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Technological and fisher's evolution on fishing tactics and strategies on FADs vs. non-associated fisheries

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1. 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 for stock assessments. Most of the tuna stock assessments rely upon CPUE data from longline fisheries with few CPUE series been developed and used for the purse seine fleet. While longline fleet has been decreasing over time, the tuna purse seine fishery has been expanding oceanwide currently accounting for around 75% of total tuna catch. Therefore, obtaining a standardized CPUE for the purse seine fleet and better understanding the factors that affect CPUE in purse seine fisheries is essential for their correct use in tuna stock assessment.

Although the general process to estimate CPUE 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, in many situations it has been observed 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, technology and fishers knowledge can strongly affect the catchability over time; which is the basic parameter to relate CPUE with abundance. 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.

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Presently, purse seine fishery targeting tropical tunas (Skipjack *Katsuwonus pelamis*, Yellowfin *Thunnus albacares*, and Bigeye *Thunnus obesus*) is one of the most technologically advanced fisheries in the world. The technological changes introduced in the last decades have significantly affected the fishing strategy and behavior of the fleets, as well as catch rates and efficiency, due to, principally, reduce the time employed in searching for tuna schools. This has been particularly evident in this fishery since the introduction and the regular use of drifting fish aggregating devices (DFADs) in late 1980s and early 1990s, respectively, depending on the ocean. Prior to the widespread use of DFADs, most modifications to purse seine technology were driven by the desire to improve the success rate for free school fishing and to be able to load and store as quick as possible the large catches made on unassociated schools (Itano, 1998). However, technological developments over the last 20 years have mainly focused on increasing the number of productive sets during a fishing trip and enhancing the catch rate on DFADs (Scott and Lopez, 2014). One of the major difficulties encountered when estimating the change in tuna purse seine vessels' ability to catch fish is to correlate technological advances with effective fishing effort. Fine-scale and detailed operational data on the application of each of the new technology is generally lacking at the regional level, which is an obstacle for scientists investigating this issue. In stock assessment evaluations for the Atlantic and Indian Oceans, an annual average 3% increase of the effective fishing effort for the purse seine fishery has been assumed, based on Gascuel et al. (1993) and Fonteneau et al. (1999). However, a smooth change over time is unlikely, and rather, these changes are more likely more abrupt and variable between years.

Modern DFADs are equipped with satellite linked echo sounder buoys, which remotely and continuously inform fishers with the accurate geolocation of the DFAD and the presence and size of tuna aggregations underneath them, resulting in rapid changes in the fleet behavior and fishing strategies and notorious advances in gaining effective effort (Lopez et al., 2014). Other technological improvements, such as sonars, bird radars, supply vessels…etc., have also increased purse seine fleet efficiency. While nominal efforts (differences among vessels, areas, seasons, and years) are usually accounted on the CPUE standardization, increasing fishing capacity through improvements of fishing gears and technological changes needs a proper quantification. Since 1980 many advances in fishing technology have been introduced, for which detailed and regular information on the time of introduction and intensity of use of these elements has not been collected. These changes hinder an appropriate definition of effective effort exerted on tuna stocks introducing uncertainties to CPUEs (Fonteneau et al. 2013). In fact, and due to this associated difficulties, the stock assessments of some tuna species use unbalanced CPUE indices for purse seiners based on search time (i.e. the time devoted to searching for tuna schools) or other fisheries data, such as longline, which increases the uncertainty in the final estimations. Obtaining a standardized CPUE for the purse seine fleet and better understanding the factors that affect it is essential for a correct stock assessment of tropical tuna species. Thus, technological advances and changes in the fishing strategies have to be incorporated in the CPUE standardization process, as they may severely bias the estimates of abundance indices.

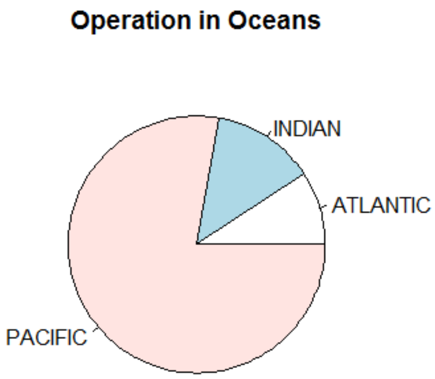
Since 1980 many changes in fishing technology and operations have occurred, each potentially affecting the fishing power and effort of tropical purse seiners. During an ISSF organized Workshop “Understanding Purse Seine CPUE” held in 2012, 23 elements were identified potentially affecting the fishing power of the purse seiners, including the likely (1) geographical scale of the influence of each factor, (2) year when the change was first introduced, (3) relative cost of the factor (low, medium or high), (4) magnitude of the factor's effect on fishing efficiency (and on fishing mortality), and (5) the rate of annual change in each factor after its introduction.. Moreover, this workshop recognized the difficulty of analyzing the potential effects of each factor on CPUE in the absence of detailed data and knowledge on the adoption of these changes by fleets or individual vessels/skippers as the technical and fishing behavior changes are neither regularly monitored nor easy to follow. Therefore, the ISSF WS recommended that a data mining of historical changes in fishing technology and operations worldwide should be carried out to identify the changes and their timing for the major factors affecting the fishing efficiency of purse seine vessel. Moreover, capturing technological change over time and how it is being introduced, in one of the world's leading fleets that relies heavily on the use of FADs can provide valuable information of primary importance to understand purse seines’ CPUE.

This work aims to investigate historical and current changes in fishing technology and operations affecting the fishing efficiency of purse seiners to be accounted for in the purse seine CPUE standardization. For this purpose, a data mining exercise of historical and current technological changes was carried out where fisher’s evolution on fishing tactics and strategies has been investigated. The methodological approach to include all this information in the CPUE standardization process is also discussed.

2. MATERIAL AND METHODS

During ISSF skipper workshops conducted between 2014 and 2015, fishers, officers and captains from the purse seine fleet were interviewed by questioning more than 100 inquiries about all aspects of their past and current experience at sea, including fishing strategies and technology onboard. A total of 53 surveys respondent from different countries were selected to provide detailed information from a wide geographic distribution and different oceans (Fig. 1). The experience of the participants in purse seine fleet varied between 1 and 43 years, with a mean and accumulated experience at sea of 18 years and more than 450 years, respectively. The interviews were divided in four main sections: fishing strategy, location and evolution of fishing zones, variability of fishing effort, and past and present of fishing technology and equipment. In the present work, the information collected from expert knowledge was primarily used to investigate the evolution and changes in the fishing tactics and strategies, as well as effort dynamics related to technological changes.

Additionally, literature available on fishing tactics and the use of DFADs have been used to collect and improve current information on the historical evolution of fishing strategies over time.



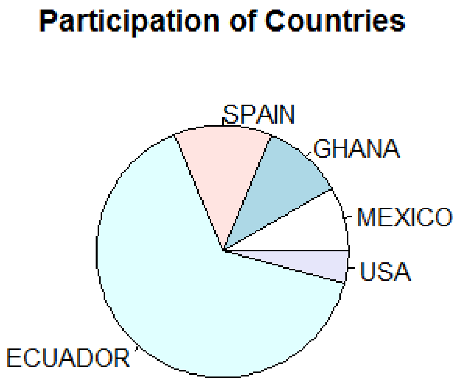


Figure 1. Participation of countries in the interviews and ratio of survey respondents operating their vessels in the Atlantic, Pacific and Indian Ocean at the time of the interview.

3. RESULTS

3.1 Technological Changes

As stated previously, prior to the widespread use of DFADs most modifications to purse seine technology were directed to improve the success rate on free-swimming schools (Itano, 1998). However, with the growing reliance on DFADs in the late 80's, the majority of technological improvements have been conducted to optimize fishing efficiency on DFADs. Besides, since the 2000s, fishers are able to monitor both natural and artificial DFADs attaching GPS buoys to them, many equipped with echo-sounder, which provide near real time information on the biomass associated to the object. However, the massive use of DFADs and GPS buoys raises several concerns for tropical tuna stock assessment and management as it is particularly difficult to know how many DFADs and GPS buoys are in use, how fishers decide to deploy new DFADs and GPS buoys as well as the proportion of fishing effort that is dedicated to fishing on DFADs and on Free Swimming Schools.

Within the captains and officers interviewed during this project, the majority of participants (47%) considered that technological advances (DFADs, acoustic equipment in dFADs, helicopters…etc.) have been the most important factor to improve their fishing capacity, whereas for the 28% of the interviewees the experience and knowledge of fishing areas-seasons contributed the most to their fishing capacity. Interestingly, the communications with other vessels and crew members has also been noted as a significant factor (~10%) positively affecting fishing efficiency and capacity. Among the most important technological improvements, the use of DFADs was considered as the most important one, followed by acoustic equipment (echo-sunder) and satellite imagery (i.e, oceanographic map services). The quality of fishing nets and supply boats and helicopters were also mentioned to contribute significantly to the fishing efficiency. However, the age of vessels was not considered to be crucial to increase fishing efficiency, as the average age of the vessels was 26 years. Because fishing vessels age is constantly increasing, most of the fishing vessels are usually repaired, maintained or checked every year or every two years, which reflects a high dependence on the correct performance of the mechanic and technological equipment onboard. This is another evidence reflecting the change in fishing strategy and adaptation of fishing methods to make the best use of floating objects: in a scenario of growing use of DFADs, using modern vessels that have more powerful hydraulic gear and faster cruising speeds may not provide critical advantages.

The most important factors affecting fishing efficiency together with the timing of their first introduction are summarized in Fig. 2. The geographical scale of the influence of each factor (global or regional) and its impact on fishing capacity are included in the graph. Based on fishers' experience, officers and captains interviewed, the factors not included in figure 2 are considered to have marginal importance in affecting fishing efficiency. When asking about the optimal number of DFADs to increase the catches, ~75% of the survey respondents considered that catches increase when increasing the total amount of available DFADs at sea, whereas the rest of the participants did not agree (21%) or were not sure (4%) about it. Fishers belief on this issue seemed to not change on time, as this result is in accordance with previous findings in the field (Lopez et al. 2014), where fishers also stated that more FADs increases the potential catch of tuna. Real time radio communication with other vessels did not changed over the last decades, but this habit varied significantly with countries. This practice was rare in the Mexican and USA fleet, but generalized in the remaining countries. Interestingly, and with the implementation of flat communication rates (i.e. internet, telephone), the vessel-to-vessel and vessel-to-land links are now much faster and more efficient, which promotes information sharing and increases vessels' fishing response to productive free school or DFAD fishing areas.

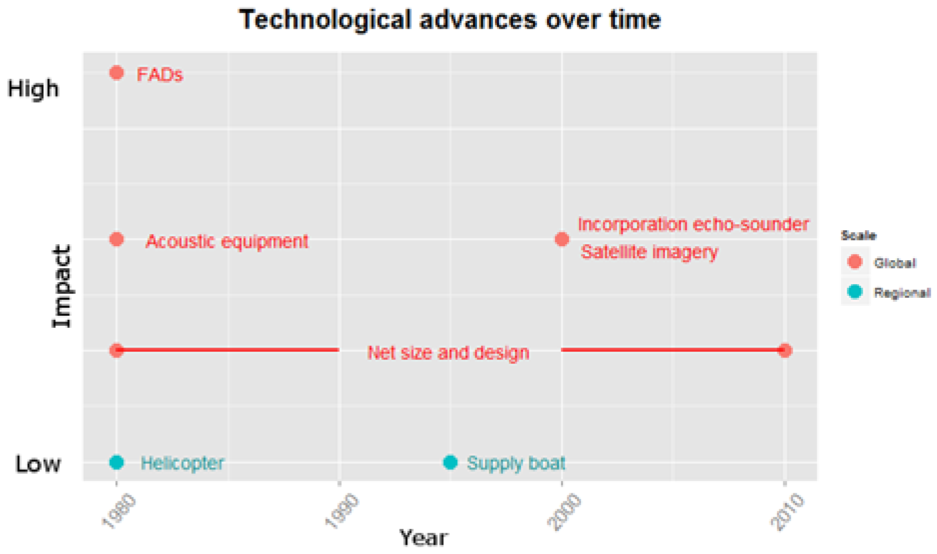


Figure 2. Historical changes in fishing technology among those with major influence in fishing efficiency of purse seine vessels over the last decades. Geographical scale of each factor was divided in two levels: global (red) and regional (green). Factor not included here were considered to have marginal influence on fishing capacity.

Table 1.- List of factors that have changed historically in purse seine fisheries and their likely importance in affecting fishing power (updated 3.1 Table in ISSF Technical Report 2012-10).

Factor	Scale	Year	Cost	Impact	Annual Change
Use of DFADs	Global	1980	Substantial	High	Steep increase
Use of supply vessels	Regional	1995	High	Substantial	Steep increase
Faster unloading	Global	2000	Low	Substantial	Slow increase
Use of computers	Global	1990	Low	Substantial	Slow increase
Satellite positioning of FADs	Global	2000	Low	High	Steep increase
Incorporation of echo sounder in FADs	Global	2000*	Low	High	Steep increase
Improved GPS positioning of vessels	Global	1994	Low	Marginal	Stable
Improved fishing memory of fisheries	Global	1990	Low	Marginal	Stable
Increased freezing capacity	Global	1990	Moderate	Substantial	Slow increase
Increasing vessel size and capacity	Global	1990	High	Substantial	Slow increase
Ageing of fleets	Global	1975		Low	Slow increase
Use of satellite imagery	Global	2000	Low	High	Slow increase
Bird radars	Global	1980	Low	High	Slow increase
Helicopters	Regional	1975	High	Substantial	Stable
Improved sonar/long range	Localized	2002	Low	High	Stable
Higher, improved crow nets	Localized	1985	Moderate	Substantial	Slow increase
Improved navigation radars	Localized	1995	Low	Substantial	Stable
Real-time private radio communication	Regional		Low	Substantial	Stable
Sonar	Global	1980	Low	High	
Improved lateral echo sounders	Global	1980	Low	High	Stable
Deeper and faster nets	Set-specific	1985	High	Substantial	Slow increase
Canon vs opening rings	Regional	1985	Low	Substantial	Stable
Larger skimming nets and mast	Set-specific	1987	Moderate	Substantial	Stable
Underwater current meters	Regional	1990	Low	Low	Slow increase
Monitoring of net fishing depths	Set-specific	1990	Low	Marginal	Slow increase

* year referred to first introduction in the Indian Ocean. 2008-2010 in Atlantic and Pacific Oceans

Text in blue: inform3.1 Table in ISSF Technical Report 2012-10

The collection of quantative and qualitative changes in purse seiner technology and DFAD design and use was reviewed during an EU research project Esther (Gaertner and Pallares, 1998) for the EU fleet which was updated recently by Torres-Ireneo et al, 2014b (Fig. 3). More specifically to the most important technological improvements (i.e. the use of DFADs), and 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 (Fig. 4). Currently, similar issues are being investigated in the EU project CECOFAD (Gaertner et al., 2014), from which interesting contributions and outputs are expected by the end of the year 2015.

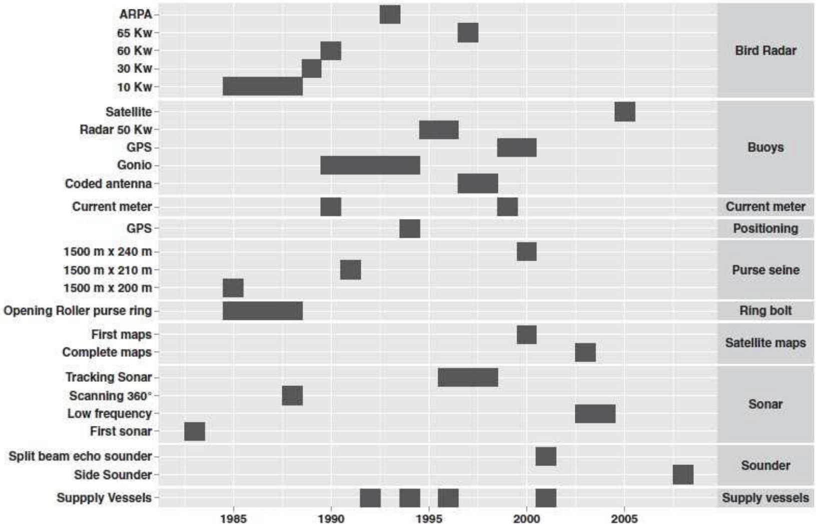


Figure 3. Dates of introduction of new fishing technology on board French purse seiners (from Torres-Ireneo et al, 2014).

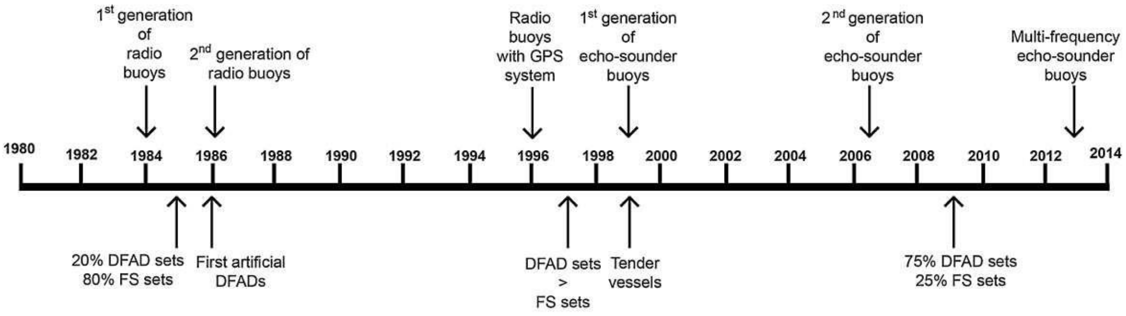


Figure 4. Evolution over the years of the equipment associated with FAD-fishing in the Spanish purse seiners (from Lopez et al, 2014).

3.2 Evolution of Fishing Strategies

The technological improving of the purse-seine fleet have produced an overall increase in the fishing efficiency as well as significant changes in fishers' behavior and fishing strategy. Although several technological improvements have positively affected the fishing efficiency of the fleets, the intensification of DFAD use can be considered the most important factor in the increase in purse-seiners' fishing efficiency. Therefore, the following section deeply investigates fishers' evolution on fishing tactics and strategies using DFADs.

Basically, DFADs increase fishing efficiency by reducing "zero catch" days, and thus, optimizing days at sea. The rapid advances in DFAD's technology over the last decade have increased effective effort considerably. Particularly notorious is the incorporation of echo sounders in the buoys attached to drifting DFADs that enable continuously and remotely tracking the biomass of tuna aggregations. All these advantages contribute to reduce the search time between two successful sets, increase the potential number of sets in a day as well as likely decrease the total duration of the fishing trip (Delgado de Molina et al. 2012; Lopez et al., 2014). Given that the search time is the metric traditionally used to reflect nominal effort in tropical tuna purse seine fisheries, the change in fishing strategy hinders a proper definition of the effective effort and introduces biases to CPUE–biomass relationship (Anonymous, 2012; Fonteneau et al., 2013).

Several indicators have identified echo-sounder buoys as one of the most important factors influencing fishing strategy in the last decade. Although little is known on their real impact on fishing effort and efficiency, recent studies have provided useful information about the utilization of echo-sounder buoys by Spanish fleet (Lopez et al., 2014), which set the foundations to estimate their relative importance on the fishery. According to this work, the ratio of buoys fitted with echo-sounder bought by the fleet has rapidly increased worldwide in the last years, as well as contributed to the expansion of DFAD fishing ground, reflected in the number of 1x1 prospected geographical area (Chassot et al., 2015). It is interesting to note that in this scenario, the proportion of buoys equipped with echo-sounders will reach 100% in the following years, many of them likely with improved biomass estimations and discrimination capability. Due to the lack of historic scientific data collected by the t-RFMOs on the use new technologies, and especially of echo-sounder buoys, interviews with key fishing officers and captains have been used to analyze the use of echo-sounder buoys and their relation with changes in the fishing strategy. Purse seine fishermen may have different opinions on the importance of the different data provided by the echo-sounder buoys (estimates, signal, range, etc.) as well as on the different products available in the market, and in some cases, opinions were contradictory and conflicting. However, most of the fishers stated that echo-sounders buoys are of primary importance determining their fishing strategy and that buoys are improving every year/model.

The work by Moreno et al. (2007) examined the knowledge and experience of Spanish and French purse-seiners in the Indian Ocean on tuna behavior in relation to drifting FADs. According to the authors, the majority of captains interviewed agreed that non-tuna species began aggregating to their DFADs one week after deployment, while 3-5 weeks are usually needed to aggregate a good tuna school, although this time may vary depending on the environmental conditions. However, and since the introduction of echo-sounder buoys in the market, this belief could have changed. The information automatically and continuously provided by the buoy since the initial deployment of the FAD may contribute to increase the knowledge of fishers on the colonization process of the floating objects. For example, recent scientific studies using echo-sounder buoys (Lopez, 2015) showed that soak time of the FAD is usually positively correlated with FAD-associated biomass. However, sometimes, the FADs can also aggregate fish at the very first stage of the deployment, which suggest that other factors like the spatial component could also be involved in the biomass aggregation process. These kind of ecological questions should be revisited and asked to fishers in the future as it would be interesting to see whether, with the introduction and regular use of new tool like echo-sounder buoys, their knowledge on fish behavior remains unchanged through time.

Since the shift in fishing strategy from free school to FADs in early 1990's, many fleets base their fishing strategy on seeding their own DFADs. An extensive seeding of DFADs enables operating fishers in particular areas where natural floating objects are lacking. These objects are deployed and left to drift freely with the intention of being exclusively used by the vessel that seed them after some days/weeks. However, it is also pretty usual to see vessels of the same company sharing DFADs, especially medium-sized purse seines. Interviewed captains and officers said that the area-season of deployment and drift are the most important components for FAD biomass aggregation. Thus, the knowledge and experience on the good seeding and fishing seasons and areas seem to be crucial to optimize fishing efficiency. During personal interviews, emphasis was placed on understanding the influence of satellite information services and echo-sounder buoys in improving fishing efficiency. Most fishers agreed that the use of echo-sounder buoys at DFADs was the most important technological improvement positively affecting fishing efficiency, but geographic location had the greatest overall influence on tuna catches. The best fishing strategy (reported by the ~40% of survey respondents) is to take advantage of fish behavior and be in the right geographic area to assure a good seeding.

3.2.1 Seeding strategy (traditional vs. Echo-sounder buoys)

According to fishers, having good seeding strategy is of primary importance to increase fishing efficiency. In this way, the most common strategy was to alternate traditional buoys and echo-sounder buoys during the seeding operation. According to Lopez et al (2014) the principal seeding strategy is the deployment of one echo-sounder buoy for every two traditional buoys. A secondary strategy was identified deploying echo-sounder buoys at the beginning, middle and the end of the seeding operation. Interestingly, some fishers shift their seeding strategy depending on the area, which suggest a highly dedicated and actively adaptive fishing strategy. Nevertheless, these habits may change in the following years as the numbers of buoys equipped with echo-sounders is expected to considerably and constantly increase up to reaching the 100% for all the vessels.

Although variability in strategies was observed among countries, 75% of the survey respondents coincided affirming that deploying more DFADs increases fishing efficiency. Because of this, purse-seiners tend to build a network of DFADs in every area of fishing interest (Fig. 5). Fishers' opinion related to this matter appeared to not change in the last years as results are in accordance with previous works in the field (Lopez et al. 2014).

The seeding process is progressively conducted on time to have a constant number of FADs available at sea anytime. As previously suggested, location is one of the most important factors determining the DFAD seeding strategy. Fishers seed DFADs in particular locations, characterized by specific oceanographic features, with the intention of finding them in productive areas after a certain period of time. In addition to these spatio-temporal considerations, the seeding strategy is primarily affected by the number of other vessels' DFADs that are encountered during fishing trip, the potential poaching rate of an area, the likely quantity of free schools available in the fishing zone, the particular economic situation of the fleet owner and/or the number of DFADs deployed by vessels of the same company, which sometimes share fishing strategy and DFADs.

It has been recently noted that catch per set at DFADs may be reducing in the last years. Some different reasons can be behind these decreasing values. First, and because DFADs are frequently encountered by vessels that do not own them, they may usually be prematurely fished, when big tuna associations have not been aggregated underneath them yet. Second, the schooling behavior of tunas may change differently when FAD densities increases (e.g. whether tunas may concentrate under few FADs or they will distribute in smaller schools around FADs)

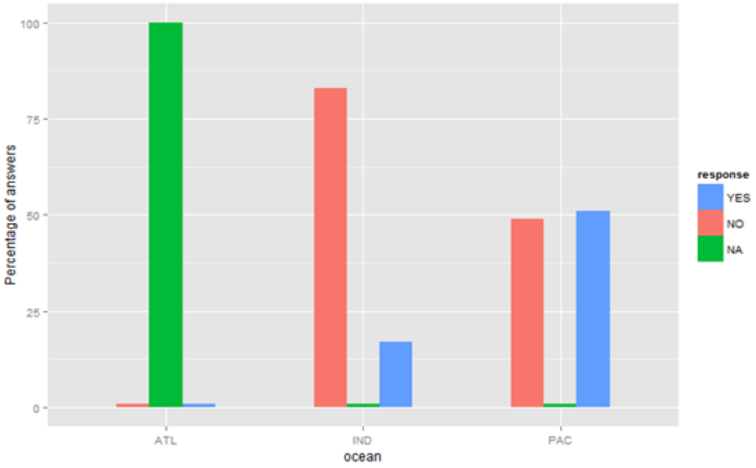


Figure 5. Answer of the fishers operating in the Atlantic, Indian and Pacific Ocean when asking if the number of DFADs is related with the improvement of catch levels.

3.2.2 Sharing FADs

As previously stated, purse seine vessels often share DFADs among vessels of the same company to reduce costs and increase the fishing rate. The habit of sharing DFADs varies between countries and oceans (Fig. 6). According to interviewed fishers, Mexican and Ecuadorian vessels generally work alone, whereas most Spanish and USA vessels share FADs with other vessels of the same company, especially in the Pacific Ocean where vessels make significant distances to reach the fishing area. About the 60% of the interviewees say that they usually or sometimes share DFADs between vessels while the 40% do not. It is interesting to note that most of the vessels share information between the vessels of the same company and that only a small part of it are sharing the information in pairs. In addition, some of the purse seine vessels use supply vessels to try to monitor and maintain the networks of FADs (shared or not) that would be available at sea for the fishing vessels. Although not specifically estimated yet, the use of supply vessels has also been considered as a factor significantly affecting the fishing efficiency of a vessel. This result is in accordance with previous works that investigated supply vessels activity and highlighted the importance of having auxiliary vessels to increase the fishing activity and efficiency of the fishing vessel (Arrizabalaga e al., 2001).

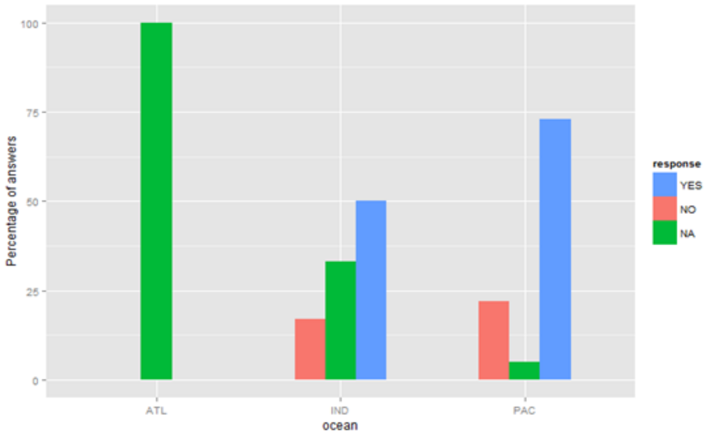


Figure 6. Answer of the fishers operating in the Atlantic, Indian and Pacific Ocean when asking about the habit of sharing DFADs among vessels. Sharing DFADS was not considered when it was limited to pairs of boat working together.

3.2.3 DFAD design

Although the structural design of the DFADs is considered less important than seeding strategy, there is an overall agreement that the underwater structure hanging down from the FAD (usually made with a recycled piece of net) is important to determine the correct drifting of the FAD to productive areas. Indeed, the underwater structure finishes with a big weight that helps keeping the net vertically so that it can work as a kite. The depth reached by the hanging nets varies with oceans, being generally shallower in the Indian and Pacific Ocean compared to the Atlantic Ocean (Scott and Lopez, 2014). It also has been noted that this depth increased during the last years everywhere. The design of the FAD can vary between fleets and oceans but they all employ common and similar elements and materials such as bamboo rafts, purse seine nets, chains… etc. for their construction. Echo-sounder buoys are generally attached to rafts constructed aboard or produced on land. More recently some fleets have being using biodegradable and non-entangling underwater parts to reduce environmental impacts and avoid the risk of entanglement of sharks and turtles in the net.

It is also interesting to note that natural FADs are also often marked and equipped with satellite linked echo-sounder buoys, especially those with good indicators of presence of tunas or by-catch species. Logs, branches, and other floating objects (including man-made FADs) of good size drifting in not beneficial locations are also sometimes retrieved from the sea, tied up if proceed, marked with buoys and transported to more productive areas.

3.2.4 Echo-sounder configuration

Echo-sounder buoys can be configured to send acoustic information to the vessel at regular and punctual intervals. Most of them can also be requested to provide a biomass information in a specific time with almost real time access. Although variability in the data request frequency between captains is considerable, Lopez et al. (2014) noticed that most captains request biomass information once or twice a day, coinciding at least once with the sunrise, and only few fishers from the Indian Ocean request acoustic information hourly. Likely, this strategy is driven by the potential amount of the aggregation that would be sampled at this time, as according to the fishers' belief, fish could be more concentrated under the FAD at sunrise. However, and with the introduction of new buoys with cheaper data connections and flat rates, other times of the day might be more frequently sampled and thus, the current information and the generalized knowledge on the maximum biomass at FADs may vary. Indeed, recent studies investigating the diel biomass fluctuations of fish species at DFADs in the Indian Ocean showed that the maximum biomass may be region-specific and that may not always be associated with dawn (Lopez, 2015). The improvements reached in the echo sounders technology as well as in the biomass estimates in the last years have increased fishers' reliability on the provided information, and according to Lopez et al. (2014) almost all fishers agree that the information obtained from this acoustic tool is important to decide DFADs visiting routes. The intensity of the acoustic signal is, according to fishers, the most important information provided by the echo-sounder. Newer buoys, improved with multi-frequency transducers and updated echo-integration algorithms, may soon provide with more accurate remote information on the size and species composition of the aggregation at particular FADs. These improvements should be well documented through initiatives like this to help identifying the progressive development of fishing tools and try to annotate their correlation and relative importance with the fishing efficiency.

4. Discussion

Quantification of abundance, either absolute or relative, is the core element of any fish stock assessment. However, it is one of the most difficult parameters to estimate, especially in the case of highly migratory fish stocks, such as tuna. The conventional fishery-independent surveys used to estimate the abundance of some fish stocks (acoustics, aerial, egg-larval surveys) are not practicable for highly migratory widely distributed tuna stocks. And, in the absence of fishery-independent information, CPUE is the standard abundance index used to guide the assessment of tuna stocks.

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. The use of CPUE as an index of abundance is based on the basic principal that CPUE is proportional to abundance, being catchability (q) - the portion of the stock captured by one unit of effort - the coefficient of proportionality. One of the associated difficulties is that q is rarely constant and depends on a number of different components, such as those related to changes in the fishing efficiency and dynamics of the fleet. As we described above, this is particularly notorious in the tropical tuna purse seine fishery, where these factors are evolving very rapidly due to the fast technological development and the sharp increase of the use of DFADs, which compromises the usefulness of the purse seine derived CPUE indices. Indeed, since the regular introduction of DFADs 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. These technological elements clearly introduced significant improvements in the purse seine efficiency, which resulted in changes in fishing patterns and strategy (Lopez et al., 2014). These changes hinder a proper definition of the effective effort and thus introduce biases and uncertainties to the CPUE-biomass relationship (Fonteneau et al., 2013).

As showed by the interviews, the use of DFADS was identified by the fishers as the most important factor affecting fishing efficiency, followed by the incorporation of acoustic equipment (echo-sounder), satellite imagery, the quality of nets, supply boats and helicopters. Thus, at least these factors should be included in the CPUE standardization process if significant progress is being pursued in the field. Since the introduction of DFADs in fishing strategy purse seine catch levels have increased considerably by optimizing search time at sea. However, it is interesting to note that many of the current stock assessments for tropical tunas use unbalanced CPUE indices based on search time. Therefore, it seems that searching time no longer provides a useful measure of fishing effort for this fishery. Interestingly, a good seeding strategy has been identified as one of the most important factors to increase fishing efficiency, and thus, need to be considered in the quantification of the effective fishing effort. The knowledge and experience on the good seeding areas and seasons were found to be crucial to optimize fishing efficiency. Several seeding strategies were identified, alternating traditional buoys and echo-sounder buoys, but these habits may change in the future as the numbers of echo-sounder buoys is expected to increase considerably. As seen above, technological changes may severely bias the estimates of abundance indices, and thus, novel approaches to develop abundance indices are needed, particularly for the DFAD associated fisheries.

Several attempts have been and are being made by the scientific community in order to better understand and characterize the changes in fishing pattern and strategies, together with the technological developments associated with the FAD fishing activity to improve the CPUE standardization procedure in tropical tuna purse seine fisheries (Anonymous, 2012; Lopez et al., 2014; Torres-Irineo et al., 2014; Gaertner et al., 2014).
One of the most important technological developments that have been recently introduced by the purse seine fleet fishing with DFADs is the satellite linked echo-sounder buoys. The first buoys equipped with an echo-sounder appeared in the market in the 2000, but they were not started to be regularly used in the fishing operations until mid-2000's, and nowadays, their use have rapidly spread between all the purse seine fleets worldwide. As Lopez et al. (2014) pointed out, this technological development is causing rapid changes in the fishing strategy and fleet behavior, due to the possibility of remotely informing in near real-time about the accurate geolocation of the DFAD and the presence and abundance of tuna aggregations underneath which increase the ability to make more set by day.

It is widely recognized by the tuna scientific community that many data on the fishing technology introduced on board over time should be useful for defining an accurate definition of fishing effort associated to FAD-fishing. When information of changes in technologies is completed, and in order to understand the effect of new technologies on the efficiency of the fishing operation, the CPUE can be decomposed into several sub-indices (Gaertner and Pallares, 1998; Chassot et al, 2012):

- the total number of sets per fishing day to depict the ability to detect a concentration of tuna schools instead of using fishing days,
- the proportion of successful sets to describe the ability of catching a school,
- the amount of catch per positive set, an index that combines a proxy of the size of the school with the ability to maximize a catch during the setting.

Katara and Gaertner (2014) followed this approach to modeling the different catch rates built from skipjack free schools in the Indian Ocean with the aim to provide an insight on the changes in fishing efficiency of the purse seine fleet. To account for the changes in the spatial distribution of the fishing effort over time, the spatial explanatory variables are treated as random effects in GLMMs. By treating space as a random effect it is assumed to make inference for the potentially fished area rather than the realized fished area, thus improving the comparability of annual standardized CPUE estimates. This study must be considered as preliminary but showed that GLM estimates may be biased because annual CPUE predictions are restricted to the sites that were fished on that specific year. Areas historically fished or with the potential of being fished are overlooked. Therefore GLMMs, with "site" as a random effect, allow for CPUE predictions outside the fished areas, in sites that are not sampled. The flexibility of GLMMs is offset by the higher uncertainty of predictions. If the sampling sites are fixed, the estimated error equals the error per site; by randomizing the sites the estimated error incorporates variability stemming from two sources: within each sampled site and the between sites.

Another possibility to incorporate the technological change knowledge in the CPUE could be methods to select variables using Lasso penalization in GLM and GLMM frameworks. Several variables, not traditionally included in tuna CPUE standardization models, are retained by the Lasso model selection process, such as: the skipper, the vessel, the use of technology, the price of targeted tuna species, the number and spatial distribution of FADs and the number/type of deployed buoys among other (Gaertner et al., 2014). With this approach, additional non-conventional information is needed to describe and quantify fishing effort due to advances in fishing technology and because vessels differentiate in the types of technologies they are using. This can be done using fishery information by vessels trying to understand the use of technology to improve the number of sets per day and the number of positive sets per day by vessels in, for example, a cluster analysis.

Despite the relative low number of surveys responded by skippers from different countries, the information presented in this report offers a review of the technological and fishing strategy changes that has occurred in the tropical tuna purse seiner over a wide geographic distribution and different oceans. The information was also completed with a literature review on fishing strategies and changes in DFAD technology and the use of them, considered as the major change in technological efficiency since the 1990s. Thus, it is the intention that the team will continue working with the aim to collect more information from skippers around the world as well as getting more detailed information from experienced EU skippers in order to complete this preliminary draft report by the end of 2015.

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