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Integrating scientific and French tropical tuna purse seine skippers knowledge for a better management of dFAD fisheries in the Indian Ocean

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Abstract

Since the mid 1990s, the use of drifting Fish Aggregating Devices (dFADs) by purse seiners, artificial objects specifically designed to aggregate fish, has become an important mean of catching tropical tunas. In recent years, the massive deployments of dFADs, as well as the massive use of tracking devices on dFADs and natural floating objects, such as GPS buoys, have raised serious concerns for tropical tuna stocks, bycatch species and pelagic ecosystem functioning. Despite these concerns, relatively little is known about the modalities of dFAD use, making it difficult to assess and manage the impacts of this fishing practice. The present paper provides an overview of a 4-year research on the use of dFADs by tropical tuna purse seiners in the Western Indian Ocean. Though our primary objective was to derive information on dFAD fisheries from a large variety of quantitative sources of information (GPS buoy positions, onboard observers, logbooks and VMS), a multi-disciplinary approach was adopted throughout our research. Quantitative results (estimates of dFAD use, fishing efficiency and impacts of dFAD use) were discussed with French purse seine skippers during semi-structured interviews to understand their perception of the impacts of dFAD use and to propose adapted management options for tropical tuna purse seine dFAD fisheries. Interviews with French purse seine skippers revealed the existence of a competition between EU purse seine fleets, encouraging the recent increase in the use of dFADs. They underlined the need for a more efficient management of the fishery, including the implementation of catch quotas, a limitation of the capacity of purse seine fleets and a regulation of the use of support vessels.

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1. Introduction

Fishers have long known that many species of fish, including tropical tunas, naturally associate with the objects drifting at the surface of the ocean. For centuries, they have known that fish associated with Floating Objects (FOBs) are easier to detect and easier to catch. They have long used natural FOBs as an indicator of higher abundance, better catchability and increased fish school size (Hall 1992, Fréon & Dagorn 2000, Castro et al 2002), until they had the idea to mimic the natural behaviour of fish with the deployment of man-made FOBs. At the end of the 1990s, these drifting Fish Aggregating Devices (dFADs) became an important mean of catching skipjack, and juveniles of yellowfin and bigeye tuna by purse seiners (Fonteneau *et al.*, 2000). Increasing numbers of dFADs were deployed in the world oceans and specific FOB fishing technologies were introduced. Among others, the use of FOB tracking devices such as GPS buoys developed (Castro *et al.*, 2002; Fonteneau *et al.*, 2013) and support vessels began to assist purse seiners for dFAD deployment and searching (Arrizabalaga *et al.*, 2001; Fonteneau *et al.*, 2000). In all oceans, these changes have supported the fast development of purse seine fleets (Fonteneau *et al.*, 2013; Miyake *et al.*, 2010), dominated by European Union (EU) purse seiners in the Indian Ocean.

Over time, FOB fisheries have become an increasing source of concern for tuna Regional Fisheries Management Organizations (RFMOs) such as the Indian Ocean Tuna Commission (IOTC). Though FOBs have positive consequences for purse seine fishing, by improving the detection of tuna schools and the success of fishing sets (Fonteneau *et al.*, 2000), they have also a number of negative consequences for tropical tunas and marine ecosystems (Dagorn *et al.*, 2013). Among others, they contribute to increased catches of juveniles of yellowfin and bigeye tuna (Fonteneau *et al.*, 2000), strong modifications of the

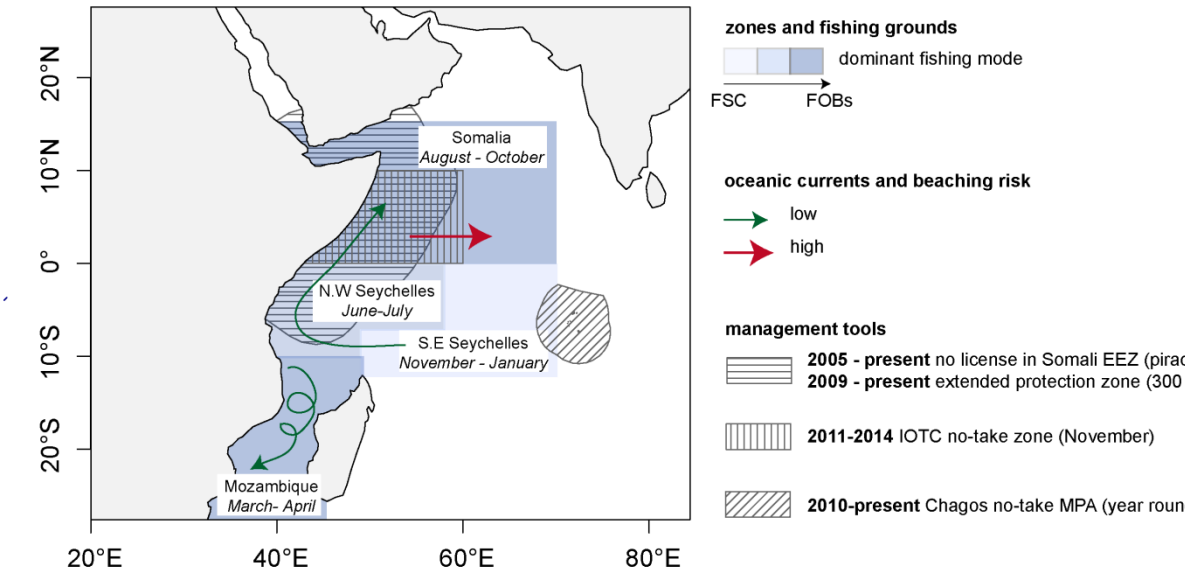

Figure 1: *study area in the Indian Ocean.* Spatial management tools have been the primary response to negative consequences of FOB use.

natural behaviour of tropical tunas (Hallier and Gaertner, 2008; Marsac *et al.*, 2000; Sempo *et al.*, 2013), increased levels of bycatch and discard (Amandè *et al.*, 2011, 2012), ghost fishing of fragile species (Anderson *et al.*, 2009; Filmalter *et al.*, 2013) and potential damages to vulnerable habitats (Maufroy *et al.*, 2015). As the increasing use of dFADs has long had little obvious effects on the state of tropical tuna stocks, there has long been little specific management of FOB impacts, except some time-area closures (Fonteneau et al., 2013; Fonteneau and Chassot, 2014, see Figure 1).

Therefore, the number of dFADs and GPS buoy-equipped FOBs has kept increasing (Fonteneau and Chassot, 2014; Maufroy *et al.*, 2016), while the fishing efficiency of tropical tuna purse seiners has continuously improved due to improving technological means (Lopez *et al.*, 2014; Torres-Irineo *et al.*, 2014), changes in fishing strategies with FOBs (Torres-Irineo *et al.*, 2014, Maufroy et al. *in prep*), and support vessels (Maufroy et *al. in prep*). In recent years, considerable attention has been drawn by scientists and NGOs on the negative impacts of FOB fishing. In response to this growing pressure for specific management of FOBs, “FAD management plans” have been implemented [Res-13/08] and the IOTC has adopted a limitation on the number of active GPS buoys [Res-15/08] and of the use of support vessels [Res 16-01] (see Supplementary Information 1 for a full list of active measures). Whilst these decisions are obviously encouraging steps, a wide variety of other management tools (e.g. fleet capacity limitation, catch quotas) could be implemented. Each of these tools may have a different efficacy, depending on their relevance to address the issues of FOB fisheries but also due to changes in the behaviour of fishers in response to their implementation.

How fishers perceive the impacts of their fishing activities and would answer to one management option or another is key to their success (Jentoft *et al.*, 1998). Achieving a successful Ecosystem Approach to Fisheries (Garcia, 2003) requires a multi-disciplinary approach combining biological, ecological and socio-economic considerations (Fischer *et al.*, 2015) in which humans are considered as part of the ecosystem (Sáenz-Arroyo and Roberts, 2008). Since the 1990s, there is a growing consensus that fishers should be involved in management decisions (Gutiérrez *et al.*, 2011; Jentoft *et al.*, 1998; Jentoft and McCay, 1995) and various examples of successful “co-management” of fisheries can be cited (Hilborn *et al.*, 2005; Pomeroy and Berkes, 1997). Fishers have indeed a practical point of view on fisheries and the knowledge they have of the ecosystems they exploit can be a valuable source of information (Chalmers and Fabricius, 2007; Johannes *et al.*, 2000; Moreno *et al.*, 2007; Neis *et al.*, 1999) to guide statistical analyses and interpret results derived from quantitative data (Johannes *et al.*, 2000). However, in general, the informal knowledge that

fishers have of their fisheries has long been disregarded by fisheries scientists and managers (Johannes and Neis, 2007), leading to inappropriate management decisions (Johannes *et al.*, 2000).

This has not been the case in tropical tuna fisheries, as purse seine skippers have regularly exchanged with fisheries scientists since the beginning of the fishery about fish behaviour (Moreno *et al.*, 2007), technological changes (Gaertner *et al.*, 2000; Lopez *et al.*, 2014), fishing strategies (Guillotreau *et al.*, 2011) or management of the fishery (Davies *et al.*, 2015). Yet, their opinion on scientific assumptions and results has rarely been solicited to identify appropriate management tools. Here, we integrate fishers' and scientific knowledge on the functioning and the management of FOB purse seine fisheries in the Indian Ocean with three main objectives (i) use skippers' knowledge to guide scientific analyses, (ii) understand the perception that skippers have of the impacts of the fishery, and finally (iii) propose adapted management tools. To achieve these objectives, we propose a two-step approach. In a first step, fishers' knowledge is used to formulate appropriate assumptions on the functioning and the impacts of the fishery, in order to guide statistical analyses. In a second step, scientific knowledge obtained by the analysis of quantitative data is confronted to the opinion of purse seine skippers, in order to validate the results and identify appropriate management tools for the fishery.

2. Phase 1: using fishers' knowledge to guide statistical analyses

2.1. Preparation of the interviews during phase 1

Several sources of quantitative information were available to address a wide variety of questions on the modalities of dFADs and GPS buoy use, their consequences and their management. Logbook, VMS, observer and GPS buoy data provided complementary but not always overlapping information, due to partial coverage (e.g. when data was only available for the French fleet), differences in spatio-temporal scales (e.g. GPS buoy data was provided on a varying time scale), or the different nature of the activities that these data were describing (e.g. observer data provided information on all types of activities on FOBs while logbook data only provided information on fishing sets). To overcome the inevitable difficulties of combining these many different sources of information, fishers' knowledge was gathered to eliminate wrong assumptions and guide statistical analyses.

First, quantitative data were explored, literature was reviewed and the opinion of the French fisheries scientists working on the fishery was solicited. Based on identified knowledge gaps and potential research questions, a semi-structured guide of interview was built to yield information on the modalities of dFAD and GPS buoy use (deployment,

monitoring and fishing) as well as the changes having occurred for the FOB fishery (technological changes and management tools). 14 French speaking skippers (including 2 French skippers working for a Spanish company and a Spanish skipper), having a long experience of the functioning of the fishery in the Indian Ocean, were interviewed in June and July 2013, on their arrival in Port Victoria (Seychelles).

Interviews were conducted aboard purse seiners as informal discussions. Rather than following a questionnaire, the guide of interview consisted of open-ended questions supplemented with examples of closed-ended questions only used to rephrase or clarify the discussion (Table 1). Interviews were noted but not tape recorded. There was no pre-determined order in these discussions and we did not insist to absolutely obtain an answer to each of our questions, so as to follow the participant's train of thought. This flexibility offered the opportunity to skippers to talk about subjects that had not been previously identified as important by fisheries scientists. This also resulted in varying numbers of answers for each question and varying length of the interviews (from 1 to 4 hours). As a consequence, a simple count of the occurrence of keywords identified in skippers' answers was used to rank their relative importance.

Table 1: *structure of the interview guide during phase 1 (detailed version in SI 2, in French)*

Theme	Sub-theme	Question
1. modalities in FOB use	a) deployment	deployment factors
	b) monitoring	number of FOBs, dFADs/natural FOBs, French/Spanish FOBs
	c) fishing	searching activities, preference for FOB or Free Swimming Schools, size of fishing sets
2. changes for FOB fisheries	a) technological and strategic changes	changes in catches, seasons and zones, echosounder buoys
	b) management tools	IOTC time-area closure, Chagos MPA, Somali EEZ

2.2. Results: qualitative information and quantitative analyses

How do French skippers decide to deploy new dFADs and GPS buoys?

Semi-structured interviews of skippers provided some insights into deployment decision making. We discussed with skippers about the conditions that determined a deployment of a dFAD or of a GPS buoy on a FOB already drifting at sea. We identified the seasonality and the use of oceanic currents as key factors for these deployments and used

French GPS buoy data to identify GPS buoy deployment seasons (Figure 2, Maufroy *et al. in press*). In 2013, due to relatively restricted numbers of GPS buoys, French skippers indicated that they were selective in their GPS buoy deployments, avoiding deploying GPS buoys in areas where currents would extract FOBs from fishing grounds and mainly deploying dFADs and GPS buoys where they were actively fishing. Measures of the correlation between French FOB deployment and French FOB fishing confirmed that deployment and fishing on FOBs were correlated in time and space for the French fleet over 2007-2013 (Maufroy *et al.*, 2016).

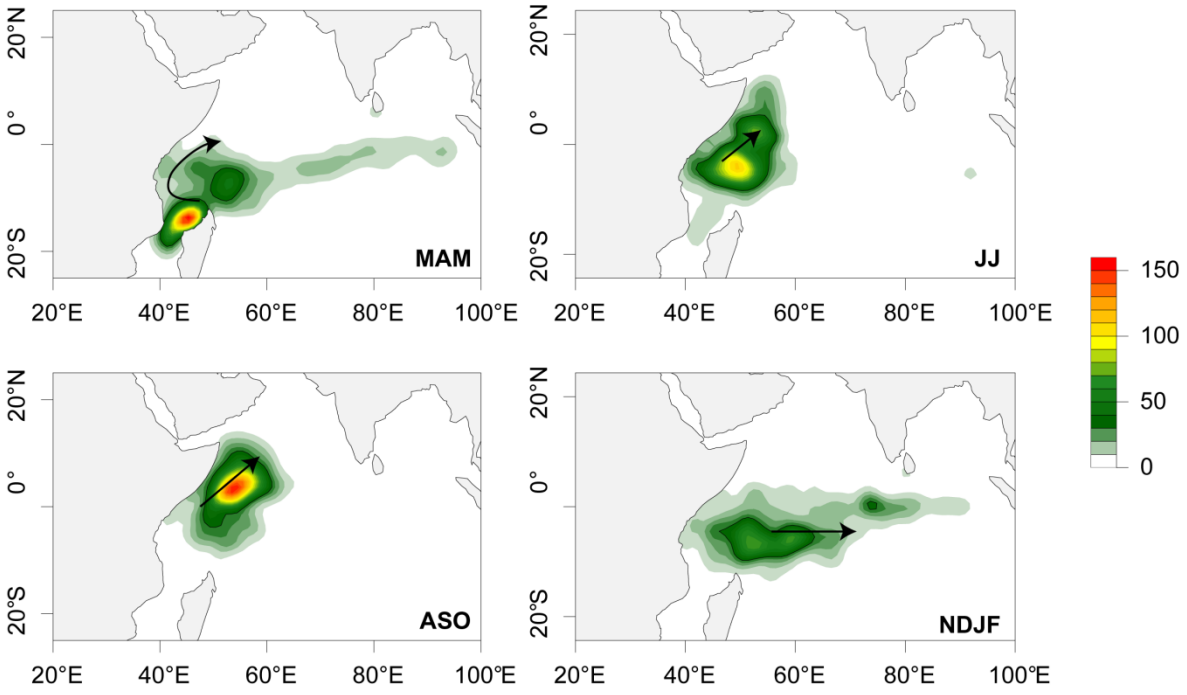

Figure 2: *GPS buoy deployment seasons in the Indian Ocean (Maufroy et al., 2016). MAM: March-April-May, JJ: June-July, ASO: August-September-October, NDJF: November-December-January-February.* Arrows indicate the direction of the main currents during the deployment season.

How many dFADs are in use in the Indian Ocean?

French skippers also suggested a strong increase in the use of dFADs and GPS as well as important differences among EU purse seine fleets. Following the interviews, tracks of French GPS buoys were combined with observations of GPS buoy-equipped FOBs aboard French and Spanish purse seiners to estimate the total number of dFADs and GPS buoys used within the main fishing grounds over the period 2007–2013. This number increased from 2250 dFADs in October 2007 to 10 300 dFADs in September 2013 (Figure 3,

Maufroy *et al.*, 2016). Differences between EU purse seine fleets were observed, Spanish purse seiners using more dFADs per vessel than French purse seiners. These differences tended to increase over time, Spanish purse seiners using 2.7 and 5.7 times more dFADs in 2007 and 2013 respectively.

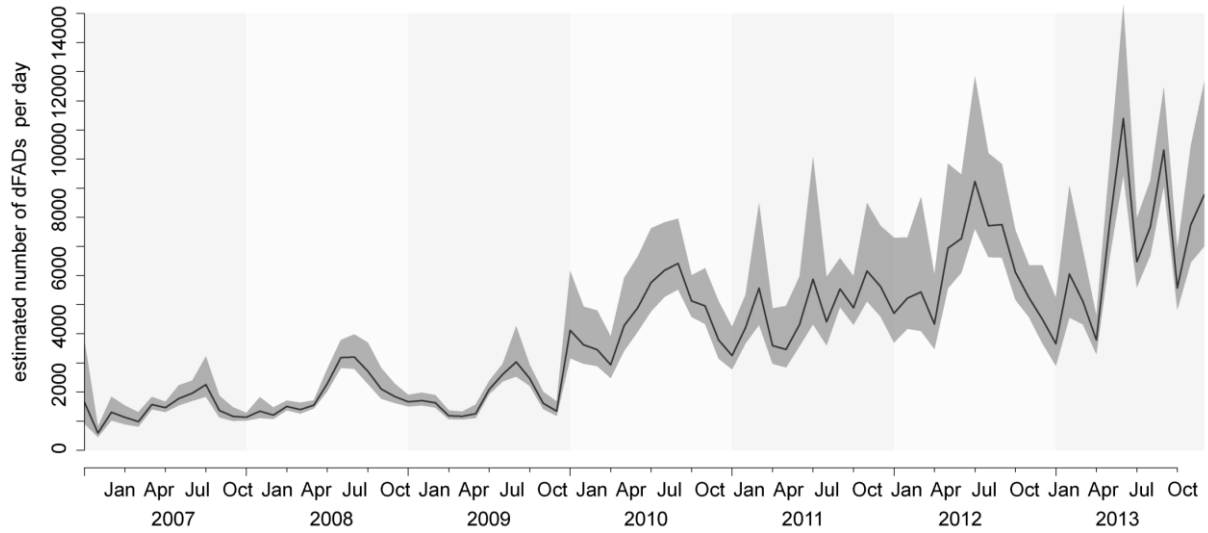

Figure 3: *Estimation of the total number of GPS buoy-equipped dFADs in Indian Ocean, at the end of each month (2007-2013, Maufroy et al, 2016).*

How do dFADs and support vessels contribute to the fishing efficiency of purse seiners?

The massive increase in the use of FOBs naturally led to questions regarding their contribution to the fishing strategies and efficiency of EU tropical tuna purse seiners. French and Spanish logbook data were used over 2003-2014 in relation to vessel characteristics (size, fleet), use of support vessels and strategies of purse seiners with FOBs and FSC (Maufroy *et al.*, *in prep*). In the Indian Ocean, the proportion of fishing sets on FOBs gradually increased over 2003-2014, indicating that the FOB strategy progressively became more important than the FSC strategy (50.9% of fishing sets to 70.6%). As suggested by interviews with purse seine skippers, Spanish purse seiners were significantly more specialized in FOB fishing with 63.0% of fishing sets on FOBs (SD 21.0) against 53.3% for French purse seiners (SD 21.8).

Results also indicated that increasing the contribution of the FOB strategy and the use of support vessels improved the efficiency of EU purse seiners over 2003-2014. During this period, an increase in the proportion of fishing sets on FOBs of 1% improved the catch of purse seiners of 0.18% per day and 0.44% per fishing set while the number of fishing sets decreased of 0.28%, probably due to less frequent null fishing sets. In addition, purse seiners

benefiting from their own support vessel (not shared with any other purse seiner) made 12.3% more catch per day and 15.3% more catch per fishing set than purse seiners without support vessel. As suggested by French purse seine skippers, Spanish purse seiners having more dFADs and GPS buoys and using more support vessels were found to be more efficient.

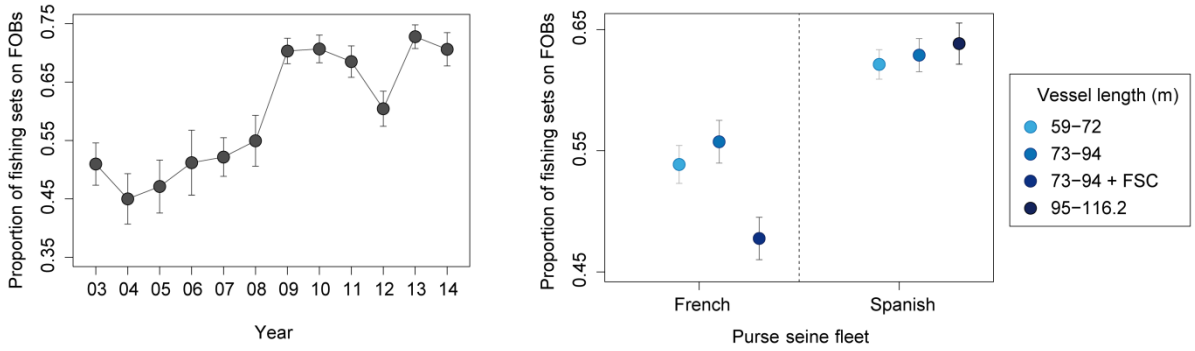

Figure 4: *Effect of the year (left panel) and the characteristics of purse seiners) on the strategies of purse seiners with FOBs from 2003 to 2014 in the Indian Oceans (Maufroy et al., in prep).* Error bars represent the standard error of the mean.

What are the negative consequences of lost dFADs?

During the interviews, purse seine skippers also drew our attention to the frequency of lost dFADs. Using French GPS buoy data, we estimated that 9.9% of FOB trajectories had ended with a beaching event over 2007-2011 in the Atlantic and Indian Oceans combined (Maufroy *et al.*, 2015). In the Indian Ocean, the increasing use of dFADs logically resulted in increased numbers of beaching events over 2007-2013 (Figure 5). These beaching often occurred in fragile ecosystems such as the coral reefs of Maldives and Seychelles, resulting in habitat degradation (Balderson and Martin, 2015).

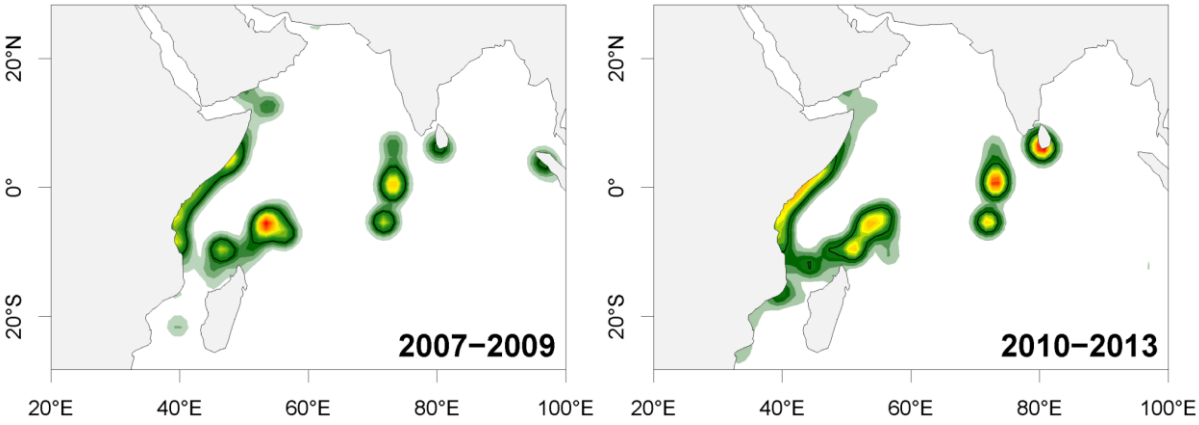

Figure 5: *evolution of the density of beached dFADs over 2007-2013.* Note that the frequent beaching events in Sri Lanka may be due to dFADs retrieved by local fishers.

3. Phase 2: confronting quantitative analyses to fishers' perception

3.1. Preparation of the interviews during phase 2

During the first phase of the study, fishers' knowledge had been used to improve scientific knowledge of functioning and consequences of FOB fisheries. From August to September 2015, the results of the ongoing research conducted were presented to 15 French skippers arriving in the port of Victoria (among which 6 had participated in the interviews in 2013). The objective of this second phase was to confront the knowledge derived from quantitative data to fishers' perception on the impacts and the existing management of the fishery, in order to propose adapted management tools. Among others, seasons of dFAD deployment, estimates of dFAD use and dFAD beaching were presented to skippers. Results on fishing strategies and fishing efficiency were not available at this stage and were replaced with simplified information (e.g. the yearly catch per French purse seiner since the 1980s that remained stable in recent years though the number of dFADs was increasing).

In addition, two years after the first interviews, important changes had occurred for FOB fisheries of the Indian Ocean. Since 2014, pressure for the management of FOB fishing had increased with NGO anti-FOB campaigns. In 2015, important decisions had been made to limit the number of active GPS buoys to 550 per purse seiner in the Indian Ocean [Res 15-08]. At the same time, French fishing companies that had restricted their use of GPS buoys to 200 per year and per vessel since 2012, finally decided to increase this limitation as well as to use support vessels. The opinion of skippers on these changes was also solicited.

Table 2: *structure of the interview guide during phase 2 (detailed version in SI 3, French)*

Theme	Sub-theme	Question
1. modalities in dFAD use	a) deployment	seasons, currents
	b) number of dFADs	increase in dFAD use, recent changes in strategies
2. consequences of dFAD use	a) tuna catch	catch, yield of fishing sets
	b) other species	bycatch, ghost fishing
	c) ecosystems	lost GPS buoys, dFAD beaching, ecological trap
3. management tools	a) existing management	seasonal closures, 550 GPS active buoys/vessel
	b)options for management	limitation of dFADs/buoys, catch quotas, support vessels

As in 2013, the occurrence of families of keywords was used to rank their relative importance. Interviews lasted from 2 hours to 4 hours and once again, our objective was not to obtain an answer to each question of the interview guide, but to understand which of these questions were important to skippers. Therefore, not all skippers answered each question, and some skippers provided several answers to the same question (i.e. the number of answers does not necessarily sum to 15). When this was possible, answers provided in 2013 where compared to answers provided in 2015.

3.2 Results obtained during phase 2

3.2.1. Recent changes in the use of FOBs in the Indian Ocean

Why is the use of FOBs increasing in the Indian Ocean?

French skippers confirmed the increasing use of FOBs by French fishing purse seiners identified by (Maufroy *et al.*, 2016). Although 69.2% of interviewed skippers were not in favour of the recent decision of French fishing companies to increase their use of GPS buoys, 80% of them also considered that they did not have any alternative. 12 skippers on 15 thought this was necessary to compensate for an increased competition with Spanish purse seiners using more FOBs and benefiting from support vessels (Figure 6). Then came considerations on potential improvement of their catches (7 skippers), compensation for GPS buoys lost outside fishing grounds or FOBs appropriated by other fishing vessels (6 skippers), relative inefficiency of fishing on FSC compared to FOB fishing (5 skippers) and the virtual absence of management of FOBs (4 skippers).

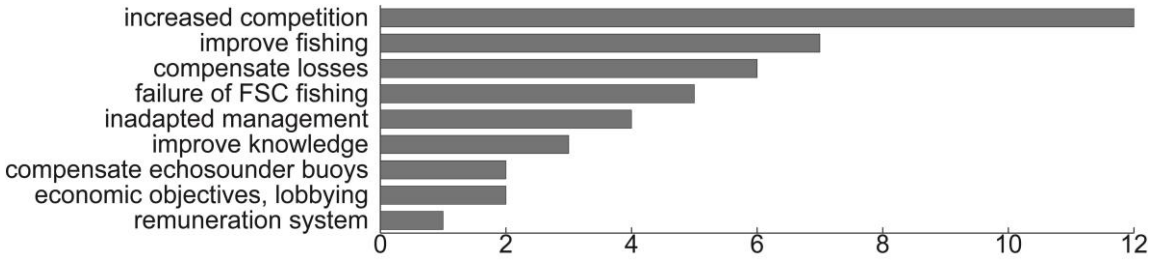

Figure 6: *reasons to increase the use of FOBs by French purse seiners in the Indian Ocean*

Does the increasing number of dFADs modify skippers' strategies?

In 2013 and in 2015, French skippers indicated that their knowledge on the appropriate zones and seasons was the main factor used to deploy their dFADs and GPS buoys (Figure 7). Though there were only two years between the two groups of interviews, some skippers interviewed in 2013 indicated in 2015 that the increasing availability of GPS buoys had slightly changed their deployment strategies. With more GPS buoys, it would be possible to maintain a relatively dense array of FOBs. Answers provided by skippers that

were interviewed in 2015 only confirmed these changes, as more skippers indicated that the density of FOBs within the area was an important factor to deploy new dFADs and GPS buoys. Also, more skippers took advantage of periods without fishing to deploy dFADs and GPS buoys.

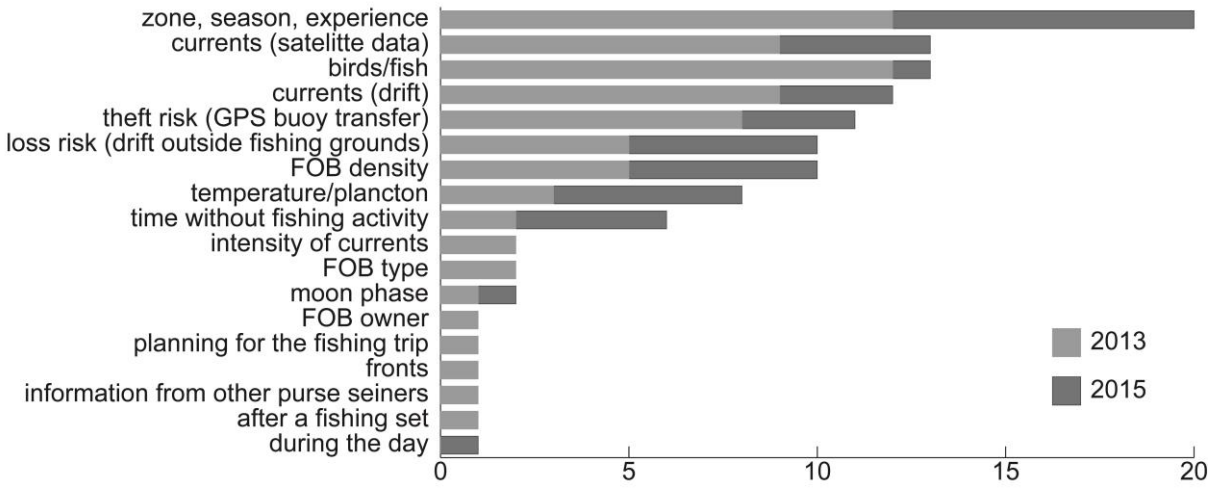

Figure 7: *factors to decide of the deployment of a new dFAD or a new GPS buoy*

3.2.2. Skippers' perception of the impacts of FOBs on tropical tunas

Do FOBs alter the natural behaviour of tropical tunas?

Among the potential effects of FOBs, assumptions regarding the alteration tuna behaviour were discussed with skippers (Figure 8). First, the idea that the increasing use of dFADs may contribute to an ecological trap (Hallier and Gaertner, 2008; Marsac *et al.*, 2000), by trapping tunas in suboptimal zones, where their condition factors decrease (Ménard *et al.*, 2000) and their natural feeding migrations are altered (Marsac *et al.*, 2000) was proposed to skippers. On the 11 skippers who answered this question directly, 7 rejected this assumption, 2 of them thinking that this would only be valid in the Atlantic Ocean where they had experienced this situation. However, 7 skippers indicated that Free Swimming Schools of tunas were progressively disappearing, while 5 of them indicated that tuna migrations seemed altered, at least on short time scales.

Second, the potential fragmentation of tuna schools between FOBs was discussed (Sempo *et al.*, 2013). Half of the skippers agreed that the situation existed or could exist while the other half rejected this possibility. On the contrary, most of them had observed a high proportion of FOBs without fish and a greater instability of schools that constantly moved from one FOB to the other, indicating possible shorter time of residence under FOBs. These discussions were principally based on decreasing trends of the catch per fishing set on FOBs since 2004. During these discussions, skippers also explained the apparent

decrease in the size of schools in catch data by improving technological means allowing to detect smaller schools of tunas (7 skippers) and a diminution of the preferred minimal size of schools to set the net (9 skippers).

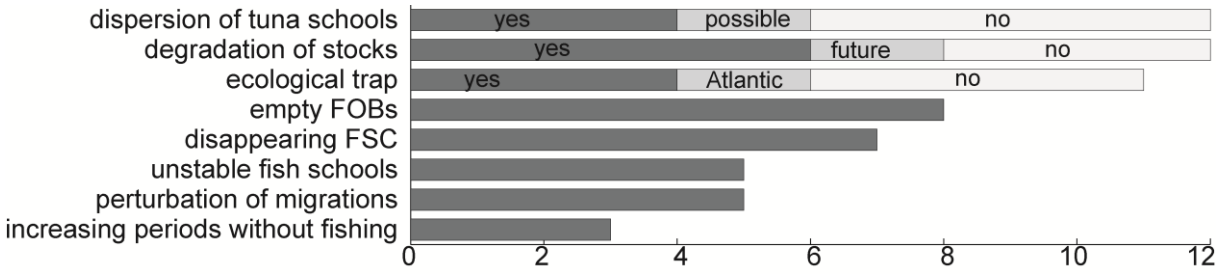

Figure 8: *perception of skippers of the impacts of FOBs on tropical tunas*

Can the increasing use of FOBs lead to overfishing?

In addition to these potential changes in the behaviour of tropical tunas, we simultaneously presented the evolution of catch per French vessel and per year and the evolution of the number of French GPS buoys. French skippers had diverse points of view regarding the absence of increase in their annual catches following their increasing use of FOBs. Half of the skippers indicated a potential degradation of tropical tuna stocks (Figure 8), though their impressions were almost always related to relatively low catches during their last fishing trip. However, they provided other possible explanation such as the increasing competition with the efficient Spanish purse seine fleet (8 skippers on 15) and the increasing use of echosounder buoys that reduced the chances to find tuna under FOBs of other purse seiners.

3.2.3. Skippers' perception of the impacts of FOBs on marine ecosystems

How do skippers perceive the issues of bycatch and ghost fishing?

One of the major source of concerns regarding the impacts of FOBs is their contribution to higher levels of bycatch (Amandè et al., 2011, 2012) and ghost fishing of sharks and sea turtles (Anderson et al., 2009; Filmalter et al., 2013). Most skippers felt the need to justify themselves before any question was asked. During discussions on the problems of bycatch and ghost fishing, most skippers indicated that these issues were minor ones for the purse seine fishery, due to relatively low volumes of bycatch (6 skippers), efforts to discard fish alive (4 skippers) and to use non-entangling dFADs (6 skippers).

They generally considered the landing obligation of tuna catches (that came into force in 2015) as irrelevant primarily because they had the impression that discarded fish could

survive and re-attract tuna to the FOB. Most of them also had the impression to have made significant effort, by discarding fish alive and using non-entangling dFADs that had visible effects on the frequency of sharks and turtles ghost fishing. Some of them also raised the issue of the trade of bycatch landed in Seychelles, due to the absence of local markets and to problems of conservation of small bycatch fishes onboard.

How do skippers perceive the issue of FOB beaching?

Interviews of 2013 had underlined the importance of lost FOBs. Examination of quantitative data revealed that an important fraction of these lost FOBs would end up beaching. In 2015, skippers had differing points of view regarding the severity on the impacts of such beaching events, as approximately 1/3 of them considered that these impacts were low, 1/3 considerate they were moderate and 1/3 considered they were high (Figure 9). They thought that these beaching events could be problematic for ecosystems, through pollution (6 skippers) and degradation of coral reefs (5 skippers). But they also discussed about the economic consequences of such beaching events due to the cost of lost GPS buoys (3 skippers) and more importantly due to detrimental effects on tourism (6 skippers). Skippers identified the increasing use of dFADs (7 skippers), the design of dFADs with long underwater structures (3 skippers) and the difficult prediction of the trajectory of FOBs (3 skippers) as aggravating factors. The use of biodegradable non entangling dFAD (5 skippers), the reduction of the number of dFADs (7 skippers) and the use of a support vessel to retrieve lost FOBs (3 skippers) would help reducing the impacts of FOB beaching.

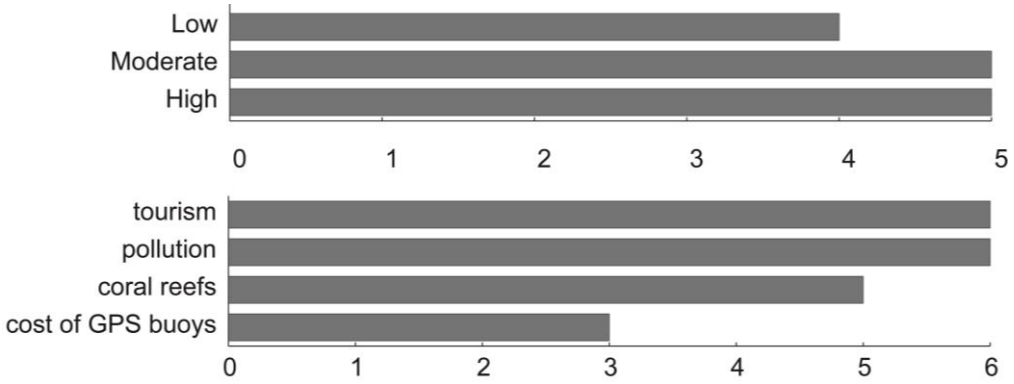

Figure 9: *perception of skippers of the impacts of beaching dFADs. Top panel: severity of FOB beaching impacts. Bottom panel: most important impacts.*

3.2.4. French skippers' perception of the management of FOB fisheries

Why should we manage FOB fisheries?

Throughout the interviews, French skippers had the opportunity to express their opinion on the general management of the fishery, as well as on the management of some specific issues (see previous sections on bycatch and FOB fishing). 14 skippers felt there was a need to manage the fishery, primarily because they thought there were too many dFADs, GPS buoys, purse seiners and support vessels (Figure 10). Most skippers were concerned about the future of the fishery and their future catches and felt that management was virtually absent (7 skippers). However, their concerns were often not related to the state of tropical tuna stocks.

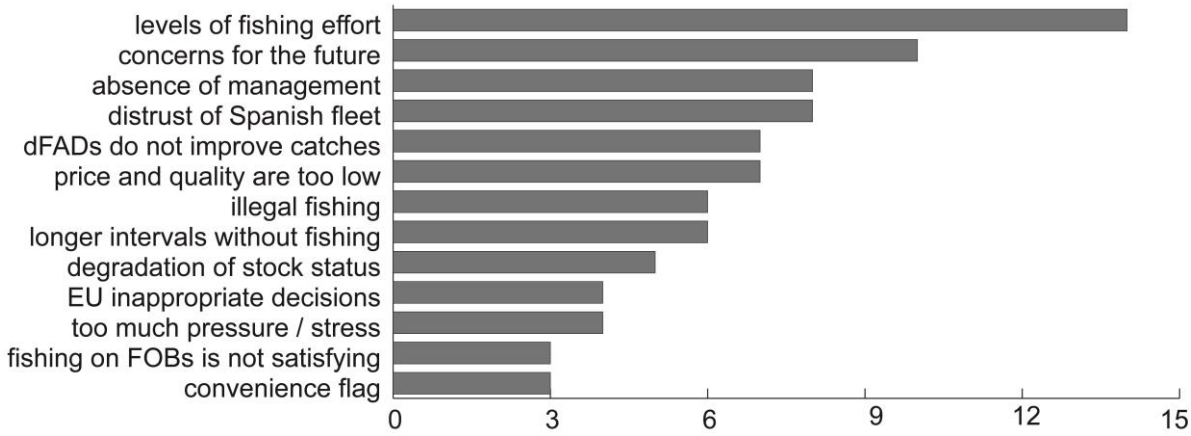

Figure 10: *reasons to manage FOB fisheries in the Indian Ocean*

The virtual absence of management had created a strong resentment against other purse seine fleets. Many French skippers thought that other purse seine fleets were not obliged to follow the same rules as French skippers (9 skippers) and were even not complying with existing rules (10 skippers). Though similar regulations obviously apply to all EU purse seiners, this resentment may be explained by different factors. First, all French skippers indicated that other skippers benefited from better fishing tools with more GPS buoys and the assistance of support vessels. Therefore, they were more efficient and French skippers had the impression that there was an increased competition to get their share of catches. Second, there were increasing conflicts between French purse seiners and support vessels from other fleets, as 8 skippers thought support vessels would steal their GPS buoys even in time-area closures or in the Somali EEZ. Finally, French fishing companies had decided since 2012 to limit their use of GPS buoys to 200 per purse seiner and per year (Decision Orthongel n°11, 2011). This voluntary limitation had not been followed by other purse seine fleets, leading to a further impression of inequity between the two fleets.

Is a limitation of the use of GPS buoys an appropriate management tool?

13 of the 15 skippers agreed that regulating the use of dFADs and GPS buoys was necessary but none of them thought that the limitation of active GPS buoys could be effective (Figure 11). They felt that there was a high risk of non-compliance, primarily due to unclear definitions in IOTC Resolution 15/08 and issues in enforcement. They were not sure whether support vessels were included in the limitation (5 skippers) and wondered if purse seiners could hide a fraction of their GPS buoys by temporary deactivations (4 skippers). In order to be effective, additional regulations should be adopted, such as a limitation of the number of buoys purchased per year (3 skippers, measure already included in Res 15/08) or a reduction of the number of purse seiners (2 skippers) and support vessels should be included in the limitation (2 skippers).

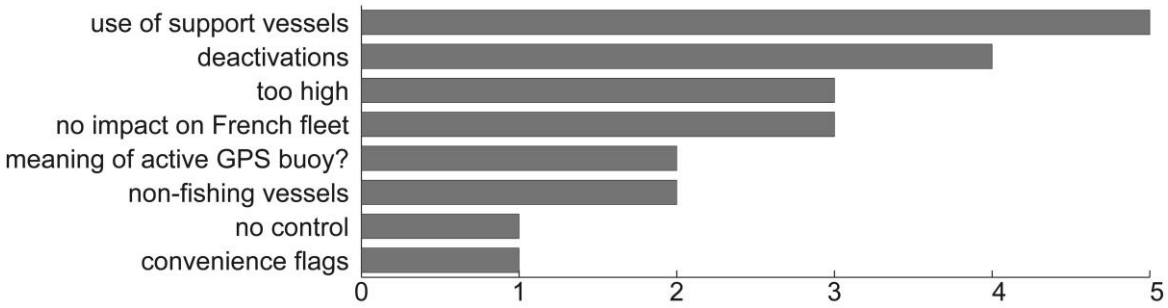

Figure 11: *problems with the limitation of active GPS buoys in the Indian Ocean*

Which management tools would be best adapted?

In addition to a limitation of the number of active GPS buoys, other management tools were discussed with skippers, to identify those that would be best adapted to the fishery and the conditions to make them efficient. Results are summarised in Figure 12 and Table 3. By order of importance, potential management included a regulation of fleet capacity, support vessels, a limitation of the number of GPS buoys, catch quotas, and no-take zones. The potential for a ban of dFADs was also discussed but strongly rejected by skippers. They disagreed with the idea that dFADs are destructive fishing gears, and raised the importance of canned tuna. In addition, they highlighted the potential difficulties of a dFAD ban for purse seiners with a dominant FOB strategy, due to their potential lack of knowledge on FSC fishing or to the size of large purse seiners that mostly rely on FOBs to be profitable.

During the interviews, all skippers indicated that the fishery suffered of a problem of excess fishing effort and excess fishing capacity due to an excessive number of purse seiners (8 skippers) and their increasing size and capacity (6 skippers). They generally considered that this problem of capacity was somehow connected to the increasing use of

dFADs, GPS and echosounder buoys, and support vessels. Though they agreed that decisions should be made to control fishing effort and capacity, they also indicated various conditions that would reduce the efficiency of fleet capacity limitations. First, several large purse seiners of the Eastern Pacific Ocean had recently left this ocean for the Indian Ocean, shifting the problem of capacity elsewhere. Second, the motivations of the governments of distant water fishing nations and coastal countries were questioned due to a possible race for fishing anteriority (in case catch quotas would be implemented, the objective would be to have more fishing vessels to have a larger share of TACs), EU subsidies and vessels flying flags of convenience.

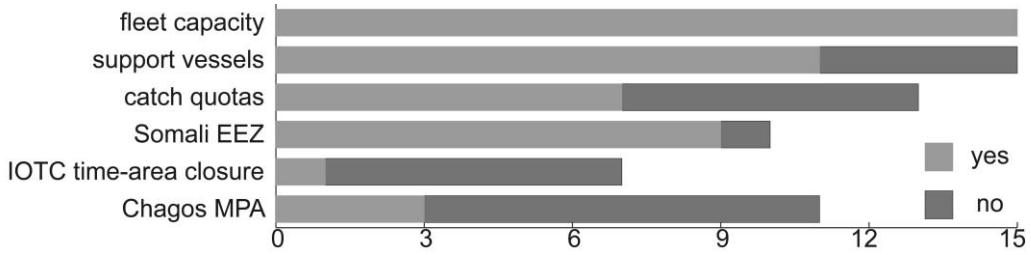

Figure 12: *agreement of skippers with potential and existing management tools*

French skippers also indicated that were growing problems with the use of support vessels and 73% of them agreed to the suggestion that their use could be banned. Most of the time, they considered that there was an insufficient control of these vessels, and even doubted that they were included in the limitation of 550 GPS buoys per vessel (see section 3.2.4). In addition, they had observed high rates of “theft” of their GPS buoys in the Somali EEZ and in the IOTC moratorium (Figure 1) and attributed them to support vessels. However, French skippers also indicated that such a decision could have important consequences for large purse seiners that heavily rely on FOBs and indicated that French fishing companies had already decided to invest in support vessels.

Then, the question of catch quotas was discussed. Half of the skippers considered that they were an appropriate management tool for the fishery, as they could increase tuna market prices, improve the state of tropical tuna stocks or rebalance fishing effort between purse seine fleets. This tool has also been successful in other fisheries and would mechanically reduce, among other gears, the number of purse seiners, support vessels and dFADs. On the other hand, 50% of French skippers considered that catch quotas would not be a good solution. They discussed about the problem of allocation criteria and consensus, race for fishing anteriority and economic difficulties for purse seiners with a dominant FOB strategy.

Finally, the question of spatial management of the fishery, that has been the main tool used so far in the Indian Ocean (Fonteneau and Chassot, 2014), was discussed. French skippers provided different answers depending on the area that was considered. They generally considered that the past IOTC no-take area of November and the Chagos Archipelago MPA had little impact on the fishery because of inappropriate choice of zones and seasons. Purse seiners generally leave the Somali fishing ground before November and target Free Swimming Schools in the vicinity of the Chagos Archipelago. On the contrary, though the Somali EEZ is not strictly speaking a fishery closure, skippers considered that the absence of fishing agreements to access this area (due to problems of piracy) could protect tuna juveniles. However, their interest in the zone was not only for the protection of juveniles, as they also indicated that they could hide their GPS buoy equipped FOBs in the area and wait for them on the border of the EEZ (in a typical “fishing the line” strategy, Kellner et al., 2007).

Table 3: *potential management of FOB fisheries, positive outcomes and possible limitations*

Management tool	**Pros**	**Cons**
Number, size and carrying capacity of purse seiners	• too many vessels : 8 skippers • too large vessels: 6 skippers • fuel consumption: 3 skippers • regulation of GPS buoys: 1 skipper improve yield per vessel: 1 skipper	• vessels may leave for another ocean: 4 skippers • this creates a race for fishing anteriority: 2 skippers • flags of convenience: 2 skippers • EU subsidies: 1 skipper • economic consequences (investments made already): 1 skipper
Support vessels	• they do not comply with EEZs: 9 skippers • there is no regulation of support vessels: 7 skippers • they appropriate fish/FOBs: 4 skippers • this could regulate the use of GPS buoys: 3 skippers • they should be accounted for in the 550 buoys	• issues of profitability for large purse seiners: 2 skippers • support vessels could be used to limit beaching: 2 skippers • French companies will soon have support vessels too: 2 skippers
Catch quotas	• to regulate prices: 3 skippers • to improve stocks/yield: 2 skippers • some fishing companies do not consider the long term : 2 skippers • they may be easier to enforce: 1 skipper • they have proven successful in other fisheries: 1 skipper • this could regulate capacity, support vessels and FOB use: 1 skipper	• allocation criteria: 2 skippers • this creates a race for fishing anteriority: 2 skippers • difficult to choose between different fleets and their strategies: 2 skippers • obligation of regularity in catches (to avoid fast quota exhaustion): 2 skippers • problem of consensus: 1 skipper • ineffective if catches are not significantly reduced: 1 skipper
Spatial management (including no-take areas)	• spillover: 5 skippers • protect GPS buoys against theft: 5 skippers • protect juveniles: 3 skippers	• supply vessels do not comply: 5 skippers • inappropriate choice of period: 3 skippers • such management measures are only communication tools: 2 skippers

4. Discussion

In the present study, scientific and local ecological knowledge were treated as equally important to gather useful information on the FOB fisheries, understand the consequences of the increasing use of FOBs on tropical tuna stocks and marine ecosystems and finally to identify possible management tools of the fishery. Among others, results indicate that French skippers have different points of view regarding the impacts of the increasing use of FOBs on tropical tunas, bycatch species and vulnerable habitats (through beaching of lost dFADs). They generally indicated that the current management of the FOB fishery was either inappropriate (e.g. discard ban or limitation of active GPS buoys) or inexistent (e.g. number and size of purse seiners). Potential for new management decisions was raised, including managing the capacity of the purse seine fleet, regulating the use of support vessels, implementing catch quotas and addressing other important issues such as illegal fishing.

4.1 Skippers perception of the impacts of the fishery

In 2015, French skippers were seemingly less concerned with the impacts of FOBs for bycatch species and marine ecosystems than for tropical tunas. They generally indicated that the issue of bycatch was a minor one while the issue of lost FOBs was partly a problem of image if dFADs ended up beaching in touristic areas such as the Seychelles and the Maldives. The perception that the use of FOBs is causing only minor collateral damages on marine ecosystems is not surprising. Though FOB fishing induces higher levels of bycatch than fishing on Free Swimming Schools (Amandè et al., 2011, 2012), levels of bycatch remain relatively low for purse seiners compared to other fishing gears such as pelagic longlines or gillnets (Gilman, 2011). Besides, purse seine skippers often pointed out the efforts made to mitigate bycatch such as the presence onboard of scientific observers or cameras (increasing in 2015 to reach 100%) and the development of non-entangling dFADs that reduced ghost fishing of sharks and sea turtles (Franco et al., 2012; Hernandez-Garcia et al., 2014). However, purse seiner skippers may also have minimized the effects of FOBs on bycatch due to the growing pressure of NGOs who are using this argument to advocate for a reduction or a ban of dFAD use (e.g. http://www.greenpeace.org/france/fr/campagnes/oceans/arrethon/). Finally, their point of view may also be related to the recent implementation of a discard ban by the IOTC (Res 15-06) that was inducing additional constraints for purse seiners.

Nevertheless, although French skippers often disagreed with the idea that bycatch is a serious issue of FOB fisheries, concerns regarding catches of yellowfin and bigeye tuna, as well as impacts on sensitive shark species remain important. French skippers raised various concerns for tropical tuna stocks, that they considered as more serious than concerns for non-target species. Though 50% of them indicated that tropical tuna stocks could suffer from

overfishing, their concerns were more related to important changes in the behaviour of tropical tuna schools. They had different points of view regarding the potential of an ecological trap due to the increased use of dFADs (Hallier and Gaertner, 2008; Marsac et al., 2000) but described other phenomena: the dispersion of schools (as suggested by Sempo et al. 2013), a progressive disappearing of Free Swimming schools (the steady decline of skipjack free schools since 1991 in the Atlantic and since 1994 in the Indian Ocean, has been described in Fonteneau, 2015; Fonteneau et al., 2000b, Fonteneau 2014) or an instability of schools under FOBs. These suggestions could guide new research on the behaviour of tropical tunas at FOBs, for example using simulations and data from echosounder – tracking buoys use by purse seiners. However, in the absence of quantification of the potential changes in the behaviour of tunas, skippers mostly relied on their personal opinions and scientific analyses are required to verify their suggestions.

Even though 50% of purse seine skippers did not have the impression that the use of FOBs would lead to overfishing, these results suggest at least that a too important use of FOBs may not be optimal. From an economic point of view, if increased densities of FOBs reduce their attraction potential (due to the dispersion and the instability of schools), deploying large number of dFADs may have a counterproductive effect. Besides, if too large numbers of GPS and echosounder buoy-equipped FOBs are in use, conflicts may arise between purse seine fleets, due to an increasing competition to get the larger share of catches.

4.2 The tragedy of the commons: once again?

During the interviews of 2013 and 2015, purse seine skippers pointed out a general problem of overcapacity. This problem is not a new one for tropical tuna fisheries and has been discussed since the end of the 1990s at least (Greboval and Munro, 1999; Morón, 2007; Reid et al., 2005). In 2015, excess fishing capacity was related to an absence of direct regulation of the capacity of the fleet (number, size and carrying capacity of purse seiners) but also an absence of indirect regulation, through a control of support vessels and a monitoring of FOB use. This virtual absence of efficient regulation seems to have created a generalized race-to-fish leading to a race-to-dFADs. This situation, well known in open access fisheries as the ‘Tragedy of the commons” (Hardin, 1968) may have encouraged over-investment during the last decade. At first, the increasing number of dFADs and GPS buoys (Maufroy *et al.*, 2016) contributed to an increase in the size of purse seiners, as building larger vessels had become profitable (Le Gall, 2000; Maufroy *et al.*, *in prep*). But at the same time, these large purse seiners became dependent on their FOBs and support

vessels and induced a competition with French purse seiners who did not benefit from equivalent FOB fishing tools.

For some time, French fishing companies decided to set an auto-limitation of their use of GPS buoys (200 per vessel and per year). This was rather an unexpected decision in the absence of regulation. In this typical case of “Tragedy of the Commons” (Hardin, 1968), each fishing company should normally choose to increase its use of FOBs to increase catches on the short term, regardless of the consequences for tropical tuna stocks on the long term. In theory, this could only last if each French fishing company agrees to comply with this decision, even if this could reduce potential catches (though the value of FSC catches is higher, Guillotreau et al., 2011). In 2015, French skippers thought that this was not the case anymore. The decision of the IOTC to limit the use of GPS buoys per vessel even had an unexpected effect. As this number was rather high (550 buoys per day i.e. 5 times more than the 100 GPS buoys per day used by French purse seiners, Maufroy et al. 2016), instead of reducing the general use of FOBs, this contributed to an increase in the use of GPS buoys by French purse seiners. French skippers explained that they had no other choice due to the competition with other purse seine fleets. This situation indicates that a sole management of the use of FOBs may not be efficient, if other components of fishing efficiency and fishing capacity are not regulated.

4.3 Other solutions: regulating fleet capacity and implementing quotas

In addition to a regulation of FOB use, other management tools may be adapted by the fishery. Ideally, as underlined by several skippers, these tools should be as simple as possible and should be easy to implement. Due to their limited effects, no-take zones, FOB moratoria and discard bans may be eliminated directly from this list (Fonteneau et al., 2015; Fonteneau and Chassot, 2014). A ban of dFAD deployment or FOB fishing suggested by environmental NGOs may not be an appropriate solution either (Davies et al., 2015) for obvious socio-economic reasons. Other solutions would therefore be: (i) a regulation on the use of support vessels (ii) a regulation on the fleet capacity for all gears (leading inter alia to a reduction of the number of purse seiners) (iii) a regulation on catches through catch quotas.

According to French skippers, all these potential solutions are connected to each other (Figure 13). Among potential tools for the management of the fishery, catch quotas may seem promising management tools, though only 50% of French skippers were favourable to this type of management. Catch quotas would indeed reduce the interest of

having large numbers of purse seiners using large numbers of dFADs and GPS buoys, in collaboration with purse seiners. This regulation could be relatively easy to enforce by controlling landings of purse seiners, but this would not solve the problems of under-estimation of artisanal catches or the problem of IUU fishing. Also, IOTC past attempts to implement such quotas have failed, as finding a consensus is difficult. However, following the last evaluation of the stock of yellowfin tuna (YFT), IOTC Rec 16-01 was adopted. This resolution implements for 2017 a reduction of 15% of YFT catches as compared to 2014 for purse seine fleets. In the future, similar decisions could be made for skipjack (SKJ and bigeye tuna, especially if as suggested by French skippers, the increasing use of FOBs becomes a source of concern for SKJ (less FSC, disturbed behaviour, etc).

An alternative would be to limit the number of purse seiners and their size. On the contrary to catch quotas, 100% of interviewed French skippers were favourable to a reduction of fishing effort and fishing capacity. This tool would only be effective it the decision was made on a global basis to avoid displacing the problem in other oceans. This would also imply addressing issues of reflagging, subsidies, and IUU fishing that were all identified by French purse seine skippers. Finally this would require having fine scale information on the use of GPS buoys and support vessels, as they greatly contribute to fishing efficiency (Maufroy et al. *in prep*) and therefore encourage overcapacity in purse seine fisheries. IOTC Rec 16/01 implements a reduction of the authorized use of GPS buoys compared to Res 15/08 (465 instead of 550 GPS buoys per vessel at any time) as well as a limitation of the use of support vessels (that should not exceed 1 for 2 purse seiners) but detailed information on the use of these fishing tools should be provided to scientists in order to evaluate the effects of such decisions.

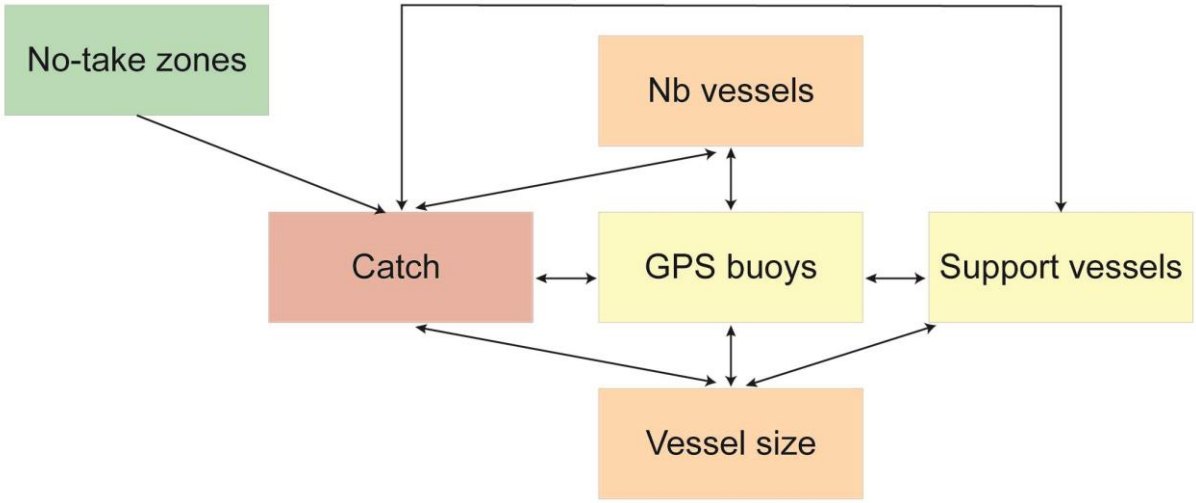

Figure 13: *potential management tools for FOB fisheries. Arrows indicate the interactions between different management solutions and colours indicate the level of restriction.*

To conclude, there was a general consensus of French purse seine skippers that the fishery needed a more appropriate management. Fisheries scientists and environmental NGOs have also called for a better management of FOB fisheries in the Indian Ocean sometimes more than a decade ago (Fonteneau 2003). Integrating scientific and fishers' knowledge like in this study seems a promising tool to prioritize and identify potential management solutions. In the future, similar studies implying more stakeholders of the fishery (NGOs, tuna cannery, fishing companies and managers) in each ocean could be used to achieve a successful Ecosystem Approach to Fisheries.

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Supplementary Information 1: List of management measures relevant to FOB fishing by tropical tuna purse seiners in tuna RFMOs. Note that some measures are not directly related to FOBs but may have an impact on FOB fishing (e.g. catch quotas).

	Tools	IOTC	ICCAT	IATTC	WCPFC
Management plans	dFAD management plans	Yes (Res 15/08)	Yes (Rec 15-01)	No	Yes (CMM 2015-01)
	FAD Working Group	Not yet (Res 15/09)	Yes (Rec 15-02)	No	
Conservation measures	Capacity/effort limitation on FOBs	No	No	No	No
	Catch quotas	YFT (Res 16/01)	YFT+BET (Rec 15-01)	No	YFT (CMM 2015-01)
	Limitation of GPS buoys	Yes (Res 15/08)	Yes (Res 15-01)	No	FOB sets (2015-01)
	dFAD moratorium	No	Yes (Rec 15-01)	Yes (Res C-13-01)	Yes (CMM 2015-01)
	Discard ban (tunas)	Yes (Res 15/06)	No	Yes (Res C-13-01)	Yes (CMM 2015-01)
	Non-entangling dFADs	Yes (Res 15/08)	Yes (Rec 15-01)	Not yet (Res C-13-04)	No
	Biodegradable dFADs	No (recommended)	No (recommended)	No (recommended)	No
	Support vessels	1 for 2 purse seiners (Res 16/01)	No	Yes (Prohibited)	No
Data collection, reporting, control	FAD logbooks	Yes (Res 15/08)	Yes (Rec 15-01)	Yes (Res C-13-04)	No
	Reporting obligation on numbers of dFADs deployed	Res 15/08: DFAD logbooks Res 15/02: support vessels' logbook	Rec 15-01 + FAD WG 2016	Yes (Res C-13-04)	FOB sets (CMM 2015-01)
	Reporting obligation on dFAD fishing sets	Yes	Yes	Yes (Res C-13-04)	Yes (CMM 2015-01)
	Reporting obligation on support vessels	Yes (but not available for scientific purposes)	Yes (but not available for scientific purposes)	No	No
	Onboard observers	100% since 2015	100% since 2015	Yes (Res C-13-01)	Yes (CMM 2015-01)
Other measures (not FOB specific)	Record of vessels	Yes	Yes	Yes	Yes
	Capacity limitation / effort	Yes	Yes (Rec 15-01)	Yes (Res C-02-03)	Yes (CMM 2015-01)

	limitation (general)				

Supplementary Information 2: *detailed guide of interview used in 2013 (in French)*

Thème	Sous-thème	Question à poser
Renseignements sur le patron	*Niveau d'expérience*	**1. Quel a été ton parcours jusqu'à aujourd'hui ?**
		a) depuis combien de temps est-tu patron ? b) depuis combien de temps sur ce bateau ? c) as-tu aussi travaillé dans l'Atlantique ? d) as-tu aussi travaillé pour un armement espagnol ?
Activités type à bord	*Déroulement d'une marée*	**2. Comment se passe une marée type à bord ?** → en t'appuyant sur des zones/saisons ?
		a) combien de temps dure une marée ? b) quelles sont les quantités pêchées ? c) comment les activités changent-elles selon la saison et la zone ? d) quel temps est dédié à la recherche, à la pêche, BL vs BO ? e) collabores-tu avec d'autres bateaux ? (supply, sistership, autre)
Modalités d'utilisation des DCP	*Mise à l'eau des DCP et balises*	**3. Pour toi, qu'est-ce que c'est un DCP ?**
		4. Comment utilises-tu les radeaux et les balises ? → toutes les questions suivantes
		5. Que se passe-t-il au moment de la mise à l'eau d'un radeau ou d'une balise ? → 6
		a) Quelles sont les étapes dans la mise à l'eau ? (avant, pendant, après) b) combien de temps ? à quelle heure ? c) sur 100 objets naturels rencontrés, combien en balises-tu ? d) idem pour les renforcements e) que se passe-t-il lorsque tu rencontres un objet déjà balisé qui pourrait t'intéresser plus tard ? f) sur 100 objets et radeaux balisés par d'autres bateaux, combien de transferts de balise réalises-tu ? pourquoi ?
		6. Quand et comment prépares-tu une mise à l'eau ? → 7,8,9
		a) à quelle heure ? b) de quoi dépend cette décision ? (ce que tu observes autour, un planning pour la marée, une information, une consigne de l'armement) c) qu'est-ce qui rend une zone intéressante pour une mise à l'eau ? (densités d'objets dans la zone, de balises dans la zone, autres bateaux dans la zone, agrégations sous l'objet déjà à l'eau, conditions de courant, présence d'oiseaux et de poissons, fleuves …) d) quelles sont les différences entre zones et saisons ? e) au total, combien de radeaux et de balises mets-tu à l'eau ? f) (selon parcours) d'après ce que tu connais/ton expérience, des différences avec les autres flottes ? g) (selon son parcours) d'après ce que tu connais/ton expérience, des différences dans l'Atlantique ?

Modalités d'utilisation des DCP	*Mise à l'eau des DCP et balises*	**7. Quand les radeaux sont-ils préparés et les balises allumées pour être mis à l'eau ?**
		a) Si la mise à l'eau ne suit pas directement la préparation, pourquoi ? b) Pendant combien de temps à bord avant la mise à l'eau ? c) (expliquer le principe de la classification) j'ai obtenu ces cartes de déploiement, qu'en penses-tu ? sont-elles cohérentes avec tes activités et tes observations ?
	Trajectoires des DCP	**8. Après mise à l'eau des balises/radeaux, quelles sont les étapes jusqu'à la pêche/récupération ?** → 9
		a) La trajectoire d'un radeau/balise est-elle prévisible ? pourquoi ? b) Sur quoi te bases-tu pour la prévoir ? (données en temps réel de courant, dérive d'un groupe de balises, expérience, informations d'autres bateaux) → question 11 c) Utilises-tu les courants pour planifier la dérive ? si oui, comment ? (échelle locale ou grands courants, comparaison trajectoire prévue et réalisée, etc) d) Combien de temps laisse-tu un radeau ou une balise en mer en général ? (min-max) e) Est-ce que ce temps varie selon le type d'objet, de balise, la zone, la saison ? → question 11
		9. Sur BL comme BO, comment prépares-tu les activités de pêche ? → 6, 7, 8, 10, 11
		a) comment se fait la recherche des bancs → 10, 11 b) quand décides-tu de changer de cap ? c) comment est prise la décision de se rendre sur une balise ? d) quand tu cherches une balise, tu continues de regarder les BL et objets non balisés par toi? e) Quand tu cherches des BL, est-ce que tu continues de t'occuper de tes balises dans la zone ? f) quand tu as décidé de visiter une balise, dans combien de cas (sur 100) dévies-tu ta route pour : un autre objet, un BL ? g) ces proportions changent-elles avec les bouées échosondeurs ? (ie peux-tu te permettre d'attendre quand tu sais qu'il y a du poisson sous un objet ?) h) idem question f, en recherche de BL, pour un objet balisé par toi ou un autre type d'objet ?
	Recherche de bancs	**10. De quelles informations disposes-tu pour visiter un objet et préparer un coup de pêche ? Comment s'organisent les activités de recherche ?**
		a) de quels instruments te sers-tu pour chercher des BL ? portée et précision ? b) idem pour les BO c) suis-tu toutes tes balises ou ne tiens tu compte que de certaines ? lesquelles ? combien ? d) y a-t-il selon toi des différences entre les flottes et l'IO vs AO ? e) échanges-tu de l'information avec d'autres bateaux ? qui et quoi ? supply ? f) quelle proportion des DCP partagés entre plusieurs bateaux ? lequel des « propriétaires » pêche ? g) si le bateau pêche avec d'autres : même armement ? même flotte ? raisons personnelles ? h) rôle de l'armement ? y a-t-il des consignes de pêche de sa part ?

<table>
<tr>
<td rowspan="4">Modalités d’utilisation des DCP</td>
<td rowspan="4">Pêche sur BO et BL</td>
<td>11. Quand tu as détecté un banc ou trouvé un objet, quand décides-tu de pêcher ?</td>
</tr>
<tr>
<td>a) Qu’est-ce qui rend un objet ou un banc intéressant ? (quelle quantité, autre)
b) Attends-tu avant de pêcher ? quand ?
c) Pour un radeau, y a-t-il un lien entre temps de dérive et quantité ? composition des captures ?
d) Pour les radeaux rencontrés, proportions suivantes :
<table>
<tr><td rowspan="2"></td><td colspan="2">Balise</td><td rowspan="2">Sans balise</td></tr>
<tr><td>Appartient</td><td>N’appartient pas</td></tr>
<tr><td>DCP</td><td></td><td></td><td></td></tr>
<tr><td>naturel</td><td></td><td></td><td></td></tr>
</table>
e) Quelles sont les différences entre zones et saisons ?
f) Combien de fois mets-tu une balise à l’eau et pêches-tu dessus ? La récupères-tu sans pêche ?
g) La perds-tu ?</td>
</tr>
<tr>
<td>12. Comment répartis-tu ton temps et l’effort entre BL et BO ? → 9, 10</td>
</tr>
<tr>
<td>a) La recherche sur BL et BO se fait-elle sur 2 temps séparés ?
b) L’effort est-il clairement réparti entre BL et BO ou est-il impossible de le séparer ?
c) Quand tu décides de mettre à l’eau une balise et un radeau, tiens tu comptes des BL ?
d) As-tu une préférence pour un mode de pêche ?
e) Si oui, préférence personnelle ou critères économiques ?</td>
</tr>
<tr>
<td>Changements</td>
<td>Technologie et Outils de gestion</td>
<td>13. Y a-t-il eu des changements dans l’utilisation des DCP ?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) De quelle nature et quelle ampleur ?
f) vont-ils durer dans le temps ?
b) Y a-t-il eu un changement dans la quantité capturée ?
c) Dans les captures accessoires ?
d) Dans les zones et saisons d’activité ?
e) Dans la répartition BL/BO ?
f) Dans les stratégies de mise à l’eau / pêche/ récupération ?
g) Plutôt positif ou négatif ?
h) Picolo, Chagos, Somalie : Influence de la période choisie ?
i) respect de la mesure par les autres flottes ?
j) possibilité de contourner la mesure par l’usage des DCP ? quelle participation des armements et des pêcheurs à la prise de décision ?</td>
</tr>
</table>

Supplementary Information 3: *detailed guide of interview used in 2015 (in French)*

Thème	Sous-Thème	Question	Support
Présentation	*Renseignements sur le patron*	**1. Quel a été ton parcours jusqu'à aujourd'hui ?** a) depuis combien de temps es-tu patron ? b) depuis combien de temps sur ce bateau ? c) as-tu aussi travaillé dans l'Atlantique ? d) as-tu travaillé pour un autre armement ?	
Utilisation des balises GPS et des DCP	*Mise à l'eau des balises GPS et des DCP*	**2. Comment utilises-tu les radeaux et les balises GPS ?** → 3 a) comment décides-tu de les mettre à l'eau ? b) En 2013, j'avais posé cette même question à 14 patrons différents, que penses-tu de ces résultats ?	Figure 1 : réponses des patrons en 2013
Utilisation des balises GPS et des DCP	*Mise à l'eau des balises GPS et des DCP*	c) Dans leurs réponses, le choix de la zone/saison semblait être la raison principale pour décider de mettre à l'eau un nouveau radeau/une nouvelle balise. Les saisons identifiées te paraissent-elles cohérentes ? Différences avec tes mises à l'eau/ ce que tu connais des autres patrons/flottes ? d) L'utilisation des courants était en deuxième position dans les réponses des patrons. A l'échelle de la saison, la direction prise par les épaves et la vitesse te paraissent-elles cohérentes ? e) Les zones et les saisons de mise à l'eau sont identiques aux zones et aux saisons de pêche. p.ex. fréquence des transferts.	Figure 2 : saisons de mise à l'eau Figure 3 : courants saisonniers Figure 4 : zones et saisons de pêche
	Augmentation du nombre de balises GPS et de DCP	**3. Combien y a-t-il de radeaux et d'épaves équipées de balises chaque jour dans l'Océan Indien?** → années, zones et saisons	
		a) les entretiens précédents et nos résultats suggèrent qu'il y a eu une forte augmentation du nombre de DCP et d'épaves balisées depuis au moins 2007. Es-tu d'accord avec ce constat ?	Figures 5 et 6 : nombre de DCP français et de toutes les flottes

Utilisation des balises GPS et des DCP	*Augmentation du nombre de balises GPS et de DCP*	b) Entre 2007 et 2013, de 20 à 80 balises par jour et par senneur Français. Ces chiffres paraissent-ils cohérents ? (avec ton utilisation des balises GPS / avec ce que tu connais des autres patrons) c) Entre 2007 et 2013, de 1500 à 7500 DCP par jour dans l'Océan Indien. Ces chiffres te paraissent-ils cohérents ? d) Fin 2014, la Commission Thonière de l'Océan Indien a fixé une limite à 550 DCP par bateau. Quel est ton avis sur cette décision ? Trop restrictif/ pas assez ? Quelles conséquences ? e) les armements français ont prévu d'augmenter leurs balises. Quel est ton avis sur cette décision. Pour quelles raisons penses-tu qu'elle a été prise ? Conséquences ?	
Effort de pêche sous DCP	*Conséquences de l'augmentation récente du nombre de DCP et de balises*	**3. L'augmentation du nombre de DCP est rapide et forte ces dernières années. Elle pourrait se poursuivre à un rythme important dans les années à venir (voir questions 2d à 2e)** **Quelles conséquences ont/pourraient avoir ces changements (positifs ou négatifs) ?**	
		a) les DCP augmentent mais pas les tonnages, comment l'expliquer ? b) Une équipe de chercheurs a montré que lorsqu'on dépasse un certain nombre de DCP, les bancs se dispersent. Que penses-tu de cette hypothèse ? c) As-tu observé des changements dans la taille des bancs ? d) Pêches-tu (volontairement) sur des bancs plus petits qu'avant ?	Figure 7 : tonnages annuels

		e) en 2013, les patrons avaient évoqué leurs pertes de balises avec les courants. Les données permettent d'estimer que 10% des DCP s'échouent et que le nombre total de DCP augmente. Observes-tu les mêmes tendances au cours du temps ? f) Quelles conséquences pourraient avoir ces pertes et ces échouages ? Est-ce important selon toi (d'en tenir compte, de les gérer) ou les impacts sont-ils négligeables (par rapport à d'autres impacts, tout court)	Figure 7, 8 : effort fantôme et échouages
Gestion des impacts de la pêche sous DCP	*Conséquences de la pêche sous DCP / évolutions récentes*	**4. Il y a aujourd'hui beaucoup de discussions autour de l'utilisation des DCP et ses impacts. Quel est ton avis sur ces discussions ?**	
		a) Y a-t-il un risque pour l'état des stocks de thons tropicaux ? Notamment, est-ce que les moyens mis en œuvre pour exploiter ces stocks te semblent modérés / nécessaires / trop importants ? b) Penses-tu qu'il y ait un risque d'augmenter les captures accessoires ? Ou d'augmenter les pêches fantômes de requins soyeux ? (DCP non éco) c) Les DCP modifient l'habitat naturel des thons et pourraient contribuer à une situation de piège écologique (migrations, alimentation, reproduction, etc). As-tu observé des changements qui vont dans le sens de cette hypothèse ? Qu'en penses-tu ? e) Ces impacts te semblent-ils faibles/modérés/importants/trop importants ? f) Y a-t-il d'autres impacts/phénomènes à prendre en compte dans cette réflexion ? Comment les prendre en compte ?	

Gestion des impacts de la pêche sous DCP	*Potentialités de gestion*	**5. Quels seraient les solutions adaptées pour gérer ces impacts ?**	
		a) limiter le nombre de DCP b) limiter le nombre de balises c) limiter les navires supply d) utiliser des zones de fermeture saisonnières (mise à l'eau, utilisation ou pêche sous DCP) e) interdire certaines zones (mise à l'eau, utilisation ou pêche sous DCP) f) autres ?	