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Managing tropical tuna purse seine fisheries through limiting the number of drifting fish aggregating devices in the Indian Ocean: food for thought

Fonteneau[1] Alain and Emmanuel Chassot[2]

Summary

This paper deals with the use of drifting fish aggregating devices (DFADs) in the Indian Ocean and of the potential interest to manage purse seine fisheries through limiting their number. Potential risks associated with a massive use of DFADs are first discussed. Based on new information on the numbers of DFADs released by the French fleet in the 2003-2014 period, this paper estimates the levels and trends of the total numbers of DFADs deployed and active at-sea. It is estimated that the total number of DFADs numbers has been increasing by about 70% since the early 2000s and that they could reach 10,500-14,500 nowadays. A good knowledge of the total numbers of DFADs is urgently needed to better estimate the fishing effort and capacity of purse seine fisheries. Future limitations in the number of DFADs could be a direct and efficient way to reduce fishing effort exerted by purse seiners and their support vessels. Following a precautionary approach, we suggest that IOTC could consider setting a cap on the number of DFADs drifting at-sea and that threshold reference levels could be based on the year 2013, at least to slow down the trend observed in the overall fishing capacity on DFADs. Such measures should be first carefully analysed by an ad hoc IOTC DFAD multidisciplinary working group to ensure their efficient implementation and to allow an improved sustainability of the concerned fisheries.

KEYWORDS: Fishery management, fish aggregating device, purse seining

[1] IRD, UMR 212 EME (IRD/Ifremer/UM2), Avenue Jean Monnet, CS 30171, 34203 Sète Cedex, FRANCE. Alain.Fonteneau@ird.fr
[2] IRD, UMR 212 EME (IRD/Ifremer/UM2), SFA, BP570, Victoria, SEYCHELLES

1. Introduction

Purse seine fishing on artificial drifting fish aggregating devices (DFADs) has been widely developed in all oceans since the late 1980s and early 1990s and has resulted in a major increase in skipjack (*Katsuwonus pelamis*) catch, but also in significant increasing catches of juveniles of bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) (Dagorn et al. 2013, Fonteneau et al. 2013). The increasing use of DFADs concurrently resulted in increasing purse seine nominal catches per unit effort (CPUE) over time (Chassot et al. 2013). Indeed, the nominal effort currently used for computing purse seine CPUEs is based on fishing, searching time or on the number of fishing sets which do not account for the increasing capacity associated with DFAD numbers and technology (Anonymous 2012, Fonteneau et al. 2013).

Despite the major changes in purse seine fishing strategies linked to DFAD-fishing development (i) no major decline in yield-per-recruit of bigeye and yellowfin fisheries, (ii) no major decline in longline CPUEs, and (iii) no recruitment failure for any of the bigeye and yellowfin stocks have been observed worldwide. Different assumptions have been put forward to explain these points, including high natural mortality rate of juvenile tunas and/or high steepness that might be due to significant cryptic fractions of spawning biomass, or compensatory density-dependent effects in recruitment for most tropical tuna stocks (Anonymous 2011).

As a consequence and in the absence of any highly visible and severe impact in the skipjack, yellowfin and bigeye stocks, purse seine DFAD fisheries have been permanently developed since the 1990s in all tropical areas, but without strong management measures taken by tuna Regional Fisheries Management Organisations (RFMOs) to reduce the impact of DFAD fisheries on tuna juveniles and associated fauna. It should be stressed however that closures of targeted DFAD-fishing areas or time area-strata (e.g., moratoria on DFAD-fishing) have been the most frequent management schemes implemented by the various tuna RFMOs and by the IOTC (for a review see Davies et al. 2012). Also, the IATTC banned the use of auxiliary vessels in support to purse seiners as early as 1999 in the eastern Pacific Ocean to reduce the pressure of DFAD fisheries[3]. The effects of time-area closures are difficult to evaluate quantitatively but it would appear that their results have been quite limited in most cases (e.g. Kaplan et al. 2014). The relative lack of efficiency in time-area closures for protecting juveniles of bigeye and yellowfin is likely due to a combination of various factors such as (i) a lack of compliance to the regulation by some fleets, (ii) a too small area closed or a too short duration of the closure, (iii) a redeployment of the purse seine DFAD fishing activities in alternate areas outside the closed strata during the closure and (iv) larger than usual catches on DFADs following the end of the closure (Harley & Suter 2007, Torres-Irineo et al. 2011, Kaplan et al. 2014).

As the efficiency of time-area closures for protecting juveniles of bigeye and yellowfin tunas appears to be limited, alternate measures allowing limiting the impact of DFAD-fishing should be explored. Limiting the numbers of sets on DFADs has been sometimes envisaged but the implementation and control of such prospects remain questionable and limited. Until now, managing the DFAD fishing pressure based on a limitation of the number of DFADs has been seldom envisaged by tuna RFMOs, including the IOTC, with the notable exception of WCPFC (WCPFC 2004, Hurry 2014). It makes sense to assume that the number of DFADs is

[3] IATTC Resolutions on Bigeye Tuna, June 1998 and on Fish-Aggregating Devices, October 1998.

a basic and major component of the DFAD fishing effort and that their reduction would ultimately result in reduced fishing mortality and associated expected ecosystem impacts (see below). The pros and cons of such management scheme should be fully studied by scientists and tuna RFMOs as suggested by Davies et al. (2014). The main goal of this paper is to initiate some preliminary scientific analysis and discussion upon recent trends in DFAD numbers and on this potentially important management prospect in the case of the Indian Ocean (IO) DFAD fisheries. This paper will not discuss the changes in the DFAD technology (e.g. Lopez et al. 2014) nor the potential closures of selected time and area strata or other management prospects of DFADs, as these prospects have been already tackled (e.g. based on the analysis of catch-effort and size data) by various works in each of the tuna RFMOs (e.g. Pallarés & Kebe 2002 for the Atlantic Ocean).

2. Why monitoring and managing DFAD fishing?

2-1-Overview

Although there has not been any evidence of major negative impact following the steady development of DFAD-fishing on tuna stock status, it has been a source of increasing concern in all tuna RFMOs for several reasons that are similar across oceans. First, DFAD-fishing has resulted in substantial increased skipjack catches and associated fishing mortality over the last decades. In addition, the lack of reliable estimates of fishing effort associated with DFAD-fishing has increased the uncertainties associated with the assessment of the status of all skipjack stocks worldwide (ISSF 2012). Furthermore, it has been noted that there was a steady and major decline of skipjack catches in free-swimming schools in most fishing zones of the Atlantic and Indian oceans, concomitantly with increasing catches of skipjack in DFAD sets (Fonteneau et al. 2000, Fonteneau 2014). It is noteworthy that the exact causes explaining such patterns might be due to density-dependent mechanisms linking stock abundance and local density as well as to some change in skipjack associative behaviour and remain to be resolved. Second, DFADs have produced moderate increases of yellowfin catches and major increases of bigeye catches characterized by an average weight close to 5 kg that is well under the optimal size in terms of yield per recruit, and also well under sizes at first spawning, i.e. about 80 cm (~11 kg) and 100 cm (~25 kg) fork length for yellowfin and bigeye, respectively (Sun et al. 2013, Zudaire et al. 2013).

2-2- DFADs producing a decline in the yellowfin and bigeye yield per recruit

For both yellowfin and bigeye, catches of small tunas on DFADs reduce the yield per recruit of each cohort recruited in the fisheries. The development of the DFAD EU and associated flags purse seine fishery has resulted in a major increase in the catch of small YFT in the IO over the last decades. Annual numbers of small yellowfin caught under DFADs have been steadily increasing since 1991, from less than 4 million fishes caught in 1991 to more than 20 million in 2013 (Fig. 1).

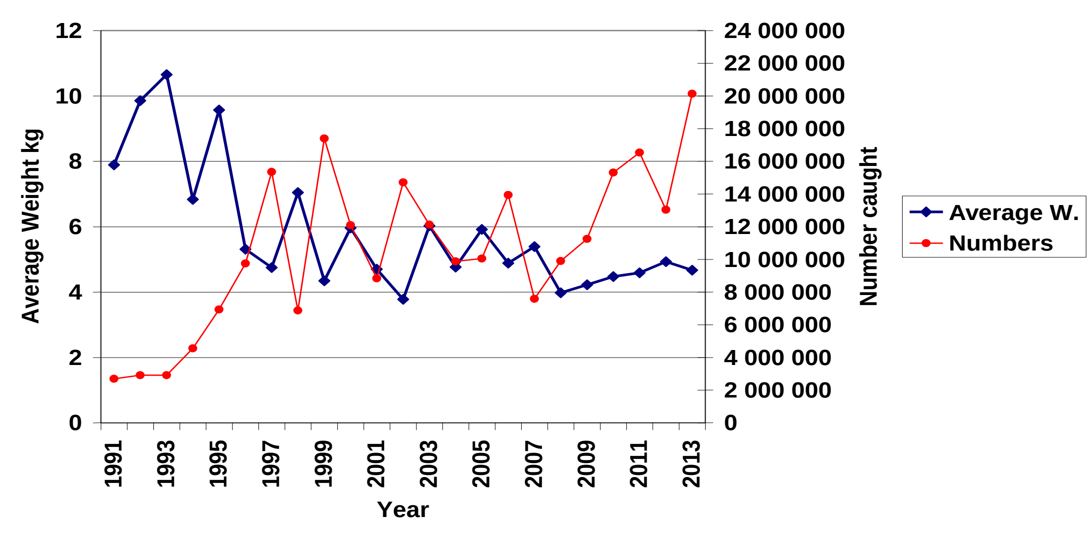

Fig. 1: Number and average weight of yellowfin caught under DFADs in the Indian Ocean by the EU and associated flags purse seine fishery since 1991

The declines in the average weights due to increased DFAD catches is more pronounced for bigeye in the IO as in all other oceans. The numbers of small bigeye (<80 cm) caught under DFADs have been steady increasing since the early 1980s and reaching levels of about 8 million of small bigeye during the last 20 years (Fig. 2b). Such increased catch of small bigeye has produced a decline of the average weight of bigeye landed by the IO fisheries (Fig. 2a), from 35 kg in the early 1980s to about 10 to 15 kg nowadays.

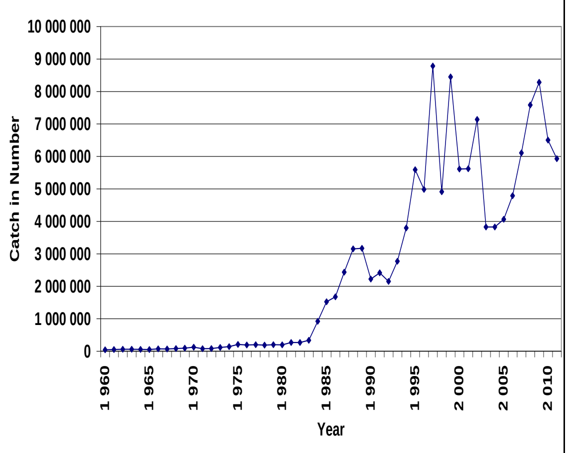

Fig. 2a: Yearly catches of small bigeye under 80 cm (in numbers) in the Indian Ocean *(most catches being caught under DFADs)*

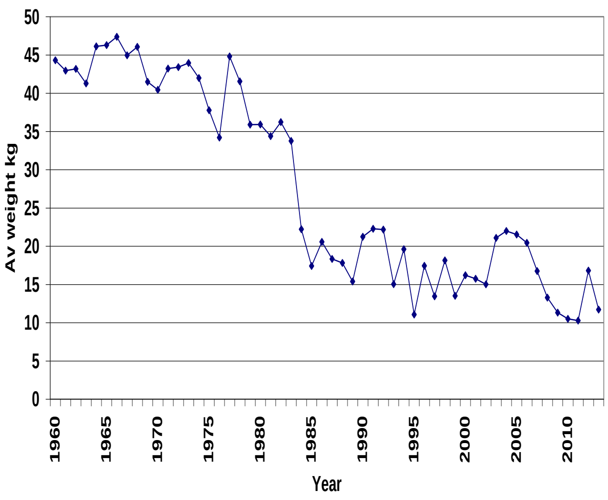

Fig. 2bs: Yearly average weight (kg) of bigeye caught in the Indian Ocean

As a consequence, the average weight of bigeye caught today by the IO fisheries is well under the biological optimal weight of bigeye, i.e. at the level when the biomass of cohort is maximal. Yield per recruit analysis of bigeye shows that the optimal weight of an exploited bigeye stock is around 1 m (i.e. at about 20 kg), then much larger than the 5 kg bigeye generally caught under DFADs. As a consequence, these DFAD catches of small yellowfin and small bigeye reduce the biological productivity of these stocks. They also result in an increased potential interaction between purse seine and longline fisheries, this latter gear mainly catching large sized tunas. Such interactions are specifically exacerbated for stocks estimated to be not far from their MSY levels, as most yellowfin and bigeye stocks today (Juan-Jordá et al. 2011), including in the IO (Indian Ocean Tuna Commission 2012). In such context, the decline of biological productivity of the yellowfin and bigeye stocks due to DFAD fishing should be reduced or at least frozen in most cases. These reductions in the DFAD catches of small yellowfin and small bigeye should increase the expected yield per recruit and resulting MSY of these two stocks.

2-3. DFADs potentially altering some biological characteristics of tunas?

DFAD-fishing has also been suspected to affect the biology and ecology of tuna and other epipelagic fish species that are associated with artificial drifting rafts through the so called “ecological trap” (Marsac et al. 2000). In this hypothesis, it is envisaged that large number of DFADs may alter some biological characteristics of epipelagic populations associated with them such as migration, growth, individual condition, predation and natural mortality. Even if the biological impacts of DFAD-fishing are difficult to assess with certainty (Anonymous 2014)(, some components of such an ecological trap have been supported by various analyses (Fonteneau et al. 2000, Ménard et al. 2000, Hallier & Gaertner 2008, Jaquemet et al. 2011, Wang et al. 2012, 2014).

The evidence that tropical tunas are showing a strong behavioural association with DFADs during long periods of their lives is reinforced by the fact that about 1.5 million t of tuna are currently annually caught worldwide associated with DFADs. As an example of the potential impact of DFAD-fishing on the tuna resources, it can also be hypothesized (as in Fonteneau et al. 2000, and from Fonteneau 2014) that the marked declines in the quantities and CPUEs of skipjack caught in free swimming school sets since 1990, and especially during recent years in the Atlantic and Indian oceans, could be widely due to the increased numbers of DFADs (**Fig. 3**).

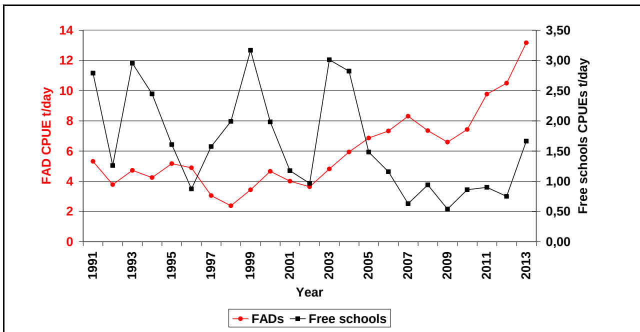

Fig. 3a. Annual time series of CPUE for skipjack caught on free swimming schools and DFADs in the EU and associated flag purse seine fishery in the Eastern Atlantic (t per fishing day)

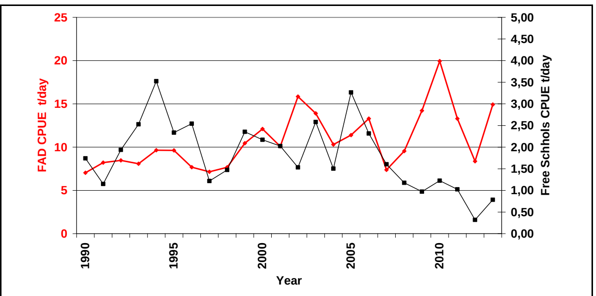

Fig. 3b. Annual time Yearly skipjack free schools and FADs CPUEs of the EU and associated flags purse seine fishery in the Indian Ocean

Furthermore, DFAD-fishing might also alter skipjack reproduction through reducing spawning potential. This assumption is based on the fact that skipjack do not keep in their flesh the fatness that will allow them to spawn (Grande 2013). As a consequence, skipjack spawning appears to be widely dependent on its short-term feeding. The limited food available to skipjack under DFADs might not be sufficient to feed the large biomass of tunas associated with DFADs, as shown by the large percentage of fish described with empty stomachs (Roger 1994, Ménard et al. 2000, Jaquemet et al. 2011) and their poor individual condition as compared to free-swimming schools (Hallier & Gaertner 2008, Robert et al. 2014). Such skipjack in poor condition might then not have accumulated enough energy to efficiently spawn. Assuming no regulation in the future, and consequently that all skipjack could be living in association with a very large number of DFADs, this situation could potentially reduce the spawning potential of the skipjack populations.

2-4. DFAD producing increased accidental mortality of various species: sharks, turtles and other species

DFAD fishing results in **s**ignificant bycatch of undesired sensitive species such as sharks, turtles, small tunas, and other fish species that can be discarded dead at-sea (Amandè et al. 2010, 2012, Hall & Roman 2013). Observer data have shown that there was most often some bycatch under DFAD. Typical discard rates are for instance close to the average levels of 5. 8% estimated in the Indian Ocean, when the discard rate of bycatch was estimated at only 1.2 % for free schools sets. This amount of discarded bycatch associated with DFADs is low compared to many bottom fisheries (Kelleher 2005), but it includes some sensitive and emblematic species such as turtles and sharks. It is noteworthy that the accidental mortality of turtles due to DFADs has been shown to be low in the Atlantic and Indian oceans, with more than 75% of them being released alive (Bourjea et al. 2014). In addition, most DFADs were until recently equipped with hanging nets to attract more tunas and reduce drift. However, various specific observer studies have shown that turtles and sharks were sometimes caught in net meshes. These accidental fishing mortalities of entangled turtles and sharks are often “cryptic”, being most often unnoticed by conventional observer programs and taking place during the entire “floating life” of each DFAD, even when DFADs have been lost by their owners, or/and drifting outside fishing grounds of purse seiners (Chanrachkij & Loog-on 2004, Anderson et al. 2009). This source of cryptic accidental mortality of sharks due to DFADs was estimated to be high in the Indian Ocean (Filmalter et al. 2013). New DFAD designs without hanging nets (Franco et al. 2009) have been recently developed and implemented on many purse seiners to reduce this ghost mortality, but to an unknown degree. Percentage of DFADs that are still equipped with potentially entangling nets is probably low today, but this hypothesis would need to be validated by at sea observations (for instance by observers). Furthermore, the real conditions of the nets that are hanging under the DFADs should also be checked several month after their setting at sea, as their long term status remains widely unknown.

2-5- DFADs a source of marine pollution

Finally, DFADs may result in some pollution of oceanic bottoms due to sinking and ending up on beaches and coral reefs. The massive release of DFAD observed since the early 1990s in most purse seine fisheries is probably a source of pollution, both in the bottom of oceans and also in coastal areas, as all the DFADs build today contain a majority of non biodegradable components (such as ropes, plastic cans and nets that will need century to disappear). This dumping is probably against the London Convention (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972, commonly called the "London Convention" or "LC '72"). This convention was an agreement to control and reduce pollution of the sea by dumping and to encourage regional agreements supplementary to the Convention. Its 1996 protocol also specifies that “the Parties are obligated to prohibit the dumping of any waste or other matter that is not listed in Annex 1 (”the reverse list”) of the 1996 Protocol”. Furthermore, large numbers of DFADs may also sometimes increase navigational hazards and risks, especially for small vessels (fishing and sailing vessels).

3. An overview of FAD fisheries in the Indian Ocean

It should be noted and kept in mind that there is a marked heterogeneity in DFAD fishing between flags. In the IO, 3 main groups of fleets could be identified:

- French purse seiners have been always showing catches on logs and DFADs that were dominant over free schools catches: an average of 59% of DFAD catches during the 1984-2013 period. This rate of DFAD catches has been increased during recent years, reaching 68% during recent years (period 2009-2013)
- Spanish purse seiners have been always showing catches on logs/DFADs that have been dominant over free schools catches: an average of 64 % of FAD catches during the 1984-2013 period. This rate of FAD catches has been increased during recent years, reaching 83 % during recent years (period 2009-2013). Similar rates of DFAD catches have been also observed for the Seychelles purse seine fleet (owned by Spanish companies and ran by Spanish crews) developed since 1997. The yearly percentages of DFAD associated catches observed for these 3 flags are shown by Fig. 4.

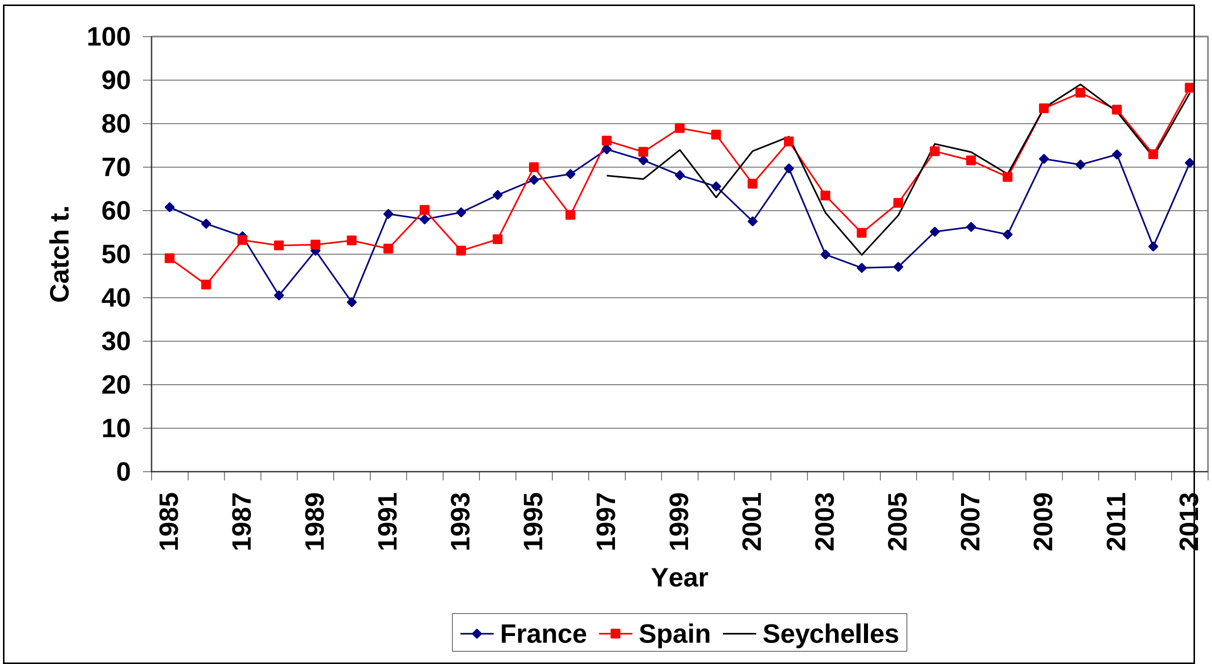

Fig. 4: Percentage of DFAD associated catches of the French, Spanish and Seychelles purse seine fisheries in the Indian Ocean

This figure is well showing the marked divergence observed between French and Spanish-Seychelles rates of FAD catches since the end of the 1990s, and since 2001 the great similarity between the average percentages of DFAD catches in the Seychelles and Spanish flags purse seiners.

- Purse seiners that have been or are still fishing in the Indian Ocean under various flags (Japan, Belize, Italy, Panama, Thailand, Russia, Korea, Iran, Mauritius, etc.) that are most often showing high rates of DFAD associated catches. Among those fleets, the only one that has been well followed in term of its DFAD catches has been the Japanese fleet: this fleet has been catching significant tuna catches (over 15,000 t) in the eastern IO during the early 1990s, an average 68% of these catches being declared under DFADs. Since 1996, Japanese purse seiners are catching a much lower amount of tunas entirely caught associated to DFADs (<5,000 t), and these vessels have been active only in the Eastern IO.

The proportion of DFAD catches was similar between French and Spanish purse seiners during the 1980s, slightly over 50% of DFAD catches, and steadily increasing during the 1990-2000 period (**Fig. 4**). The highest proportion of DFAD catches was observed since 2009 for all the fleets.

It must also be noted that in the IO, Spanish-Seychelles and French purse seiners are showing characteristics that are widely distinct in terms of vessel sizes (**Fig. 5**).

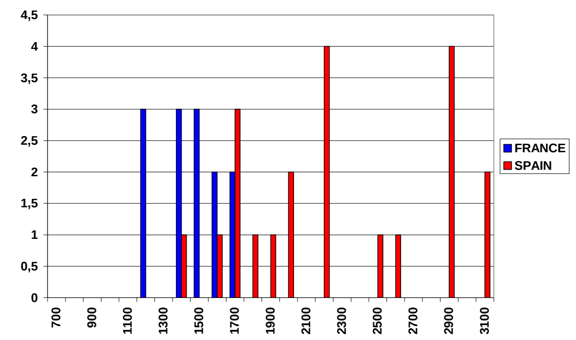

Fig. 5: Distribution of purse seiners by class of carrying capacity of their wells, for French, Spanish+Seychelles purse seiners active in the Indian Ocean in 2013

The average capacity of French purse seiners wells is close to 1,400 m^3, and close to 2,200 m3 for Spanish-Seychelles purse seiners. The structural marked difference in the levels of DFAD catches of the French and Spanish owned fleets is also due to the fact that Spanish and Seychelles purse seiners are supported by an active fleet of support vessels allowing to seed at sea and to manage a much larger number of DFADs. The fleet of support vessels has been permanently used by the Spanish and associated flags fleet since the late 1990s, mainly in order to seed new DFADs and to control the levels of tuna biomass under the DFADs of its purse seiners. This fleet is currently composed of 13 vessels, while French purse seiners do not use any supply vessel in the Indian Ocean. It is noteworthy that 2 of the support vessels were used as anchored FADs on the Travin Bank for several years. The major structural difference in the French and Spanish-Seychelles purse seiners in the targeting of DFADs is also well shown by the average yearly catches on DFAD caught by each average French and Spanish (and associated flags) purse seiners (**Fig. 6**).

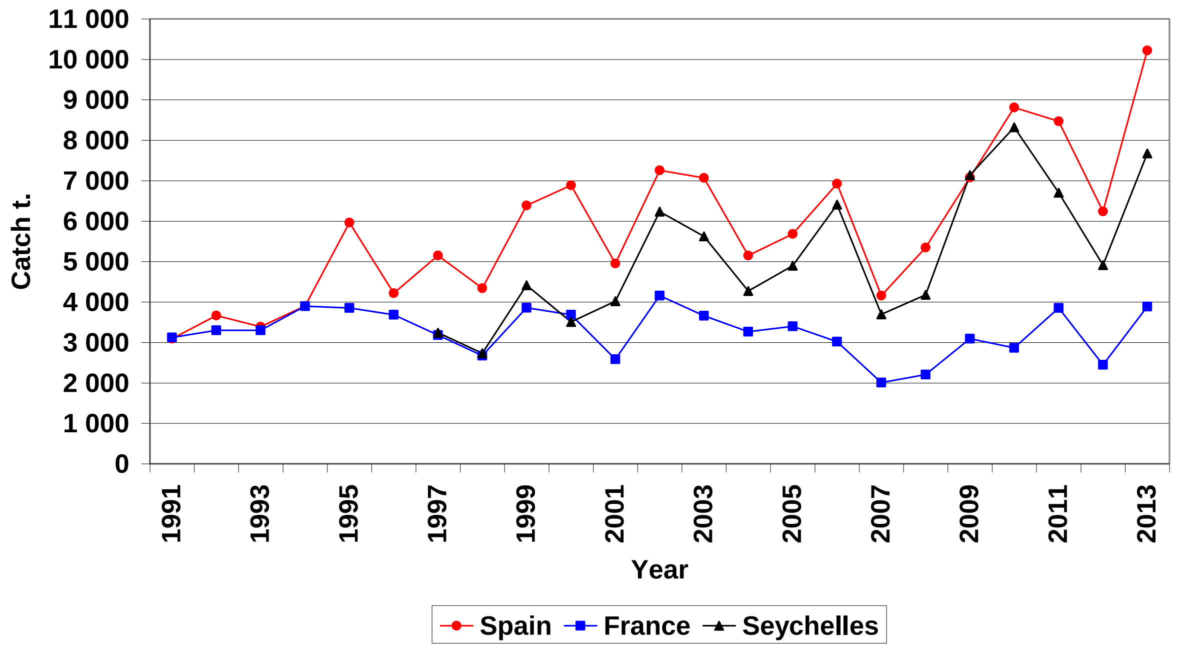

Fig. 6: Yearly catches on DFADs by average French, Spanish and Seychelles purse seiners in the Indian Ocean during 1991-2013

This figure shows the differences in absolute levels and trends of the DFAD associated catches of individual vessels belonging to each of these 3 fleets: average Spanish and

Seychelles purse seiners catching during the last 10 years much more tunas on DFADs than an average French purse seiner: showing an average ratio of 2.0 between the average yearly DFAD catches of French and Spanish-Seychelles purse seiners during the last 11 years. It should also be noted that at its beginning, yearly rates of DFAD tunas caught by the Seychelles fleet was similar to the French purse seiners, while since 2001 they are similar to Spanish purse seiners. This change is simply due to the fact that during the early years, the Seychelles flag was used by some French purse seiners, and later by some Spanish purse seiners.

The size of purse seiners is an important factor in determining the fleet fishing power on DFADs and its fishing strategy: very large purse seiners need to catch more tunas than small vessels in order to compensate their larger investment and higher running costs. DFAD-fishing may then be for them the only way to obtain high catch rates throughout the year and produce the required high levels of catch (because the number of free schools available is limited by “mother nature” and because they are difficult to catch, when DFAD schools can be “artificially created by DFADs seeding” and later on, they are quite easy to catch. Overall, the marked difference in the proportion and magnitude of DFAD catches of purse seine fishing fleets is a critical factor to consider with regards to management: most Spanish companies tend to give high priority to DFAD fishing and high level of catches dominated by skipjack, while French companies tend to maintain a more balanced equilibrium between free schools catches dominated by large yellowfin and DFAD fishing.

However, as the purse seine catches are always made with a combination of FAD and free schools catches, it is also interesting to follow the yearly catches caught on free schools by each purse seiner depending of its flag (**Fig. 7**).

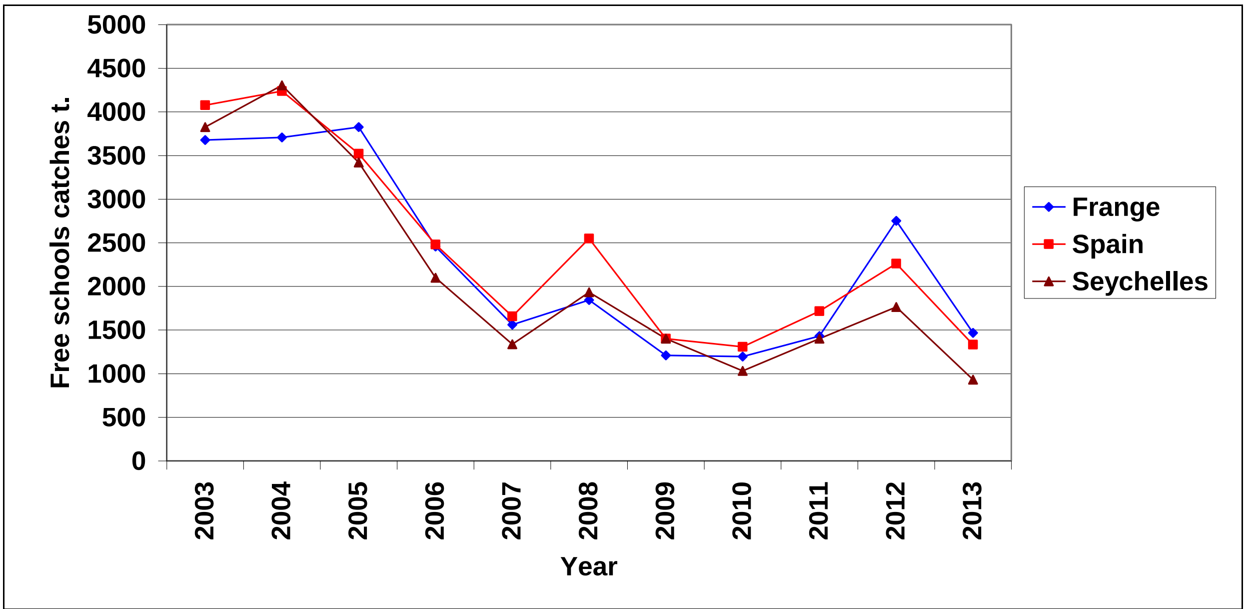

Fig. 7: Yearly catches on free swimming schools by average French, Spanish and Seychelles purse seiners in the Indian Ocean during the studied period 2003-2013

This figure shows that the yearly levels of free schools catches were nearly identical each year for each category of purse seiners. This result is widely distinct from the permanent heterogeneity observed in DFAD fishing. Figures 6 and 7 show that even when the Spanish and Seychelles purse seiners are heavily targeting DFADs, they also permanently and efficiently maintain a high level of fishing effort targeting free swimming schools.

4. Trend in numbers of active DFADs in the Indian Ocean

4.1. Quantifying DFAD numbers

The numbers of DFADs is an important topic that has been often discussed in the analysis of tropical tuna fisheries, but unfortunately this information is seldom available. In the IO, detailed information on the number of DFADs deployed has been requested by the IOTC resolution 12/08 since 2012. However, the information appears incomplete and heterogeneous between fleets and therefore limited for scientific analyses. Baske et al. (2012) proposed an estimated numbers of DFADs active in each ocean, but these estimates were widely uncertain and variable depending upon the source of information used, the best data set being obtained in the IATTC area because of the 100% of observers on the purse seine fleet. In the IO, they gave a conservative estimate of 7,600 DFADs deployed annually. The lack of information on the numbers of DFADs is probably due to a combination of factors such as: (i) The confidential nature of this sensitive information that until recently was not legally requested by tuna RFMOs (and rather for compliance than for scientific purpose), (ii) The complexity of collecting and using an index representing the “numbers of FADs” which can be expressed in different forms such as:

(1) Total numbers of **new buoys** and DFADs (of all types) **released yearly**/monthly by each fleet and by their associated support vessels; this number is for instance the number of new buoys bought during the year by each fleet.

(2) **Average numbers of active DFADs in the fishing zone** that have been followed daily by each purse seiner; this number is for instance an average (daily, monthly or quarterly) of the numbers of active DFADs that are followed by each purse seiner on its computer screen,

(3) Average numbers of lost DFADs that are still active, i.e. DFADs that have been drifting outside the fishing zone (same information, but for DFADs that cannot be fished) but that still transmit information on position to their mother boat.

It is not clear if the comprehensive data on DFADs that have been requested by the IOTC resolution 13/08 through DFADs management national plans will allow to estimate these 3 basic indicators concerning the numbers of DFADs; these general indices are difficult to estimate because of various cumulative reasons: (i) some DFADs may be shared between various purse seiners from the same tuna owner company or by a given group of vessels, (ii) there is a permanent flow of electronic buoys that are successively activated or deactivated and transferred from one DFAD to another, each DFAD being potentially moved to another location, (iii) DFADs are frequently stolen through buoy transfer, and buoys of origin are still active but brought back to port where they are often recovered later by their owner.

As a consequence, while the number of active purse seiners, their nominal fishing efforts and their catches are now quite well monitored by tuna RFMOs including the IOTC, the numbers of active and deployed DFADs remain today very poorly known following the previously described rules (keeping in mind that the numbers of buoys installed on DFADs, the only data that has been released by Spain are of very little interest).

4-2: Numbers of buoys: data available for French purse seiners

The number of buoys annually used per vessel has been available for the French purse seine fleet since 2004, and the number of active and deployed buoys has been known since 2010 through automatic quarterly reports generated on a vessel basis by the communication satellite companies in charge of managing purse seiners signal sent by buoys (**Table 1**). This new data set was recently submitted to the CECOFAD program data base by ORTHONGEL, the French association of tuna purse seiners owners. Yearly numbers[4] of purse seiners active in the French, Spanish and Seychelles fleets have been taken from Chassot et al. (2014), while the catch data on DFADs caught by each fleet was obtained in the IOTC catch and effort file by 1° square.

Table 1. Numbers of DFADs used by French purse seiners: seeded yearly and active ones on a quarterly basis, number of purse seiners and total catches on DFADs

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

The average yearly catch of the French fleet per each buoy deployed was estimated based on the information on the yearly DFAD catches by French purse seiners and the yearly number of buoys deployed (**Table 1).** These estimated DFAD catches per each buoy deployed would have been showing a marked decline between the early period studied (average of 35.4 t per each DFAD seeded during 2003-2007) and recent years (average <20 t per DFAD seeded during 2010-2013).

The data on French DFADs also allows following the seasonality of DFADs and shows that there was no seasonal pattern in the number of DFADs monitored by French purse seiners during the period 2011-2013 (**Fig. 8**).

[4] Number of purse seiners used are the numbers weighted by their time of activity under the flag and in the Indian Ocean

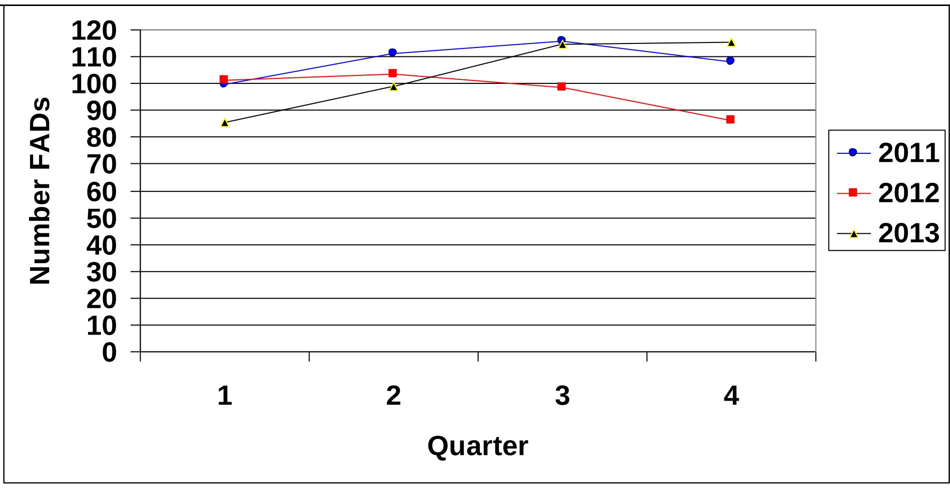

Fig. 8: Quarterly numbers of DFADs monitored by an average French purse seiners during the 2011-2013 period

4-3: Numbers of buoys: data and hypotheses concerning the other fleets

Various converging sources of observations, at-sea and in the landing ports strongly indicate that the numbers of DFADs active at-sea and deployed by the Spanish and Seychelles fleets, including by their support vessels, are much higher than for French purse seiners. However and unfortunately, the numbers of DFADs seeded yearly or monitored by these fleets are not yet available. Such data have started to be collected for Spanish purse seiners since 2011 within the Spanish FAD management plan (Delgado de Molina et al. 2013). Some data on the number of DFADs have been already submitted by Spain to the IOTC, but this data set only covers the years 2010 to 2012 and it does not allow following the numbers of new buoys or the average number of buoys that have been followed by the Spanish fleet during this period. To our knowledge, there was no data submitted by Seychelles on its numbers of DFADs released.

The data on Spanish DFADs also allows following the seasonality of DFADs that have been followed on a quarterly basis by Spanish purse seiners during the period 2010-2012 **(Fig. 9**).

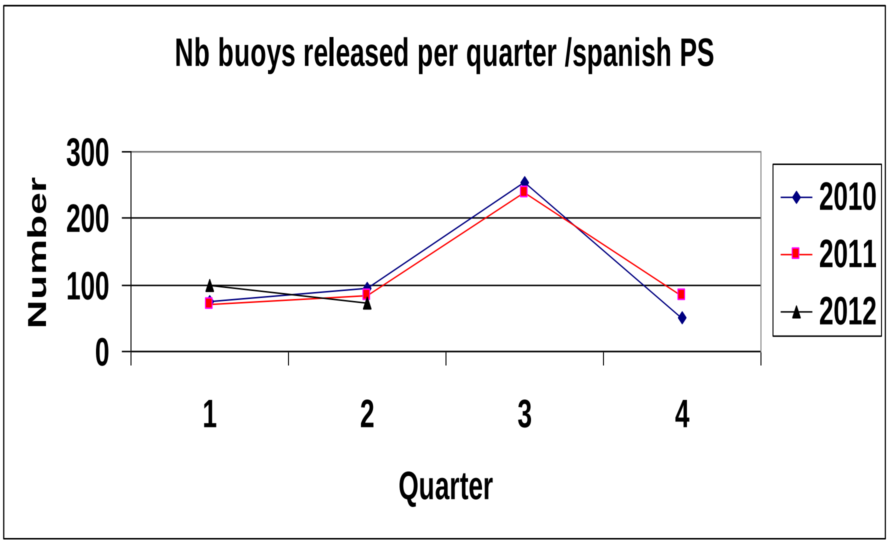

Fig. 9: Quarterly numbers of DFADs deployed by an average Spanish purse seiners during the 2010-2012 period

Figure 9 is showing a marked seasonality in the numbers of DFADs that have been seeded by Spanish purse seiners during this period: maximum numbers of DFADs being seeded each year each 3rd quarter (54% of the total numbers of DFADs seeded during the period being observed during the 3rd quarter. This pattern would remain rather strange as the DFAD catches by the Spanish fleet during the 3rd and 4th quarters of this period was at an average level of 26% of its yearly catches (but showing a peak in September and October of each year). Monthly total catches on FADs taken by Spanish purse seiners during this period are shown by figure 10.

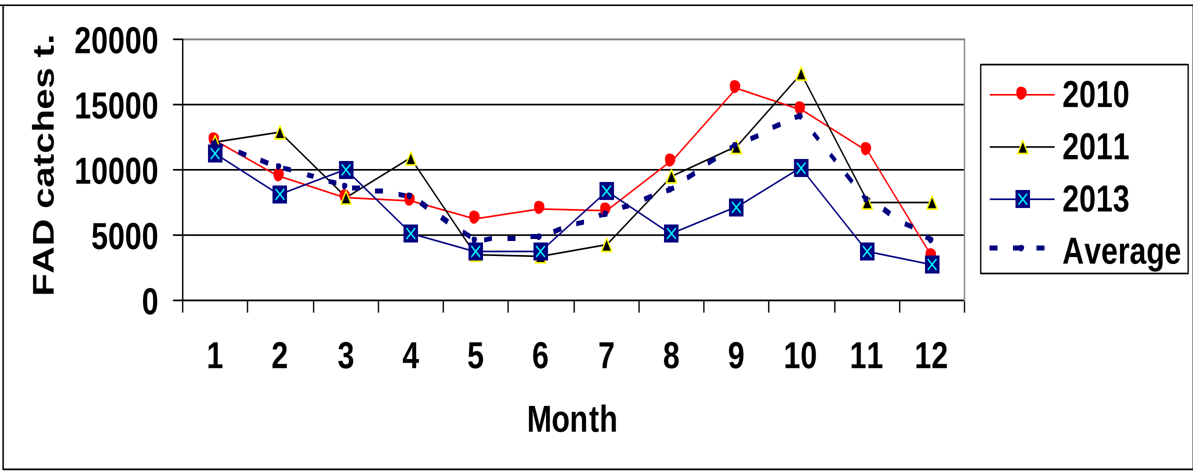

Fig. 10. Monthly catches on FADs by Spanish purse seiners in 20010, 2011 and 2012 (and average)

In this absence of sufficient data concerning our 2 series of FAD numners, these numbers of Spanish and Seychelles DFADs can be estimated by 2 methods:

(1) Hyp. RF1: It can be hypothesized that the higher DFAD catches are in proportion of the larger number of DFADs seeded yearly (and fished daily) by the Spanish-Seychelles fleet and its support vessels. In this hypothesis,

the numbers of DFADs seeded per each Spanish purse seiner could be estimated at an average level of being **1.7** times more important than for the average French purse seiner, based on the average ratio of DFAD yearly catches per vessel during the last 5 years (period 2009-2013). This hypothesis that DFAD catches per vessel are proportional to their number of DFADs remains of course widely questionable because of various reasons (e.g. distinct fishing strata or rates of stolen buoys).

(2) Hyp. RF2: It can also be estimated, as it was estimated in 2007 by Moreno et al. (2007) and in 2011 by Guillotreau et al. (2011), that each Spanish-Seychelles purse seiner has been seeding each year (including the DFADs seeded by supply vessels) 3 times more DFADs than an average French purse seiner.

Based on these 2 hypotheses RF1 and RF2, the numbers of Spanish and Seychelles DFADs deployed by vessel and total was tentatively estimated (**Tables 2-3**).

Table 2: Numbers of DFADs estimated for the Spanish flag purse seiners in our 2 hypotheses RF1 and RF2.

Year	Nb PS	FAD catches	Catch /PS	Nb FADs RF1	Nb FADs RF2	Nb FADs /PS RF1	NB FADs /PS RF1
2003	15,8	111 717	7071	3 202	4 743	203	300
2004	16,4	84 420	5148	3 116	4 616	190	281
2005	19,8	112 488	5681	4 237	6 277	214	317
2006	21,4	148 211	6926	3 581	5 304	167	248
2007	19,4	80 663	4158	3 910	5 791	202	299
2008	15,7	83 933	5346	3 750	5 555	239	354
2009	13,2	93 427	7078	3 048	4 514	231	342
2010	12,9	113 622	8808	4 734	7 012	367	544
2011	12,8	108 388	8468	5 123	7 588	400	593
2012	13	79 213	6093	4 739	7 020	365	540
2013	13	129 674	9975	5 003	7 410	385	570
Average 2003-2013	16	104 160	6 796	4 040	5 985	269	399
Average 2010-2013	13	107 724	8 336	4 900	7 258	379	562

Table 3: Numbers of DFADs estimated for the Seychelles flag purse seiners in our 2 hypothesis RF1 & RF2.

Year	Nb PS	FAD catches	Catch /PS	Nb FADs FR1	Nb FADs RF2	Nb FADs /PS RF1	NB FADs /PS RF1
2003	7,8	43 846	5621	1581	2341	100	148
2004	9,7	41 453	4273	1843	2730	112	166
2005	10,5	51 418	4897	2247	3329	113	168
2006	9,3	59 605	6409	1556	2305	73	108
2007	9,9	36 572	3694	1995	2955	103	152
2008	9,2	38 438	4178	2198	3255	140	207
2009	8,0	57 116	7139	1847	2736	140	207
2010	8,1	67 420	8323	2973	4403	230	341
2011	7,8	52 280	6703	3122	4624	244	361
2012	8,0	36 829	4604	2916	4320	224	332
2013	8,0	49 882	6235	3079	4560	237	351
Average 2003-2013	9	48 624	5 643	2 305	3 414	156	231
Average 2010-2013	8	51 603	6 466	3 022	4 477	234	346

Figure 11 is showing the average catch per each new buoy seeded yearly, as observed for French purse seiners and as estimated for Spanish and associated flags purse seiners in our previously described hypotheses.

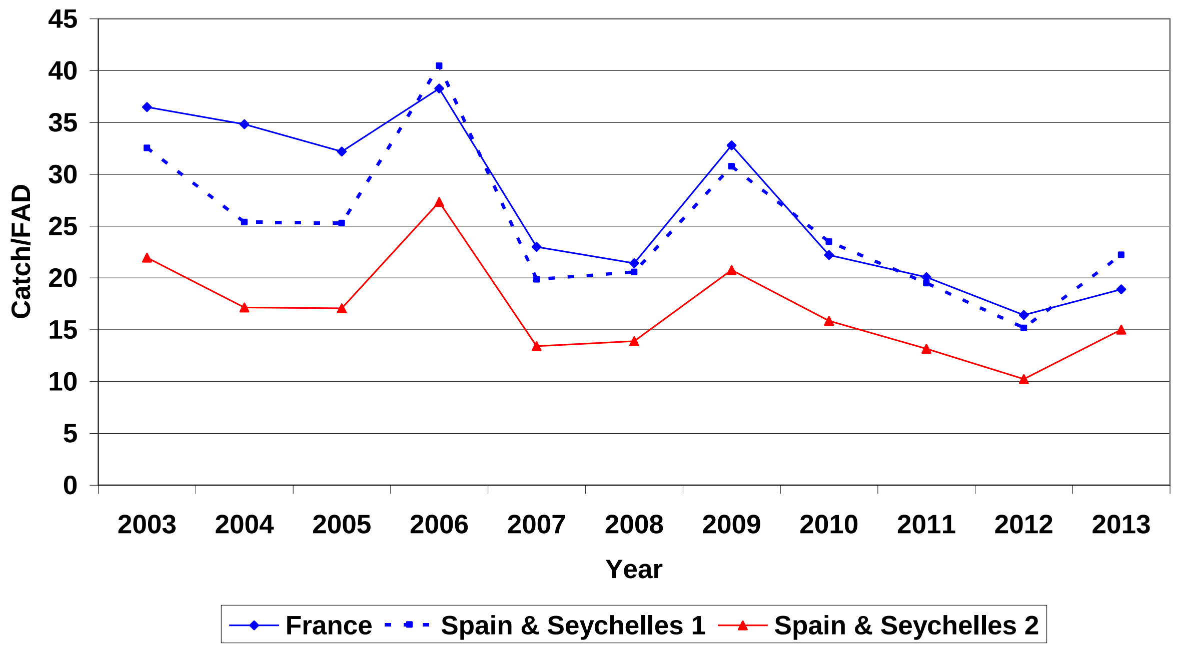

Fig. 11: Average yearly catch per deployed buoy observed for French purse seiners and estimated for combined Spanish and Seychelles purse seiners (based on our 2 hypotheses RF1 and RF2) in the Indian Ocean.

There was no data on the numbers of DFAD used submitted to the IOTC by the various other fleets of purse seiners fishing on DFADs during recent years (Japan, Belize, Panama, Thailand, Korea, Iran, Mauritius, etc.). The numbers of DFADs seeded by these purse seine fleets are not estimated in this preliminary work, but they should of course be estimated in future studies based on the total numbers of DFADs.

Based on this dataset and on our hypotheses, it could be estimated that the total numbers of new buoys released yearly by French, Spanish and Seychelles purse seiners has been following the curves shown by figure 12.

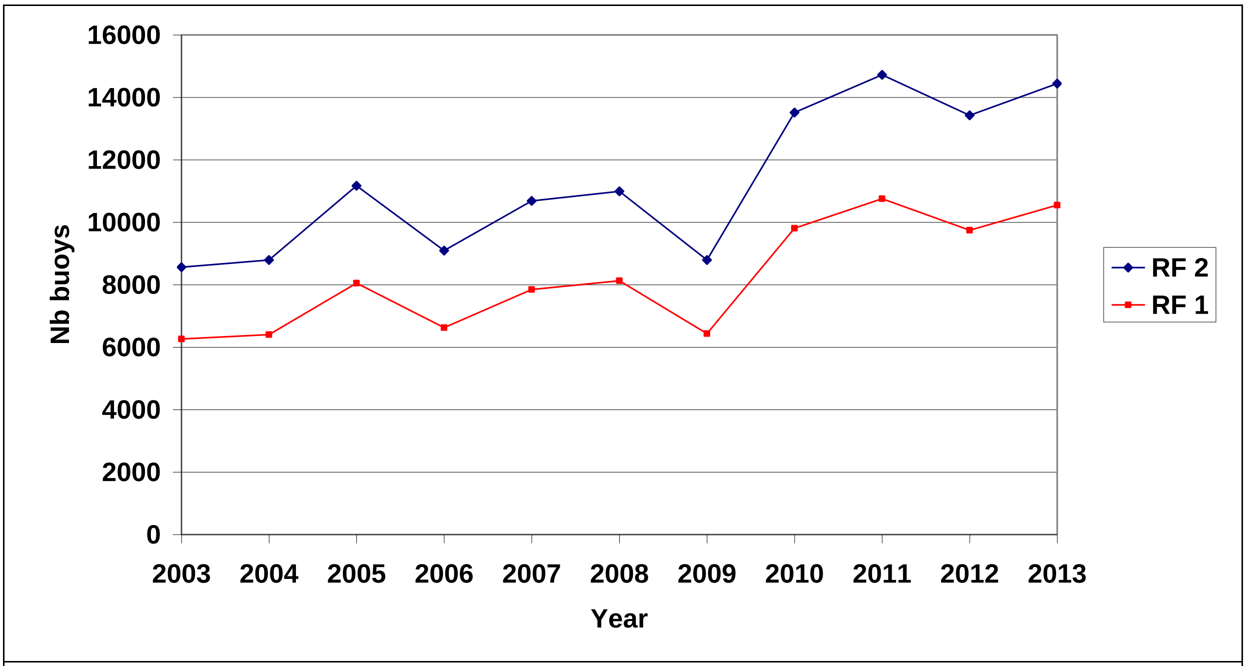

Fig. 12: Estimated total numbers of new buoys released yearly by French, Spanish and Seychelles flag purse seiners

Based on these data and assumptions, the estimated total numbers of DFADs released yearly in the western Indian Ocean by all the EU and Seychelles purse seine fleets could have increased from 6,200 or 8,500 FADs in 2003 to 10,500-14,500 DFADs in 2013, then showing an estimated 70% increase during this period. Furthermore, based on the 2013 French data concerning DFAD numbers seeded and that have been followed by French purse seiners, it could also be estimated that the average numbers of active DFADs followed daily by EU and Seychelles purse seiners in the Indian Ocean in 2013 would be in a range between 4,100 and 7,000 FADs.

4-4- Overview and discussion concerning FAD numbers in the Indian Ocean

Our estimates of DFAD numbers are characterized by major uncertainties and would be improved by: (i) The collection of data on the numbers of buoys deployed through seeding and transfer as well as information on the number of DFADs monthly[5] monitored by all major purse seine fleets of the IO and (ii) a wider range of alternate hypotheses and methods

[5] Quarterly, monthly, weekly or daily numbers of FADs that are followed by each purse seiner would all be OK; the important point is to know this average number of FADs that are active and followed by purse seiners

allowing to better estimate the uncertainties associated with the number of DFADs used by each fleet. These uncertainties have been already noted and discussed by Baske et al. (2012), taking note that our estimated numbers of DFADs presently seeded are well above their average estimates. Recently, Scott & Lopez (2014) assumed that Spanish and French purse seiners would currently release the same average numbers of DFADs, i.e. 180 per year. These figures as well as the assumption of similar strategy between the two fleets are not supported by any of the published analyses or by testimonies from skippers.

One of the serious limitations in our work is that the basic data used concern the average catch per vessel caught on DFADs. A standardized catch rate on DFAD per vessel based on logbook data should preferably be computed in the future. Based on current available data and knowledge, our preliminary conclusion would be that, although the present numbers of DFADs (seeded or active) in the IO are still widely uncertain, our estimated numbers are possibly somehow indicative of the absolute levels and of their major increase over the last decade. We argue that our estimate of a 70% increase may be representative of the overall increase of DFAD numbers developed during recent years in the IO by the studied fleets. It should also be noted that the increases in the numbers of DFADs deployed by purse seiners estimated or observed in the Indian Ocean during recent years are not unique. Larger rates of increase in the DFAD numbers have been simultaneously observed in the Atlantic ocean (Fonteneau et al. 2014) and also in the Eastern Pacific, where the number of deployed DFADs estimated by the IATTC has been multiplied by a factor of 3.3 during the period 2005-2012.In the Eastern Pacific Ocean, 4,300 DFADs were seeded in 2005 and about 14,000 in 2012 (Martin Hall *pers. com.*).

The estimated increase in the number of DFADs can be explained by various combined factors:

1) The increased value of skipjack in the recent years. The average skipjack prices corrected for inflation at the canneries were multiplied by 2 between 2004-2006 and 2011-2013 (ICCAT 2014, FFA Fisheries Development Division.). This was a strong incentive for purse seine fishing companies to catch more skipjack during that period, and the best/only way reach this target was to invest in the seeding of more DFADs.
2) The increased efficiency of DFADs equipped with echo-sounders: when this equipment was very rare 10 years ago, echo-sounders appear to be very common today on most DFADs. Although there was no detailed study in the IO on this topic, the IATTC work has showed that the average catch of DFADs sets in the EPO was increased by 25% for each DFAD equipped with an echo-sounder during recent years (2011-2013) (M. Hall *com.pers.*).
3) The large proportion of large purse seiners with a carrying capacity over 2,000 m^3 (i.e. 1,500 t of tuna) in the Spanish-Seychelles fleet operating in the IO (**Fig. 3**).

These 3 factors are probably the main reasons that have recently accelerated the deployment of DFADs during recent years in the IO, as well as in other oceans, keeping in mind the fact that the declining prices of skipjack observed since the end of 2013 could reduce this tendency in a near future.

4.5. Numbers of DFADs: an indicator of nominal DFAD fishing effort?

It is currently difficult to estimate an accurate "DFAD fishing effort" solely based on searching/fishing time or on the numbers of DFAD sets, particularly when the number of

DFADs are continuously increasing. Another difficulty is due to the fact that all purse seiners are always "keeping an eye on free swimming schools" and on natural logs or DFADs belonging to other fleets, even when their main activities consist in targeting their own DFADs. This conclusion is well supported by the similar yearly catches on free schools obtained each year by the 3 flags studied (**Fig. 7**). Whatever the difficulty to reallocate the part of the fishing day devoted to a specific fishing mode, a good knowledge of the numbers and density of DFADs would likely provide, in addition to the various sources of information already available on DFAD fishing effort (such as fishing times, numbers of DFAD sets, catch per set, etc.), valuable indicators on DFAD fishing pressure. These numbers should be first examined independently, and eventually incorporated in normalized CPUEs models, preferably in addition to the present knowledge concerning searching time and set information.

We propose that the following 2 basic indicators of DFAD numbers should be obtained each year for each purse seine fleet: (1) Total numbers of new buoys deployed yearly (2) Average numbers of active DFADs, i.e. average number of DFADs monitored on a daily or monthly basis by purse seiner for each fleet and when possible, this basic indicator should also be stratified in 2 categories: number of active DFADs monitored within the fishing zone and DFADs that are still monitored by the purse seiners but outside its fishing range (DFADs stolen by another boat, and then lost for the purse seiner owner of the DFADs). These sets of DFADs indicators would clearly help to measure the trend in the fishing pressure of DFADs within purse seine fishing grounds and to evaluate the average density of DFADs in the area exploited by the purse seine fishery, this parameter being important to condition the DFAD CPUEs, DFAD catches and average catch per DFAD set. The statistical requirements of the IOTC should be clearly requesting to each CPC to provide these indicators on their DFAD activities, and these data should cover all the purse seine fleets and their support vessels.

5. Reasonable or optimal numbers of DFADs?

There is probably no hope to estimate and define an "ideal maximum number of DFADs" that should be used in each fishery and ocean. There will never be in the management of DFADs the equivalent of a MSY based on the results of statistical of stock assessment models that are well accepted by scientists and Commissioners. Then, any potential maximum number of DFADs deployed by purse seiners should be based on a wide range of scientific and bio-economic information on the stocks and fisheries. This choice can only be made following a precautionary approach, keeping in mind that today most, if not all, DFAD fisheries are engaged in a one way trip of permanent increase in their numbers of DFADs and associated technology such as echo-sounders that now equip most DFADs (Chassot et al. 2014, Lopez et al. 2014).

Future limitations in the numbers of DFADs used could for instance be established:

- At least, limiting the numbers of DFADs to their most recent levels observed in 2013 in the Indian Ocean: freezing these numbers of DFADs and buoys until detailed information is provided to allow the analysis of their effects. One of the serious difficulties faced by this measure being that the numbers of DFADs that have been deployed in 2013 remain widely or totally unknown for several major fleets.
- However, our analysis suggests that there are now several reasons supporting the fact that the numbers and densities of DFADs currently in use in the IO are already excessive and unsafe to allow an optimal exploitation of the 3 main tropical tuna stocks and of the pelagic ecosystems. Then a precautionary

management of the DFADs fisheries in the IO could be to reduce the numbers of DFADs to their levels estimated in the mid-2000s, for instance at the numbers of DFADs estimated at around 2,100 by Moreno et al. (2007). Such a significant reduction in the numbers of DFADs might not affect to much the DFAD fisheries as these numbers have been proven to be efficient for the same fleets at that time and no decreasing trend in the recruitment has been observed in the recent years for yellowfin and bigeye.

6. Conclusion and recommendations

Statistical data are unfortunately lacking today concerning the numbers and trend of the numbers of DFADs seeded yearly and active daily in the IO during recent years. However, even if our estimated numbers are widely uncertain, there is no doubt that there has been a steady increase of these numbers and that today large numbers of DFADs are drifting in the entire Equatorial areas, especially in the West but also in the East. Taking into account the various known and potential problems introduced by DFADs (see section 2), the IOTC should obtain and make available to scientists the detailed data on the numbers of drifting DFADs used today and in the past by all their purse seine fisheries[6], because this basic data set is an essential component of the DFAD fishing effort exerted by purse seiners. As recommended by Baske et al. (2012): "*It is now time for those who rely on drifting FADs to take responsibility and to communicate in what numbers they are used*". Furthermore, taking note of the complexity in these DFAD data, all data on DFADs provided to RFMO by its CPC should follow valid, simple and explicit technical recommendations. The 2 series of numbers of FADs that are proposed in this document, (1) **total number of buoys seeded yearly** and (2) **average number of active DFADs followed daily** would probably constitute a good basis and a minimal data set concerning these 2 series.

There are strong reasons to hypothesize that the very large numbers of DFADs that are active today may have negative impacts on the rational use of tunas and of pelagic resources. One of these potential effects of an excessive number of DFADs could be, in addition to the decline of yield per recruit for the yellowfin and bigeye stocks, the major declines recently observed in the skipjack free-swimming schools catches, a decline that would directly affect purse seine fisheries that are targeting MSC labels which are mostly based on skipjack caught in unassociated tuna schools. In such context, **the IOTC could start to envisage developing input controls in its DFAD fisheries**: for instance limiting the numbers of actively monitored DFADs that are released yearly by their purse seine fleets and also potentially limiting the numbers of support vessels. Following **a precautionary approach**, we suggest that the IOTC could consider setting a cap on the number of FADs drifting at-sea and this monitoring could be based on the year 2013. The objective would be to at least slow down as much as possible the recent increasing trends observed in the overall fishing capacity on DFADs.

There are good reasons to consider that such permanent limitations in the numbers of DFADs would probably be an efficient ways to limit the "DFAD fishing capacity" of the purse seine fleets. Such prospect to establish a maximum number of DFADs seeded annually was also

[6] This information is already a potential component of the IOTC 2012 FAD management plans requirements requesting: "*FAD numbers and/or FADs beacons numbers to be deployed (per FAD type)*"; but unfortunately this IOTC requirement concerning FADs numbers is not enough detailed and not explicitly requesting the 2 basic series described in our work that are estimated to be essential for scientists.

recently envisaged by the WCPFC scientific committee in 2014 (Hurry 2014) and this prospect will be further studied by a technical WCPFC working group on the use and limitation of DFADs. It should also be kept in mind that a similar WG on FADs was also created by the 2014 SCRS meeting (see appendix 1). On the opposite, when there is already a structural overcapacity of the DFAD fishing fleets, most traditional management measures that are envisaged or developed by the tuna RFMOs and by the IOTC, such as the closure of DFAD strata or limitations in the numbers of DFAD sets allowed, tend to be fairly difficult to apply and most often poorly efficient. A good example of this problem was recently observed in the IOTC area following the quite poor results of the DFAD closure off the Somalia coast in November (IOTC 2012).

A major difficulty for good fisheries management is to elicit and put into action management measures that are realistic and efficient with regards to their practical implementation and control. Potential regulation or limitation in the numbers of DFADs deployed by purse seiners and support vessels could face major difficulties in their future implementation. Such potential limitation could primarily target control and limitation of the numbers of electronic equipments that are installed on the DFADs (i.e. buoys) and also possibly the satellite transmission companies that allow locating them. These prospects would need further studies but automatic quarterly reports of buoy activations/deactivations by buoy supplier companies currently in use in the French fleet may provide a way ahead. The recent increasing coverage of observers onboard European and Seychelles purse seiners could also be useful to implement some control measures on DFADs use. Overall, such management measures would need a full cooperation by fishing companies: if a majority of the tuna boats associations are convinced that there is a need to limit the numbers of buoys and DFADs, they should find efficient ways to efficiently promote these limitations.

The large heterogeneity of the various purse seine fleets with regards to DFAD fishing should be carefully considered in the analysis of management measures. Such heterogeneity might create a political divergence in the points of view expressed concerning policies and management of purse seine fisheries. For example, considering an even "Total Allowable number of DFADs", i.e. a quota of DFADs attributed to each purse seiner on a yearly basis could be discriminatory for the vessels that heavily rely on DFAD fishing. Historical aspects of the fishery and strategies of fishing companies should be taken into account in management measures proposals. Alternate or additional potential management measures limiting support vessels would also solely target the Spanish and Seychelles fleets, introducing another type of discrimination. The heterogeneity in the use of DFADs by the various purse seine fleets will add difficulties in the potential discussions on DFAD limits within tuna RFMOs. Overall, any potential limitation of the DFAD fisheries should be studied in close consultation between tuna scientists, fishermen (skippers and companies) and the IOTC Commissioners. Many/most tuna fishermen should be convinced today that the use of DFADs should be somehow controlled and limited at "reasonable" levels and as recommended by Grafton et al. (2006), "much greater emphasis must be placed on fisher motivation when managing fisheries". This increased role of responsible fishermen in the IOTC work should be a prerequisite to efficiently plan and implement any future limitation of DFAD numbers and/or limitations of its DFAD fisheries. The initiatives and active collaboration of Spanish and French fishing companies with scientist in the development of DFAD management plans seems to support this view.

Our main conclusions would be: (1) as in Davies et al. (2014), that an "*explicit management of the use of FADs is undoubtedly a necessity to ensure future sustainability of the FAD* *fisheries*" and (2) that limiting the number of actively monitored DFADs would be an efficient way to limit the various potentially negative impacts of DFADs on tunas and ecosystems, this goal being potentially reached without significantly hampering the efficiency and profitability of purse seine fisheries. If DFAD fisheries continue to develop in the future without any control by RFMOs as observed today, they may soon face severe commercial pressure at the level of consumers and international market of tuna cans through striking media campaigns developed by NGOs such as Greenpeace and PEW.

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Appendix 1: Agenda of the ICCAT FAD WG created by SCRS in 2014

The SCRS should recommend creating a temporary working group on DFADs. The Working Group would need to have members that are scientists, fishery managers, fishing industry administrators and fishermen.

The objectives of this Working Group would be to:

- initiate an active exchange of views concerning FAD management options;
- better estimate the past and present numbers of buoys, FADs and changes in FAD-related technology;
- evaluate ways to improve the use of information related to FADs in the process of stock assessment,
- evaluate the consequences of future FAD-related management options on ICCAT-managed species and on the pelagic ecosystems.