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Review

Data Provision for Science-Based FAD Fishery Management: Spanish FAD Management Plan as a Case Study

José Carlos Báez [1,2,*], Santiago Déniz [3], María Lourdes Ramos [3], Maitane Grande [4], Jon Ruiz [4], Hilario Murua [5], Josu Santiago [4], Ana Justel-Rubio [5], Miguel Herrera [6], Isadora Moniz [6], Jon Lopez [7], Pedro José Pascual-Alayón [3], Anertz Muniategi [8], Nekane Alzorriz [8], Marta González-Carballo [3], Vanessa Rojo [3] and Francisco Abascal [3]

1 Instituto Español de Oceanografía (IEO-CSIC), Centro Oceanográfico de Málaga, 29640 Málaga, Spain
2 Instituto Iberoamericano de Desarrollo Sostenible (IIDS), Universidad Autónoma de Chile, Av. Alemania 1090, Temuco 4810101, Región de la Araucanía, Chile
3 Instituto Español de Oceanografía (IEO-CSIC), Centro Oceanográfico de Canarias, 38180 Santa Cruz de Tenerife, Spain; santiago.deniz@ieo.es (S.D.); mlourdes.ramos@ieo.es (M.L.R.); pedro.pascual@ieo.es (P.J.P.-A.); marta.gonzalez@ieo.es (M.G.-C.); vanessa.rojo@ieo.es (V.R.); francisco.abascal@ieo.es (F.A.)
4 AZTI, Sustainable Fisheries Management, Basque Research and Technology Alliance (BRTA), 48395 Sukarrieta, Spain; mgrande@azti.es (M.G.); jruiz@azti.es (J.R.); jsantiago@azti.es (J.S.)
5 International Seafood Sustainability Foundation (ISSF), Washington, DC 20005, USA; hmurua@iss-foundation.org (H.M.); ajustel@iss-foundation.org (A.J.-R.)
6 Organización de Productores Asociados de Grandes Atuneros Congeladores (OPAGAC), Calle de Ayala 54, 28001 Madrid, Spain; miguel.herrera@opagac.org (M.H.); fip@opagac.org (I.M.)
7 Inter-American Tropical Tuna Commission, 8901 La Jolla Shores Drive, San Diego, CA 92037, USA; jlopez@iattc.org
8 Asociación Nacional de Armadores de Buques Atuneros Congeladores (ANABAC), Txibitxiaga, 24 Entreplanta, Apartado 49, 48370 Bermeo, Spain; anertz@anabac.org (A.M.); nekane@anabac.org (N.A.)
* Correspondence: josecarlos.baez@ieo.es

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Abstract: The use of fish aggregating devices (FADs) in tropical tuna fisheries has increased significantly during recent decades. Concurrently, concern about juvenile tuna mortality, bycatch, and marine debris associated with FAD fisheries increased, and this led to the implementation of FAD management measures and more sustainable designs (e.g., non-entangling or biodegradable FADs, limits on active FADs, etc.). This document reviews data collection and reporting requirements of tuna-Regional Fisheries Management Organizations (t-RFMOs) on drifting FADs and summarizes the work carried out since 2010 under the Spanish FAD management plan to create an adequate standard data collection aimed at improving science-based decision making. The aim of this study is to assist in the strengthening of data collection systems through: (1) a review of the existing data requirements, (2) a review of the status of FAD data collection worldwide and identification of data gaps, and (3) recommendations aimed at improving FAD management through the strengthening of FAD data requirements. Due to the complexities of data collection, we summarize the difficulties faced when processing the data and propose concrete and practical solutions to improve both the data collection system and information quality.

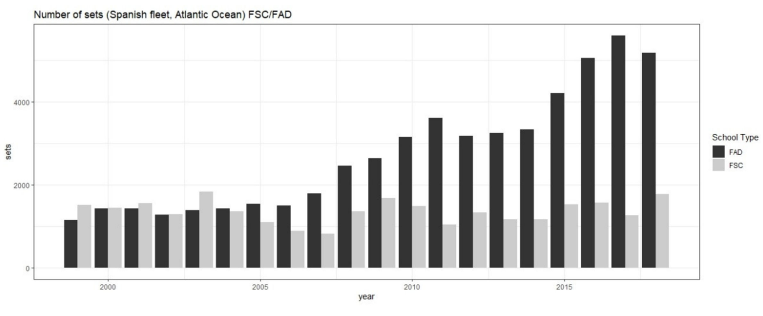
Keywords: data collection; fish aggregating device (FAD); floating object (FOB); management plan; tropical purse-seine; data requirements

1. Introduction

Tropical tuna species, skipjack tuna (*Katsuwonus pelamis*) (SKJ), yellowfin tuna (*Thunnus albacares*) (YFT), and bigeye tuna (*Thunnus obesus*) (BET) are important sources of animal protein and have a central role in food security, especially for many developing countries [1,2].

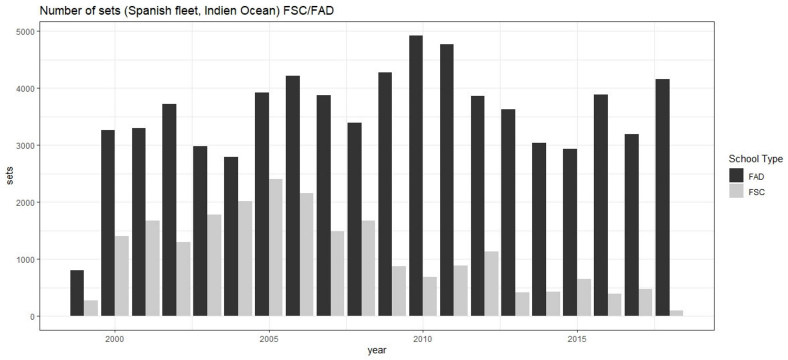
Tropical tuna purse seine fisheries operate globally. From the origin of the purse seine fishery, the fleet has taken advantage of the aggregative behavior of pelagic species, forming large free-swimming schools or associated schools beneath natural drifting objects, to fish more efficiently [3]. Traditionally, tropical purse seine sets are classified into three different categories: (a) setting on free-swimming or unassociated schools (where either mature YFT or SKJ specimens catch predominates); (b) setting on schools associated with floating objects (FOBs) (where SKJ catch predominates but with a significant presence of juveniles of YFT and BET); and (c) setting on dolphin associated tuna schools (only in the eastern Pacific Ocean, where pre-adult and adult YFT are caught). Free school fishing involves the detection of freely swimming surface tuna schools, which are detected through direct observation (i.e., tuna breaking the ocean surface observed using binoculars) and/or by tracking the activity of other animals (notably birds) or other fishing vessels.

Typically, a 'purse seining' operation implies setting and hauling a net that is cast vertically and closed at the bottom, kept afloat by buoys or floats that form a barrier on the surface. To drop the net, there is a steel wire that runs around the bottom edge of the net. To close the net, there is a series of metal rings. The mesh size of the net usually varies between 110–150 mm, and the dimensions of these nets can reach a length of 2000 m and 300 m in depth. In the past, fishing on schools associated with natural floating objects was opportunistic. In the early 1990s, there was a US trade embargo on tuna catches from purse seine sets conducted in association with marine mammals (mainly spotted dolphins) in waters of the Eastern Pacific Ocean [4]. The YFT was the species most typically associated with dolphins and on which the embargo was imposed. Consequently, the purse seine fleet changed the fishing strategy in this region by introducing man-made floating objects, called fish aggregating devices (FADs). In a similar way, purse seiners in other regions, taking advantage of the aggregation behavior of tuna around floating objects, started constructing FADs, extending their use to the whole tropical belt at that time (Figure 1). Since then, the use of FADs has expanded, and the associated technology has evolved. Nowadays, FADs are equipped with echosounder global positioning Ssystem (GPS) buoys which provide a real-time tracking and estimation of the aggregation size underneath [5,6]. The support vessels (also called supplies or "maciceros") are used to assist purse seiners in building, deploying, tracking, and maintaining floating objects. These navigating vessels monitor, visit, repair, and recover, and they also inform the purse seines about school size and species underneath the FADs.

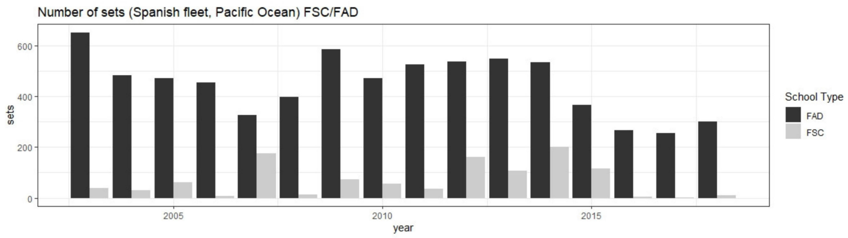


(a)

Figure 1. *Cont.*



(**b**)



(**c**)

Figure 1. Trend of sets frequency by Spanish fleet per fishing systems recorded in recent years for the Atlantic Ocean (**a**), Indian Ocean (**b**), and Pacific (**c**).

For Spanish purse seiners fishery, more than 80% of the catch in the Indian Ocean, 60% in the Atlantic, and 90% in the Pacific comes from FOBs (Spanish Institute of Oceanography databases, pers. obs.). In recent years, increased concern about several impacts associated with FAD fisheries, such as yellowfin/bigeye juvenile tuna catch, the bycatch of sensitive species or marine debris, led to the adoption of a suite of FAD management measures across all tuna-Regional Fisheries Management Organizations (t-RFMOs) [7–10]. These include the use of non-entangling FADs, time/area closures, limitations in the number of active FADs per vessel, or the promotion of the use of biodegradable FADs [11–14]. Yet, improving the data and knowledge of the FAD fishery activities and use is essential to ensure its sustainability. In this context, in recent years, t-RFMOs adopted various measures to improve the collection of information related to FAD structure, activities and impact on target and bycatch species, and, more generally, to collect the data required to assess their impacts over the ecosystem. This information is crucial for developing science-based effective management, monitoring and the assessment of FADs, and assessing their impacts on the pelagic ecosystems and coastal habitats. Therefore, collecting more detailed data on FADs became a priority for t-RFMOs, in conjunction with stakeholders, which actively collaborated on improving the best standards and procedures for data collection and reporting [15–17].

Based on t-RFMOs requirements and guidelines, national efforts led to the adoption of FAD management plans, intended, among other things, to streamline data collection, reporting, and dissemination, while ensuring high data quality standards. Due to the complexity of the FAD purse seine fishery, each RFMO adopted specific provisions on FADs leading to requirements that are not harmonized. This absence of clear t-RFMO guidelines or harmonized definitions for relevant terms, plus the ambiguity of some definitions, led to significant data gaps worldwide [14–17].

As such, the Spanish Ministry of Agriculture, Food, and Environment, in close collaboration with the IEO (the Spanish Institution of Oceanography) and the Spanish tropical tuna purse seine fleet organizations ANABAC (National Association of Tuna Freezer Vessel Shipowners) and OPAGAC (Organization of Associated Producers of Large Tuna Freezers), implemented a FAD management plan (FADMP). This pioneering initiative, promoted by a flag state, led the implementation of FADMPs in t-RFMOs. Indeed, the FAD logbook developed in the framework of the Spanish FADMP (Table S1) is used as a template for various t-RFMOs and t-RFMO member countries. The Spanish initiative and the preliminary results of that initial work were detailed in Delgado de Molina et al. [18,19].

Since then, the Spanish FADMP is under constant review to adapt the data collection tools used by the skippers onboard and to improve data management [15]. On a global scale, FAD-related projects were promoted in recent years, and scientific efforts also focused on standardizing data collection and the development of globally harmonized definitions of technical terms related to this fishery [15,17,20–22].

In each interaction with a FAD, Spanish purse seiner and supply vessel skippers must collect information on the type of activity and provide information on the specific characteristics of the floating object and the attached buoys, as required in the new version of the Spanish FAD logbook form (Table S1) [15]. This is a new integrated and updated version of the first logbook implemented in 2011 [18,19], which was jointly re-designed by scientists and industry stakeholders [15]. The data collected on the Spanish FAD logbook respond to the t-RFMO FAD-related data requirements worldwide, collecting detailed information on the activities associated with FADs and other floating objects, its components and structure (both for the floating and hanging components), the electronic equipment (buoy type and echosouder capability), ownership, nature of the floating object, entangling character of the materials used, and interactions with target and bycatch fauna [15,17,20].

The Spanish tropical tuna purse seine fleet operates in the Atlantic, Indian and Pacific oceans and is currently composed of 28 fishing vessels, all with a minimum carrying capacity of 700 tons (15 operating in the Indian Ocean, 9 in the Atlantic Ocean, and 4 in the Pacific Ocean). Additionally, the fleet receives assistance from five supply vessels in the Indian Ocean [23] and three supply vessels in the Atlantic Ocean [24]. The Spanish fleet does not use supply vessels in the Eastern Pacific Ocean, where it is prohibited since 1998 [25,26], or in the Western and Central Pacific Ocean, despite the allowance of one supply vessel per at least two purse seiners according to the Western and Central Pacific Fisheries Commission (WCPFC) current regulations [27].

In this paper, we reviewed the challenges faced when adopting the Spanish FADMP to respond to t-RFMOs FAD data requirements and measures. The ultimate goal is to provide concrete recommendations to streamline both the data collection and data management systems in place to achieve improved timelines and quality of the information submitted to t-RFMOs.

2. The FAD Fishery: Challenges for a Science-Based Assessment and Management

Catch per unit effort (CPUE) abundance indices derived from commercial data and used in stock assessment are generally standardized to account for changes in catchability in long time series of data [25]. However, the standardization of purse seine CPUE is problematic due to the challenge of attributing effective effort to the tropical tuna purse seiners. This is particularly true for the FAD fishery, where catchability increased steadily throughout the years due to technological improvements that impact fishing efficiency [6,28–30].

The introduction of FADs in the tropical tuna fishery and the associated improved technology [30] is the most significant innovation introduced historically in this fishing sector [5], and this has compromised establishing a relationship between searching time and effective fishing effort [5,31]. The use of satellite-tracked buoys attached to FADs, and the monitoring of the biomass aggregated underneath FADs by means of echosounders integrated into the buoys, contributes to reducing the searching time between fishing operations. Moreover, the use of FADs could have modified skippers' behavior, namely increasing the number of sets by fishing day, exploring new fishing grounds, making the fishery more dynamic and with less marked seasonality [32]. Thereby, the skippers are not subject to the seasonal movements of the schools, nor to the run-off of plant debris washed from the coast during the rainy season, as in the origin of the fishery.

Given that abundance indices for tuna are mainly derived from commercial fisheries CPUE, distinguishing between the impacts of technological innovations and natural variations in perceived fish abundance is crucial [7,8]. Thus, while traditional catch rates for free-swimming schools mainly take into consideration the quantity of fish caught per set and the searching time, catch rate calculations for fishing on FAD-associated schools must take into consideration additional factors (for example, opportunistic changes from searching for free-swimming schools to fishing on FAD-associated schools, increase in sensor technology of FADs, collaboration between ships, or density of FADs in the water, among others) which can further complicate the task of the CPUE standardization process. Although difficulties still exist, scientists working on purse seine CPUE standardization recently made progress by including several FAD-related variables in the process [29–31]. However, long-term, accurate, and comprehensive information is needed for both historical and current use of FADs to improve FAD fishing derived CPUEs.

The original FAD designs, which consisted of floating bamboo rafts and purse seine net panels hanging underneath, received much attention due to their potential impact on the marine ecosystem [8,14]. Therefore, it is also very important to track the evolution of the materials used in the construction of FADs and assess the impact that different designs have on marine ecosystems. These impacts involve, among other things, interactions with marine megafauna, such as marine turtles and sharks, and stranding events in sensitive habitats such as coral reefs.

3. Tunas Regional Fisheries Management Organizations (t-RFMO) Requirements on FADs

Currently, there are four t-RFMOs managing tropical tuna fisheries: the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), and the Western and Central Pacific Fisheries Commission (WCPFC).

t-RFMOs called for FAD management plans in recent years, including data collection on FAD structure and materials, and the use of FADs by purse seiners and supply vessels, through different resolutions and recommendations in t-RFMOs (Table 1). Table 2 summarize the main requirements and management measures in force for FADs for the different t-RFMOs. For historical overview on FAD data requirements and report requests by Tuna RFMOs see also Table S2 in Supplementary Materials.

Table 1. Tuna-Regional Fisheries Management Organizations (t-RFMOs) resolutions and recommendations for data collection and reporting requirements on FAD fisheries.

t-RFMOs	Data Collection Requirements	Data Reporting Requirements
IOTC	Res. 19/02 [Annex I and II]; Res. 15/01—[Annex I and II]; No form provided	Res. 19/02 [1]; Res. 15/02 [2]; Guidelines for the reporting of fisheries statistics to the IOTC—Form 3FA/3FD/3BU
ICCAT	Rec. 21-01 Annex 2 [FAD logbook, activities with FADs] Annex 3 types of activities; Rec. 21-01—Annex 4 form [list of deployed FADs and buoys]	Rec. 21-01 [3]; Rec. 13-01 [4] Form: ST08-FadsDep form
IATTC	Res. C-19-01 (2 and Annex I) FAD Form 9/2018 Res. C-21-04	Res. C-19-01 [5]; Res. C-21-04 (20, 21, 24 and Annexes II, III and IV) [6];

Table 1. *Cont.*

t-RFMOs	Data Collection Requirements	Data Reporting Requirements
WCPFC	WCPFC ROP Minimum Standard Data Fields (available online at https://www.wcpfc.int/doc/table-rop-data-fields-including-instructions, accessed on 01-03-2022)	Not specified in the Resolutions

[1] Res. 19/02: IOTC resolution 19/02. Procedures on a fish aggregating devices (FADs) management plan 2019; [2] Res. 15/02: IOTC resolution 15/02 mandatory statistical reporting requirements for IOTC contracting parties and cooperating non-contracting parties (CPCS); [3] Rec. 21-01: ICCAT recommendation 21-01, recommendation by ICCAT replacing recommendation 19-02 replacing recommendation 16-01 on a multi-annual conservation and management programme for tropical tunas; [4] Rec. 13-01: ICCAT recommendation 13-01, recommendation by ICCAT amending the recommendation on a multi-annual conservation and management program for bigeye and yellowfin tunas 2013; [5] Res. C-19-01: IATTC resolution, Amendment to resolution C-18-05 on the collection and analyses of data on Fish-Aggregating Devices; [6] Res. C-21-04:. Conservation measures for tropical tuna in the eastern Pacific Ocean during 2022–2024.

Table 2. Summary of the main data requirements and current management measures on FADs for the different t-RFMOs on FADs for the different t-RFMOs.

	Requirements	ICCAT	IOTC	IATTC	WCPFC
(1)	Obligation to report school association	YES	YES	YES	YES
(2)	Specific form for data collection	YES	YES	YES FAD form 9/2018 (C-19-01) and Annexes II, III, and IV in C-21-04	NO
(3)	Obligation to report the total number of FADs deployed with beacon	YES	YES	YES	YES
(4)	Type of FAD activity	YES	YES	YES	YES
(5)	Number of operational buoys per day	YES	YES	YES	YES
(6)	Estimated number of FADs lost	YES	YES	NO	YES
(7)	Number of FADs transferred per month and 1 × 1 square	YES	YES	NO	NO
(8)	Utilization policy for by-catch reduction	YES	YES	YES	YES
(9)	Limitation area for deployed FADs	YES	YES	NO	YES
(10)	Limitation in the total number of active FADs with beacon	300 [1]	300 [2]	Progressive; 66–400 in 2022, 50–340 in 2024 [3]	350 [4]
(11)	Limitation of number of sets on FADs	NO	NO	NO	YES

[1] FADs with instrumental buoys (ICCAT recommendation 21/01); [2] 300 instrumented buoys are active at sea, moreover a maximum of 500 instrumented buoys may be acquired annually by each of its fishing vessel (IOTC resolution 19/02); [3] according to the carrying capacity of the vessel (IATTC resolution C-21-04); [4] Conservation and management measure for bigeye, yellowfin, and skipjack tuna in the Western and Central Pacific Ocean, Conservation and Management Measure 2021-01.

3.1. International Commission for the Conservation of Atlantic Tunas (ICCAT) Requirements

ICCAT recommendation 21-01 [33] establishes the obligation for contracting parties to provide data on FAD activities and FAD characteristics in the Atlantic Ocean. Moreover, recommendations 13-01 [34] and 16-01 [35] contain the data reporting requirements adopted by ICCAT, performed through the development of form ST08. During the ICCAT ad hoc working group on FADs in 2017 [36], the Secretariat highlighted that very few members had provided data using the official template (i.e., ST08 form), and other issues were observed such as compliance with the spatio-temporal resolution requirements or lack of homogenization in the criteria. In this line, Báez et al. [22] summarized how Spain interpreted ICCAT's data reporting requirements for activities on FADs. The paper described the difficulties to fulfill the official ST08 template and the need to harmonize the data types and coding systems across all t-RFMOs to avoid any issues of interpretation. The main observations and recommendations of that study were: (i) harmonization of the requirements from ST08 form; (ii) definition of terms and detailed description of each field (e.g., deployed FAD, active beacon, deactivated beacon, lost beacon); and (iii) harmonization on required information and codes among different t-RFMOs (e.g., FAD and beacon types).

In 2018 at the Standing Committee Research and Statistics (SCRS-ICCAT) meeting, a set of definitions on FAD and buoy related terms were proposed to the Commission, and the ST08 form was reviewed and is now composed of two sections: ST08A, to collect information on FAD activities with FADs (i.e., deployments, transfers and loss) by FAD type; and ST08B, to collect information on operational buoy densities. In addition, Rec 21-01, Annex 1 includes detailed guidelines for the preparation of FAD management plans, and Annex 5 of the same Rec 21-01 details how FADs can be designed and with which materials and characteristics.

3.2. Indian Ocean Tuna Commission (IOTC) Requirements

The IOTC has established guidelines for FAD management plans in the Indian Ocean. The most recent, resolution 19/02 [32] on procedures on a FADMP, includes: (a) a set of terms and definitions related to FADs and buoys; (b) a limitation on the number of operational buoys and instrumented buoys at any one time, and buoy purchase limits (it is highlight that this is a unique requirement t-RFMO wise, as IOTC is the only one that limits it); (c) more detailed specifications of catch reporting from FAD sets; and (d) the development of improved non-entangling FAD designs to reduce the incidence of entanglement of non-target species [32]. This conservation and management measure requires the following data to be collected on each interaction of a fishing vessel with a FAD: date, position, unique identifier, FAD type, design, type of visit, and catch reporting of target and non-target species if the visit is followed by a set. Moreover, it requires the number of instrumented buoys onboard, including each unique identifier of the instrumented buoy before and after each fishing trip, and daily information on all active FADs and position of all individual operational buoys followed by a vessel. However, similar to other t-RFMOs, some data requirements are not clear enough, and they are not defined in Resolution 19/02 [32] and integrated into the data reporting forms (i.e., 3FA, 3FD, 3BU). IOTC Secretariat developed the Form 3FA for the reporting of total numbers and types of FAD sets by purse seiners and supply vessels, by quarter, and fleet [20]. With the aim of harmonizing FAD terminology and requirements, Baez et al. [20] described the difficulties, raised questions, and provided interpretations on the FAD collection requirements under forms 3FA for IOTC to allow standardization in data submission. This paper also proposed a reorganization of Form 3FA, based on the results of the EU project CECOFAD, but the proposal was not adopted [37]. More recently, forms 3FD and 3BU were developed, but still, the ambiguity in the interpretation of FAD data requirements may result in the development of FAD logbooks not meeting IOTC's requirements or, worse, not addressing the scientific objectives.

3.3. Inter-American Tropical Tuna Commission (IATTC) Requirements

In the Eastern Pacific Ocean, the IATTC establishes data collection and reporting requirements for purse seine vessels operating with FADs on the IATTC convention area through resolutions C-19-01 [38] and C-21-04 [39]. Beginning on the 1st of January 2017, the purse seine vessel owners and operators shall collect and report the information contained in Annex I of resolution C-19-01 [38] for all the activities concerning FADs, including position, date, hour, identification, type, design characteristics, type of the activity, the resulting catch (both target and non-target species) when a FAD interaction leads to a set, and buoy or positioning equipment characteristics, if any are attached to the object. To record this information, the IATTC staff developed a standard format to be used onboard (i.e., FAD Form 9/2016, which was recently updated to FAD Form 09/2018 [40]). The form, which can be used in both paper or electronic format, is composed of two sheets, one dedicated to recording activities on FADs, including buoy changes to allow FAD tracking, and a second one to complete the inventory of FADs available or with which the vessel had an interaction, including specifications and characteristics of the raft and the hanging structure. The form also contains a field where the FAD's unique identification code should be input, which is either the code (which include alphanumeric and symbols characters) of the buoy provided by the manufacturer or the unique FAD identification number provided by the IATTC staff. However, so far, only buoy ID is used for this purpose for all flags [16]. The two-sheet structure of the form (i.e., activity and inventory in separate sheets), which is similar to the original version of the Spanish FAD logbook that is used to collect data since 2011, as well as the possible use of FAD IDs, make the form less user-friendly, according to some Spanish operators. The new version of the form, includes information on different buoy types and how they are codified by manufacturers. Besides, the macro-enabled digital version of the FAD form allows operators to reduce typing errors in both the numeric and character part of the buoy ID, which has significantly improved data quality and, therefore, usability. Not having access to correct buoy IDs prevents scientists from tracking FADs effectively and is identified by the IATTC staff as one of the most important drawbacks to advance science [16].

In 2021, with the establishment of tropical tuna conservation measures for 2022–2024 [39], which includes limits on the number of active FADs that a single purse seine vessel can use at any given time, new data reporting requirements were established. Starting on 1 January 2022, member states shall report, or request their vessels to report, raw daily information (both the buoy position data and echosounder biomass records received by the original users) of all active FADs to the Secretariat for scientific purposes, with a delay of between 60 to 90 days, following the guidelines established in the resolution (Annexes II, III and IV). These guidelines, also establish the data reporting format for remote activations and deactivations of the active FADs tracked by a vessel, including the reason to request such a service.

López et al. [16] recently reviewed FAD data collection and reporting requirements in the IATTC convention area, identifying data gaps, inconsistencies, and potential solutions with regard to FAD logbooks and active FAD's information. The document highlighted the need to harmonize FAD-related terms for consistency in IATTC resolutions and data collection and reporting. Similarly, a web-based application was proposed as a data collection tool to facilitate data reporting, improve quality, and adapt to the technology era [16]. Similar problems were discussed at the Ad Hoc FAD Working Group [41], which recommended continuing working across t-RFMOs on the harmonization of data collection, definitions, indicators, and other cross-cutting issues. In the meantime, the IATTC adopted a series of working-definitions for the FAD fishery, which can be found in Annex I of Resolution C-21-04.

3.4. Western and Central Pacific Fisheries Commission (WCPFC) Requirements

The scientific data requirements in this t-RFMO include the provision of operational-level (by fishing event) reporting. In the case of the purse seine fleet, CCMs (members, cooperating non-members, and participating territories) must provide information on the position, date, time, type of set, and catch composition of each set. Hence, information related to FAD sets catches is available at the maximum possible resolution. As for other information related to FAD activities, the scientific work of this t-RFMO heavily relies on the information collected by scientific observers. CMM 2008-01 [42] established the obligation for purse seiners, from 2010, to carry an observer of the Commission's Regional Observer Programme (ROP) for those vessels fishing on the high seas, within the area bounded by 20° N and 20°, those fishing on the high seas and in waters under the jurisdiction of one or more coastal states, or vessels fishing in waters under the jurisdiction of two or more coastal states [43] expanded the obligation to carry an observer to those vessels fishing solely within its national jurisdiction. The 100% observer coverage requirement for purse seiners has remained since under the subsequent amendments of this management measure for tropical tunas. According to the ROP minimum standard data fields [44], observers are required to, at a minimum, record information on FAD structure, origin, electronic-associated equipment, activity, any ID, etc.

In this t-RFMO, there are regional initiatives aimed at the collection of information on FADs, such as the standardization of protocols for Pacific Islands Forum Fisheries Agency (FFA) member countries (SPC/FFA form GEN5 for FAD-related data) or the Parties to the Nauru Agreement (PNA) FAD tracking programme. The latter, initiated in 2016, is unique in its nature since it requires fishing companies to report data from satellite buoys deployed on FADs to the PNA via the satellite service provider [45,46], and has provided a wealth of information on some of the least assessed ecosystem impacts of FADs (rate of FAD loss and beaching), as well as a better understanding of the actual number of FADs with active buoys used per vessel annually.

3.5. Work across t-RFMOs

During 2017, a technical joint working group on FADs (TJWGF) was created to progress intersessionally on the priorities identified by the Joint t-RFMO FAD Working Group (JWG). A road map was defined to work on harmonization of terms to be presented in the second joint FAD working group, to be held in 2019 [47]. These had to be reviewed by each t-RFMOs for adoption, as the process still used in IATTC, IOTC, and ICCAT, including the set of definitions in Res. C-21-04, Res. 19/02, and Rec. 21/01, respectively [32,33,39]. The JWG recommended that minimum standards for data collection should be reviewed by the relevant technical or scientific working groups within each t-RFMO, and revised or adopted as appropriate, which is in progress. Discussions on minimum data collection standards should be prioritized in the future work of the JTWG. The reactivation of the JTWG to work in these subjects was also requested by the Ad Hoc FAD working Group at IATTC.

In addition, the JWG identified the need of submitting the high-resolution buoy position for research purposes as a priority. Two main data sources are generally sought for FAD fishery research: (i) information collected by skippers in FAD logbooks and (ii) buoy transmission data (both on buoy position and echosounder biomass records) directly reported to research institutes. Data collection and reporting based on these two datasets is intended to provide scientists with the necessary information to assess the impact of FADs (e.g., stranding events) and inform the development of more effective conservation and management measures.

Onboard observer's data can sometimes complement this information. In the Atlantic and Indian oceans, the Spanish observer program was established in 2003 under the scope of the European Union (EU) Data Collection Framework [48]. The observer coverage was around 10% until 2015, when the monitoring coverage increased significantly through private programs funded by the industry. From this year, the coverage achieved is close to 100% (either by human observers onboard and/or by electronic monitoring systems). In the Eastern and Western Pacific Ocean, the coverage of the regional observer programs was 100% since 2009 and 2010, respectively. The EU developed a National Tuna Observer's

Program in the IATTC convention area in 2003, which covers 50% of these trips, while the remaining 50% are covered by the IATTC Regional Observer Program. All these programs collect detailed information on FAD activities and FAD structure/design that can be cross-checked with that collected by skippers in FAD logbooks or obtained through buoy track information.

On the other hand, it is important to note that a common practice in the purse seine fishery is to fish on both owned and tracked FADs and on untracked FADs (FADs found opportunistically in the water but belonging to, or tracked by, a different vessel), or other floating objects such as logs encountered by chance that are tagged and tracked later with a buoy, becoming part of the vessel's FADs stock. FAD and buoy exchange-replacement among vessels (including of different flags) is a very common practice and complicates the data collection and reporting process. Because of that, Ramos et al. [19] recommended specifying the ownership (whether you track the FAD or found the FAD opportunistically), if available, in each FAD activity recorded in the FAD logbooks and to establish mechanisms to make the exchange of the information between different member states possible. Some t-RFMOs, such as the IATTC, are aware of this issue and thus, ask the observers to specify, whenever possible, the ownership of the FAD involved in the activity. Similarly, certain FAD logbooks include two fields for buoy ID, where the original and the replacement codes of the buoys must be recorded (e.g., FAD form 9/2018 of IATTC and Spanish FAD logbook—see below), which ideally allows tracking individual FADs in the case of buoy replacement.

4. Spanish FAD Logbook: Integrating All t-RFMOs Requirements and Fleet Needs

In the case of the Spanish FADMP [18,19], the main aim was to merge in a single FAD logbook all the current t-RFMOs FAD-related requirements to collect high-quality data in a user-friendly format. This included information on buoy ownership and buoy type, activities with floating objects, the FAD construction characteristics, design, and materials. Data from the FAD logbook, in conjunction with FAD position data from buoys, allows us to assess: (i) effort changes and dynamics, (ii) to track the FADs during their lifetime, (iii) to improve knowledge on the potential impacts of FADs on the aggregations, including both target and non-target species, and (iv) to increase the knowledge on the impact of FADs on the ecosystem.

The Spanish FADMP was reviewed several times since it was first implemented in 2010. The first version of the FAD logbook had two forms, one for the inventory of FADs and another one for the activities on FADs. Later, due to the numerous issues that implied matching each FAD activity with the inventory (coding, changes in FAD structure, encounters with foreign FADs), a single FAD logbook form was developed in 2017, where information on FAD structure and activity is recorded jointly.

The new common data collection FAD logbook was developed by integrating the particular data collection and reporting requirements of different t-RFMOs while developing, at the same time, a form that facilitates operators' data collection and minimizes workload and errors (e.g., the form has to be easy to fill in by skippers), and ultimately improves the data quality and usefulness. This "new" FAD logbook was progressively adopted by the fleet since 2017.

The experience of the Spanish FADMP suggests that a FAD logbook that can be used globally, hence meeting the requirements of the different t-RFMOs, should: (i) be user-friendly so as to allow the recording of good quality information while decreasing data entry errors, (ii) preferably merge all the information in a unique form, including details of activities and FAD and buoy characteristics, (iii) include the definition and description of the parameters/data required to fill in to avoid misinterpretation and ambiguity, and (iv) allow the skippers to record information in an objective way and as disaggregated as possible to allow the scientist to classify each activity and FAD type (e.g., non-entangling or entangling FAD).

The FAD logbook includes information on metadata (number of trip, date, time, owner of FAD, buoy), activity (deployment, verification, set, modifications over previous objects, retrieval at sea, loss, recovery at port), description of floating parts, description of the underwater hanging structure, catches, and bycatches. Moreover, a user-manual and improved communication mechanisms were developed to facilitate information exchange and feedback with skippers. For example, an email address was created to solve any inquiry that the skippers may have. This feedback facilitates and reduces the time spent preparing the data to be reported to the t-RFMOs.

Apart from the FAD logbook, buoy providers working with all the Spanish purse seine companies operating in all oceans provide daily operational FAD tracking data on a monthly basis (with a time-lag of two months), information of the biomass from echosounder data on a yearly or monthly basis to research institutes and time-series of the number of FADs from 2010 [17] with the objective to (i) verify the compliance with the FAD limitations in each t-RFMO and (ii) carry out scientific analysis to inform the scientific management advice in t-RFMOs (e.g., CPUE and Tuna Biomass Abundance Indices using FAD echosounder biomass information), for example [49].

5. Error Quantification in Spanish FAD Logbooks

Once received, FAD logbooks are subject to depuration routines to ensure that the information is collected following a standardized procedure. Due to the nature of the data collection tool (Microsoft Excel templates), there can be errors in the values entered (e.g., positions inland), in the field formats (e.g., skippers may insert numeric values with points or commas as decimal separators) or in the way information is entered (e.g., sometimes, the structure of a FAD when it is left back in the water is registered in the logbook before the recording of the original FAD structure—when it is found and hauled onboard).

All these depuration routines ensure that data can be then post-processed for the provision of mandatory information to t-RFMOs or for scientific studies.

In order to quantitatively evaluate temporal trends in the quality of data collection, an ad hoc procedure based on the computation of Levenshtein distance was performed. The Levenshtein distance measures the difference between two-character strings as the minimum number of single-character edits (insertions, deletions or substitutions) required to change one word into the other [50]. In brief, each field in the "original" and "modified" depurated FAD logbook was transformed into lower and upper case letters, all the fields were merged into two character strings, and they were compared by measuring the Levenshtein distance between both. An example of the procedure is provided in Table 3.

Table 3. Example on the computation of the error rate in FAD logbooks of how we performed character-strings from the fields of the FAD logbook. For the "original" example, the character-string is ABBABCABBAAB, while in the "modified" example, the character-string is ABABBACCAAB.

Nº Buoy	Vessel	Date	Activity		Nº Buoy	Vessel	Date	Activity
Original					**Original**			
ISL+123545	Seahorse	27 January 2015	Set	=>	A	A	A	A
M3I125567	Bluefin	28 January 2015	Set		B	B	B	A
M3I125567	Manta ray	28 January 2015	Modification		B	C	B	B
ABBABCABBAAB								
Modified					**Modified**			
ISL+123545	Seahorse	27 January 2015	Set	=>	A	A	A	A
M3I125567	Bluefin	29 January 2015	Set		B	B	C	A
	Bluefin	29 January 2015	Modification		C	B	C	B
ABCABBACCAAB								

Levenshtein distance (4): ABBABCABBAAB→ ABCABCABBAAB→ ABCABBABBAAB→ ABCABBACBAAB→ ABCABBACCAAB; Error rate = 4/12.

The error ratio (measured as the number of fields modified during the depuration process divided by the total number of fields) was computed by year and by logbook type ("old" and "new" formats) for the period 2015–2019.

Results show that the rate of error has decreased from the old to the new format (Figure 2). It also evidences a general improvement in the quality of data collected within each format, except for an increase in the error rate in the old format concomitant with the introduction of the new template. The adoption of the new format was encouraged from the beginning, but its adoption was progressive across the fleet. It is hypothesized that those skippers that were more committed and more familiar with the collection of the information were the first to shift to the new template, while those less "enthusiastic" and more prone to errors in the recording of data might have continued using the old templates.

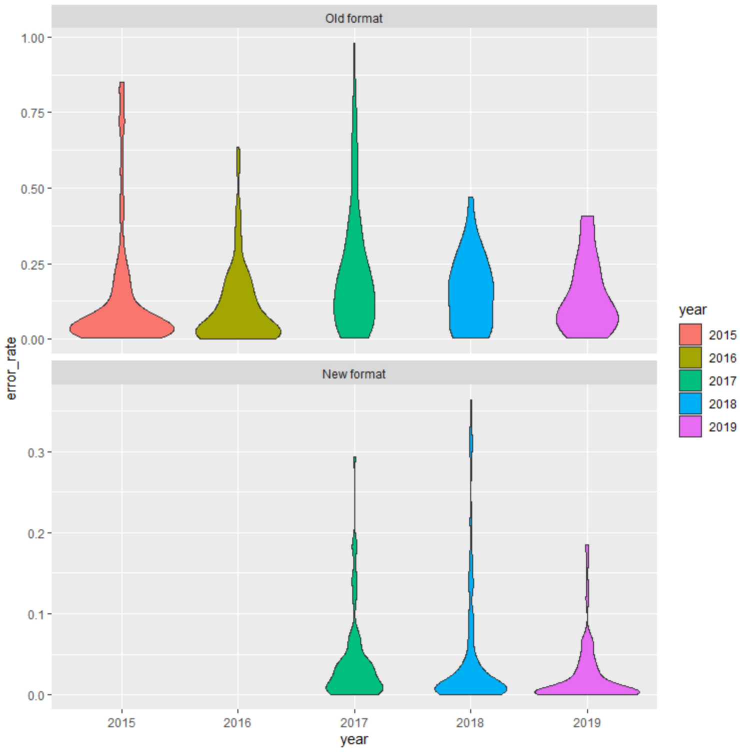


Figure 2. Error rate (number of modifications/total number of fields) in FAD logbooks by year and logbook type.

6. Final Remarks

FAD data collection programs need to respond to both scientific and management objectives. Among the scientific objectives, improving the knowledge of the FAD fishery, evaluating aspects such as fishing effort (e.g., for the standardization of the catch per unit effort), estimation of biomass abundance indices using the FAD echosounder biomass signals, or the impacts on the ecosystem associated with their use, are paramount and meeting them will help provide the best scientific advice to assist fisheries managers and decision makers.

Ideally, this information should contribute to the estimation of purse seine indices of abundance (for example, estimating independent biomass abundance indices from FAD echosounder buoys) and a better understanding of fishing effort. There are other important tasks that would benefit from more information on activities with FADs (e.g., fishery closures intended to reduce the catches of juveniles, impacts of different FAD designs on bycatch, etc.).

The Spanish FAD logbook is a tool to record the characteristics of the FADs and buoys (model and ownership) and all the activities performed on FADs and buoys, including modifications or replacement of buoys or other components. This information is complemented with information on daily operational FAD buoy tracking and biomass data provided by buoy providers directly to scientific institutions, which can hardly be derived from the FAD logbook. The information collected in the FAD logbook can be used to monitor evolution on buoy technology, FAD materials used in its construction (entangling character and biodegradable nature of the materials) and the dimension of FAD components (i.e., raft and underwater structure). The data can be used to evaluate the implementation of mitigation measures (e.g., entanglement character of FADs or the implementation of biodegradables FADs), evolution on the technology associated with FADs and derived indicators of FADs used by the Spanish fleet that should be integrated to derive tuna abundance indices.

The experience with the Spanish logbook shows that the data collection and reporting requirements of the t-RFMOs should be clearly defined and harmonized and be based on management goals and the subsequent use of the data. This could be accomplished by either adopting common data collection protocols among all member states participating in the fishery or by coordinating national FAD data collection protocol plans from all those member states so that data from each flag state could be easily merged at the t-RFMO level. This harmonized information could also help to monitor changes and developments in FAD designs. The ultimate goal should be to achieve a sustainable design for FADs, made of both biodegradable and non-entangling materials in all oceans.

Finally, it is necessary for the t-RFMOs to continue work on harmonization, through the joint-FAD group, towards the adoption of a global FAD logbook in t-RFMOs and to integrate it into an electronic tool or software to facilitate and standardize the data collection, data sharing, and processing, and provide training to operators and member countries.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14063278/s1, Table S1: Spanish FAD logbook. Table S2: Historical overview on FAD data requirements and report requests by Tuna RFMOs.

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