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Using local ecological knowledge (LEK) to provide insight on the tuna purse seine fleets of the Indian Ocean useful for management

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Abstract – The purse seine fishery in the Western Indian Ocean is dominated by Spanish and French vessels that rely heavily on the use of drifting fish aggregation devices (DFADs) to capture tropical tuna species (skipjack, yellowfin and bigeye tuna). This study uses local ecological knowledge (LEK) obtained through standardized interviews of fishing masters to compare and characterize the body of local ecological knowledge, fishing technology and fishing strategies of both fleets, with the goal of obtaining useful information for the management of the fishery. A notable difference between fleets was the number of DFADs actively monitored per vessel at any given time, which was much higher for Spanish vessels (ca. 60 versus 20 DFADs). Spanish vessels also achieved higher vessel CPUE (catch per DFAD set) than their French counterparts. The use of supply vessels to manage, monitor and protect productive DFADs, and the latest satellite-based technology to track and remotely monitor DFAD aggregations is restricted to the Spanish fleet. The French do not use supply vessels and deploy less sophisticated tracking buoys. These technological disparities resulted in some fishing strategy differences between both fleets, but few differences were found in the knowledge of tuna behavior accumulated by the fishers.

Key words: LEK / Fisher knowledge / Drifting fish aggregating device / FAD / floating objects / Fishing strategy / Tuna behavior

Résumé – Utilisation du concept de « connaissance écologique locale » (LEK) pour améliorer nos connaissances des flottilles de thoniers-senneurs de l'océan Indien, utiles pour la gestion de la pêcherie. La pêche thonière à la senne coulissante de l'ouest de l'océan Indien est dominée par les flottilles espagnoles et françaises qui utilisent des dispositifs de concentration de poissons (DCP) dérivants afin de capturer les principales espèces de thons tropicaux (le listao, l'albacore, le thon obèse/patudo). Cette étude utilise les « connaissances écologiques locales » (LEK en anglais) obtenues par l'intermédiaire d'enquêtes standardisées lors d'entrevues auprès des capitaines de pêche afin de comparer et caractériser ces connaissances, la technologie de pêche et les stratégies de pêche des deux flottilles, et dans le but d'obtenir des informations utiles pour la gestion de la pêcherie. Une différence notable entre les flottilles concerne le nombre de DCP dérivants activement contrôlés par bateau, à un instant donné ; ce nombre étant beaucoup plus élevé pour les navires espagnols (60 contre 20 DCP environ). Les captures par unité d'effort (CPUE) par navire (captures par coup de pêche sur DCP dérivant) des thoniers espagnols sont également plus importantes que celles des navires français. L'usage de navires auxiliaires d'appui pour gérer, contrôler et protéger les DCP productifs, ainsi que la récente technologie basée sur le suivi par satellite des DCP dérivants, sont limités à la flottille espagnole. Les Français n'utilisent pas de navires auxiliaires et déploient des bouées moins sophistiquées. Ces disparités technologiques ont pour conséquences des stratégies de pêche différentes entre les deux flottilles, mais peu de différences sont observées en ce qui concerne la connaissance accumulée par les pêcheurs à propos du comportement du thon.

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1 Introduction

Fisheries scientists have collaborated with fishers in diverse ways to study fish populations, by collecting biological data onboard commercial fishing boats, installing sensors on vessels to collect biotic and abiotic environmental data, analyzing catch and effort data and species and size composition of landings. Other studies have analyzed fishers' behavior to understand its influence on catchability (Gaertner et al. 1999), to study the spatial organization of fish schools (Bertrand et al. 2005) and to examine the technological factors which have a potential to influence increases in fishing power and CPUE of tuna purse seiners (Gaertner and Pallares 1998). However, few studies have focused on collecting and analyzing in a scientific manner the empirical knowledge accumulated by fishers themselves. Some studies have applied Local Ecological Knowledge (LEK) of fishers to study the spatial distribution (Poizat and Baran 1997), migration (Valbo-Jorgensen and Poulsen 2001), habitat use (Silvano and Begossi 2005), predation (Davis et al. 2004), meso-scale behavior (Mackinson 2001), and more recently fine-scale behavior of fishes (Moreno et al. 2007), indicating the valuable scientific potential of utilizing this type of information. Because fishers spend so much time at sea and depend on their knowledge to succeed they have developed a large body of knowledge of fish behavior. However, one may also expect the accumulation of different or conflicting empirical knowledge if fishers (of different fleets for instance) utilize different gear and fishing strategies.

The tropical tuna purse-seine fishery in the Western Indian Ocean (WIO) is an example of a technologically advanced fishery that is largely dependent on the use of drifting fish aggregating devices[1] (DFADs). More than half of the 200 000 to 300 000 tons of tropical tuna, mainly skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna, captured every year by purse seiners in this ocean are caught around DFADs (Fonteneau 2000). Simultaneously, this fishery also targets free schools of large yellowfin, which are difficult to locate and to catch but highly valuable compared to DFAD associated tuna which are more often small fishes of lower value but are easier to catch. This duality in fishing modes needs to be considered when examining differences in fishing strategies and effort between purse seine fleets (Fonteneau 2003). This fishery is dominated by a European fleet mainly composed of French and Spanish vessels. Although both fleets exploit the same tuna populations with essentially the same fishing gear (tropical purse seine), differences in specific gear and fishing strategies exist. French purse seiners are known to be more dedicated to fishing on free schools than on DFADs (Fig. 1a). However, both the Spanish and French purse seine fleets make about the same number of sets per vessel (Fig. 1b), but Spanish vessels show significantly higher catches per vessel on DFADs since the mid-1990s when the use of artificial DFADs became common (Fig. 1c) (Delgado de Molina et al. 2006; Pianet et al. 2006). Such differences can influence their empirical knowledge base of fish behavior, and can also result in different consequences to the fish populations due to different fishing practices.

[1] DFADs in this paper refer to both natural and artificial drifting objects capable of attracting fish

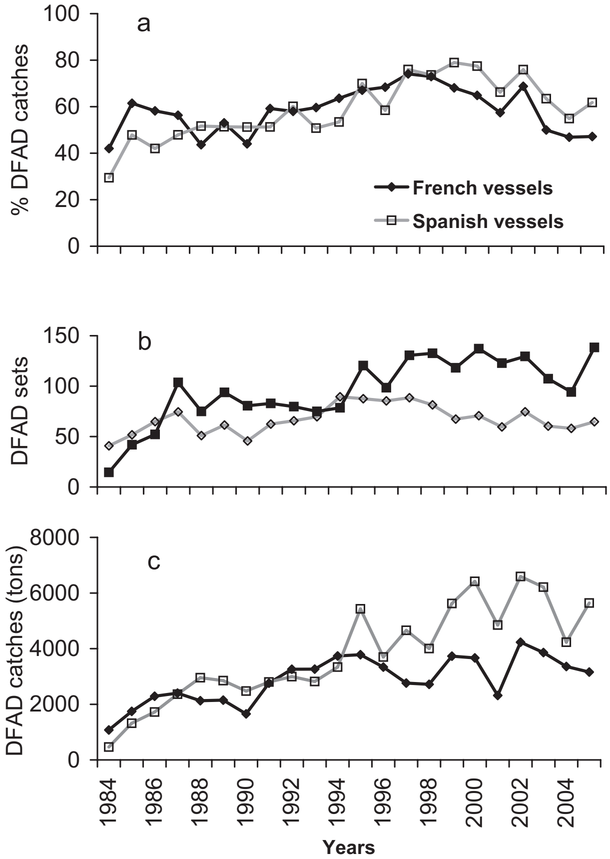

Fig. 1. a) Percentage of DFAD catches over the period 1984-2005 for Spanish and French purse seiner fleets; b) Number of FAD sets per vessel; c) Average FAD catches per vessel. From Delgado de Molina et al. (2006) and Pianet et al. (2006).

The main objective of this work was to examine the knowledge base of both fleets and characterize the main differences between the fleets in terms of their fishing strategies and use of FAD related equipment. This paper examines this fishery information to (i) investigate if these differences produce similar or differing empirical knowledge among fishers, (ii) how fisher empirical knowledge can help direct management efforts and (iii) help direct future management-related research.

2 Materials and methods

2.1 Data collection framework

LEK data was obtained through structured, personal interviews with the primary fishing master of European purse seine vessels actively engaged in the Western Indian Ocean tuna fishery. At the time of the interviews (2003–2005), the European purse seine fleet was composed of 30 Spanish vessels[2] and 15 French vessels. A total of 23 Spanish and 11 French

[2] From those "Spanish" vessels, 15 had Spanish flag and 15 were under Seychellois flag but belonged to the same Spanish companies and fishing masters and captains were also Spanish thus, in terms of strategy were considered as the same group.

purse seine fishing masters were interviewed, covering 76.6% and 73.3% of the Spanish and French fleets respectively. Interviewed Spanish fishing masters had an average of 13.3 years of personal experience in the Indian Ocean fishery (standard deviation: 7.1 years) while French fishing masters had 14.8 years of experience (standard deviation of 6.0 years). The accumulated time spent at sea in the Western Indian Ocean, calculated by summing all interviewed fishing masters' years at sea while removing time spent on land, added up to 163.4 and 129.6 man-years of practical DFAD experience for Spanish and French fishing masters, respectively. Forty percent of interviewed fishing masters had been active in the fishery during the 1980's, when only natural DFADs were exploited, allowing them to account for changes in fish behavior that may be related to the increasing number of total DFADs in the Western Indian Ocean.

2.2 LEK methodology

Gathering fisher's knowledge implies applying a well developed methodology which needs time to be dedicated explicitly. A critical factor is searching effectively for the most appropriate experts. As stated by Johannes (2000), we do not search at random when we want specialized advice in other context; we seek out experts.

Spanish and French purse seine vessels were the first to operate in the Western Indian Ocean around drifting FADs. These fishers originate from regions of Spain and France that have strong and long standing cultural traditions of fishing and seafaring. Fishers originating from such localities have a deeply engrained historical and cultural knowledge of environmental and ecological factors relevant to successful fishing based on the accumulated knowledge of several generations (Davis and Wagner 2003).

These men have become fishing masters through a demonstrated ability to locate and capture large quantities of tuna, suggesting that they have become experts in their profession. In this study specific experts were not sought out within fleets, because our initial goal was to interview one primary fishing master from each vessel ($n = 45$) covering all the Spanish and French fleets. Interviews were halted after covering 75% ($n = 34$) of the fleet after a clear pattern of responses was reached indicating that a demonstrated "saturation point" had been reached (Felt 1994; Neis et al. 1999; Davis and Wagner 2003).

Interview design and strategy were designed to gather information on their individual experience at sea (phase 1), their knowledge on the behavior of fishes around DFADs (phase 2) and their fishing strategies on DFADs (phase 3). Phase 1 was designed to test fisher's experience at sea. Questions within this first phase of the interview process included the years of experience fishing in WIO, number of years fishing with DFADs, number of years as fishing master, etc.

Different strategies were employed in the interview process to avoid or detect potentially false information. On one hand, fishers were instructed to refuse answering sensitive questions rather than provide false or misleading information. On the other hand, fishers were not subjected to a formal questionnaire format which usually makes them more suspicious, but in a conversational way in an informal and comfortable setting. Finally, we showed that their experience was being taken seriously and that interviewers were somewhat knowledgeable but interested in learning more on the topic, which encouraged fishing masters to show their degree of knowledge. This point should not be dismissed by future scientists working with LEK methodology. The knowledge and social skills of the interviewers are crucial, to pick up the details that are important for the study and to steer the discussion toward new and productive directions. An effective interviewer clearly acknowledges the experience and status that a successful fishing master deserves, which in turn makes them feel that their answers will be seriously considered and relevant to the study.

During phase 2 of the interview, fisher's did not consider any of the questions relating to fish behavior as being too sensitive to answer. On the contrary they made every effort to discuss and exchange their observations and knowledge related to fish behavior around DFADs. Within phase 3 on DFAD fishing strategy, only one question was considered sensitive, which related to the number of DFADs a vessel monitored per trip. If the question was not answered by some fishing masters, some information could still be obtained from other fishing masters since fishers from a same company usually have a similar amount of monitored DFADs and some of them were sharing DFADs with other vessels of the same company.

Other questions related to fishing strategy were not considered to be overly sensitive or confidential by fishers, and we considered their answers to be valid. The validity of answers to such questions as "Do you share buoys with other vessels?" or "Which type of tracking buoy do you use?" could also be confirmed during the interviews which took place onboard the vessels, as well as by scientists examining observers data. It did not seem logical that the fishers would lie about many of the questions, such as those related to the time of set or life expectancy of a DFAD buoy. General or unanimous agreement by interviewed fishing masters within fleets for some of these questions also suggested that the responses were valid.

However, as with any research method, LEK has its limitations and fisher's responses maybe self-serving and misleading, for instance when they are in contradiction with scientific data collected by observers. As stated by Johannes (2000), sometimes this may be true, but biologists have the responsibility not to dismiss such claims before investigating carefully what lies behind them.

Interviews were conducted onboard purse seine vessels in Victoria port, Seychelles during 2004 and 2005. In the present study, data on fish behavior around DFADs and fishing strategy with DFADs were analyzed by fleet in order to identify differences in LEK due to different fishing strategies while working with DFADs (see Moreno et al. 2007, for a more detailed description of the interview process).

2.3 Model to test differences by fleet

In order to test differences in responses of French and Spanish fishing masters regarding questions related to fish behavior around DFADs, a likelihood ratio test of multinomial models was conducted for each question (Venables and Ripley 2002). The answers to the different questions did not follow a normal distribution. Thus, to test if the responses from Spanish and French fisher's were significantly different, a test for a multinomial distribution, fulfilled by our data, was used. The objective was to test if "nationality" (Spanish or French fleet) of the fisher's helped to explain the variance in the answers which was tested through the application of multinomial generalized linear models (GLM). First, two multinomial linear models were fitted to the replies, one without explanatory variables (the null model) and another incorporating nationality as the explanatory variable (the alternative model). If the answers differed by nationality, the second model would provide a better fit to our data (as the nationality variable will explain a significant percentage of the variance in the data) and the likelihood ratio test selected the second model.

$$M0 : Y_i \sim \rho_i$$
$$M1 : Y_i \sim \rho_i + \beta_i$$

For each question, *Yi* represents the number of individuals that answered i, ρ_i is the intercept and β_i is the coefficient of Nationality. To test which of the models provided a better fit to the data, as they were nested models, a likelihood ratio test (LRT) was performed for each question. The LRT is a statistical test of the goodness-of-fit between two nested models and the LRT statistic is defined as:

$$LRT = -2 \cdot \log\left(\frac{L0}{L1}\right)$$

where $L0$ and $L1$ are the likelihoods of the simpler and more complex model respectively. Under the null hypotheses the LRT statistic is distributed as a chi-squared random variable, with degrees of freedom equal to the difference in the number of parameters between the two models. For each question the LRT value and the corresponding p-value were calculated. If the p-value of a particular question was lower than a significance level $\alpha = 0.05$, the null hypotheses was rejected according to the LRT test, i.e., the alternative model, the one which includes nationality as explanatory variable, was considered to fit better to the data. This would mean that the answers of the individuals to this particular question were significantly different depending on their nationality.

3 Results

Detailed answers from fishers to the questions related to the fishing strategy are presented in Table 1. The total number of responses for each question did not always match the total number of fishing master interviews, because some fishing masters did not answer every question, and some often provided multiple answers to open-ended questions on fish behavior, since no specific answers were suggested by the interviewers.

Table 1. Fishing strategy according to Spanish and French fishing masters. The number of monitored drifting FADs at sea, in average, are 60 by Spanish vessel and 20 by French vessel.

Question/Response	% Spanish	% French
Do you share buoys with other vessel/s of the company?		
yes	70 (14)	0
no	30 (6)	100 (4)
Ratio of the FAD type used?		
natural	30	22
own FADs	9.3	58
transferred	67.2	20
Type of tracking buoy used?		
GPS tracking radio-buoy	4.4 (1)	100 (8)
satellite linked buoy	30.4 (7)	0
various types	65.2 (15)	0
Which is the life time of a buoy?		
1–3 months	57.1 (12)	50 (5)
6 months max	38.1 (8)	40 (4)
1 year max	4.7 (1)	0
< 1month	0	10 (1)
Has the time of day for FAD fishing changed?		
yes	100 (14)	100 (7)
no	0	0
At what time do you usually fish?		
1–4 h after sunrise	71.4 (10)	16.6 (1)
depends on the area	28.6 (4)	0
anytime	0	83.3 (5)
Do you have supply vessel?		
yes	48 (11)	0
no	52 (12)	100 (11)

( ) Number of observations.

3.1 Fishing with FADs

3.1.1 FAD-Related equipment

Number and type of DFADs used

We asked each fishing master how many actively monitored buoy-equipped DFADs (radio or satellite transmitters) they have in operation on a daily basis while at sea. It is important to note that 70% of the interviewed Spanish vessels share DFADs with other vessels of their company, which allowed us to check the consistency of their responses regarding the number of buoys estimated by fishing masters from the same company. Responses were found to always be consistent and in agreement with each other. The estimated average number of actively monitored DFADs was approximately 60 drifting objects at any given time at sea for each Spanish vessel and 20 for French vessels. The estimated total number of actively monitored DFADs for the entire European fleet in the Western Indian Ocean was approximately 2100 drifting objects at any given time (Moreno et al. 2007). Fishing masters acknowledged that this estimate is highly dynamic, as FADs can sink or be appropriated by other purse seiners. Also, Spanish vessels can carry the same amount of additional buoys onboard as are deployed at sea, ready to attach to newly seeded artificial FADs or when natural logs or FADs from other vessels are located.

Type of tracking buoys used

Most of the Spanish vessels (65.2%) worked with a mixture of buoy types: radio transmitting GPS tracking buoys, satellite reporting tracking buoys, and/or satellite linked sonar buoys capable of providing crude biomass estimates (Morón et al. 2001). A few Spanish vessels (4.4%) used only GPS

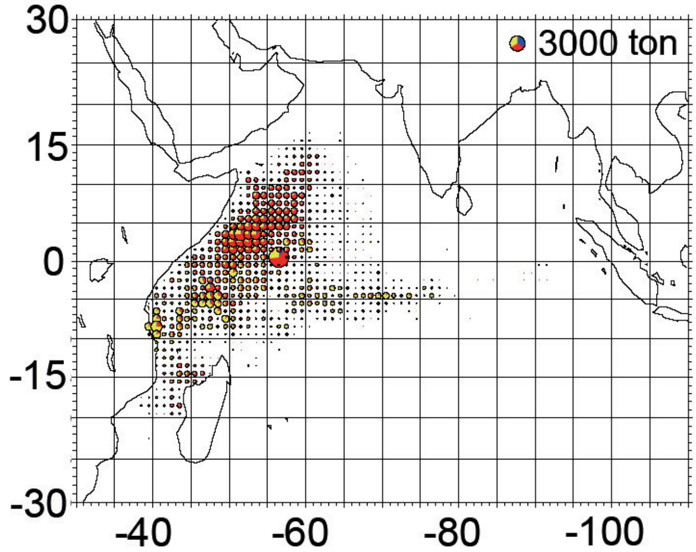

Fig. 2. Spanish fleet: Distribution of catches on DFADs by species and 1° × 1° squares of the purse seine Spanish fleet in 2000-2004. Circle diameter are proportional to catches of skipjack (red), yellowfin (yellow) and bigeye (blue) tuna. From Delgado de Molina et al. (2006).

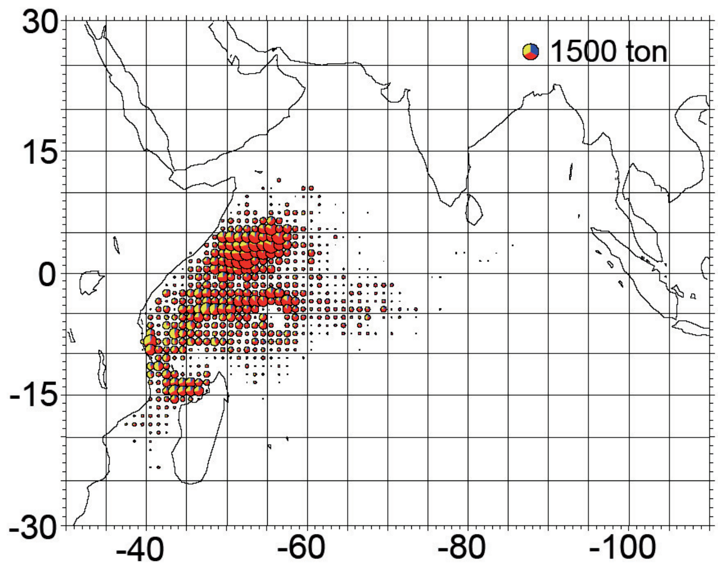

Fig. 3. French fleet: Distribution of catches on DFADs by species and 1° × 1° squares of the purse seine French fleet in 2000-2004. Circle diameter are proportional to catches of skipjack (red), yellowfin (yellow) and bigeye (blue) tuna. From Pianet et al. (2006).

tracking radio-buoys, and around a third of the vessels (30.4%) used only satellite linked buoys. All French vessels (100%) exclusively employed GPS tracking radio-buoys. More than half (58%) of the DFADs fished by Spanish vessels were set and owned by those vessels, while two thirds (67%) of DFADs fished by French vessels were transferred from other sources. All fishing masters, French and Spanish, agreed that the newer generation of tracking buoys promoted the discovery of new fishing areas in the Western Indian Ocean when DFADs drifted away from known fishing grounds, often citing the case of fishing grounds in northern latitudes above 15° N, such as those northern than Socotra Island area. Figures 2 and 3 indicate the distribution of tuna catch on DFADs by the Spanish and French purse seine fleets over the period 2000-2004 in the Western Indian Ocean fishery.

Monitored DFADs' life time

About half of Spanish (57.1%) and French (50%) fishing masters thought their DFADs had a useable life time of 1 to 3 months, while 38.1% of Spanish and 40% of the French fishing masters felt their buoys lasted up to six months. Some Spanish fishing masters (4.7%) estimated the maximum time at sea for a DFAD as high as 1 year. All agreed that the life time of a DFAD is highly variable depending on the area and

Table 2. Fish behavior around drifting FADs according to Spanish and French fishing masters.

Question/Response	% Spanish	% French
Radius (nautical mile) of attraction of drifting FAD?		
0–2 nmi	35 (7)	40 (4)
2–5 nmi	45 (9)	50 (5)
>5 nmi	15 (3)	0
species dependent	5 (1)	0
area dependent	0	10 (1)
Time needed for non-tuna species to aggregate around a drifting FAD?		
1 week	75 (3)	44.4 (4)
2–3 weeks	25 (1)	44.4 (4)
4 weeks	0	11.1 (1)
Time needed for tuna to aggregate around a drifting FAD?		
not time dependent	90.9 (10)	0
1 week	0	0
2 weeks	9.1 (1)	9.1 (1)
1 month	0	72.7 (8)
>1 month	0	18.2 (2)
Drifting FAD with only tuna aggregated?		
never	63.6 (14)	40 (4)
rare	36.4 (8)	60 (6)
sometimes	0	0
Number of shoals or schools of tuna that form a drifting FAD aggregation?		
one	0	18.2 (2)
multiple	100 (18)	81.8 (9)
Organization into different shoals?		
species	41.2 (7)	63.6 (7)
size	5.9 (1)	0
both species & size	41.2 (7)	27.3 (3)
order of arrival	11.7 (2)	0
time of day	0	9.1(1)
Reasons for tuna to leave a drifting FAD?		
current/trajectory change	43.5 (10)	30 (8)
lack of trophic resources	4.4 (1)	0
presence of marine mammals	8.7 (2)	30 (8)
temperature	39.1 (9)	0
excessively large sized aggregation	0	3.7 (1)
continental platform	0	37 (10)
storms	4.4 (1)	0

( ) Number of observations.

the season. For instance, in the Somalia fishing grounds in October, which is an important DFAD fishing area and season, DFAD life time is shorter because the fleet is concentrated in the area and many buoys are lost to other vessels. Spanish fishing masters commented that in this area and season, they will deploy DFADs further apart one from the other to lessen their chance of discovery by competing vessels.

3.1.2 DFAD fishing strategy

Time of fishing operations

All French and Spanish fishing masters agreed that the starting time for DFAD fishing operations has changed over time in the Western Indian Ocean fishery. When DFAD fishing began in the 1980's, fishers believed that tuna were more abundant and more easily caught around FADs early in the morning. Consequently, they mainly made sets around DFADs at sunrise. Currently, the majority of French fishing masters (83.3%) said that they could set around DFADs at any time of the day and the majority of Spanish (71.4%) fish around DFADs from 1 to 4 hours after sunrise. Some Spanish fishing masters (28.6%) precised that the fishing time depends on the area, explaining that in specific zones, through the use of sonars, echosounders and binoculars, they commonly observe tuna schools arriving at FADs from 1 to 4 hours after the sunrise.

Table 3. ANOVA table showing the number of observations, the residual degrees of freedom of the complete model, the percentage of total variance explained by fleet (Spanish or French fleet) and the *p*-value obtained when comparing the null model with the alternative one.

Question	n	Resid. df	%Var	p-value*
Attraction distance	29	21	8	0.24
Time for non-tuna species to aggregate	13	9	6	0.48
Time for tuna species to aggregate	22	16	54	$< 10^{-5}$
Only tuna on DFADs	32	30	4	0.21
Number of shoals	29	27	28	0.04
Shoal organization	28	20	9	0.21
Departure from FAD	50	38	22	$< 10^{-5}$

* The likelihood ratio tests the difference of residual log-likelihood between two nested models.

Use of supply vessels

An important difference between Spanish and French fleets when working with DFADs is the use of supply vessels. Supply vessels are used to deploy, monitor and maintain DFADs for use by one or more purse seine catcher vessel(s) belonging to the same company (Itano et al. 2004). One of the primary roles of a FAD supply vessel is to search for and appropriate DFADs belonging to other vessels by replacing the existing radio buoy with one of their own (Arrizabalaga et al. 2001). FAD supply vessels regularly visit buoy-equipped DFADs to estimate the size of the aggregated tuna schools and report this information to their associated catcher vessel. Particularly promising DFADs are actively protected by supply vessels from setting by competing purse seiners. At the time of the interviews, none of the French vessels worked with supply vessels, while almost half (48%) of interviewed Spanish vessels operated with the assistance of a supply vessel (12 supply vessels were used by six of the seven Spanish companies).

3.2 Fish behavior

Answers regarding fish behavior around DFADs were divided by fleet as shown in Table 2. Fishers from both fleets were in general agreement on the following questions (Table 3): *Attraction distance of DFADs* was thought to be from 0 to 5 nautical miles (nmi) for 90% of French and 80% of Spanish respondents; *the time required for non-tuna species to aggregate around DFADs* was stated as 1 to 3 weeks for 100% of Spanish and 89% of French fishing masters; and *the organization of tuna shoals when aggregated to DFADs* was thought to be by species or by species and size for 83% of Spanish and 81% of French captains. Both fleets also agreed that DFAD fish aggregations consisting of only commercial tuna species (without the presence of by-catch species) rarely or never occurred.

Nationality, which would account for the different strategy working with the DFADs for French and Spanish i.e. different number of DFADs, different effort devoted to DFAD fishing, etc., explained the differences in responses to three questions (Table 3): *time required for tuna to aggregate around DFADs,* which is not considered time-dependent for most (91%) of the Spanish and one month for the majority (73%) of French fishing masters. Most of Spanish fishing masters (83%) felt that *tuna schools left DFADs* due to changes in current/trajectory and sea surface temperature while French fishing masters thought that trajectory, the appearance of marine mammals and movement over shallow areas contributed to tuna departures. Finally, all the Spanish (100%) and 82% of French fishing masters felt that DFAD tuna aggregations consisted of several different schools massed at the FAD. However, 18% of French responses suggested that DFAD aggregations were composed of a single shoal.

4 Discussion

Our interviews indicate that Spanish purse seine vessels normally monitor three times more DFADs than French vessels and work cooperatively by sharing the DFADs of other Spanish seiners, effectively doubling their pool of monitored FADs. Having a larger number of accessible DFADs could lead one to think that Spanish boats would be making more FAD sets on average than the French, but both fleets make about the same number of sets per year. However, the Spanish fleet has a significantly higher catch per FAD set per vessel than the French vessels, suggesting that other operational differences are responsible for increasing the catches of Spanish vessels around DFADs. Key differences between fleets noted during the interviews included the Spanish use of FAD supply vessels and a variety of monitoring buoys. The supply vessels provide clear advantages to their catcher vessel by extending their searching range, protecting productive DFADs from theft and taking care of FAD maintenance, thus allowing the purse seiner to concentrate effort on the most productive areas and DFADs (Arrizabalaga et al. 2001). Their use of satellite linked buoys and sonar buoys, both of which are difficult to locate by competing vessels due to the lack of a visible antenna, provide the Spanish fleet with longer range remote monitoring of aggregations with a reduced likelihood of theft from other vessels. In other words, a larger number of DFADs to choose from over a broader area that are remotely monitored produce higher catches rather than simply making larger numbers of sets. From a management perspective, this reinforces the importance of the number of FADs deployed per vessel, the use of supply vessels and sophisticated satellite buoy technology to purse seine efficiency and the need to incorporate these factors into calculations of effective fishing effort.

Fishing masters of both fleets recognize the importance of having as many tracking buoys to monitor DFADs as possible, and believe that monitoring more DFADs is the most efficient way to increase DFAD catch. However, the economic circumstances of the fishery and fishing companies at any given time will play an important role in determining the number of DFADs deployed at sea. If management measures restrict the number of monitored DFADs allowed per vessel, the impact of the regulations would be felt more strongly by the Spanish fleet. This would be particularly acute if the limit were less than 60 DFADs per vessel. French vessels may also be influenced as this study found that they depend heavily on encounter rates with FADs belonging to other vessels. We have seen with the Spanish that more monitored FADs did not result in more FAD sets, but contributed to higher catch rates. Therefore, a general limitation in the number of monitored FADs available to the fishery might not lead to fewer FAD sets, but to lower tuna CPUE on FAD sets. This would then contribute to decreased tuna catches, which could benefit species such as bigeye tuna that are taken at juvenile sizes on DFADs (Fonteneau et al. 2000). However, by-catch levels of non-tuna finfish species would probably not be affected as the overall number of FAD sets remains more or less equal, and DFADs are first colonized by non-tuna species (Moreno et al. 2007). Undoubtedly, vessels would eventually respond to declining target CPUE by increasing effort which could then result in increased quantities of by-catch. Specific modelling and simulations that incorporate the dynamic nature of gear and operational differences between fleets that were investigated in this study should be performed to further investigate these fishery issues. Our study indicates that it is of primary importance to further investigate the possible consequences of management measures that reduce the number of monitored DFADs.

The French fleet uses GPS tracking buoys equipped with long radio antennas with an effective transmission range of around 1000 nmi. Spanish vessels use several types of buoys to monitor their DFADs, including satellite tracking buoys and satellite transmitting sonar buoys equipped with vertical echosounders for biomass estimations. At the time of the study interviews (2003-2005) most of the fishing masters did not trust biomass estimates from these buoys. However, sonar buoy technology is improving rapidly, providing clearer images and more accurate estimates of fish species and aggregation size. Currently Spanish fishers are reporting favorable results with newly marketed sonar buoys that appeared after our interviews were made (G. Moreno pers. observation). Satellite tracking buoys offer unlimited reporting range with power significantly supplemented with solar panels. All of these factors highlight the constant and rapid improvements made to fishing gear, and electronic equipment in particular, that can significantly increase the effective effort and efficiency of purse seine vessels. Obviously, these developments need to be closely monitored and factored into attempts to manage fishing effort and manage the fishery, as it is recognized world-wide by each of the tuna commission which are trying to use the purse seine fishery catch and effort data in order to evaluate the status of the tuna stocks (Fonteneau et al. 1999).

The type of buoys used by each fleet determines the theoretical longevity and drifting range for buoys and DFADs, with a longer life and greater distance potential for solar panel equipped satellite buoys that are used by many Spanish vessels. However, the effective life time of a DFAD to a particular vessel depends on the detection rate of DFADs by other vessels, which normally replace the original tracking buoy with their own if a newly found DFAD appears promising. Our results indicated that the expected life time of DFADs does not significantly differ between French and Spanish fleets that mainly use radio buoys and satellite buoys respectively. This is surprising as satellite buoys use flat plate antennas that reduce their visibility making them more difficult to detect by other vessels (Itano et al. 2004). This suggests that fishers have become very efficient at locating and appropriating DFADs that do not belong to them. The active use of sonar to detect tuna schools on DFADs and bird radars which allow remote identification of bird flocks that are often associated to all types of DFADs assist vessels in detecting DFADs owned by other vessels. DFAD management should be based on the total number of DFADs on the fishing grounds and consider that all DFADs are potentially available to all vessels in the region.

There was a clear difference regarding the diel time of fishing, as most of the French fishing masters said that they could now fish around DFADs at any time of the day if tuna are detected, while Spanish generally fish 1–4 hours after sunrise. All (100%) of French and Spanish fishing masters agreed that DFAD fishing time had changed in recent years, even if sets in the morning are still predominant. This result should not be dismissed, because it might indicate that the change is taking place in specific areas, or that this perception of change is not yet reflected on fishery data. It is difficult to consider that fisher's could have lied in their answers to this question that is not sensitive. However, potential bias could also come from other sources of uncertainties, such as fishers providing simple answers when addressing complex questions. A simple basic answer can not be obtained when the perfect answer is very complex and needs to be estimated by a complex statistical situation/evolution. Our results should be compared with the DFAD sets observer data that have been collected by the IOTC on the EU purse seiners in Western Indian Ocean since 1984. Gaertner et al (1999) showed that in the Atlantic Ocean, about 50% of DFAD sets were observed between 6h-8h in the morning, but this type of data can not be extrapolated to other oceans as each tropical ocean has its own characteristics in DFAD fishing. A significant consequence of changing the time of set to after sunrise and throughout the day could be a reduction in the amount of juvenile bigeye catch as bigeye are known to descend deeper in the water column during the day. This situation should be investigated further as any possible means to reduce bigeye catch on floating object sets should be promoted, including changes in set times.

During the initial development of the Indian Ocean FAD fishery (before the implementation of tracking buoys), Spanish and French had more or less the same level of experience using DFADs. The current difference in the timing of DFAD fishing between the two fleets could be a consequence of the fact that Spanish monitor a greater amount of DFADs, and often have supply vessels visiting DFADs for them before they arrive, helping to plan and maximize their fishing efforts on DFADs and allowing to plan for making sets at their preferred morning period. However, Spanish fishing masters also observed that in specific areas tuna can behave differently than in others, displaying different arrival times to DFADs. It is unclear if the different diel fishing patterns displayed by fishers are related to real diel differences in tuna abundance and catchability under DFADs, or if they are the result of fleets having different degrees of fish monitoring efforts.

Detailed analyses of the fisher's knowledge on fish behavior are presented in Moreno et al. (2007). The existence of agreement or differences in knowledge regarding fish behavior within the fishery can help direct management efforts and direct future management-related research. One of the major conclusions from our interviews is that there were very few differences in the perception of fish behavior between the two fleets. For many years (until the late 1990's), French and Spanish were somewhat equal in terms of FAD effort. This is the period when the fleets acquired most of their FAD related knowledge, which explains the consensus on most of behavioral questions. This could indicate that fisher's knowledge may have reached a saturation point. New knowledge could develop when fishers start to use new technologies or address new issues. For example, if they were forced to reduce their catch of bigeye tuna or small yellowfin tuna on DFADs, it is likely that they would develop a broader knowledge base of tuna behavior to address these issues.

It appears that during the first years of the FAD fishery, both Spanish and French thought that the time required for tuna to aggregate around new DFADs was about one month. Currently, Spaniards consider that aggregation time is highly variable and not time dependent. Since Spanish fishers responded that (i) you do not find tuna around DFADs without the presence of non-tuna species, and (ii) it takes 1–3 weeks for non-tuna species to aggregate around FADs, it seems that Spanish fishers consider that there is a minimum of 1–3 weeks for tuna to aggregate. But their answers mainly imply that the "maturation" and aggregation process could be much faster than were initially thought. Several years ago DFADs were usually seeded and left to "soak" for one month, and fishers had no information of what happened during this month long period, which is the present scenario for the French fleet. The current measured differences between the two fleets may be due to the fact that Spanish vessels can monitor seeded DFADs through the use of supply vessels and recently with sonar buoys. Therefore, Spanish skippers have a larger "knowledge database" on the presence of tuna during the life time of DFADs and can harvest an aggregation as soon as it forms.

Change of currents or DFAD trajectory was cited by both French and Spanish as an important reason for tuna to depart from DFADs. But Spanish fishing masters also suggested changes in temperatures as an important factor (independent of current changes), while the French suggested the crossing over continental platforms (not mentioned by Spanish) and appearance of marine mammals as important factors causing tuna departure from DFADs. It is important to note that the reasons for tuna to leave the DFAD can be more than one. We believe that differences between French and Spanish answers could be related to the fact that French tend to operate in areas closer to the continental platform than Spanish vessels (Fig. 2). This is an example of the value of interviewing both fleets to better understand fish behavior in different environments, since both fleets provided different but valid responses to the same question, likely due to their different fishing strategies.

All (100%) of the Spanish and 82% of French answered that multiple schools form a DFAD aggregation, few (18%) French fishing masters also advanced that unique school of tuna can be found around DFADs. It appears that the acoustic equipment used to observe schools around FADs can play a major role on the fisher's knowledge, as new high-tech sonars and echosounders provide more detailed views of the aggregations than older equipment still present on some vessels. However, the main result is that the vast majority of fishmasters consider that usually, a DFAD aggregation is composed of several schools.

5 Conclusion

LEK data obtained from purse seine fishing masters appear to be a useful tool to study fish behavior around DFADs (see Moreno et al. 2007). Although some of the results on fishing strategy can be better obtained from observers' data, we gathered this information to investigate if differences in strategy produced similar or differing empirical knowledge among fishers. Because fishing strategy and technological developments are evolving so rapidly we considered it necessary to gather technical information from fishers at the same time with information on fish behavior. However, fishing strategy should also be gathered using fishery observer data, especially for describing the evolution of fishing strategies. We have shown the Spanish fleet's expanded use of remotely monitored DFADs in recent years compared to the French fleet has not led to major differences in terms of their knowledge of fish behavior, which seems to have peaked for both fleets. We suggest that both fleets have similar empirical knowledge because most of it was acquired during the initial phase of the fishery, when they shared similar fishing strategies and reinforced them through frequent dialogue between many of the fishing masters. However, some differences were found, which justifies the importance of multi-national fishery studies instead of studies based on single fleets in order to obtain complete and balanced information. Fishers, as scientists, depend on the tools they use to obtain data and build their knowledge base. Technological developments and differences between fleets (e.g. the adoption of improved sonar buoys by the Spanish following this study) could rapidly result in additional differences in knowledge or perception of fish behavior around DFADs. Future LEK studies should be developed for the next few years as their knowledge may evolve rapidly with new technological advancements. One recommendation would be to identify the most appropriate experts among fishing masters of both fleets, in order to address them with more specific and complex questions (Johannes et al. 2000). However, a variety of fishers should be consulted, as interviewing fishers with different strategies enriches the knowledge and provides information on different operational scenarios. Fishery scientists have developed protocols to collect on a regular basis data on size and species composition of catches, catch and effort through logsheets and fishery data from observer programs, and new efforts are being made to develop FADs as observatories of pelagic ecosystems. We here propose that fisheries, ecological and behavioral knowledge of fishers based on regular and standardized interviews, should be collected to compliment the other traditional sources of information.

Some people could consider that fisher's could lie to questions asked by scientists, this is a possibility, but we have shown that there are several ways to avoid such issue. However, other sources of uncertainties may arise from answers that may be honest but not entirely accurate to mask sensitive issues of by catch, discards, appropriated FADs, etc. As stated before, LEK has its limitations. Recognizing them and comparing results to traditional data sources is of primary importance as with any source of information. It could also be true that when entering logsheet data fisher's do not always report catch and effort data with the accuracy required by scientists, which could also lead to false interpretations of logbook data. We believe LEK studies are complimentary to traditional fishery data and we consider that fisher's knowledge is a very useful source of information that should be regularly documented and fully integrated into scientific analyses and stock assessments conducted by international tuna commissions.

Local knowledge is important to give qualitative viewpoints in uncertain systems (Nielsen et al. 2004). Moreover, such regular interviews with the objective of using empirical knowledge of fishers for scientific and management purposes would have a great value by insuring a close dialogue between scientists and fishers. When we talk about managing a resource we really mean managing the people who use that resource. In order to do so more effectively, studying and putting to use their knowledge, with their collaboration and endorsement does not seem unreasonable (Johannes 1981). This would allow more meaningful analyses of catch data and foster a better collaborative environment between both groups. The more thorough understanding of the components of effort then allows more informed management to be applied to the fishery.

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Erratum

Using local ecological knowledge (LEK) to provide insight on the tuna purse seine fleets of the Indian Ocean useful for management

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In Figure 1b, an inversion of symbols occurred for Spanish and French series. This information is now correctly shown in Figure 1.

Additionally, in Table 1: Fishing strategy according to Spanish and French fishing masters. Answers to the question: *Ratio of the FAD type used?* were also inverted, answers corresponding to French were allocated in Spanish column and vice versa. This question should be read as follows:

Ratio of the FAD type used?

	% Spanish	% French
Natural	22	30
Own FADs	58	9.3
Transferred	20	67.2

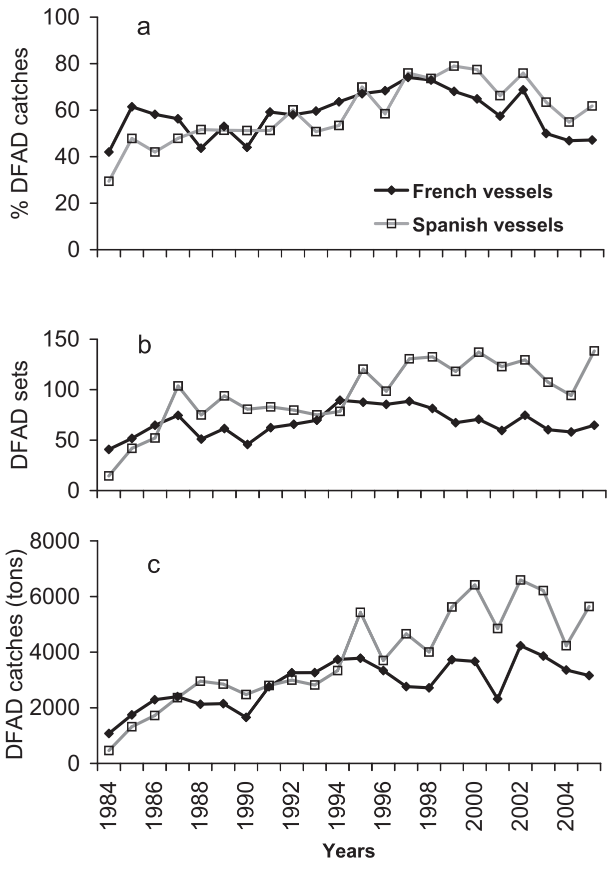

Fig. 1. a) Percentage of DFAD catches over the period 1984-2005 for Spanich and French purse seiner fleets; b) Number of FAD sets per vessel; c) Average FAD catches per vessel. From Delgado de Molina et al. (2006) and Pianet et al. (2006).