CECOFAD REPORT

Catch, Effort and eCOsystem impacts of FAD-fishing

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ANABAC OPTUC ASOCIACIÓN NACIONAL DE ARMADORES DE BUQUES ATUNEROS CONGELADORES

ORGANISATION DES PRODUCTEURS DE THON CONGELÉ ET SURGELÉ ORTHONGEL ASSOCIATION LOI DE 1901

Sommaire

1 Title of the project

Catch, Effort, and eCOsystem impacts of FAD-fishing (CECOFAD)

2 Objectives

The overall objective of the CECOFAD project was to provide insights into the definition of the fishing effort associated with drifting fishing aggregating devices (DFADs) and to introduce factors describing the technology associated with this fishing mode into the standardization of tropical tuna purse seiner catch-per-unit-of-effort (CPUE) in the Atlantic, Indian and Pacific oceans, where the European fleets are operating. Within the framework of the Ecosystem Approach of Fisheries, it was assumed that the CECOFAD project would help to improve knowledge on the effect of FAD fishing on the associated fauna, specifically vulnerable species (sharks, turtles, etc), in the bycatch.

Given the number of different species associated with tropical tuna purse seine fishery and the regular requests from tuna RFMOs to European scientists to provide reliable estimates of abundance and accurate indicators of the effect of FAD fishing on juvenile bigeye and yellowfin tuna and on bycatch species, the main objectives of the project were:

1. to define a unit of fishing effort for purse-seiners using FADs that accounts for factors influencing catchability,
2. to standardize catch-per-unit-effort series of the EU purse seine fleet, for juveniles and adults of the three tropical tuna species,
3. to provide information on catch composition around FADs and estimate the impacts on other marine organisms (e.g. bycatch of sharks, rays and turtles).

To achieve these objectives, CECOFAD was organized into 4 Work Packages (WPs), as follows:

- WP 1- Definition of a unit of fishing effort for purse-seiners using DFADs that accounts for different factors influencing catchability (Objective 1 of the project),
- WP 2- Standardization of catch-per-unit-effort series of the EU purse seine fleet, for juveniles and adults of the three tropical tuna species and exploration of some FAD-regulations in management strategies (Objective 2, in conjunction with WP 3),
- WP 3- Alternatives to CPUE (Objective 2, in conjunction with WP 2),
- WP 4- Catch composition around FADs and estimation of potential effects on other marine organisms (Objective 3).

In addition to these four WPs, transversal activities were conducted to coordinate the technical aspects of the project, the database management, the website development and the project administration and management. Given the importance of data management (definitions, minimum data requirement and links between the various databases) these activities were grouped into a separate work package, WP5.

3 Executive summary

The European Research project "Catch, Effort, and eCOsystem impacts of FAD-fishing" (CECOFAD) set out to improve our understanding of the use of drifting fish-aggregating devices (DFADs) in tropical purse seine tuna fisheries in open ocean ecosystems. As there are no suitable procedures for the standardization of purse-seiner CPUE indices, most of the assessments of tropical tuna stocks worldwide are based on longline CPUE indices which rarely take account of the implementation of new technology in the standardization process and only reflect the biomass of the older fraction of tuna populations. Consequently the main tasks defined in CECOFAD were to provide insights into the fishing effort units for DFAD and free school sets to be used in the calculation of European purse-seiner CPUEs to provide standardized indices of abundance for juvenile and adult tropical tuna. Taking account of the implementation of DFADs in the early 1990s and, more generally, the continuous implementation of new fishing technology by purse seiner fleets is acknowledged by tuna RFMOs to be a major challenge in the CPUE standardization procedure.

Despite delays in starting the project owing to administrative constraints and recruitment problems, data from unofficial technology information related to FAD-fishing were retrieved during the first 12 months of the project. Important data, such as the link between individual purse seiners and supply vessels, are still lacking for some fleets but new information on changes in fishing devices over time, in particular quantification of the technological changes in terms of systems used for positioning buoys at-sea (radio or satellite transmitters) and the numbers of echo sounder buoys became available for the first time in 2014. Maps of DFADs deployed at sea and associated fishing strategies were also analyzed and published. The total number of DFADs deployed at sea over the last ten years was estimated for the Atlantic and Indian oceans based on the number of active DFADs per vessel provided by the French tuna association, the catch per DFAD set and the total catch on DFADs for the various purse seiner fleets. Another approach, based on GPS buoy tracks of the DFADs and logs for the French fishery, combined this DFAD data with orders from French fishing companies for buoys, surveys of purse seine skippers and scientific observations onboard the whole EU purse seiner fleet to evaluate the total number of DFADs and total number of buoys at sea. Data collected within the framework of the Spanish and French FAD National Management Plans were used to determine the proportion of time spent on the various activities carried out when using DFADs (deployment, visits, retrieval and changing buoys). For the first time, the relationship between the number of active DFADs and the catch per Spanish purse seiner (with or without the assistance of a supply vessel), per ocean and per quarter was explored.

Owing to the difficulty of gathering unofficial information, the standardization of CPUE was limited to juvenile bigeye caught using DFADs and to non-standard explanatory variables provided by the French fleet. Generalized linear models and generalized linear mixed models for delta-lognormal distributions were developed and Lasso approaches were used to select the variables rather than standard variable selection methods, as there were a large number of initial variables which could lead to over-fitting and computational problems. The analysis was repeated for the combined French and Spanish fleets but with a smaller number of predictors because data for the Spanish fleet was missing. However the relevance of some non-traditional factors was highlighted, in particular the links between each supply vessel and its associated purse seiners. In addition, it was suggested that the moderate range of variation in some explanatory variables for the French fleet (e.g., each vessel deploys about the same number of DFADs and/or buoys) might be a limiting factor during the process for selecting the predictors for CPUE standardization. To take account of the spatio-temporal dynamics of the French DFAD fishing activity, an attempt was made to incorporate geographical distance into the standardization process. However, because no spatial organization was found, only the geographical distribution of DFAD sets in relation to the area explored by the fleet was analyzed.

Data collection and the organization of non-standard information for standardizing the Spanish purse seine CPUEs are still in progress.

As an alternative to CPUE, direct indices of tuna abundance through the use of echo sounder buoys attached to DFADs in the Spanish fleet were investigated during CECOFAD. Estimating the abundance of tuna and non-tuna species directly using echo sounder buoy acoustic biomass data requires gathering and processing heterogeneous echo sounder buoy information. For this reason, developing a consistent echo sounder buoy database was considered to be a priority. This led to the identification of several criteria required for cleaning datasets before standardizing an abundance index derived from echo sounder buoy data. It was assumed that the "alternate" Buoy-derived Abundance Index (BAI) was linked to abundance using a coefficient of proportionality. Because this coefficient is not constant, nominal measurements from echo sounder buoy records were standardized using a GLMM approach and a delta-lognormal distribution was used to estimate BAI as the product of the probability of presence of tuna and the mean relative abundance where there was a positive observation. Behavioral models representing the continuous process of association and disassociation, as well as the residence time under FADs, were also identified as an alternative to commercial catch data for estimating abundance. Electronic tagging data, coupled with measurements of the FAD-associated biomass obtained from echo sounder buoys, could be used to obtain fisheries-independent indices of tropical tuna abundance. However, to date these behavioral models have been used only to assess the proportion of the fish population associated with anchored FADs (AFADs). Because industrial purse seiners do not usually use AFADs, further research is required to determine the temporal and spatial dynamics of fish aggregations under DFADs.

The information collected by national FAD management plans, preliminary data on the rate of deployment of non-entangling DFADs and the apparent survival rate of released species of incidental catch were analyzed to evaluate the impact of FAD fishing on oceanic epipelagic ecosystems. Because concerns over the incidental capture below the DFADs of entangled pelagic sharks has been the subject of several regulatory measures by tuna RFMOs, a preliminary analysis was conducted to characterize environmental factors determining the habitat of silky sharks in the Atlantic and Indian oceans. Observing good practices continues to be one of the objectives of the EU purse seine fleets as a means of reducing mortality of vulnerable species. Preliminary observations of release operations from some Spanish purse seiners suggested an improvement in shark release conformity between consecutive fishing trips. Attempts to determine how the DFAD density and soak time affect the bycatch biomass and taxonomic composition was conducted by the French tropical tuna purse seine fishery. However, it proved difficult to match fishing sets in the observer datasets with DFAD spatio-temporal trajectory data, and the resulting dataset was too small to produce meaningful results. As the ratio of French to Spanish vessels was not the same in each 1°x1° square, this spatial variability in DFAD density should be taken into account in the future.

Time-area moratoria on DFADs, introduced regularly by tuna RFMOs since the mid 1990s, are limited to the protection of juvenile tuna and do not take account of the potential impact on bycatch or associated megafauna (whales and whale sharks). A simple iterative "fishing-day" model was developed to investigate the consequences on tropical tuna and bycatch of introducing wide area, six-month moratoria on DFAD sets. The model took account of the probability of the occurrence of several different fishing events and skippers' on-the-spot decisions based on European purse-seine fishery data. Monte Carlo simulations included realistic scenarios in terms of difference in fishing strategies (e.g., DFAD targeting as observed for the Spanish fleet or combining DFAD and free schools fishing as seen for the French fleet) and reallocation of the fishing effort (e.g., at the periphery of the regulated area or to traditional fishing grounds). As expected, for both the Atlantic and Indian oceans, the models predicted a decrease in DFAD sets and an increase in free school sets. As a consequence, the catch of small tuna (<10 kg) decreased (except for the French fleet in the Atlantic Ocean) while the catch of large tuna (≥10 kg) increased, leading to an overall decrease in tuna catch of ~100 t/yr/boat in the Atlantic Ocean and 600–1800 t/yr/boat in the Indian Ocean. The bycatch for all groups considered (other bony fishes, billfishes, sharks and turtles) decreased, except in the Atlantic Ocean, where the turtle and shark bycatch increased slightly for both fleets. Because the fishing practices were modified, whale and whale shark associated sets increased slightly in the Indian Ocean. As the effects of moratoria on fishing strategies are difficult to predict, simulations based on fishery data are a useful means of evaluating the trade-offs of time-area closures as part of an ecosystem approach to fisheries.

Another important aspect is the potential damage of lost DFADs on vulnerable coastal ecosystems. French GPS buoy trajectories were analyzed to detect DFAD beaching events in the Atlantic and Indian oceans. This showed that, for the period 2007-2013, around 10% of the trajectories of floating objects with GPS-buoys ended with a "beaching event" in the Atlantic and Indian Oceans, suggesting that 1,500-2,000 may be lost onshore each year, with significant portions of these beaching events occurring in areas with sensitive habitats, such as coral reefs. Maps of smoothed densities of DFAD beaching events and their deployment positions were produced and published in a peer-review journal.

Bycatch data collected under the EU observer programs in the Indian, Pacific and the Atlantic Oceans, was used to evaluate the effect of FAD-fishing in terms of alpha and beta diversity, rarefaction curves and biomass metrics. Regional differences were identified but the species diversity associated with the DFADs was found to be richer than for free school sets. The species composition and the structure of the community were directly related with the fishing mode and the environment in which the species lived. Diversity was explained by surface currents, wind patterns and upwellings at global scale, and by front systems, domos and eddies for both fishing modes at local scale.

One of the challenges of the CECOFAD research project was to provide links between the various sources of information (logbooks, observer data, VMS, echo sounder data, etc) used in the project. As a first task, the two French versions of the *Balbaya* (logbooks) and *ObsTuna* (observer data) databases were linked using the Standard Data-Exchange Format used within the EU Data Collection Framework (DCF). This format allows a data aggregation level which is as low as possible while respecting data confidentiality issues and consequently should be considered as a good candidate for the exchange of data within the tropical tuna fishery research community. Furthermore, this format can be used with the R "COST" package to export the national databases.

FAD-fishery indicators are presented regularly at annual tRFMO meetings. However, when these indicators are calculated, various problems are found in the logbook data owing to the lack of definition or imprecision of DFAD-fishing activity data. Consequently, one task of CECOFAD was to review the definitions of variables required for evaluating DFAD-fishing activities that should be continuously recorded in logbooks (regardless of whether an electronic or paper logbook is used). On the basis on the most recent recommendations from tRFMOs (ICCAT and IOTC), the original electronic fishing logbook data model (ERS) was extended to floating objects and then updated to meet IATTC and WCPFC recommendations. To incorporate the information required for measuring the DFAD-fishing effort and to produce indicators of the effect on the ecosystem of deploying floating objects, these extensions now include a new classification of floating objects and a detailed list of operations (including buoy activity) to be filled in by the skipper.

In order to bring the objectives and achievements of the project to the notice of a wide audience, a website (http://www.cecofad.eu/) was developed right from the start of CECOFAD. The website will be maintained for 2 years after the completion of the project.

4 Detailed description

4.1 Bodies involved

Because science-industry partnerships can improve the quality and availability of data and knowledge, the project research is fostering collaborative research between operators and scientists, without compromising the independence of the latter. CECOFAD is co-funded by EU-DG Mare, 3 scientific institutes (IRD, IEO and AZTI) and 3 professional tuna owner company associations (ANABAC, OPAGAC and ORTHONGEL).

4.2 Workshops of CECOFAD

Kick-off meeting

The kick-off meeting was conducted in Montpellier (France), 1-3 April, 2014. The IRD was in charge of the Workshop organization. A total number of 25 participants attended the kick-off meeting. Table n° 1 shows the list participants by institutions. The report of this meeting is presented in **Annex 1**).

Paricipant	Institution	Country	Presence/visio	Funding
Capello Manuela	ULB	Belgique	Present	ULB
Clermidy Sonia	IRD	France	Present	Cecofad
Daniel Patrick	CE	Belgique	Present	CE
Ariz Javier	IEO	Spain	Present	Cecofad
Delgado Alicia	IEO	Spain	Present	Cecofad
Chavance Pierre	IRD	France	Present	Cecofad
Moreno Gala	AZTI	Spain	Present	Cecofad
Dagorn Laurent	IRD	France	Present	Cecofad
Billet Norbert	IRD	France	Present	Cecofad
Lebranchu Julien	IRD	France	Present	Cecofad
Monteagudo Juan Pedro	OPAGAC	Spain	Present	Cecofad
Sharma Rishi	IOTC	Seychelles	Present	IRD
Cauquil Pascal	IRD	France	Present	Cecofad
Menard Frederic	IRD	France	Present	Cecofad
Simier Monique	IRD	France	Present	Cecofad
Kaplan David	IRD	France	Present	Cecofad
Bessigneul Guillaume	IRD	France	Present	Cecofad
Escalle Laurianne	IRD/UM2	France	Present	Cecofad
Saulnier Erwan	IRD	France	Present	Cecofad
Maufroy Alexandra	IRD	France	Present	Cecofad
Gaertner Daniel	IRD	France	Present	Cecofad
Floch Laurent	IRD	France	Present	Cecofad
Goni Nicolas	AZTI	Spain	Present	Cecofad
Muniategi Anertz	ANABAC	Spain	Present	Cecofad
Roubion Jean-Jacques	IRD	France	Present	Cecofad

Table n° 1 : List of participants to the "kick-off meeting" held at Montpellier (France), 1-3 April, 2014

Final meeting

The final meeting was conducted in Pasaia, Guipuzcoa (Spain), 3-5 November, 2015. The AZTI was in charge of the Workshop organization. A total number of 22 participants attended the final meeting, some of them by visio-conference. Table n° 2 shows the list participants by institutions. The report of this meeting is presented in **Annex 2**).

Paricipant	Institution	Country	Presence/visio	Funding
Clermidy Sonia	IRD	France	Present	Cecofad
Escalle Lauriane	IRD/UM2	France	Present	Cecofad
Merigot Bastien	UM2	France	Present	Cecofad
Moreno Gala	ISSF	Spain	Present	ISSF
Snouck-Hurgronje Julia	VIMS	USA	Present	IRD
Soto Maria	IEO	Spain	Visio-conf	N/A
Sotillo Begona	IEO	Spain	Present	Cecofad
Maufroy Alexandra	IRD	France	Present	Cecofad
Santiago Josu	AZTI	Spain	Present	Cecofad
Fraile Igaratza	AZTI	Spain	Present	Cecofad
Goni Nicolas	AZTI	Spain	Present	Cecofad
Orue Blanca	AZTI	Spain	Present	Cecofad
Lopez Jon	AZTI	Spain	Present	Cecofad
Murua Jefferson	AZTI	Spain	Present	Cecofad
Murua Hilario	AZTI	Spain	Present	Cecofad
Gaertner Daniel	IRD	France	Present	Cecofad
Floch Laurent	IRD	France	Visio-conf	N/A
Lebranchu Julien	IRD	France	Visio-conf	N/A
Billet Norbert	IRD	France	Visio-conf	N/A
Goujon Michel	ORTHONGEL	France	Visio-conf	N/A
Bez Nicolas	IRD	France	Present	Cecofad
Lezama Nerea	AZTI	Spain	Present	Cecofad

Table n° 2 : List of participants to the "final meeting" held at Pasaia (Spain), 3-5 November, 2015

5 Activities by Working Package

5.1 WP1 - Definition of a unit of fishing effort for purse-seiners using DFADs that takes into account various factors affecting catchability

WP1-Objectives

Until recently, the fishing effort for purse seine fisheries, dominated by sets on free-swimming schools (FSCs) and natural floating objects ("logs"), has been expressed as the daylight hours spent looking for visual cues of tuna schools minus the time taken for the set (i.e., the searching time). However, the increase in fishing efficiency due to new technologies that have been introduced and the use of drifting artificial fish aggregating devices (DFADs) since the early 1990s (Ariz et al, 1999; Hallier and Parajua, 1999) have broken the link between searching time and effective fishing effort for DFAD sets (Fonteneau et al, 1999). Remote detection of satellite-tracked dDFADs often allows purse seiners to move directly towards a buoy, sometimes at night, avoiding or significantly reducing searching time. In addition, the recent development of satellite-tracked echo sounder / fish finder units attached to floating objects gives purse seiners real-time information about fish schools aggregating around DFADs and has resulted in an increasing proportion of successful DFAD sets. The use of supply vessels, which can visit DFADs and inform purse seiners on the fish aggregations around these DFADs, also contributes to the efficiency of some purse seiners (Arrizabalaga et al, 2001).

WP1-Data used

The following time line (Figure n° 1) for quantitative and qualitative changes in onboard fishing technologies for purse seiners, including DFAD design and use, was determined during the EU research project ESTHER (Gaertner and Pallares, 1998) for the French fleet and updated by Torres et al. (2014) for the period 1980-2008.

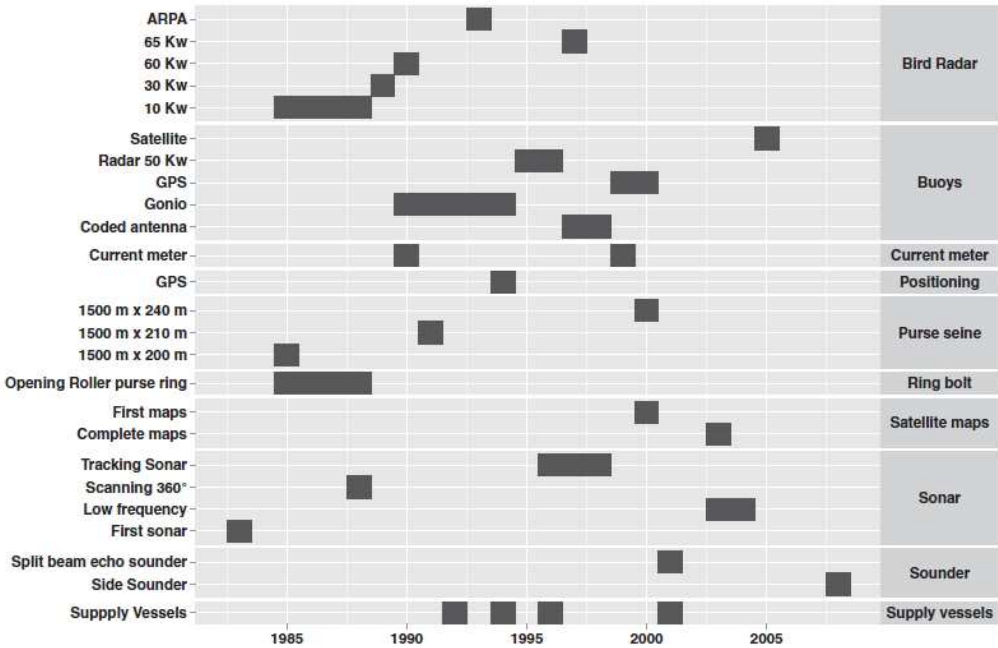

Figure n° 1 : Dates of introduction of new onboard fishing technologies for French purse seiners (Torres-Ireneo et al, 2014)

Recently, following the study by Moreno et al (2007), new information on the technologies associated with DFAD-fishing was collected by Lopez et al (2014) for the Spanish fleet for the period 1980-2014 (Figure n° 2).

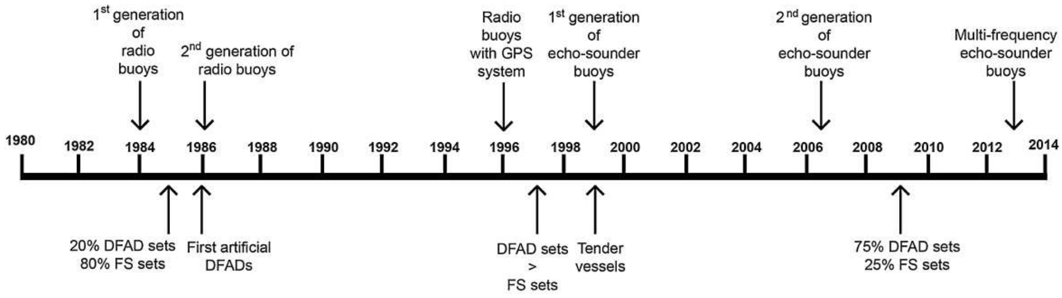

Figure n° 2 : Time line of changes in the equipment used for DFAD fishing by Spanish purse seiners (Lopez et al, 2014)

The European Research project "Catch, Effort, and eCOsystem impacts of FAD-fishing (CECOFAD) used various types of additional data, including the following:

- Catch per fishing mode per year from tuna Regional Fisheries Management Organizations (tRFMOs) such as ICCAT and IOTC to extrapolate the estimated number of DFADs deployed by French purse seiners to the whole of the purse seiner fleet in the Atlantic (2004-2013) and Indian oceans (2003-2013)
- Data collected by observers aboard French and Spanish purse seiners within the Data Collection Framework (DCF) (2006-2013) which was used to estimate the number of DFADs and GPS buoys deployed
- Annual orders for various types of buoys: HF radio, GPS, GPS-echo sounders (2002-2014 in the Indian Ocean and 2004-2014 in the Atlantic), quarterly reports of buoy activation/deactivation (2010-2013) and GPS buoy tracks (2007-2013) provided by several French purse seiner companies to estimate French DFAD-fishing strategies and the total number of DFADs used per day or per year
- French VMS data (2001-2014), provided by the French purse seiners companies, used to assign "on board" or "at-sea" states to individual buoy positions in the analysis of the GPS buoys trajectories
- Spanish VMS data (2007-2014), provided in 2015 by the Spanish fishery administration, to explore the Spanish fleet fishery strategy
- Various surveys of French and Spanish fishermen (2013-2015) to determine skippers' behavior at sea and DFAD-fishing strategies developed by EU fleets
- French (2013) and Spanish (2013-2014) national management plans used to determine the proportion of time devoted to each activity for purse seiners and supply vessels separately, as well as, in the case of Spain, the relationship between the catch per year per vessel and the number of DFADs used (for purse seiners with, or without a supply vessel)

WP1-Evaluation and Results

Despite the difficulties experienced in the collection of unofficial information related to DFAD fishing technology and method of use, significant progress was achieved during CECOFAD:

Overview of skippers' perception of the changes in efficiency due to the new technologies

In addition to the studies mentioned above, various surveys were conducted as part of CECOFAD, to determine how tuna purse seiner skippers perceived the implementation of the new onboard technologies and the related benefits in terms of fishing efficiency.

As part of the PhD thesis undertaken by A. Maufroy (IRD), 14 skippers of the French and Spanish purse seine fleets operating in the Indian Ocean from June to August 2013 were questioned to determine their strategies regarding DFAD deployment, monitoring and fishing and their perception of the effect of the use of DFADs on their efficiency, in comparison with the use of other new fishing technologies (Figure n° 3).

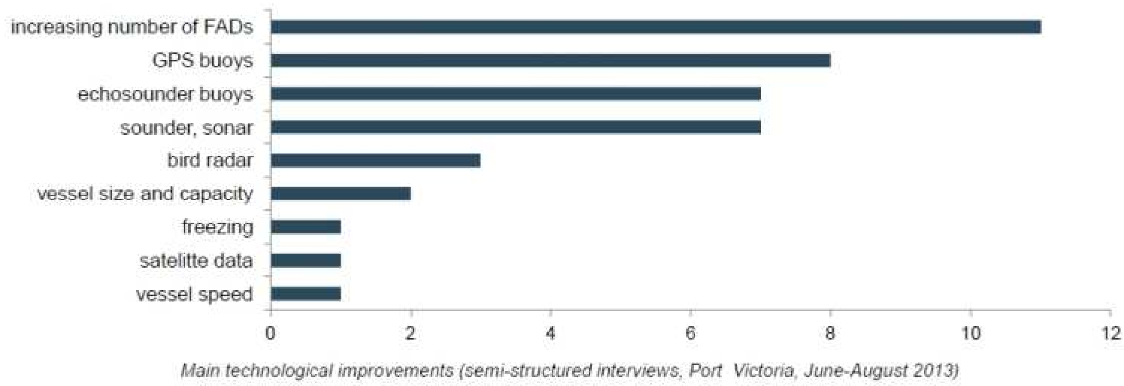

Figure n° 3 : Technological improvements in fishing efficiency established from interviews with skippers (Maufroy, pers. comm.)

In addition of the predominance of the number of DFADs and GPS buoys, an independent survey of a group of 15 French skippers operating in both oceans showed that echo sounder buoys were considered very effective for DFADs while bird radar, sounder and sonar helped to increase fishing efficiency when they were targeting large yellowfin in free schools (Figure n° 4).

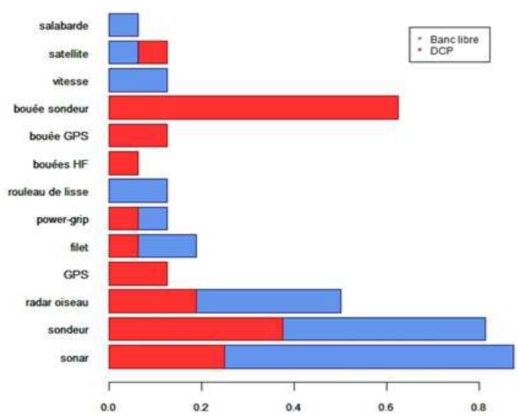

Figure n° 4 : Relative effectiveness of various fishing devices according to the French skippers questioned (Carlot, pers. comm.) for free school (blue) and DFAD-fishing (red)

During the International Seafood Sustainability Foundation (ISSF) skipper workshops conducted between 2014 and 2015, skippers from the Spanish and associated fleets operating mainly in the Pacific Ocean were questioned on more than 100 aspects of the technology onboard (Lopez et al, 2015). Most of the respondents (47%) considered that technological advances (DFADs, echo sounders for DFADs, helicopters, etc.) were the most important factors in improving their fishing capacity, whereas 28% of respondents considered that experience and knowledge of fishing areas and seasons contributed the most to their fishing capacity (Figure n° 5). Communications with other vessels and crew members was also regarded as a significant factor (~10%) with a positive effect on fishing efficiency and capacity. Of the major technological improvements, the use of DFADs was considered to be the most important, followed by echo sounders and oceanographic map services. The fishing net quality, supply boats and helicopters were also mentioned as contributing significantly to fishing efficiency. However, the age of the vessel was not considered to play a major role in increasing fishing efficiency (the average age of vessels being 26 years). Because of the increasing age of fishing vessels, vessels tend to be repaired, maintained or checked every one or two years, which makes them highly dependent on the performance of the mechanical and electronic equipment onboard. When asked about the optimum number of DFADs to maximize catches, ~75% of respondents considered that catches increased with an increase in the total number of available DFADs at sea.

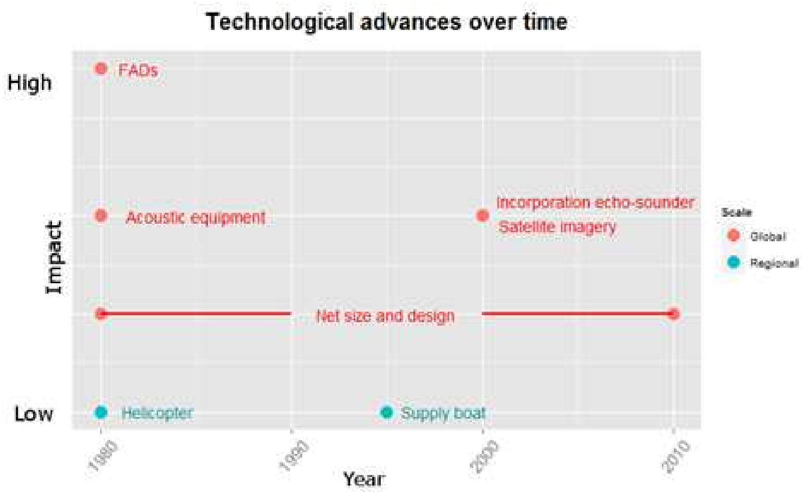

Figure n° 5 : Historical changes in fishing technology among those with major effect on fishing efficiency of purse seine vessels over recent decades (Lopez et al, 2015)

The geographical scale of each factor was divided into two levels: global (red) and regional (green). Factors not included here were considered to have a marginal effect on fishing capacity.

Changes in fishing technology related to DFAD fishing

As already stated, various studies have described the introduction of new onboard technology for tuna purse seiners. However, this information was only qualitative. One of the main achievements of CECOFAD was to estimate the changes in the proportion of the various systems used for locating buoys at-sea by the French purse seiners in the Atlantic and Indian oceans, from HF radio / GPS to

GPS / echo sounder buoys. A detailed description of these technological changes in locating systems is shown in Figure n° 6 for the Indian Ocean.

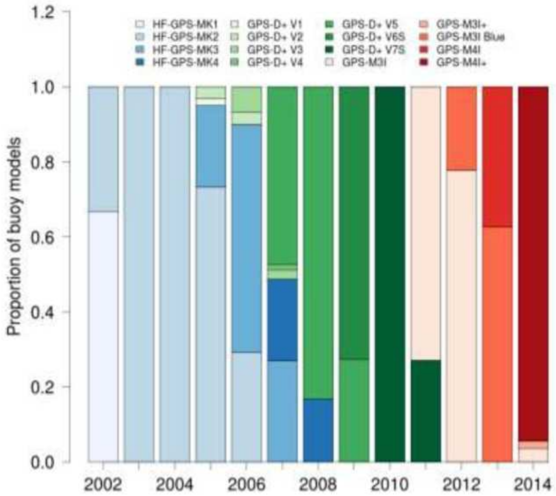

Figure n° 6 : Proportion of buoys by type for a French fishing company during the period 2002-2014 (Chassot et al, 2014)

Buoys have been subject to constant technical innovation over the past decade. The type of buoy used by French fishing companies changed on average every 2 years during the period 2002-2014, with one main model generally predominating each year. Overall, despite progressive technical developments, French fishing companies have generally relied on one main buoy supplier and their current model of buoy. The French fleet operating in the Indian Ocean only started to use echo sounder buoys in 2011.

A similar pattern was observed for the French fleet operating in the Atlantic Ocean (Figure n° 7).

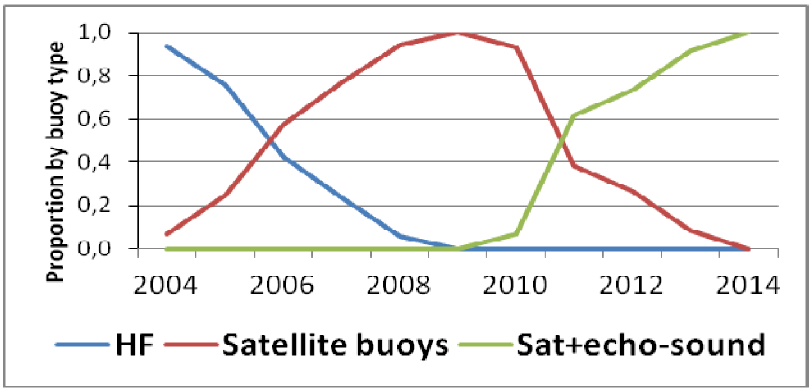

Figure n° 7 : Transition from HF buoys to GPS buoys equipped with echo sounder for the French fleet operating in the Atlantic Ocean (from table 5 in Goujon et al, 2015)

Unfortunately this type of information was not available for the Spanish fleet and only guesstimates are available from past studies (Figure n° 8). The efficiency of different makes of echo sounder buoy varied (e.g., the first of the three types of echo sounder buoy was rarely used) and consequently care must be taken to avoid possible bias when defining the parameters associated with buoys for the catch per unit effort (CPUE) standardization procedure.

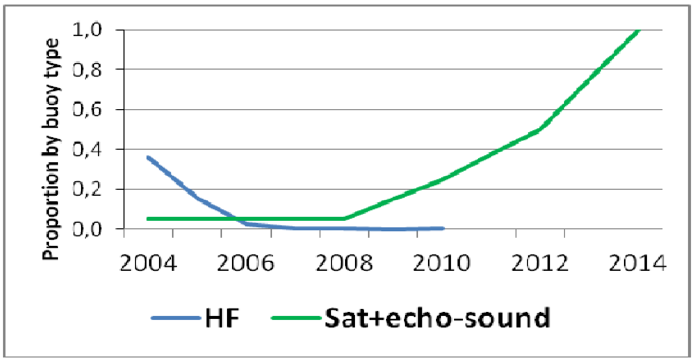

Figure n° 8 : Guesstimates for the transition to most modern buoys for the Spanish (taken from Ramos et al, 2010 and Lopez et al, 2014)

Another important aspect is the direct effect of the number of buoys deployed at sea on the total tuna catch per vessel. With this in mind, the relationship between the number of active DFADs and the catch per Spanish purse seiner (with or without the assistance of a supply vessel), per ocean and per quarter was explored. This is the first time that data has been available to gauge the relationship between the catch per boat per year (or per quarter) and the number of DFADs used (more precisely the number of activated GPS buoys) for purse seiners with or without the assistance of a supply vessel in the Atlantic and Indian oceans. The size category of the purse seiner was also taken into account (**Erreur ! Source du renvoi introuvable.**). On average, having a supply vessel allowed purse seiners to have more DFADs although some vessels seeded a relatively low number of DFADs. Other factors, not accounted for in this preliminary analysis, may be relevant: e.g., the type of echo sounder buoy, whether or not purse seiners from the same company shared all the buoys, the proportion of buoys stolen (this might be larger for purse seiners without supply vessels and it was suggested that the supply vessels might reduce theft), etc.

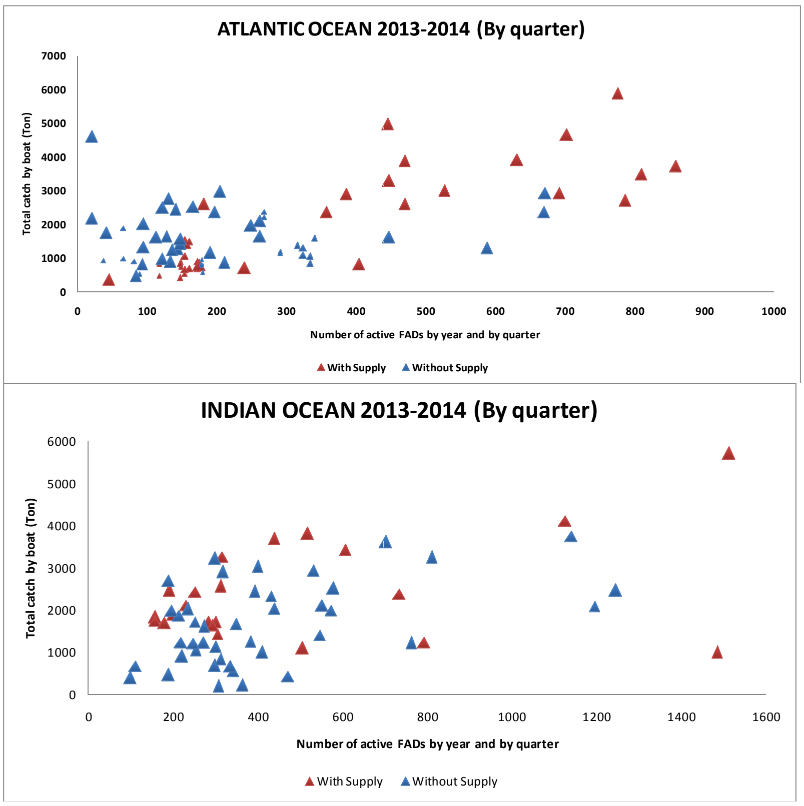

Figure n° 9 : Relationship between the quarterly catch (all species combined) for each Spanish purse seiner and the number of buoys used in the Atlantic Ocean (top) and in the Indian Ocean (bottom) with a supply vessel (red) and without (blue); small purse seiners are represented by smaller triangles (Sotillo et al, pers. comm.)

To quantify the increased efficiency provided by a supply vessel in DFAD fishery, a generalized linear model (GLM) was created for the daily catch rates of purse seiners operating in the Indian Ocean during the period 2003-2014. The GLM which explained 61% of the variance was built using the effects of the year, the month, the interaction between the month and the year, the vessel characteristics and the use of a supply vessel. As expected, it showed that catch rates increased with the overall length of the vessel and with the size of the wells. It also showed that purse seiners with a supply vessel had better catch rates. A supply vessel shared by two purse seiners improved catch rates by 2.7 tons a day (compared with purse seiners with no supply vessel) and having a "full time" supply vessel increased catch rates by 10.4 tons a day over the period 2003-2014 (**Figure n° 10**).

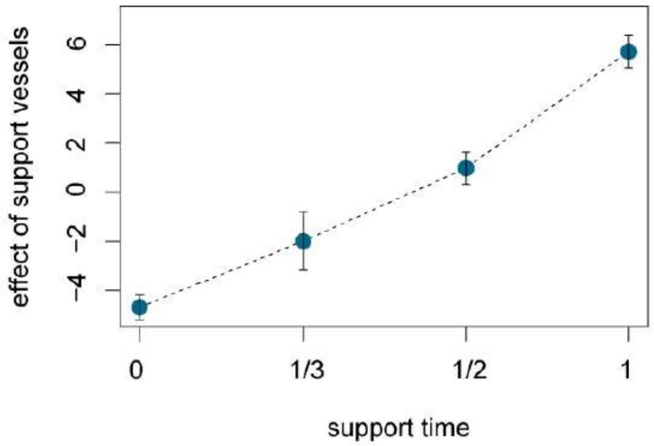

Figure n° 10 : Effect of the assistance of a supply vessel on the daily catch rates of purse seiners over the period 2003-2004 in the Indian ocean, after taking account of the length, well capacity and age of the purse seiner (model GLM1, from Maufroy et al, 2015b)
No supply vessel, one supply vessel shared by 3 seiners, one supply vessel shared by 2 seiners and one supply vessel for each purse seiner are represented as 0, 1/3, 1/2, and 1 share, respectively.

Estimated number of DFADs and buoys at sea

Since the mid 1990s, the use of DFADs has increased considerably in tropical tuna purse seine fisheries. Furthermore, since the 2000s, purse seiners have been able to monitor both natural floating objects and DFADs with GPS buoys while they are drifting. This extensive use of DFADs and GPS buoys raises several concerns for tropical tuna stock assessment and management. It is particularly difficult to know how many DFADs and GPS buoys are in use, how purse seiners deploy new DFADs and GPS buoys and the proportion of the fishing effort spent on setting on DFADs and logs or on free schools.

To address the question of how many DFADs and GPS buoy tracked objects are currently drifting in the Atlantic and the Indian Ocean, various complementary sources of information derived from declarations and observations at-sea were used. One source of unofficial data was based on historical purchase orders for buoys and declarations of activities related to DFAD activities. For the Atlantic Ocean, the data collected for the French fleet showed the various types of buoy purchased each year (Table n° 3). As stated above, there was a clear transition towards more modern buoys (i.e., from HF-buoys to GPS-buoys equipped with echo sounders).

Années	Nb navires	HF	BS	BSE	Total
2004	9	285	20	0	305
2005	9	275	90	0	365
2006	6	117	157	0	274
2007	5	50	162	0	212
2008	5	15	246	0	261
2009	8	0	614	0	614
2010	10	0	668	50	718
2011	9	0	335	544	879
2012	9	0	280	780	1060
2013	9	0	120	1286	1406
2014	9	0	0	1510*	1510*

Table n° 3 : Number of main types of buoy purchased each year by the French purse seiner fleet operating in the Atlantic Ocean (Goujon et al, 2015)

The number of buoys purchased and the quarterly information on the activation/deactivation provided by the satellite communications operators were used to estimate that each vessel purchased an average of 156 buoys in 2013, 90 of which were active. It should be noted that French tuna-boat owners association limited the number of buoys purchased each year by each purse seiner to 200 and the number of active buoys to 150.

For the Indian Ocean, Chassot et al, (2014) combined 3 three data sources to describe the use of DFADs and buoys by French purse seiners over the period 2002-2014. Records of buoy purchase orders were provided by fishing companies to give an insight into the historical use of DFADs. Satellite transmission metadata were available for the period 2010-2013 based on the quarterly reports produced by buoy supplier companies for each vessel. Activities related to DFADs and buoys were included in purse seiner logbooks from 2013 onwards. In order to use data that was comparable with that available for the Atlantic Ocean, only purchase order data was used. The number of buoys available for French purse seiners increased by an average rate of about 10 per year over the period with the average number of buoys available per vessel increasing from 60 in 2002 to 200 in 2014 (**Figure n° 11**).

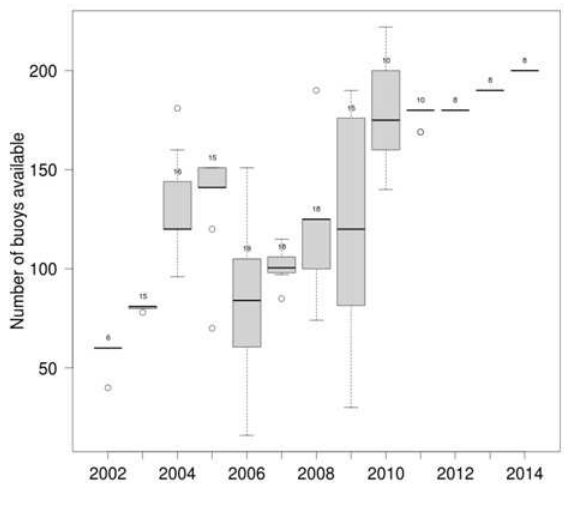

Figure n° 11 : Annual number of buoys available per French purse seiner during the period 2002-2014 (Chassot et al, 2014)

Numbers indicate the number of vessels for which data were available.

The number of active buoys per French purse seiner in the Indian Ocean at the start of each quarter, as well as the average number of buoys that emitted a signal during each quarter, remained stable over the period 2010-2013 with the overall average number of buoys per French purse seiner being 89 with SD=30. However, at the same time, there was an increase in the number of activations/deactivations, suggesting that the buoy utilization was dynamic to ensure the renewal of the DFAD standing stock for each vessel.

Data on the number of active buoys used by the Spanish purse seiners operating in the Atlantic and Indian oceans were collected within the framework of the Spanish DFAD management plan in 2013. This showed the considerable variability in the number of buoys used by purse seiners (Figure n° 12).

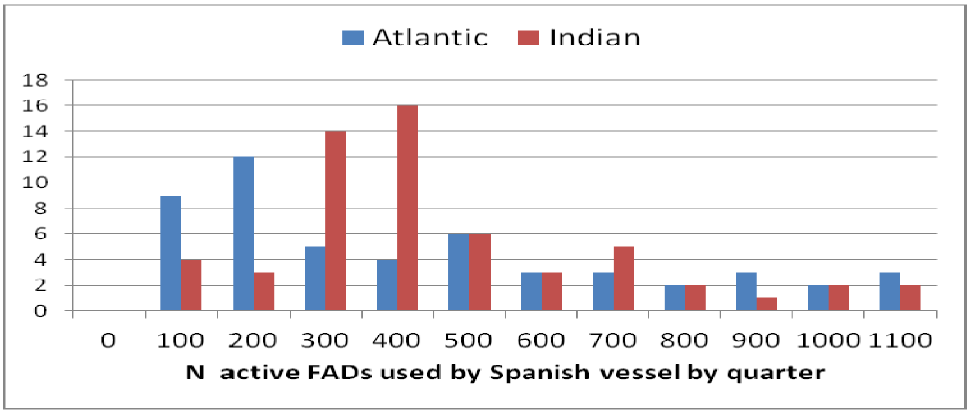

Figure n° 12 : Number of active buoys equipped with DFADs used by the Spanish fleets operating in the Atlantic and Indian oceans in 2013 (taken from Delgado et al, 2014, 2015)

For the Spanish fleet operating in the Atlantic Ocean, each purse seiner followed an average of 429 active DFADs per year (Delgado et al, 2015). However, as for the French purse seiners, this might give an overestimate of the total as some active DFADs were followed by more than one vessel and, might, therefore, be double counted. On average, 401 active DFADs were followed by each Spanish purse seiner operating in the Indian Ocean (Delgado et al, 2014). The average number of DFADs deployed by Spanish flag vessels was around 854 per year, if only purse seiners are considered.

The average annual catch per buoy deployed was estimated based on the average number of buoys deployed by French purse seiners per year (Table n° 3) and the corresponding annual DFAD catch (Table n° 4).

	Nb of Active buoys/PS	Nb buoys seeded yearly/PS	Ratio Nbs FAD Seeded & active	Nb French PS	Average Nb of active FADs	Total Nb of seeded buoys yearly	Yearly FAD catches France	Average Catches on FAD by each PS	Average catch per buoy seeded yearly
2004		41		13		533	20 246	1557	38,0
2005		41		9		369	13 531	1503	36,7
2006		47		7		329	5 178	740	15,7
2007		42		5		210	4 453	891	21,2
2008		54		7		378	3 044	435	8,1
2009		60		10		600	7 552	755	12,6
2010	68	72	1,05	10	683	720	16 125	1613	22,4
2011	71	82	1,16	9	635	738	13 195	1466	17,9
2012	96	118	1,23	9	861	1062	16 956	1884	16,0
2013	90	156	1,74	9	808	1404	16 749	1861	11,9
2014		200		9		1800			
Average 2004-2013		71		9	747	634	11703	1270	20,0
Average 2010-2013	81	107	1,30	9	747	981	15756	1706	17,0

Table n° 4 : Number of DFADs used by French purse seiners in the Atlantic Ocean : seeded per year and DFADs active within a quarter, number of purse seiners and total catches using DFADs (Fonteneau et al, 2015)

In the absence of data for the Spanish fleet at the time of the analysis, it was assumed that annual DFAD catches per vessel for the period 2004-2013 were proportional to the number of DFADs. The number of DFADs seeded by each Spanish purse seiner was estimated at an average of 2.5 times greater than for the average French purse seiner (as opposed to three times greater in previous studies). This method estimated the average number of DFADs for each Spanish purse seiner in 2013 at 385 DFADs, which is close to the number of 426 active DFADs seeded for each Spanish purse seiner estimated by Delgado et al (2015).

No data was submitted to the ICCAT on the number of DFADs or buoys used by non-European fleets of purse seiners (Ghana, Cote d'Ivoire and Guinea). However, assuming that the average annual catch for each seeded DFAD was identical to the average annual DFAD catch for each buoy of the French and Spanish fleets, the number of DFADs seeded by these fleets was estimated from their total catches using DFADs. Based on these data and assumptions, the estimated total number of DFAD sets per year in the Atlantic Ocean by all purse seine fleets increased significantly from less than 7,000 DFADs before 2008, to 17,300 DFADs in 2013 (Figure n° 13). This corresponds to a 2.6 fold increase between the period 2004-2007 and 2010-2013.

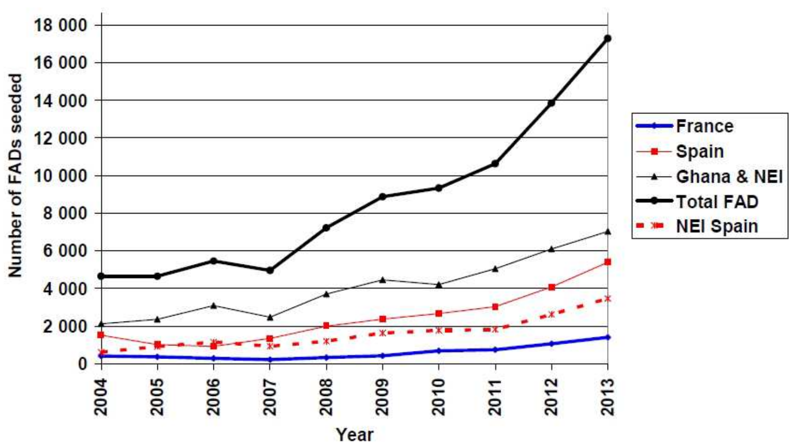

Figure n° 13 : Estimated number of DFAD sets seeded per year for each flag and the total for the Atlantic Ocean (Fonteneau et al, 2015) NEI is "Not Elsewhere Included" for unreported catches.

The French DFAD database (Table n° 5) was extrapolated to give the total number of DFADS active in the Indian Ocean using the method described above for the Atlantic Ocean.

	Nb of Active buoys/PS	Nb buoys seeded yearly by each PS	Ratio Nbs FAD Seeded & active	Nb French PS	Total Average Nb of active FADs	Total Nb of seeded buoys yearly	Yearly FAD catches France	Average FAD Catches by each PS	Average catch per buoy seeded yearly
2003	20	100	5,00	14,8		1481	54 017	3 650	36,5
2004	20	94	4,69	15,4		1445	50 311	3 267	34,8
2005	20	106	5,28	14,8		1564	50 337	3 401	32,2
2006		83		18,0		1487	56 911	3 162	38,3
2007		100		19,5		1940	44 617	2 288	23,0
2008		118		18,5		2182	46 713	2 525	21,4
2009		114		13,5		1539	50 463	3 738	32,8
2010	88	181	2,07	11,6		2102	46 674	4 024	22,2
2011	106	198	1,86	12,7	1348	2510	50 374	3 966	20,1
2012	87	180	2,07	11,6	1008	2088	34 246	2 952	16,4
2013	80	190	2,37	13,0	1042	2470	46 663	3 589	18,9
Average 2003-2013		133		14,9		1 892	48 302	3 324	27,0
Average 2009-2013		173	2,09	12,5	1133	2142	45684	3654	22,1

Table n° 5 : Number of DFADs used by French purse seiners: in the Indian Ocean seeded per year and DFADs active within a quarter, number of purse seiners and total catches using DFADs (Fonteneau and Chassot, 2014)

Various sources of observation, both at-sea and in landing ports, agreed that the number of DFADs active at-sea and deployed by the Spanish and Seychelles fleets, including by their supply vessels, was much higher than for French purse seiners. However, the number of DFADs seeded, or monitored, per year by these fleets is not yet available. Consequently, the number of Spanish and Seychelles DFADs were tentatively estimated on the basis of the 2 following assumptions:

1. Assumption RF1: it was assumed that the larger DFAD catches reported by the Spanish-Seychelles fleet were due to a larger number of DFADs seeded per year. On the basis of the average ratio of DFAD catches per vessel per year during the period 2009-2013, each Spanish purse seiner could seed 1.7 more DFADs than a French purse seiner.
2. Assumption RF2: based on previous studies, it was assumed that each Spanish-Seychelles purse seiner seeded (including the DFADs seeded by supply vessels) 3 times more DFADs per year than an average French purse seiner.

Based on these 2 assumptions, the number of Spanish and Seychelles DFADs deployed per vessel and in total was tentatively estimated (Figure n° 14).

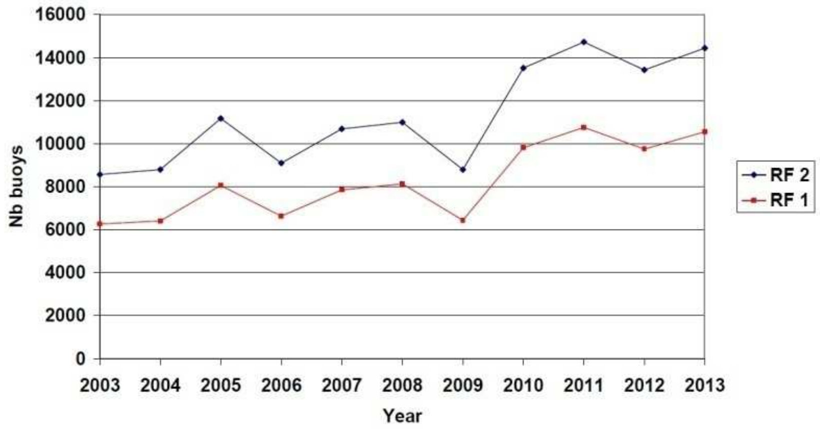

Figure n° 14 : Total of the average catch per buoy per year observed for French purse seiners and estimated for the combined Spanish and Seychelles purse seiner fleets (based on assumptions RF1 and RF2) in the Indian Ocean (Fonteneau and Chassot, 20014)

Based on the GPS data available for the French fishery (Figure n° 15), another approach was proposed by Maufroy et al (2014) for evaluating the total number of DFADs and total floating objects at sea.

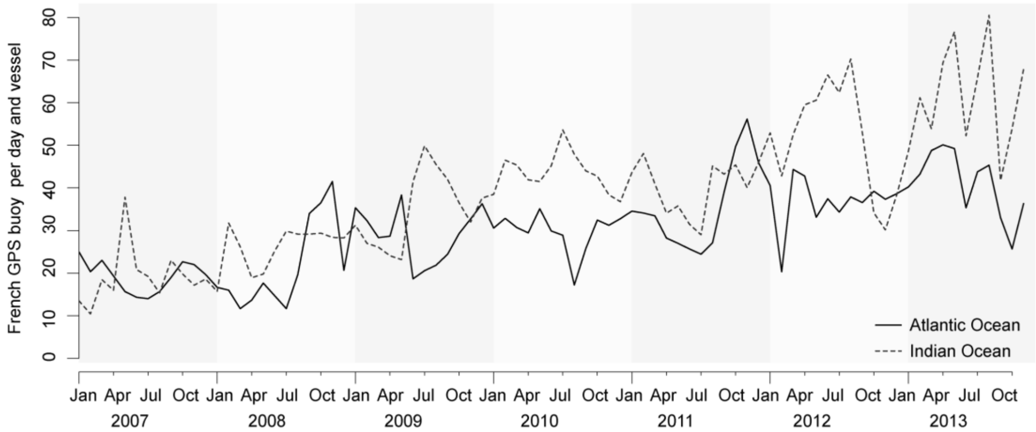

Figure n° 15 : French GPS buoys per vessel per day in the Atlantic and Indian oceans based on GPS buoy tracks and orders provided by the French fishing companies (Maufroy et al, pers. comm.)

This method combined 4 different sources of data: (1) GPS buoy tracks of the DFADs and logs followed by the French fleet, (2) quarterly French fishing company orders for buoys, (3) surveys of purse seine skippers and (4) observations of DFADs and logs by observers onboard French and Spanish purse seiners. The proportion of buoys used on DFADs or logs as well as the proportion of French and foreign GPS buoys were estimated as follows (Figure n° 16):

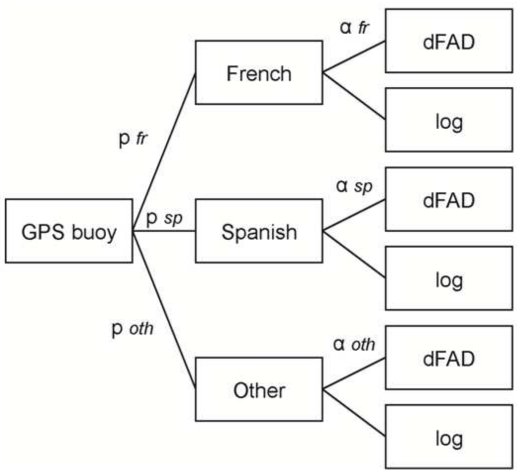

Figure n° 16 : Extrapolation process used to estimate the total DFADs and floating objects (Maufroy et al, 2014)

After extrapolation to give the total number of DFADs and GPS buoys used by all purse seine fleets operating in the Atlantic and Indian oceans, the total number of DFADs used per day increased from 1,175 in January 2007 to 8,575 in August 2013 in the Atlantic Ocean and from 2,250 DFADs in October 2007 to 10,300 DFADs in September 2013 in the Indian Ocean (Figure n° 17).

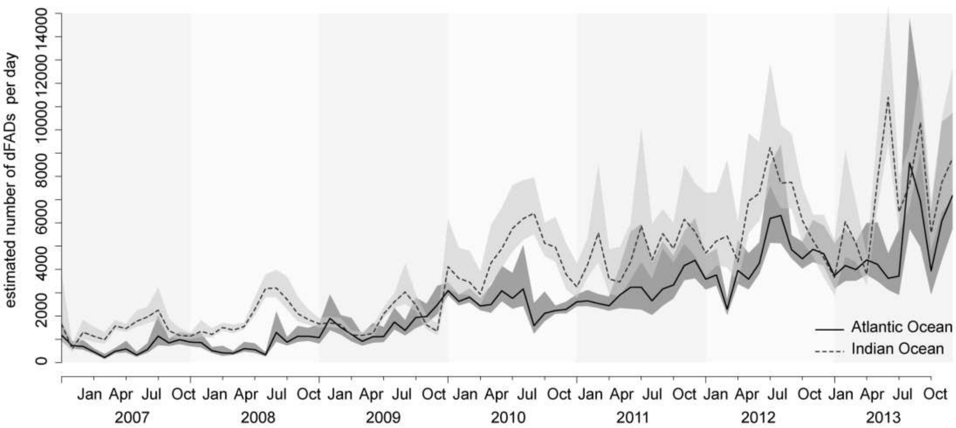

Figure n° 17 : Estimates of the number of DFADs drifting at sea in the Atlantic and the Indian oceans (Maufroy et al, pers. comm.)

Activities at sea and fishing strategies adopted by the EU tuna purse seine fishery

Data collected within the framework of the Spanish and French FAD National Management Plans were used to determine the proportion of time spent on the various activities carried out when using DFADs (deployment, visits, retrieval, changing buoys). As supply vessels provided valuable assistance, the activities of the Spanish purse seiners were compared in the Atlantic and Indian oceans with and without the support of a supply vessel (Figure n° 18).

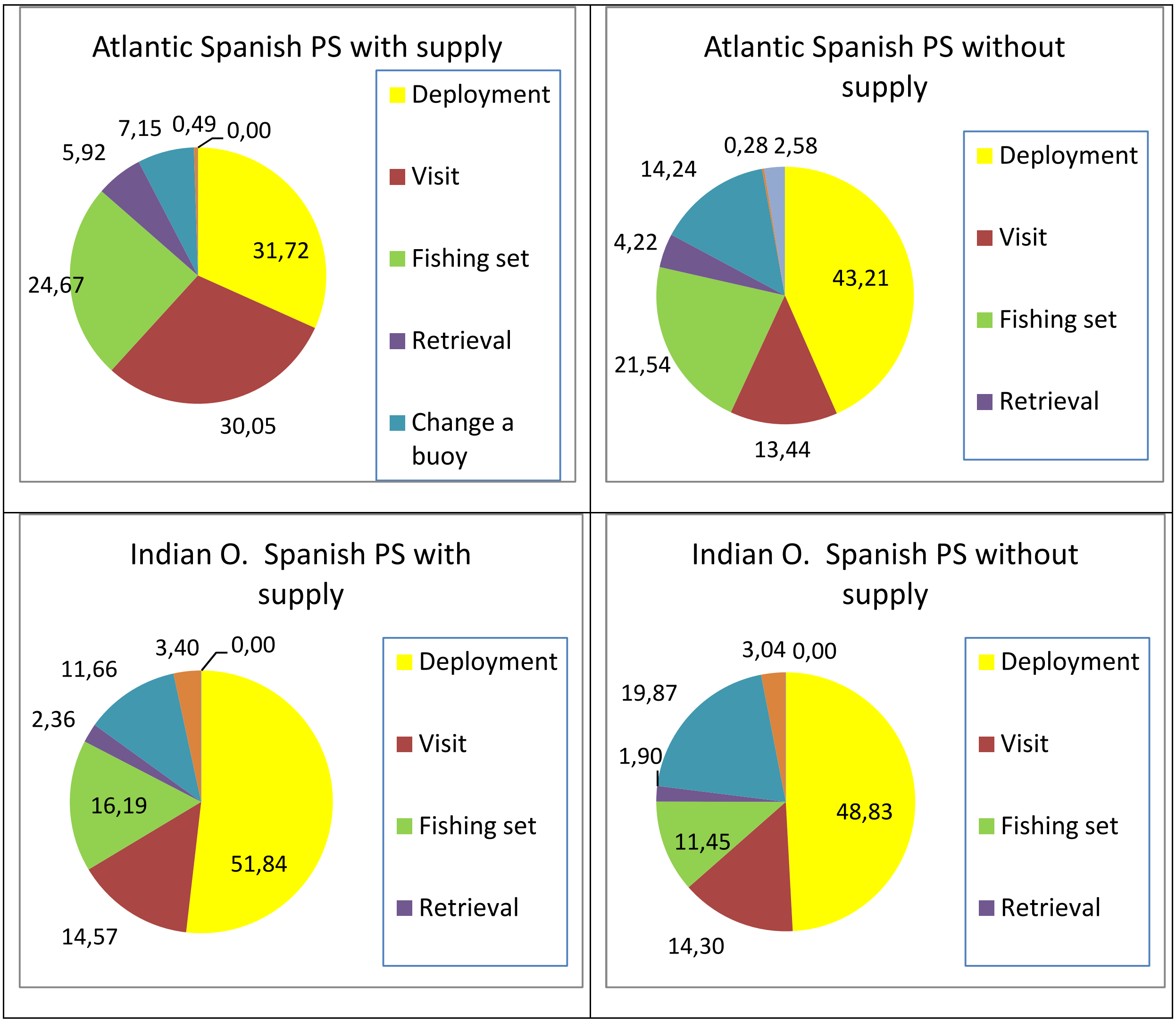

Figure n° 18 : Proportion of time spent on fishing activities of the Spanish purse seiners with (left) and without (right) the assistance of a supply vessel in the Atlantic ocean (top) and in the Indian ocean (bottom); taken from Sotillo et al, pers. comm.; (2013 and 2014 combined)

The proportion of time spent on each activity appeared to be specific to each ocean but in both cases, on average, the assistance of a supply vessel increased the amount of time spent on sets by 3-4 percentage points.

Deploying DFADs was the main role of Spanish supply vessels in the Atlantic and in the Indian oceans (Figure n° 19). However, given the difference in trajectories in the two oceans (in the Atlantic, most of the DFADs drift progressively westward, outside the tuna fishing grounds), retrieval was the second most important activity in the Atlantic whereas a considerable amount of time was spent visiting DFADs in the Indian Ocean.

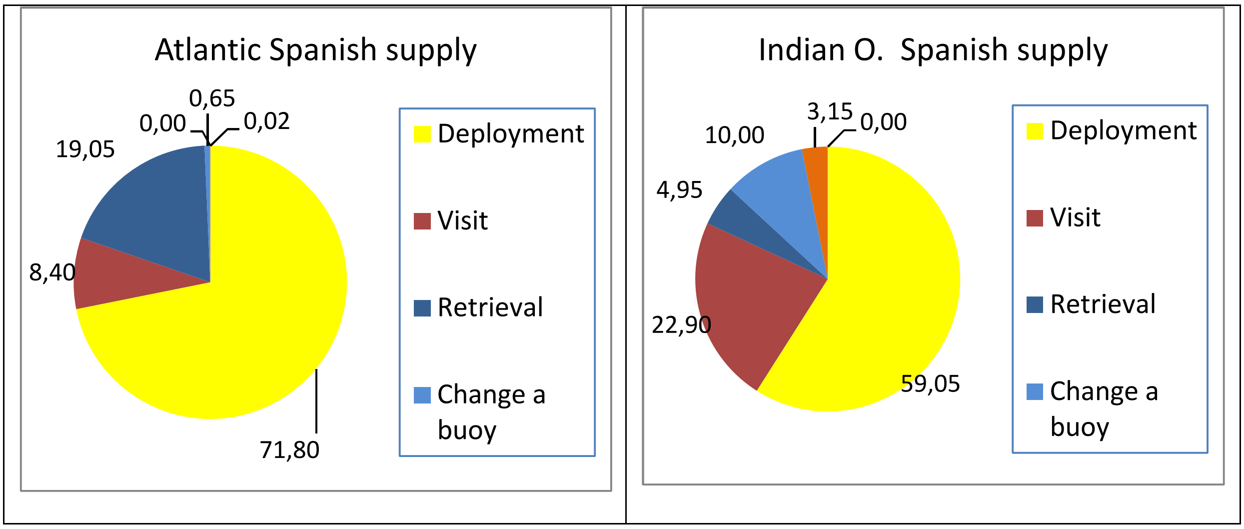

Figure n° 19 : Proportion of time spent on activities for Spanish supply vessels operating in the Atlantic Ocean (left) and in the Indian Ocean (right); taken from Sotillo et al, pers. comm.; (2013 and 2014 combined)

The activity pattern at-sea was also obtained from the French DFAD management plan (Figure n° 20) but, as observed when collecting the data for DFAD fishing parameters, the lack of a common definition for each activity makes it difficult to compare the French and Spanish purse seiner fleets.

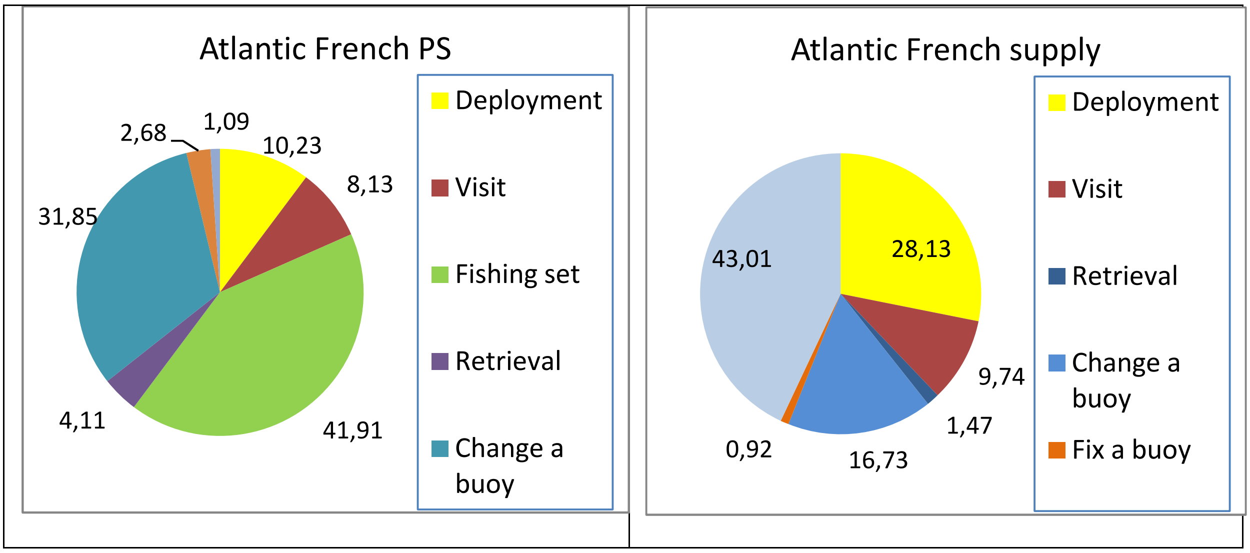

Figure n° 20 : Proportion of time spent on activities for French purse seiners (left) and French supply vessels (right) operating in the Atlantic Ocean; taken from Goujon et al (2014)

Despite these limitations, the introduction of the new onboard logbook system which records the various activities related to DFAD-fishing provided some interesting information. For instance, 62.8% of the activities of a French purse seiner were related to DFADs deployed by the same vessel against 36.2% for DFADs that had been deployed by other vessels and only 1% for DFADs without a radio beacon. The situation was different for logs of which 37.9% had been fitted with beacons by the same vessel and only 3.8% had been fitted with beacons by another vessel. 58.3% of the logs found at sea did not have beacons. Furthermore, whereas 7.7% of the visits to a DFAD did not result in a set, only 3% of the logs encountered did not result in a set (Goujon et al, 2014).

According to Spanish purse seiners, it was essential to have a good seeding strategy to increase fishing efficiency. The most common strategy was to alternate conventional buoys and echo sounder buoys during the seeding operation. As reported by Lopez et al (2014), the strategies consisted in either deploying one echo-sounder buoy for every two traditional buoys or deploying echo sounder buoys at the beginning, middle and the end of the seeding operation. Nevertheless, these practices may change as the number of buoys equipped with echo sounders is expected to increase until echo sounders are used 100% by all vessels. Although strategies varied between countries and oceans, 75% of the ISSF survey respondents agreed that deploying more DFADs increased fishing efficiency. Because of this, purse seiners tended to build a network of DFADs in every area of fishing interest (Lopez el al, 2015). The seeding strategy was based on zones for each season but was strongly affected by the number of DFADs deployed by other vessels DFAD that were encountered during fishing trips, the potential poaching rate within an area, the probability of finding free schools in the fishing zone, the financial resources of the fleet owner and/or the number of DFADs deployed by vessels of the same company, which sometimes shared fishing strategy and DFADs. The practice of sharing DFADs between vessels of the same company to reduce costs and increase the fishing rate varied between countries and ocean (this practice was more common in the Pacific Ocean where vessels must travel significant distances to reach the fishing areas (**Figure n° 21**).

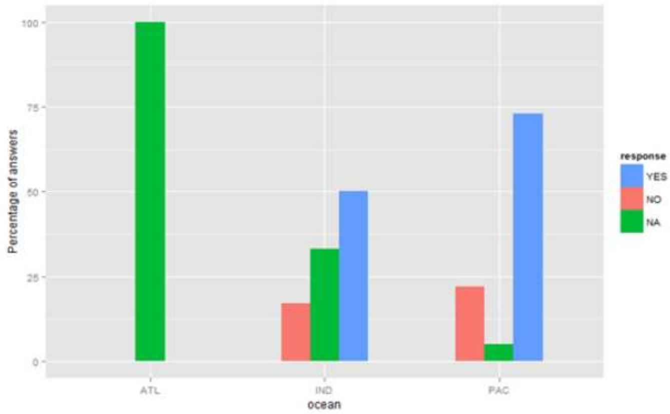

Figure n° 21 : Sharing DFADs between purse seiners operating in the Atlantic, Indian and Pacific oceans (Lopez et al, 2015)
Sharing DFADS between of boats working together was not considered to be sharing.

French skippers were also asked which factors they considered relevant for deploying DFADs equipped with buoys (Figure n° 22). Zone/season and currents were the most important factors.

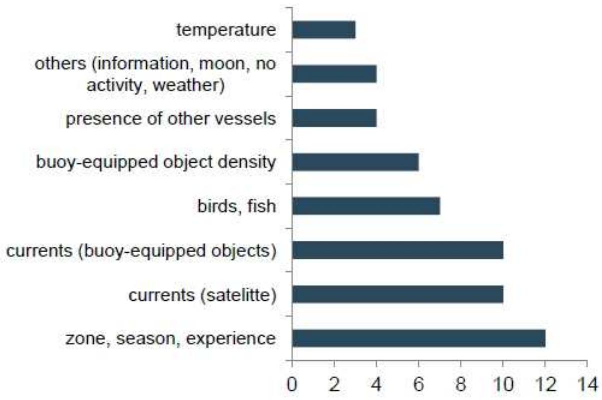

Figure n° 22 : Factors considered by French skippers to be important for determining buoy deployment (Maufroy, pers. comm.)

Another aspect of Maufroy's PhD study was related to the trajectories of the drifting DFADs and the time spent at sea. The time at sea was estimated for each ocean for each month of the year (Figure n° 23). On average, DFADs have a far longer time at sea in the Atlantic than in the Indian Ocean.

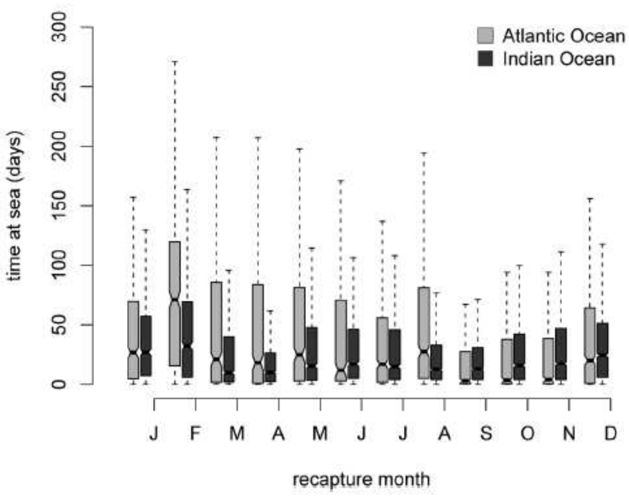

Figure n° 23 : Time at sea for DFADs for each ocean and each month of the year for the French fleet operating in the Atlantic and Indian oceans (Maufroy et al, 2015a)

The time and distance between consecutive DFAD deployments were generally shorter for the Spanish fleet than for the French fleet (Table n° 6).

Purse seine fleet	Time (min)	Distance (km)
France	82.4	57.1
Spain	63.2	24.2

Table n° 6 : Time and distance between consecutive DFAD deployments for Spanish and French purse seiners (Maufroy et al, 2014)

As the Spanish fishery administration did not submit vessel monitoring system (VMS) data to IEO scientists until the 3rd quarter of 2015, only explanatory analyses have so far been conducted. Based on the methodology used by Walker et al (2010), the speeds of Spanish purse seiners and supply vessels were compared between oceans and between day-time and night-time in the Atlantic using the R package “VMSbase” (Figure n° 24). The first results suggested than there were minor differences between oceans but that there was no difference between day-time and night-time. Additional analysis of the VMS datasets is required to discriminate setting time from searching time and, possibly, between free school and DFAD sets.

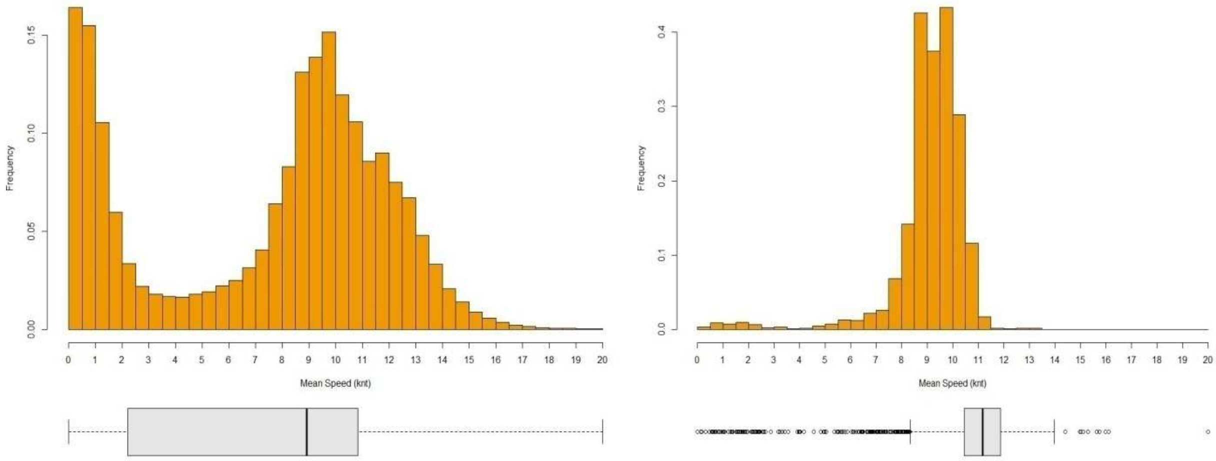

Figure n° 24 : Speed of Spanish purse seiners (left) and supply vessels (right) in the Atlantic Ocean from VMS data (Lopez et al, pers. comm.)

WP1-Success factors

The full collaboration of skippers in their responses to surveys was one of the major success factors for the acquisition of information on fishing strategies and on the effectiveness of the technologies associated with DFADs. Unofficial data not requested in a mandatory form by tRFMOs provided by tuna purse seiner associations to scientists were used and made a useful contribution to the CECOFAD WP1 objectives, particularly in the case of the French fleet. In the case of the Spanish fleet, although some data were submitted late or could not be fully exploited by the team owing to the difficulties encountered in taking on temporary personal (see below), preliminary analyses showed that such information could be valuable and would be used more fully in the near future.

WP1-Difficulties encountered

The difficulties encountered during the project were related to (1) the recruitment of temporary personal and (2) unofficial data.

The IEO experienced certain problems during the project: retirement of two full-time scientists, long delays in the recruitment of 2 temporary CECOFAD personnel (one was involved in WP1 and WP2) owing to the administrative procedures for controlling public spending). As this aspect also affected WP4 where the IEO was mainly involved, this aspect is described in the WP4-Difficulties encountered section.

The qualifications required for the post-doctoral contract were quantitative ecology, spatio-temporal modeling, Bayesian statistics and fisheries. The call for the post-doctoral contract managed by IRD for WP1 and WP2 was issued on January 13th, 2014. Unfortunately several candidates successively dropped out a few weeks after they were selected and, after a new call and selection process conducted in summer 2014, the final candidate selected joined the project in October 2014. For family reasons, combined with the situation in her country, Mrs I. Katara was obliged to give notice in October 2015. A Masters student from IRD also decided to quit his internship up after two months for personal reasons.

With regard to the unofficial information required for the analysis of the main objectives of WP1, the response of the fishing organizations was different for the French fleet and Spanish fleet. While useful information not required by tuna RFMOs was provided regularly by the French tuna association to French scientists, unofficial information for the Spanish fleet was either submitted very late to Spanish scientists, or if submitted, was not fully exploited (Spanish tuna companies claim that some information on DFADs and supply vessels has been provided in the past for the Indian ocean). As full use of VMS data by Spanish scientists must be authorized by the Spanish fishery administration, the use of this relevant information was delayed (Spanish VMS data are now available to Spanish scientists but were submitted very late during the project).

The lack of information on the number of DFADs is probably due to a combination of factors, such as the confidential nature of this sensitive information that was not formally requested until very recently by tRFMOs (more for compliance with regulations than for scientific purposes, as was the case for VMS data until recently), as well as the complexity of collecting and using an index representing the "number of DFADs". The "number of DFADs" can be used to express: (1) the total number of new buoys and DFADs (of all types) deployed during a unit of time by each fleet and by their associated supply vessels (e.g., the number of new buoys bought during the year) or (2) the average number of active buoys in the fishing zone that were followed daily by each purse.

WP1-Recommendations

Particular problems were experienced in relating the activity of a supply vessel to the purse seiner that it is assisting. Companies should be required to provide this information systematically to the corresponding organizations.

WP1-Deliverables (publications/presentations) in relation to the working package

Chassot E, Goujon M, Maufroy A, Cauquil P, Fonteneau A, Gaertner D. (2014) The use of artificial fish aggregating devices by the French tropical tuna purse seine fleet: Historical perspective and current practice in the Indian Ocean. *IOTC–2014–WPTT16–20*

Delgado de Molina A, Ariz J, Murua H, and Santana J. C. (2015) Spanish Fish Aggregating Device Management Plan. Preliminary data. *Collect. Vol. Sci. Pap. ICCAT, 71(1): 515-524*

Delgado de Molina A, Ariz J, Murua H, Santana J.C, Ramos L, and Soto M. (2014) Spanish Fish Aggregating Device Management Plan. Preliminary data in the Indian Ocean. *IOTC–2014–WPTT16–19.*

Fonteneau A, Chassot E, and Gaertner D. (2015) Managing tropical tuna purse seine fisheries through limiting the number of drifting fish aggregating devices in the Atlantic: food for thought. *Collect. Vol. Sci. Pap. ICCAT, 71(1): 460-475*

Fonteneau A, and Chassot E. (2014) Managing tropical tuna purse seine fisheries through limiting the number of drifting fish aggregating devices in the Indian Ocean: food for thought. *IOTC–2014–WPTT16–22.*

Goujon M, Claude A , Lecouls S, and Mangalo C. (2015) Premier bilan du plan de gestion des DCP mis en place par la France en Océan Atlantique. *Collect. Vol. Sci. Pap. ICCAT, 71(1): 573-591*

Lopez J, Fraile I, Murua J, Santiago J, Merino G, and Murua H (2015) Technological and fisher's evolution on fishing tactics and strategies on FADs vs. non-associated fisheries. *IOTC–2015–WPTT17–32 Rev-1*

Maufroy A, Bez N, Kaplan D, Delgado de Molina A, Murua H, and Chassot E (2014) How many Fish Aggregating Devices are currently drifting in the Indian Ocean? Combining sources of information to provide a reliable estimation. *IOTC–2014–WPTT16–21*

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5.2 WP2 - Standardization of catch-per-unit-effort series of the EU purse seine fleet, for juveniles and adults of the three tropical tuna species and exploration of some FAD-regulations in management strategies

WP2-Objectives

Reliable estimates of the catch per unit effort (CPUE) should consider the effective fishing effort, i.e. the amount of effort effectively deployed at sea to achieve the corresponding unit catch. The effective fishing effort is never measured in practice and must be estimated. In particular, there is no reliable abundance indicator for drifting artificial fish aggregating devices (DFADs) used by the tuna purse seine fishery.

Ideally, it should be possible to compare two different CPUEs where all parameters are the same except for the parameter being tested. However, this is not possible in practice as two CPUEs are never produced at the same location, on the same date, for the same vessels, etc. The general principal is, therefore, to use one of the many regression techniques to estimate the effect of (certain) major parameters. Some of the work carried out relates to both WP1 (defining fishing effort) and WP2 (standardization of CPUE). One of the common problems in using regression techniques is that the results rely strongly on the selection of the explanatory variables. Variables can be selected using various methods but the selection must take account of theoretical (e.g. independence), practical (e.g. parsimony) and operational (e.g. qualitative versus quantitative variables) considerations.

These techniques are not new and are used routinely to standardize CPUE series before they are used in stocks assessment models. The CECOFAD project used standard variables based on data from purse seiner logbooks, sampling in ports and records provided by onboard observers. These provide time series for analyzing changes in the fisheries. Other variables, collected more recently, such as those reported in the FAD Management Plans, metrics extracted from VMS data and the extent to which Spanish purse seine fleets use supply vessels, can be exploited to improve knowledge of the fleets' strategies, to redefine the fishing effort and standardize the measurement of CPUE.

Two activities were included in WP2. During the CECOFAD project, IEO made progress in organizing these new sources of information for standardizing the CPUE datasets from the Spanish purse seine fleet operating in the Atlantic, Indian and Pacific oceans into a global database in order to provide new inputs to the CPUE standardization process. These parameters included the identification of the skipper, the proportion of echo sounder buoys used per vessel per year, the number of DFADs echo sounder shared by vessels and the potential cooperation between vessels, the number of DFADs deployed per vessel per year and the number of DFADs re-deployed per vessel per year. This work is still in progress because of problems in relating the activity of supply vessels to the purse seiners that are being assisted. The second activity was to set out a comprehensive standardization approach. This document deals exclusively with this second activity.

An attempt was made at the beginning of CECOFAD project, based on a publication by Laurec (1977), to incorporate geographical distance into the standardization process. However, the results were disappointing as they revealed no spatial organization and did not support the work that was originally planned. We therefore analyzed the geographical distribution of DFAD sets in relation to the area covered by the fleet.

The WP2 report is divided into two parts. The first part describes the spatio-temporal dynamics of the French DFAD fishing effort and the second part presents proposals for CPUE standardization.

In order to evaluate the effects of certain DFAD regulations included in management strategies, Monte Carlo simulations were used to simulate purse seine behavior after the introduction of moratoria on DFAD. However, this study focused on the consequences of large-area moratoria on DFAD sets on tuna resources as well as on the main groups of bycatch and megafauna species. Consequently, although these simulations were initially scheduled as part of WP2, they were transferred to the WP4 section of the report

WP2-Data used

Different types of data and periods were used:

(1) VMS data submitted on a quarterly basis by the French tuna association Orthongel were used for the analysis of the spatio-temporal patterns of the DFAD fishing effort of French purse seiners in the Indian Ocean for the period 2000-2012;

(2) Logbooks collected by the Institut de Recherche pour le Développement (IRD) were used for the CPUE standardization for French purse seiners operating in the Atlantic Ocean for the period 2007-2013. The analysis focused on fishing sets associated with floating objects, i.e. natural logs and DFADs, and bigeye tuna (BET) was selected as the study case. In addition, a comprehensive list of candidate predictors of changes in fishing efficiency was drawn up. This was based on information from the French purse seiner tuna association ORTHONGEL (2007-2013), the Observatoire Thonier (IRD) and the literature; these included technological advancements, vessel characteristics and proxies for fishing strategy (Table n° 7, and
Table n° 8 in the Results).

Dataset	Description	Time Period	Format	Source
DFAD distribution	Location of DFADs	2007-2014	Monthly point maps	*Maufroy* et al., *2015*
Buoy purchases	Total number of buoys of each type purchased by the French fleet.	2004-2014	Time series, annual	*Goujon et al., 2014*
Buoy purchases	Number of buoys bought by each vessel (French fleet).	2002-2014	Time series with a variable time interval	*ORTHONGEL*
Vessel characteristics	Length, carrying capacity, age, company, flag, fleet		Records for each vessel	*IRD* *(Obs. Thonier)*
Skippers	Skippers' ID for each vessel and trip	2004-2014	Records for each vessel and trip	*IRD* *(Obs. Thonier)*

Table n° 7 : Datasets collected to provide additional information on changes in fishing effort

WP2-Evaluation and Results

Spatio-temporal dynamics of the French FAD fishing activity

The DFAD fishing effort was defined as the local density of DFAD fishing sets and was determined per quarter (3 monthly period), using logbooks and VMS data for the Indian Ocean during the period 2000-2012. The quarters were defined to minimize the variance within each quarter (quantified by k-means analyses of the center of gravity of the DFAD sets). The size of the quadrat (0.5°x 0.5°) was defined to provide a compromise between quadrats that were too small to provide enough information and quadrats that were so large that they concealed the spatial patterns of interest. VMS data was used to delimit the area covered by the fleet. The precise locations of DFAD sets were taken from the Balbaya database of the French "Observatoire Thonier" (IRD).

The analyses were carried out in two stages. Firstly, three areas were determined:

- the area explored, i.e. the area where there were vessels (VMS data)
- the fishing area, i.e. the area where there were DFAD sets
- the areas where the fishing effort was above a predefined threshold (e.g. 3 sets in a quadrat in a quarter)

Although this approach did not reveal anything about the form of these areas, it quantified them. The main results were the large differences between the trends in the first and last quarters over the period 2000-2010 (Figure n° 25 and Figure n° 26).

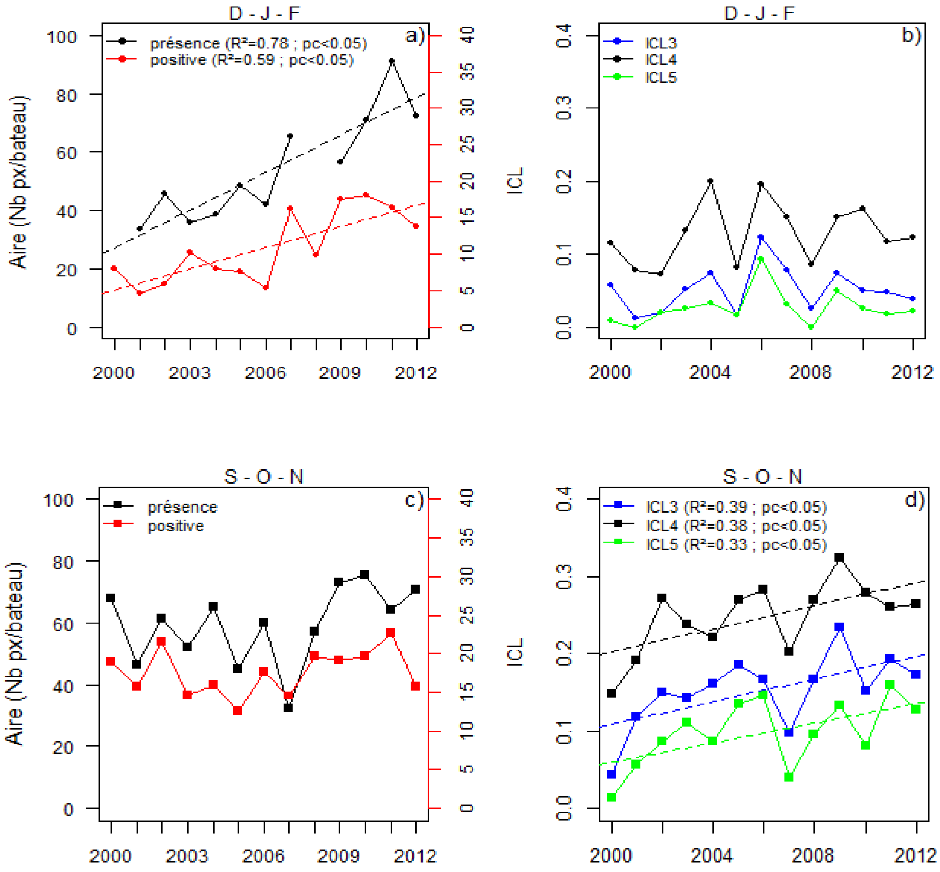

Figure n° 25 : Change over time in surface areas (explored and with DFAD sets) in each quarter (Saulnier, 2014)

Only the first and fourth quarters are shown here.

During the first quarter (December/January/February), the main trends were the significant increase in the area explored and the fishing area (4 and 3 fold respectively). In the intervening quarters, the proportion of the fishing area with intense fishing activities remained stable which is consistent with the increase in the number of DFAD sets per boat that was also observed (increasing from 10 DFAD sets per vessel per quarter to 22).

During the fourth quarter (September/October/November), the area explored, the fishing area and the number of sets per vessel remained stable. However, the area of intense DFAD fishing effort increased with a resultant reduction in the area with a low fishing effort. The spatial concentration of the DFAD fishing effort increased.

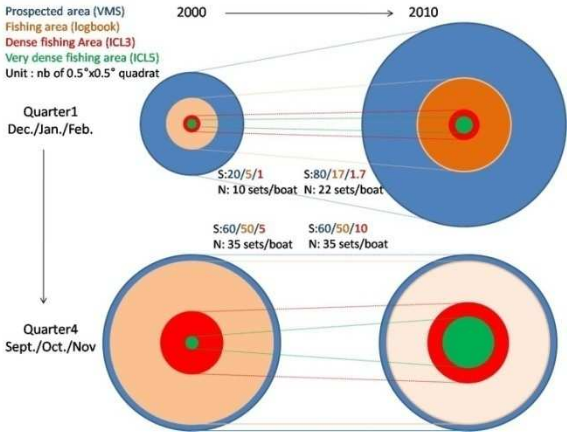

Figure n° 26 : Spatial characteristics of the DFAD fishing effort of French purse seiners in the first and fourth quarters of the period 2000 - 2010 (Saulnier 2014)

Secondly, using geostatistical tools (e.g. variogram, see Figure n° 27) the temporal variability of the spatial organization of the fishing effort was investigated using spatially explicit simulations to compare the temporal variability observed in the data with that obtained for a time-independent model. This showed that the spatial organization of the fishing effort was stable over time but significantly different between quarters.

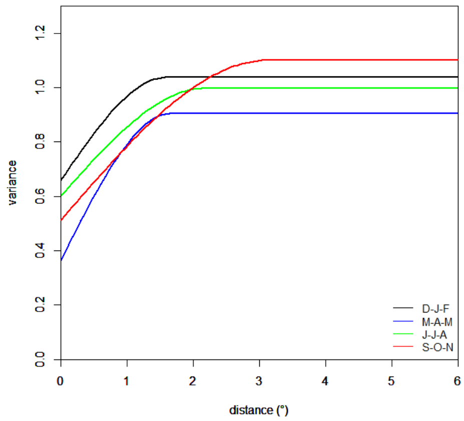

Figure n° 27 : Variogram models by quarter (Saulnier, 2014)

This showed that the DFAD fishing effort at regional scale was different during the first quarter (M-A-M) and at local scale was different during the fourth quarter (D-J-F). This suggests that the fishing power and capturability vary from quarter to quarter.

LASSO regression for standardizing CPUEs

The identification of the main predictors was essential for standardizing CPUE for DFAD purse seine fishing for tuna.

Application of statistics and numerical techniques have allowed fisheries scientists to develop models for standardizing CPUE that allow for the structure of fishery data, such as dependencies and missing values. Mixed models were developed for standardizing CPUE as they have been shown to deal with hyperstability and temporal autocorrelation issues (Nishida & Chen, 2004; Cao *et al.*, 2011). These models were extended to include factors relating to the longitudinal structure of the data, at the levels of vessels and skippers.

Variables	Short description
Year	
Month	
Time at Sea	Duration of the fishing trip
Fishing Time	Duration of the fishing sets
Sample Area	Areas covered by the landing samples
EEZ	Exclusive Economic Zone
Grid Cell	1° x 1° cell
Skipper	Name of the skipper on each vessel and trip
Vessel	Vessel identifier
Vessel age	Year vessel entered service
Vessel length	In meters
Vessel power	In horsepower
Vessel capacity	In tonnage
Vessel category	Vessel category based on vessel length and capacity
YFT price	Yellowfin tuna price at Bangkok auction
SKJ price	Skipjack tuna price at Bangkok auction
YFT/SKJ price ratio	Ratio between yellowfin and skipjack tuna prices
GPS buoys bought per vessel	
HF-GPS buoys bought per vessel	The data on GPS, HF-GPS, and HF-GPS/GPS buoy purchases is only available for a small number of vessels
HF-GPS/GPS buoys bought per vessel	
HF buoys deployed per vessel	
BS buoys deployed per vessel	Parameters from Goujon et al 2014 (BSE = echo sounder buoy)
BSE buoys deployed per vessel	
Distance of fishing set from a FAD	Distance of a set from the nearest FAD (monthly average)
Distance of fishing set from the centre of the FAD area	Distance of a set from the centroid of the FAD area (monthly average)
FAD counts around fishing set in a fixed (143 nm) buffer zone	Number of FADs around a fishing set. 143nm is the nearest neighbor distance between sets and FADs occurring in a given month, averaged over the time series.
FAD counts around fishing set in a variable buffer zone	Number of FADs around a fishing set. The buffer zone is equal to the maximum nearest neighbor distance between the fishing sets and the FADs for the given month.
FAD area	Total area occupied by FADs: the sum of the areas of the polygons of the standard distance for each FAD trajectory. Overlapping polygons were merged.

Table n° 8 : Predictors used in the elastic net GLMs and the Lasso GLMMs (Katara et al, 2015)

The numbers of positive and null fishing sets are used as predictors in the lognormal models.

Delta-lognormal models were developed for the standardization of CPUE for BET. Lasso models were used to select the variables rather than standard variable selection methods, as there was a large number of initial variables which can lead to over-fitting and computational problems (Tibshirani, 1996, 2011). The GLMs were extended to GLMMs by treating the skipper and the vessel as crossed effects and the year - grid cell interaction as a random effect (Maunder & Punt, 2004; Campbell, 2015). Both GLMs and GLMMs were developed and the resulting standardized CPUE time series were compared. The process for the standardization of the CPUE is shown in Figure n° 28. The analysis was repeated for the combined French and Spanish fleets, but a smaller number of predictors was used because information for the Spanish fleet was missing.

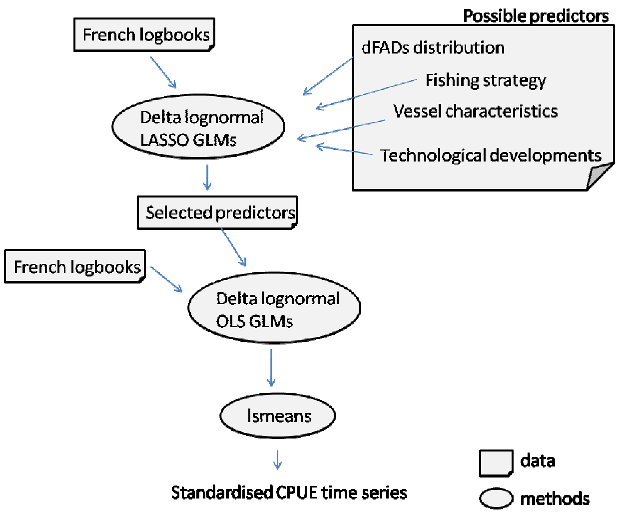

Figure n° 28 : Process for the standardization of CPUE (Katara et al, 2015)

The same process was followed for the combined Spanish and French fleets but the list of possible predictors was shorter.

Models for standardizing tropical tuna CPUE are usually based on information contained in logbooks: location (latitude, longitude, EEZ), date, time and duration of fishing sets. A large number of other predictors, non commonly recorded in logbooks, were identified for improving the standardization of CPUE. A total of 24 predictors were selected for the GLMMs developed for the combined French and Spanish fleets (Table n° 9), giving more complex models than for the French fleet on its own.

The first reliable CPUE trend for purse seine DFAD fishery was established by adding predictors to describe the type of fishery using GLMMs. The time series were short but there was a significant trend for both the French and the combined French – Spanish fleet (Figure n° 29) with the CPUE for BETs peaking in 2010 and then dropping.

	French Fleet	
	$Pr(C_s>0)$	Lognormal
Year	(f)	(f)
Month		
Time at Sea		
Fishing Time		
Positive sets		
Null sets		
Sample Area		(f)
EEZ		(f)
Grid Cell		
Skipper	0.65	0.001
Vessel	0.49	0.1
Vessel age		
Vessel length		
Vessel power		
Vessel capacity		
Vessel category		
YFT price		-1e-14
SKJ price		-4e-16
YFT/SKJ price ratio		
GPS buoys bought per vessel		
HF-GPS buoys bought per vessel		
HF-GPS/GPS buoys bought per by vessel		
Number of HF buoys deployed per vessel	-0.08	9e-15
Number of BS buoys deployed per vessel		
Number of BSE buoys deployed per vessel		-8e-16
Distance from a FAD		-5e-02
Distance from the centre of the FAD area		
FAD counts in buffer zone = 2.39dd		
FAD counts in buffer zone = max		
FAD area		
Year*month		
Year*Cell	1.76	0.5
Year*vessel age*category		

	Spanish and French Fleets	
	$Pr(C_s>0)$	Lognormal
Year	(f)	
Month	(f)	
Time at Sea	3.5e+09	5.7e-14
Fishing Time	-8e+09	7.05e-14
Positive sets		
Null sets		
Total Sets		
Sample Area	(f)	(f)
Flag		
Fleet	(f)	(f)
# of supply vessels (annual)	-5e-01	8.5e-13
EEZ	(f)	(f)
Grid Cell:year	0.9	0.459
Vessel		0.22
Vessel age	-7e+08	-3.7e-14
Vessel length	9.8e-01	-6.9e-13
Vessel power	4.7e+09	-7.2e-13
Vessel capacity	4.8e+09	-7.99e-13
Vessel category	(f)	(f)
YFT price	-2.6e-01	-8.6e-14
SKJ price	-1.5e-01	-1.5e-13
YFT/SKJ price ratio		-4.2e-14
Number of HF buoys deployed per vessel	2e-01	-8.6e-14
Number of BS buoys deployed per vessel		
Number of BSE buoys deployed per vessel	-2e+08	1.06e-14
Distance from a French FAD	9e-02	3.1e-13
Distance from the centre of the French FAD area	6.6e-02	3.4e-13
French FAD counts in buffer zone = 2.39dd	-5e-02	3.4e-13
French FAD counts in buffer zone = max	4e-02	-1.18e-13
French FAD area	-2.6e-01	-8.6e-14
Year*month		
Year*vessel category		

Table n° 9 : Lasso GLMMs for the French fleet and the combined Spanish and French fleets

A two stage approach was followed, modeling the probability of the presence of BET in a set ($Pr(C_s>0)$) and a positive BET catch (lognormal) in two different GLMs. Coefficients are listed for continuous predictors while factor variables with one or more non-zero coefficients are denoted as (f). The standard deviation is given for random effects (grey cells).

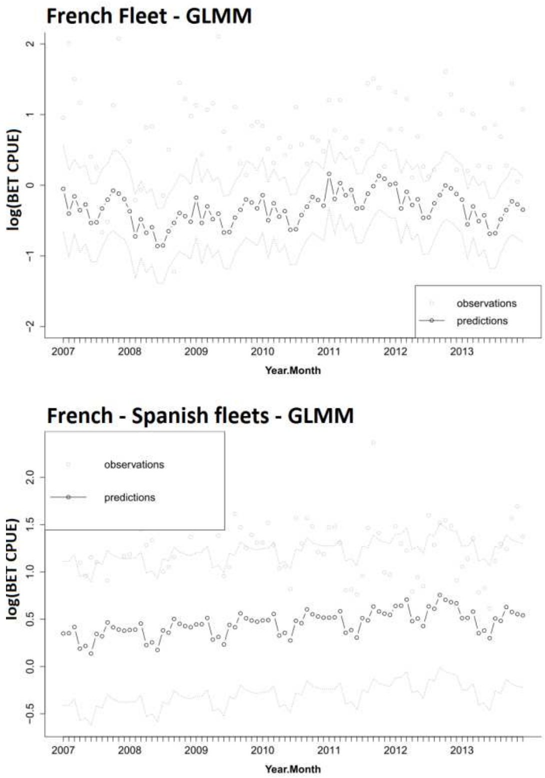

Figure n° 29 : Standardized CPUE time series for the Atlantic BET

Standardization was performed with GLMMs. The top graph is for to the French fleet and the bottom is for the combined Spanish and French fleets.

WP2-Success factors

This project to standardize the CPUE for the DFAD purse seine fishery was made possible owing to two main factors:

1. the availability of data on the technological developments leading to the establishment of the DFAD fishery in its current form,
2. the application of recent statistical and numerical techniques for analyzing multidimensional datasets.

The IRD and IEO have been collecting commercial data on fisheries since the start of the EU purse seine fishery and have established a long-lasting relationship with the fishing industry. This long term, on-going effort allowed fisheries scientists to identify changes in the fishery industry and collect relevant information. The CECOFAD project collated this information and used recent statistical techniques to standardize CPUE.

WP2-Difficulties encountered

Owing to time constraints and difficulties in gathering unofficial data on DFAD-fishing practices, it was not possible to extend the analysis of CPUEs on DFADs to skipjack and yellowfin juveniles of or to CPUEs of large yellowfin in free school sets.

There is no data collection system followed by all European countries for unofficial data. Logbooks follow the same format but more information is needed for DFAD fishery. A broader data collection system would allow comparability and collation of data from different fleets. Our results showed that this is essential to:

1. increase the number of observations and allow for more complex models
2. have enough contrast in the data to identify important predictors in standardization models.

In general, vessels belonging to the same fleet appear to adopt technologies that improve their fishing efficiency at the same time and, therefore, the data cannot be used to compare vessels that use a given technology and vessels that do not. Consequently, important predictors describing the new technology used in the fishery were not selected for the standardization model. Collating the data from two fleets may solve this problem as the fleets develop their strategies in different ways and adopt new technologies at different times.

The quality of data is often poor. The scales of the predictors differ, from annual to monthly, from fleet to vessel and from ocean to the specific location of a fishing set. There were missing data and data that only covered a small subset of the fleet. Some data were guesstimated and it was assumed that the distribution of the French DFADs was indicative of the distribution of the DFADs deployed by both the French and the Spanish fleets. This is probably not a valid assumption as the Spanish fleet deploys more buoys than the French fleet (Fonteneau *et al.*, 2013; Lopez *et al.*, 2014).

Finally, trends derived from short time series are often unreliable as they may reflect short term events or be parts of longer cycles and it is difficult to identify a baseline.

WP2- Best practices identified

Long term data collection systems are a valuable source of information and they can easily be expanded to record more information on changes in the fishery that could affect fishing efficiency. The scale at which data need to be collected is debatable. Our results suggest that some variables, such as the number of buoys deployed, can be recorded for a whole fleet because the deployment is uniform across the fleet. Other variables, such as the distribution of DFADs, require data at a fine spatial scale.

Collating data between different fishing fleets is essential to ensure sufficient spread of individual values to be able to include significant predictors in the standardization model. Data exchange requires collaboration between countries and confidence between the scientific community and the fishing industry.

A mixed models approach to CPUE standardization must be adopted. These models can deal with some of the disadvantages of deriving abundance indicators from fishery dependent data, such as hyperstability and the hierarchical structure of the data.

WP2- Solutions to barrier identified

European fleets need to develop a common data collection system that will expand the conventional logbook data, record changes in fishing efficiency – especially changes related to technological developments – and account for these changes as they occur. Confidentiality issues often arise when such systems are developed. These can be dealt with using a widely accepted policy, between institutions and the fishing industry, that will establish guidelines for accessing, disseminating and managing the information collected. One of the most important results of this project is a comprehensive list of predictors for CPUE standardization for the DFAD fishery. This list could become the basis for developing the extended data collection system suggested here. Data on some of the predictors are readily available (e.g. the ID of the skipper working on each vessel and trip) and other data requires intensive research efforts (e.g. DFAD distribution).

More efficient statistical algorithms and increased computational power provides fisheries scientists with improved tools for developing CPUE standardization models. The use of mixed models should replace the typical GLMs for tropical tuna CPUE standardization and these models should be revised regularly to exploit new, powerful algorithms and tools that allow us to overcome computational constraints.

WP2- Recommendations

As mentioned in the WP1 section, one practical recommendation from WP2 is that fishing companies should be required to provide systematically the information relating the activity of supply vessels (including foreign vessels) to the purse seiners that are being assisted to the national institutes or tuna RFMOs.

WP2-Deliverables (publications/presentations) in relation to the work package

Katara, I and Gaertner D. (2014) Some news approaches for standardizing tropical purse seiners CPUEs. IOTC–2014–WPTT16–16.

Katara I, Gaertner D, Maufroy A, Chassot E. (2015) Standardization of catch rates for the Eastern tropical Atlantic bigeye tuna caught by the French purse seine FAD fishery. SCRS-2015-106

Saulnier, E., (2014). Dynamique spatio-temporelle de l'effort de pêche sur DCP des thoniers senneurs français dans l'océan indien. Agrocampus Ouest, Rennes, 63 pp.

Soto M, Fernandez F, Pascual, P., Gaertner D. (2015) Standardized CPUE for juveniles of bigeye caught by the European and associated Purse Seine fishery on FADs in the Atlantic Ocean during 1991 to 2014. SCRS/2015/105

WP2-Other references

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Cao J, Chen X, Chen Y, Liu B, Ma J, Li S (2011) Generalized linear Bayesian models for standardizing CPUE: an application to a squid-jigging fishery in the northwest Pacific Ocean. *Scientia Marina*, **75**, 679–689.

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5.3 WP3- Alternatives to CPUE

WP3-Objectives

Relative abundance indices based on CPUE data are notoriously problematic (Maunder et al., 2006), as catch data is usually biased by fishing effort, coverage and other limiting factors of fishery data. This is particularly true in the tropical tuna purse seine fishery, where catchability changes very rapidly owing to fast technological development and the marked increase in the use of DFADs, both of which compromise the usefulness of the conventional CPUE indices. WP3 provides an initial insight into alternative tuna and non-tuna abundance indices that could be used for stock assessment. One of the major features of the CECOFAD project was the exploration of alternative fishery-independent indices of the abundance of tuna and non-tuna species associated with DFADs. The CECOFAD project aimed to develop new methods for obtaining direct indices of tuna and non-tuna species abundances using echo sounder buoys attached to DFADs. Behavioral models, calibrated using tagging data, representing the continuous process of association and disassociation, as well as the residence time under DFADs were identified as an alternative to commercial catch data for estimating abundance. Estimating the probability and abundance of tuna and non-tuna species directly using the information obtained from echo sounder buoy acoustic biomass data requires gathering, collating and processing a large dataset of heterogeneous echo-sounder buoy information and developing a methodology which considers all the factors for the standardization of the acoustic information.

This work package covered 3 tasks, which required the full cooperation of the professional partners: (1) develop a consistent echo sounder buoy database, including different types of acoustic measurements from different sources, (2) a preliminary analysis of alternative indices of abundance collected from different sources of information, particularly echo sounder buoys, and (3) measuring the direct local abundance from echo sounder buoys and modeling the aggregation process of biomass under DFADs.

This report described the results of the collaboration between EU institutes and fisheries. The Spanish fleet provided information on the acoustic records and trajectory information from echo sounder buoys to develop and investigate methodologies for improving the use of echo sounder buoys to obtain alternative fisheries-independent indices, and the IRD developed methods for integrating tagging information for the similar purpose.

WP3-Data used

A wide variety of data was used, such as fishery data from echo sounder buoys (trajectories and acoustic records), tagging data from scientific surveys in the tropical areas, observer data and fishing logbooks from the EU purse seine fleet. Observer data and fishing logbooks containing complementary information about the species composition of the catch (tunas in fishing logbooks, non-tuna species in the observer data) as well as information on the fishing activity of the fleet (setting time, location, fishing mode, etc.) were also used.

In order to produce a preliminary analysis of data for alternative indices of abundance collected by echo sounder buoys and define a data processing methodology (tasks 1 and 2), the information from the Spanish tropical tuna purse seine fleet operating in the Atlantic, Pacific and Indian Ocean was collected and loaded into a database for further processing (Table n° 10 and Table n° 11). This database includes data on the major buoy manufacturers:

Marine Instrument: These buoys are equipped with a 50 KHz / 500 W echo sounder. The range extends from 6 m to 150 m. At an angle of 42°, the cone of observation under the buoy has a diameter of 116 m at a depth of 150 m. The echo sounder provides acoustic information in 50 different layers, each 3 m deep.

Satlink: These buoys are equipped with a 190.6 kHz / 140 W echo sounder. The range extends from 3 m to 115 m. At an angle of 40°, the cone of observation under the buoy has a diameter of 78.6 m at a depth of 115 m. The echo sounder provides acoustic information in 10 different layers, each 11.2 m deep.

Zunibal: These buoys are equipped with a 120 kHz / 400 A echo sounder. The range extends from 0 m to 100 m. At an angle of 45°, the cone of observation under the buoy has a diameter of 111 m at a depth of 100 m.

The database includes information recorded in March 2011 In the Atlantic and Pacific Ocean, and, in October 2011, in the Indian Ocean. Apart from the geographical location, trajectory information (speed and bearing) and GMT/UTC time, each buoy records an acoustic signal related to the aggregated biomass beneath the floating object. The sampling configuration (number of emitted pings, sampling duration, time of the day in which the acoustic sample is taken, etc.) and the technical specifications of the echo sounder buoys (beam angle, transducer frequency, etc.) depend on the model. The internal algorithms used for echo integration are also proprietary to each manufacturer (Table n° 10). This implies different units of measurements and outputs for different models of buoy, making it difficult to compare the raw acoustic samples and estimates of the different models easily.

Characteristics	Zunibal	Satlink	Marine Instruments
ID buoy	x	x	x
Name of vessel	x	x	-
Type of buoy	x	x	-
Date/Time	x	x	x
Position	x	(*)	x
Water temperature	-	(*)	x
Speed	x	(*)	x
Direction	x	(*)	x
Overall acoustic index	x	x	(**)
Acoustic index by layer	-	x	(**)
Biomass unit	% pixels occupied	Tons of skipjack target	Coloured graph

(*) Due to limits on the size of data transferred, some acoustic data had to be interpolated.

(**) Acoustic information has to be viewed using specific software from "Marine Instruments".

Table n° 10 : Data recorded by the three main buoy manufacturers

	Marine Instruments	Satlink	Zunibal
Operating frequency (kHz)	50	190.5	130
Range (m)	150	115	100
Number of layers	50	10	Undefined
Energy source	Solar panels	Battery/Solar panels	Solar panels

Table n° 11 : Main characteristics of the three makes of echo sounder buoy used by the Spanish fleet during the period of reference (adapted from Lopez et al., 2014)

A description of these datasets and the corresponding preliminary analyses (Santiago et al, 2015) is given in Table n° 12. As an example, 1 month in the Atlantic Ocean provided 427,050 records, about 30% of which (140,592) included acoustic measurements.

	Marine Instruments		**Satlink**		**Zunibal**		**All**	
	All	Atlantic	All	Atlantic	All	Atlantic	All	Atlantic
Vessels			38	26	31	9	38	26
Buoys	1634	373	5522	2862	4549	1355	11705	4590
Buoys with echo sounder	1634	373	2271	1078	291	24	4196	1475
% Buoys with echo sounder	100	100	41.1	37.7	6.4	1.7	35.8	32.1
Number of records	575966	139758	262361	185126	459915	102166	1298242	427050
Acoustic records	486109	118647	28528	17833	53368	4112	568005	140592
Daily acoustic records	38799	9862	17902	11482	7825	528	64526	21872
Daily positive records	23443	8129	14247	9302	6792	475	44482	17906
% positives	60%	82%	80%	81%	87%	90%	69%	82%

Table n° 12 : Datasets used in the preliminary analyses for the Atlantic Ocean in March 2011 and for all the oceans (AO-PO: March 2011; IO: October 2011) for the Spanish fleet

The number of messages recorded by a buoy depends largely on the transmission frequency for which it was programmed, as well as on the useful life of the buoy. In general, a drifting buoy can record about 60,000 positions and 12,000 acoustic messages over 3 months. The database created using the information recorded over one month covered 8,811 buoys providing more than 1.2 million messages (~5.6 10^5 acoustic records), which gives an idea of the dimension and complexity of the task to be undertaken (Figure n° 30). The development of this database and the routines for incorporating and processing the data was one of the main tasks during the project.

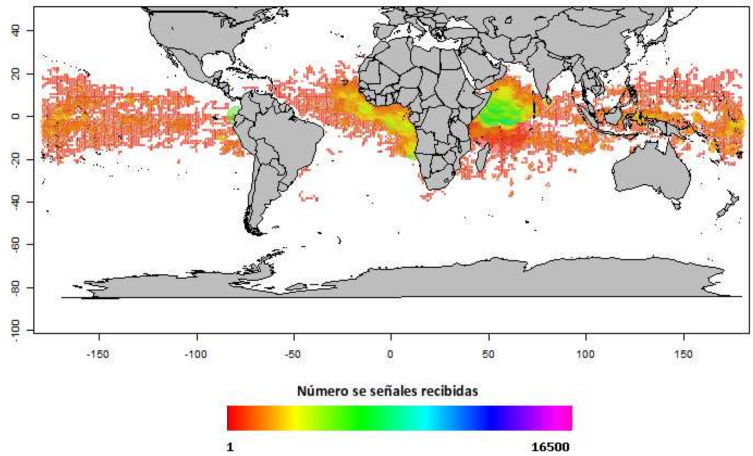


Figure n° 30 : Spatial coverage of data and number of messages received from the Spanish acoustic buoys in March 2011 in the Atlantic and Indian oceans and in October 2011 in the Pacific Ocean

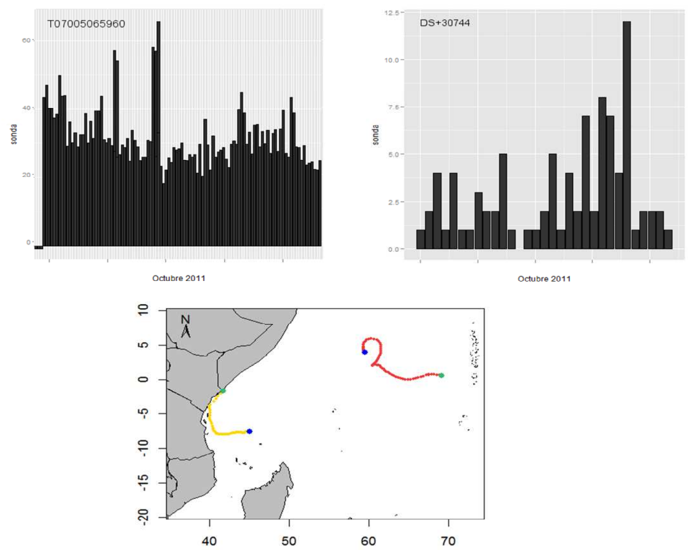


Figure n° 31 : Examples of acoustic time series recorded by a Zunibal (top left) and a Satlink (top right) buoy in the Indian Ocean in October 2011
The Y-axis represents the number of pixels occupied by the acoustic signal for the Zunibal buoy and tons of acoustic target for skipjack tuna for the Satlink buoy. Below: trajectories of the Zunibal (red) and Satlink (yellow) buoys between October 1st (blue circle) and October 31st (green circle).

The IEO provided 97 fishing logbooks, corresponding to 31 Spanish purse seiners starting or finishing their fishing trips in March and October 2011 in the Atlantic and Indian oceans. Information from onboard observers for the same period and area was analyzed to estimate the non-tuna biomass. However, the data from this source was limited, owing to the low coverage rate in both the Atlantic (5%) and Indian oceans (0%, due to piracy) during these months. An effort was made to collate different sources of information into a single dataset to allow comparisons between catches with detailed species and size compositions and acoustic measurements to quantify the proportion of the aggregation that may be sampled by the beam of the buoy.

Task 3 focused mainly on the use of acoustic tagging data in conjunction with behavioral models. The model developed in Capello et al. (2015) describes the associative dynamics of tuna in a network of anchored FADs (AFAD) and uses residence and absence times obtained from acoustic tagging data to estimate the probabilities of reaching the AFADs (when the tuna is not associated) or leaving a AFAD (when the tuna is associated). For this, the first application of this model used a dataset of bigeye scads (*Selar crumeophthalmus*) with acoustic tags that was collected from an array of acoustic receivers near Reunion (South Western Indian Ocean) and a dataset of yellowfin tuna that was collected from an array of anchored FADs in Hawaii by IRD before the CECOFAD project (Dagorn et al., 2007; Soria et al., 2009).

WP3-Evaluation and results

Data cleaning and modeling a Buoy-derived Abundance Index

In order to standardize fishery independent abundance indices from echo sounder buoys, Santiago et al. (2015) analyzed 140,592 acoustic records from the Atlantic Ocean, which were integrated into 21,872 daily records. A daily record for a particular buoy was considered to be the maximum value of all records recorded by the buoy on a given day. After a preliminary analysis, echoes from layers less than 25 m deep were excluded because echoes from these shallow layers are more likely to correspond to non-tuna species (Robert et al., 2013). This adjustment could be done with layer-specific values which were provided only by Marine Instruments. Acoustic measurements require additional data cleaning and transformation for further modeling (Figure n° 32).

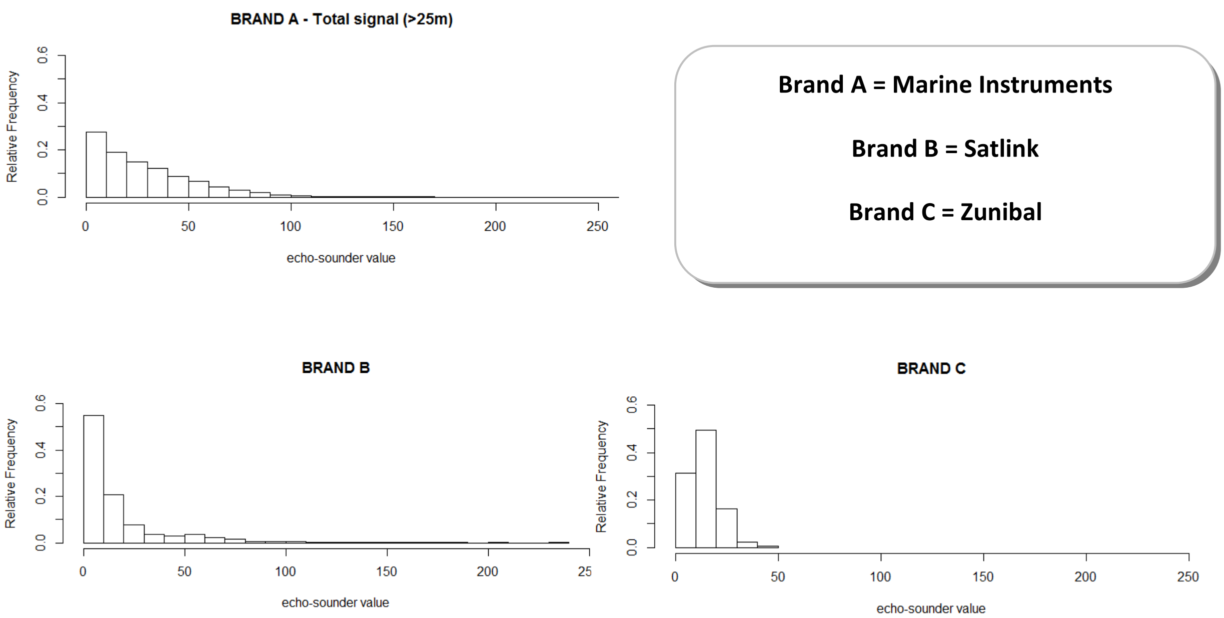


Figure n° 32 : Histograms showing the frequency distribution of the daily acoustic record values provided by the three different models of echo sounder buoy in March 2011. SOURCE: Fleet associated with the Spanish organizations, ANABAC and OPAGAC, fishing in the Atlantic Ocean

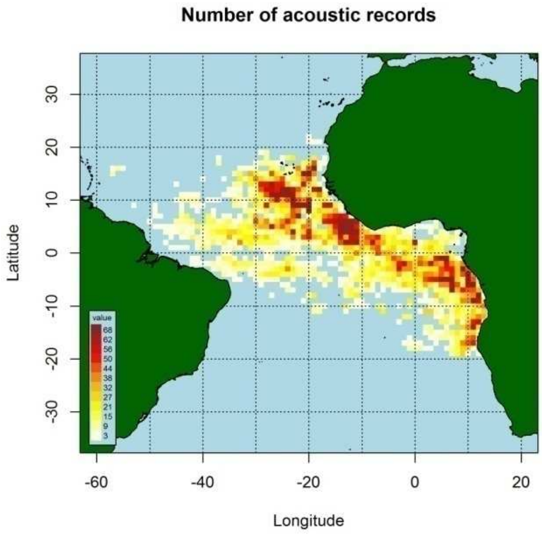


Figure n° 33 : Number of echo sounder daily records in 1°x1° squares in March 2011. SOURCE: Fleet associated with the Spanish organizations, ANABAC and OPAGAC, fishing in the Atlantic Ocean

The comparison between the spatial distribution of the number of daily acoustic records and the catches during the same period by the Spanish purse seine fleet is shown in figures Figure n° 33 and Figure n° 34, respectively.

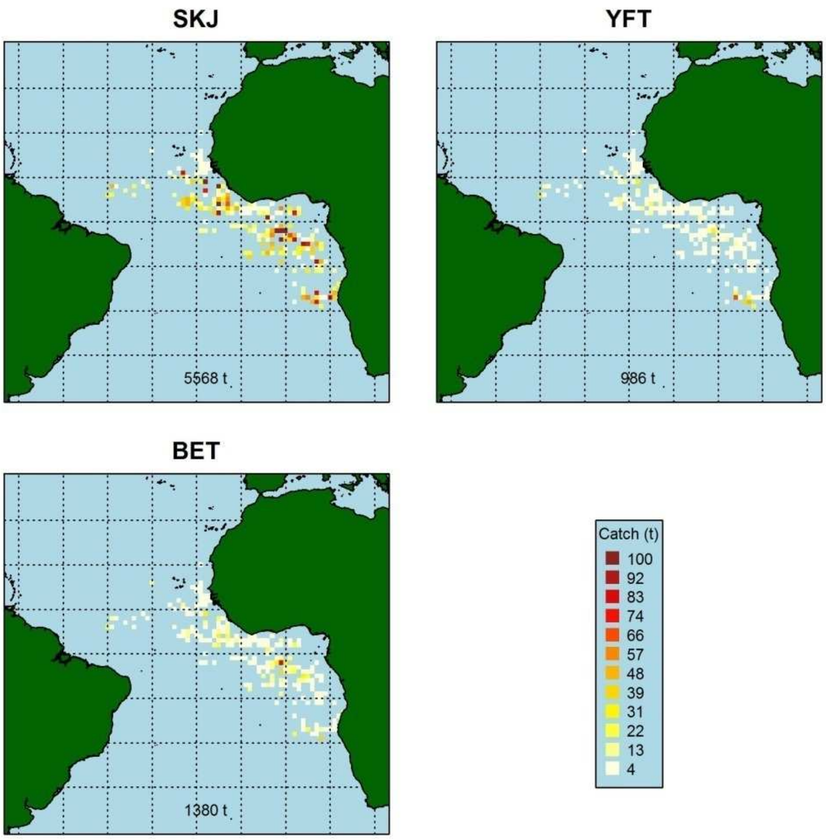


Figure n° 34 : Catches of SKJ, YFT and BET by the Spanish PS fleet in 1°x1° squares in March 2011. (from ICCAT Task II)

The model proposed is based in an assumption very similar to the fundamental relationship between CPUE and abundance, where CPUE is considered proportional to the abundance and catchability is the coefficient of proportionality. In our case, the signal from the echo sounder was assumed to be proportional to the abundance of fish.

$$BAI_t = \varphi \,.\, B_t$$

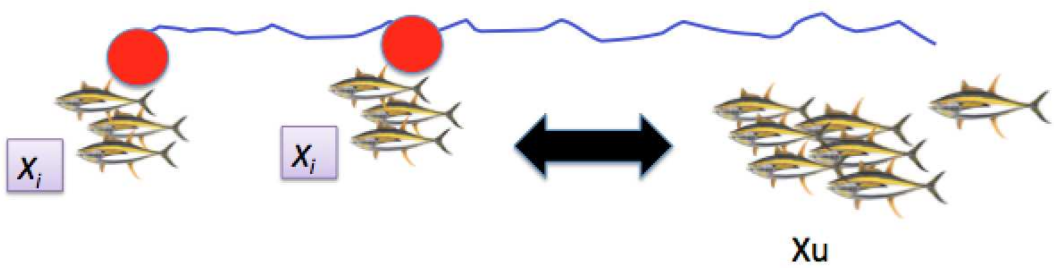
where BAI_t is the Buoy-derived Abundance Index, φ is the coefficient of proportionality, and B_t is the abundance in time t.

Because the coefficient of proportionality φ is not constant, nominal measurements of the echo sounder buoy records were standardized using a Generalized Linear Mixed Modeling approach. Due to the significant proportion of records with zero abundance (18% in the tropical Atlantic Ocean in March 2011), a delta-lognormal distribution (Lo et al., 1992) was used in the model to estimate BAI as the product of: i) the probability of finding tropical tuna in the acoustic observations (proportion of positives) and ii) the mean relative abundance where there was a positive observation.

The methodology presented here describes the initial stages of estimating an abundance index from echo sounder buoys remotely, showing the basic principles and taking account of the most significant features to be considered for the standardization process. Standard data cleaning should be carried out including the removal of outliers (invalid, impossible or extreme values) related to bad geolocation, time, or other factors. Apart from the normal exclusions due to inconsistencies, several factors *that* should be considered in the standardization process, either because they may affect the assumption that the acoustic records are proportional to the tropical tuna abundance or because they may influence the coefficient of proportionality, *are suggested in the WP3 Lessons learnt section.*

Modeling the aggregation process of biomass under DFADs.

The behavioral model focused on developing a methodological framework for estimating the site fidelity of tunas and non-tuna species at AFADs, as this information is essential for improving estimates of tuna abundance based on the associated/unassociated ratio of the population (Figure n° 35).



Figure

Figure n° 35 : Schematic of the association dynamics of the behavioral model. The tuna population is split into an associated population (Xi, where i denotes the AFAD) and an unassociated population Xu. (from Capello et al. 2015)

In theory, the ratio between the associated and total-population of tuna in a network of anchored FADs. may be expressed in terms of residence and absence times, using the behavioral model with the following steps:

i) Continuous residence times (CRT)

Ohta and Kakuma (2005) defined a continuous residence time (CRT) as the duration within which a tagged fish was continuously monitored at a specific location without absences of more than 24 hours. This 24 hour period was later generalized and referred to as the Maximum Blanking Period (MBP, see Soria et al. (2009), which corresponds to the maximum amount of time that is allowed between two subsequent acoustic detections for considering that a fish is still present (or resident) at a particular listening station. Based on this approach, CRTs was defined in time units where the temporal separation between subsequent acoustic detections was less than the MBP.

ii) Maximum Blanking Period (MBP)

The MBP was considered as a discrete variable whose value was optimized as appropriate.

iii) Identification of the optimum timescale for determining continuous residence times.

iv) Validation of the method by simulation using 3 possible distributions: single exponential model with noise, time-dependent sigmoidal model and time-dependent sigmoidal model with noise.

The model defined above was applied to two targets: a non-tuna species (bigeye scads) and a tuna species (yellowfin tuna) and acoustic array characteristics. To give an example, for the cleaned dataset of residence and absence times of yellowfin tunas in Hawaii indicated that, during the period covered by the tagging experiments (2003), about 70% of all tuna in the size classes that were tagged (FL 50-90 cm) present in the waters around Hawaii were associated with AFADs.

Electronic tagging data from arrays of anchored FADs were used to assess the proportion of the fish population associated with floating objects. This coupled with measurements of the FAD-associated biomass obtained from echo sounder buoys could be used to obtain fisheries-independent indexes of tropical tuna abundance. Because industrial purse seiners do not usually exploit AFADs, further research should be carried out on drifting FADs to determine the temporal and spatial dynamics of fish aggregations on drifting floating objects. It must, however, be borne in mind that it might be difficult to estimate this relationship for DFADs, especially owing to the lack of data on the density of floating objects in the ocean as well as on the associative behavior of tuna in a dynamic array of DFADs.

It must be stressed that the great disparity between manufacturers and models of buoy makes it significantly more difficult to obtain a reliable biomass index for tuna and non-tuna species. As mentioned, considerable research is being undertaken to gain a better understanding of inter-buoy variability, including differences between manufacturers and models. Even though these differences have not yet been fully determined, these preliminary analyses are of primary importance for future study. Unlike catch data, buoy derived data is not affected to the same extent by fishery-data limitations and consequently abundance indexes derived from echo sounder buoys should be developed as they can provide high resolution data in a non-invasive way.

WP3-Lessons learnt

The preliminary analyses carried out in this Work Package showed that there were several criteria that should be used for cleaning the datasets before standardizing an abundance index derived from echo sounder buoy data:

- **Time after deployment (or fishing event)**: records for less than 1 day after deployment, or after a known fishing event, should be excluded owing to noise in the final estimates. According to Moreno et al. (2007b) and Hall (2011), DFADs are deployed and left to drift freely so that they can be used exclusively by the boat or fleet that set them afloat after a certain period of time, usually 3 to 5 weeks.

- **Vertical range of the buoy**: acoustic information from layers above a depth of 25m should be excluded. According to Robert et al. (2013), Lopez (2015), there is a boundary between non-tuna species and tunas at a depth of about 25 m and so excluding the upper 25 m eliminates noise from non-tuna species associated with the DFAD.
- **Time of day**: The time when purse seiners initiate sounding varies between regions, companies and buoy manufactures and models used but the vast majority always sound at dawn (Lopez *et al.*, 2014). Selecting only acoustic data at a common standard time could reduce the effect of local time. An alternative should be to take the maximum daily biomass value, without considering the time of the day but this might be less satisfactory as many buoys are not configured to sample throughout the 24 h period.
- **Bottom depth:** Using high resolution bathymetry data (British Oceanographic Data Centre, UK, www.gebco.net), acoustic records from buoys located in areas where the sea bed is at a depth of less than 200 m should be excluded. This should eliminate acoustic records of FADs that have drifted into coastal areas and might provide false positives.
- **Speed of the buoy:** Satellite linked buoys automatically record information on their trajectory speed and bearing. As buoys are usually turned on minutes or hours prior to deployment and are turned off after an undefined period of time, some of their acoustic measurements could be compromised and give false positives. As surface currents in the tropical oceans rarely exceed 3-5 knots (Lumpkin and Garzoli, 2005; Sikhakolli et al., 2013), higher values could indicate whether the DFADs are still onboard or have been deployed and consequently the validity of the records.

Using the same principles as for CPUE standardization, in addition to the basic factors (year, month and area) the following parameters should be considered for the standardization of buoy derived abundance indexes:

- **Soak time:** The time spent by the buoy in the water since initial deployment. This is only valid for virgin DFADs and for DFADs for which the time at sea is known.
- **Type of buoy**: Buoy manufacturer and model. Technical specifications and operation procedures vary considerably between companies and models. The following should also be considered as relevant covariates for standardization:
- **Frequencies at which buoys operate**: A priori, different frequencies provide acoustic measurements that cannot be compared or combined in a dataset and these must be pre-processed to obtain common signals.
- **Units provided by the buoy:** The raw acoustic information used by the buoys, the echo-integration procedure and final records significantly differ between manufacturers and models. It is, therefore, of primary importance to investigate the relationship among them. Studies are in progress to try to standardize and better understand these inter and intra-buoy differences (Sancristobal *et al.,* 2014)
- **Sampled volume:** As the beam angle and ranges are also model-specific, these parameters should be included in the standardization process.
- **Acoustic filters automatically applied by the buoy:** Some buoys use an internal automatic filter to try to reduce the noise produced by non-tuna fish at DFADs, which could result in the loss of useful data. These differences should be taken into account and, if possible, compensated or corrected.
- **Depth of the acoustic layers**: Two sections of the observed water column should be considered: 25-80 m and >80 m. Although further investigation is needed, there seems to be a boundary between small and large tunas at about 80 m (Lopez, 2015). This boundary might be ocean or region specific and might fluctuate depending on local environmental conditions. Further studies should investigate this in greater detail.

- **Bearing and speed of DFADs**: according to Lopez (2015), the bearing and speed of FADs are key factors determining the presence of non-tuna species and tuna and the amount of biomass at DFADs.
- **Density of DFADs**: The number of DFADs in a particular area surrounding the buoy should be recorded (number within a radius of nm to be decided).
- **Environmental variables:** Oceanographic conditions can also affect the accuracy of data provided by the buoys. Furthermore, environmental factors, particularly those related to productivity such as sea surface temperature (SST), sea level anomalies (SLA), chlorophyll *a*, mixed layer depth, etc. seem to affect fish presence and abundance at DFADs, as well as their associative behavior.
- **Species composition beneath DFADs:** The size and species composition of the associated aggregation may also affect the final acoustic biomass value. Investigating the catch composition of a particular spatial-temporal set or strata might be beneficial for the standardization process. Studying the variability of size and species composition between DFADs would also be an advantage.

WP3-Best practices identified

The methodology developed to derive an echo sounder buoy abundance index for tropical tunas and non-tuna species identified data exclusion parameters and a list of factors that should be taken into account for the standardization of acoustic measurements from echo sounder buoys.

Passive acoustic telemetry, in particular acoustic tagging, is already used for studying animal behavior and spatio-temporal patterns for conservation purposes. Behavioral models based on passive acoustic telemetry data can be used for estimating residence times over a range of timescales. In particular, the exact proportion of time animals spend closely associated with a receiver (e.g corresponding to habitat types) within a day or over an entire experiment (site fidelity) are important behavioral metrics that need to be assessed for management purposes. Special techniques are required for quantifying these metrics. Given the high cost of tagging and field campaigns, optimizing the quantity and quality of data yielded by acoustic tagging experiments and processing to allow comparison between different datasets would represent a significant contribution to the field.

WP3-Recommendations

The tasks undertaken in WP3 will open new lines of investigation in the field and will foster collaboration between research institutes and industry. These tasks set out to find an alternative abundance index of tuna and non-tuna species using different approaches. However, they share similar concerns and recommendations in terms of availability of non-conventional data.

Future work must be supported by an increased exchange of data and collaboration between scientists and fishermen, to allow for large-scale investigations. The availability of the full echo sounder buoy datasets for both the French and Spanish fleets (or at least enough to be representative of the fishery) is key for scientific purposes. Such a dataset would provide both statistically-sound information on the spatio-temporal variability of the associated biomass and a valuable indicator of the number of artificial DFADs present in tropical waters. The number of DFADs is essential for using the fisheries-independent abundance indexes developed in this WP and for assessing the impact of an increasing number of DFADs on tuna and non-tuna populations. Having a dataset not limited to one month of echo sounder buoy data would also increase the capability of the abundance index estimation approach proposed in this WP. Agreements are, therefore, required between EU institutes (e.g. IRD/AZTI/IEO) and fleet owners (e.g. Orthongel/ANABAC/OPAGAC) to deliver echo sounder buoy records from the EU fleets to the institutes. This kind of initiative should be endorsed by RFMOs and governments, which should guarantee the confidentiality of the data (for a reasonable period) and support continuing collaboration between industry and research institutes.

WP3-Deliverables (publications/presentations) in relation to the working package

Capello, M., Robert, M., Soria, M., Potin, G., Itano, D., Holland, K., Deneubourg, J.-L., Dagorn, L., (2015). A Methodological Framework to Estimate the Site Fidelity of Tagged Animals Using Passive Acoustic Telemetry. PLoS ONE 10, e0134002. doi:10.1371/journal.pone.0134002.g009

Santiago, J., Lopez, J., Moreno, G., Murua, H., Quincoces, I., Soto, M., (2015). Towards a Tropical Tuna Buoy-derived Abundance Index (TT-BAI). SCRS/2015/90.

WP3-Other references

Capello, M., Deneubourg, J.L., Robert, M., Holland, K., Schaefer, K., Dagorn, L., (2013). A new fisheries independent method to estimate abundances of tropical tunas IOTC–2013–WPTT15–12.

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Lopez, J., Moreno, G., Boyra, G., Dagorn, L., *in press*. A behavior-based model to estimate biomass of fish species associated with fish aggregating devices (FADs) using fishers' echo-sounder buoys. Fishery Bulletin -, -.

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Ohta, I., Kakuma, S., (2005). Periodic behavior and residence time of yellowfin and bigeye tuna associated with fish aggregating devices around Okinawa Islands, as identified with automated listening stations. Marine Biology 146, 581-594.

Robert, M., Dagorn, L., Lopez, J., Moreno, G., Deneubourg, J.-L., (2013). Does social behavior influence the dynamics of aggregations formed by tropical tunas around floating objects? An experimental approach. Journal of Experimental Marine Biology and Ecology 440, 238-243.

Sikhakolli, R., Sharma, R., Basu, S., Gohil, B.S., Sarkar, A., Prasad, K., (2013). Evaluation of OSCAR ocean surface current product in the tropical Indian Ocean using in situ data. J Earth Syst Sci 122, 187-199.

Soria, M., Dagorn, L., Potin, G., Fréon, P., (2009). First field-based experiment supporting the meeting point hypothesis for schooling in pelagic fish. Animal Behaviour 78, 1441-1446.

5.4 WP4 Catch composition around FADs and estimate of potential effects on other marine organisms

WP4-Objectives

Although Tuna RFMOs have recently improved fishery statistics for sharks, these are still unable to provide quantitative information on stocks that is sufficiently precise to provide input to fishery management decision-making on optimum harvest levels. This work package, therefore, analyzed, several fishery indicators related to sharks. Most of the data was obtained from previous observer programs and, for this reason, a special effort was made to produce tools to merge information from logbook and observer databases.

The impact of FAD-fishing may be evaluated in various ways: the total catch, the bycatch species and the size composition for DFAD sets, depending on the DFAD location, trajectory and soaking time, when these parameters are available. These approaches were extended by examining several diversity and biomass metrics for both target species and bycatch removed by FAD-fishing. Regional differences were identified and the species diversity associated with the DFADs was found to be richer than for free school sets which may be useful for future conservation issues. The effect of a DFAD moratorium on bycatch as well as on whale sharks and marine mammals was explored.

WP4-Data used

The CECOFAD project used logbooks from the EU tropical purse seine fleets in the Atlantic and Indian Ocean, information from the EU DFAD Management Plans, observer data, incomplete information on supply activity provided voluntarily by the Spanish purse seine companies, GPS buoy tracks provided by several French purse seiner companies and oceanographic data from the MyOcean-Copernicus EU consortium. The time period covered by each dataset was different and is summarized in Table n° 13.

Data	VMS	Environmental data	Logbooks	Observer	DFAD plans	GPS buoy tracks
Period	2007-2014	2003-2013	2005-2012	2003-2015	2013-2014	2007-2013

Table n° 13 : Main types of information used in WP4

To illustrate the type of information used in WP4, total catches (targeted species and other tuna, landed and discarded) and bycatch (billfishes, rays, sharks, turtles and other bony fish) classified by set type, free school sets and drifting Fish Aggregating device sets, are summarized in Table n° 14 for the period 2003-2015 in the Atlantic and Indian oceans based on information from observers onboard French, Spanish and associated flag vessels. Number of whale sharks and marine mammals encircled are also shown as well as the number of sets.

ATLANTIC OCEAN (IEO+AZTI+IRD+TAAF)

				2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
FREE SCHOOL SETS (FSC)	CATCH (landed+discarded)	YFT	Weight (t)										13258,6	22785,2	30344,9	14044,3
		SKJ	Weight (t)										1150,7	5925,9	3698,2	1772,4
		BET	Weight (t)										900,3	615,0	995,7	143,0
		Other tuna	Weight (t)										334,7	247,0	444,2	396,5
			TOTAL	1072,65	295,6	867,192	825,825	2023,4	4011,26	2874,445	6867,765	8836,792	15644,2	29573,1	35482,9	16356,2
	BYCATCH	Billfishes	Weight (t)	0,86	0,12	1,04	2,86	8,45	5,07	4,2	12,63	12,09	30,0	42,4	31,4	15,7
			Nº	43	1	42	59	311	73	88	228	370	929,0	1381,0	887,0	439,0
		Rays	Weight (t)			0,15	4,35	1,64	0,76	1,84	6,26	2,46	10,8	22,2	9,2	3,0
			Nº	3		1	30	18	9	18	60	28	144,0	184,0	117,0	55,0
		Sharks	Weight (t)	0,38	0,10	0,24	0,07	0,13	0,70	83,7	40,05	7,35	21,7	179,7	174,7	72,4
			Nº	66	1	2	4	2	7	750	325	145	310,0	1775,0	1770,0	718,0
		Turtles	Weight (t)	0,4		0,13	0,06	0,11	0,15	0,33	1,41	1,26	3,4	4,8	4,5	1,3
			Nº	4		3	3	9	8	10	25	15	66,0	109,0	126,0	37,0
		Other bony fish	Weight (t)	0,3	0,23	0,17	2,4	5,95	0,59	0,96	11,11	7,64	16,3	162,7	10,4	6,1
			Nº	134	6	19	85	438	108	135	9093	4116	8436,0	76124,0	7337,0	1180,0
FISH AGGREGATING DEVICE (FAD)	CATCH (landed+discarded)	YFT	Weight (t)										3928,4	10575,9	11635,5	5315,7
		SKJ	Weight (t)										14188,3	48822,2	61605,6	20061,8
		BET	Weight (t)										1654,8	6553,9	5938,2	2368,7
		Other tuna	Weight (t)										1395,9	2978,8	4454,8	1439,4
			TOTAL	515	512,5	971,647	1257,135	1919,043	3634,009	3744,318	6933,769	8150,99	21167,5	68930,8	83634,1	29185,5
	BYCATCH	Billfishes	Weight (t)	0,19	0,33	2,06	1,23	5,13	13,25	7,46	16,86	18,37	45,5	119,6	140,2	48,4
			Nº	15	11	30	27	52	151	82	122	152	440,0	1147,0	1272,0	468,0
		Rays	Weight (t)			0,01	0,31	0,72	0,9	0,3	0,76	1,36	12,1	55,1	67,0	10,0
			Nº			1	2	6	7	2	14	16	107,0	461,0	516,0	113,0
		Sharks	Weight (t)		0,1	2,12	0,59	2,15	2,28	7,64	11,37	25,75	51,8	324,7	357,1	98,5
			Nº	34	6	113	37	1121	91	276	324	665	1395,0	6904,0	7801,0	2806,0
		Turtles	Weight (t)		0,02	0,05	0	0,16	0,27	0,58	2,14	0,77	6,2	15,1	20,3	5,8
			Nº	8	1	2	1	4	5	8	35	25	146,0	422,0	561,0	217,0
		Other bony fish	Weight (t)	0,03	9,62	18,94	18,49	14,73	157,46	42,27	267,26	179,83	650,5	1562,2	1077,4	728,2
			Nº	1375	11319	12824	11552	7238	216244	24659	71588	138200	742321	1385684	852144	986650
		Whale shark	Weight (t)	3,65	25,53	0	7,44	0	50,51	25,57	31,22	0	46,0	97,6	264,9	53,3
			Nº	8	7	0	2	0	21	7	15	0	19,0	23,0	77,0	15,0
		Cetaceans	Weight (t)	0	10	0	0	0	0	91	150		171,5	259,1	352,5	80,0
			Nº	-	-	-	-	-	-	-	-	-	25,0	53,0	80,0	13,0
SETS (Nº)			FSC	78	41	80	59	125	206	249	438	361	792	1528	1832	1065
			FAD	24	33	52	43	87	170	166	322	355	775	2213	2534	1143
			Total sets	102	74	132	102	212	376	415	760	716	1567	3741	4366	2208
TOTAL CATCH (FSC+FAD)				1588	808	1839	2083	3942	7645	6619	13802	16988	36325	96837	117475	45064

Table n° 14 : Breakdown of bycatch reported during French and Spanish (and associated flags) observer programs in the Atlantic and Indian Oceans by taxon and by fishing mode for the period 2003-2015

WP4-Evaluation and results

DFAD characteristics, new materials and fishing practices

Characteristics of the DFADs were described based on information collected from skippers within the framework of the Spanish and French DFAD Management Plans:

1. surface structure with nets and bamboos,
2. surface structure with metal or PVC,
3. non-entangling DFADs: with the surface structure of the dFAD
    - o not covered
    - o only covered by non-meshed materials such as ropes or canvas sheet or
    - o with netting rolled up and securely tied in "sausages“ with nets of maximum 3 cm
4. natural objects,
5. unknown DFADs,
6. surface structure without net coverage or non-entangling coverage

In the case of the Spanish fleet, despite a large proportion of DFADs with unknown characteristics (approximately one third of the DFADs in the Atlantic and in the Pacific oceans), the decrease in the proportion of non-entangling DFADs used between 2013 and 2014 is due to the increase in DFADs without net coverage or non-entangling coverage. This was shown for the Atlantic and the Indian oceans but less information was available for the Pacific ocean (Figure n° 36).

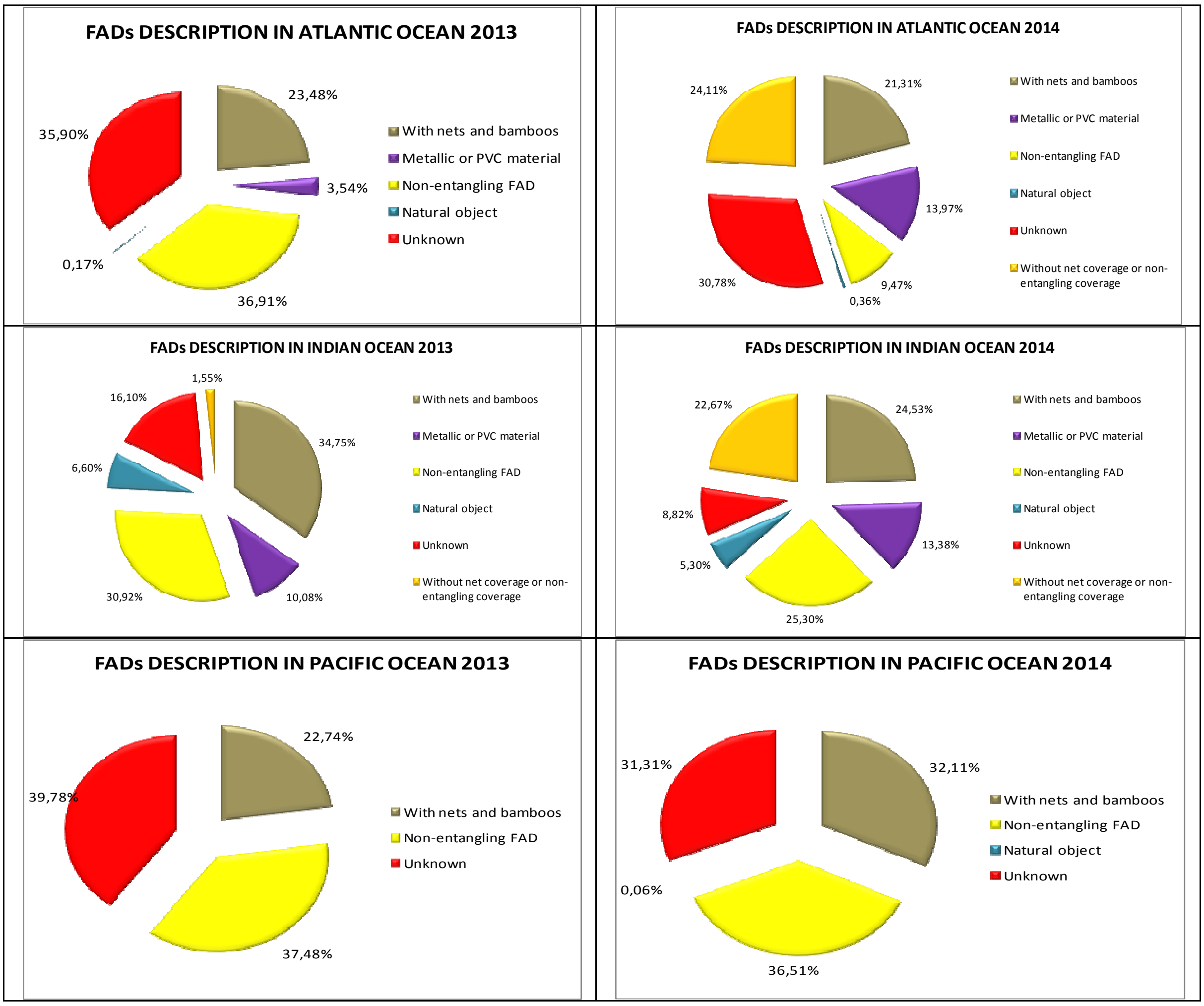

Figure n° 36 : Characteristics of the Spanish DFADS deployed in the Atlantic, Indian and Pacific oceans (from top to bottom, respectively) in 2013 (left) and 2014 (right) from Delgado et al 2014, 2015 and updated by Sotillo et al (pers. comm.)

For the French fleet, Goujon et al (2014) reported that the first non-entangling designs were introduced in 2010 in the Indian Ocean and in 2011 in the Atlantic ocean. Since 2012, French purse seiners are authorized to deploy only non-entangling DFADs.

The ecosystem approach to fisheries aims to reduce by-catch mortality and so discarding practices have been introduced in the EU purse seine fleets. A manual has been drawn up and disseminated to increase the probability of survival for released fish and megafauna (Poisson et al., 2014).

Observing good practices continues to be one of the objectives of the EU purse seine fleets as a means of reducing mortality of vulnerable species. Preliminary observations of DFAD structure and release operations from on board Spanish purse seiners between December 2014 and July 2015, showed that, for the 6 vessels observed in the Indian Ocean, more than 90% of the DFADs had a non-entangling raft for 60% of the fishing trips observed and more than 90% of the DFADs had a non-entangling submerged structure for 60% of the fishing trips. For the 19 vessels observed in the Atlantic Ocean, more than 80% of the DFADs had a non-entangling raft for 59% of the fishing trips observed and more than 80% of the DFADs had a non-entangling submerged for 50% of the fishing trips. For several Spanish vessels operating in the Atlantic Ocean, initial results showed significant improvement in shark release conformity between consecutive fishing trips (Goñi et al, 2015). These results should be validated using scientific observer data to determine any potential bias in skippers' reports. However, they are encouraging in terms of correct fauna release operations as well as in improvement made by individual vessels during consecutive fishing trips.

Impacts of lost DFADs

French GPS buoy trajectories were analyzed to detect DFAD beaching events and the potential damage to fragile coastal ecosystems. A beaching event was defined as the same position repeated at least three consecutive times with the location a long way from a port (more than 10 km) and close to the coast (less than 5 km). It was showed that for the period 2007-2013, around 10% of the trajectories of floating objects with GPS-buoys ended with a "beaching event" in the Atlantic and Indian Oceans, suggesting that 1,500-2,000 may be lost onshore each year, with significant portions of these beaching events occurring in areas that might have sensitive habitats, such as coral reefs.

In the Atlantic Ocean, beaching events tend to be concentrated in the Gulf of Guinea but some buoys travel across the ocean and beach on the Brazilian coast. In the Indian Ocean, beaching events occur over a wider range of areas, mainly on the coast of Somalia, the Seychelles, the Maldives and Sri Lanka. Beaching events also occur within the Marine Protected Area of the Chagos Archipelago (Figure n° 37).

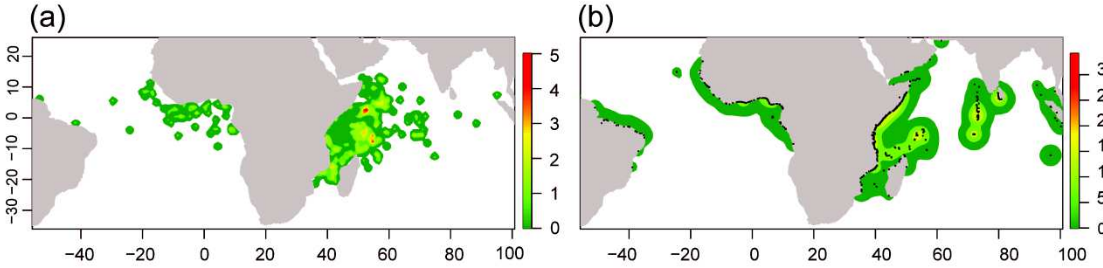

Figure n° 37 : Smoothed densities of DFAD beaching events (b) and their deployment positions (a); black dots correspond to individual beaching positions (Maufroy et al. 2015)

In addition, observations showed that non-entangling DFADs with 'sausage nets' still entangled sea turtles when they beached on coral reefs.

Relationship between DFAD density, soak time and bycatch

Three datasets (logbooks, observer data of bycatch and spatio-temporal locations of DFADs) from the French tropical tuna purse seine fishery in the Atlantic and Indian Oceans were combined to determine how the DFAD density and soak time affect the bycatch biomass and taxonomic composition. It proved difficult to match fishing sets in the observer dataset to the DFAD spatio-temporal trajectory data, and the resulting dataset was too small to determine how the soak time affected the bycatch biomass or taxonomic diversity. The accuracy of the estimates of DFAD density in 1°x1° square was limited by the use of a single multiplying factor to extrapolate the French data to the combined French and Spanish fleets as the ratio of French to Spanish vessels was not the same in each area. This spatial variability should be taken into account in the future.

Exploration of some FAD-regulations in management strategies

It is commonly accepted that fisheries have a direct impact on the whole of the marine ecosystem and, for this reason, the Ecosystem Approach to Fisheries (EAF) is being promoted as a framework for sustainable development, recognizing the interdependence between human well-being and ecosystem health (Garcia et al. 2003). However, although this approach is generally accepted, the types of action needed to set up EAF management plans are not considered as main priorities by the tRFMOs. For various reasons (lack of time, lack of data on non-targeted species), the multi-annual management plans adopted by tRFMOs, even with the recent application of the Management Strategy Evaluation (MSE), have had very limited scope. For instance, the focus has been on the risk that the spawning-stock biomass (SSB) of the targeted tuna species might fall below the level at which recruitment is likely to be impaired. Furthermore, there has been little, if any, consideration of the ecological impact of fishing restrictions.

Given the increasingly extensive use of drifting Fish Aggregation Devices in the eastern tropical Atlantic and western Indian Oceans, fishing effort restrictions, such as time-area moratoria on DFADs, have been adopted regularly by tuna RFMOs since the mid 1990s. However, these measures are limited to the protection of juvenile tuna and do not take account of the potential impact on bycatch or associated megafauna (whales and whale sharks). Within the framework of the PhD study by L. Escalle (IRD/UM2), a simple iterative “fishing-day” model was developed to investigate the consequences on tropical tuna and bycatch of introducing wide area, six-month moratoria on DFAD sets (Figure n° 38). The “fishing-day” model took account of the probability of the occurrence of several different fishing events (such as visual cues, size and species of tuna school, etc) and skippers’ on-the-spot decisions based on European purse-seine fishery data for the period 2005–2014.

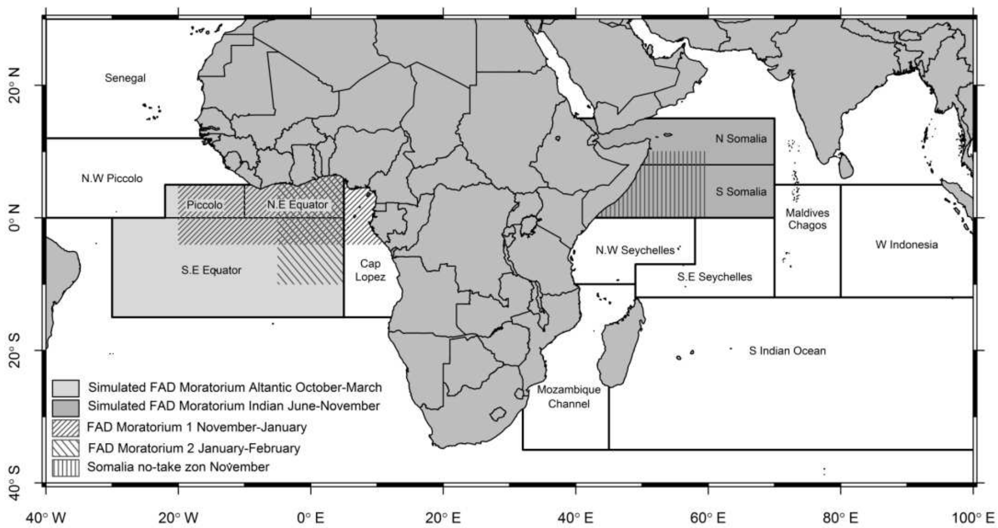

Figure n° 38 : Examples of different six-month moratoria on DFADs used in the Monte Carlo simulations

Monte Carlo simulations were carried out 1000 times to examine various scenarios for reallocating the fishing effort or changing fishing practices following the introduction of a six-month moratorium on DFAD sets for the European purse-seiners. The simulations included realistic scenarios in terms of difference in fishing strategies (e.g., DFAD targeting as observed for the Spanish fleet or combining DFAD and free schools fishing as seen for the French fleet) and reallocation of the fishing effort (e.g., at the periphery of the regulated area or towards the historic best fishing grounds). As this study set out to detect the effects of potential six-month moratoria on DFAD sets, a scenario without any ban was tested to provide a baseline. Each scenario was then simulated for the moratorium on DFAD sets defined for each ocean for one fishing year of one boat. The major difference from the baseline scenario was that, when a moratorium was simulated, the probability of the occurrence of a DFAD set inside the restricted area was redistributed among the remaining fishing modes in proportion to their respective probabilities

As expected, for both the Atlantic and Indian oceans, the models predicted a decrease in DFAD sets and an increase in free school sets (Figure n° 39). As a consequence, the catch of small tuna (<10 kg) decreased (except for the French fleet in the Atlantic Ocean) while the catch of large tuna (≥10 kg) increased, leading to an overall decrease in tuna catch of ~100 t/yr/boat in the Atlantic Ocean and 600–1800 t/yr/boat in the Indian Ocean. The bycatch for all groups considered (other bony fishes, billfishes, sharks and turtles) decreased, except in the Atlantic Ocean, where the turtle and shark bycatch increased slightly for both fleets. Because the fishing practices were modified, whale and whale shark associated sets increased slightly in the Indian Ocean. As the effects of moratoria on fishing strategies are difficult to predict, simulations based on fishery data are a useful means of evaluating the trade-offs of time-area closures as part of an ecosystem approach to fisheries.

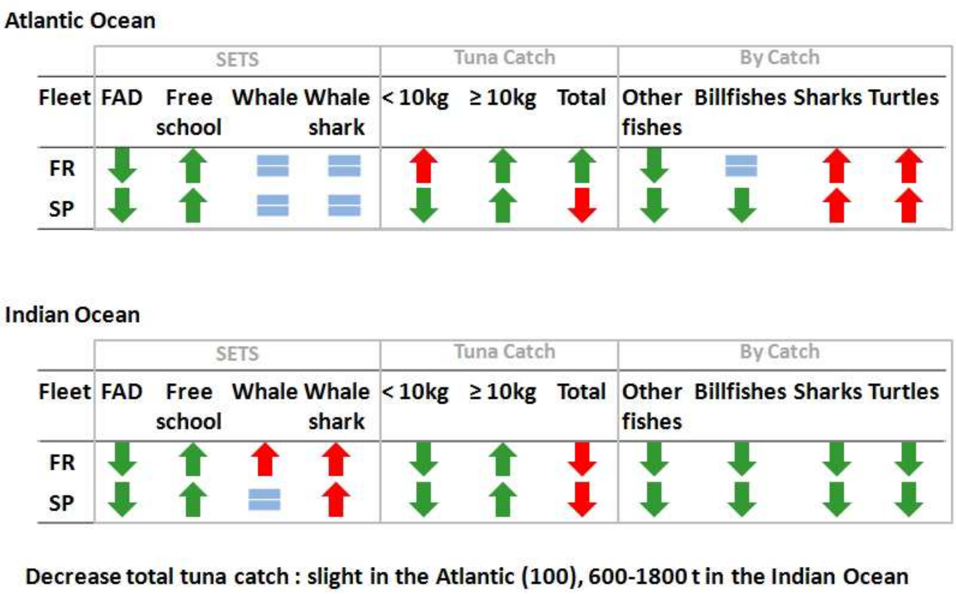

Figure n° 39 : Monte Carlo simulations for the main scenarios of six-month moratoria on DFADs in the Atlantic and Indian oceans (Escalle, pers. comm.)

Effect of FAD-fishing on emblematic and vulnerable species

Concerns over the incidental capture of pelagic sharks has been the subject of several regulatory measures in tuna RFMOs (ICCAT-Rec [11-08], IOTC-Res [13_06], IATTC-Antigua convention), specifically because these species regularly become entangled in the netting that hangs below the

DFADs. From observer-at-sea data collected by IEO and AZTI in the period 2003-2015, combined with the EU Copernicus data base for environmental data, a preliminary analysis used a delta-lognormal approach to characterize relevant environmental factors conditioning the habitat of silky sharks in the Atlantic and Indian oceans. However, due to time constraints, only an exploratory analysis was performed (Figure n° 40)

Figure n° 40 : Spatial distribution of the silky shark Carcharhinus falciformis from Spanish scientific observer data (free schools and DFADs; Lopez et al pers. comm.)

Impact of FAD-fishing on the ecosystem

Estimates of the total number of bycatch species for each fishing mode might be biased due to the low coverage of trips with observers on board in the past. As there has been 100% observer coverage under observer programs in the past 2-3 years, it may assumed that there is sufficient data to give an unbiased estimates of the total number of bycatch species. It would be interesting to compare these estimates with the estimates of the total number of species before 2014 (i.e., without 100% coverage).

The bycatch data collected under the European observer programs in the Indian, Pacific and the Atlantic Oceans between 2003 and 2010 were used to assess alpha and beta diversity and Generalized Additive Models (GAMs) were applied to DFADs and free school sets. The MaxEnt habitat distribution model was also used to determine the potential habitat of two different bycatch species: ths silky shark, *Carcharhinus falciformis*, and the rough trigger fish, *Canthidermis maculata*. Results from the PhD study by N. Lezama-Ochoa (AZTI) showed that bycatch communities in DFAD sets were good indicators of diversity as they contained a larger number of species, were evenly distributed and, therefore, had a higher diversity than the bycatch communities in Free School sets (Figure n° 41).

These measurements can be considered as good indicators for describing the variability of diversity in space and time and for identifying priority areas for conservation. Nevertheless, the sample size and coverage rate play an important role in obtaining a good inventory of the population and obtaining good results from the diversity measures. The species composition and the structure of the community were directly related with the fishing mode and the environment in which the species lived. Diversity was explained by various oceanographic processes at global and local scale. At a global scale, diversity was explained by surface currents, wind patterns and upwelling systems. At a local scale, diversity was explained by front systems, domos and eddies for both fishing modes.

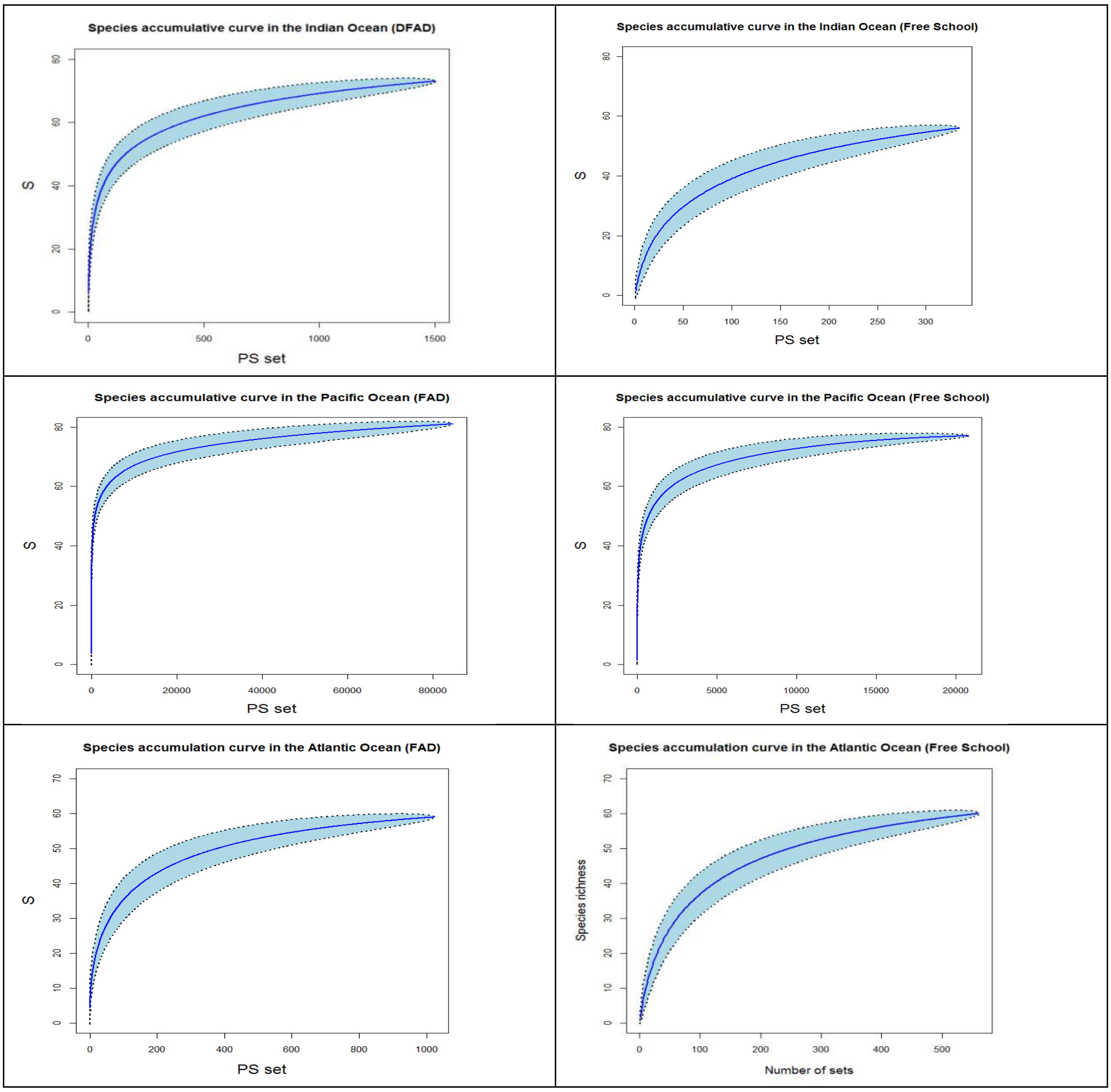

Figure n° 41 : Species accumulation curves for bycatch in DFADS (left) and free school sets (right) in the Indian, Pacific and Atlantic oceans, from top to bottom, respectively (Lezama-Ochoa, pers. comm.)

When producing maps of high and low biodiversity areas, the key "take-home" message for managers should be viewed with caution to avoid any confusion to avoid protecting or not protecting certain areas on this criterion alone.

French observer datasets in the Atlantic and Indian oceans (2006-2013) also used in a similar approach but at a smaller scale. Results indicated that, for DFAD sets, there was a higher percentage of discards (bycatch species released) compared to landings (targeted tuna and bycatch kept onboard for sale) in the Indian Ocean (6.4% for DFADs vs. 3.8% for free school) and particularly in the Atlantic Ocean (10.7% vs. 2.4%). Rarefaction curves confirmed that the number of taxa under DFADs was higher than for free school sets in both oceans. Simpson diversity and evenness were also significantly higher using DFADs rather than free school sets in both oceans. The overall size spectra of the bycatch showed no significant difference between oceans but there were more small individuals using DFADs. The 114 taxa in the bycatch were divided into 22 taxonomic groups to be compared in terms of biomass between oceans, fishing mode (DFAD/free school) and landings/discards (Widehem, 2015).

WP4-Success factors

To deal with the problems encountered by IEO (see below), one of the IRD master students initially taken on to work in WP2 (CPUE standardization) was redirected to a theme related to WP4 (comparison of diversity between free school and DFADs sets). In addition, some IEO activities in WP4 provided the opportunity of collaborating with other IEO scientists involved in other projects related to some of the CEDOFAD objectives, such as analyzing environmental variables (Bluefin tuna project, IEO Baleares/SOCIB) or VMS data (IEO-Santander). Some tasks initially developed by AZTI within the framework of the PhD thesis produced by Lezama-Ochoa, before the start of the CECOFAD project, were incorporated into several aspects of WP4.

WP4-Difficulties encountered

The IEO had to deal with certain problems during the project. Firstly, two full-time scientists involved in the WP4 retired in 2015, one in April and another in November. Secondly, there were significant legislative changes in Spain during recent years in relation to the administrative processes for handling and controlling public spending, which caused serious delays and loss of flexibility when taking on new staff. These internal administrative issues generated significant delays in the recruitment of two persons in Canary and Madrid. Thirdly, another consequence of these legislative changes was the delay in receiving the digitalized sampling data from ports in the Seychelles and the supply logbooks which are still held by the SFA for 2014. Fourthly, the six month contract for external staff in Madrid was reduced to four months with no possibility of replacement for the remaining two months.

WP4-Best practices identified

As expected, the feasibility and adoption of a protocol to mitigate the impact of purse seine fishery on vulnerable species in the bycatch during setting are closely linked to the recommendations and technical solutions proposed by the skippers themselves.

WP4-Solutions to barrier identified

Progress achieved between consecutive trips of the same vessel in terms of release of sharks suggests the need for continuous dialogue between scientists and skippers to demonstrate the feasibility of good practices and to resolve any problems that could arise (e.g., safety of the crew during the operation) which might prevent the protocol being applied to the entire purse seine fleet.

WP4-Recommendations

Collecting a wide variety of current and historic data is laborious and difficult. This has not yet been reflected in the final results of CECOFAD, but it is essential as a starting point to initiate some progress on the objectives of WP4 of CECOFAD, such as the scientific analysis of fleet activities in general and the effect of DFADs on the ecosystem in particular. With this in mind, special attention needs to be paid to the collection of certain biotic and abiotic environmental data and to the processing and production of environmental indicators. These tasks are very time consuming and go

beyond the scope of CECOFAD. However, the collection and cleaning of these datasets has laid the foundation for future work in the field.
As for previous work packages, WP4 demonstrated the value of analyzing logbooks and observer data for both the French and Spanish fleets.

WP-4 Deliverables (publications/presentations) in relation to the working package

Delgado de Molina A, Ariz J, Murua H, and Santana J. C. (2015) Spanish Fish Aggregating Device Management Plan. Preliminary data. Collect. Vol. Sci. Pap. ICCAT, 71(1): 515-524.

Delgado de Molina A, Ariz J, Murua H, Santana J. C, Ramos L and Soto M. (2014) Spanish Fish Aggregating Device Management Plan. Preliminary data in the Indian Ocean. IOTC–2014–WPTT16–19 Rev_1.

Goujon M, Claude A , Lecouls S, and Mangalo C. (2014) Premier bilan du plan de gestion des DCP mis en place par la France en Océan Atlantique. SCRS/2014/187

Lezama-Ochoa N, Murua H, Chust G, Ruiz J, Chavance P, Delgado de Molina A, Caballero A & Sancristobal I. (2015) Biodiversity in the by-catch communities of the pelagic ecosystem in the Western Indian Ocean. Biodiversity and Conservation, 24 (11): 2647-2671

Maufroy A, Chassot E, Joo R, and Kaplan, D. M. (2015a) Large-scale examination of spatio-temporal patterns of drifting fish aggregating devices from tropical tuna fisheries of the Indian and Atlantic Oceans. PLoS ONE.

Widehem C. (2015) Impact de la pêche thonière à la senne sur les communautés pélagiques de l’océan Atlantique et de l’océan Indien : comparaison de la pêche sous les dispositifs de concentration de poissons et de la pêche en bancs libres. Mémoire d'ingénieur de l'institut Supérieur des Sciences agronomiques, agroalimentaire, horticole et du paysage. Spécialité : Halieutique, Agrocampus Ouest Rennes 46p.

WP4-Other references

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., and Lasserre, G. (2003). The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper. No. 443. Rome, FAO. 71 p

Poisson F, Seret B, Vernet A.L., Goujon M, Dagorn L (2014) Collaborative research: Development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries Marine Policy, Volume 44, February 2014, Pages 312-320

5.5 WP5-Data Management

WP5-Objectives

Right from the start of CECOFAD it was clear that transversal activities were required in addition to the four Work Packages to coordinate the technical aspects of the project, the database management, the website development and the project administration and management.

One of the challenges of the CECOFAD research project was to provide links between the various sources of information (logbooks, observer data, VMS, echo sounder data, etc) collected in the work packages. This was the core of the transversal activity undertaken by WP5 which focused on the relationships between these datasets and future requirements for the various WPs in the project. Another important aspect was the absence or imprecision of FAD-fishing activity data which should be incorporated into records in ERS or paper logbooks in the future.

WP5-Evaluation and results

Links between databases

One of the challenges of the CECOFAD project was to create bridges between the various datasets (logbooks, observer programs, sampling in ports, etc). Priority was given to the two databases *Balbaya* (information declared in logbooks) and *ObsTuna* (on board observer data) collected within the Data Collection Framework (DCF)[1] by the Tropical Tuna Observatory of IRD (OT-IRD) for French purse seiners operating in the Atlantic and Indian oceans (Figure n° 42).

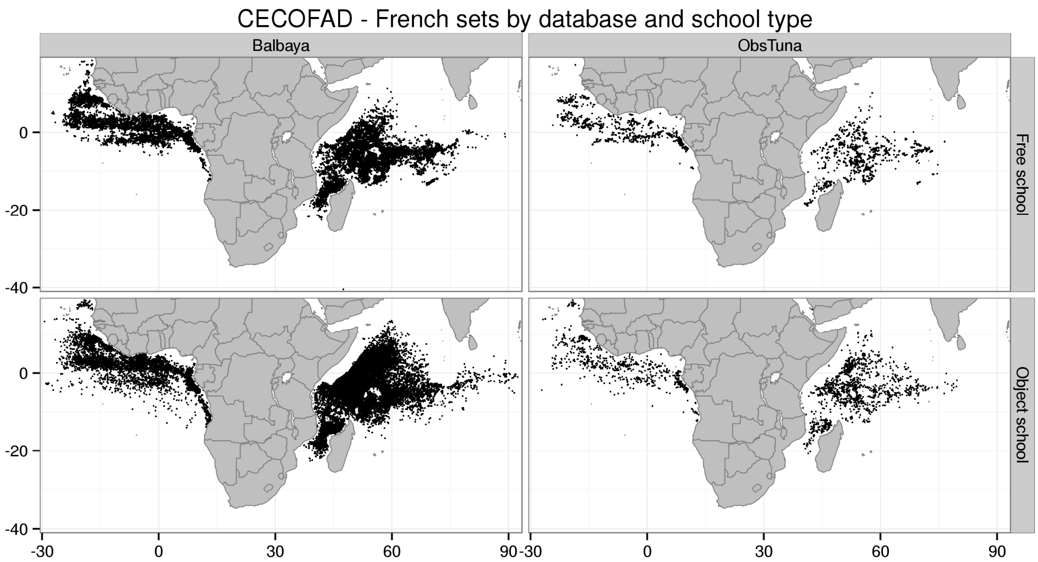

Figure n° 42 : DCF French sets classified by database and fishing mode (Billet, pers. comm.)

These databases are linked using the Standard Data-Exchange Format[2], a human-readable file format for samplings, landings and effort data from commercial fisheries currently used within the EU DCF context. This format allows a data aggregation level which is as low as possible while respecting data confidentiality issues and consequently should be considered as a good natural candidate for the exchange of data between partners in the tropical tuna fishery research community.

[1] Council Regulation (EC) No 199/2008 dated 25 February 2008 concerning the establishment of a Community framework for the collection, management, and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. 12 pp

[2] Jansen, T. (Ed). 2009. Definition of Standard Data-Exchange Format for Sampling, Landings, and Effort Data from Commercial Fisheries. ICES Cooperative Research Report No. 296. 43 pp. This should not be confused with the American SDEF data exchange standard.

The Standard Data-Exchange Format can be used with the R "COST"[3] package to export the French databases (see Table n° 15) as well for data processing.

Level	**Main variables**	**Records** **Balbaya / ObsTuna**
Trip	• Sampling type (market, onboard, etc..) • Vessel ID (encrypted) • Vessel size • Days at sea	2121 / 174 trips
Fishing operation	• Date • Time: 100% for onboard observer dataset and 30% for on-shore • Location • School type: free or log for on-shore, detailed for onboard (free, DFAD, whale, Whale-shark)	52455 / 4393 sets
Species caught	• Species • Landed / discard • Fate of discards: alive or dead (for onboard dataset) • Catch weight • Sampled weight	105232 / 22139 records
Size structure	• Length class • Number at length	714563 / 63898 records

Table n° 15 : Main variables and metrics of the French DCF dataset in Standard Data-Exchange Format

This work was a deliverable of the CECOFAD project (see Delivrables section).

The EU Electronic Reporting System (ERS)

Fishery indicators are submitted regularly to national/EU fishery administration and presented at yearly tRFMOs meetings. However, at the time of calculating such fishery indicators, various problems were found in the logbook data system: there was no clear definition of FADs, logs, natural or artificial floating objects, there were no common references for collecting data for activities on floating objects (e.g., deployment of DFADs, with or without a buoy, etc.), and there was no international agreement on FAD data formats.

On the basis on the latest recommendations from tRFMOs (ICCAT and IOTC), an extension of the electronic fishing logbook data model (European ERS project) has been produced. The ERS project was set up in 2009 to monitor fisheries (Council Regulation (EC) No 1224/2009 and Commission

[3] COST: EU funding FISH/2006/15, see http://wwz.ifremer.fr/cost/Cost-Project

implementing Regulation (EU) No. 404/2011]) and a preliminary version was produced in December 2013 for the French fishery administration (DPMA). The original ERS version was updated, focusing on floating objects and was extended to meet IATTC and WCPFC recommendations and to take account of the progress achieved within the CECOFAD project in terms of the information required for measuring DFAD-fishing effort and indicators of the environmental impact of the deployment of floating objects. These extensions included the type of floating object, operations on floating objects, description of the floating objects (materials, dimension, etc). A task force[4] was set up including the main participants involved in data management, with the collaboration of the professional partners in the project, to review the definitions and standardization of variables required for evaluating DFAD-fishing activities that should be continuously recorded in logbooks (regardless of whether an ERS or paper logbook was used). ERS logbooks now include a new classification of floating objects and a detailed list of operations to be filled by the skipper. This was one of the deliverables of CECOFAD (see Deliverables section).

Website and Wiki

One of the requirements of any public funded project is to demonstrate at the application stage that the deliverables of the project will not be lost at the end of the funding period. It was, therefore, specified in the call that the project should have a website for communication and dissemination of information, where the core information on the project is available (e.g. objective, partners, activities, main outputs such as good practice guides).

In order to disseminate the objectives and the achievements of the project to a wide audience, more specifically to the sectors most directly involved in the exploitation of the resource, a website (http://www.cecofad.eu/) was developed right from the start of CECOFAD. The website will be maintained for 2 years after the completion of the project. Following the recommendations of the kick-off meeting of CECOFAD, an associated wiki has been online since july 2014 (**Annex 3**). The wiki allows direct contact between the participants of CECOFAD and any interested parties (decision-makers, professional fisheries organizations, scientists, NGOs) can follow the progress of the different tasks undertaken within the project framework.

WP5-Delivrables

Bridges between databases

Exporting the various databases from logbooks and on board observer information into a common container within the “Standard Data-Exchange Format” made it possible to achieve significant data reconciliation. This file format is currently used for the EU fisheries data collection framework. The bridges between the two datasets were based on common identifiers of vessels, trips and fishing operations. Different types of observation require different values for the same event, and so trips that were in both datasets were identified using the vessel ID and the period, and for these trips sets that were in both datasets were identified by date (as well as time of the day when available), order

[4] This task force was led by J. Lebranchu (IRD) and comprised N. Goñi (AZTI), A. Maufroy (IRD), N. Billet (IRD), L. Floch (IRD), M. Goujon (ORTHONGEL), and M. Herrera (OPAGAC).

on that date, location and catch weight. One advantage of this file format is the linkage with the R package COST for data post-processing. The resulting dataset combines the reports of fishing operations by skippers and by scientific observers and was submitted for the French fleet to the CECOFAD project.

Floating object data model for fishing logbook and on-board observer data

One of the conclusions, mentioned in the previous sections of the Work Packages, is the need to define the information characterizing floating object-fishing (including FAD-fishing) that should be collected and to standardize the terminology describing these variables. The format may differ slightly between the French and Spanish fleets but it was considered very important to have an agreement covering the minimum data requirement and the meaning of the variables collected.

In order to clarify certain definitions and to harmonize FAD data requirements between EU purse seine fleets, it was agreed that the information to be collected should:

(1) measure the fishing effort,

(2) measure the extent of changes in habitat caused by floating object fishing activities and

(3) measure potential pollution (plastics, bamboo, netting, metal).

A floating object data model for the fishing logbook and on-board observer data was drawn up on the basis of these three objectives. The first point concerns the definition of the floating object[5]. A floating object at sea (FOB) is defined as a FAD (Fish Aggregating Device) if it is a man-made FOB specifically designed to encourage fish aggregation at the device, while any FOB other than a FAD, i.e. a natural (branches, carcasses, etc) or artificial (wreckage, nets, washing machines, etc) object will be termed a LOG. FADs and LOGs are then broken down into different categories depending on their features.
In the case of logbooks the new information to be collected can be summarized as described in Figure n° 43 and **Table n° 16**.

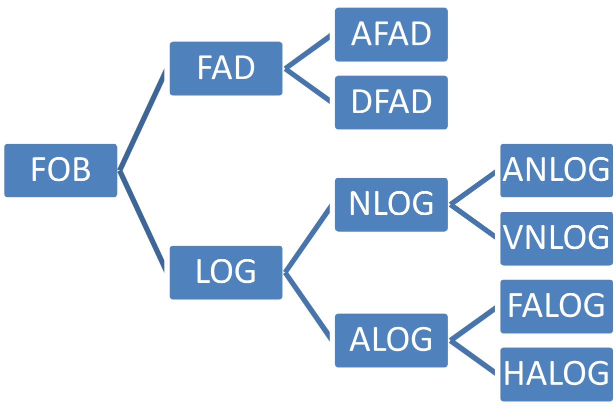

Figure n° 43 : Schematic subdivisions of the terms used in the floating object data model for the logbook

[5] Note: adding a beacon to a DFAD or LOG does not change its type. The main function of a buoy is to locate the FOB and estimate the aggregate biomass.

Code	Name	Example
DFAD	Drifting FAD	Bamboo or metal raft
AFAD	Anchored FAD	Very large buoy
FALOG	Artificial log resulting from human activity (and related to fishing activities)	Nets, wreck, ropes
HALOG	Artificial log resulting from human activity (not related to fishing activities)	Washing machine, oil tank
ANLOG	Natural log of animal origin	Carcasses, whale shark
VNLOG	Natural log of plant origin	Branches, trunk, palm leaf

Table n° 16 : Codes, names and examples of different types of floating object (Examples pictures in Annex 4) that should be collected in the fishing logbook as a minimum data requirement

The activities of the purse seiner associated with a FOB were defined as follows (

Table n° 17).

	Name	Description
FOB	Encounter	Random encounter (without fishing) of a log or a FAD belonging to another vessel (unknown position)
	Visit	Visit (without fishing) of a FOB (known position)
	Deployment	FAD deployed at sea
	Strengthening	Consolidation of a FOB
	Remove FAD	FAD retrieval
	Fishing	Fishing set on a FOB[6]
BUOY	Tagging	Deployment of a buoy on FOB[7]
	Remove BUOY	Retrieval of the buoy equipping the FOB
	Loss	Loss of the buoy/End of transmission of the buoy

Table n° 17 : Names and description of the activities related to floating objects and buoys that should be collected in the fishing logbook as a minimum data requirement (codes are not listed here)

In order to improve the quality of data collected by the skippers, a "User Interface" (UI) could be developed with the collaboration of the skippers. For example, a droplist with each operation being clearly represented by a photo might be proposed. For a quick implementation of the floating object model in the logbook it might be relevant to discuss this UI with some skippers.

[6] A fishing set on a FOB includes two aspects: fishing after a visit to a vessel's own FOB (targeted) or fishing after a random encounter of a FOB (opportunistic).

[7] Deploying a buoy on a FOB includes three aspects: deploying a buoy on a foreign FOB, transferring a buoy (which changes the FOB owner) and changing the buoy on the same FOB (which does not change the FOB owner).

For data collected by on-board observers, several properties of the floating objects were added to the form in order to comply with the recommendations of the tuna RFMOs on FOB/FAD data (Table n° 18).

Properties	DFAD	AFAD	HALOG	FALOG	ANLOG	VNLOG
FOB built using biodegradable materials (true/false/undefined)	X	X	X	X		
FOB is non-entangling (true/false/undefined)	X	X	X	X		
Meshed material (true/false/undefined) in FOB	X	X		X		
Size of largest mesh (in millimeters)	X	X		X		
Distance between the surface and the deepest part of the FOB (in meters)	X	X	X	X		
Approximate surface area of the FOB	X	X	X	X		
Specifies the FOB's ID whenever present	X	X	X	X		
Fleet owning the tracking device / echo sounder buoy	X	X	X	X	X	X
Vessel owning the tracking device / echo sounder buoy	X	X	X	X	X	X
Anchorage type used for mooring (AFAD registry)		X				
Radar reflectors (presence or not) (AFAD registry)		X				
Lighting (presence or not) (AFAD registry)		X				
Visual range (in nautical miles) (AFAD registry)		X				
Materials used for the floating part of the FOB (list to be defined)	X	X	X	X		
Materials making up the FOB underwater structure (list to be defined)	X	X	X	X		
Tracking device TYPE+ID if possible, otherwise no or undefined.	X	X	X	X	X	X

Table n° 18 : FOB/FAD information added to observer onboard form to comply with RFMOs recommendations

The aim is again to define the minimum data requirement and harmonize the various definitions. As mentioned for the logbooks, the format and the medium (electronic, paper) may be slightly different between the French and Spanish fleets.

6 List of figures

7 List of tables

8 List of annexes

The annexes of the report are in another document entitled "CECOFAD_ANNEXES_Final_Report"; to help the reader, the paragraph number in which annex is cited is written next to the title.

Annex 1: Report of the Kick-off meeting (paragraph 4.2)

Annex 2: Report of the Final meeting (paragraph 4.2)

Annex 3: Tutorial of the wiki (paragraph 5.5)

Annex 4: Examples of the different types of floating object by code (paragraph 5.5)