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MANAGING TROPICAL TUNA PURSE SEINE FISHERIES THROUGH LIMITING THE NUMBER OF DRIFTING FISH AGGREGATING DEVICES IN THE ATLANTIC: FOOD FOR THOUGHT

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SUMMARY

This paper makes an analysis of the numbers of drifting fish aggregating devices (DFADs) in the eastern Atlantic Ocean and of the potential interest to manage purse seine fisheries based on limitations of FADs numbers. Potential risks of massive DFADs use are discussed. Numbers of FADs released by the French fleet (2004-2014 period) are now available; this paper estimates levels and trends of deployed and active FADs numbers. It is estimated that FADs numbers have been widely increasing during recent years, potentially reaching 18000 or more FADs today, and potentially resulting in an estimated 3.7 fold increase since 2004. Good knowledge of total numbers of DFADs is urgently needed to better estimate the fishing effort and capacity of DFAD fisheries. Future limitations in the number of DFADs could allow an efficient way to reduce FAD fishing effort. Following a precautionary approach, we suggest that ICCAT could consider setting a cap on the number of DFADs; this monitoring could be based on the year 2013. The objective would be to slow down the increasing trends observed in the overall fishing capacity of DFADs. Consequences of such measures should be carefully analysed to ensure the sustainability of the fisheries concerned.

RÉSUMÉ

Le présent document analyse les nombres de dispositifs de concentration des poissons dérivants (DCP dérivants) dans l'océan Atlantique Est et de l'intérêt éventuel de gérer les pêcheries de senneurs en se fondant sur les restrictions du nombre de DCP. Les risques potentiels de l'utilisation massive de DCP dérivants sont abordés. Les nombres de DCP déployés par la flottille française (entre 2004 et 2014) sont désormais disponibles. Le présent document estime les niveaux et les tendances des nombres de DCP déployés et actifs. Il est estimé que le nombre de DCP s'est largement accru ces dernières années, atteignant probablement 18.000 DCP ou plus à l'heure actuelle, ce qui pourrait correspondre à 3,7 fois plus depuis 2004. Une bonne connaissance du nombre total de DCP dérivants est impérieuse afin de mieux estimer l'effort de pêche et la capacité des pêcheries utilisant les DCP dérivants. Des restrictions à l'avenir du nombre de DCP dérivants pourraient permettre de réduire efficacement l'effort de pêche sous DCP. Selon une approche de précaution, nous suggérons que l'ICCAT songe à fixer une limite au nombre de DCP dérivants. Cette approche pourrait se fonder sur l'année 2013. L'objectif consisterait à ralentir les tendances à la hausse observées dans la capacité de pêche globale des DCP dérivants. Les conséquences de ces mesures devraient être analysées avec soin afin de garantir la durabilité des pêcheries concernées.

RESUMEN

Este documento realiza un análisis del número de dispositivos de concentración de peces a la deriva (DCPd) en el Atlántico oriental y del posible interés de gestionar las pesquerías de cerco basándose en limitaciones al número de DCP. Se discuten también los posibles riesgos del uso masivo de DCPD. Se dispone ahora del número de DCP plantados por la flota francesa (2004-2014), este documento estima niveles y tendencias del número de DCP plantados y activos. Se estima que el número de DCP ha ido creciendo mucho en años recientes, alcanzando posiblemente los 18.000 o más DCP actualmente, lo que posiblemente supone que desde 2004 se han multiplicado por 3,7. Es urgentemente necesario un buen conocimiento del número total de DCPD para estimar mejor el esfuerzo pesquero y la capacidad de las pesquerías de DCPD. Una forma eficaz de reducir el esfuerzo pesquero de los DCP podrían

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ser limitaciones futuras en el número de DCPD. Siguiendo un enfoque precautorio, sugerimos que ICCAT considere establecer un límite al número de DCPD, que podría basarse en el año 2013. El objetivo sería ralentizar las tendencias crecientes observadas en la capacidad pesquera global de los DCPD. Deberían analizarse cuidadosamente las consecuencias de dichas medidas para garantizar la sostenibilidad de las pesquerías afectadas.

KEYWORDS

Fishery management, Drifting Fish Aggregating Device, Purse seining, Atlantic, Tuna

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*; skipjack) catch, but also in significant increasing catches of juveniles of bigeye (*Thunnus obesus*; bigeye) and yellowfin tuna (*Thunnus albacares*; yellowfin) (Fonteneau *et al.* 2013). The increasing use of FADs concurrently resulted in apparent increasing purse seine catches per unit effort (CPUE) over time (Chassot *et al.* 2013; Delgado de Molina *et al.* 2014a), see **Figure 1**, since the nominal effort currently used for computing purse seine CPUEs is based on fishing-searching time, or number of fishing sets, which do not account for the increasing capacity associated with FAD numbers and technology (ISSF, 2012, Fonteneau *et al.*, 2013). Despite the major changes in purse seine fishing strategies linked to FAD-fishing development (i) no major decline in yield-per-recruit (Y/R) of bigeye and yellowfin fisheries, (ii) no major decline in longline (LL) 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 (ISSF 2012). As a consequence and in the absence of any highly visible and severe impact in the skipjack, yellowfin and bigeye stocks, purse seine FAD 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 FAD fisheries on tuna juveniles and associated fauna. It should be stressed however that closures of targeted FAD-fishing areas or time area-strata (e.g. moratoria on FAD-fishing) have been the most frequent management schemes implemented by the various tuna RFMOs and by ICCAT (for a review see Davies *et al.,* 2012). Also, the IATTC banned, in order to reduce the pressure of FAD fisheries, the use of auxiliary (or support) vessels in support to purse seiners as early as 1999 in the eastern Pacific Ocean (IATTC 1998). Because the nominal fishing effort changes from year to year, the effects of time-area closures are difficult to evaluate quantitatively but it would appear that in most cases, these effects have been quite limited (ICCAT 2010; IOTC 2012). 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 FAD fishing activities in alternate areas outside the closed strata during the closure and (iv) larger than usual catches on FADs following the end of the closure (Harley and Suter 2007; Torres-Irineo *et al.,* 2011). As the potential interest of time-area closures for protecting juveniles of bigeye and yellowfin tunas appears to be limited or questionable, alternate measures allowing limiting the impact of FAD-fishing should be explored. Indeed, the component of fishing effort due to support vessels, increasing use of FADs, and improvements in FAD technology (e.g. echo-sounders) is currently poorly monitored by CPCs and tuna RFMOs although it may significantly increase overall purse seine fishing capacity active on DFAD, as well as blur the relationship between purse seine CPUE and abundance. Until now, managing the FAD fishing pressure based on a limitation of the number of FADs has been seldom envisaged by tuna RFMOs or by ICCAT (with the exception of WCPFC, WCPFC 2004 and Hurry 2014). It makes sense to assume that the number of FADs is a basic component of the FAD fishing effort and that their reduction would ultimately result in reduced fishing mortality. The pros and cons of such management scheme should be fully studied by scientists and tuna RFMOs as suggested by Davies *et al.* (2013) but the main goal of this paper is to initiate some preliminary scientific analysis and discussion upon recent trends in FAD numbers and on this potentially important management prospect in the case of the Atlantic FAD fisheries. This paper will not discuss the changes in the FAD technology nor the potential closures of selected time and area strata, as these points have been already tackled (based on the analysis of catch-effort and size data) by various works in each of the tuna RFMOs.

2. Why monitoring and managing FAD fishing?

2.1 Overview

Although there has not been any evidence of major negative impact following the steady development of FAD-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, FAD-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 FAD-fishing has increased the uncertainties associated with the assessment of the status of 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 FAD sets (Fonteneau *et al.*, 2000, Fonteneau 2014) (keeping in mind 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, FADs 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 Y/R, and also well under sizes at first spawning, i.e. about 80 cm and 100 cm fork length for yellowfin and bigeye, respectively (Zudaire *et al.,* 2013; Sun *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 individuals caught associated to DFADs reduce the yield per recruit of each cohort recruited in the fisheries. As a consequence these catches also reduce the biological productivity of the stocks, and they create an increased potential interaction between purse seine and longline fisheries (that are only catching large tunas) (when skipjack sizes caught in free and in FAD sets are nearly identical). Such interactions are specifically exacerbated for stocks estimated to be close to MSY levels, as most yellowfin and bigeye stocks today (Juan-Jorda *et al.,* 2011). In such context, this decline of biological productivity of the yellowfin and bigeye stocks due to FAD fishing should be reduced or at least frozen in most cases so as to increase the expected Y/R and MSY. An example of the estimated decline of MSY of the Atlantic yellowfin stock is shown in **Figure 2**. This decline of MSY was mainly due to increased catches of small yellowfin in the FAD fisheries developed since the late 1980s. Similar results have been also observed worldwide and in the Atlantic at various degrees for all the yellowfin and bigeye stocks.

2.3 FADs potentially altering some biological characteristics of tunas?

Furthermore, it could also be hypothesized that FAD-fishing might also alter skipjack spawning 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 dependent on short-term feeding. The food available to skipjack under FADs might not be sufficient to feed the large biomass of tunas associated with FADs as shown by the large percentage of fish described by empty stomachs (Roger 1994; Ménard *et al.,* 2000; Jaquemet *et al.,* 2011) and their poor individual condition as compared to free-swimming schools (Hallier and 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 FADs, this situation could reduce the spawning potential of the skipjack populations (while by contrast, the increasing number of FADs might benefit skipjack spawning by increasing the rates of encounter between mature fish).

2.4 FAD producing increased accidental mortality of various species: sharks, turtles and other species

Fourth, FAD fishing results in **s**ignificant by catch 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; Amandé *et al.,* 2012; Hall and Roman, 2013). Observer data have shown that there was most often some bycatch under FAD. Typical discard rates are for instance close to the average levels of 5.3% estimated in the Atlantic by Amandè 2008, when the discard rate of bycatch was estimated at only 1.2 % for free schools sets. This amount of discarded bycatch associated with FADs 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 FADs 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 FADs 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 FAD, even when FADs have been lost by their owners, drifting outside fishing grounds. This source of cryptic accidental mortality of sharks due to FADs was estimated to be high in the Indian Ocean (Filmater *et al.,* 2013). New FAD designs without hanging nets (Franco *et al.,* 2009) have been developed and implemented to reduce ghost mortality, but to an unknown degree, as the percentage of FADs still equipped with potentially entangling nets remains 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 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 FADs may also increase navigational hazards and risks, especially for small vessels (fishing and sailing vessels).

3. An overview of FAD fisheries in the Atlantic

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

- French purse seiners: showing variable (in time) but quite moderate rates of FAD associated catches, at an average low rate of 40%,
- Most (but not all) Spanish and associated flags purse seiners (Seychelles, Cabo Verde, Panama, Netherlands Antilles, Belize, etc.), showing much higher and recently increasing rates of FAD associated catches (80% of total catches),
- Ghanaian purse seiners and other flags with Korean skippers (Belize, Ivory Coast, Guinea) showing very high rates of FAD associated catches (probably close to 100% although the real rates of FAD catches remain undeclared to ICCAT). In 2012, logbooks available and considered to be of good quality for the Ghanaian purse seiners indicated that during recent years about 94% of the sets were made on FADs (Chassot *et al.,* 2013).

The yearly percentages of FAD associated catches observed for each fleet are shown by **Figure 3**. The proportions of FAD sets were similar between French and Spanish purse seiners during the early 1990s, and close to 50% of FAD catches. Such situation has changed during recent years and the Spanish fleet is now catching a much higher proportions of FAD associated tunas than French purse seiners: the Spanish and associated flags fleet has been catching 65% of its catches under FAD during the last 10 years and over 70% since 2011, against only 33 % of FAD catches for French purse seiners. It must be noted that in the Atlantic Ocean, Spain and France have similar fleets in terms of vessel size and age (**Figure 4**). The structural marked difference in the levels of FAD catches of the two fleets is also due to the fact that Spanish purse seiners are supported by an active fleet of support vessels combined with a much larger number of FADs per vessel. The fleet of support vessels has been permanently used by the Spanish and associated flags fleet since the late nineties, mainly in order to seed new FADs and to control the levels of tuna biomass under the FADs of its purse seiners. This fleet is currently composed of 13 vessels in the Atlantic, when French purse seiners are using only 1 supply vessel. This major structural difference in the French and Spanish purse seiners in the targeting of FADs is also well shown by the average catches on FAD caught by each average French and Spanish (and associated flags) purse seiners, a result shown by **Figure 5**. This figure is showing well the differences in the absolute levels and trends of the FAD associated catches of individual vessels belonging to each of these 2 fleets: an average Spanish purse seiners catching during the last 10 years an average of recent years 2.5 times more tunas on FADs than a French purse seiner (period 2004-2013) (but showing a high between years variability). It should also be kept in mind that the size of purse seiners shown by **Figure 4** is an important factor in determining the fleet fishing strategy: very large purse seiners need to catch more tunas than small vessels in order to compensate their larger investment and running costs and FAD-fishing may be for them the only way to obtain high catch rates throughout the year and produce the required high levels of catch.

In the Atlantic, the average current carrying capacity of French and Spanish (and associated flags) purse seiners is very similar, showing for both fleets an average capacity close to 1400 m^3. This minor difference would not explain the major differences in strategy that are clear between the 2 fleets. It should also be noted that pole and liners from Ghana, Spain, and Senegal have recently, started to build and deploy artificial FADs and that Ghanaian pole and liners work in collaboration with some purse seiners to attract the tuna schools or indicate their presence in a similar way as Spanish support vessels. Quantitative information are not yet available on these activities. Overall, the marked difference in the proportion and magnitude of FAD catches of purse seine fishing fleets is a critical factor to consider with regards to management: most Spanish and Korean companies tend to give high priority to FAD 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 FAD fishing.

4. Trend in numbers of active DFADs in the Atlantic

4.1. Quantifying FAD numbers

The numbers of active FADs is a fundamental and continuous topic discussed in the analysis of tropical tuna fisheries, but this information is seldom available, keeping in mind that in the Atlantic detailed information on the use of FADs has been requested by ICCAT since 2011 (recommendation 2011-01 and at a very detailed scale by the recommendation 2013-01). However, very few results have been submitted today to the ICCAT secretariat following these recommendations. The PEW 2012 report by Baske *et al.* 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). This lack of information on the numbers of FADs is probably due to a combination of factors such as: (i) The confidential nature of this sensitive information that was not legally requested until very recently 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 FADs (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 FADs 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 FADs that are followed by each purse seiner on its computer screen,

(3) Average *numbers of active lost FADs*, i.e. FADs that have been drifting outside the fishing zone (same information, but for FADs that cannot be fished). It is not clear if the complex data requested by the ICCAT recommendation 2013-01 will allow to estimate these 3 basic indicators concerning the numbers of FADs, as these global indices are difficult to estimate because:

   (a) some FADs may be shared between various purse seiners from the same tuna owner company or by a given group of vessels,

   (b) there is a permanent flow of electronic buoys that are successively activated or deactivated and transferred from one FAD to another, each FAD being potentially moved to another location,

   (c) FADs are frequently stolen through buoy transfer, and buoys of origin are still active but brought back to port where they are often later recovered by their owner.

As a consequence, while the number of active purse seiners, their nominal fishing efforts and their catches are quite well followed by the ICCAT (as well as for the various tuna RFMOs), the numbers of active and deployed FADs remain today very poorly known as they are never declared, remaining poorly estimated by scientists and it is not clear if the ICCAT recommendation 2013-01 will allow to estimate them and without bias for all the fleets.

4.2 Numbers of buoys: data available from the French purse seine fleet

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 the management of buoy GPS signal. This new data set was presented in the Goujon *et al.,* 2014 paper (and also submitted to the CECOFAD program data base). The number of purse seiners active in the French fleet (and in the Spanish and associated flag fleet) has been taken from Delgado *et al.*, 2014a, while the catch data on FADs caught by each fleet was obtained in the ICCAT statistical Task II[3]. The average yearly catch of the French fleet per each buoy deployed was computed from the information on the yearly FAD catches by the French purse seiners and the yearly number of buoys deployed. This estimated parameter is given in **Table 1** and shown in **Figure 6**. This indicator is showing that after a period of 2 years of high catch per FAD (2004-2005), there was a 2006-2010 period of marked variability, followed by a steady decline during the 2010-2013 period.

4.3 Numbers of buoys: hypotheses for other fleets

Various converging sources of observations, at-sea and in the landing ports, would strongly indicate that the numbers of FADs active at-sea and deployed by the Spanish and associated fleets, including by their support vessels, are much higher than for French purse seiners. However and unfortunately there is currently no data available for the Spanish and other fleets concerning the numbers of FADs that are followed daily by each purse seiner, when 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). In this absence of data, it can be hypothesized that these higher FAD catches are in proportion of the larger number of FADs seeded yearly (and fished daily) by the Spanish fleet (and its supply vessels). In this hypothesis the numbers of FADs seeded per each Spanish purse seiner could be estimated at an average level of being 2.5 times more important than for the average French purse seiner, based on the average ratio of FAD yearly catches per vessel during the period 2004-2013. This hypothesis that FAD catches per vessel are proportional to their number of FADs is of course widely questionable because of various reasons (such as distinct fishing strata or rate of stolen buoys), but at least it allows to obtain a preliminary estimate of these numbers of FADs. Furthermore this result would appear to be at least a realistic order of magnitude, as this estimated ratio of 2.5 more FADs seeded by Spanish purse seiners would appear to be a logical rate: knowing the active FAD targeting by this fleet and its large fleet of supply vessels. This rate of 2.5 is lower, but also consistent compared to the ratio of 3.0 between Spanish & French numbers of FADs per vessel previously estimated by various authors in the Indian Ocean (Moreno *et al.,* 2007, Guillotreau i 2011). Based on this hypothesis, the numbers of Spanish FADs deployed by vessel was tentatively estimated, the average number of French FADs released by each French purse seiner being multiplied by a ratio of 2.5 (**Table 2**). Based on this set of data and hypothesis, it could be estimated that during recent years (2010-2013), each Spanish and associated flags purse seiner was following daily an average of 200 active FADs, and seeding at sea a yearly average of 264 buoys (and new FADs) in 2013, when less than 130 buoys were estimated to have been seeded each year by each purse seiner before 2008. Our estimate of the average number of FADs released by each Spanish purse seiner in 2013, 385 FADs, is lower but very close to the number of 426 FADs seeded per Spanish purse seiner given by Delgado *et al.,* 2014b for the same fleet. **Figure 6** 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 hypothesis. There was no data on the numbers of FAD used submitted to the ICCAT by other fleets of purse seiners fishing on FADs (Ghana, Côte d'Ivoire, Guinea), but the numbers of FADs seeded by these fleets can be indirectly estimated based on their total catches on FADs[4]: simply assuming that the yearly average catch per seeded FAD was identical to the average yearly FAD catches per buoy of the French and Spanish fleets in our hypothesis. These estimated catches, catch per FAD seeded and number of seeded FADs estimated for these fleets (called NEI fleet) by this simplified method is given in **Table 3**. Based on these data and assumptions, the estimated total numbers of FADs released yearly in the Atlantic Ocean by all purse seine fleets (**Figure 7**) could have increased from less than 7000 FADs before 2008, to 17,300 FADs in 2013, then showing an estimated 2.6 fold increase between the 2 periods 2004-2007 and 2010-2013. Furthermore, based on the 2013 French data concerning the FAD numbers, it could also be estimated that the average numbers of active FADs followed daily by purse seiners in the eastern Atlantic in 2013 would be close to 13,000 FADs.

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[3] Task II: ICCAT file with catch and effort data, by 1 degree squares and month.

[4] The FAD catches of these fleets has been estimated at 94% of their total catches by Chassot 2014, probably a realistic order of magnitude.

4.4 Overview and discussion concerning FAD numbers in the Atlantic

Our estimates of FAD numbers are characterized by major uncertainties and they would be improved by:

(1) The collection of data on the numbers of buoys seeded and observed by all the major purse seine fleets, especially purse seiners from the Spanish (and associated flags) and Ghanaian fleets.

(2) A wider range of alternate hypotheses and methods allowing to estimate the uncertainties associated with the number of FADs used by each fleet, for instance based on yearly FAD catches and effort of each vessel (based on log book data and well standardized).

These uncertainties in the numbers of FADs have been already noted and discussed by the Baske *et al.,* (2012), taking note that our estimated numbers of DFADS presently seeded are well above the estimated average numbers of FADs they estimated. The other estimates of the numbers of FADs recently given by Scott and Lopez (2014) suggest that that Spanish and French purse seiners were releasing the same average numbers of FADs during recent years, an assumption not supported by our analysis) and that this average number was of only 180 FADs, which seems very low as compared to every field observations. One of the serious limitation in our work is the basic data presently used concerning the average catch per vessel caught on FADs: there is no doubt that a well standardized catch on FAD per vessel, based on log book data, should preferably be calculated and used. There is no doubt for instance that the numbers of French and of Spanish vessels given by Delgado *et al.,* (their Table 5, presently used) are not even fully valid to calculate a valid average yearly catch on FAD, simply because some of the vessels had limited catches because of their limited fishing activities in the Atlantic during some years. Based on current available data and knowledge, our preliminary conclusion would be that, although the present numbers of FADs seeded or active in the Atlantic are still widely uncertain, our estimated numbers of FADs are probably somehow at least indicative of the absolute levels and of their major increase during the last 10 years: based on today data and knowledge on FADs, our 2.6 folds increase estimated for the total numbers of FADs seeded each year during the last 10 years may well be representative of the major increase of FAD numbers developed during recent years. It should also be noted that if the increases in the numbers of FADs deployed by purse seiners estimated or observed in the Atlantic Ocean during recent years appear to be spectacular ones, they are not unique. Similar rates of increase in the FAD numbers have been simultaneously observed in the Indian ocean and also in the Eastern Pacific, where the number of deployed FADs measured by the IATTC has been also multiplied by a factor of 3.3 during the period 2005-2012, as in the Eastern Pacific 4,300 FADs were seeded in 2005 and 14,000 FADs in 2012 (Martin Hall pers. com.). It should also be kept in mind that the steady increase in the number of FAD presently estimated in the Atlantic is also well explained by 2 combined factors:

1) The increased value of skipjack: the average skipjack prices at the cannery, corrected for inflation, (report of the ICCAT skipjack Working Group 2014) have been multiplied by 2 between the 2 periods 2004-2006 and 2011-2013. This was clearly for purse seine fishermen a strong pressure to catch more skipjack, the best/only way being to invest in the seeding of more FADs.

2) The increased efficiency of FAD equipped with echo sounders: when this equipment was very rare 10 years ago, sounders appear to very common today on most FADs. Although there was no study in the Atlantic on this topic, the IATTC work has been showing (Hall com. pers. that during recent years (2011-2013) the average catch of FADs sets in the EPO was increased of 25% for FADs equipped with echosounders.

These 2 factors, increased skipjack landing values and increased fishing efficiency of today FADs, are probably 2 reasons that have recently accelerated the seeding of FADs, in the Atlantic as well as in the other oceans.

4.5 Numbers of FADs: an indicator of nominal FAD fishing effort?

It is commonly admitted in the stock assessment work that it is difficult or unrealistic to estimate an accurate "FAD fishing effort" solely based on searching/fishing times or on the numbers of FAD sets, particularly when the number of FADs is supposed to increase continuously. Another difficulty is due to the fact that all purse seiners are always "keeping an eye on free schools" and on natural logs or FADs belonging to other fleets, even when their main activities consist in targeting their own FADs. Whatever the difficulty to reallocate the part of the fishing day devoted to a specific fishing mode, many scientists consider that a good knowledge of the numbers and density of FADs would bring, in addition to the various information already available on FAD fishing efforts (such as fishing times, numbers of FAD sets, catch per set, etc.), valuable indicators on the FAD fishing pressure. These numbers should be first examined independently, and also incorporated in normalized CPUEs models, preferably in addition to the present knowledge concerning fishing/searching times/set information.

We propose that the following 3 basic indicators of FAD numbers should be calculated each year for each purse seine fleet: (1) Total numbers of FADs deployed yearly (2) Numbers of active FADs, i.e. average number of FADs monitored on a daily or monthly basis by purse seiner for each fleet. (3) When possible, this basic indicator should also be stratified in 2 categories: number of active FADs monitored within the fishing zone and FADs that are still monitored by the purse seiners but outside its fishing range or stolen by another boat, and then lost for the purse seiner owner of the FADs. These sets of indicators would clearly help to measure the trend in the fishing pressure of FADs within purse seine fishing grounds and to evaluate the average density of FADs in the area exploited by the purse seine fishery, this parameter being important to condition the FAD CPUEs and FAD catches. The statistical requirements of each tuna RFMO should be clearly requesting to each CPC to provide these indicators on their FAD 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 FADs" that could be used by scientists and by managers in each fishery and ocean: there will never be in the management of FADs the equivalent of an 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 FADs 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 FAD fisheries are engaged in a one way trip: permanently increasing and very quickly their numbers of FADs, as well as the technology of these FADs, most FADs being now equipped with sounders and other improvements (Lopez *et al.,* 2014). Future limitations in the numbers of FADs used could for instance be established:

- At least limiting the numbers of FADs to their most recent levels observed in 2013 in the Atlantic: freezing these numbers of FADs 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 FADs that have been deployed in 2013 remain widely or totally unknown for several major fleets.

- However, as there are strong reasons to hypothesize that the numbers and densities of FADs active today in the Eastern Atlantic are already excessive and unsafe to allow an optimal exploitation of tunas stocks and of the pelagic ecosystems. Then a precautionary management of the FADs fisheries could be to reduce the numbers of FADs to their levels estimated 10 or 15 years ago. Such a major reduction in the numbers of FADs might not damage the FAD fisheries, as these reduced numbers of FAD have been proven to be efficient for the same fleets.

6. Conclusion and recommendations

Even if data are lacking today concerning the numbers and trend of the numbers of FADs seeded yearly and active daily in the Atlantic ocean, even if our estimated numbers are widely uncertain, there is no doubt that there has been a major increase of these numbers. Taking into account the various know and potential problems introduced by FADs (chapter 2), the ICCAT should obtain and make available to scientists the detailed data on the numbers of drifting FADs used today and in the past by all their purse seine fisheries[5], because this basic data set is an essential component of the FAD fishing effort exerted by purse seiners. As it was recommended by the Baske *et al.,* 2012 PEW report "*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 FAD data (cf paragraph 4.1), all data on FADs provided to RFO by its CPC should follow valid and explicit technical recommendations done by the RFMOs. The 2 series of numbers of FADs, total number of buoys seeded yearly and average number of active FADs followed daily (as described in paragraph 4.1) probably constitute a good basis and a minimal data set concerning these series. There are strong reasons to hypothesize that the very large numbers of FADs that are active today may have serious 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

[5] This data set being already requested by the ICCAT Commission and its recommendations 2011-01 and especially 2013-01.

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 target MSC labels mostly based on fishing on unassociated tuna schools. In such context of a potentially dangerous major increase in the numbers of FADs, the tuna RFMOs should start to envisage developing input controls in FAD fisheries: limiting the numbers of actively monitored FADs 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 ICCAT 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 the recent increasing trends observed in the overall fishing capacity on FADs. There are good reasons to consider that such permanent limitations in the numbers of DFADs would probably be one of the most efficient ways to limit the "FAD fishing capacity" of the purse seine fleets. Such prospect to establish a maximum number of FADs seeded annually was also 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 FADs. On the opposite, when there is already a structural overcapacity of the FAD fishing fleets, most traditional management measures that are envisaged or developed by the tuna RFMOs, such as the closure of FAD strata or limitations in the numbers of FAD sets allowed, tend to be fairly difficult to apply and often poorly efficient. Furthermore, it should be kept in mind in the management of tuna fisheries that one of the major difficulties is to choose and to put into action management measures that are realistic and efficient with regards to their practical implementation. Potential regulation or limitations in the numbers of FADs deployed by purse seiners would clearly face these potential difficulties: it would appear that their potential limitation would primarily target control and limitation of the numbers of electronic equipments that are installed today on the FADs and also possibly the satellite transmission companies that allow locating them, but these prospects would need further careful studies. Another major difficulty faced in the Atlantic (and also in the Indian oceans) will be the major heterogeneity observed in the EU FAD fishing. At a management level, this major heterogeneity in the EU purse seine fleets in the FAD fisheries is clearly difficult to handle as in general, future management measures aimed at limiting or reducing the number of FADs in purse seine fisheries will likely affect more Spanish (and Ghanaian) fishing fleets that are currently characterized by strategies oriented towards FAD-fishing. This important heterogeneity of the fleets should be kept in mind in the analysis and management of FAD fisheries, and there is no doubt that the great heterogeneity between the various fishing countries tends to create a political heterogeneity in the potential points of view expressed concerning policies and management of FADs fisheries. For example, a given "Total Admissible number of FADs", a quota of FADs given yearly to each purse seiner could be discriminatory against the Spanish and Ghanaian vessels. Alternate or additional potential management measures limiting support vessels would also solely target the Spanish fleet, introducing another type of discrimination. This heterogeneity in the use of FADs by the various purse seine fleets will clearly add difficulties in the potential discussions on FAD limits within tuna RFMOs. However, there is no doubt that, at least at a scientific level, such measures should be better studied and potentially developed by tuna RFMOs. Furthermore, because of the complexity of its feasibility, such potential limitation of the FAD fisheries should be carefully studied in close consultation between tuna scientists (expert in biology, fisheries and in economy), fishermen (skippers and companies) and Commissioners. These potential limitations in the numbers of active FADs would be a complex management target that should be designed and implemented appropriately: this goal will likely be challenging to negotiate within the IOTC and difficult to efficiently enforce, but a high priority should be given by the tuna RFMOs to conduct in each ocean the active investigations that are needed today on these urgent and important management prospects. Furthermore, most tuna fishermen should be convinced that the use of numbers of FADs should be controlled. As it was 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 ICCAT work should be a prerequisite to efficiently plan and implement any future limitation of FAD numbers and of FAD fisheries.

Our two basic conclusions would be, as in Davies *et al.,* 2014, that "explicit management of the use of FADs is undoubtedly a necessity to ensure future sustainability of the FAD fisheries" and furthermore that limiting the number of actively monitored FADs would be the more efficient way to limit the various negative impacts of FADs on tunas and ecosystems, this goal being reached, and without significantly hampering the efficiency and profitability of purse seine fisheries. Keeping in mind that if FAD fisheries are maintaining their expansion without rigorous control, as today, they may soon be facing severe commercial bans at the level of the consumers and of international market of tuna cans developed under the pressure of powerful NGOs such as Greenpeace, PEW, etc.

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

Year	Nb of Active buoys/PS	Nb buoys seeded yearly by each PS	Ratio Nbs FAD Seeded & active	Nb French PS	Average Nb of active FADs	Total Nb of seeded buoys yearly	Yearly FAD catches France	Average FAD Catches by each PS	Average catch per buoy seeded yearly
2004		41,0		10		410	20 246	2025	49,4
2005		41,0		9		369	13 531	1503	36,7
2006		47,0		6		282	5 178	863	18,4
2007		42,0		5		210	4 453	891	21,2
2008		54,0		6		324	3 044	507	9,4
2009		60,0		7		420	7 552	1079	18,0
2010	68	72,0	1,05	10	649	684	16 125	1697	23,6
2011	71	82,0	1,16	9	635	738	13 195	1466	17,9
2012	96	118,0	1,23	9	861	1062	16 956	1884	16,0
2013	90	156,0	1,74	9	808	1404	16 749	1861	11,9
2014		200,0		9		1800			
Average 2004-2013		71,3		8	738	590	11703	1378	22
Average 2010-2013	81	107,0	1,30	9	738	972	15756	1727	17,3

Table 2. Numbers of FADs estimated for the Spanish and associated flags purse seiners in the hypothesis RF1: each purse seiner seeding yearly 2.5 more FADs than a French purse seiner.

Year	*No. Active buoys/ PS*	*No. buoys seeded yearly/PS: France*2,47*	*Ratio No. FADs Seeded/ active*	*No. PS Spain et al.*	*No. PS Spain*	*Total No. of seeded buoys yearly Spain et al.*	*FAD catches (Spain et al.)*	*Average Catches on FAD by each PS*	*Average catch per buoy seeded*
2004		101		21	15	2 125	54 867	2 613	25,8
2005		101		19	10	1 923	54 922	2 891	28,6
2006		116		18	8	2 088	53 947	2 997	25,8
2007		104		22	13	2 281	65 389	2 972	28,7
2008		133		24	15	3 199	74 855	3 119	23,4
2009		148		27	16	3 999	78 179	2 896	19,6
2010	135	178	1,32	25	15	4 443	85 083	3 403	19,2
2011	153	202	1,32	24	15	4 858	97 071	4 045	20,0
2012	221	291	1,32	23	14	6 699	101 679	4 421	15,2
2013	292	385	1,32	23	14	8 856	119 222	5 184	13,5
2014		494							
Average 2004-2013		176		22,6	13,5	4 047	78 521	3 454	22,0
Average 2010-2013	200	264	1	23,8	14,5	6 214	100 764	4 263	16,9

Table 3. Yearly catches on FAD estimated for the purse seine fleets other than the EU (and associated flags) purse seiners (called Ghana&NEI) and numbers of seeded FADs estimated for this fleet in our hypothesis.

	FAD catches of Ghana & NEI PS	Average Catch/FAD France & Spain	Numbers Ghanaian & NEI FADs estimated
2004	79 783	37,6	2122
2005	76 912	32,6	2358
2006	68 267	22,1	3089
2007	61 680	24,9	2473
2008	60 754	16,4	3705
2009	83 675	18,8	4459
2010	89 926	21,4	4210
2011	95 500	18,9	5045
2012	95 005	15,6	6101
2013	89 300	12,7	7034

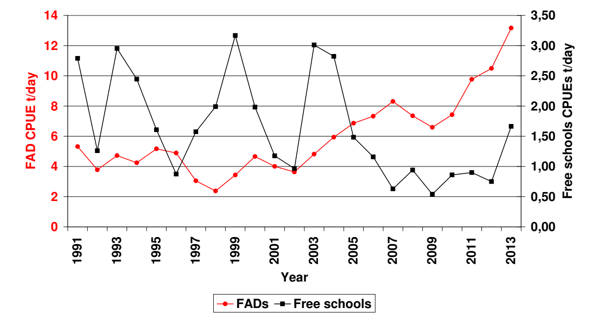

Figure 1. Yearly skipjack free schools and FADs CPUEs of the EU and associated flag purse seine fishery in the Eastern Atlantic (tons per fishing day).

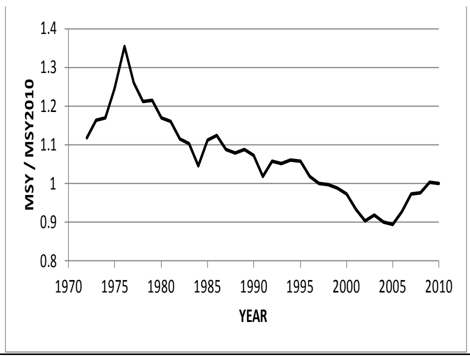

Figure 2. Change of MSY of the yellowfin stock during the 1970-2010 period as estimated by ICCAT (an ICCAT SCRS report 2013).

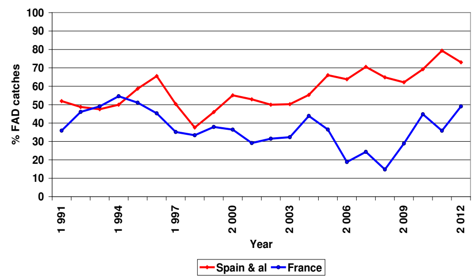

Figure 3. Percentage of FAD associated catches of the French and Spanish (and associated) purse seine fisheries in the Atlantic.

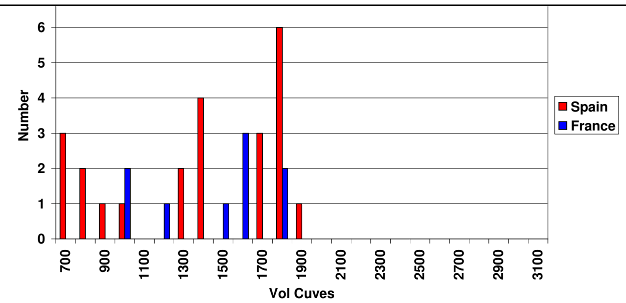

Figure 4. Distribution of purse seiners by class of carrying capacity of their wells, French and Spanish (and associated flags) purse seiners active in the Atlantic Ocean in 2013.

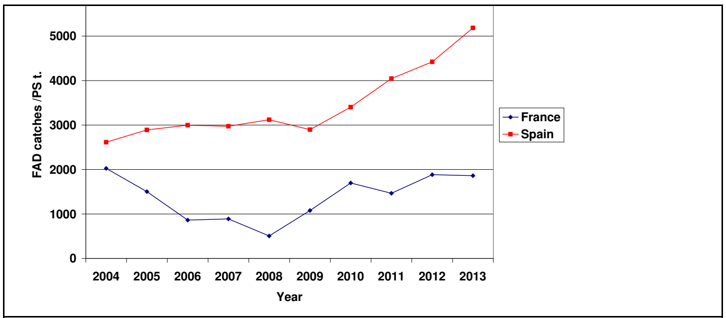

Figure 5. Yearly catches of FAD associated catches by an average French and Spanish (and associated) purse seiner in the Atlantic (i.e. an average ratio of yearly catches per vessel=2.5).

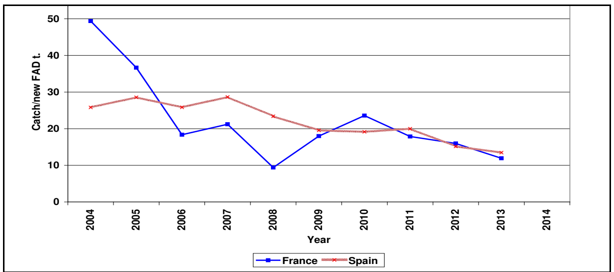

Figure 6. Average yearly catch per deployed buoy observed for French purse seiners and estimated for Spanish purse seiners (based on our 2 hypotheses) in the Atlantic.

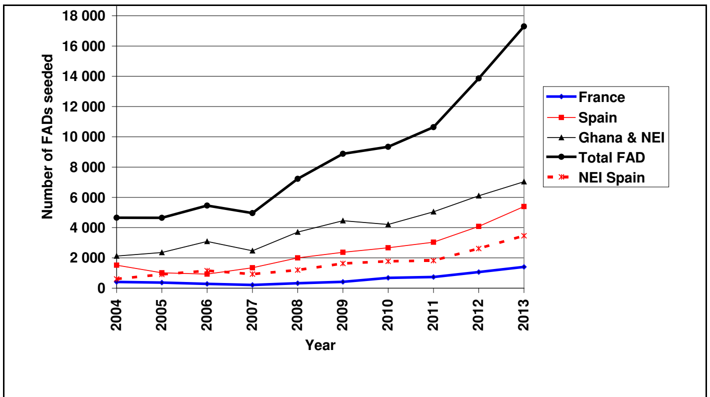

Figure 7. Estimated yearly numbers of FADs seeded, by categories of flag and total