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CATCH, EFFORT, AND ECOSYSTEM IMPACTS OF FAD-FISHING (CECOFAD)

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SUMMARY

The objective of the European Research project "Catch, Effort, and eCOsystem impacts of FAD-fishing" (CECOFAD) is to improve our understanding of the use of fish-aggregating devices (FAD) in tropical purse seine tuna fisheries on open-sea ecosystems. Due to the relevance of accurate indices of abundance derived from catch per unit of effort, the project will attempt to define a unit of fishing effort for FAD-fishing and to provide reliable estimates of abundance indices and accurate indicators on the impact of FAD-fishing on juveniles of bigeye and yellowfin tunas and on bycatch species. 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).

RÉSUMÉ

L'objectif du projet de recherche européen « Catch, Effort, and ecosystem impacts of FAD-fishing » (CECOFAD) (Prise, effort et impacts écosystémiques de la pêche sous DCP) consiste à améliorer nos connaissances sur l'utilisation des dispositifs de concentration de poissons (DCP) dans les pêcheries des senneurs tropicaux qui opèrent dans les écosystèmes de haute mer. Compte tenu de l'importance des indices précis d'abondance calculés à partir de la prise par unité d'effort, le projet tente de définir une unité d'effort de pêche applicable à la pêche sous DCP et de fournir des estimations fiables des indices d'abondance et des indicateurs précis de l'impact de la pêche sous DCP sur les juvéniles de thon obèse et d'albacore et sur les prises accessoires. Étant donné que des partenariats entre le monde de la science et de l'industrie permettent d'améliorer la qualité et la disponibilité des données et des connaissances, le projet de recherche encourage les projets conjoints de recherche entre les opérateurs et les scientifiques, sans compromettre l'indépendance de ces derniers. CECOFAD est cofinancé par la DG Mare de l'Union européenne, trois institutions scientifiques (IRD, IEO et AZTI) et trois associations professionnelles d'armateurs thoniers (ANABAC, OPAGAC et ORTHONGEL).

RESUMEN

El objetivo del proyecto de investigación europeo "Captura, esfuerzo e impacto ecosistémico de la pesca sobre DCP (CECOFAD)" es mejorar nuestros conocimientos acerca del uso de dispositivos de concentración de peces (DCP) en las pesquerías de túnidos tropicales de cerco en sistemas en mar abierto. Debido a la importancia de índices de abundancia precisos derivados de la captura por unidad de esfuerzo, el proyecto intentará definir una unidad de esfuerzo pesquero para la pesca con DCP y proporcionar estimaciones fiables de índices de abundancia e indicadores precisos sobre el impacto de la pesca con DCP sobre los juveniles de patudo y rabil y las especies de captura fortuita. Dado que la asociación ciencia-industria puede mejorar la calidad y disponibilidad de los datos y los conocimientos, el proyecto de investigación está fomentando la investigación colaborativa entre los operadores y los científicos, sin comprometer la independencia de estos últimos. CECOFAD está cofinanciado por EU-DG Mare, 3 institutos científicos (IRD, IEO y AZTI) y 3 asociaciones profesionales de armadores atuneros (ANABAC, OPAGAC y ORTHONGEL).

KEYWORDS

Tropical tunas, FADs, Research programmes,
Ecosystem, Fishing effort, Abundance indices, Purse seiners

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Introduction

The relationship between catch per unit effort (CPUE) and abundance is central to stock assessment models and thus, changes in this relationship will ultimately result in changes in scientific diagnostic and associated management advice. In the lack of fishery-independent information in tuna fisheries, commercial data are traditionally used to compute CPUE and to derive spatio-temporal indices of abundance in stock assessments. Although the general process may seem simple in essence, it needs the proper quantification of the effective effort exerted on tuna stocks. While Nominal efforts are usually standardized to account for difference among vessels, areas, seasons, and years, but it was shown in many situations that final estimates of standardized CPUES remained close to nominal values. One of the major reasons for this is that increasing fishing efficiency through improvements of fishing gears can strongly modify the relationship between CPUE and abundance over time (Gaertner and Pallares, 1998; Fonteneau et al, 1999). In addition, the spatial dimension of fishing activities and resources has to be accurately accounted for in the standardization process as it may severely bias the estimates of abundance indices (Walters, 2003).

For tropical tuna: yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye (*Thunnus obesus*), an additional problem is that since the implementation of Fish Aggregating Devices (FAD) in the early 1990s (Ariz *et al*., 1999; Hallier and Parajua, 1999), progressively equipped with electronic devices, a fishing effort unit is difficult to be defined for purse seiners and where catchability can be affected by many factors. In the absence of suitable standardization of purse-seiner CPUE indices, most of the stock assessments of tropical tunas worldwide are based on longline CPUE indices which rarely account for changes in technology in the standardization process and only depict the biomass of the older fraction of tuna populations. In addition, skipjack stock assessments mainly depend on the accuracy of abundance indices obtained from purse-seiner CPUEs and do not account for the major changes in purse-seiner strategies that have taken place over the last two decades through the development of FAD technology and their increasing use. Also, purse seine fishing using FADs may have a high by-catch of yellowfin and bigeye juveniles and a potential negative impact on sharks and other marine organisms and the ecosystem.

The Common Fisheries Policy reform of the European Union identified a number of priorities aimed at achieving ecological sustainability as well as orientating governance of fisheries towards a regionalised implementation of principles, defined at Union level. The call for proposals lauched by UE DG MARE:“Standardization of tropical tuna catch and effort time series for EU purse seine fleets using FADs in the Atlantic, Indian and Pacific Ocean and estimation of by catch and ecosystem impacts” (MARE/2012/24) aims to encourage science-industry partnerships to improve the quality and availability of data and scientific knowledge underpinning decisions on fisheries management strategies. The expected outcome of the project is to obtain standardized catch-per-unit-effort series of tropical tuna for the purse seine EU fleet using FADs and information on catch composition and estimates of potential negative impacts to the ecosystem.

The research project “Catch, Effort, and eCOsystem impacts of FAD-fishing” (hereatfter termed CECOFAD), is leadered by IRD (France) and included two other Scientific partners: Instituto Español de Oceanografía (IEO, Spain), AZTI Tecnalia (AZTI, Spain), and 3 professional partners: Organisation des producteurs de thon tropical congelé et surgelé (ORTHONGEL (France), Asociación Nacional de Buques Atuneros Congeladores (ANABAC, Spain), Organización de Productores Asociados de Grandes Atuneros Congeladores (OPAGAC, Spain). Tuna RFMOs, such as the International Tuna Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Inter-American Tropical Tuna Commission (IATTC), as well as the International Seafood Sustainability Foundation (ISSF) are associated to the project as observers. The project, co-funded by UE-DG Mare and the partners, began in January 2014 and has a duration of 18 months. The kick-off meeting was held in Montpellier (France) on 1-3 April 2014.

Further information can be found on the web site: http://www.cecofad.eu/ and at the WIKI pages at http://www.cecofad.eu/w/index.php?title=Main_Page

Objectives

The overall objective of the CECOFAD project is to provide insights into the fishing effort units (for both fishing modes: FADs and free schools) to be used in the calculation of purse-seiner CPUEs in the Atlantic as well as in the Indian and the Pacific Oceans, where European purse-seiners also operate, to ultimately obtain standardized indices of abundance for juveniles and adults of tropical tunas. With regards to the Ecosystem Approach of Fisheries, the CECOFAD project will contribute to improve knowledge on the impact of FAD-fishing on the epipelagic ecosystem.

Bearing in mind the multispecies nature of the tropical tuna purse seine fishery and the regular requests expressed by tuna RFMOs to European tuna scientists to provide reliable estimates of abundance indices and accurate indicators on the impact of FAD-fishing on juveniles of bigeye and yellowfin tunas and on bycatch species, the main objectives of the project are:

1) to define a unit of fishing effort for purse-seiners using FADs that accounts for different 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 and
3) to provide information on catch composition around FADs and estimate impacts on other marine organisms (e.g. by-catch of sharks, rays, turtles).

Methodology

Structure of the project

The project is organized into 4 Work Packages (WPs), as follows (**Figure 1**):

- WP 1- Definition of a unit of fishing effort for purse-seiners using FADs 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),
- WP 3- Alternatives to catch rates (WP 2 and 3 in conjunction will address (Objective 2),
- WP 4 - Provision of information on catch composition around FADs and estimation of potential impacts on other marine organisms (e.g. by-catch of sharks and criptic mortality; Objective 3).

In addition to these four WPs, transversal activities will be conducted to ensure the coordination and technical aspects of the project, the data bases management, the web site development and the administration and management of the project.

Description of Work Packages:

WP1- Definition of a unit of fishing effort for purse-seiners using FADs that accounts for different factors influencing catchability (leader IRD)

Tropical tuna purse seine fisheries capture different species and size of tunas. Large yellowfin, and in some strata skipjack, are caught in free-swimming schools, while skipjack and juveniles of yellowfin and bigeye are mainly associated with natural or artificial floating objects. In the traditional tuna purse seine fishery (characterized by free-swimming schools and natural floating objects), the fishing effort was expressed as searching time, i.e., the daylight hours devoted to the detection of tuna schools minus the setting times (Fonteneau, 1978). While this simple definition may be criticized even for free-swimming schools sets (e.g., due to the non-random distribution of fishing effort, the increase in fishing power over the years, etc) the implementation of drifting artificial fish aggregating devices (FAD) since the early 1990s (Ariz *et al*., 1999; Hallier and Parajua, 1999), progressively equipped with electronic devices (Moreno *et al*., 2007; Lopez *et al*., 2014) have broken the link between searching time and effective fishing effort for FAD sets. Remote detection of satellite-tracked FADs often allows fishers to move directly towards a buoy, sometimes at night, avoiding or significantly reducing searching time (**Figure 2**).

In addition, the recent development of satellite-tracked echo-sounder fish finder units attached to floating objects gives fishers realtime information about fish schools aggregating around FADs and has resulted in an increasing proportion of successful FADs sets. The use of supply vessels, which can visit FADs and inform purse-seiners on the fish aggregations around these FADs, also contributes to the efficiency of some purse-seiners (Arrizabalaga *et al*., 2001, Pallares *et al*., 2002; Goujon, 2004, Moreno *et al*., 2007). For all of these reasons, the increasingly extensive use by tropical tuna purse seine vessels of FADs has dramatically changed the nature of tuna fishing over the last two decades (**Figure 3**). Obviously, the complexity increases when the fishing strategy is based on transitions between both fishing modes: free-swimming schools and FAD-fishing, which is the most common situation (Guillotreau et al, 2011). These changes have major consequences for our ability to calculate useful CPUE values for these fisheries.

During the kick off meeting of CECOFAD the participants agreed that many data on the fishing technology introduced on board over time should be useful for the project. The collection of the dates of quantitative and qualitative changes in FAD design and use, as well as in new fishing devices was initiated during the EU research project Esther (Gaertner and Pallares, 1998) for the French fleet (**Figure 4**). Recently, following the study of Moreno *et al.* (2007), new information on technology associated with FAD-fishing has been collected by Lopez *et al*. (2014) for the Spanish fleet (**Figure 5**) and surveys on fishing practices have been made on the French fleet operating in the Indian Ocean within the framework of the PhD thesis of A. Maufroy (IRD). All these informations will be updated in cooperation with expert knowledge for both fleets, e.g., questionnaires filled by tuna fishermen on how and when they perceive a change in catchability over time for both fishing modes (i.e., FAD sets and free school sets). The active cooperation with the industry which is partner of the project should ensure that comprehensive data on floating object sets, especially on FADs, and on fishing operations will be made available to national scientists. The information on the main periods of introduction of new technology can be used during the standardization of CPUEs or be integrated in a Bayesian surplus production modelling approach so as to account for increasing fishing power over time. In the same order of ideas, collecting information on the numbers of active FADs seeded ovet the years by the EU purse seine fleets is a fundamental. Unfortunately this information is seldom available, keeping in mind that in the Atlantic and in the Indian Oceans detailed information on the use of FADs, including the activities conducted by supplies, has been requested only in 2013 in the Indian Ocean and in 2014 in the Atlantic Ocean (IOTC Res[13-08], and ICCAT Rec. [13-01], respectively). However, some information has been recently collected for the French fleet operating in the Eastern Atlantic Ocean (**Table 1**) by Fonteneau *et al.* (2014). Based on some assumptions on the total catch and the catch per set for FAD-fishing for the other purse seiner fleets, these authors provide preliminary estimates of the change in the number of FADs used in the Eastern Atlantic since 2004 (**Figure 6**).

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As mentioned previously, one another important component of FAD-fishing is the contribution of the assistance provided by supply vessels. Consequently, effects of such assistance on the FAD activities will be explored by means of performance indicator comparisons between individual purse-seiners.

FAD-based fishery indicators are a way to follow the trend in the exploitation level exerted on tuna juveniles and some by-catch species, e.g., the size of the area fished is a key factor in the potential catches of a fishery but owing to the mobile nature of the fishery, the total surface explored must account for the trajectory of the FADs. Individual trajectory obtained from VMS data are essential to analyze the fishing behaviour of a purse-seiner over a fishing trip (Walker *et al*., 2010), with the aim to identify which proportion of the searching time should be related to a fishing effort associated with FADs and if the FAD was detected at random or with the aid of radio satellite beacons (**Figure 7**). The production of a nominal effort splitting the FAD activities from the conventional daylight searching time should be a first challenge in this approach.

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

For reason explained previously in WP1, fishing effort on PS (FAD and free school) cannot be expressed in its traditional form. An alternative to calculate a catch rate depicting as close as possible the abundance was the concept of catch per set. Until now the standardization process was done for each fishing mode separately: free school sets or FAD sets (Soto et al, 2009a; Soto et al, 2009b, respectively). The main explanatory variables traditionally used in the GLM to fit the nominal CPUEs were: Year, Quarter, Area, a factor termed CatPais (combining the flag and the carrying capacity of the vessel), the age of the vessel, a factor reflecting the proportion of the species targeted in the catch and the interactions between the main factors. To account for the presence of a high amount of zero-catch per fishing day, the delta-lognormal method (Lo et al, 1992) was commonly used and the specific index for each year was finally calculated as the product of year average fitted values of lognormal model (for the positive CPUEs) and binomial model (for the proportion of days with catch). To account for to unbalanced designs, the Least squares means (LSMEANS procedure) are computed for each factor as it should be for estimate the marginal means over a balanced population.

Based on the conclusions of the U.E. Research Project ESTHER (Gaertner and Pallares, 1998), for a better understanding on the specific impact of the new technologies introduced on board, the CPUE can be decomposed into several sub-indices, such as the number of sets per fishing days (i.e., depicting the ability to detect a concentration of tuna schools), the proportion of successful sets (the ability of catching a school) and finally, the amount of catch per positive set (i.e., combining a proxy of the size of the school and the ability to maximise a catch during the setting). Such approach has been developed for standardizing CPUEs of yellowfin in free schools in the Indian Ocean by Chassot et al. (2012). During the kick-off meeting of CECOFAD it was also suggested to explore additional explanatory factors as the price of the species targetted (or the diference in prices between large yellofin and skipjack), the density of FADs by strata and a factor identifying the strategy followed by each captain in terms of fishing mode (obtained for instance asking to each captain who are the 5 fishermen specialized in each fishing mode).

However, other CPUE indicators or standardization procedures (GLMM, Bayesian methods) should also be explored: integrating spatial correlation in the standardization (Nishida and Chen, 2004), checking if there is a correlation between catch and effort and an additional spatial correlation (Pereira et al, 2009), accounting for the changes in the spatial distribution of the fishing effort over time (Campbell, 2004, Hoyle et al, 2014), which can be done with different methods to integrate the predicted CPUEs of unfished areas in the calculation of the annual index of abundance (Zhang and Holmes, 2010; Cao et al, 2011; McKechnie et al, 2013). Effects of spatial distribution and movements of tuna resources and fishing fleets on the CPUE standardization (i.e., sensitivity to spatial stratification, application of Poisson kriging to catches and fishery effort data), extension to temporal data using co-regionalization modeling and Spatial GLM and kriging methods applied to local vs global CPUEs should be an important part of this working package. It should be stressed that depending the time unit used (quarter, month, fornight) in the standardization, environmental factors and short-term decisions taken by fishermen may cause different levels of spatial variability, which should be integrated in the definition of the spatio-temporal strata (Saulnier, 2014). Furthermore, using VMS data, associated with the detection of FAD sets, may be used to perform indices of presence of tuna schools (Bez et al, 2011). Another important aspect is how to estimate the increase in CPUE due to the assistance brought by a supply vessel or by echo-sounder buoys (Pallares et al, 2002). The Group agreed that such analysis should be done in priority on the Spanish fleet operating in the Indian Ocean.

In parallel to the standardization procedure, the participants to CECOFAD recognized the relevance of different FAD-indicators related to the abundance indices: e.g., Catch per FAD set, Catch / distance between FAD, Catch per soaking time, Time-at-sea and distance travelled, Density of FAD sets by 1°square, ratio number of FADs fished / number of FADs visited and other related metrics. Another aspect, not directly related to the estimate of abundance but with FAD-fishing, and consequently useful for the tuna RFMOs, should be the standardization of the ratio juveniles of bigeye / total bigeye catch.

WP3- Alternatives to catch rates

Direct indices of tuna abundance may be obtained through the use of echo-sounder buoys attached to FADs. Behavioral models, calibrated by electronic tagging data, representing the continuous process of association and non-association, as well as the residence time under FADs can be an alternative to commercial data in order to perform an abundance estimate. The main tasks identified in this Work package, whose several are dependent of the full cooperation of the professional partners, are:

- Direct local abundance by echosounder and modeling the aggregation process of biomass under FADs: behavior of tunas in terms of residence time and spatial distribution within an array of FADs.

- Preliminary analysis of alternative indices of abundance collected from different sources of information (e.g. from echosounders).

- Index of FAD density and aggregated abundance derived from VMS data combined with multispecies sampling data.

Two important aspects of accessibility of fish to be explored in the WP3 will be how to improve the usability of acoustic data and refine behavior data. This work package is mainly structured around 2 steps: (1) convert acoustic raw data into biologically relevant measures, and (2) link these measures (number of individuals or biomass at FADs) with tuna abundance around and off the FADs, to help assessing the population.

First, It was necessary to review if the existing technology is useful for our scientific goals, and if fishers will continue using these tools in the future (Lopez et al, 2014). Based on interviews conducted with more than 60 Spanish fishers, 31% of Spanish fishers said that 50 to 75% of the FADs they use are fitted with echo-sounder buoys and 42% said that 75%-100%. The trend is moving towards 100% of FADs with echo-sounder buoys, which is promising for our scientific purposes. Regarding the technology and current measures by these buoys, outputs for the 4 different brands : Zunibal, Satlink, Marine Instruments and Thalos used by fishers are heterogeneous and cannot be compared (**Figure 8**). For one of the brands, raw data was obtained and new algorithms used to convert acoustic raw data into biomass of 3 main groups (by-catch/ small tuna/large tuna).
There is ongoing work with the other 3 manufacturers to find the way to provide acoustic data in dB, as currently for some of the buoys, data is processed internally in the buoy to be able to deliver it via satellite and is not possible to have pre-processed data. Another potential field study that could be conducted is the intercalibration of the 4 buoys with a known target, to obtain a standardized output suitable for common analyses.

Nowadays, the biological relevant measures expected from fishers echo-sounder are biomass or number of individuals for 3 main groups: by-catch, small tuna and large tuna. There is hope for better discrimination due to new echo-sounder buoys equipped with more than one frequency. These tools have the potential to discriminate skipjack (no swim-bladder) from bigeye and yellowfin (both with swimmbladder). Remote target classification could be done in the future by means of using vertical fish behaviour from electronic tagging in the same area, and also by using species composition and sizes in the area. That is why for the latter would be interesting to conduct an exploratory analysis to see the variability of species composition in a given area between adjacent FADs.

The second step on the way to an abundance index is linking our measurements at FADs with the population. Based on the approach of Sempo et al (2013), a model has been developed to obtain abundance indices using the time of residence at FADs and out of FADs as well as the number of aggregation points (Capello, com. pers.). The simplest model assumes that the probability of join and leave the FAD is constant. Field studies on tuna behaviour from electronic tags would allow feeding this model.

WP4- Catch composition around FADs and estimation of potential impacts on other marine organisms (e.g. by-catch of sharks and criptic mortality)

Within the framework of the ecosystem approach of fisheries, Tuna RFMOs, international bodies, national administrations and NGOs have raised concern for the status of the non-targetted species caught incidentally by different type of gears (**Figure 9**). Even discards and by-catch in the purse seine fishery are moderate compared to other gears, the increase in FAD-fishing impacts not only the tuna resource, even if this effect is not simple and should be carefully analyzed (Dagorn et al, 2013), but also other non-target species (e.g., sharks, rays, turtles) as showed by different studies (Delgado de Molina et al, 2000; Amande et al. 2008; 2010; Capietto et al, 2014). Both fishing modes produce bycatch to a different extent and have a different species composition. FAD-fishing bycatch is considerably greater than that obtained from fishing on free-swimming schools (**Table 2**), and this might have impacted differently over time the different taxonomic groups composing the epipelagic fauna associated with the tropical tunas (**Figure 10**). A recent study based on changes in sample-based rarefaction curves suggests that the species composition of sharks caught on FADs decreased over time (Torres-Ireneo, 2014a), even if it should be kept in mind that other fishing gears may also have affected these species.

A great variety of shark species are found within the Tuna RFMO Convention areas, from coastal to oceanic species, and specifically associated with FADs. As a consequence of the increase in fishing pressure supported by these species, the recent 30th Session of the Committee on Fisheries (COFI) of the FAO of the United Nations, encouraged States and RFMOs to take further actions for shark conservation and management. As an example, ICCAT Res [12-05] asked to all its CPCs to submit, previously to the 2013 annual meeting, details of their implementation of and compliance with shark conservation and management measures [Recs. 04-10, 07-06, 09-07, 10-08, 10-07, 11-08 and 11-15]. The main species of sharks associated with FADs are silky shark (*Carcharhinus falciformis*) and whitetip shark (*Carcharhinus longimanus*). In the Atlantic and in the Mediterranean areas of its jurisdiction, ICCAT has put in place recommendations that prohibit the retention of shark species identified as at risk due to the impact of fisheries such as thresher sharks (*Alopias* spp; 09-07), oceanic whitetip (10-07), hammerhead (*Sphyrna* spp.*;* 10-08), silky sharks (11- 08). Similar resolutions concerning threther sharks exist in the Indian Ocean (Resolution IOTC-2012-09). In addition to sharks, by-catch generated by FAD-fishing is also known for other species of bony fish, blue marlin, as well as some turtles, specifically the Green turtle (*Chelonia mydas*) and the Loggerhead turtle (*Caretta caretta).*

Even if progress on fishery statistics for sharks has been recently evidenced by Tuna RFMOs it is admitted that it is still insufficient to provide quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels. Consequently several fishery indicators related to sharks will be analyzed at a family taxonomic level and as well as possible at a species level for the shark species listed as endangered. It should be mentioned that the major part of information used in this Work Package will be obtained from past observer programs and for this reason special effort will be done to the production of tools allowing to merge information between logbook and observer data bases.

The impact of FAD-fishing will be evaluated in different ways: in terms of overall quantification of catch and by-catch species and size composition aggregated under FAD depending on the location, trajectories, soaking time of the FAD, whenever possible, or accounting for some characteristics of the FAD (e.g. the length of underwater appendages or the mesh size of the net under the FAD). target species and bycatch removed by FAD-fishing. Comparative quantitative analysis of biomass removed by FAD-fishing and for school fishing of both targeted and bycatch (retained or discarded) species (commonly identified as the Gerrodette approach; Gerrodette et al, 2012): use of different metrics (diversity indices and species composition for both fishing modes). Part of the PhD thesis of N. Lezama-Ochoa (AZTI) is related to biodiversity aspects and tuna fisheries.

The assessment of the ecological effects of FAD-fishing would require a precise taxonomic identification of the species that is usually not recorded. To overcome this problem, groupings will be defined taking into account the ecological functions of the different taxa, and case studies will investigate endangered shark species. Regional differences and rich structures in species diversity should be highlighted and might be used for future conservation issues. In addition, as it was evidenced that a moratorium on FAD for protecting juveniles of tuna may have different consequences on the associated fauna (Gaertner et al, 2002), the resulting impact of such type of regulation measure on whale-sharks and marine mammals will be tentatively analyzed within the PhD of L. Escalle (UM2/IRD).

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Table 1. Numbers of FADs used by French purse seiners: seeded yearly in the Atlantic ocean and active ones on a quarterly basis, number of PS and total catches on FADs. (From Orthongel, in Fonteneau *et al.* 2014).

	Nb of Active buoys/PS	Nb buoys seeded yearly/PS	Ratio Nbs FAD Seeded & active	Nb PS	Average Nb of active FADs	Total Nb of seeded buoys yearly	FAD catches	Average Catches on FAD by each PS	Average catch per buoy seeded
2004		41		13		533	19 818	1524	37,2
2005		41		9		369	13 521	1502	36,6
2006		47		7		329	4 896	699	14,9
2007		42		5		210	4 452	890	21,2
2008		54		7		378	3 051	436	8,1
2009		60		10		600	7 311	731	12,2
2010	68	72	1,05	10	683	720	16125	1613	22,4
2011	71	82	1,16	9	635	738	13195	1466	17,9
2012	96	118	1,23	9	861	1062	16956	1884	16,0
2013	90	156	1,74	9	808	1404	16749	1861	11,9
2014		200		9		1800			
Average 2	81	71	1,30	9	747	634	11607	1261	19,8

Table 2. Ratio of bycatch (FADs vs Free school) in weight for the UE purse-seiner fleets operating in the Atlantic and Indian oceans (from Amande *el al*., 2008; 2010).

Ratio FADs / Free school	*Atlantic Ocean*	*Indian Ocean*
Total by-catch	**5.3**	**3.9**
Tunas	**6.2**	**3.6**
Bony fishes	**21.3**	**5.8**
Billfishes	**0.5**	**2.0**
Sharks	**6.0**	**3.6**
Rays	**0.1**	**0.5**

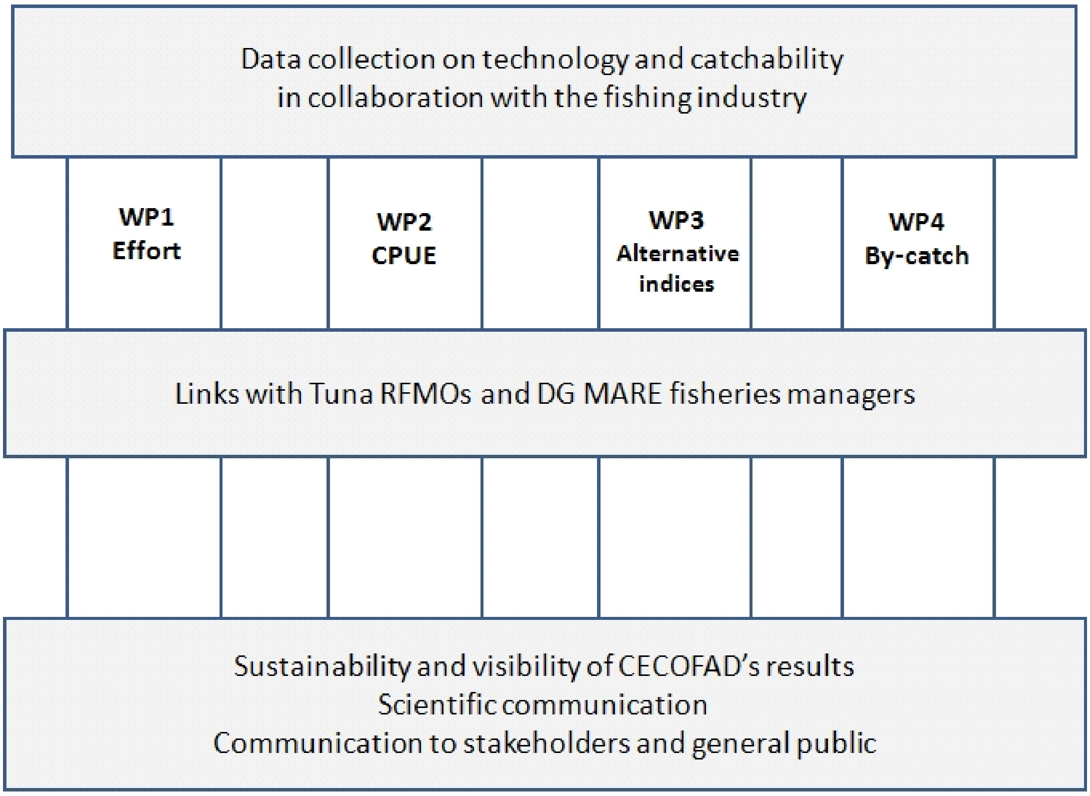

Figure 1. Structure of the CECOFAD project depicting the links between the Work Packages and the different partners, the Tuna RFMOs, the fisheries managers, stakeholders and public.

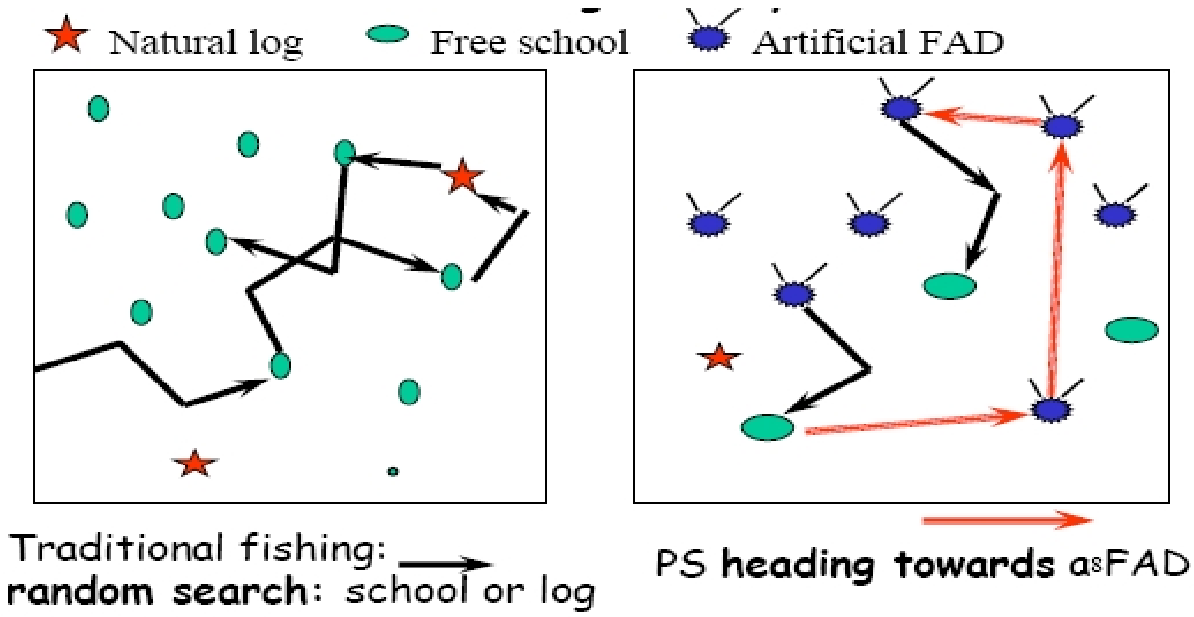

Figure 2. Before FADs fishing, Free schools and natural logs were randomly detected, while after FADs fishing the purse-seiner detects electronically its own FADs and may run directly in the good direction. Free school, logs and foreign FADs continue to be randomly searched during daily hours (from Fonteneau *et al.*, 1999).

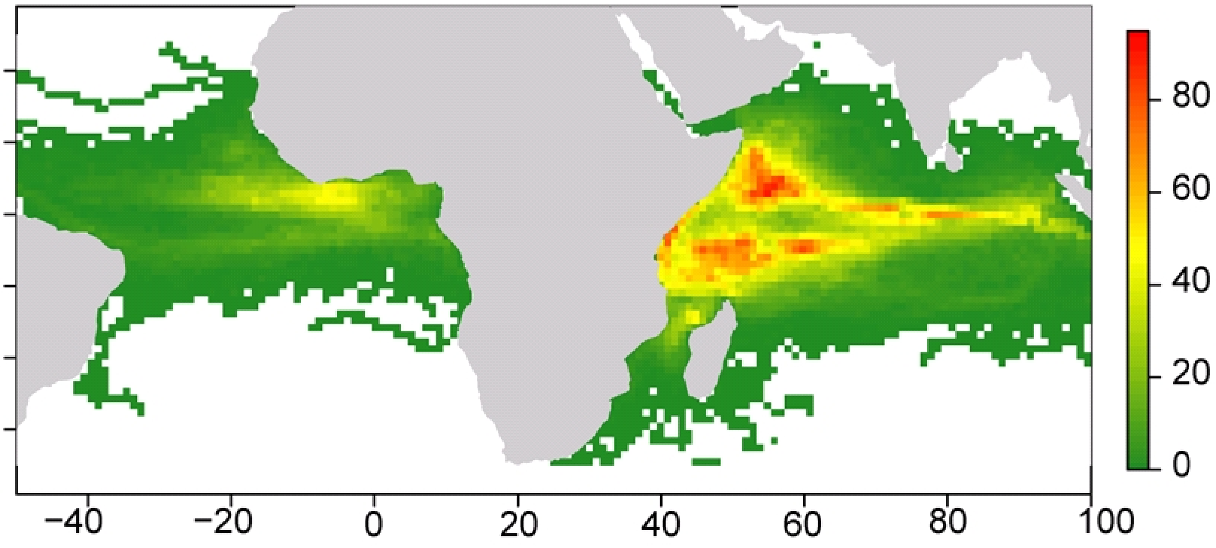

Figure 3. Example of spatial distribution of satellite-tracked FADs for the period 2007-2011 (from Maufroy, 2012).

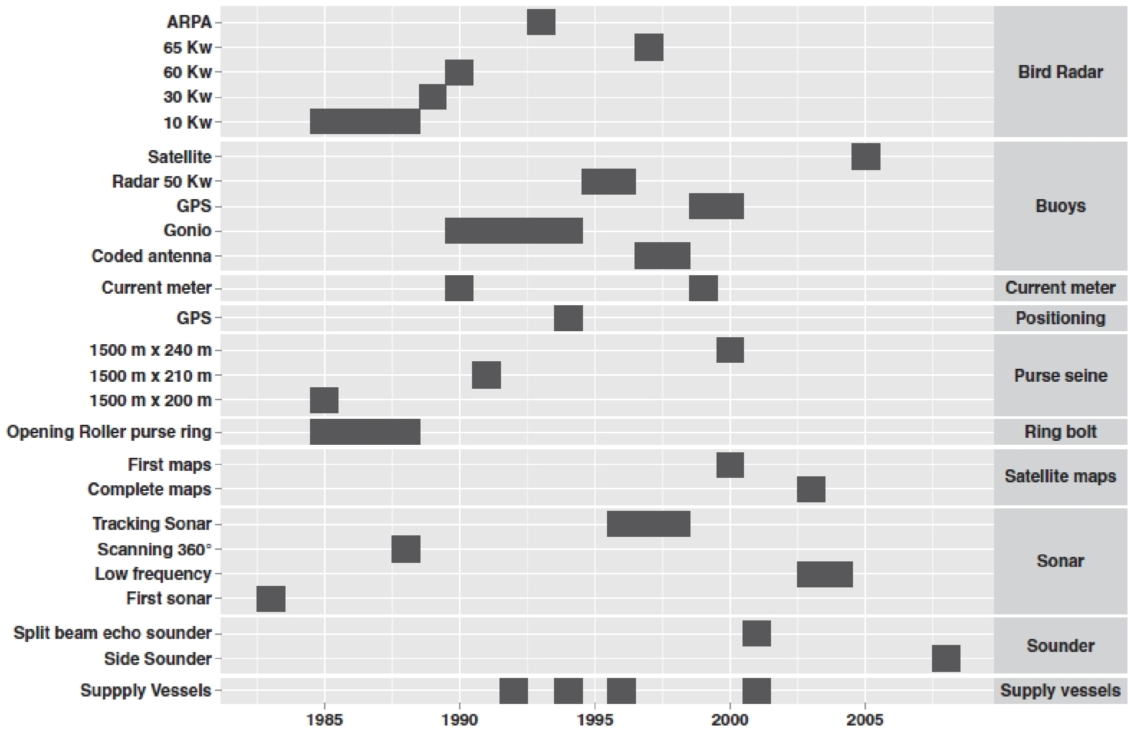

Figure 4. Year (or time period), as indicated by rectangles, in which a new technology was introduced to the French tropical tuna purse seine fleet operating in the eastern Atlantic Ocean Right side identifies the broad technology type whilst the left side distinguishes the different model specificationswithin the technology type. Some devices are specific-fishing mode (e.g., automatic radar plotting aid (ARPA), radio equipped buoys, supply vessels for FAD fishing), othersare affecting the fishing efficiency at a whole (from Torres-Irineo *et al.*, 2014b).

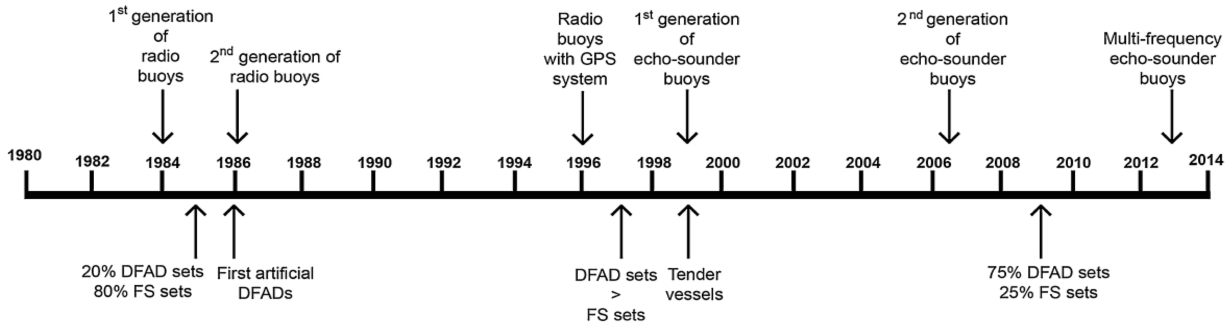

Figure 5. Timeline of the most important events that occurred in the development of buoys technology and the Spanish tropical purse seine DFAD fishery in the Indian Oceanfor the last 30 years (from Lopez *et al.*, 2014).

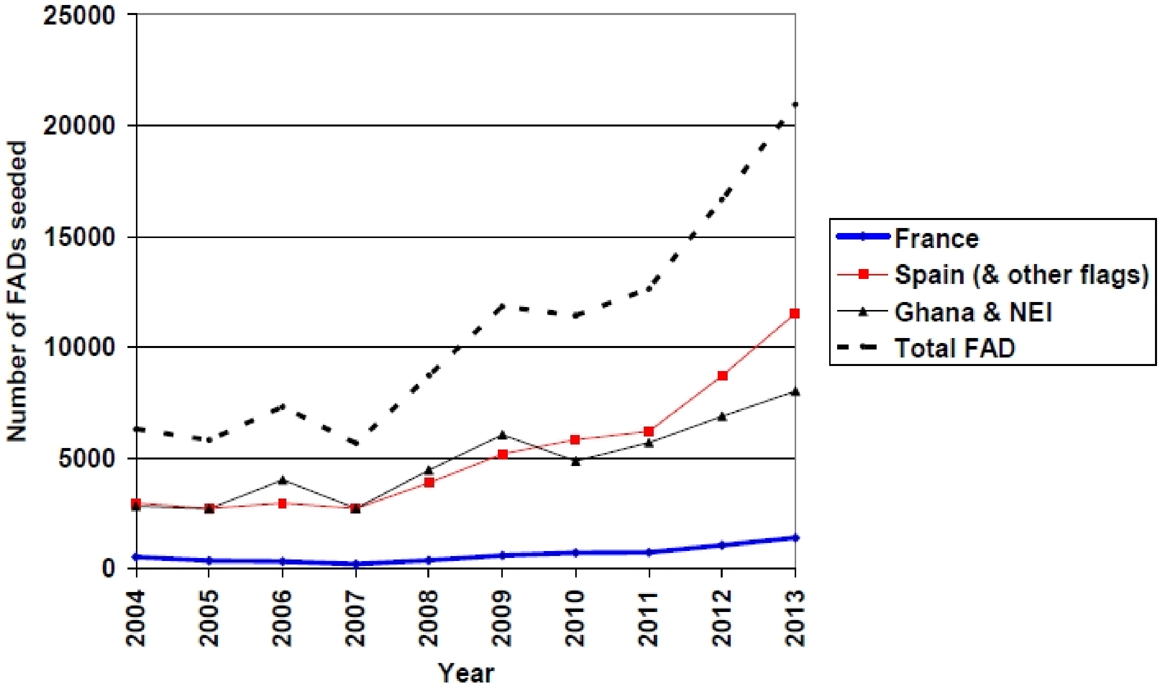

Figure 6. Estimate of total number of FADs seeded yearly in the Eastern Atlantic ocean, based on French data (Orthongel) and estimated for the other PS fleets (from Fonteneau *et al.*, 2014).

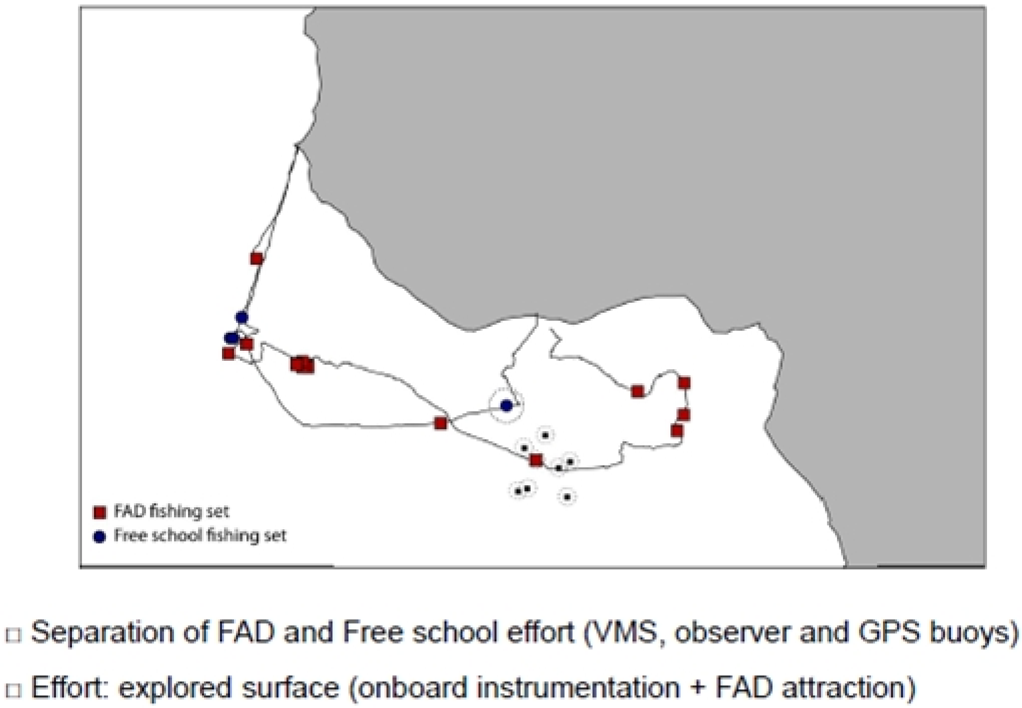

Figure 7. Example of an individual trajectory of a tuna purse-seiner during a fishing trip from VMS data (Maufroy, comm.. pers.).

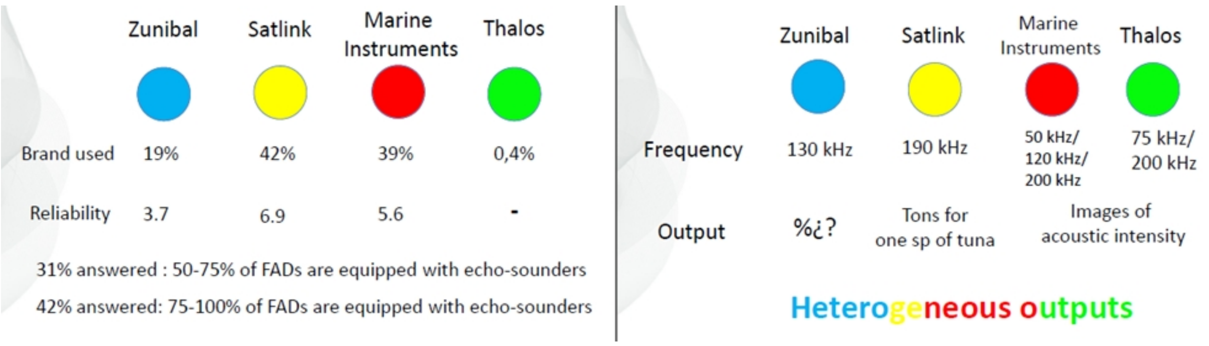

Figure 8. Use of the different brands of echo-sounder buoys by the Spanish fleet in the Indian Ocean showing the heterogeneity in the information available for scientific studies (G. Moreno, comm.. pers.)

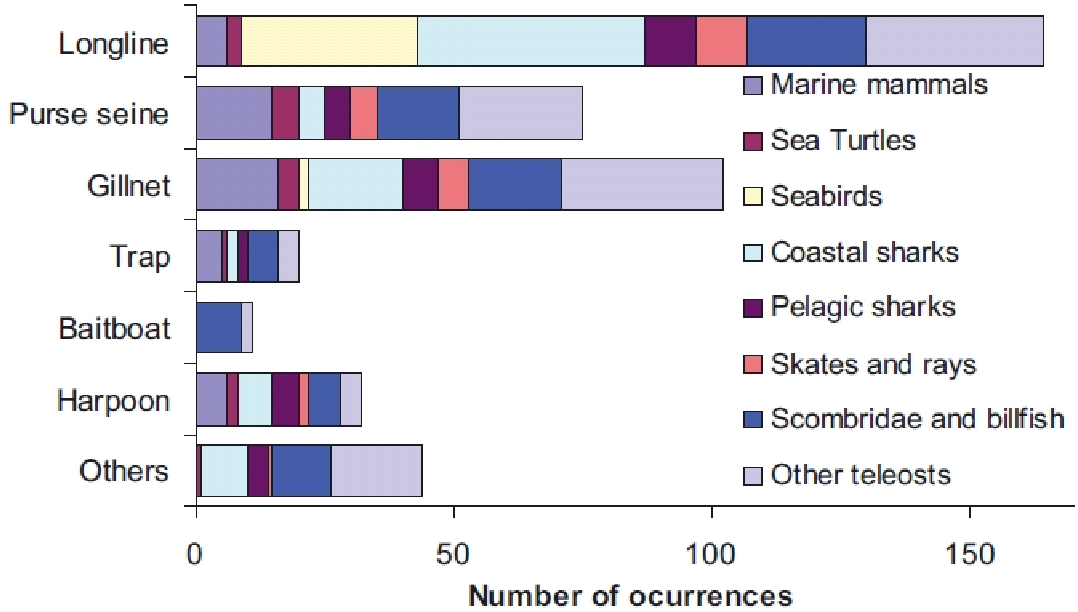

Figure 9. Summary plots of the ICCAT bycatch list. Number of species reported to have interacted with each species group, by fishing gear. An occurrence is defined as a species reported to have interacted at least once with a given fishing gear. The presence of a species in the list does not imply that it is caught in significant quantities, or that individuals that are caught necessarily died as a result of the interaction (from Arrizabalaga *et al.*, 2011).

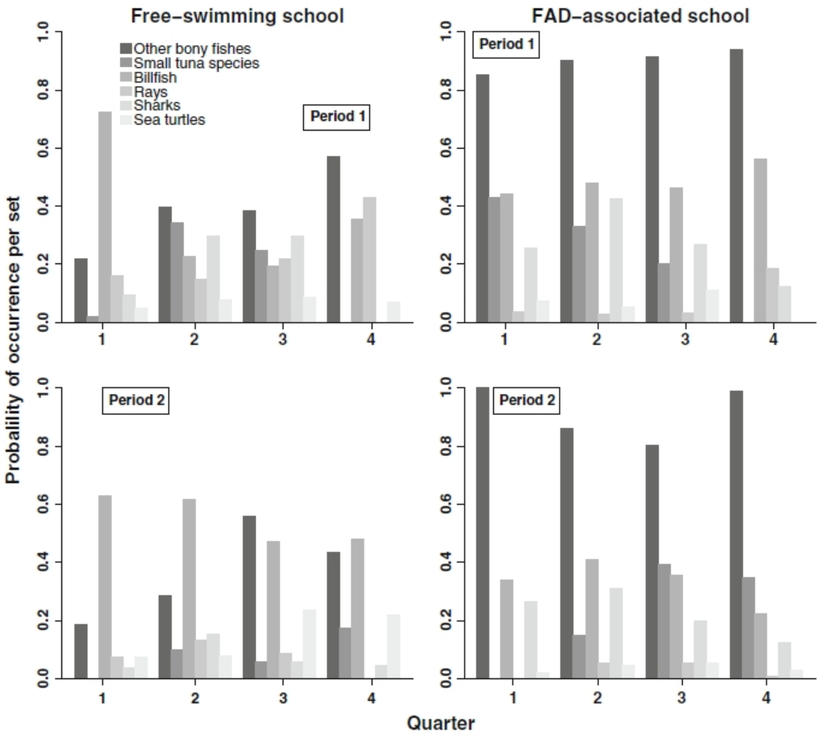

Figure 10. Quarterly occurrence probability per set by species group for each fishing mode (Free-swimming school and FAD-associated school) during time period 1 (1997–1999), and 2 (2005–2008). Quarter: 1 January–March, 2 April–June, 3 July–September, 4 October–December (From Torres-Ireneo *et al.* 2014a).