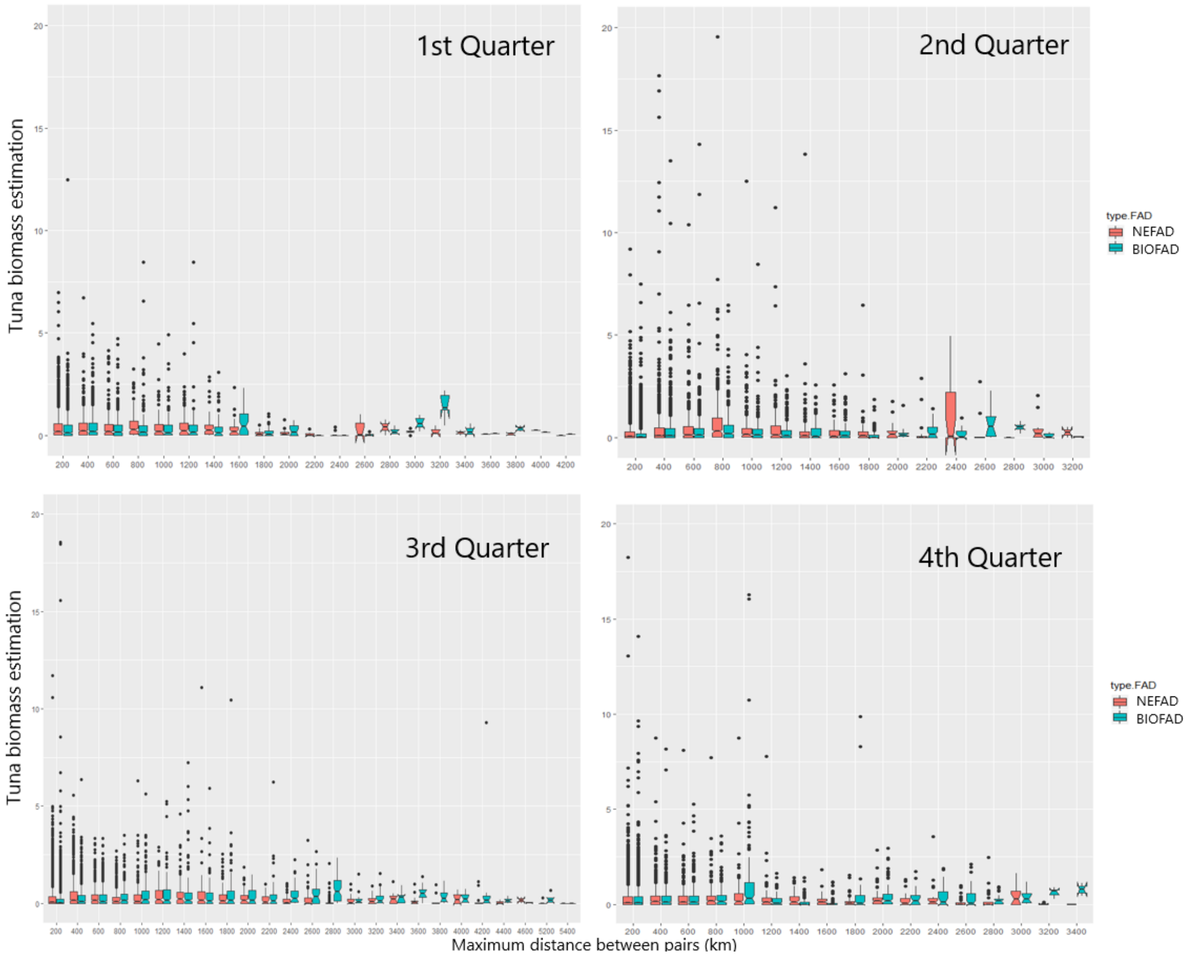


Figure 4.3.3.1.14. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by distance between pairs in km. Biomass estimation was done using acoustic energy from M3i buoy model. Data was grouped by deployment quarter to assess seasonal effect on tuna aggregation.

Catch data.

BIOFAD efficiency in comparison with NEFADs was further evaluated through the catch data. In total, from April 2018 to August 2019, 68 sets were associated to the experimental FADs, 36 to BIOFADs and 32 to paired NEFADs. This is a positive result by itself as the rate of fishing sets on BIOFADs and equivalent synthetic NEFADs seems very similar. Besides, there were no significant (at 5% level) differences between medians when all species were considered jointly; the P value (0.808) was > 0.05. Thus, the catchability with NEFADs did not differ significantly, from the catchability with BIOFADs. The same analysis, but considering the different species, lead to the same results, with no significant differences in catches. Although the differences were not significant, according to data from the project, catches with NEFADs were, on average, 13% larger than with BIOFADs. The spatio-temporal effect was not considered in the analysis. Table 4.3.3.1.2. shows the catch information by FAD type and prototype. Most of the sets were conducted in A1 prototype in both FAD types, which could be due to the much higher number of deployments of this prototype relative to the others. 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 on some of the prototypes did not allow to perform comparative analysis between prototypes.

Table 4.3.3.1.2. Catch data (maximum, mean and standard deviation (SD) 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			
±SD	33.61	48.66			
Sets	36	32			
Deployments	771	736			
% use	5%	4%			
BIOFAD	A1	A2	B1	B2	C1
Max (tons)	150	75	0	0	0
Mean (tons)	32.21	40	0	0	0
±SD	34.36	49.49	--	--	--
Sets	26	5	2	0	2
Deployments	545	142	29	18	37
% use	5%	4%	7%	0%	5%
CONFAD	A1	A2	B1	B2	C1
Max (tons)	98	225	0	0	70
Mean (tons)	29.38	75.71	0	0	67.5
±SD	23.83	81.56	--	--	3.53
Sets	21	8	0	0	3
Deployments	497	128	43	20	42
% use	4%	6%	0%	0%	7%

Drifting pattern.

The drifting pattern of experimental FADs was assessed by pairs (BIOFAD vs NEFAD) without considering the effect of area, season of deployment or prototype. As observed in Figure 4.3.3.1.15. the distance between pairs can increase or decrease during their lifecycle, although generally an increase of distance between paired FADs with days after deployment was shown.

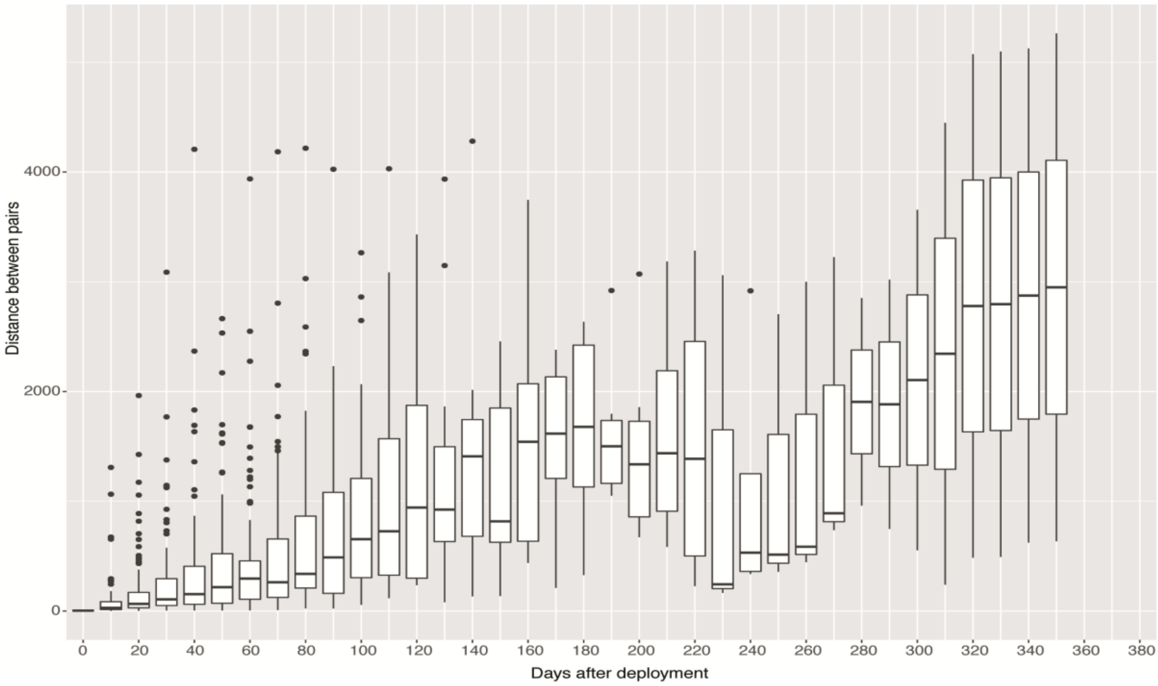


Figure 4.3.3.1.15. Distance (in km) between pairs (BIOFAD and NEFAD) with days after deployment

Variability in the drifting patterns was observed showing pairs with i) totally different drift patterns (Figure 4.3.3.1.16.), ii) partly similar drift patterns (Figure 4.3.3.1.17.) and iii) pairs following same patterns (Figure 4.3.3.1.18.).

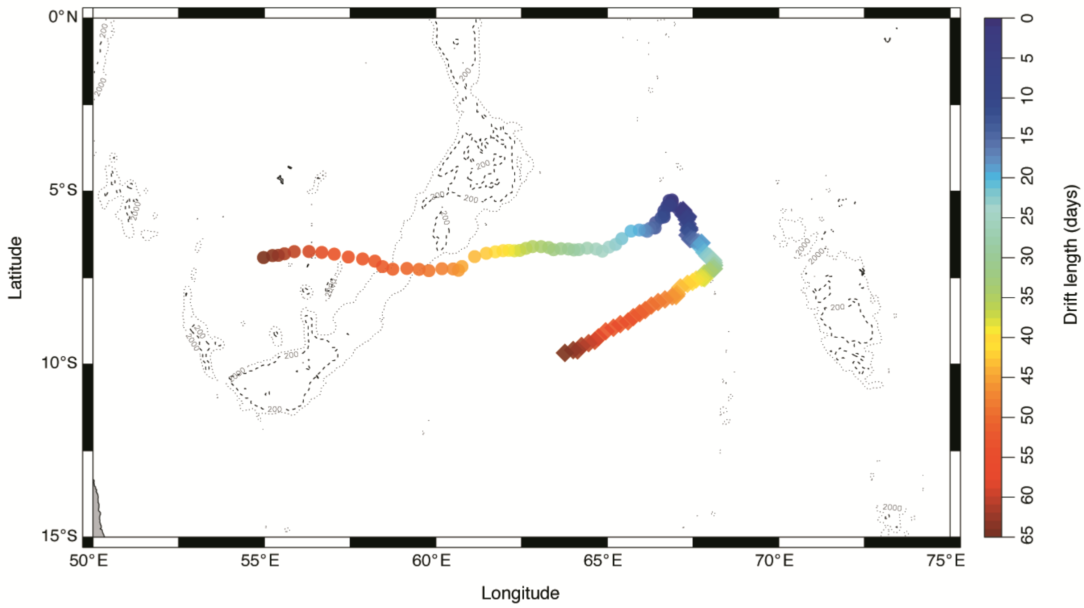


Figure 4.3.3.1.16. Drifts shown by paired BIOFADs (represented by circles) and NEFADs (represented by circles) in the Seychelles region. Color palette represents drift length in days since deployment day (from 0 to 65 days at sea).

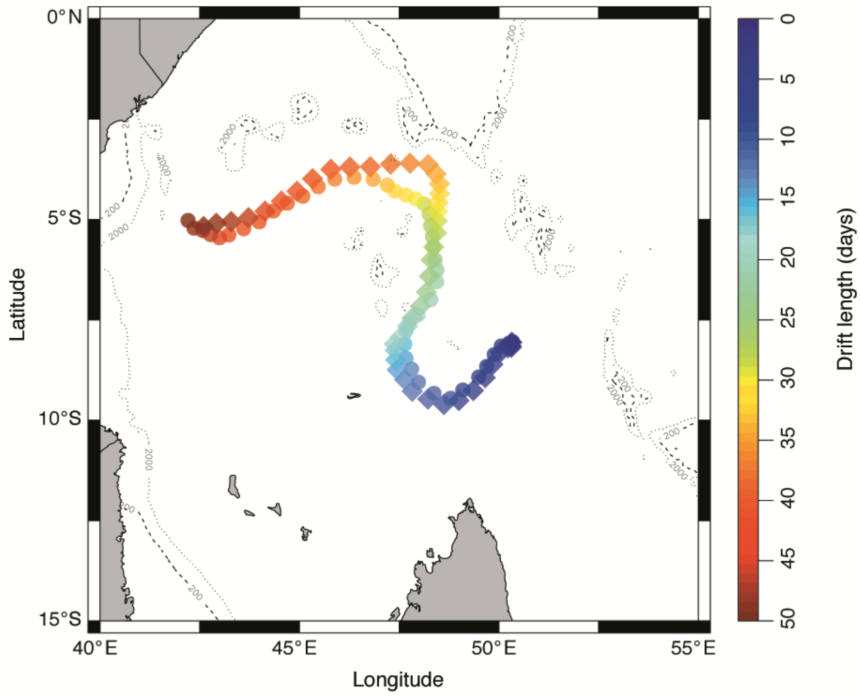


Figure 4.3.3.1.17. Drifts shown by a paired BIOFADs (represented by circles) and NEFADs (represented by circles) in the region north of Madagascar. Color palette represents drift length in days since deployment day (from 0 to 50 days at sea).

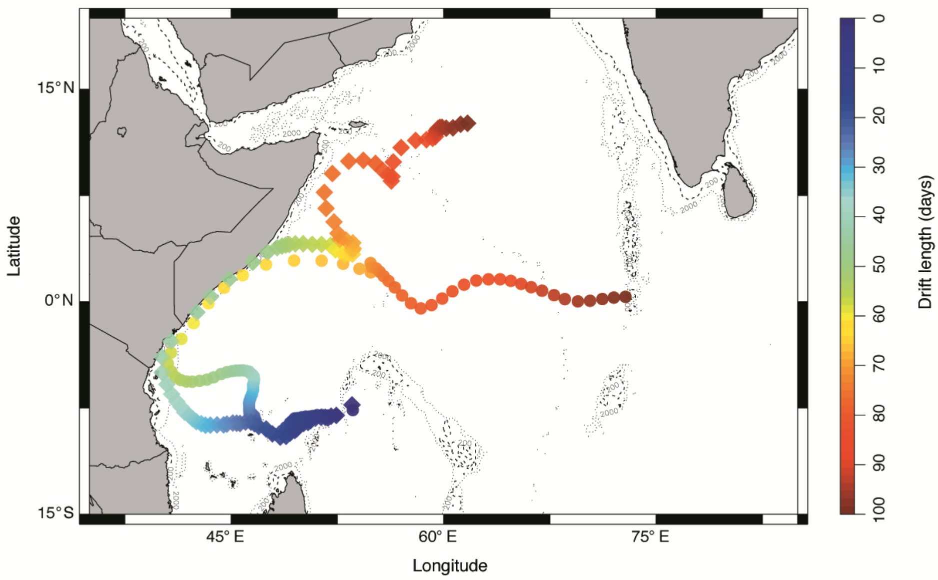


Figure 4.3.3.1.18. Drifts shown by paired BIOFADs (represented by circles) and NEFADs (represented by circles) in the Western Indian Ocean. Color palette represents drift length in days since deployment day (from 0 to 100 days at sea).

Lifespan pattern

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 as the day when the FAD was eliminated/retrieved and/or the attached buoy was deactivated, and the Consortium was no longer able to track the FAD. This information was provided by the vessels and/or buoy suppliers. Figure 4.3.3.1.19. shows lifespan estimations by FAD type (BIOFAD and NEFAD) and prototype. All the prototypes, for both FAD types, showed a maximum lifespan over 1 year (e.g., max lifespan for a BIOFAD of 483 days and for a NEFAD of 493 days), except for prototype B2, which had a very limited number of deployments during the experiment. Highest mean lifespan values were observed in BIOFADs B1 and A1, 242 and 191 days, respectively (Table 4.3.3.1.3.). In the case of NEFADs, prototypes A1 and C1 showed the highest mean lifespan values with 209 and 182 days, respectively (Table 4.3.3.1.3.). 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.

Table 4.3.3.1.3. Catch data (maximum and mean in tons), number of sets, number of deployments and % of use by FAD type and prototype.

FAD type	Prototype	Mean (days)	Min	Max	±SD
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

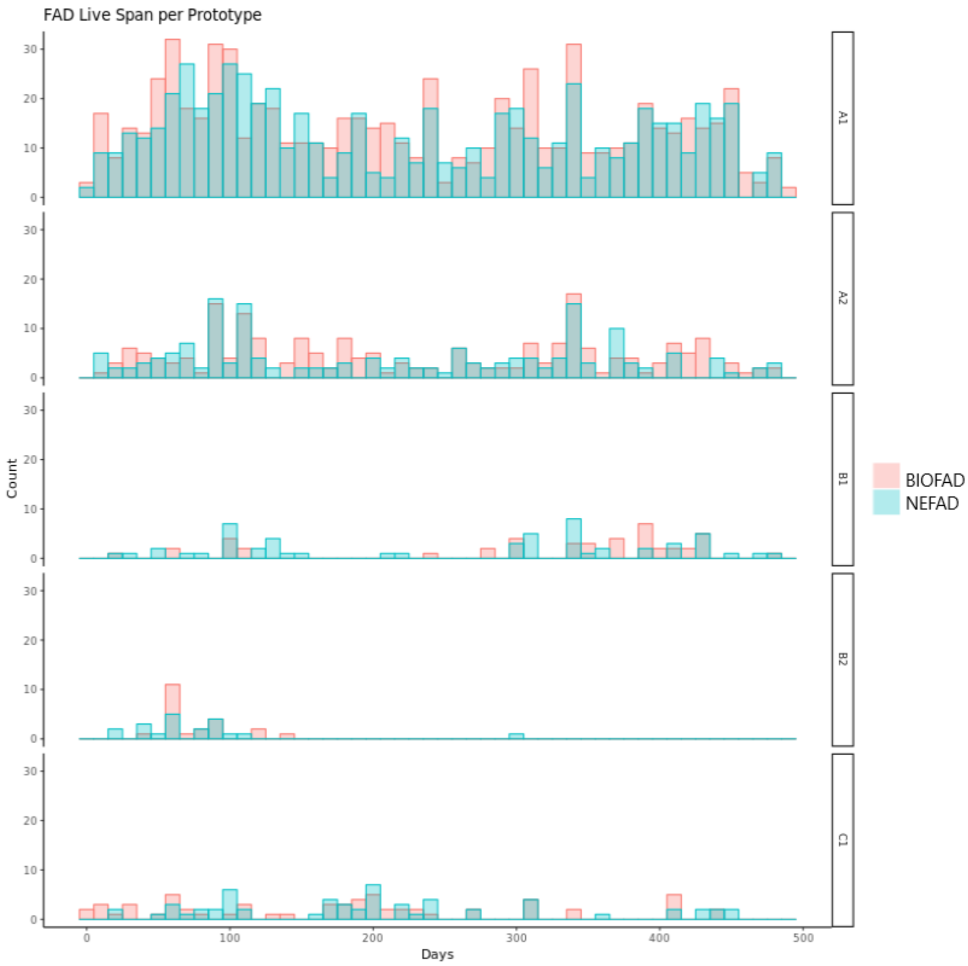


Figure 4.3.3.1.19. Lifespan results by FAD type (BIOFAD and NEFAD) and prototype.

4.3.3.2. Sub-task 3.2- Validate results and collect detailed information on species composition in FADs through observer data

A new form to collect and monitor information by observers was developed in the project. This form aimed to link observer information and fleet activity. However, relatively few sets on experimental FADs were performed during the project and thus, available observer data was to scarce to adequately validate the efficiency of BIOFADs in aggregating target and non-target species, and to better understand the species composition attached to them with observer data. Besides, bycatch composition under FADs is strongly conditioned by area and season (Lezama-Ochoa et al., 2015; Ruiz et al., 2018) and appropriate analysis for this issue required balanced data stratification. Data available from the BIOFAD project did not provide the means to perform a reliable analysis. The acoustic data collected by echo-sounder buoys attached to the experimental FADs was considered an alternative option to perform this study. However, the existing echo-sounder algorithms still require further work to better calibrate and test its applicability to estimate bycatch biomass.

BIOFAD prototypes were built in a totally non-entangling manner according to ISSF's guide for non-entangling FADs (ISSF, 2019) and IOTC specifications. This design was developed to avoid any type of entanglement and thus reduce impacts on non-target species (e.g., sharks, turtles, etc.) and coastal habitats compared to lower entanglement risk FADs. During the BIOFAD project no accidental FAD entanglements were observed. These canvas and rope designs, with no netting, would virtually eliminate any entanglement events of non-target species in the Indian Ocean (Ruiz et al., 2018).

Further analysis of quantity and quality fleet-provided data using observer data was also rejected as the response pattern (e.g., number of responses by fishing trip) depended on the number of interactions with project's FADs, which mainly dependent on several factors such as the fishing strategy, crew experience, operative area or season. The observation type (i.e., observer on-board or by electronic monitoring system) could also affect. However, this project was not designed to evaluate factors affecting the response of the crew to data collection requirements and thus the database was not built with this purpose. This fact challenged *a posteriori* assessment of changes in the response of skippers in the presence of human or electronic observers. Furthermore, some of the activities with BIOFADs and NEFAD could be carried out by both vessel types, the tuna purse seiner and its corresponding supply vessel. However, any activity with FADs was assigned to the purse seine vessels and consequently noted in this manner in the database. Thus, it was not possible to properly identify and link recoded FAD activities and the presence of a human or electronic observer onboard tuna purse seiners.

4.3.3.3. Sub-task 3.3- Develop life-cycle assessments for the different FAD designs and materials, including their expected biodegrading time and the subsequent potential negative and positive environmental effects (e.g., carbon print, impact of chemicals used to extend FADs durability, etc.)

The LCA methodology was employed to analyse potential environmental problems associated to the different prototypes.

This methodology is a widely recognised and used one. Based on the ISO 14040 series specifications, LCA studies assess the environmental impacts of a product or a service based on the raw material and energy consumption, and the resulting emissions and waste production that occur on each of the life stages of that product or service, from the raw material acquisition until its end of life (as illustrated in Figure 4.3.3.3.1).

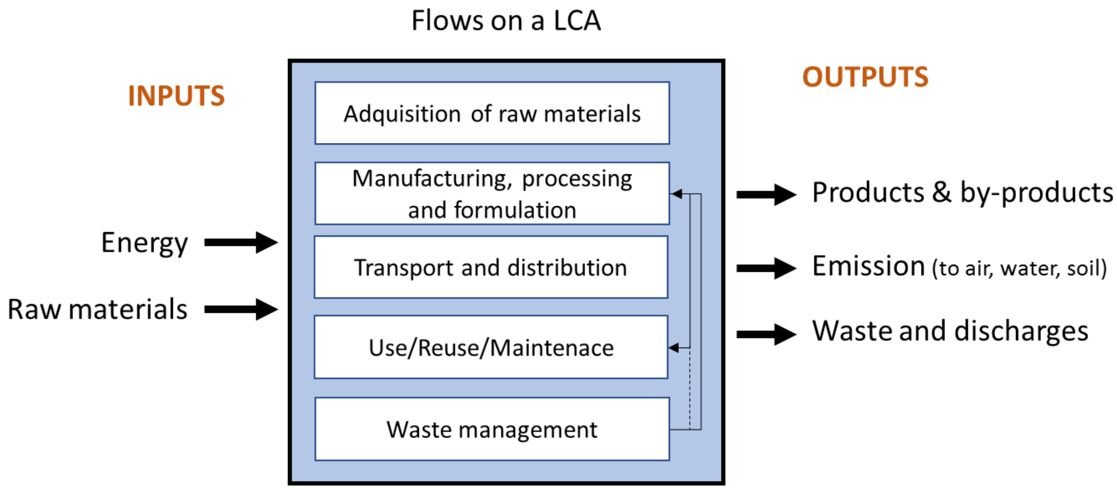


Figure 4.3.3.3.1. Product life stages and associated input and output flows.

In the BIOFAD project, the LCA analysis was conducted using SimaPro software, a science-based software that includes a variety of databases and impact assessment methodologies that are used to collect, assess and monitor life cycles' burdens in a systematic and transparent way.

Our analysis, similar to any LCA, includes four phases, as shown in Figure 4.3.3.3.2. These are the:

- Definition of the **Goal and Scope** of the study, which consists of defining the objectives and reasons for conducting the LCA, the assumptions adopted, limitations faced, the functional unit and system boundaries considered, and the way allocations problems have been dealt with.
- Building of the **Life Cycle Inventory** (LCI) or the data collection, which is one of the most demanding phases in any LCA.
- The **Life Cycle Impact Assessment** (LCIA). In this phase, the inventory is assessed by standard impact assessment methodologies, which are selected to be able to answer the Goal and Scope set at the beginning. Likewise, the most appropriate impact categories are chosen to represent the results.
- The **Interpretation** of the data. In this last phase, results are assessed to draw conclusions of the LCA study.

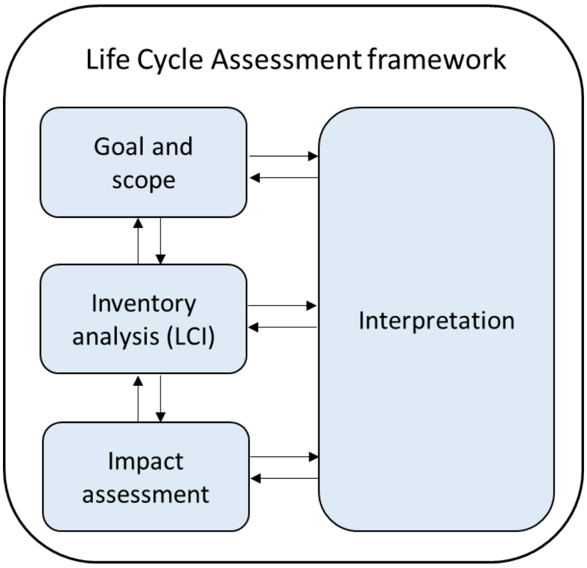


Figure 4.3.3.3.2. Main phases of a LCA.

Goal and Scope:

The **objective** of the LCA study was twofold:

- to assess and compare the environmental performance of 9 different FAD designs, 5 BIOFADs (A1, A2, B1, B2, C) and 4 NEFADs (NEFAD1, NEFAD2, NEFAD3, NEFAD4)
- to rank them from the most to the least environmental-friendly.

Originally in this subtask the environmental performance of 8 different prototypes (5 BIO FADs and 3 NEFADs) were to be analysed. But during the 3rd BIOFAD workshop, the discussion led to the decision of widening the scope to incorporate different design possibilities. As a result, 9 prototypes (5 BIOFADs and 4 NEFADs) were assessed with the LCA, including 14 design alternatives for the BIOFAD prototypes (A1, A1.1, A1.2, A2, A2.1, A2.2, B1, B1.1, B1.2, B1.3, B1.4, B1.5, B2, B2.1, B2.2, C, C1, C2, C3). Figure 4.3.3.3.3 shows the components each prototype and alternative include. The amounts of each of the component are listed in Table 4.2.3.2.1 of Appendix II.

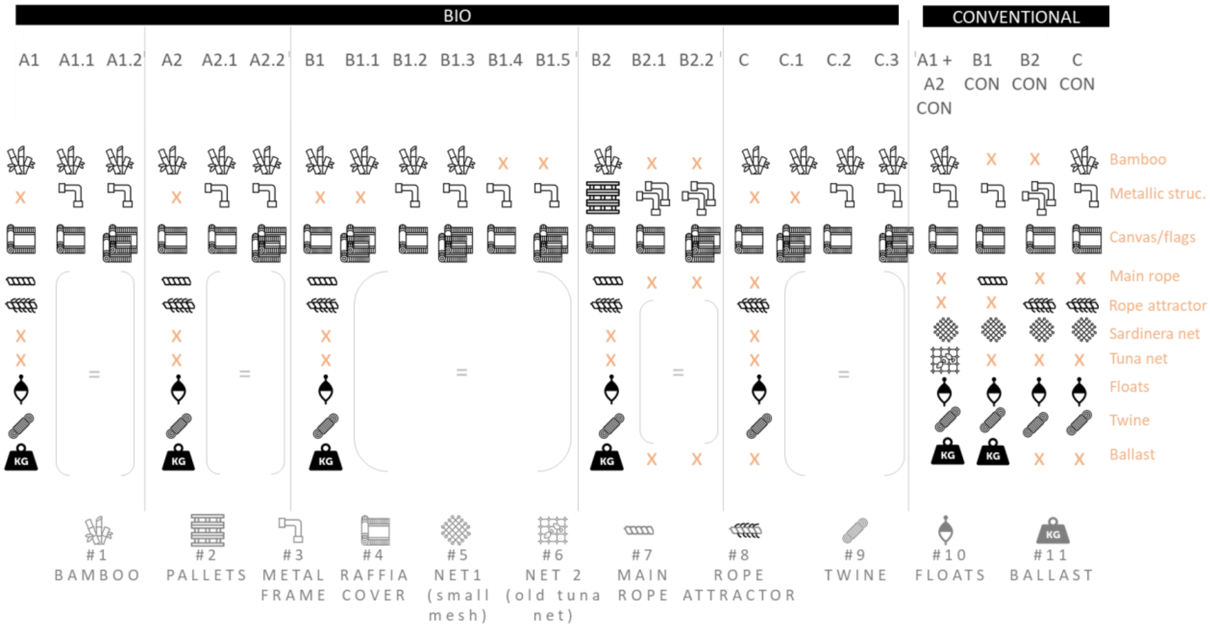


Figure 4.3.3.3.3 FAD prototypes and their components.

To calculate the environmental performance of the prototypes, a common functional unit was defined. The **functional unit** is the measure that defines the service that needs to be delivered by (in our case) the FADs. It enables the comparison between prototypes. The functional unit adopted in the study was 1 ton of tuna catch (or potential biomass equivalent estimated by the echo-sounder buoy) that is associated to each of the FAD prototypes over 1 year of operation. By tuna, we mean all target species (bigeye tuna, yellowfin tuna and skipjack tuna).

System boundaries: The LCA study assessed the design, manufacturing and use stages of each of the FADs prototypes (Figure 4.3.3.3.4). This included the acquisition of material, the consumption (i.e. quantity) of materials and energy associated to the manufacturing of each of the FAD prototypes, and their performance at sea (required to fulfill with the functional unit). The replacement of the components that may have occurred over the 12 month period was also considered (e.g., replacement of the canvas, the bamboos, etc.) to (i) reflect the expected time spent at sea, (ii) accurately estimate component degradation rates or losses, and (iii) the likelihood of requiring a replacement. Likewise, the transport was also considered, since many of the materials and components are usually shipped from Europe to the Seychelles, and it can represent an important contribution to the environmental impact scores, for example those associated to carbon footprint.

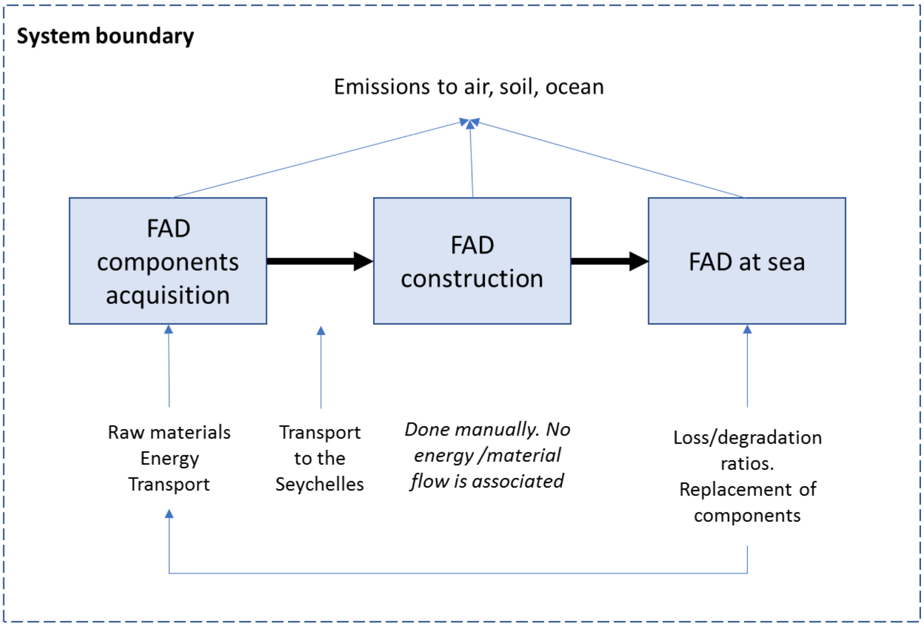


Figure 4.3.3.3.4. System boundary of the considered FADs comparison study. Note: The production and usage of the vessels excluded.

Inventory analysis:

Different means were employed to gather the data for the LCA. Figure 4.3.3.3.5. lists as a summary the data used in the LCI as a foreground data, the stakeholders contacted, and the template used to request the information. Manufacturing of plastic-based components and metal transformation processes were based on background data of SimaPro, which provides average data for processes carried out in Europe.

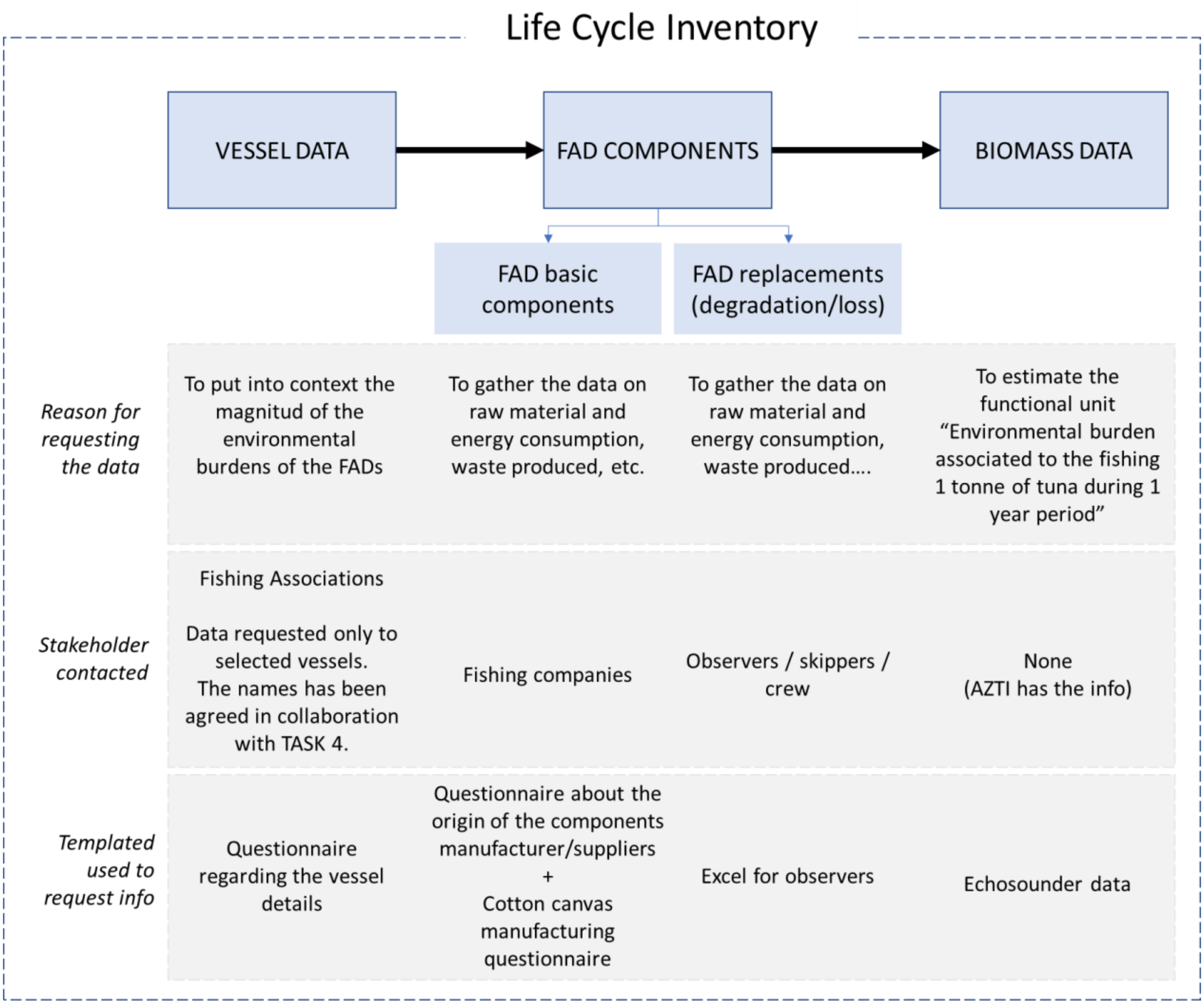


Figure 4.3.3.3.5. Sources of foreground data used in the life cycle inventory.

The characterization table (Appendix II - Table 4.2.3.2.1) of the FAD components was used as a baseline in the description of the FADs. This table lists the components of each of the FAD designs, and their materials and quantity.

To complete the table and collect additional data, a word template was prepared for Spanish and French fishing companies (Appendix II - Table 4.3.3.3.6.) regarding the components conforming further details of the FADs and logistics. The template requested the following information:

- The origin of each of the components (the name and location of the manufacturers' and suppliers' headquarters),
- materials used in each of the components and if the components involved the assembly of different parts (e.g., the metallic frame present on the NEFAD designs), the procedure followed to assemble the parts,
- mode of transport employed to send each of the components to the Port of Mahé (Seychelles),
- the assembly procedures for the FADs (either on-board or in port).

Additionally, for the case of the biodegradable components (i.e., the cotton canvas and ropes), a Word template was prepared to collate the information, especially regarding the production details. Table 4.3.3.3.7 of Appendix II lists the information requested to cotton canvas manufacturer (i.e., Ternua) to gather information regarding the manufacturing process and details of the cotton canvas. In the case of the traditional and biodegradable ropes manufacturing (i.e., Itsaskorda), the Consortium had access to a previously conducted LCA study by the rope manufacturer, which led the Consortium to have precious and detailed information regarding the material acquisition and manufacturing processes. These data were partially included in our LCA.

Lastly, French and Spanish associations were also contacted through Skype and email to request Vessel Details (Appendix II Table. 4.3.3.3.8.).

Limitations, assumptions and data quality: As background process data, mainly the Ecoinvent 3.4 database was used (Ecoinvent 2018)[5], which provides the latest average datasets of the industry. The foreground dataset was retrieved from the questionnaires (word templates) requested to shipowners, bio-based product manufacturers and data produced by BIOFAD project, such as tuna catch, replacement rates, etc.

The answers to the questionnaires by different fishing companies were employed to estimate average data and the standard deviations, mainly for transportation distances. Although the weight of each of the components may differ from FAD to FAD, even if they are of the same design, we have assumed that the weights are those listed in Appendix II Table 4.2.3.2.1. Foreground data on the manufacturing of the metallic frame and the synthetic black raffia canvas were not accessible, thus, the results were based on background data (i.e., industry's average datasets).

In some of the NEFAD prototypes, old and discarded fishing nets (small mesh size pelagic nets "sardinera" and the large mesh size nylon tropical PS nets "atunera") were used to build the FAD. The normal practice in the LCA methodology is to avoid double counting of the inputs that can be overlapped on several LCAs. This includes, for example, the processes associated with the reuse of materials or products. Contributions of such reused materials or products are normally allocated to the original function they were specifically designed for. In the case of the NEFADs, the fishing nets that are reused in their designs were indeed originally manufactured for tuna fishing, not for being reused in the FADs. Consequently, neither of the inputs associated to the production and consumption of nylon,

[5] Ecoinvent 2018. Ecoinvent data v3.8 – life cycle inventory database. Retrieved from www.ecoinvent.org, 14/8/2018.

polyester nor the processes associated to the acquisition of the materials and the manufacturing the nets were originally consider in the FAD related LCA. The net preparation for being used in the FADs is done manually; hence no energy was involved in the process either. Only transportation was computed to the material and energy flows of those components. However, in order to see the potential contribution of using new polyamide and polyester nets in FADs, the exercise has also considered the impact of the FAD if the nets employed were new.

For the prototypes using bamboo, only the transport of the bamboo to the FAD assembly locations was considered for two reasons: bamboo grows naturally in Seychelles, hence no crop associated impacts were considered, and bamboo is cut by hand, and no machinery is used in the process.

Waste disposal model: FADs are usually lost at sea, stolen by other vessels, or repaired if found by the owner or others. For all the first two cases, one could assume that the FADs would end up as marine litter eventually, thus as a discharge to the ocean. In those cases, the materials and weights of each of the components would have to be computed as waste released to the ocean. In the third case, however, the material and energy flows associated to the reparation or replacement would also have to be included in the LCA. And in the case that during the visit to the FAD a component was lacking, that loss would also have to be added as a discharge to the ocean or marine litter. Nonetheless, currently the LCA methodology presents some limitations to address marine litter. This was confirmed by the experts that attended the workshop "Connecting Expert Communities to Address Marine Litter in Life Cycle Assessment"[6] organized by Plastic Europe on the 23 May 2018. Some speakers mentioned that the LCA methodology presents limitations to model plastic emission and classes of impacts (Sonnemann G., 2018), others called for a development of a new LCIA methodology for assessing micro- and macro-plastics emissions into the environment (Maga D., 2018), and there are those who stated that although marine aquatic ecotoxicity is the best methodology to assess marine litter emissions, yet there are lots of uncertainties to be solved (Vázquez-Rowe I., 2018). As a response, a new project was launched in 2019 that is coordinated by key members of the LCA society to deal with marine litter in LCAs (http://marilca.org/). Therefore, due to the difficulties of assessing marine litter in the LCA methodology, the impact generated by the BIOFAD or NEFAD components once they become marine litter was omitted in the study.

[6] https://www.plasticseurope.org/en/newsroom/news/archive-news-2018/unprecedented-scientific-workshop-lca-and-marine-litter-sponsoredhosted-plasticseurope

In contrast, for the cases in which some of the components were missing or needed replacement a replacement factor was applied; Table 4.3.3.3.1 list them. These factors were extracted from State of Degradation reports presented by the fishing associations (Figures 4.2.3.2.1-4.2.3.2.3). In order to establish the replacement ratios, an assumption was made based on the state of Degradation. If a component presented half or more of the observations with either a "Stage 4" or "Stage 5" in one specific month at sea after deployment, it was assumed that this was the month that a replacement was required. Therefore, if for example the Main rope required a replacement in Month 5 because > 50% of the observations scored Stage 4 or 5, then that FAD prototype required 2 main ropes (1 replacement) over a 1 year period; hence the applied replacement factor was 2.

Table 4.3.3.3.1. Replacement frequency of the FAD components over a 1-year period

	Replacement for BIOFADs		Replacement for CONFADs	
Component	Month replacement	Applied factor	Month replacement	Applied factor
Bamboo	> 12 months	None	> 12 months	None
Metallic structure	na	na	> 12 months	None
Canvas	Month 4	x 3	> 12 months	None
Main rope	Month 5	x 2	Month 5	x 2
Rope attractor	Month 5	x 2	> 12 months	None
Floats	> 12 months	None	> 12 months	None

The calculation of the functional unit: two approaches were followed to estimate the tons of tuna that can be associated to a FAD prototype. The first approach considered the reported catch that is associated to each of the FAD prototypes. To calculate the tons of tuna/FAD prototypes, the reported catches were classified by prototype. The summation of all the catches for each of the prototypes was divided by the total number of deployments reported for each prototype.

In contrast, for the case of the aggregation of biomass, the estimation was based on the potential biomass detected by the echo-sounder buoy attached to the FAD. It has to be clarified that this is not a real tuna catch estimation, but due to for several prototypes no data were reported, the biomass was considered as an alternative functional unit as replacement of the catch. For the functional unit estimation, the tons of tuna/FAD prototypes, was computed diving the potential biomass provided by the echo-sounder by the nº of associated deployments. This alternative estimation introduces an important bias as part of these FADs from which biomass was estimated will never be used by the fleet.

The numbers obtained by each prototype are listed in Table 4.3.3.3.2.

Table 4.3.3.3.2. Tons of tuna catch reported by fishers and the potential of biomass aggregation based on the echo-sounder buoys for each of the FAD prototypes

Prototype	Catch			Biomass		
	Tons (sum)	Nº total deployments	tons/FAD (with catch)	Tons by echo-sounder	Nº total deployments with value	tons/FAD (with biomass)
A1 BIOFAD*	658	545	1.21	256.5	289	0.9
A2 BIOFAD*	80	142	0.56	15.9	17	0.9
B1 BIOFAD*	NA	29	NA	16.5	10	1.6
B2 BIOFAD*	NA	18	NA	NA	NA	NA
C BIOFAD*	NA	37	NA	45.5	11	4.1
NEFAD1	1124	625	1.80	372.1	264	1.4
NEFAD2	NA	43	NA	7.9	15	0.5
NEFAD3	NA	20	NA	0.6	2	0.3
NEFAD4	135	42	3.21	14.3	21	0.7

* including the alternatives

Impact assessment:

In order to reflect the impact on marine environment associated to FADs, two categories were selected to represent such impact: the global warming potential, in terms of carbon footprint (kg CO_2 equivalents / functional unit), and the Marine Ecotoxicity following the suggestion by the experts attending the workshop "Connecting expert communities to address marine litter in Life Cycle Assessment". The Marine Ecotoxicity refers to impacts of toxic substances released into marine ecosystems, and it is expressed using the reference unit kg 1,4-dichlorobenzene equivalent (1,4-DB). The Impact assessment methods used were the IPPC 2013 - 100 years and the CML-IA 3.05.

The LCA results regarding the carbon footprint are shown in Figures 4.3.3.3.5 and 4.3.3.3.6. Both shows the results considering the catch and biomass, with and without the replacement: the first when the LCA is conducted considering the nets used in the FADs as reused; and the second when the nets are considered to be exclusively manufactured for the FADs, as new.

Regarding the results for **CARBON FOOTPRINT**:

- If the nets are considered as reused material in the LCA (Fig. 4.3.3.3.5 and Table 4.3.3.3.3):

  With the available reported catch data (Prototypes BIOFAD A-s and NEFAD 1 and NEFAD 4) no difference was observed between results with and without replacement. In general terms, NEFAD prototypes performed better than the

BIOFAD As. Considering the biomass, however, BIOFAD C prototypes seem to be the ones with less carbon footprint with and without replacement, followed by the NEFAD 1 and some of the BIOFAD B1 alternatives. NEFAD 3 presented the highest carbon footprint, followed by NEFAD2 and some of BIOFAD A designs. Although the ranking and the scores varied when considering or not the replacement, the general trend was maintained in both with and without replacement.

Considering the carbon footprint of the FAD without the functional unit (i.e. the efficiency of catching or aggregating fish), all the NEFAD designs performed better than the BIOFAD ones when including the replacement rate; in contrast without the replacement the differences between the NEFAD and the BIOFAD (without the alternatives) were not significant.

- If the nets are considered new materials in the LCA (Fig. 4.3.3.3.6 and Table 4.3.3.3.3):

  As expected, the carbon footprint of the NEFAD prototypes increased when the fishing nets were considered as new materials. The most considerable change was observed for NEFAD1, which was linked to the incorporation of important amounts of tuna nets in the FADs. In contrast, the use of small mesh size nets had little effect on the overall LCA, and few changes were observed in the ranking, neither of them significant. In terms of catch, NEFAD1 prototype moved from being one of the best options to the worst. Despite thatA2 prototype and alternatives stayed as the worst option; and NEFAD4 the best. In terms of biomass, the same trend was observed in respect to NEFAD1, which moved to the latest positions in the ranking, by becoming one with the worst carbon footprint, only followed by NEFAD3 and BIOFAD A1.2. BIOFAD C prototypes presented the best carbon footprint scores.

  Considering the carbon footprint of the FAD without the functional unit (i.e., the efficiency of catching or aggregating fish), little changes were observed in comparison to allocating the fishing nets as reused material in the LCA. Only the NEFAD moved from the best to the worst position in the ranking but the rest remain almost the same.

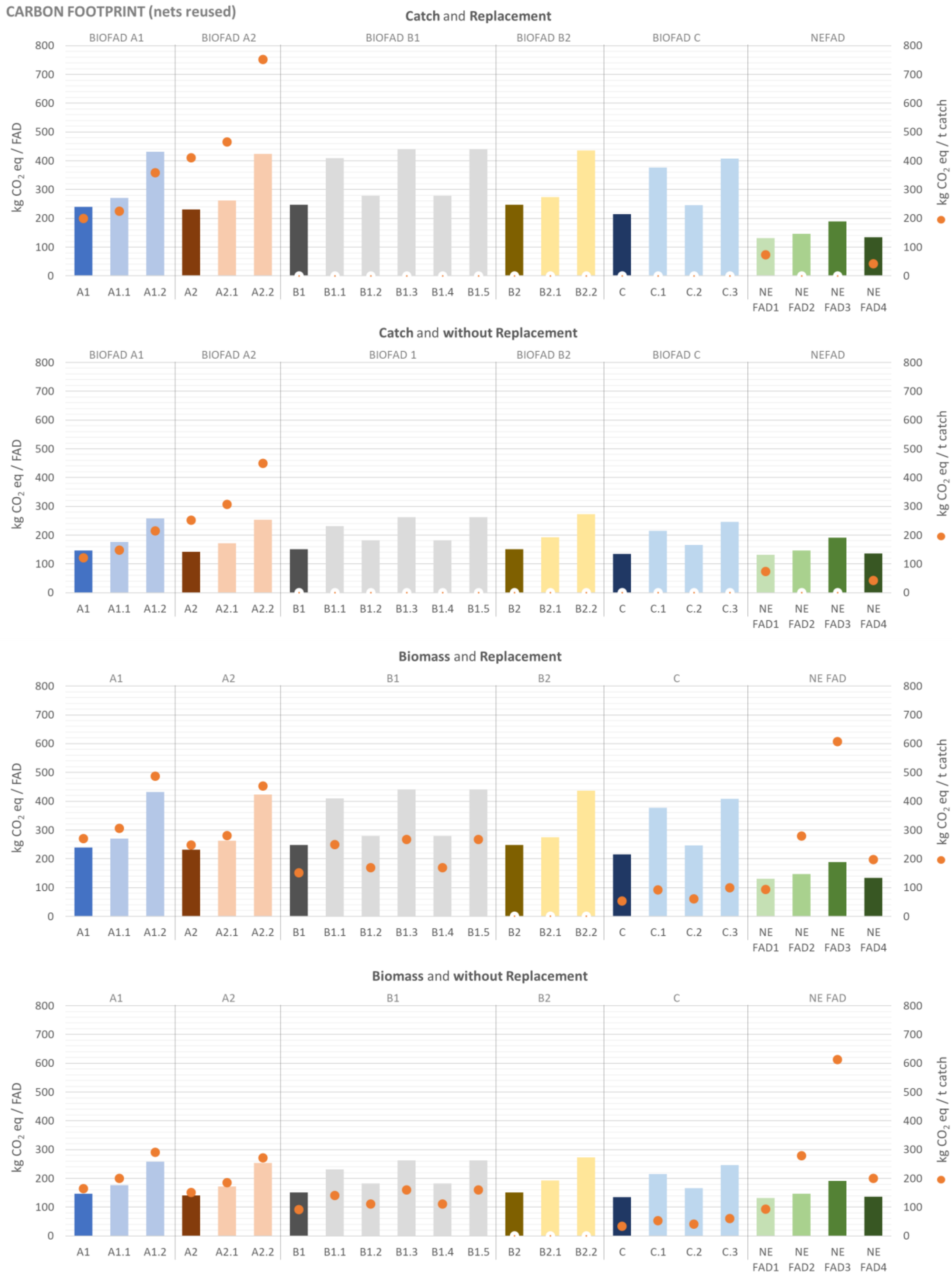


Figure 4.3.3.3.5 Carbon footprint of different FAD types, considering the catch (top two) or biomass (bottom two), and with and without the replacement, considering that the nets reused in the NEFADs are reused.

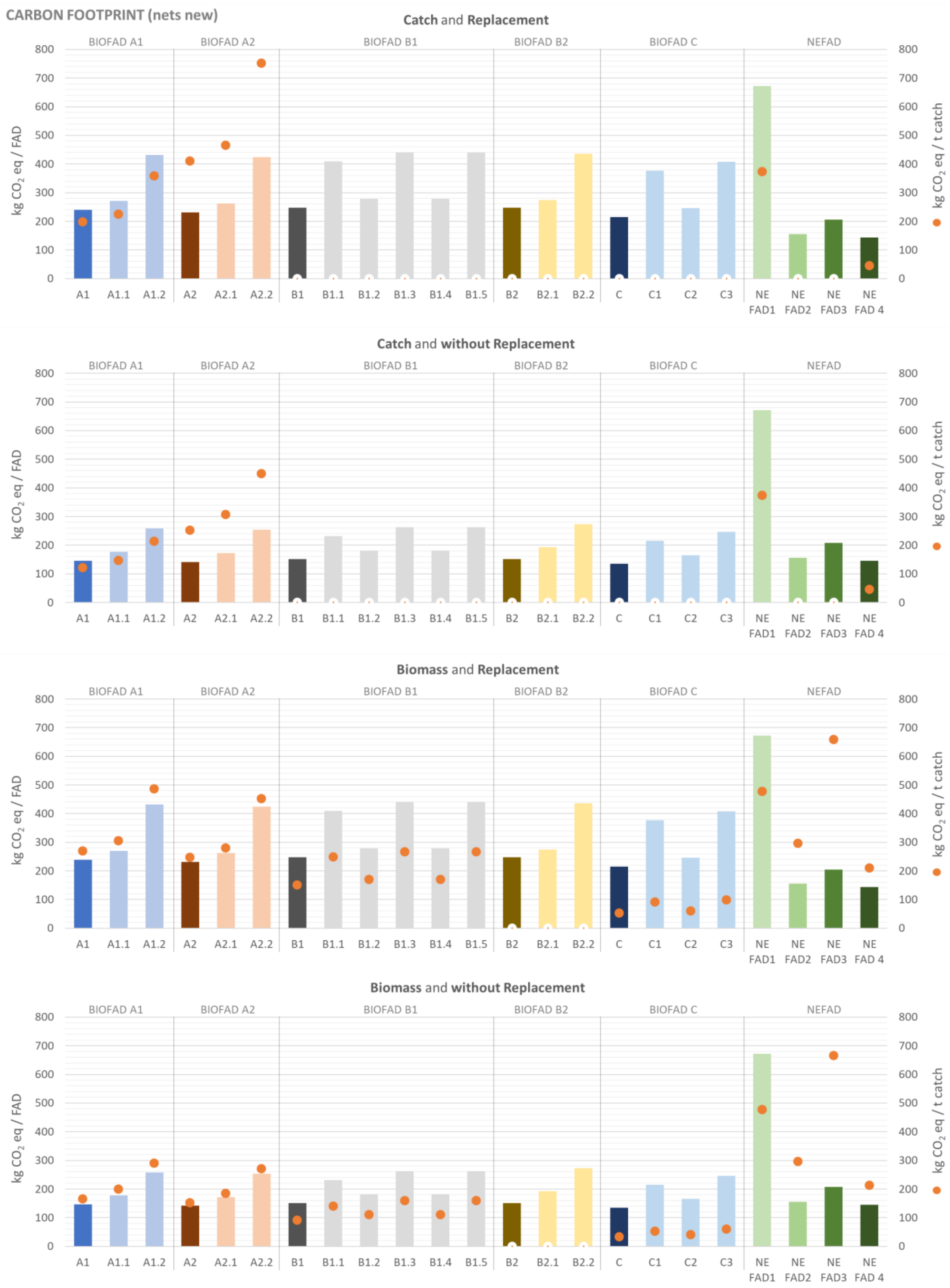


Figure 4.3.3.3.6 Carbon footprint of different FAD types, considering the catch (top two) and biomass (bottom two), without replacement, considering that the fishing nets used in the NEFADs are new.

Table 4.3.3.3.3 Ranking of prototypes according to their carbon footprint (from best to worst performance, NEFAD in bold, BIOFAD in normal).

With CATCH (kg CO_2/t)				With BIOMASS (kg CO_2/t)				FOR FAD (kg CO_2/FAD)			
without repl.		with repl.		without repl.		with repl.		without repl.		with repl.	
Considering that fishing nets used in the FADs are reused nets											
NEFAD4	42	**NEFAD4**	42	C	33	C	52	**NEFAD1**	131	**NEFAD1**	131
NEFAD1	73	**NEFAD1**	73	C2	40	C2	60	C	134	**NEFAD4**	134
A1	121	A1	198	C1	52	C1	91	**NEFAD4**	136	**NEFAD2**	147
A1.1	147	A1.1	224	C3	60	**NEFAD1**	93	A2	141	**NEFAD3**	189
A1.2	213	A1.2	358	B1	91	C3	99	A1	146	C	215
A2	251	A2	410	**NEFAD1**	93	B1	150	**NEFAD2**	147	A2	231
A2.1	306	A2.1	465	B1.4	110	B1.4	169	B2	151	A1	239
A2.2	449	A2.2	752	B1.2	110	B1.2	169	B1	151	C2	246
				B1.1	140	**NEFAD4**	197	C2	165	B2	248
				A2	151	A2	247	A2.1	172	B1	248
				B1.5	159	B1.1	248	A1.1	177	A2.1	262
				B1.3	159	B1.5	267	B1.4	182	A1.1	270
				A1	164	B1.3	267	B1.2	182	B2.1	275
				A2.1	184	A1	270	**NEFAD3**	191	B1.4	279
				A1.1	199	**NEFAD2**	279	B2.1	192	B1.2	279
				NEFAD4	199	A2.1	280	C1	215	C1	377
				A2.2	270	A1.1	305	B1.1	231	C3	408
				NEFAD2	279	A2.2	452	C3	246	B1.1	409
				A1.2	290	A1.2	487	A2.2	253	A2.2	424
				NEFAD3	613	**NEFAD3**	606	A1.2	258	A1.2	432
								B1.5	262	B2.2	436
								B1.3	262	B1.5	440
								B2.2	273	B1.3	440
Considering that fishing nets used in the FADs were new											
NEFAD 4	45	**NEFAD 4**	45	C	33	C	52	C	134	**NEFAD 4**	143
A1	121	A1	198	C2	40	C2	60	A2	141	**NEFAD 2**	156
A1.1	147	A1.1	224	C1	52	C1	91	**NEFAD 4**	145	**NEFAD 3**	205
A1.2	213	A1.2	358	C3	60	C3	99	A1	146	C	215
A2	251	**NEFAD 1**	374	B1	91	B1	150	B2	151	A2	231
A2.1	306	A2	410	B1.4	110	B1.4	169	B1	151	A1	239
NEFAD 1	374	A2.1	465	B1.2	110	B1.2	169	**NEFAD 2**	156	C2	246
A2.2	449	A2.2	752	B1.1	140	**NEFAD 4**	210	C2	165	B2	248
				A2	151	A2	247	A2.1	172	B1	248
				B1.5	159	B1.1	248	A1.1	177	A2.1	262
				B1.3	159	B1.5	267	B1.4	182	A1.1	270
				A1	164	B1.3	267	B1.2	182	B2.1	275
				A2.1	184	A1	270	B2.1	192	B1.4	279
				A1.1	199	A2.1	280	**NEFAD 3**	207	B1.2	279
				NEFAD 4	213	**NEFAD 2**	296	C1	215	C1	377
				A2.2	270	A1.1	305	B1.1	231	C3	408
				A1.2	290	A2.2	452	C3	246	B1.1	409
				NEFAD 2	296	**NEFAD 1**	477	A2.2	253	A2.2	424
				NEFAD 1	477	A1.2	487	A1.2	258	A1.2	432
				NEFAD 3	665	**NEFAD 3**	658	B1.5	262	B2.2	436
								B1.3	262	B1.5	440
								B2.2	273	B1.3	440
								NEFAD 1	672	**NEFAD 1**	672

The LCA results regarding the Marine Ecotoxicity are shown in Figures 4.3.3.3.7 and 4.3.3.3.8. Both show the results considering the catch and biomass, with and without the replacement: the first when the LCA is conducted considering the nets used in the FADs as reused; and the second when the fishing nets are considered to be exclusively manufactured for the FADs, as new.

Regarding the results for **MARINE ECOTOXICITY**:

- If the nets are considered as reused material in the LCA (Figure 4.3.3.3.7 and Table 4.3.3.3.4):
  In line with the results obtained for Carbon footprint and catch, no significant differences were observed in the ranking between results with and without replacement. Prototypes NEFAD 4 and 1 presented the best scores for marine ecotoxicity, and the BIOFAD A-s were the worst, being the BIOFAD A2.2 the worst in all. Considering the biomass results, BIOFAD C prototypes presented the best performance regarding Marine Ecotoxicity. BIOFAD C-s were followed by the NEFAD 1. BIOFAD B1 and NEFAD 4 were positioned after the BIOFAD Cs in the ranking but present almost 3 times more impact than the best BIOFAD C. Prototypes A1 and A2 and their alternatives and NEFAD 2 and NEFAD 3 presented high values for Marine Ecotoxicity in comparison to the firsts in the ranking. Nonetheless, it seems that NEFAD 3 and the alternatives with double materials presented the worst performance in regard to this impact category.

  Considering the Marine Ecotoxicity of the FAD without the functional unit (i.e. the efficiency of catching or aggregating fish), all the NEFAD designs performed better than the BIOFAD when including the replacement rate (as happened for the carbon footprint); but without the replacement the original BIOFAD prototypes (no alternatives) did better than the NEFAD counterparts, although the differences were not significant.

- If the nets are considered new materials in the LCA:
  Unlike in carbon footprint, the scores did not suffer major changes, and no significant differences were observed in the ranking in comparison to using the fishing nets as reused materials.

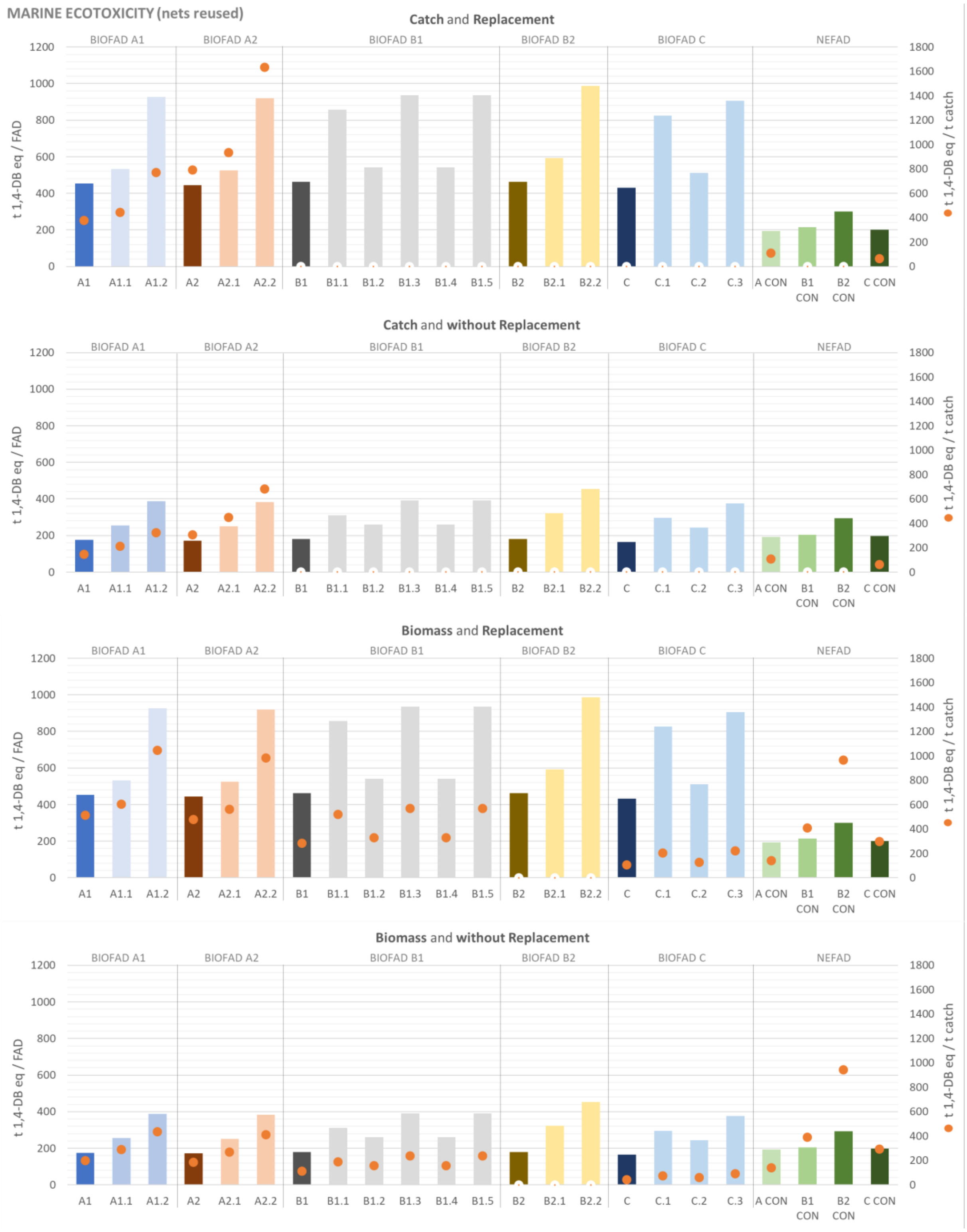


Figure 4.3.3.3.7 Marine Ecotoxicity of different FAD types, considering the Catch (top two) and biomass (bottom two), with and without replacement, considering the fishing nets reused in the NEFADs as reused in the LCA.

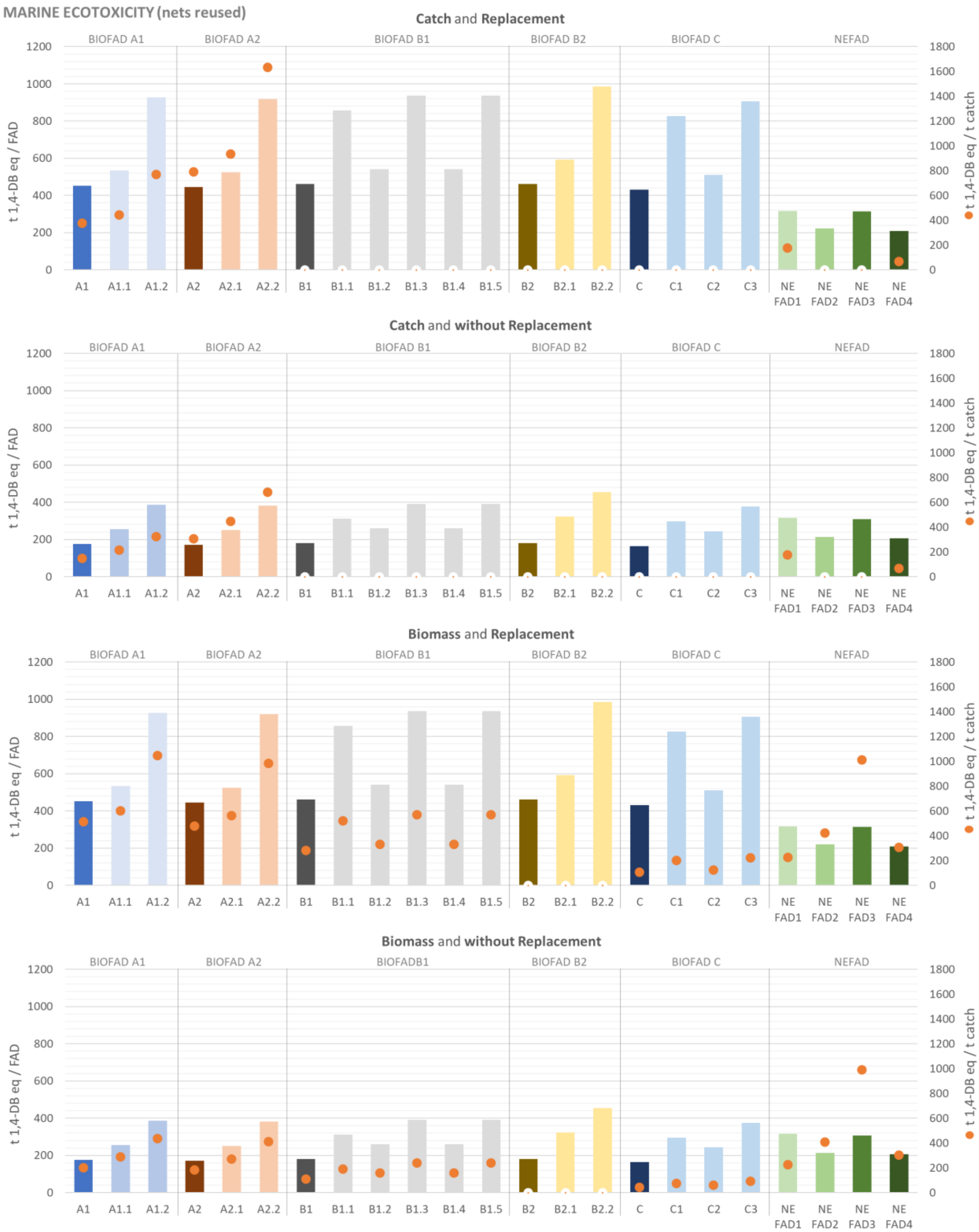


Figure 4.3.3.3.8 Marine Ecotoxicity of different FAD types, considering the Catch (top two) and biomass (bottom two), with and without replacement, considering the fishing nets new in the NEFADs as reused in the LCA.

Table 4.3.3.3.4 Ranking of prototypes according to their Marine Ecotoxicity (from best to worst performance, NEFAD in bold, BIOFAD in normal).

With CATCH (t 1,4-DB/t)				With BIOMASS (t 1,4-DB/t)				FOR FAD (t 1,4-DB/FAD)			
without repl.		with replacement		without repl.		with replacement		without repl.		with repl.	
Considering that fishing nets used in the NEFADs are reused nets											
NEFAD4	62	**NEFAD4**	62	C	40	C	104	C	165	**NEFAD1**	193
NEFAD1	108	**NEFAD1**	108	C2	59	C2	124	A2	172	**NEFAD4**	201
A1	146	A1	375	C1	72	**NEFAD1**	137	A1	176	**NEFAD2**	214
A1.1	211	A1.1	441	C3	91	C1	200	B2	180	**NEFAD3**	300
A2	304	A1.2	768	B1	109	C3	219	B1	180	C	431
A1.2	320	A2	790	**NEFAD1**	137	B1	280	**NEFAD1**	193	A2	445
A2.1	446	A2.1	931	B1.4	157	**NEFAD4**	294	**NEFAD4**	198	A1	453
A2.2	679	A2.2	1631	B1.2	157	B1.4	328	**NEFAD2**	205	B2	462
				A2	183	B1.2	328	C2	244	B1	462
				B1.1	189	**NEFAD2**	406	A2.1	251	C2	511
				A1	198	A2	475	A1.1	255	A2.1	525
				B1.5	237	A1	511	B1.4	260	A1.1	533
				B1.3	237	B1.1	519	B1.2	260	B1.4	542
				A2.1	268	A2.1	560	**NEFAD3**	294	B1.2	542
				A1.1	288	B1.5	567	C1	296	B2.1	592
				NEFAD4	290	B1.3	567	B1.1	312	C1	826
				NEFAD2	389	A1.1	600	B2.1	323	B1.1	856
				A2.2	408	**NEFAD3**	963	C3	376	C3	905
				A1.2	436	A2.2	981	A2.2	383	A2.2	919
				NEFAD3	943	A1.2	1045	A1.2	387	A1.2	927
								B1.5	391	B1.5	936
								B1.3	391	B1.3	936
								B2.2	454	B2.2	986
Considering that fishing nets used in the NEFADs were new											
NEFAD4	64	**NEFAD4**	65	C	40	C	104	C	165	**NEFAD4**	209
A1	146	**NEFAD1**	176	C2	59	C2	124	A2	172	**NEFAD2**	222
NEFAD1	176	A1	375	C1	72	C1	200	A1	176	**NEFAD3**	315
A1.1	211	A1.1	441	C3	91	C3	219	B2	180	**NEFAD1**	316
A2	304	A1.2	768	B1	109	**NEFAD1**	224	B1	180	C	431
A1.2	320	A2	790	B1.4	157	B1	280	**NEFAD4**	206	A2	445
A2.1	446	A2.1	931	B1.2	157	**NEFAD4**	306	**NEFAD2**	213	A1	453
A2.2	679	A2.2	1631	A2	183	B1.4	328	C2	244	B2	462
				B1.1	189	B1.2	328	A2.1	251	B1	462
				A1	198	**NEFAD2**	422	A1.1	255	C2	511
				NEFAD1	224	A2	475	B1.4	260	A2.1	525
				B1.5	237	A1	511	B1.2	260	A1.1	533
				B1.3	237	B1.1	519	C1	296	B1.4	542
				A2.1	268	A2.1	560	**NEFAD3**	308	B1.2	542
				A1.1	288	B1.5	567	B1.1	312	B2.1	592
				NEFAD4	302	B1.3	567	**NEFAD1**	316	C1	826
				NEFAD2	405	A1.1	600	B2.1	323	B1.1	856
				A2.2	408	A2.2	981	C3	376	C3	905
				A1.2	436	**NEFAD3**	1011	A2.2	383	A2.2	919
				NEFAD3	990	A1.2	1045	A1.2	387	A1.2	927
								B1.5	391	B1.5	936
								B1.3	391	B1.3	936
								B2.2	454	B2.2	986

Interpretation of results:

- For both the carbon footprint and the Marine Ecotoxicity, the C BIOFAD prototypes performed the best regarding the carbon footprint; and they were followed by the BIOFAD B1.
- The results indicate that the more material it is used in the FADs the higher the environmental impact score. The use of double materials (i.e., double canvas or double metallic frame) increases the environmental impact in both carbon footprint and marine ecotoxicity significantly. In fact, the BIOFAD A and BIOFAD B1 alternatives that used double canvas or/and double metallic structure are ranked as the worst.
- The use of the bamboo helps reducing the environmental performance for the selected impact categories. Nonetheless, the massive use of bamboo may create problems locally as it can lead to reducing the bamboo forests in Seychelles; hence, additional impact would be generated by this activity.
- The contribution of each component to the overall environmental impact of each of the FAD prototype is shown in Figure 4.3.3.3.9 (top for carbon footprint and bottom for Marine Ecotoxicity).
- The raffia, metallic structure, the floats seem to be the components contributing the most to the environmental impact; and the fabrication process is in all of them stage contributing the most to the impact. For example, the weaving of the cotton presents around the 70% of the impact associated to the canvas.

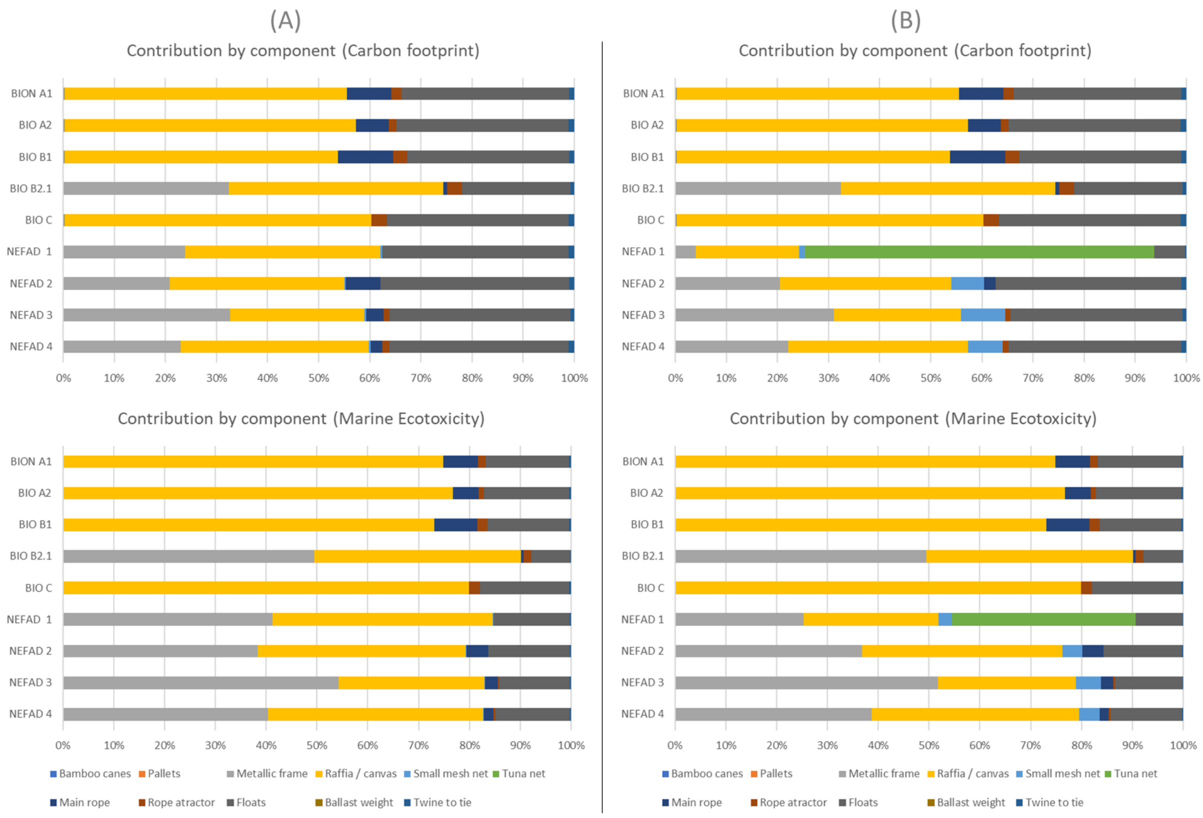


Figure 4.3.3.3.9 Contribution of each component to the total environmental impact of each FAD prototype (top: to the carbon footprint; bottom to the marine ecotoxicity), and using the fishing nets as (A) reused materials, and (B) as new materials.

The difference between the BIOFAD and NEFAD prototypes is less significant than the originally expected. The difference may be explained by the following reasons:

- In the case of the NEFAD prototypes, the netting (small pelagic nets or tuna PS net) and the chains used as ballast are reused elements from old nets. The impact associated to acquiring the material for and the manufacturing of the nets and chains have not been included in the present LCA. This is a normal procedure in LCAs to avoid the double counting. In fact, the impact associated to those processes are usually allocated to the function they were created for (i.e. that is to fish tuna). This is the main reason why the NEFAD prototypes score better than BIOFAD prototypes. Nonetheless, when considering the fishing nets as new nets, the BIOFAD designs, especially the Cs and the B1s are in general better than the NEFAD prototypes.
- It has been mentioned that the LCA current methodology presents limitations on addressing marine litter. Thus, the LCA conducted in BIOFAD have omitted the impact generated by the FADs or their components when they are lost. However, if the impact of marine litter derived from FAD losses was to be included, it may be expected that the NEFAD prototypes would score worst especially in the Marine Ecotoxicity impact category.

- We have made different assumptions regarding the replacement ratios based on the reported states. In general terms, despite some components may have been degraded and lost in some occasions, the durability of the BIOFADs has been proved to be more than a year. Hence, the replacement rate could be discussed further for future works.
- The results are based on the reported catch and potential biomass estimated by the echo-sounder buoys (model M3i) for each of the prototypes (Table 4.3.3.3.5). While more than 300 data are available for either NEFAD or BIOFAD prototypes with the biomass, the reported catch observations do not reach 30. Therefore, results presented from the biomass are more consistent than those from catch.

Table 4.3.3.3.5 Nº of observations available for catch (reported) and Biomass (emitted by M3I).

	CATCH		BIOMASS	
	BIOFADs	NEFADs	BIOFADs	NEFADs
A1	21	20	289	250
A2	2	7	17	14
B1	2	0	10	15
B2	0	0	0	2
C	1	2	11	21

- Tuna fishing by tropical purse seiners has been assessed in the literature. The carbon footprint associated to catching 1 ton of tuna ranges from 1,100 to 2,200 kg CO_2 depending on the author and the ocean targeted (Atlantic, Indian, Pacific) (Parker and Tyedmers., 2015; Hospido and Tyedmers, 2005). The impact associated to the FADs represents less than 5% for the best scored prototypes. Hence, although the relative difference between the two types seems significant, in absolute terms, it is not so much.
- Marine litter generation: Fishing companies try to maximize the use of the FADs but occasionally they drift to locations where the recovery is not possible, in other cases FADs are stolen, it may also happen that certain components of the FADs get lost before they can be recovered. Hence, once FADs are deployed, they have a large potential to become marine litter. Maufroy and colleagues (2015) suggested that 10% of FAD deployments end with a beaching event; these figures are in line with the global trend that suggest that 15% of the marine litter floats on the sea surface and eventually ends up beaching, 15% remains in the water column and 75% sinks (UNEP, 2005). The number of real lost FADs (i.e., FAD that can no longer be tracked by any vessel because the information of the buoy attached is no longer received due to several reasons such as beaching, sinking, malfunction, deactivation) are still unknown. The ideal would be to know this loss rate to calculate the real contribution of FADs to marine litter. But provided that no official data exist on this

regard at present, a rough approximation was conducted considering the mean weight of the BIOFAD and NEFAD prototype designs. The weight associated to bamboo canes was omitted from the BIOFAD weight calculations due to bamboo canes being considered unprocessed materials, and therefore they fall out of the scope of the marine litter definition.

Considering that:

1. the mean weight of BIOFAD prototypes (excluding bamboo canes) is 50 kg/FAD, 71 kg for NEFADs
2. 771 BIOFAD and 736 NEFAD deployments were performed
3. 10% of the deployments may be washed up on beaches (Maufroy et al., 2015)

The marine litter washed up on beaches related to this project would be: 3.8 t and 5.2 t of marine litter associated to BIOFADs and NEFADs respectively. Nonetheless, it must be noted that an important part of the BIOFAD designs include biodegradable materials. Such materials are more prone to be degraded in the environment, potentially reducing their contribution to the marine litter generation.

4.3.3.4. Sub-task 3.4- Identify best performing designs.

A short questionnaire was developed for the fleet in order to collect feedback regarding the acceptance of tested biodegradable materials and prototypes. This information, together with the results obtained from the other sub-tasks were used to identify the best performing FAD designs and materials with good performance. So far 20 questionnaires were received out of 44 potential submitters. Response to this questionnaire together with industry's feedback received during the three BIOFAD workshops organized during the project provided a good representation of fleets opinions.

A) To the question "What is your opinion about tested biodegradable materials?" the majority of participants concluded the cotton canvas as good or fair, similar to what they thought about the two types of ropes (Figure 4.3.3.4.1). This opinion about the cotton canvas is not in line with what degradation rate results showed. Also, industry noted that performance of cotton canvas worked below expectations as it degraded very fast in the first months at sea (notes from 2nd and 3rd BIOFAD workshops). On the other hand, the positive rating for cotton ropes was in accordance with degradation results and feedback from industry received during the workshops. The cotton ropes did not totally meet the highest industry's expectations regarding material durability; however, it is a good biodegradable candidate as an alternative to netting materials for the submerged part of the FAD. Indeed, several companies are using them in their current FAD operations.

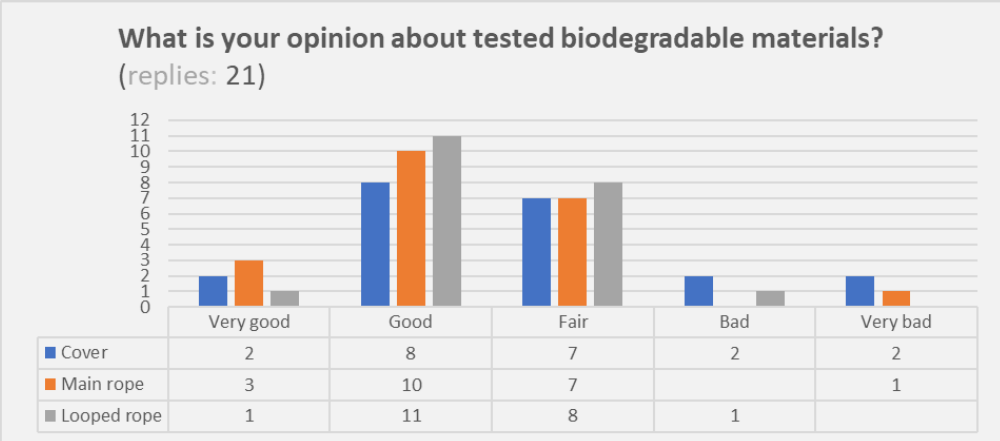


Figure 4.3.3.4.1. First question of the questionnaire.

B) To the question "Would you suggest other type of biodegradable material?" most of them selected the option "NO", mainly because they do not know which other alternative materials are available in the market (Figure 4.3.3.4.2.). This result also indicates to some extent how biodegradable materials still require investigation for more alternatives to solve important practical/technical aspects for the operationalization in FAD. Thus, and as it was noted in the 2nd and 3rd BIOFAD workshops, further research with natural and synthetic materials that meet the BIOFAD definition is required.

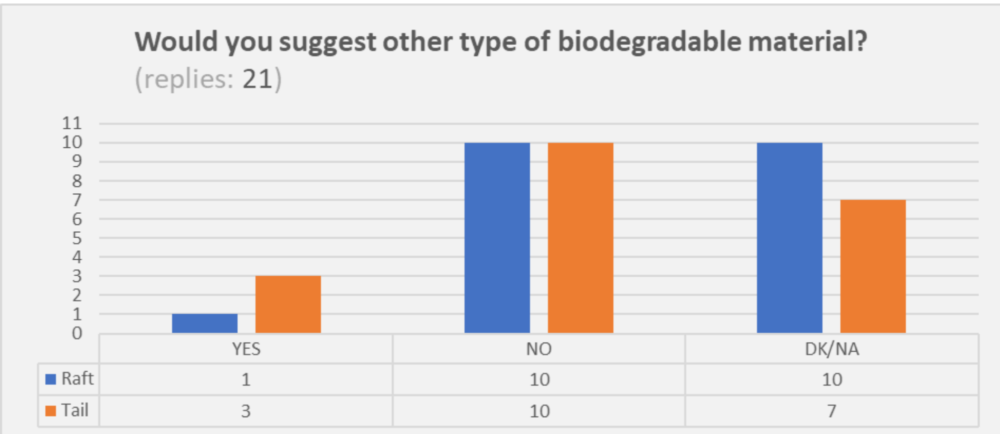
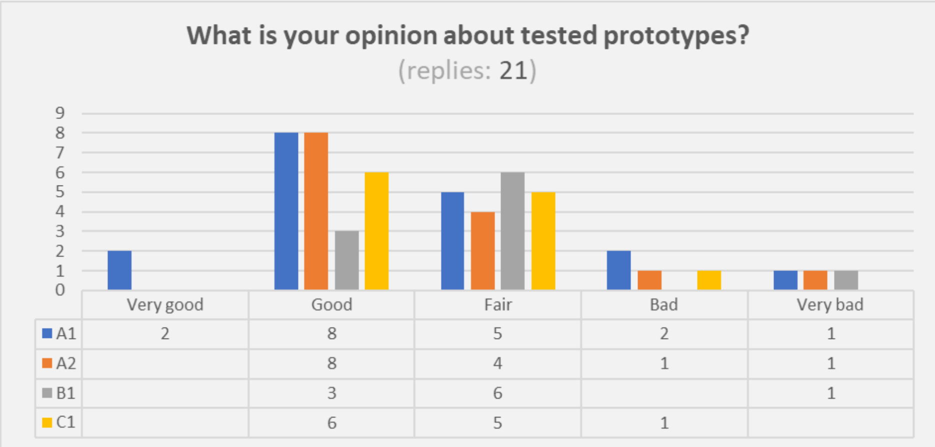


Figure 4.3.3.4.2. Second question of the questionnaire.

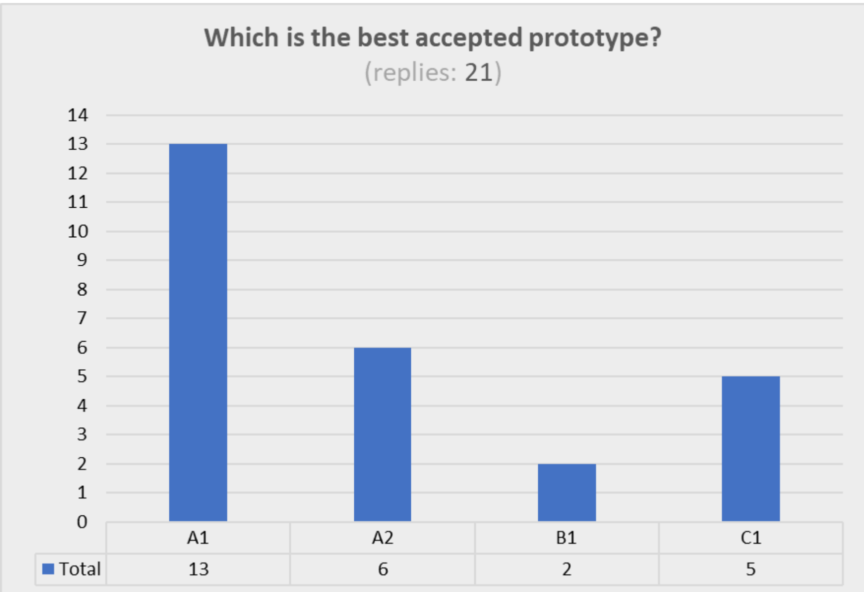
C) To the question "What is your opinion about tested prototypes?" most of them marked all four BIOFAD prototypes as good or fair, with A1 and A2 prototypes receiving the most positive feedback (Figure 4.3.3.4.3). This result is in line with the numbers of deployments for each prototype during the project, with 71% and 18%, A1 and A2 respectively. However, it is in contradiction with what the industry translated to the Consortium during the 2nd and 3rd workshops describing some prototypes as obsolete and with low efficiency.



	Very good	Good	Fair	Bad	Very bad
A1	2	8	5	2	1
A2		8	4	1	1
B1		3	6		1
C1		6	5	1	

Figure 4.3.3.4.3. Third question of the questionnaire.

D) To the question "Which is the best accepted prototype?" most of them marked option A1 followed by prototypes A2 and C1 (Figure 4.3.3.4.4). Like in the previous question, this corresponds with what vessels deployed in the project. The prototype A1 and A2 comprised most of the sets performed on experimental FADs.



	A1	A2	B1	C1
Total	13	6	2	5

Figure 4.3.3.4.4. Fourth question of the questionnaire.

E) When asked to provide reasons for their favored prototype, the majority of participants select the option of "easy to construct" or "Other". This last option usually was selected to note that this prototype was the most similar one to the NEFADs currently used by them (Figure 4.3.3.4.5). Aggregation was the fourth reason selected by the fleet, which is in line with catch data.

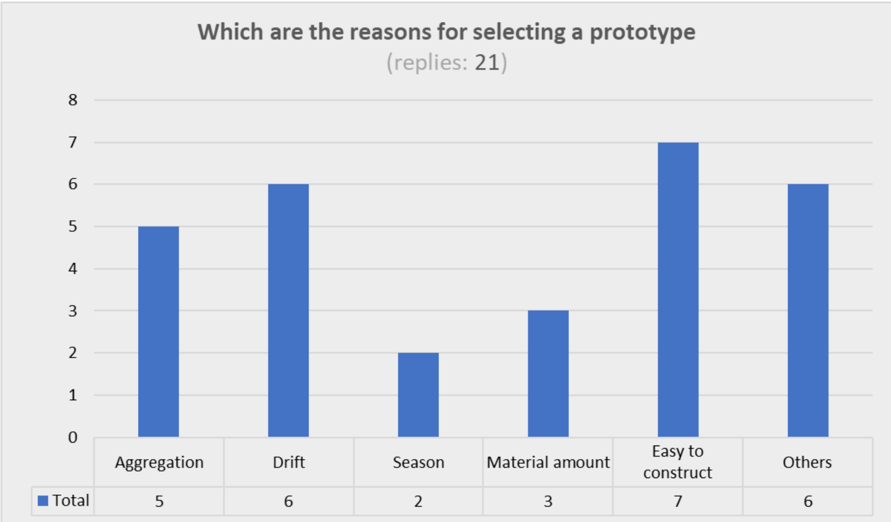


Figure 4.3.3.4.5. Participant responses to the fifth question of the questionnaire.

F) When asked to "Evaluate the prototypes according to their fishing efficiency" participants marked the majority of the BIOFAD prototypes as fair or bad with only prototype A1 receiving a significant response valuing it as "good" (Figure 4.3.3.4.6). The result of this question disagrees with question C in which prototypes obtained good ratings. This could be because *a priory* the designs are acceptable for the fleet but their performance due to different reasons did not meet their expectations. Again, prototype A1 was the one having highest rating followed by C1 and A2.

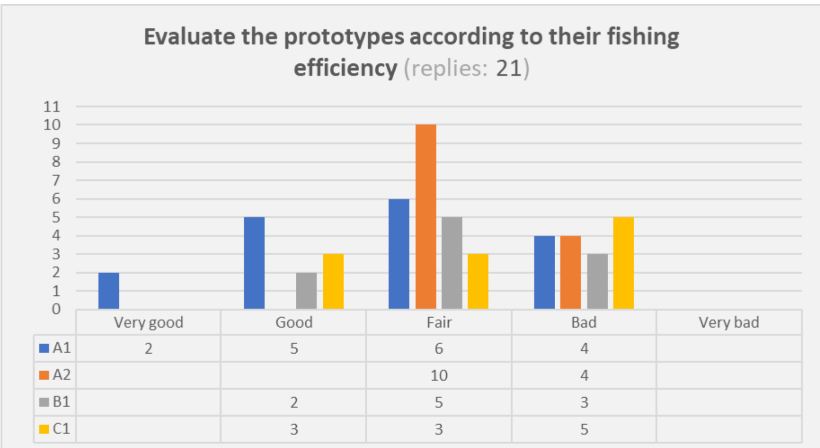


Figure 4.3.3.4.6. Sixth question of the questionnaire.

G) When asked "Would you suggest changes in the prototypes or a new prototype?" the majority selected "NO" or "do not know/No available" in reference to both parts of the FADs. However, some suggestions were made, similar to those discussed at the 2nd BIOFAD workshop (Figure 4.3.3.4.7). For example, more flexibility to adapt defined designs and the inclusion of the metal frame was proposed.

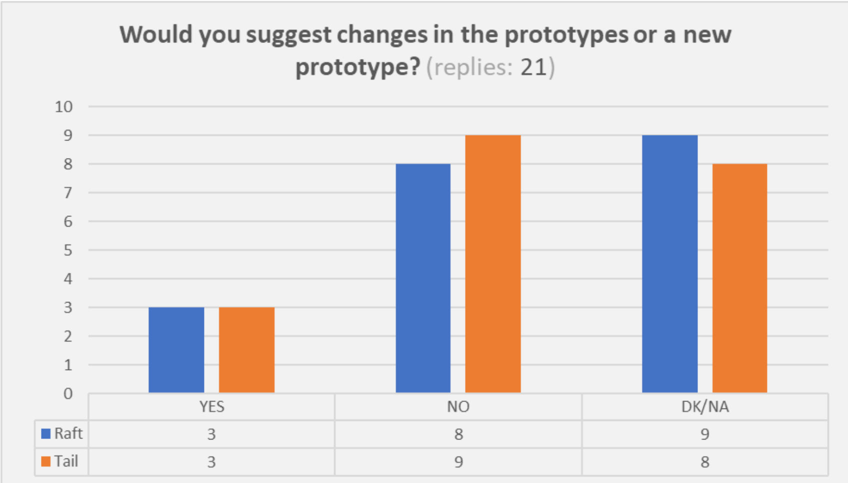


Figure 4.3.3.4.7. Seventh question of the questionnaire.

H) A final question related to their interest in following the research on biodegradable FADs was also posed. Most of them select the option "Yes", which shows their interest in the project and finding suitable materials (Figure 4.3.3.4.8). This point was also noted in the 2nd and 3rd BIOFAD workshops. The Consortium and industry recommended that an effective replacement for non-biodegradable FADs by those fully/partly biodegradable FADs still requires investigation to solve important practical and technical aspects for their use in daily fishing operations. Thus, further research with those natural and synthetic materials that meet the BIOFAD definition is required.

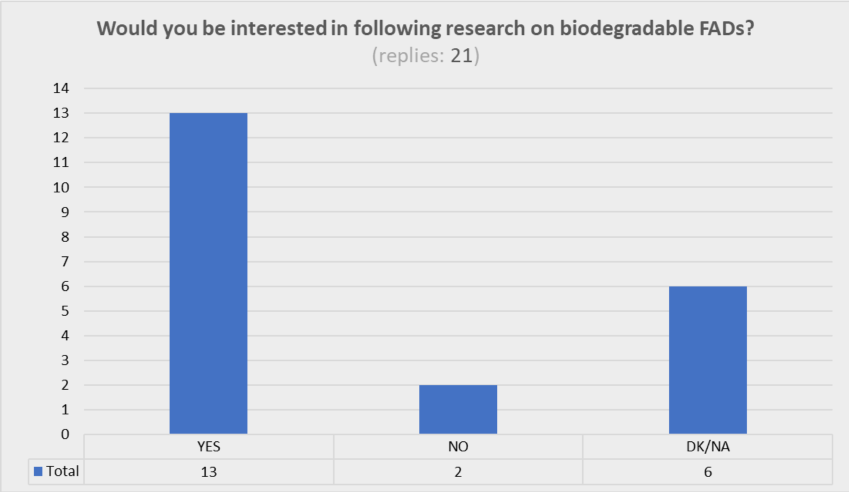


Figure 4.3.3.4.8. Eighth question of the questionnaire.

4.3.4. DIFFICULTIES AND RECOMMENDATION FOR FUTURE WORKS.

Difficulties:

Lack of industry related information for LCA:

The Consortium made sustained efforts through the organization of several meetings to obtain required information related to FAD components manufacturing data to conduct Sub-Task 3.3. However, some fishing companies showed reluctance to provide such data as they considered it sensitive information.

Lack of information regarding material's condition status:

Little information regarding the condition status of the submerged components was received from the EU PS. This was partly because only a few vessels lifted the FADs up during the operational activities, which made it difficult to gather data regarding the state of the submerged components. Note that many vessels do not generally lift conventional FADs either during fishing operations for various reasons. These include beliefs such as that when lifting FADs out it can cause structural stress and affect their longevity, when a FAD is taken out of the water the small community of bycatch fish that helps attract larger tuna will escape, or simply not wanting to spend the extra time it takes to lift a FAD. This information was required to conduct Sub-Task 3.3, however, and despite the Consortium evaluating the possibility of asking the PS fleet to lift at least the BIOFAD during activities at sea, no change was finally applied. Partly not to contribute to breaking or accelerating the degradation of the FAD structure due to the lifting procedure.

Recommendation for future works:

- Further efforts can be to obtain this key information and if necessary, a contract with the fishing companies can be signed agreeing on the way data can be used and confidentiality terms, so they are more inclined to share it.

- Program for a large enough fixed number of control material degradation samples to obtain a minimum number of samples to ensure reliability of the study.

4.4. TASK 4 - ASSESSMENT OF THE SHORT AND LONG-TERM SOCIO-ECONOMIC IMPACTS (INCLUDING THE FISHERIES ITSELF) OF REPLACING NEFADs WITH BIOFADs.

4.4.1. OBJECTIVES.

The international purse seine fleet maintains approximately 50 000 – 100 000 FADs world-wide at any point in time (Baske et al., 2012). The annual tracking buoy production for the five major buoy companies that supply this fishery has been estimated at between 47 500 – 70 000 units, further corroborating these estimates. Additionally, some estimates on the number of active FADs at any one time in the Indian Ocean are between 3 750 and 7 500 (Filmalter et al., 2013), while others calculated this number to be 5 700 in 2013 (Maufroy et al., 2014). Nearly 100 000 FADs are deployed by fishers every year in the world's tropical oceans (Moreno et al., 2016a).

Abandoned, lost and otherwise discarded FADs cause ghost fishing, damage sensitive coastal habitats and litter coastlines. The cost to the purse seine sector of abandoning drifting FADs and replacing them with new ones is thought to be much lower than the costs associated with having to retrieve them. Fuel expenses, lost fishing opportunities and provision of supply vessels to retrieve FADs over extensive areas would be main costs for FAD retrieval. Given the large numbers of FADs at sea, if not responsibly monitored and managed, lost and abandoned FAD structures can result in adverse ecological and socioeconomic effects (FAO, 2018).

The switch to NEFADs reduced partially one of the aforementioned effects, primarily avoiding entanglement of vulnerable species like sharks and turtles, but do not mitigate other problems. Now, the BIOFADs can reduce to a great extent several deleterious FAD effects (e.g., marine pollution, coral reef damage, etc.). However, the substitution of current plastic based NEFADs by BIOFADs involves an economic impact on the fleet that needs to be studied. The objective of this task is to assess socio-economic impacts of biodegradable FADs use and their phasing-in. Results from previous tasks are used to assess possible changes in costs and profits of replacing NEFADs by BIOFADs in the EU fleet. This includes a short- and long-term assessment of socio-economic impacts of the implementation of this new BIOFAD in the tuna purse seine fishery. Furthermore, potential market incentives (e.g., eco-friendly labelling, etc.) are explored to encourage the implementation of BIOFADs and the potential job creation linked to BIOFADs production.

To accomplish this, Task 2 is divided into the following sub-tasks:

- Sub-task 4.1 – Assessment of possible changes in cost and profit of gradually replacing NEFADs with BIOFADs

- Sub-task 4.2 – Identify potential market incentives (e.g., eco-friendly labelling, etc.) to encourage the use of BIOFADs
- Sub-task 4.3 – If feasible, assess the potential of BIOFAD production for job creation

4.4.2. METHODOLOGY.

This task is a desk-based work undertaken through three sub-tasks, as follows:

4.4.2.1. <u>Sub-task 4.1</u> – Assessment of possible changes in cost and profit of gradually replacing NEFADs with BIOFADs

With current practices and price materials, biodegradable FADs may be more expensive to make. However, a broader use of them may also lead to reduced cost (e.g., more manufacturers, price reduction for large orders), greater implementation and ultimately less/lower ecosystem impacts. The socio-economic implications of gradually replacing NEFADs with BIOFADs was assessed taking into account all these considerations. To successfully achieve this goal, researchers need detailed information on several socio-economic data: (i) data on the construction of FADs, (ii) cost of the use of FADs, (iii) and fishing efficiency of each type of FAD. Additionally, income data in terms of catch prices would be needed. The analysis of this last parameter (i.e., income data) was considered in aspects developed in sub-task 4.2. It was expected that fleets would provide the above mentioned data (data described in points i, ii, and iii) when necessary, following strict confidentiality rules.

4.4.2.2. Sub-task 4.2 – Identify potential market incentives (e.g., eco-friendly labelling, etc.) to encourage the use of BIOFADs.

Markets are constantly evolving, and some existing economic incentives could already be associated to the production and use of BIOFADs. Many tropical tuna purse seine companies are currently involved in fishery improvement projects (FIPs) with views to obtain an eco-certification (e.g., Marine Stewardship Council label), as these initiatives may show market advantages. This subtask aimed to investigate the impact of ecolabelling, or any other market incentives associated to the use of BIOFADs. For that purpose, market trends were taken into account to explore other initiatives that have been developed worldwide as potential examples.

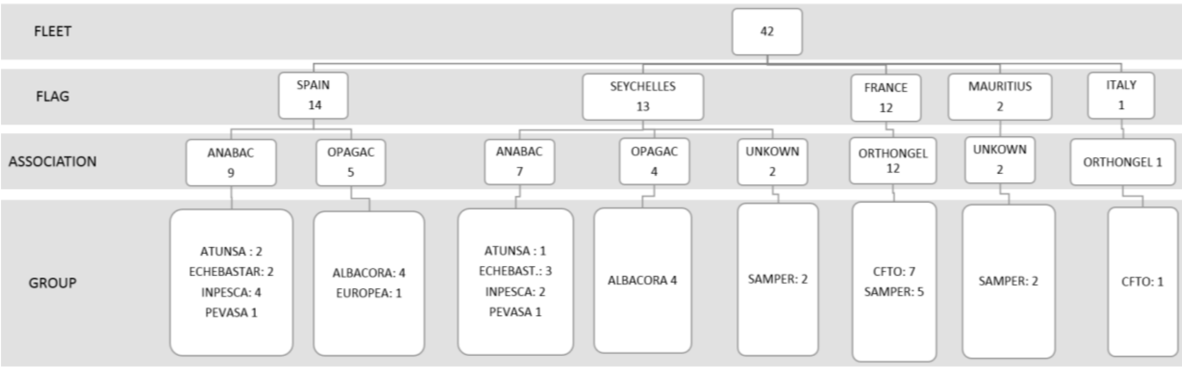
4.4.2.3. Sub-task 4.3 – If feasible, assess the potential of BIOFADs production for job creation

Although FADs used to typically be manufactured on board the purse seiner, many FADs nowadays are made on land. FADs are used worldwide, and not only by the EU fleet. The successful application and test of BIOFADs may provide robust designs and materials to be applied at the whole fleet level. Today, it is estimated that about 100,000 FADs are deployed annually worldwide. Here, we studied the potential economic impact of using BIOFADs worldwide and, tried to evaluate how BIOFAD implementation could impact the labor market (both qualitatively and quantitatively) in different regions of the world and Europe.

4.4.3. MAIN RESULTS.

The target fleet were 42 purse seiner vessels, that operate together with 12 supply vessels. The flags corresponding to that fleet are Spain (14), Seychelles (13), France (12), Mauritius (2) and Italy (1). All these vessels belong to 3 main associations: ANABAC, OPAGAC and ORTHONGEL (**Error! Reference source not found.**).

Table 4.4.3.1. Fleet description by flag, association and group.



The economic data was collected through the existing literature and a survey from the fishing owners. In order to simplify the process for the fishing sector, a sampling process was carried out in order to select just a representative sample from all the vessels involved in the current project.

For the sampling process the technical characteristics and fishing profile of all the vessel of each association were analyzed, by assessing how homogeneous were these characteristics.

To analyse the characteristic of the fleet, several databases were consulted:

- **Vessels by company**: Database that contains the target fleet by vessel name, flag, type of vessel, owner, group and association.
- **Vessels technical characteristics**: This database contains only data for OPAGAC and ANABAC.
- **Data Collection Regulation (DCR) AZTI**: This corresponds to data collected within the framework of the Data Collection Regulation by AZTI. This data contains technical characteristics of the vessels and catches (e.g., weight) by trip, position,

set and species. Note that this data base contains only a sample of the whole Spanish fleet with base harbor in the Basque Country and operating in the Indian Ocean.

- **Landings data by set**: Landing by species and set of Spanish and French fleets.

Additionally, technical data was requested to the involved associations, and they provided detailed data that was the input for the sampling process.

Are vessels of target fleets homogeneous?

Firstly, the gross tonnage (GT), length and power of the vessels by flag were examined. In order to analyse vessel characteristics, GT data was represented using boxplot figures. Boxplot is a graphical representation of the 5 quartiles (minimum, first quartile, median, third quartile, maximum). As Fig. A1 shows, there are large differences between vessels with different flags, then, vessels of both flags need to be sampled.

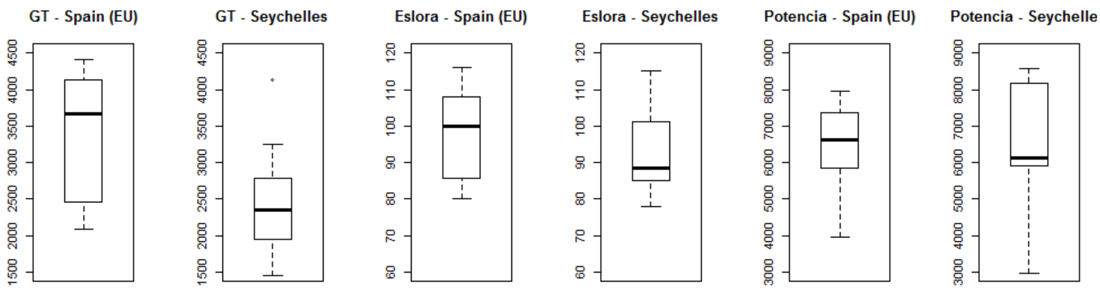


Figure 4.4.3.1. Technical characteristics (gross tonnage [GT], vessel length [Eslora] and horsepower [Potencia]) of the fleet.

The same representation was done with the GT, vessel length ('*eslora*'), and horsepower ('*potencia*') by flag and association. Differences between associations were also noticeable, therefore all associations needed to be sampled. When representing the GT boxplot by group, we could see how there were differences between the values of GT by group, so the sample should be done for all the associations.

Although in this report the data by vessel is not presented due to confidentiality issues, it has been analyzed. In some cases, there were strong differences in the fishing profile by vessel and also examined landings from 2014 to 2017.

The preliminary data analysis allowed a reduction in the number of vessels to be sampled. Following this, the sampling was grouped by vessels according to the group, association and in order of GT and horsepower. Then, a random number was assigned to each vessel. The selected vessels were those with a higher random number for each group. This process resulted in 15 randomly selected vessels from the 42 vessels involved in the project. Based on this selection economic data was requested to the ship owners but most of them refused to provide it.

4.4.3.1. ***<u>Sub-task 4.1 -</u> Assess possible changes in cost and profit of gradually replacing NEFADs with BIOFADs in the EU fleet***

<u>Understanding FADs dynamics</u>

Prior to explaining the methodology, FADs dynamics need to be understood. Considering that:

FADs deployed in year *Y*: number of deployments of FADs in the current year (*Y*). A deployment is registered when a new FAD is deployed at sea with an instrumented buoy.

FADs deployed, year *Y - y*: number of deployments of FADs in previous years *(Y - y), y = 1, …, Y-1.*

FADs used, year *Y*: total number of FADs used in year *Y*.

Reutilized FADs, year *Y*: number of FADs used in year *Y* that were deployed in year *Y* or year *Y - y*.

The number of FADs used in a year *Y* by a given fleet may have been deployed by the fleet itself or by other fleets. Additionally, taking into account the temporal dimension, used FADs may have been deployed[7] in the current year (*Y*) or in the previous years (*Y – y*; where *y = 1, … Y-1*). And there is another variable, the fleet may reutilize FADs that were already used by the fleet itself or by other fleets. The scheme of the deployment FADs and available FADs for their use is summarized in Table 4.4.3.1.1.

Table 4.4.3.1.1. Deployment and availability of FADs.

	Previous Years (*Y - y*)	**Current year (*Y*)**
FADs deployed by the fleet itself	A_{Y-y}	A_Y
FADs deployed by other fleets	B_{Y-y}	B_Y
Available FADs for use year *Y*	$C_{Y-y} = \%\ [A_{Y-y} + B_{Y-y}]$	$C_Y = [A_Y + B_Y]$
Used FADs in *Y*	$D = \%\ C_{Y-y} + \%\ C_Y$	

[7] A deployment is registered when a new FAD is deployed at sea with an instrumented buoy.

Considering the explained FADs dynamics, it can be said that additional costs for using BIOFADs instead NEFADs come from three different sources:

1. Costs of the **FAD itself**: The materials of BIOFADs are more costly than those of NEFADs.
2. Additional **component replacement costs**: Several components of BIOFADs have a shorter lifespan than NEFAD components. Thus, the replacement of elements for BIOFADs is more costly.
3. '**Loss of profits**' due to the more rapid disappearance of objects that will decrease the available FADs for use in a given year. The amount corresponding to the last row of Table 4.4.3.1.1. is expected to be lower for BIOFADs due to its intrinsic characteristics of biodegradability. But, at the same time, fleets could modify their behavior to achieve a better use of FADs.

Data and methodology

A specific simulation model was designed in order to analyze the costs and benefits of replacing NEFADs by BIOFADs. The time step of this model is on an annual basis and the time horizon is 10 years (i.e., the model will be projected 10 years onwards). The model is run in R (*R Core Team (2017)).*The scheme of the model is defined in **Error! Reference source not found.**

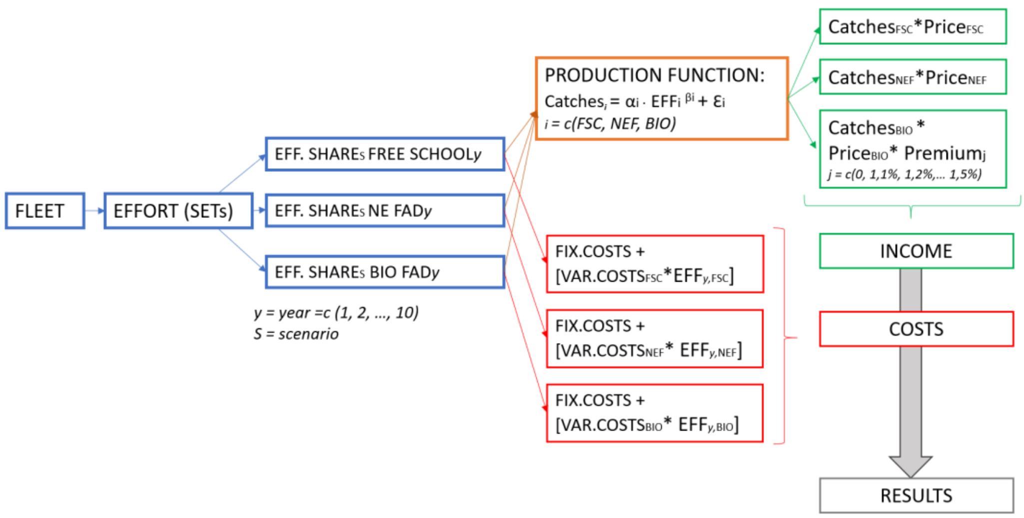


Figure 4.4.3.1.1. Scheme of the model to analyse the impact of the replacement of NEFADs for BIOFADs.

Fleet: The fleet is heterogeneous in technical characteristics and in catches. For that reason, a representative sample was selected to respond a questionnaire about costs, catches, prices, effort, etc. However, a really low level of responses was received and for that reason the economic related data was collected from the official databases of the public administration[8]. Additionally, some assumptions have been considered (Table 4.4.3.1.2.).

Table 4.4.3.1.2. Description of assumptions considered for the socio-economic analysis.

Item	Description	DATA	Assumption	Source
Landings (vessel)	Observed set Not by species: Species in general	Landings (weight) by vessel, species and set.	If there are any differences in catch composition by species depending on the FAD, it is not considered because we do not have the value by species.	IEO, IRD, AZTI data base and data from the BIOFADs project.
Price (vessel)	Average price Net sales/Total Landings	EUR/KG	The average net sales of the Basque Government Official Statistics of the are representative of the landing value of the tuna freezer vessel.	Basque Government Official Statistics and AZTI database and data collected during BIOFAD project.
Effort (vessel)	Effort will be split into effort allocated to FSC, NEFADS and BIOFADs	Number of sets by year and vessel.	All vessels behave as Basque vessels	IEO data base.
Variable costs (vessel)	Variable costs of fishing operations	EUR/Métier	All vessels behave as Basque vessels	AZTI database and Basque Government Official sStatistics and AZTI database.
Fixed Costs (vessel)	Average fixed costs by vessels	EUR/Vessel	All vessels behave as Basque vessels	Basque Government Official Statistics and AZTI database.
Cost of FADs components	Average costs by component	EUR/Component	Costs of data is the same for all vessels	BIOFADs project

Effort: The effort exerted by the fleet can be measured in many ways, but for simplification and in order to differentiate the effort exerted using NEFADs and BIOFADs, effort was defined as the number of sets (i.e., the unit of the effort is the set). The **effort share** is the percentage of the effort that is allocated to each métier, considering three métiers: Free school (FSC), NEFADs and BIOFADs. In principle, the plan was to test several replacement options in order to assess which one would be the best one. But, given the fact the replacement is established by regulation, the simulation was carried out according to the regulation. The IOTC Resolution 19/02 establishes the limitation of active buoys in

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8 https://www.euskadi.eus/estadistica/distribucion-de-la-flota-pesquera-por-subsectores-y-material-de-construccion-cae/web01-a2estadi/es/

300 buoys by vessel at any time from 2022 onwards. Additionally, each vessel can sum up 500 of buoys bought and stock from 2020 onwards. Furthermore, from 2022 onwards all FADs should be BIOFADs. In the simulation, the effort was shared between FSC and NEFADs from 2019 to 2021, and then, it will be shared between FSC and BIOFADs, according to the regulation that is described in Table 4.4.3.1.3.

Table 4.4.3.1.3. Number of buoys and FADs according to Resolution 19/02.

Average by vessel			
Data by vessel	**Number of buoys (acquired + stock)**	**Number of active BIOFADS**	**Number of active NEFADS**
2019	700	0	350
2020	500	0	300
2021	500	0	300
2022- 2029	500	300	0

Production Function: The **catch** production function determines catches. The selected function is Cobb-Douglas production function (Clark, 1990; Cobb and Douglas, 1928), where catches depend on the available biomass of the stock and the exerted effort. In the current study, economic data (i.e., price by stock), is not available by stock, then all the main target stocks (BET, SKJ and YFT) were considered jointly avoiding the biomass from the function, due to the fact the variation rates of one species could have offset those of the others. The production function was set at métier level. According to the data of the project, the average catches per métier, NEFADs and BIOFADs, were very similar (Figure 4.4.3.1.2.).

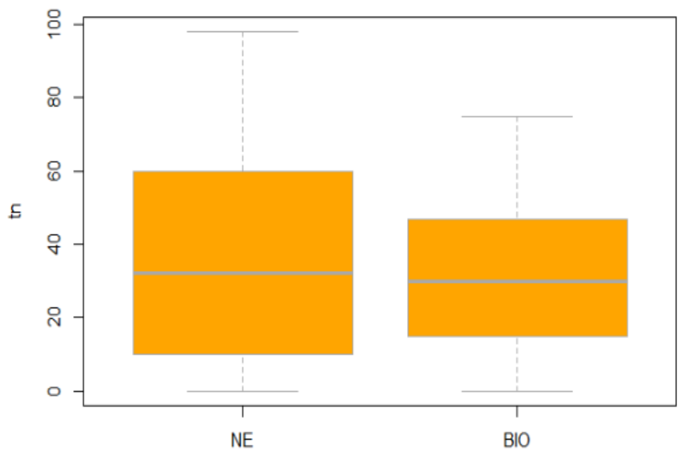

Figure 4.4.3.1.2. Boxplot of total catches by set from NEFADs to BIOFADs.

To test if the differences in the catches using NEFADs or BIOFADs were significative or not, an analysis of variance (ANOVA) was carried out. ANOVA is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyse the differences among group means in a sample. Considering the data of the sets using NEFADs and BIOFADs during the project, there was no significant differences (at 5% level) between medians when all stocks were considered jointly; the P value (0.808) was > 0.05. Thus, the catchability of NEFADs did not differ significantly from the catchability of BIOFADs.

```
ANOVA <- aov (Total tuna catches ~ FAD_type, data = sample data)
Summary (ANOVA)
              Df     Sum Sq        Mean Sq     F value      Pr(>F)
FAD_type      1      4.051e+07     40510887      0.06       0.808
Residuals     29     1.947e+10     671277155
```

The same analysis, but considering the different species, lead to the same results; there were not significant differences in catches between FAD types. Although the differences were not significant statistically, according to data from the project, NEFADs caught on average, 13% more than BIOFADs. Three scenarios were considered regarding the catchability:

Scenario C0: Catchability of BIOFADs = Catchability NEFAD; [Differential (13%) *0]
Scenario C1: Catchability of BIOFADs < Catchability NEFAD; [Differential (13%) *0.5]
Scenario C2: Catchability of BIOFADs << Catchability NEFAD; [Differential (13%) *1]

Income were estimated as catches multiplied by the fish price. In this case, several scenarios were run depending on the assumption of the price premium for using BIOFADs. According to the literature (see section 4.4.3.2.) the is not a clear evidence about what the price premium would be, it depends on the product, target market and other factors. In any case, the use of BIOFADs would help to achieve the sustainability labels, such as MSC, and it could have an effect on the price. In this study several scenarios were considered in order to analyze what should be the price premium to offset the additional costs of using BIOFADs instead NEFADs. In particular, a price premium from 0% to 10% was tested. This increase was enough to assess the necessary price premium to offset the additional costs of the use of BIOFADs.

Prices by species data were not available, it needed to be estimated. From the Basque Country official data on fisheries[9], we had the net sale value of the fishery (in those statistics, data of the cod fishery and tuna freezers fishery are presented jointly, so there is a bias in the net sales value for only tuna freezers). The net sale value has been divided by total catches for several years, resulting in an estimation of a price about 1.25 EUR/kg. Additionally, according to a ship owner that collaborated in the project, the average price

[9] https://www.euskadi.eus/pesca-cuentas-economicas/web01-a2estadi/es/

is 1.084 EUR/kg. Additionally, from the Annual Economic Report (STECF 19-06)[10], the average price is estimated as 1.9 EUR/kg. The weighted average of both prices (1.3 EUR/kg) were considered for the simulations.

Costs were differentiated between fixed and variable costs.

Fixed costs: were defined for the vessel and on an annual basis. These costs did not depend on the effort or activity of the vessel. From the Basque Country official data on fisheries[11], fixed costs were estimated at boat level (in those statistics, the cod and tuna freezers data are presented jointly, so there was a bias in the net sales value for only tuna freezers).

Variable costs: depend of the activity of the vessel, or on the level of effort exerted**.** Variable costs were defined for each métier and according to the experience of this project, it seems that variable costs are equal when using NEFADs and BIOFADs. The unique difference is the cost of the FAD itself. The BIOFAD was more expensive (206 EUR/BIOFAD) than a NEFAD (116 EUR/FAD), as Table 4.4.3.1.4. shows.

Table 4.4.3.1.4. Costs of NEFADs and BIOFAD. Data source: AZTI – BIOFADs project.

	BIOFAD (A1 MODEL)		**NEFAD**	
Material	**Units**	**Costs (Total EUR)**	**Unit s**	**Costs (Total EUR)**
Metallic frame [units]	-	-	11	2
Floating structure [units]	10	30	12	12
Canvas for cover [m]	3	24	-	-
Main ropes [m]	74	67	74	24
Rope - atractor [m]	30	27	30	10
Floats [units]	7	33	7	33
Ballast weight [kg]	-	-	-	-
Twine to tie [kg]	-	-	-	10
Labour		25		25
Total		**206**		**116**

[10] Scientific, Technical and Economic Committee for Fisheries (STECF): The 2019 Annual Economic Report on the EU Fishing Fleet (STECF 19-06), Carvalho, N., Keatinge, M. and Guillen Garcia, J. editor(s), EUR 28359 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-09517-0, doi:10.2760/911768, JRC117567.

Logically, BIOFAD components degrade faster than NEFAD components, thus, there is an additional replacement cost for BIOFADs. To estimate the additional component replacement costs, from Table 4.3.3.3.1. it has been estimated that additional replacement costs for BIOFADs sum up 212 EUR/FAD (Table 4.4.3.1.5.). However, the additional replacement costs will not be applied to all used FADs but only to those FADs that are used after the minimum period of replacement, in this case 4 months. Assuming that the FADs are used homogeneously along the year, we assigned replacement costs to the 33% [(4 months/12 monthsx100] of the used FADs.

Table 4.4.3.1.5. Replacement frequency and costs of the FAD components over a 1-year period. Data source: BIOFADs project.

Component		**Bamboo**	**Metallic structure**	**Canvas**	**Main rope**	**Rope attractor**	**Floats**	**Total costs in EUR**
Replacement for BIOFADs	Month replacement	> 12	-	4	5	5	> 12	
	Cost by component (EUR)	30		24	67	27	33	
	Applied factor	None	None	x 3	x 2	x 2	None	
	Total cost by year (EUR)	**-**	**-**	**72**	**134**	**54**	**-**	**260**
Replacement for NEFADs	Month replacement	> 12	> 12	> 12	5	> 12	> 12	
	Cost by component (EUR)	-	2	-	24	10	33	
	Applied factor	None	None	None	x 2	None	None	
	Total cost by year (EUR)	**-**	**-**	**-**	**48**	**-**	**-**	**48**
Additional replacement costs of BIOFADs (EUR)								**212**

The number of new FADs (average by vessel) was estimated at 550[12] by year. The number of deployed FADs by vessel was estimated at 726[13]. We know the number of buoys that, according to the IOTC regulation (Resolution 19/02) a vessel is able to buy. But, the number of FADs is not necessarily equal to the number of buoys because sometimes, for example, the buoys are attached to natural floating objects. Then, it is assumed that the number of FADs that each vessel built in one year is 10% less than the number of used buoys. The price of each buoy has been estimated as 1000 EUR/buoy.

Scenarios

Several scenarios have been tested depending on the price premium and catchability (Table 4.4.3.1.6.). Regarding the catchability, this has been explained in the previous section. The price premium considered goes from 0% to 10%, because with a premium of 10% is enough to know how much the price is needed to be increased to offset the additional costs of using BIOFADs.

Table 4.4.3.1.6. Definition and acronyms of scenarios

Scenarios	**Catchability**		
Price premium (%)	**C0**	**C1**	**C2**
P0 = 0	C0_P0	C1_P0	C2_P0
P1 = 1	C0_P1	C1_P1	C2_P1
P2 = 2	C0_P2	C1_P2	C2_P2
P3 = 3	C0_P3	C1_P3	C2_P3
P4 = 4	C0_P4	C1_P4	C2_P4
P5 = 5	C0_P5	C1_P5	C2_P5
P6 = 6	C0_P6	C1_P6	C2_P6
P7 = 7	C0_P7	C1_P7	C2_P7
P8 = 8	C0_P8	C1_P8	C2_P8
P9 = 9	C0_P9	C1_P9	C2_P9
P10 = 10	C0_P10	C1_P10	C2_P10

Indicators

To analyse the results, three indicators have been selected.

1. **Revenue percentage change:** This indicator assesses the variation rate of the revenues (revenue includes landing income and other income) in a base case scenario against the rest of scenarios:

$$REV\ VR = \frac{REV_{\ SCENARIO\ i} - REV_{\ BASE\ CASE\ SCENARIO}}{REV_{\ BASE\ CASE\ SCENARIO}}$$

[12] Own estimation.

[13] Data collected by FAD Logbooks.

Where;

i = 1, …33. Scenarios

CF = cash flow

Scenario base = There is not replacement from NEFADs to BIOFADs.

2. **Costs percentage change**: This indicator assesses the variation rate of the costs in a base case scenario against the rest of scenarios:

$$COSTS\ VR = \frac{COSTS_{\ SCENARIO\ i} - COSTS_{\ BASE\ CASE\ SCENARIO}}{COSTS_{\ BASE\ CASE\ SCENARIO}}$$

3. **NPV percentage change**: The net present value (NPV) of the cash flow of all projected years. The discount rate (the rate of return used to discount future cash flows back to their present value) is assumed to be 5%.

$$NPV\ VR = \frac{CF_{\ SCENARIO\ i} - CF_{\ BASE\ CASE\ SCENARIO}}{CF_{\ BASE\ CASE\ SCENARIO}}$$

Results

The maximum decrease of revenues for replacing NEFADs by BIOFADs was 9%, when there was no price premium and the catchability of BIOFADs was lower than that of NEFADs. But if the price premium of 10% occurs and the catchability of BIOFADs equals NEFAD catchability, the revenues could increase by 10%.

The additional costs that the fleet would support for replacing NEFADs by BIOFADs was estimated as 1.05% due to the additional costs associated to the BIOFADs.

The minimum price premium needed to offset the additional costs of using BIOFADs depends on a set of scenarios (Figure 4.4.3.1.7.).

- If the catchability of BIOFADs = Catchability of NEFADs, then the necessary price premium to offset the additional costs of BIOFADs would be a price premium of approximately 1%.
- If the catchability of BIOFADs < Catchability NEFADs, then the necessary price premium to offset the additional costs of BIOFADs would be a price premium of approximately 5%.
- If the catchability of BIOFADs << Catchability of NEFADs, then the necessary price premium to offset the additional costs of BIOFADs would be a price premium of approximately 10%.

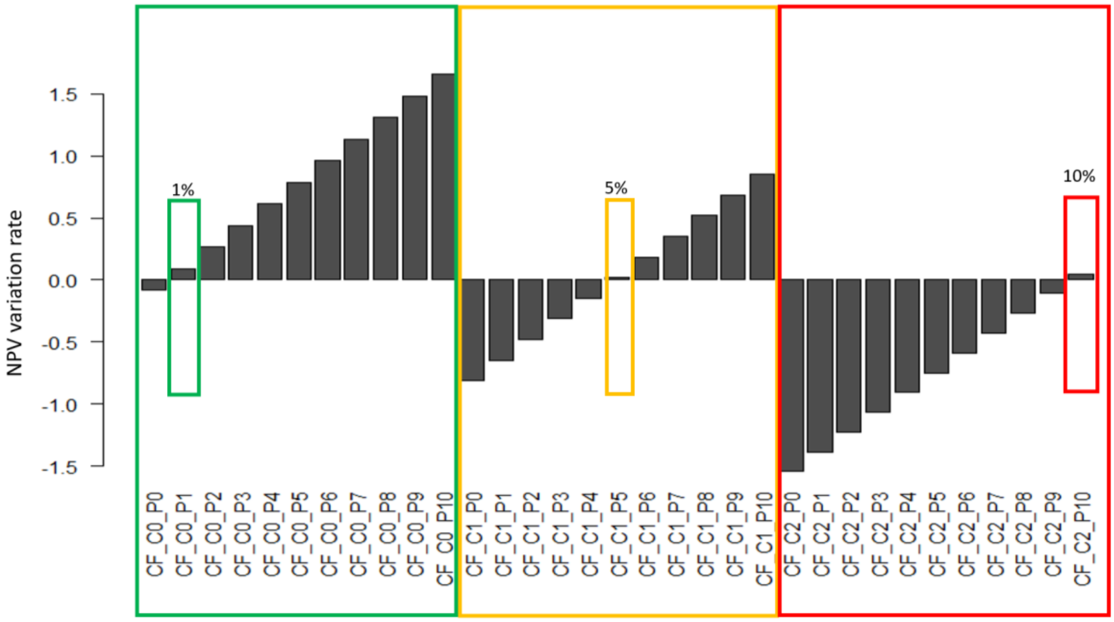

Figure 4.4.3.1.7. NPV variation rate

Representativeness

The representativeness of the model would have been improved if we had received more responses from the survey carried out to the selected representative sample. But the low level of responses drove us to seek data from the official statistics and literature. Collected data was showed to the involved stakeholder during the 3rd BIOFAD workshop and there were no objections, which seems to at least to confirm the representativeness of data. In any case, in this section the rationale of the representativeness is explained. In particular, the costs of NEFADs and BIOFADs are the same for all vessels. Catchability by each typology of FAD has been estimated using data from IEO for the whole Spanish fleet participating in the project, and it has been compared against the catchability of French fleet given by IRD, being approximately equal (FAD catches by unit of effort resulted from IEO data 36 tn/set; from IRD 34 tn/set). The effort share of both data sources is also similar (FAD effort share from IEO data is around 93% while FAD effort share from IRD data is around 90%).

The first sale price estimated from the Basque Country official statistics is in line with the only response received by a shipowner, and the price estimated from the Annual Economic Report (AER) is higher. Thus, a weighted average of all those values was used. Additionally, in a global market as is the tuna market it is logical to assume that the price for the rest of the European fleet should be similar. There is a difference between both data sources but given that the first one was contrasted with stakeholders and due to the fact that it is more in line with the received response, a greater weight was given to contrasted figures.

Operational costs of the fleet are related to the Basque statistics, which represent the whole Spanish fleet because 96% of the Spanish vessels belong to Basque companies. Spanish and French vessels use the same technology and the fleet segment is similar. Therefore, it could be assumed that operational costs of Spanish vessels will be representative of the whole Indian Ocean fleet, although obviously there will be some bias.

Regarding the effort dynamics it was conditioned by the new regulation on the FAD limitation (IOTC Resolution 19/02), that affects equally all fleets. Finally, note that the model is not spatially explicit, so spatial variability was not taken into account.

Sensitivity analysis

It is desirable to assess to what extent the assumptions taken are robust or the impact of biological-market uncertainties affect the results. From the market perspective, two additional scenarios has been simulated: in the first one, the maximum price given by the AER 2019 of 1.9 EUR/kg was considered, and in the second one, the minimum required price that in the base case scenario by equalling the landing value and operational costs (1.22 EUR/kg). The estimated gross profit for each scenario was estimated. As Fig. 4.4.3.1.8. shows, the result of the fleet is sensitive to the tuna price or market and also to the catchability. In general terms, the gross profit will be positive if the average price by kilogram of the tuna is equal or higher than 1.22 EUR/kg, except for those scenarios related to C2, where the catchability of BIOFADs were 13% lower than NEFADs.

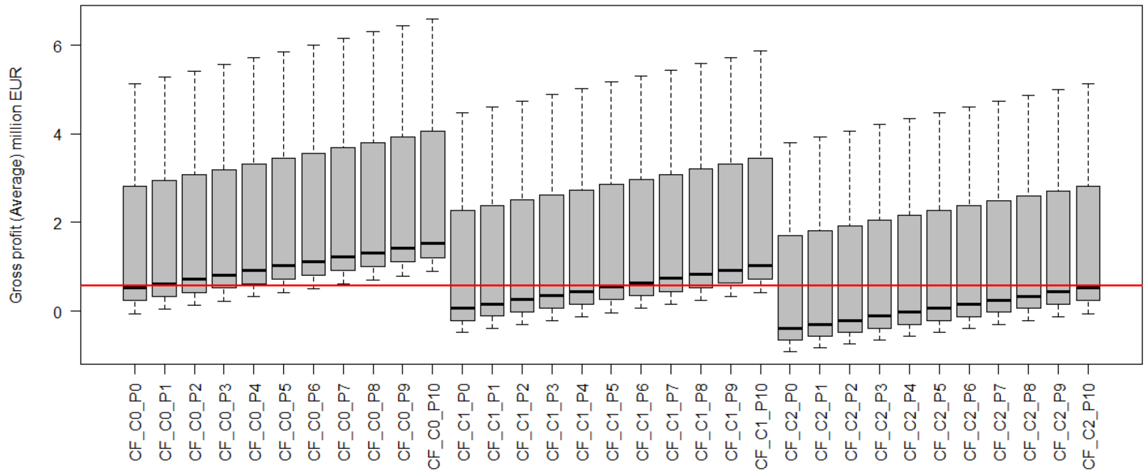

Figure 4.4.3.1.8. Gross Profit (average by vessels and year) by scenario. The rede line is the gross profit of the Base Case scenario.

From a biological perspective, no biological dynamics were included and the model did not consider the species separately.

Some additional figures

The implementation of BIOFADs could decrease the income from 0% to a 9% depending on the scenario, due to the potential decrease of catchability. But, if the catchability does not vary and there is a price premium, the income can increase until the percentage that this price premium represents over the price of the base case scenario. Regarding the gross profit[14], if the price does not change, the vessels will support a decrease of gross profit from 9% to 162%, depending on the catchability variation. A price premium of 1% can offset the gross profit decreases in the case of C0 related scenarios. On the contrary, for C2 related scenarios, the gross profit offset is not achieved even with a price premium of 10%; and in the case of C1 related scenarios, the gross profit becomes negative if the price premium is lower than 6%.

The replacement of the NEFADs by BIOFADs can reduce the gross profit margin. The gross profit margin is a measure of profitability that can be used to analyse how efficiently a sector is using its inputs to generate profit. It is calculated as the ratio between gross profit and revenue and expressed as a percentage. Gross profit margin indicates the normal profitability of a firm and is of most interest to fishers, as it represents the share of income they are left with at the end of the year. In the base case scenario, the average gross profit margin is 5.6%, while in the other scenarios without no price premium the gross profit margin ranges from 5.1% to -4.1%.

4.4.3.2. Sub-task 4.2 - Identify potential market incentives (e.g., eco-friendly labelling, etc.) to encourage the use of BIO FADs

The purse seiner fleet that operates in the Indian Ocean decides to invest in biodegradable FADs to address the commitment by the European Commission and different tRFMOs of reducing FAD ecological impacts. Together with the reduction of ecological impacts associated with regulatory bodies, this investment decision could also be related to market incentives for fishing companies such as an access to a new market or a price premium. The first thing needed to identify potential market incentives is analyze the tuna market. Then, identify the market incentives that the investment on BIOFADs can achieve. Finally, the tuna market incentives will be traduced in a potential price premium that was incorporated in the income assessment of the Sub-task 4.1. After, the output of the current task fed the model of the cost-benefit assessment.

[14] – Gross profit: the normal profit after accounting for operating costs, excluding capital costs. Also referred to as gross cash flow, i.e. the flow of cash into and out of a sector or firm over a period of time.

Tuna products are extensively traded in a global tuna market that is integrated by price among the world's major markets for landed tuna (Guillotreau et al., 2017). Two main products drive tuna production: traditional canned tuna and sashimi/sushi (Polanco, 2016). These products demonstrate relevant differences in terms of the species utilized, quality requirements and production systems. In the canned market, light meat species – namely skipjack and yellowfin tuna – are dominant, whereas in the sushi and sashimi market, the fatty meat of bluefin tuna and other red meat species like bigeye tuna are preferred. The canned tuna industry is entirely supplied by the wild fishery. For the sushi/sashimi sector, tuna ranching of bluefin tuna has emerged as a supplier in the last two decades, supplying somewhere around 20 percent or less (Polanco, 2016).

The major markets for canned tuna are the USA, the EU, Egypt, Japan and Australia. However, consumption in the last decade has stagnated in the EU and the USA and has increased only moderately in Japan. Consumption is growing in the less traditional markets of Latin America and the Near East, where the volume of imports has risen by around 50 percent in the last five years. According to FAO (Polanco, 2016), markets for tuna products continue to increase based on the growth of consumption in new regions of the world and the dissemination of sushi as a global dietary trend. The traditional markets show signs of maturation but still represent a significant and profitable volume for business. Growing interest is focused on developing new value-added products, which may help increase margins for the sector in the likely scenario of growing raw material prices.

The purse seine/cannery-grade market is now under more careful scrutiny by environmental non-governmental organizations (NGOs), for example, the see the recent support for a ban on FAD-caught tuna in the UK canned tuna market. Retailers are now very concerned by such claims, since the USA banned the import of tuna in the early 1990s that were caught in the Eastern Pacific Ocean associated with dolphins (Guillotreau et al., 2017). Eco-labeling and tuna products certified for seafood sustainability are growing in importance at the retail level, with responses throughout the supply chain to satisfy this market demand. A large number of tuna fisheries are currently undergoing MSC certification processes. Certification, not just by MSC, is growing in importance to gain access to certain markets, although there may not be a commensurate increase in price even though certification is costly.

Producers' initiatives being certified under defined environmental and social-welfare production standards are increasingly popular. These initiatives could create financial incentives for producers to improve their environmental, social, and economic performance (Blackman & Rivera, 2011). Finally, tuna markets show a quite responsive (flexible) market in prices: a global reduction of landing for cannery-grade tuna species (e.g., because of quota restrictions) would be compensated by a comparable relative increase in prices, leaving fishers' revenue unchanged on the global scale (Guillotreau et al., 2017). However, fishers respond poorly to price differences between species to target the most valued one: catch yields still matter far more than prices and values.

Consumers' demand is rather price inelastic in Europe, but not so much in the USA, and particularly for eco-friendly products (Guillotreau et al., 2017). There are economic incentives for supermarkets to offer a lower retail price and continue to source cheaper skipjack tuna caught on FADs, thus putting additional pressure on the marine environment. In natural and organic product supermarkets, in contrast, eco-friendly canned albacore tuna is estimated as a luxury good for which demand increases more than proportionally as income rises, and its own-price elasticity is wide; for which price increases would lead to a more than proportional decrease in quantity demanded and therefore a decrease in sales revenue. Consumer demand for canned tuna varies depending on the species, whether it is sold in an organic shop or conventional supermarket, and whether it is considered a conventional or eco-friendly product.

The question is: could there be a price premium that will compensate in some extent the investment on BIOFADs for vessel owners?

In the literature we can find several examples about willingness to pay for eco-labelled wild seafood. There is ample evidence from stated preference surveys and field experiments showing that consumers express a preference for eco-labelled seafood (Blomquist et al., 2015). The price premium can go from 4.6% to 5.5%. The price premium of organic salmon in Danish retail sale, for example, reached a 20% (Ankamah-Yeboah et al., 2016; Blomquist et al., 2015). At retail level MSC-certified frozen processed Alaskan pollock gets a price premium of 14.2% (Ronheim et al*.,* 2011). Other studies indicate that MSC premiums in Germany vary substantially between species, from a hefty 30.6% for the high-end cod species, to a 4% premium for Alaska pollock, and no premiums for saithe (Asche and Bronnmann, 2017). In the canned tuna trade, branding is estimated to generate a 20% price premium approximately. In the case of the tuna, the willingness to pay for eco-labelled tuna ranged from 24% (eco-labelled tuna in Japan) to 103% (eco-friendly canned tuna in USA); some differences were related to the brand, and the "eco-friendly" canned tuna registered the highest value, compared to the "dolphin safe" (ranged from 31% to 63% in USA) and the eco-labelled ones (Vitale et al., 2017). According to Guillotreau et al. (2017), around 15% of canned tuna sales in the Natural Supermarkets Channel were identified as eco-friendly albacore tuna, where consumers demonstrated a willingness to pay $6.45 (US dollars) per pound premium over the conventional canned albacore tuna. However, price premiums may be evidenced more in processed/canned/frozen products than in fresh/wet products (Macfadyen and Huntington, 2007).

Studies of price premiums at the producer level are few. Producers will respond to higher prices and/or market access by altering their production methods only if the prices the producers receive in raw materials markets increase revenues (Chin-Hwa et al., 2017). After a certain degree of initial hype and promotion, it is now generally recognized that most eco-labeling in the tuna industry is more likely to result in providing producers improved market access and not attract price premiums. Some studies, like that ofNimmo and Cappell (2014) conclude that there are no price premiums attributable to MSC certification at first point of sale. Other studies (EUMOFA, 2016) indicate that plaice under MSC allows a price premium for fishermen (about 0.10 EUR/kg - ~ 5%). In the grey literature we can find some data about the 'potential' price premium for producers, for example, some MSC certified fisheries have seen prices of their products that are 10% to 45% higher than prices of seafood caught by non-certified fisheries, according to MSC[15]. Another study concluded that after the MSC certified a US albacore tuna (*Thunnus alalunga*) fishery in the Pacific in 2007, the price fishermen received increased by 32% (Pope, 2009; Christian et al., 2013).

In conclusion, it is not clear that a price premium would exist at producer level when substituting NEFADs by BIOFADs. In the hypothetical case that there would be a price premium, the amount would be still uncertain. In this study we have done the economic analysis considering several scenarios in which the price premium ranges from 0% (no price premium) to a maximum price premium of 10%. The maximum value has been selected in order to identify what should be the price premium that is needed to cover all additional costs of use BIOFADs instead of NEFADs. However, the price premium due to the ecolabels may be even higher.

It should be taken into account that prices depend not only on the certification labels, but also on the amount of the tuna in the market. A 1% increase in the quantity of canned tuna would result in a 2.58% decrease in its normalized price (García del Hoyo et al., 2010). Then, if the use of BIOFADs impacts the amount of catches, it will also have an impact on the price. But note that the tuna market is a global market, thus, this statement can be met only if applied at a global level. Additionally, markets higher in the supply chain are vertically integrated and display concentration with a limited number of companies. Canning industry competitiveness is also sensitive to trade restrictions and policies (Guillotreau et al., 2017).

[15] https://www.seafoodsource.com/news/supply-trade/msc-label-could-bring-price-premium-to-spsg-mackerel

4.4.3.3. Sub-task 4.3 - If feasible, assess the potential of BIO FADs production for job creation

In principle, the number of workers involved in the NEFADs and BIOFADs are the same and labor costs of both types of FADs are the same. However, the location of each component can vary depending on the type of FAD. Additionally, given the shorter lifespan of BIOFADs, the component needs to be replaced more often, impacting positively in the employment of the several regions (Spain, Madagascar or Seychelles). It is estimated that with BIOFADs, on average the labor costs due to higher component replacements would increase from 24% to 34% when using BIOFADs and therefore, the employment would also increase.

Conclusion

- Understanding FADs dynamics is key to assess the economic impact of the replacement of NEFADs by BIOFADs. The number of FADs built, the number of deployments, the period from the deployment to the end use of the FAD and the strategy of the fleet when the number of available FAD decreases will impact in the economic performance of the replacement.
- It is estimated by some scenarios that the FAD type replacement will drive an increase in costs of 1.05%.
- The revenue depends on the efficiency of the object (i.e., catchability) and on the potential tuna price premium.
- If the catchability of BIOFADs equal catchability of NEFADs, then the necessary price premium to offset the additional costs of BIOFADs is of approximately 1%.
- If the catchability of BIOFADs is lower than that of NEFADs, then the necessary price premium to offset the additional costs of BIOFADs is of approximately 5%.
- If the catchability of BIOFADs is much lower than that of NEFADs, then the necessary price premium to offset the additional costs of BIOFADs is approximately 10%.
- In the base case scenario, the average gross profit margin is 5.6%, while in the other scenarios, without no price premium, the gross profit margin ranges from 5.1% to -4.1%.
- There are some studies that concludes that there are no price premiums attributable to MSC certification at first point of sale, only better access to more markets. Other studies indicate that there can be a price premium. The uncertainty about the price premium is high.

- The labour costs to produce FADs are the same for both, BIOFADs and NEFADs.
- But in the case of BIOFADs the components need to be replaced more often, which means an increase from 24% to 34% of labour costs for BIOFADs.

4.4.4. DIFFICULTIES AND RECOMMENDATION FOR FUTURE WORKS

Difficulties:

Lack of industry related information for the socio-economic analysis:

The economic data required to conduct this analysis proved difficult to obtain due to the reluctance of fishing companies to share this sensitive information. Thus, an agreement signed with each fishing company/association to establish the terms of data use and confidentiality would be useful. Where fishing companies fail to provide such data, it should be gathered from open source official data from the public organisms.

Recommendation for future works:

- Improvements in knowledge of FAD dynamics in terms of spatial and temporal parameters, in order to understand the use of FADs by the fleets that will impact directly to the economic performance of the fishery.
- Assessment of potential impacts of the different FADs on target species and its implications in the fleet due to the biomass variations.
- Improve data collection at set level by each type of FAD to increase data availability to assess the catchability of each FAD type.

4.5. TASK 5 - RECOMMENDATION AND BIOFAD PROTOTYPES

4.5.1. OBJECTIVES

For this task, we assessed the feasibility of using new biodegradable materials by the tropical tuna purse seine European fleet in the Indian Ocean and recommended several optimum BIOFAD prototypes, on the basis of the results from previous tasks.

4.5.2. METHODOLOGY

This task was a desk-based work. The feasibility of using new biodegradable materials by the European fleet was assessed on the basis of the results obtained from the previous tasks.

The final outputs from the completion of Task 1 to 4 as well as the conclusions obtained from the final workshop, were used to recommend optimum BIOFAD prototypes.

4.5.3. MAIN RESULTS

Based on previous tasks results, the feasibility of using new biodegradable materials by the European fleet, as well as the performance of different tested prototypes was assessed. The final goal was to recommend the optimum BIOFAD prototype and compare it with currently used NEFADs. However, and according to the results shown in the document, each tested prototype and material can provide different features that improve FAD performance in general. This can to some extent prevent the Consortium from providing a unique and optimum BIOFAD. However, it indicates which could be the appropriate modifications that non-entangling and biodegradable FADs might follow. Thus, each of the parameters measured during the project were analyzed separately to provide an accurate picture of the prototypes' performance. In the following tables analyzed features in NEFADs and BIOFADs are summarized including the main result:

Table 4.5.3.1. BIODEGRADABILITY: The total amount of material and its biodegradable fraction used in the construction of different FAD prototypes was assessed by FAD type (BIOFAD and NEFAD) regarding the total weight.	
BIOFAD	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% of used material, respectively. This represents a reduction of 54 kg, 61kg and 6 Kg of material in each of them, respectively. Besides the decrease in the total amount of material used in their construction, the use of biodegradable material increased significantly. Prototype A1 used around 48kg (66% of total weight) of biodegradable material, prototype A2 used around 36 kg (61%) and B2 used 37kg (46%) of biodegradable material. BIOFAD prototypes B1 and C1, increased the weight of total amount of used material (27% and 1%, respectively) in comparison with their equivalent NEFADs. This represents an increase of 17 kg and 0.5 kg. Despite the increase of total weight in B1 and C1 BIOFAD prototypes, the use of biodegradable material in prototype B1 is around 48kg (60%) and in prototype C1 31 kg (66%) while their equivalent NEFADs used 0% and 26% of biodegradable materials respectively.
NEFAD	NEFAD 1 and 4 used 9% and 26% of biodegradable material in their construction, while NEFAD 2 and NEFAD 3 used 0% of biodegradable materials. Only NEFAD 2 and NEFAD 4 used less material in their construction than their equivalent BIOFAD prototypes.
OPTIMUM PROTOTYPE	Most of the BIOFAD prototypes significantly contribute to the reduction of the total used material weight in FAD construction. All the BIOFAD prototypes increase the use of biodegradable material in the FAD construction. Prototype A1 with a reduction of 44% of total used material and an increase of 65% of the biodegradable fraction used in the construction seems the optimum prototype according to these parameters. Prototype C1 is also a good candidate as the prototype using less total material and an increase of 65% in the biodegradable fraction.

Table 4.5.3.2. PLASTIC COMPONENTS: The plastic fraction of the total material used in the construction of different FAD prototypes was assessed for both FAD type (BIOFAD and NEFAD). Table 4.2.3.2.7. developed in the Task 2 was used to estimate the amount of plastic material at each prototype in regard to the total weight.	
BIOFAD	All BIOFAD prototypes reduced the amount of synthetic materials used for their construction in a range of 40-81% with respect to their NEFAD equivalent. The amount of plastic fraction also decreased and BIOFAD prototypes used plastic materials that correspond to 14-20% of their total weight. These plastic materials in BIOFADs correspond to the floats and the twine to tie the raft. Prototype A1, the most used prototype by the fleet, required 81% less synthetic materials than its equivalent NEFADs. The plastic fraction with 9.4kg represent 14% of the total weight. In A2 the reduction of synthetic material was around 81% and the plastic fraction 16%. In B1 the reduction of synthetic material was around 12% and the plastic fraction 16%. In B2 the reduction of synthetic material was around 40% and the plastic fraction 14%. In C1 the reduction of synthetic material was around 54% and the plastic fraction 20%.
NEFAD	All NEFAD prototypes used more amount of synthetic materials for their construction than their equivalent BIOFADs. The plastic fraction represents between 47 to 60% of the total weight. This plastic portion is mainly the result of using plastic derived netting materials for the hanging part of the FAD.
OPTIMUM PROTOTYPE	All the BIOFAD prototypes significantly contribute to the reduction of the synthetic material in FAD construction. All the BIOFAD prototypes decreased considerably the use of plastic material in the FAD construction. Prototype A1 with a reduction of 81% of synthetic material and the use of plastic fraction around 14% of the total weight seems the optimum prototype according to these parameters. Prototype A2 is also a good candidate as this prototype reduced by 81% the synthetic materials and the plastic fraction represented 16% of its total weight.

Table 4.5.3.3. FLEET PREFERENCE: The results of the questionnaire sent to the fleet was used to assess the preference of the fleet for one or more prototypes. This questionnaire recompiles important information regarding prototype preference, reasons for a preference, efficiency of prototypes, etc.	
BIOFAD	All the BIOFAD prototypes were marked as good or/and fair by most of the fleet to the question about defined prototypes, with A1 and A2 prototypes receiving the most positive feedback Regarding the most accepted prototypes option A1 followed by the prototypes A2 and C1 obtained the best rating. Regarding the fishing efficiency the fleet marked the majority of the BIOFAD prototypes as fair or bad with only prototype A1 receiving a significant response valuing it as "good".
NEFAD	No reference to the NEFAD was provided in the questionnaire sent to the fleet.
OPTIMUM PROTOTYPE	Despite most of the prototypes being valued as good or fair, only prototype A1 obtained the best rating when the prototypes were assessed according to their fishing efficiency by the fleet.

Table 4.5.3.4. DEGRADATION: The degradation rate shown by the biodegradable material and their synthetic alternative material was assessed based on the report provided by the fleet.	
BIOFAD	COTTON CANVAS: This material showed high degradation from the first month at sea, with more than 60% of the observations valuing the state of the cotton canvas as in very bad condition or absent during the fourth and fifth month at sea. COTTON ROPE_1 used as tail: This material showed low degradation in the first 6 months at sea. More than 50% of the observations valuing the state of the cotton rope as in very good or good conditions. The observations marked as absent are more related to problems in FAD construction than the degradation of the material. COTTON ROPE_2 used as attractor: This material showed low degradation in the first 6 months at sea. More than 50% of the observations valuing the state of the cotton rope with loops as in very good or good conditions. The observations marked as absent are thought to be more related to problems in FAD construction than the degradation of the material.
NEFAD	SYNTHETIC CANVAS: This material showed low degradation in the first 6 months at sea. Around 50% of the observations valuing the state of the synthetic material canvas as in very good condition. SYNTHETIC MATERIAL used as tail: The synthetic net material used as main tail component showed a degradation rate similar to its biodegradable alternative. SYNTHETIC MATERIAL used as attractor: The synthetic material used as attractor showed a lower degradation rate than its biodegradable alternative.
OPTIMUM PROTOTYPE	The two cotton ropes are good candidates to replace the synthetic materials used currently in FAD construction for the hanging tail part. The degradation rates shown by these two biodegradable materials do not differ much from those shown by the synthetic alternatives.

Table 4.5.3.5. CATCH: The catch data regarding the number of sets and total tuna caught was assessed by FAD type (BIOFAD and NEFAD) and prototype.	
BIOFAD	BIOFAD prototypes had 36 sets: 26 sets on A1, 5 sets on A2, 2 sets on B1 and 2 sets on C1. These values could be affected by the number of deployments of each prototype. BIOFAD prototypes had a mean tuna catch of 27.96 tons: a mean value of 32.2 tons in A1 and a mean value of 40 tons in A2 (B1 and C1 information was not available to the Consortium).
NEFAD	NEFAD prototypes had 32 sets: 21 sets on A1, 8 sets on A2 and 3 sets on C1. These values could be affected by the number of deployments of each prototype. NEFAD prototypes had a mean tuna catch of 44.2 tons: a mean value of 29.38 tons in A1, a mean value of 76 tons in A2 and a mean value of 67 tons in C1.
OPTIMUM PROTOTYPE	BIOFADs obtained more sets than NEFADs. However, there were no significant differences between both FAD types. Then, the catchability of NEFADs did not differ, significantly, from the catchability of BIOFADs. Although the differences were not statistically significant NEFADs caught 13% more than BIOFADs. Prototypes A1 and A2 are likely the optimum prototypes according to these parameters. A1 with highest number of sets and A2 with highest mean catch value among all tested BIOFAD prototypes.

Table 4.5.3.7. FIRST DETECTION AND FAD OCCUPATION BY TUNA: Tuna Presence/Absence data was used to assess the colonization time and lifetime of the aggregation by FAD type (BIOFAD and NEFAD).	
BIOFAD	BIOFADs had a median value of 35 days for first detection of tuna. Regarding BIOFAD prototypes A1 had a median value of 17 days, 47 days in A2, 54 days in B1 and 4 days in C1. Regarding tuna presence in 53% of the cases, both pairs showed presence of tuna; in 13% of the pairs both, BIOFADs and NEFADs, did not show any presence of tuna; in 21% of the cases NEFADs had presence of tuna while its BIOFAD pair did not and; in 13% the opposite pattern was observed.
NEFAD	NEFADs had a median value of 35 days for first detection of tuna. Regarding NEFAD prototypes A1 had a median value of 20 days, 44 days in A2, 33 days in B1 and 12 days in C1. Regarding tuna presence in 53% of the cases, both pairs showed presence of tuna; in 13% of the pairs both, BIOFADs and NEFADs, did not show any presence of tuna; in 21% of the cases NEFADs had presence of tuna while its BIOFAD pair did not and; in 13% the opposite pattern was observed.
OPTIMUM PROTOTYPE	First detection of tuna was similar in both types of FADs (BIOFAD and NEFAD). More variability was observed when this indicator was assessed by FAD type and deployed prototypes. According to the distance between pairs a faster (in days) presence of tuna in NEFADs than in BIOFADs was found and this pattern was kept throughout the different range of distances between pairs. Prototypes A1 and C1 are likely to be the optimum prototypes according to first detection of tuna parameter. However, regarding the ratios of FAD occupation and presence of tuna it is difficult to identify an optimum prototype between BIOFADs, although BIOFADs in general did not differ from NEFADs.

<table>
<tr><th colspan="2">Table 4.5.3.6. BIOMASS ESTIMATION:

Echo-sounder buoy data was also used to estimate the tuna biomass from acoustic energy values</th></tr>
<tr><td>BIOFAD</td><td rowspan="2">This analysis was made by combining both FAD type results:

Low tuna biomass estimations for both FAD types were observed in the three buoy models (M3i, M3i+, ISL+).

Tuna biomass estimation analysed grouped by the month after deployment:

Biomass estimation resulted in slightly constant values during the first months after deployment for both FAD types. Afterwards, in the month five and six values of biomass showed more variability between pairs, and different patterns were observed depending on the buoy model.

M3i and ISL+ showed higher values in NEFADs, while with M3i+ the pattern was not clear with higher values in BIOFADs and NEFADs depending on the month.

Tuna biomass estimation analysed grouped by distance between pairs:

Differences between FAD types were slightly constant when distance between them was not larger than ~2000 km. Afterwards values of biomass showed more variability between pairs, and different patterns were observed depending on the buoy model.

M3i and M3i+ models showed higher values in BIOFADs than in NEFADs, while in ISL+ the pattern was not clear as the distance between pairs increased.</td></tr>
<tr><td>NEFAD</td></tr>
<tr><td>OPTIMUM PROTOTYPE</td><td>BIOFAD prototypes were not analyzed separately and thus, to recommend a unique optimum BIOFAD prototype is not possible. However, the data corresponding to the group of BIOFAD prototypes did not differ clearly from the group of NEFADs in terms of tuna biomass estimation derived from acoustic signal of buoys.</td></tr>
</table>

Table 4.5.3.8. LIFE CYCLE ANALYSIS: The life cycle analysis results in terms of carbon footprint and marine aquatic ecotoxicity were assessed by FAD type (BIOFAD and NEFAD). Different functional units were also considered during the comparison.	
BIOFAD	**Carbon footprint** Estimated impact of BIOFAD production in terms of carbon footprint ranged between 134.4 – 273.2 kg CO_2. - *Considering Catch as functional unit & replacement*: The best BIOFAD prototype in terms of carbon footprint was A1 with 198.3 kg CO_2 / tons of tuna; and the worst A2.2 with 751.2 kg CO_2 / tons of tuna. There is not estimation for prototype B1, B2 and C1. - *Considering Biomass as functional unit & replacement* The best BIOFAD prototype in terms of carbon footprint was C1 with 52 kg CO_2 / tons of tuna; and the worst A1.2 with 486.6 kg CO_2 / tons of tuna. There is not estimation for prototype B2. **Marine aquatic ecotoxicity** Estimated impact of BIOFAD production in terms of marine aquatic ecotoxicity ranged between 164.7 – 454 t 1,4 – DB. - *Considering Catch as functional unit & replacement:* The best BIOFAD prototype in terms of marine aquatic ecotoxicity was A1 with 375.4 t 1,4 – DB / tons of tuna; and the worst A2.2 with 1631.1 t 1,4 – DB / tons of tuna. There is not estimation for prototype B1, B2 and C1. - *Considering Biomass as functional unit & replacement* The best BIOFAD prototype in terms of marine aquatic ecotoxicity was A1 with 375.4 t 1,4 – DB / tons of tuna; and the worst A2.2 with 1631.1 t 1,4 – DB / tons of tuna. There is not estimation for prototype B1, B2 and C1.
NEFAD	**Carbon footprint** Estimated impact of NEFAD production in terms of carbon footprint ranged between 145 – 672 kg CO_2. - *Considering Catch as functional unit & replacement*: The best NEFAD prototype in terms of carbon footprint was NEFAD 4 with 45 kg CO_2 / tons of tuna, and the worst NEFAD1 with 374 kg CO_2 / tons of tuna. There is not estimation for prototype NEFAD 2 and NEFAD 3. - *Considering Biomass as functional unit & replacement* The best NEFAD prototype in terms of carbon footprint was NEFAD 4 with 210 kg CO_2 / tons of tuna, and the worst NEFAD 3 with 658 kg CO_2 / tons of tuna. **Marine aquatic ecotoxicity** Estimated impact of NEFAD production in terms of marine aquatic ecotoxicity ranged between 206 – 316 t 1,4 – DB. - *Considering Catch as functional unit & replacement*: The best NEFAD prototype in terms of marine aquatic ecotoxicity was NEFAD 4 with 65 t 1,4 – DB / tons of tuna, and the worst NEFAD 1 with 176 t 1,4 – DB / tons of tuna. There is not estimation for prototype NEFAD 2 and NEFAD 3.

	- *Considering Biomass as functional unit & replacement* The best NEFAD prototype in terms of marine aquatic ecotoxicity was NEFAD 1 with 224 t 1,4 – DB / tons of tuna, and the worst NEFAD 3 with 1011 t 1,4 – DB / tons of tuna.
OPTIMUM PROTOTYPE	For both the carbon footprint and the marine ecotoxicity, the C BIOFAD prototypes performed the best regarding the carbon footprint; and they are followed by the B1 BIOFAD. The results indicate that the more material it is used in the FADs the higher the environmental impact score. The use of double materials (i.e. double canvas or double metallic frame) increases the environmental impact in both carbon footprint and marine ecotoxicity significantly. In fact, the BIOFAD A and BIOFAD B1 alternatives that used double canvas or/and double metallic structure are ranked as the worst.

Table 4.5.3.9. SOCIO ECONOMIC ANALISIS: Socio-economic analysis results were assessed by FAD type (BIOFAD and NEFAD).	
BIOFAD NEFAD	This analysis was made by combining both FAD type results: The construction of a BIOFAD is more expensive (206 EUR/BIOFAD) than a NEFAD (116 EUR/FAD). It is estimated that the replacement will drive an increase in costs of 1.05%. The revenue depends on the efficiency of the object (i.e., the catchability) and on the potential price premium. If the catchability BIOFADs = catchability NEFAD, then the necessary price premium to offset the additional costs of BIOFADs is approximately 1%. If the catchability BIOFADs < catchability NEFAD, then the necessary price premium to offset the additional costs of BIOFADs is approximately 5%. If the catchability BIOFADs << catchability NEFAD, then the necessary price premium to offset the additional costs of BIOFADs is approximately 10%.
OPTIMUM PROTOTYPE	The prototype C is the optimum prototype if the cost of the construction is the only parameter considered. This is related to the amount of material required for the construction of this prototype. However, the catchability of each prototype needs to be taken in to account to compensate the additional cost of the biodegradable materials.

4.5.4. MAIN CONCLUSION AND RECOMMENDATION.

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 and for a short time period, all prototypes showed a maximum lifespan longer than 1 year in both FAD types. This statement does not consider the degradation status.
- The cotton canvas showed high degradation during the first months at sea, while cotton ropes were less degraded until the fifth month.
- Few sets were observed in both FAD types, being the number of sets slightly higher on BIOFADs. 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, NEFADs had higher values of biomass during the first month, while BIOFADs showed higher biomass values after the ninth month at sea.
- Based on the data available, prototypes C1 (BIOFAD, NEFAD) seemed to be the most environmentally friendly designs in terms of carbon footprint, both considering catch and biomass data.
- Understanding FAD dynamics is a keystone to assess the economic impact of the substitution of NEFADs by BIOFADs. The number of FADs built, the number of deployments, the period from the deployment to the use of the FAD and the strategy of the fleet when the number of available FAD decreases will impact the economic performance of this replacement.
- It is estimated that the replacement to BIOFADs will drive an increase in costs of 1.05% and the revenue will depend on the efficiency of the object (i.e., the catchability) and on the potential price premium.
- Depending on the catchability of BIOFADs, then the necessary price premium to offset the additional costs of BIOFADs is a price premium of approximately 1-10%.
- BIOFAD components need to be replaced more often, which means an increase from 24% to 34% of labour costs for BIOFADs.

Recommendation:

- Following the preliminary definition proposed in the context of this project for biodegradable FADs (Zudaire et al., 2018b), it is essential to advance towards an agreed BIOFAD definition by tRFMOs, ideally in the context of the Joint tRFMOs FAD Working Group. This will allow providing clear guidance and clarity at RFMOs when the term biodegradable is used to define the materials 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's classification for FAD entanglement risk (ISSF, 2019).
- An effective replacement of non-biodegradable FADs by those partly/fully 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 FADs should be considered based on the current state of art of available materials. In this gradual process different options could be discussed:
- As a first step, the Consortium proposes Option 1 BIOFAD classification (defined in section 4.2.3.1.3) as the most feasible option to be implemented in a short- to medium-term. Option 1 considers the implementation of BIOFADs by 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). For this process, the following categories were defined:
    - Category I. This category corresponds to 100% biodegradable FADs. This means all parts (i.e., raft and tail) of a FAD are built with biodegradable materials. Used materials should fulfil proposed BIOFAD definition.
    - Category II. This category corresponds to FADs using biodegradable materials for whole FAD except for the floating component (i.e., plastic floats). This means that all parts (i.e., raft and tail) of a FAD are built with biodegradable materials fulfilling the proposed definition for BIOFAD but have additional non-biodegradable floatation elements.
    - Category III. This category corresponds to FADs using only biodegradable materials in the construction of the tail but non-biodegradable materials in the raft (e.g., synthetic raffia, metallic frame, plastic floats). This means all underwater hanging parts (i.e., tail) of a FAD are built with biodegradable materials fulfilling the proposed BIOFAD definition.

  - Category IV. This category corresponds to FADs with all parts (i.e. raft and tail) only built partly or with no biodegradable materials.

- Progressively, as soon as new materials become available, the % of biodegradability should be increased for the construction of other parts of the FADs (e.g., floats, buoy) in order to target 100% biodegradability for the FAD as per BIOFAD definition above. In the meantime, plastic based materials should be reduced as much as possible.
- Gradual modification of current FAD designs, 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 in the short-term while medium- to long-term implementation of biodegradable NEFADs is in progress.
- The effective development and implementation of biodegradable FADs requires the collaboration of all stakeholders, fishing industry and research centres including experts in material development.

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APPENDIX I: LIST OF ACRONYMS.

Table I.1. List of acronyms used in the report (note that this list is preliminary and is being updated for the final report).

Acronym	Name
AER	Annual Economic Report
AFAD	Anchored Fish Aggregating Device
ALBACORA	Purse seine fishing company
ANABAC	Asociación Nacional de Armadores de Buques Atuneros Congeladores
ALDFG	Abandoned, lost or otherwise discarded fishing gear
ATUNSA	Purse seine fishing company
AZTI	AZTI-Tecnalia
BIOFAD	Experimental biodegradable Fish Aggregating Device
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CFP	Common Fisheries Policy
CFTO	Purse seine fishing company
CONFAD	Experimental non-entangling and non-biodegradable Fish Aggregating Device
CSP	Centre de Surveillance des pêches
DCR	Data Collection Regulation
DFAD	Drifting Fish Aggregating Device
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DONGWON	Korean purse seine company
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
ECHEBASTAR	Purse seine fishing company
EU	European Union
EUPOA	EU Plan of Action
EUROPEA	Purse seine fishing company
EVA	Ethylene Vinyl Acetate
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organization of the United Nations
GAIKER	GAIKER-IK4
GT	Gross tonnage
HERFADS	High entanglement risk Fish Aggregating Device
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IEO	Instituto Español de Oceanografía

INPESCA	Purse seine fishing company
IOTC	Indian Ocean Tuna Commission
IPMA	Instituto Português do Mar e da Atmosfera
IRD	Institut de Recherche pour le Développement
ISSF	International Seafood Sustainability Foundation
ITSASKORDA	Cotton ropes supplier/manufacturer
LCA	Life-cycle assessment
LERFADS	Low entanglement risk Fish Aggregating Device
MRAG	MRAG
MSFD	Marine Strategy Framework Directive
NEFAD	Non-entangling Fish Aggregating Device
OPAGAC	Organización de Productores de Atún Congelado
ORTHONGEL	Organisation des producteurs de thon tropical congelé et surgelé
PA	Polyamide
PEVASA	Purse seine fishing company
PHA	Polyhydroxyalkanoates
PLA	Polylactic acid
PS	Purse seine
PVC	Polyvinyl chloride
RFMO	Regional Fisheries Management Organization
SAPMER	Purse seine fishing company
SFA	Seychelles Fishing Authority
TAAF	Terres Australes et Antarctiques Françaises
TERNUA	Cotton canvas supplier
tRFMO	tuna Regional Fisheries Management Organization
WCPFC	Western and Central Pacific Fisheries Commission

APPENDIX II: EXTRA TABLES.

Table 4.2.3.2.1. Characterization of BIOFADs and conventional NEFADs. Cells in green are measurements for biodegradable components and cells in grey are measurement for synthetic components. Missing = information being collected. The % of biodegradability was estimated as the ratio between the sum of total biodegradable material weight and total material weight for each of the prototypes.

	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_A1.1	4 bamboo canes Metallic frame	12 12.2	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	63.6	37	26.6	58.2
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_A2.1	4 bamboo canes 	12 12.2	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	56.1	29.5	26.6	52.6

	Metallic frame															
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_B1.1	**10 bamboo canes**	**30**	**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**	**89.4**	**65**	**24.4**	72.7
BIOFAD_B1.2	**4 bamboo canes** **Metallic frame**	**12** **12.2**	**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**	**81.4**	**44.8**	**36.6**	55.0
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_B1.4	**Metallic frame**	**12.2**	**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**	**69.4**	**32.8**	**36.6**	47.3
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)	18	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
	Pallet (31kg)	31														
BIOFAD_B2.1 "Cube"	Doble Metallic frame	24.4	Black cotton cover	2.2	-	0	cotton rope 4 x 3 m (12 m)	3.6	3+3=6	7.6	0	0.5	46.2	13.7	32.5	29.7
							Looped cotton rope 16 x 3 m (48 m)	7.9								
BIOFAD_B2.2 "Cube"	Doble Metallic frame	24.4	Doble Black cotton cover	4.4	-	0	cotton rope 4 x 3 m (12 m)	3.6	3+3=6	7.6	0	0.5	48.4	15.9	32.5	32.9
							Looped cotton rope 16 x 3 m (48 m)	7.9								
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.1	10 bamboo canes	30	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	50.4	41	9.4	81.3
BIOFAD_C.2	4 bamboo canes	12	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	42.4	20.8	21.6	49.1
	Metallic frame	12.2														
BIOFAD_C.3	4 bamboo canes	12	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
	Metallic frame	12.2														
	Metallic frame	12.2	Synthetic black raffia	2.1		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 _1 "conventional"	**4 bamboo canes**	**12**	**Polyester net mesh size < 3 mm**	**2.2**	**80m* Twisted polyamide net and tied**											
NE FAD_2 "semi-surmerged"	**Metallic frame**	**12.2**	**Synthetic black raffia**	**2.1**	**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
			Polyester net mesh size < 3 mm	**2.2**												
NE FAD_3 "cube"	**Doble Metallic frame**	**24.4**	**Synthetic black raffia**	**2.1**	**No**	**0**	**Flags of synthetic raffia**	**1.2**	**4+6=10**	**12.6**	**0**	**0.5**	**54.4**	**0**	**54.4**	0.0
			Polyester net mesh size < 3 mm	**4**			**Polyethylene rope 16 x 3 m (48 m)**	**9.6**								
NE FAD_4 "superficial"	**Metallic frame**	**12.2**	**Synthetic black raffia**	**2.1**	**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
	4 bamboo canes	**12**	**Polyester net mesh size < 3 mm**	**2.2**												

* 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)

Table 4.2.3.2.2. Technical specification of the cotton cover.

Characteristics+B3:B3:G23	*Sarga 1e 3b 1,3*	*Cover made of 100% cotton BCI teinted in black color with Indanthren teint*		
Structural qualities				
	Characteristics	Method	Specification	Tolerance
	Weave:	**UNE 40.161**		
	Global composition:	**UNE-EN ISO 1833-1:20**	**Cotton 100%**	**± 3**
	Weight gr per sq.m:	**UNE 40.339**	**395**	**± 5 %**
	Usable width:	**UNE EN 1773**	**158**	**± 1 cm**
Mechanics qualities				
	Characteristics	Method	Specification	
	Tensile strenght:	**UNE-EN-ISO-13934-1**	**U: 100 kg. T: 80 kg.**	
Dimensional stability washing process				
	Characteristics	Method		
	Washing 60 min at 60º Drying in tumbler:	**UNE-EN-ISO 5077 Max. 70 ºC**	**U: -2 % Max. tol.: 3**	**T: -3 % Max. tol.: 3 %**
Colour fastness				
	Characteristics	Method	Color change	Staining
	To light:	**UNE-EN ISO 105-B02**	6	
	To water:	**UNE-EN ISO 105-E01**	4	4
	To domestic and commercial wash: Temperature 40°C	**UNE-EN ISO 105-CO6**	4	3
	To dry rubbing:	**UNE-EN ISO 105-X12**		4

Table 4.2.3.2.3. Technical specification of the twisted cotton rope.

Product:	Twisted Cotton Rope
Commercial brand	NATUKOR
Diameter:	20 mm
Twist pattern:	Z/S/Z
Rope construction:	4 strands Z twist
Strand construction:	11 yarns
Inner core	2/3 yarns in Z twist
Rope:	100% Carded Cotton
Cover:	Food Grade Wax
Breaking Strength (Previous to use) Kg	1.400

Table 4.2.3.2.4. Technical specification of the twisted looped cotton rope.

Product:	Twisted Looped Cotton Rope
Commercial brand	TUNAKO-BIO
Diameter core	16 mm
Diameter total	22 mm
Twist pattern:	Z/S/Z
Rope construction:	3 strands Z twist
Strand construction:	8 yarns
Loop construction	1 yarn without twist
Loop density	Araound 400 loops per meter
Core	100% cotton
Loops	100% cotton

Table 4.2.3.2.5 Technical specifications of the floats.

Reference	***Fishing Float Asas laterales***
Manufacturer	Urlaplast, S.L.
Material	PSAI, High impact polystyrene mixed at 50% with glass polystyrene of current use (GPPS, General Purpose Polystyrene)
Diameter Ø	240 mm
Weight [gr]	1.273
Thinkness [mm]	6-8
Buiyancy [gr]	5.800
Impact strength [kg/m]	16
Color	Black

Table 4.2.3.2.6 Technical specification of the bamboo canes.

								Watertight			Non Watertight		
Sample	**Weight [kg]**	**Ø Ext [mm]**	**Ø Int [mm]**	**Thickness [mm]**	**Length [cm]**	**Perimeter [mm]**	**Spaces between walls**	**Volume [m3]**	**Thrust [kg]**	**Buoyancy**	**Volume [m3]**	**Thrust [kg]**	**Buoyancy**
1	6.44	71	48	13	210	23	6	0.00831430	8.54	Floating	0.00451423	4.64	Sinking
2	2.52	69	59	8	190	22	4	0.00710463	7.30	Floating	0.00191009	1.96	Sinking
3	1.98	55	50	7	200	20	5	0.00475166	4.88	Floating	0.00082467	0.85	Sinking
4	3.74	77	49	12	200	24.5	4	0.00931325	9.56	Floating	0.00554177	5.69	Floating
5	1.80	72	57	7	200	21	4	0.00814301	8.36	Floating	0.00303949	3.12	Floating
6	3.06	59	46	8	202	18	5	0.00552262	5.67	Floating	0.00216558	2.22	Sinking
7	3.76	68	48	10	200	23	4	0.00726336	7.46	Floating	0.00364425	3.74	Sinking
8	2.90	58	41	10	200	17.5	6	0.00528416	5.43	Floating	0.00264365	2.72	Sinking
9	4.08	61	32	16	199	19	5	0.00581571	5.97	Floating	0.00421526	4.33	Floating
10	3.90	68	42	13	200	21	5	0.00726336	7.46	Floating	0.00449248	4.61	Floating
11	2.70	74	59	8	203	23	4	0.00873071	8.97	Floating	0.00318074	3.27	Floating
12	2.08	68	56	6	195	19.5	4	0.00708178	7.27	Floating	0.00227891	2.34	Floating
13	2.48	76	64	6	195	23	4	0.00884610	9.08	Floating	0.00257296	2.64	Floating
14	1.26	52	42	5	200	16	5	0.00424743	4.36	Floating	0.00147655	1.52	Floating
15	3.62	69	46	12	203	22.5	4	0.00759074	7.80	Floating	0.00421708	4.33	Floating
16	3.74	65	51	8	207	20.5	4	0.00686890	7.05	Floating	0.00264026	2.71	Sinking
17	2.66	64	45	11	192	21	4	0.00617662	6.34	Floating	0.00312299	3.21	Floating
18	3.40	62	38	13	200	20	4	0.00603814	6.20	Floating	0.00376991	3.87	Floating
19	2.82	86	73	8	200	25.5	4	0.01161761	11.93	Floating	0.00324684	3.33	Floating
20	3.00	68	56	7	200	22	4	0.00726336	7.46	Floating	0.00233734	2.40	Sinking
Mean	**3.097**	**67.1**	**50.1**	**9.4**	**199.8**	**21.1**	**4.45**	**0.00716187**	**7.36**		**0.00309175**	**3.18**	
SD	1.10	8.05	9.60	2.98	4.50	2.38	0.69	0.00173118	1.78		0.00115220	1.18	

Table. 4.3.3.3.6 Questionnaire addressed to fishing companies for the study of environmental impacts of FADs.

ITEM	ANSWER	UNIT	COMMENT
Bamboos			
Location bamboo canes are provided from (city, country)		-	
In the hypothetical case that there was no local bamboo supplier, location (country) bamboo canes would be imported from.			
Price per unit		€/bamboo	
Pallets			
Location pallets are provided from (city and country)		-	
In the hypothetical case that there was no local pallet supplier, location (country) they would be imported from.			
Price per unit		€/pallet	
Metallic frame of the FAD			
Manufacturer of the tubes conforming the metallic frame		-	
Location of the metallic tubes manufacturer (city, country)		-	
Supplier of metallic tubes		-	
Location of metallic tubes supplier (city, country)		-	
Material conforming the tubes		-	For example: galvanised iron.
Please detail how the metallic frame is assembled			For example: the tubes are shipped to the Seychelles. Once there, they are moulded by hand or they are cut to length to assemble the frame. Then, the pieces are joined by an elbow, so the structure takes a square-shape.
Nº elbows by FAD			By elbow we understand the piece that serves as union between the metallic tubes.
Material of the elbows			
Weight of the elbows		g	
Manufacturer of the elbows			
Location of elbow manufacturer (city, country)			
Supplier of elbows			
Location of elbow supplier (city, country)			
Please detail how the metallic frame (tubes and elbows) are transported to the Seychelles			For example: the tubes and elbows are transported from the suppliers to a French Port (detail which one) and

			then they are transported to the Seychelles by ship.
Price per unit		€/full metallic frame (incl. the elbow)	
Black Raffia canvas (used on the structure frame, as a covering canvas and as flags)			
Manufacturer			
Location of canvas manufacturer (city, country)			
Supplier			
Location of canvas supplier (city, country)			
Please detail how the black canvas is transported to the Seychelles			
Is the 100 % of canvas used to produce the FADs or is there any waste produced in the process? If yes, how much does the waste represent in weight?			
Price per unit		€/m^2 raffia canvas	
Polyester net (“small mesh size net”)			
Manufacturer /net-maker			
Location of the manufacturer / net-maker (city, country)			
Please detail how the net is transported to the Seychelles			
Price per unit		€/m^2 net	
Polyamide net (“old tuna net”)			
Original manufacturer /net-maker			
Location of the manufacturer / net-maker (city, country)			
Please detail how the net is transported to the Seychelles			
¿Is the polyamide net in fact an old and disused tropical tuna purse seiner net?		YES/NO	
Price per unit		€/m^2 net	
Polyethylene rope (“coral” type main rope)			
Manufacturer			
Location of manufacturer (city, country)			
Please detail how the net is transported to the Seychelles			
Price per unit		€/m rope	
Polyethylene rope (“fantasy type rope attractor)			
Manufacturer			
Location of manufacturer (city, country)			
Please detail how the net is transported to the Seychelles			
Price per unit		€/m rope	
Ballast weight			
Material used as ballast weight			
Supplier of the ballast weight			We are aware that as weight a reused material from the nets is commonly

			used. We would like to know who the supplier of the original pieces was.
Location of the manufacture of the original pieces			
Price per unit		€/kg ballast	
Twine to tie			
Manufacturer of the braided twine coil			
Location of the braided twine coil (city, country)			
Supplier of the braided twine coil			
Location of the braided twine coil (city, country)			
Price per unit		€/m rope	

Table. 4.3.3.3.7 Questionnaire to gather LCI information regarding the manufacturing of cotton canvas.

COTTON CANVAS FOR BIOFADS		
PROCESSES	AMOUNT	UNIT
PREPARATION OF THE COTTON		
Origin of the raw cotton (location)		
Consumption of raw cotton to produce the yarn		kg raw cotton / kg yarn
Energy		
Energy consumption during the cotton cleaning stage		kWh/kg cotton
Water		
Water consumption during the cotton cleaning stage		m^3/kg cotton
Waste water produced		m^3/kg cotton
Spinning of the cotton		
Dtex of the thread used to manufacture the canvas		dtex
Energy		
Energy consumption associated to the machinery used for the spinning of the cotton to produce the yarn		kWh/kg hilo
Waste		
¿Is any waste produced in the process?		yes/no
If yes, define which type and the amount		kg rejected or waste material per kg of yarn
What do you do with the rejected material or the waste?		
WEAVING PROCESS OF THE CANVAS		
Materials		
Yarn consumption		kg yarn/m^2 textile
Energy		
Energy consumption by the weaving machines		kWh/m^2 textile
Waste		
¿Is any waste produced in the process?		yes/no
If yes, define which type and the amount		kg rejected material or waste / m^2 of textile

What do you do with the rejected material or the waste?		
TEXTILE TREATMENT PROCESS - PREPARATION		
Consumables for the treatment		
Type of consumable or additive used for the preparation of the textile		Made and model
Amount of consumable or additive used for the preparation of the textile		kg consumable / m^2 textile
Water		
Water consumption during the treatment		m^3 water / m^2 textile
Waste water produced		m^3 wastewater/ m^2 textile
Energy		
Energy consumption during the treatment		kWh/kg textile treated
Type of energy used		E.g. electricity, combined cycle, generators, etc.
Waste		
¿Is any waste produced in the process?		yes/no
If yes, define which type and the amount		kg rejected material or waste / m^2 of textile
What do you do with the rejected material or the waste?		
TEXTIL TREATMENT PROCESS – DYEING		
Raw materials		
Amount of dyes used		kg dye / m^2 textile
Type of dye used (make and model)		
Water		
Water consumption during the treatment		m^3 water / kg treated textile
Waste water produced		m^3wastewater / kg treated textile
Energy		
Energy consumption during the treatment		kWh/kg textile treated
Type of energy used		E.g. electricity, combined cycle, generators, etc.
Waste		
¿Is any waste produced in the process?		yes/no
If yes, define which type and the amount		kg rejected material or waste / m^2 of textile
What do you do with the rejected material or the waste?		
TEXTILE TREATEMENT PROCESS – FINAL CONDITIONING & DRYING		
Raw materials		
Type of consumable or additive used during the final conditioning and drying		Made and model
Amount of consumable or additive used during the final conditioning and drying		kg consumable / m^2 textile
Water		
Water consumption during the treatment		m^3 water / kg treated textile
Waste water produced		m^3wastewater / kg treated textile
Energy		

Energy consumption during the final conditioning and drying		kWh/kg textile treated
Type of energy used		E.g. electricity, combined cycle, generators, etc.
Waste		
¿Is any waste produced in the process?		yes/no
If yes, define which type and the amount		kg rejected material or waste / m^2 of textile
What do you do with the rejected material or the waste?		

Table. 4.3.3.3.8. Information requested to gather information regarding Vessel Details.

INFORMATION REQUESTED		ANSWER
Vessel name		
Hull	Hull material	
	Amount of material in the hull (tn)	
Antifouling paint	Paint used as antifouling (brand and type)	
	Amount of antifouling required at each repainting event (tn)	
	Frequency of drydock to repaint the hull	
Refrigerant	Refrigerant used in the cooling system of the vessel	
	Refilling frequency	
	Refilling amount each time (tn)	
Fuel	Type of fuel used by the vessel (MDO, HFO…)	
	Annual fuel consumption of last 5 years (tn)	
Luboil	Type of luboil used	
	Luboil consumption per year	

APPENDIX III: EXTRA FIGURES.

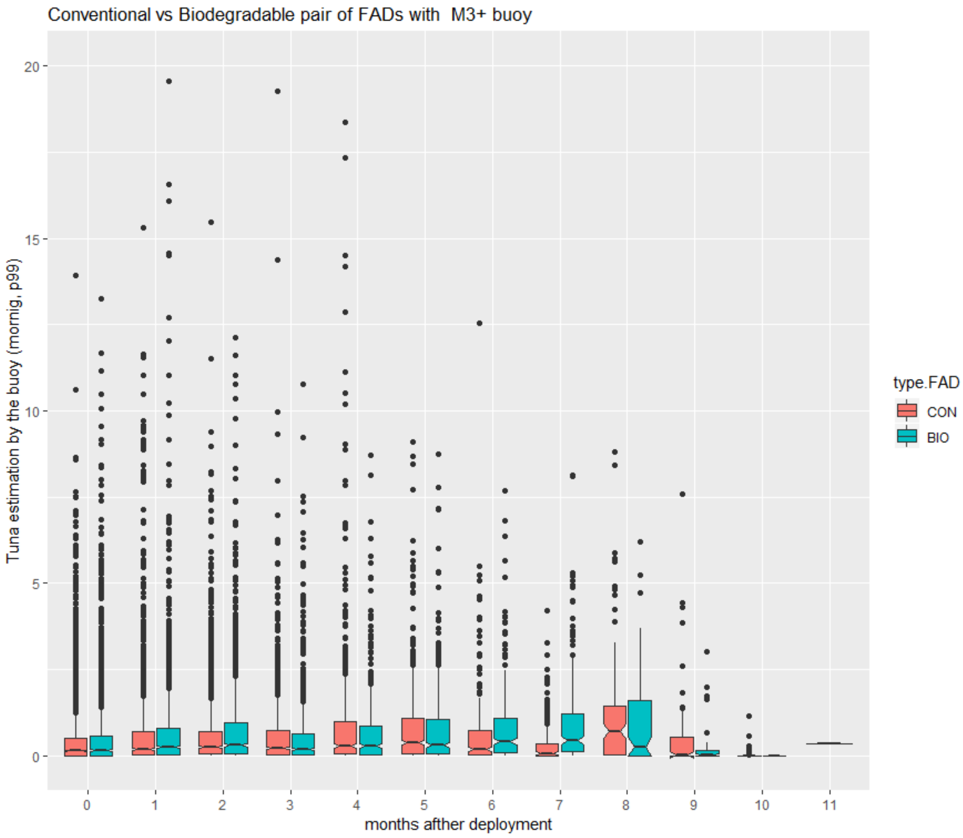


Figure 4.3.3.1.20. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by months since first deployment. Biomass estimation was done using acoustic energy from M3i+ buoy model.

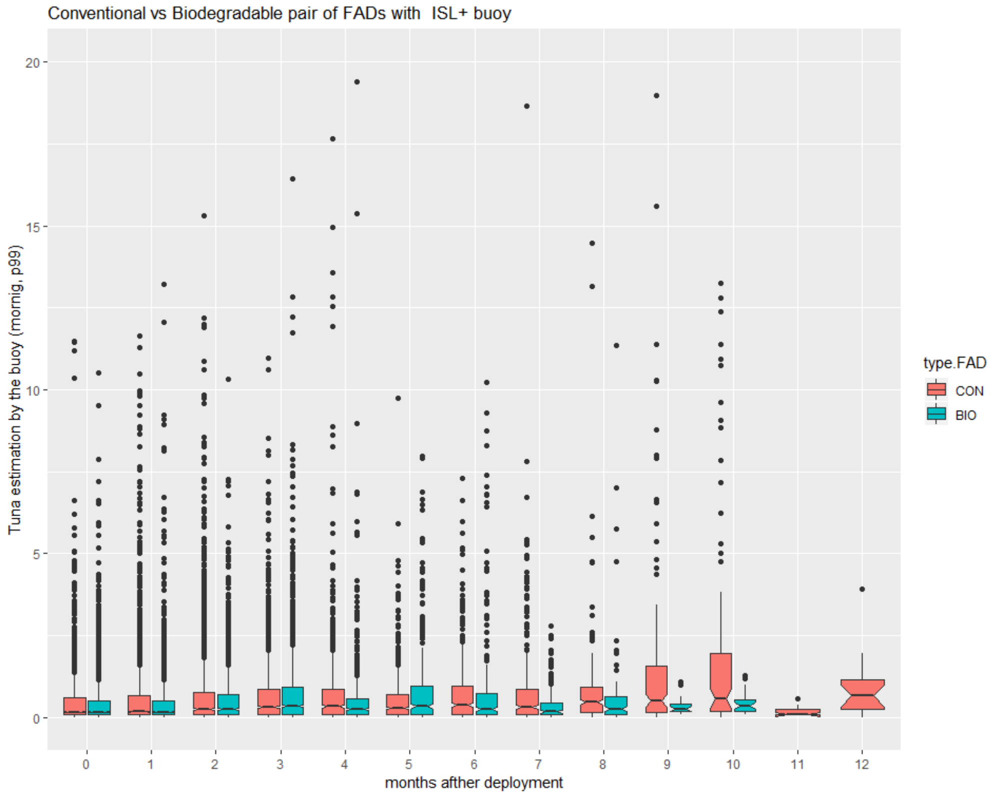
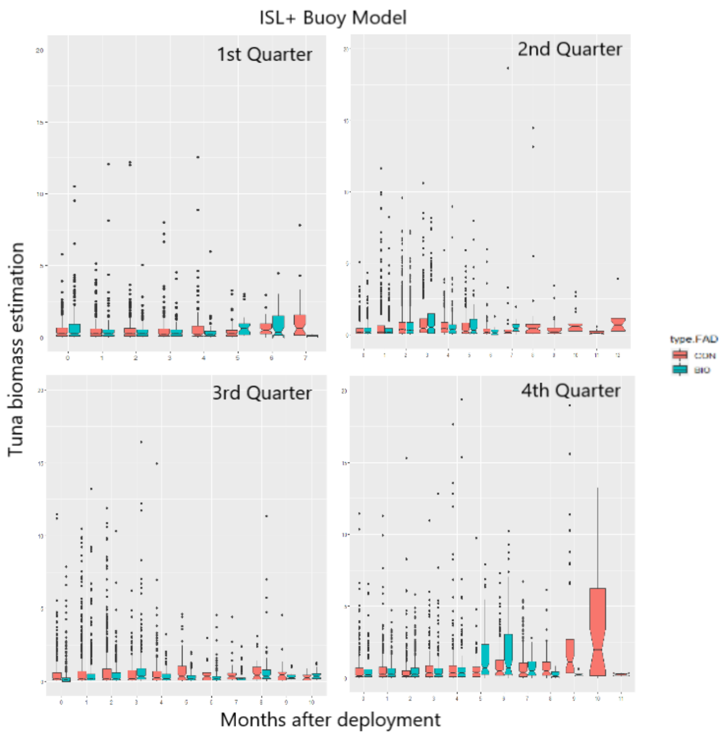


Figure 4.3.3.1.21. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by months since first deployment. Biomass estimation was done using acoustic energy from ISL+ buoy model.



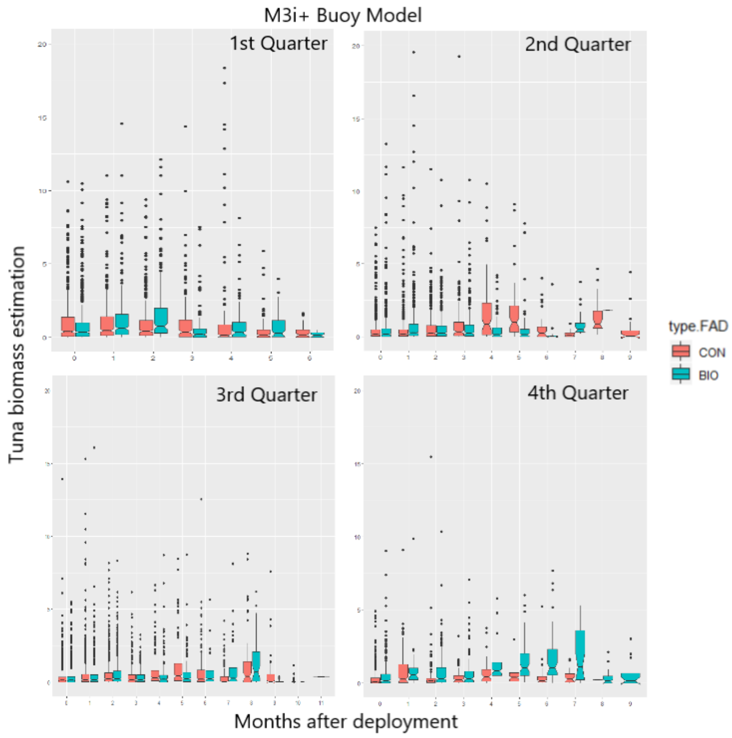


Figure 4.3.3.1.22. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by months since first deployment. Biomass estimation was done using acoustic energy from ISL+ and M3i+ buoy models. Data was grouped by deployment quarter to assess seasonal effect on tuna aggregation.

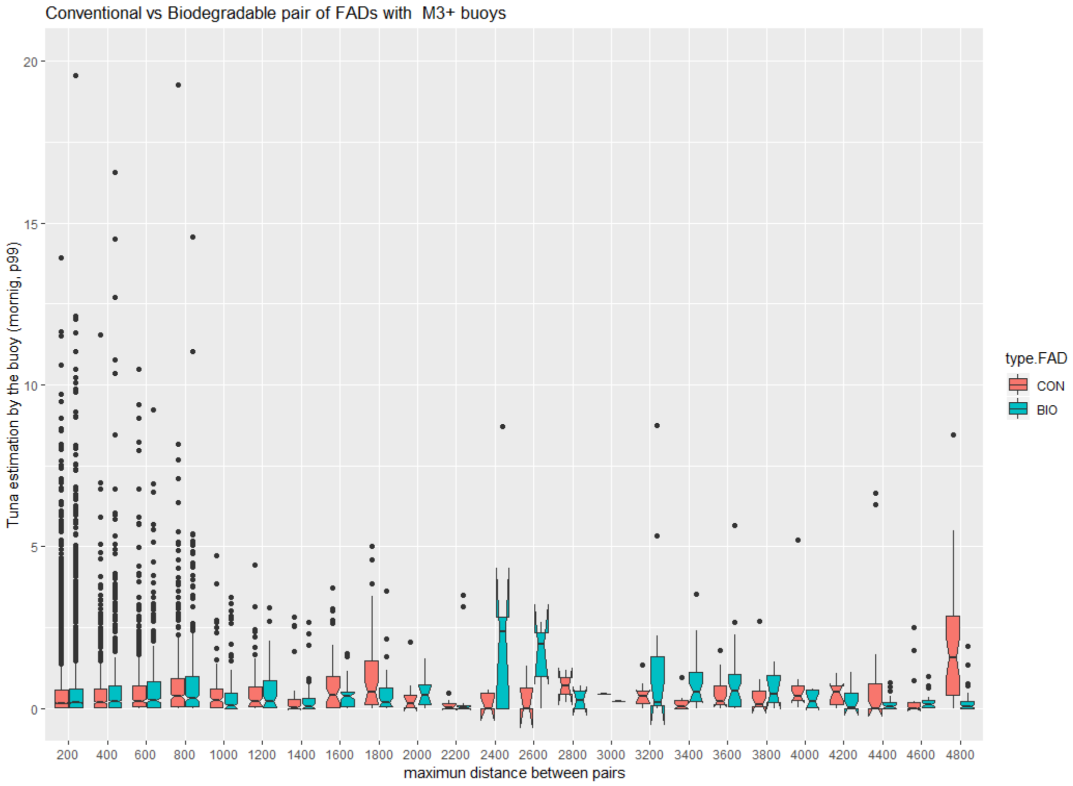


Figure 4.3.3.1.23. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by distance between pairs. Biomass estimation was done using acoustic energy from M3i+ buoy model.

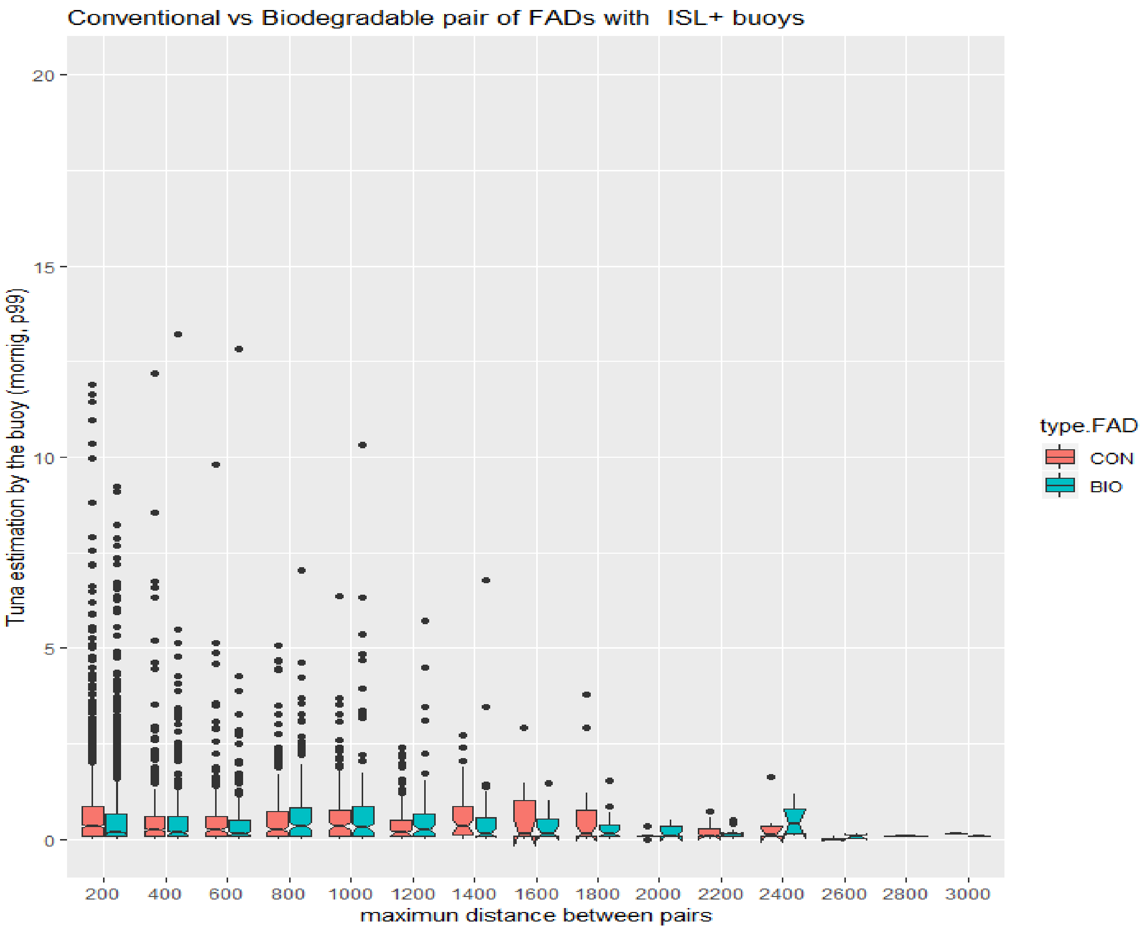


Figure 4.3.3.1.24. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by distance between pairs. Biomass estimation was done using acoustic energy from ISL+ buoy model.

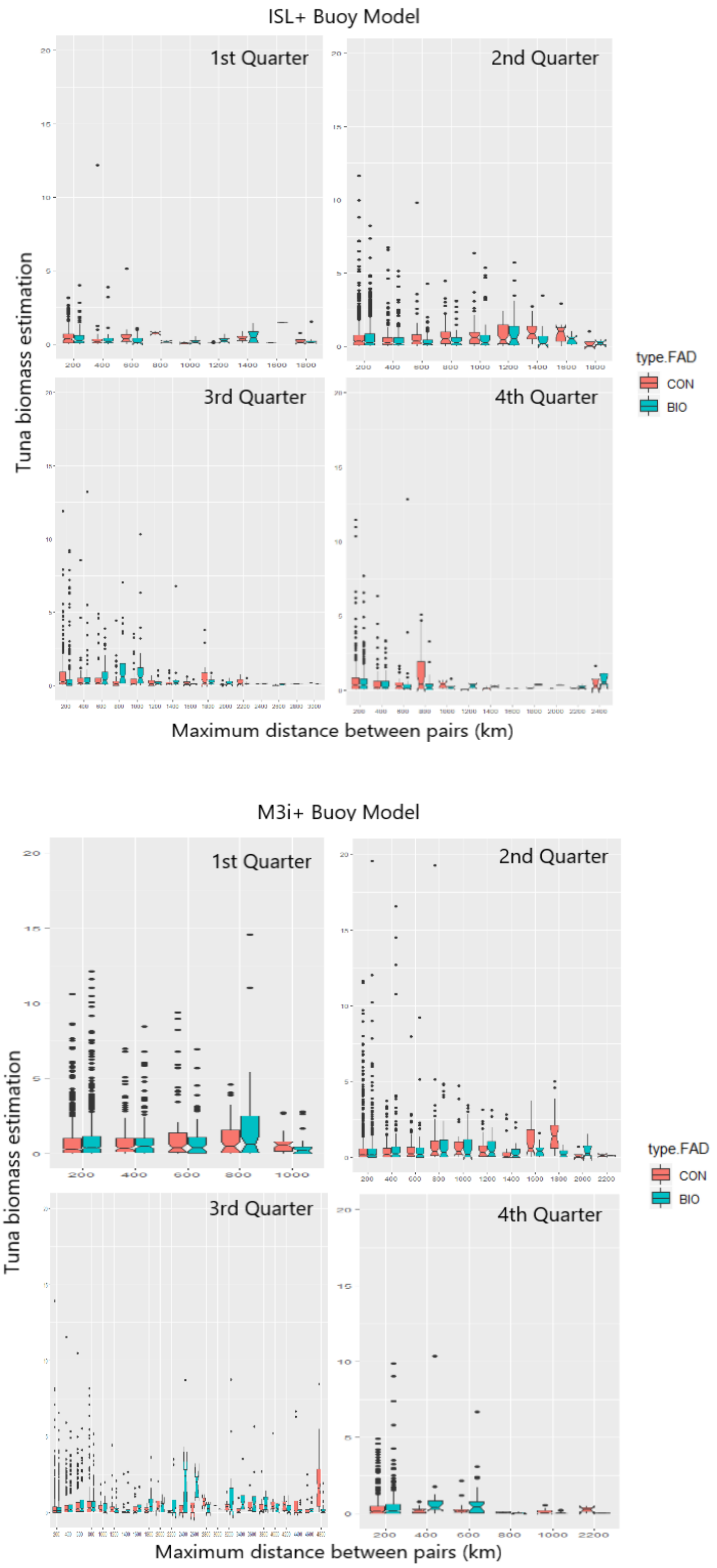


Figure 4.3.3.1.25. Tuna estimation (in tons) by FAD type and by grouping FAD pairs by distance between pairs in km. Biomass estimation was done using acoustic energy from ISL+ and M3i+ buoy models. Data was grouped by deployment quarter to assess seasonal effect on tuna aggregation.

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