Fish behaviour from fishers' knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs)

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Abstract: Purse-seining for tropical tuna is one of the most technologically advanced fisheries in the world. The purpose of this study was to apply local ecological knowledge (LEK) to assist in the planning of future in situ studies of fish behaviour around drifting fish aggregating devices (DFADs) by prioritizing research topics, thereby reducing the number of potential hypotheses to explore. Interviews of fishing masters of the purse-seine fleets working in the western Indian Ocean provided an alternate, independent, and previously unexplored source of behavioural information, specifically on the attraction, retention, and departure behaviours of tuna schools in relation to DFADs. Most fishing masters agreed that the maximum attraction distance of a DFAD is approximately 10 km and generally agreed to the following statements. Tuna form distinct schools under FADs, commonly segregated by species and size. The main reasons for the departure of tuna aggregations from FADs are changes in currents or FAD movements and location in relation to physical or oceanographic features. The number of actively monitored DFADs at sea in the western Indian Ocean was estimated at approximately 2100. Incorporating fishers into the planning and design stages of future research projects will facilitate collaborative and integrated approaches.

Résumé : La pêche thonière tropicale à la senne coulissante est l'une des pêches commerciales les plus avancées technologiquement au monde. Le but de notre travail est d'utiliser les connaissances écologiques locales (« LEK ») pour aider à planifier les études futures in situ sur le comportement des poissons autour des dispositifs dérivants de concentration des poissons (« DFADs ») en établissant une priorité dans les sujets de recherche, réduisant ainsi le nombre potentiel d'hypothèses à explorer. Des entrevues avec les capitaines de pêche des flottes qui utilisent la senne coulissante dans l'ouest de l'Océan Indien fournit une source de remplacement indépendante et encore inexplorée de renseignements comportementaux, en particulier sur les comportements d'attirance, de rétention et de départ des bancs de thons en relation avec ces DFAD. La plupart des capitaines de pêche sont d'accord que la distance maximale d'attraction d'un DFAD est d'environ 10 km et ils conviennent généralement des propositions suivantes : les thons forment des bancs distincts sous les FAD, souvent séparés en fonction de l'espèce et de la taille; les raisons principales de l'abandon des FAD par les rassemblements de thons sont des changements dans les courants ou alors les déplacements et les positionnements des FAD par rapport aux caractéristiques physiques ou océaniques. Le nombre de DFAD qui sont suivis activement en mer dans l'ouest de l'Océan Indien est estimé à environ 2100 objets en dérive. L'implication des pêcheurs dans les phases de la planification et de la conception des futurs projets de recherche favorisera la collaboration et l'intégration.

[Traduit par la Rédaction]

Introduction

Studies on fish behaviour have typically been carried out by animal behaviourists working at fine scales with the aim of understanding fundamental behaviour patterns (Pitcher 1993). Researchers in population dynamics understand that fish behaviour can introduce bias into fishery stock assessments, but most joint studies have only examined the effects of behaviour from a theoretical point of view. As stated by Fréon and Misund (1999), it is surprising how few applied studies in population dynamics have incorporated fish behaviour because of the lack of knowledge in this field.

For the commercial fishers, the behaviour of their quarry is a day-to-day concern that directly impacts their livelihood. Fishers must understand the three-dimensional spatial dynamics of the fish, schooling, swimming, and escape behaviours in order to decide where, when, and how to operate at peak efficiency. Because fishers spend so much time at sea and depend on their knowledge of fish behaviour to succeed, they consciously acquire large amounts of empirical knowl-

Received 5 January 2007. Accepted 14 July 2007. Published on the NRC Research Press Web site at cjfas.nrc.ca on 24 October 2007. J19741

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edge on fish behaviour. This represents a large and valuable body of knowledge on fish behaviour that has rarely been tapped by fishery researchers. Likewise, few studies examining local ecological knowledge (LEK), nonscientific information provided by local resource users, have dealt with fine-scale fish behaviour. Most of the LEK studies published thus far relating to fish behaviour have been devoted to describing spatial distribution (Poizat and Baran 1997), migration (Valbo-Jorgensen and Poulsen 2001), habitat (Silvano and Begossi 2005), and predation (Davis et al. 2004), with few devoted to the study of fine-scale behaviours. Johannes and Hviding (2000) described fine-scale movements and behaviour of reef fish aggregations from fisher's knowledge, showing the high degree of detailed information gathered by fishers and, therefore, the potential of LEK as a valuable source of knowledge of fine-scale behaviours. However, in general, few studies examining LEK have applied fine-scale fish behaviour as Mackinson (2001) did with mesoscale behaviour, providing quantitative and qualitative predictions on the structure, dynamics, and distribution of herring shoals integrating scientific and local knowledge in a heuristic model.

The objective of this study was to use knowledge acquired by fishers on the behaviour of fish in order to identify priorities in future scientific behavioural studies. Specifically, we studied the associative behaviour of tropical tuna schools around drifting fish aggregating devices (DFADs). This study case was chosen for two main reasons. First, the origin of this associative behaviour and its impacts on tuna dynamics are still unknown. Second, this striking behaviour plays a key role in worldwide tuna fisheries, as about 50% of the world's tuna catches come from fish associated with FADs (Hampton and Bailey 1993; Pianet et al. 2004, 2005). (In this paper, the term FAD refers to any object floating at the surface that can attract pelagic fish, such as natural logs or man-made structures such as buoys and rafts.)

Background and research context

Drifting fish aggregating devices (DFADs)

Pelagic fishes such as skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tuna are often found in association with floating objects (Parin and Fedoryako 1992; Castro et al. 2002). Fishers have been deploying purpose-built FADs for years to attract and harvest pelagic fishes. These FADs are often anchored (here referred to as anchored FADs or AFADs) close to tropical island coastlines to allow the development or maintenance of artisanal fisheries that can play an important role in local economies (Fréon and Dagorn 2000). However, the majority of FADs used worldwide are free-drifting objects, or drifting FADs (DFADs), exploited by industrial tropical tuna purse-seine fleets (Fonteneau et al. 2000). Two main types of DFADs are exploited in purse-seine fisheries. Natural DFADs are most commonly logs and branches drifting from coastal areas but also include floating debris of human origin such as ropes, oil drums, fishing buoys, etc. Man-made (artificial) floating structures are purpose built and deployed specifically for the purpose of fishing. Artificial DFADs used in the western Indian Ocean are often bamboo rafts, with purse-seine corks to increase strength and floatation (Fig. 1) and pieces of netting hanging down to act as a drift anchor and provide hiding places for small associated fishes (Armstrong and Olivier 1995; Itano et al. 2004). When deploying an artificial DFAD, or when finding a natural DFAD, fishers attach a radio or satellite-linked transmitting buoy to monitor its movements and location.

Tuna purse-seine fishery of the western Indian Ocean

Presently, purse-seining for tropical tuna is one of the most technologically advanced fisheries in the world (Fig. 2). In the Indian Ocean, tuna purse-seining began in the early 1980s following exploratory fishing by European live-bait pole-and-line and purse-seine vessels. Purse-seine landings of tuna associated with natural floating objects accounted for about 50% of the catches in the Indian Ocean in the early 1980s (Fonteneau 2003). In the second half of the 1980s, radio buoys were utilized to monitor and relocate DFADs (Moron et al. 2001). In the late 1990s, global positioning system (GPS) technology was incorporated into drifting buoys, revolutionizing purse-seine fishing. Later models of GPS sonar buoys provide fishing masters with remotely monitored biomass estimates beneath their DFADs. These tuna purse-seine vessels are equipped with sophisticated detection and environmental monitoring technology, such as long-range sonar (6000 m horizontal maximum range), scientific-grade echosounders (600 m depth), bird-detecting radars (20 km horizontal range), surface temperature meters, and ADCP (Doppler) current meters. Environmental data such as sea surface temperature, surface currents, productivity estimates, and meteorological data are obtained via satellite services and are incorporated into fishing operations. The rapid improvement in marine electronics and buoy technology over the past 15 years allows for highly efficient purse-seining of tuna on DFADs. In the last 10 years, the western Indian Ocean (WIO) fishery (Fig. 3) has landed an average of 225 000 tonnes of tropical tuna per year around DFADs (Pianet et al. 2005), which corresponds to 50%–70% of the total purse-seine catch in this region, the highest FAD-derived percentage observed worldwide (Fonteneau 2003). The high incidence of DFAD-based fishing makes this fishery ideal for a study examining fishers' perceptions on tuna behaviour and FADs. Tuna landings consist of skipjack, yellowfin, and bigeye tuna at a proportion of approximately 64.4%, 27%, and 8.6%, respectively (Fonteneau et al. 2007).

Research on FADs

Concerns over targeted DFAD purse-seining are related to the fact that DFADs tend to attract (*i*) juvenile as well as commercially undersized tuna and (*ii*) nontarget species such as rainbow runner (*Elagatis bipinnulata*), dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), rough triggerfish (*Canthidermis maculatus*), marlins, and oceanic sharks, mainly silky sharks (*Carcharinus falciformis*) (Hampton and Bailey 1993; Hall 1998). Catches of juvenile bigeye tuna by purse-seine gear are also directly related to the level of fishing that takes place on drifting objects such as DFADs. Regional fishery management organizations (RFMOs) and regional research oriented commissions including the Indian Ocean Tuna Commission (IOTC), International Commission for the Conservation of Atlantic Tuna (ICCAT), Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), and the Secretariat of the Pacific Commission

Fig. 1. Pictures of artificial drifting fish aggregating devices (DFADs) in the Indian Ocean and global positioning system (GPS) tracking radio buoy: (*a*) surface view (©Fadio/IRD-IFREMER/G. Moreno); (*b*) subsurface view (©Fadio/IRD-IFREMER/M. Taquet).

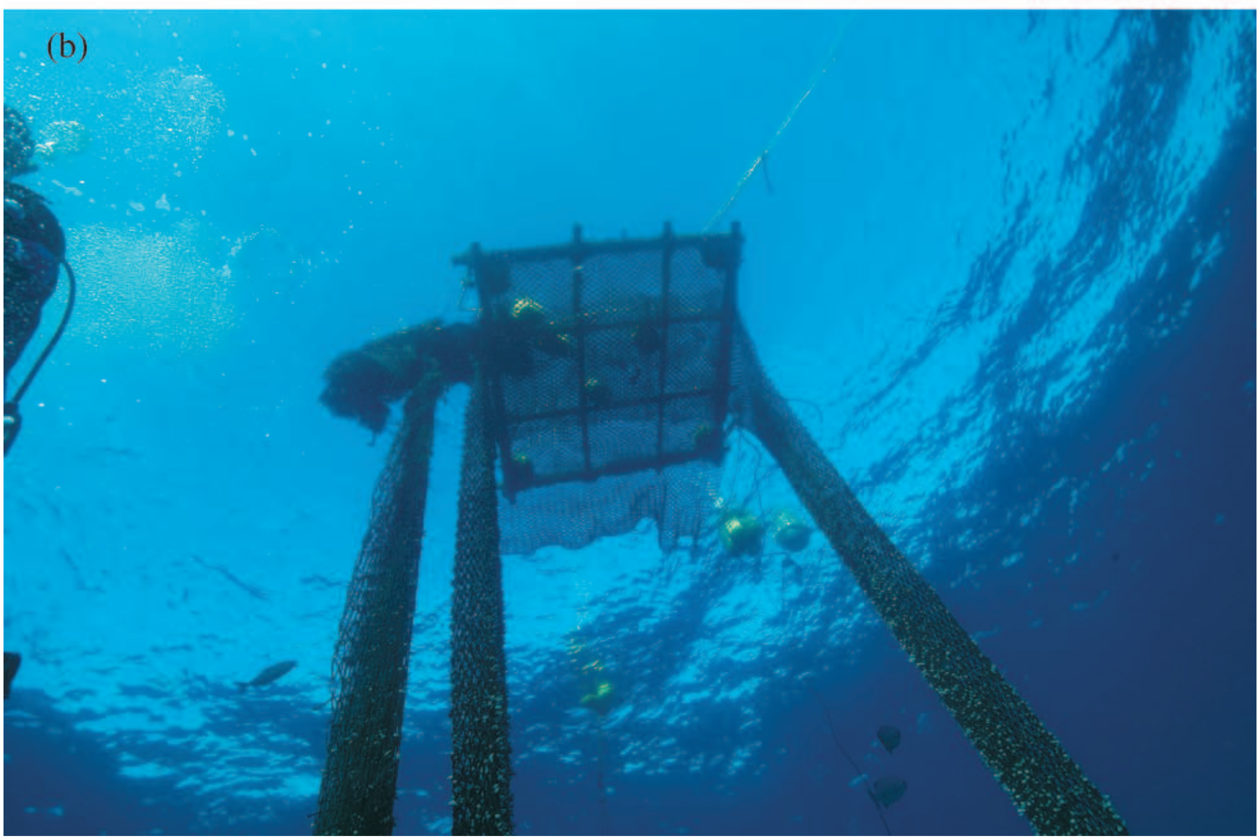


Fig. 2. Picture of 107 m long purse-seiner operating in western Indian Ocean (©Fadio/IRD-IFREMER/G. Moreno).

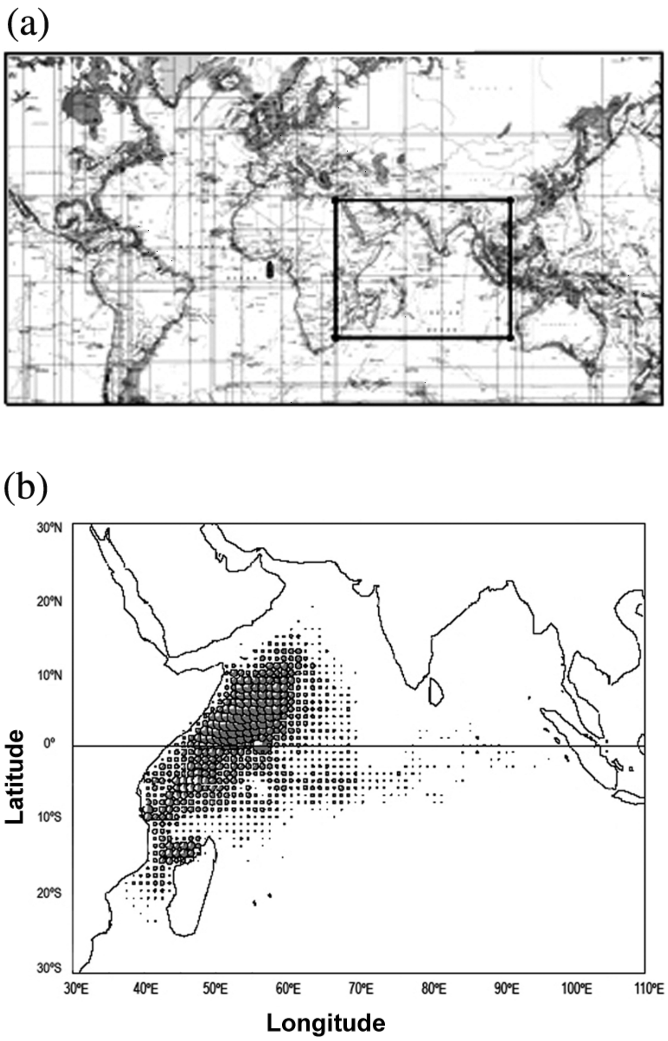
(SPC) have all called attention to the need for better understanding of (*i*) the effects of the thousands of DFADs in the oceans on the spatial dynamics and biology of tuna and (*ii*) the effects of fishing around DFADs on fish stocks and pelagic ecosystems. This fundamental knowledge is a key step towards developing an ecosystem approach to tropical tuna fisheries management. Mathematical models have attempted to determine the optimum number of FADs and vessels in purse-seine fisheries (Clark and Mangel 1979; Samples and Sproul 1985; Hilborn and Medley 1989). However, these models require information on tuna behaviour around DFADs such as attraction distance, conditions that cause fishes to remain associated or abandon DFADs, schooling strategies of tuna, and influence of DFAD design on their attractiveness to fish. Unfortunately, accurate data on these parameters are lacking.

Most of the scientific studies on the behaviour of fishes around FADs have been conducted on AFADs close to tropical islands (Dempster and Taquet 2004). Several sonic tracking experiments of fishes in relation to AFADs have been conducted, providing information on movements over temporal scales of a few days (Holland et al. 1990; Brill et al. 1999; Dagorn et al. 2000*a*). Tracking studies have led to estimates of attraction distances of tuna to AFADs (Girard et al. 2004). More recently, Ohta and Kakuma (2005) and Dagorn et al. (2007) equipped AFADs with acoustic receivers to determine tuna residence times around AFADs. Few studies have addressed the collective behaviour of fishes around AFADs or the role of the habitat in establishing AFAD associations (Klimley and Holloway 1999; Josse et al. 2000; Doray et al. 2006). These studies have contributed to a better knowledge of tuna behaviour around AFADs, but scientists still do not know the answers to the two basic questions: (*i*) why do tuna associate with FADs? and (*ii*) what are the effects of FADs on their behaviour? Moreover, do pelagic fishes treat anchored and drifting FADs differently (Holland et al. 1990; Fréon and Dagorn 2000)? Consequently, because of the present scarcity of studies on DFADs, information on the behaviour of pelagic fishes at AFADs can not be directly extrapolated to understanding ecological processes at DFADs. Directed studies on the behaviour of tuna associated with DFADs are required. However, compared with AFADs, which are easily accessible, DFADs are difficult to access and monitor over time in offshore fishing grounds, which explains why FAD-based research is devoted primarily to AFADs (Dempster and Taquet 2004).

Objectives of the study

Given the scarcity of knowledge on fish behaviour around DFADs and the difficulty in directly conducting research on DFAD aggregations, the objectives of the present study were (*i*) to collect information on fish behaviour based on fishers knowledge, (*ii*) to provide an estimate of the number of DFADs in the Indian Ocean useful for research and fisheries management, and (*iii*) to use this knowledge to help prepare future in situ studies on fish behaviour around DFADs by prioritizing research topics and reducing the a priori number of testable hypotheses. More specifically, we examined the

Fig. 3. (*a*) Location of study area. (*b*) Enlarged view of area outlined in (*a*) (modified from Pianet et al. 2005) indicating the relative magnitude and spatial distribution of the main purse seine fleet catches of tropical tunas taken on DFADs for the average situation over the period 1999–2003.



attraction, retention, and departure behaviour of tuna associated with DFADs.

Materials and methods

Identifying experts

To obtain valid LEK data, it is of primary importance to identify the most appropriate experts to address with well-researched questions (Johannes et al. 2000). Spanish and French fishers were the first to develop the WIO purse-seine fishery and have been exploiting tuna schools found in association with DFADs since the beginning of the fishery in the early 1980s. Fishing masters of these purse-seiners are solely in charge of making all of the long-range planning and short-term decisions onboard concerning where, when, and how to proceed with fishing operations, selection of fishing grounds, and direction of all operations during purse-seine sets. On Spanish purse-seiners, the licensed captain or navigator is in charge of administrative paper work and offloading operations and assists in fishing operations but remains secondary to the fishing master, who directs all fishing operations and the overall vessel movements. The situation is different on French purse-seiners where both roles are filled by the same person. The initial goal of the study was to interview one primary fishing master from each vessel (n = 45) of the European purse-seine fleet (Spanish and French) during the study period (2004–2005) to avoid bias due to differences in age, experience, and vessel technology (Johnson 1992; Neis et al. 1999). A clear pattern of responses was reached after covering 75% (n = 34) of the fleet. Interviews were stopped at this point as it was considered that a demonstrated "saturation point" had been reached and the sample size was presumed adequate (Felt 1994; Neis et al. 1999; Davis and Wagner 2003).

Interview design and strategy

Personal interviews of fishing masters were designed to gather information on their individual experience at sea (phase 1) and their knowledge on behaviour of fishes around DFADs (phase 2). The aim of phase 1 was to gather information on experience and reliability, as "Fishers' knowledge, like scientists' is fallible" (Johannes et al. 2000). Within this initial phase, fishing masters were questioned as to the number of years they had fished in the Indian Ocean and the number of years of experience specifically fishing on drifting FADs. Phase 2 of the interview process was devoted to their perceptions of the behaviour of fishes associated with drifting FADs, specifically attraction, retention, and departure behaviours. Other questions related to individual fishing skills and historical catches were included in order to maintain the interest of fishers in the interview process.

Competition between fishing masters in the tropical tuna purse-seine fishery is very high, resulting in a general reluctance by fishers to share personal fishing knowledge and experiences. Requiring fishing masters to fill out and submit prepared forms of standardized questions was not considered because of the lack of interaction and dialogue. Personal interviews with each fishing master were considered the most appropriate method to achieve the level of confidence necessary to obtain accurate and representative information. Personal interactive oral interviews were considered essential to obtaining more precise responses in a collaborative and informal environment. In a typical interview with a fishing master, the initial answers would be general and descriptive, requiring the interviewer to encourage the fishing master to quantify his answers in a more specific manner. Face-to-face interviews also enhanced communication and cooperation between scientists and the fishing community. Although interviews were precisely structured with specific objectives in mind, their format remained informal and conversational to allow the fishing masters to feel as comfortable as possible. The interviewers avoided leading questions and never suggested answers, allowing, in principle, a free flow of unbiased information from the fishers. The identification of new areas of investigation was an important goal, as it is presumptuous to assume that scientists know all the important questions and issues concerning fisheries (Johannes et al. 2000).

To test the quality of a given observation, interviewers would regularly ask fishing masters, "Why and how do you know this?”. Only answers that were well supported were considered, discarding replies not accompanied by a proper line of reasoning. The explanations advanced as justification to the initial observation were not considered in our analyses. Although observations may be clear and concise, the conclusions drawn from them may not be accurate (Johannes 1993). Fishing masters were also instructed to decline answering any questions that might be considered strategically or operationally sensitive, rather than provide misinformation on the subject.

Interviews were conducted onboard purse-seine vessels in Victoria Port, Seychelles, during 2004 and 2005. To maintain consistency throughout the interviews and to develop confidence within the fleets, a Spanish scientist (G. Moreno) conducted all the interviews of Spanish fishing masters and a French scientist (L. Dagorn) conducted the interviews of French fishing masters.

Results

A total of 34 interviews of Spanish and French fishing masters of tuna purse-seiners in the western Indian Ocean were conducted in 2004 and 2005, covering 75% of the European fleet. Interviewed fishing masters had an average of 14 years of individual fishing experience in the Indian Ocean (standard deviation of 6 years, maximum of 26 years). The accumulated time spent at sea in the western Indian Ocean, calculated by adding all interviewed fishing master’s years at sea and removing the time each fishing master spent on land, added up to 293 man-years. Our sample included fishing masters (n = 14) that had been active in the fishery in the 1980s, when only natural DFADs (mostly logs) were exploited, before fishers started in the early 1990s to deploy their own artificial DFADs. These fishing masters lived through the evolution of the DFAD fishery, potentially allowing the identification of changes in fish behaviour related to the increasing number of DFADs in the western Indian Ocean.

The total number of responses for each question did not always equal the total number of fishing master interviews, because some fishing masters did not answer every question. Also fishing masters often provided multiple answers to open-ended questions (average number of answers per question was 3.8; standard deviation 1.7), as no specific answers were suggested by the interviewers.

Number of DFADs in the western Indian Ocean

We asked each fishing master how many active buoy-equipped DFADs (radio- or satellite-transmitting) they have in operation on a daily basis. When we had no interview data for a given vessel, we used the mean number of buoys deployed by other vessels of the same fishing company. At the time of the interviews, there were seven Spanish companies with 30 vessels and one French company with 15 vessels operating in the western Indian Ocean. It is important to note that most of the Spanish vessels share DFADs with other vessels of their company, which allowed checking the reliability of the number of buoys estimated by each fishing master. The estimated total number of actively monitored DFADs in the western Indian Ocean was approximately 2100 drifting objects at any given time. This number is a highly dynamic estimate as FADs can sink or be stolen by other purse-seiners, plus fishers regularly seed new artificial FADs and find natural FADs that are marked with buoys. As an anecdote, one of the most successful fishing masters with the highest catches in the fleet, and identified by other fishing masters as the most knowledgeable, provided an estimated average of 2500 active buoys for the whole European fleet at a given time, suggesting the validity of the magnitude of our estimate.

Table 1. Fishers’ answers related to the attraction behaviour of tuna to DFADs.

	Attraction behaviour	
	Response	%[a]
Radius of attraction to drifting FADs	0–2 nm	35.5 (11)
	2–5 nm	48.4 (15)
	>5 nm	9.7 (3)
	Species dependent	3.2 (1)
	Area dependent	3.2 (1)
Type of drifting FAD attracting or aggregating more tuna	Man-made	17.6 (6)
	Natural	50.0 (17)
	Any	32.4 (11)
FADs with only tuna aggregated	Never	56.3 (18)
	Rare	43.7 (14)
Time needed for non-tuna species to aggregate around a DFAD	1 week	53.8 (7)
	2–3 weeks	38.5 (5)
	4 weeks	7.7 (1)
Time needed for tuna to aggregate around a DFAD	Not time dependent	45.4 (10)
	2 weeks	9.1 (2)
	1 month	36.4 (8)
	>1 month	9.1 (2)

[a]Number of observations in parentheses.

Attraction behaviour

Detailed answers from fishers to the questions related to the attraction behaviour of tuna to FADs are presented in Table 1. The attraction distance of a DFAD (the distance at which a school of tuna is attracted to a FAD) is estimated by fishers in an empirical way, usually by spotting a tuna school at some distance from an unpopulated FAD (where they have not seen any tuna) and, a few hours later, finding what they presume to be the same school aggregated under the FAD. Also, fishers on occasion observe tuna schools escaping from a set and, while tracking the school, observe tuna orientating directly towards a FAD located a certain distance away. The majority of fishers (48%) believe that the attraction distance of tuna to FADs is between 2 and 5 nautical miles (n.mi) (1 n.mi = 1852 m), while other fishing masters (35%) proposed between 0 and 2 n.mi. A few (9%) suggested distances greater than 5 n.mi, while others (6.4%) indicated that the distance can vary between tuna species or by area.

The majority of fishers (50%) indicated that natural DFADs such as logs attract more tuna than man-made objects, but a third of the fishing masters (32%) consider that there is no discernable effect of the FAD type on their aggregative success.

Table 2. Fishers' answers related to the retention behaviour of tuna around DFADs.

	Retention behaviour	
	Response	%[a]
No. of shoals or schools of tuna that form a DFAD aggregation	One	6.9 (2)
	Multiple	93.1 (27)
Organization into different shoals	Species	50.0 (14)
	Size	3.6 (1)
	Both species and size	35.7 (10)
	Order of arrival	7.1 (2)
	Time of day	3.6 (1)
Has the time of day for FAD fishing changed?	Yes	100 (21)
	No	0

[a]Number of observations in parentheses.

Table 3. Fishers' answers related to the departure behaviour of tuna from DFADs.

	Departure behaviour	
	Response	%[a]
Reasons for tuna to leave a DFAD	Current or trajectory change	36 (18)
	Lack of trophic resources	2 (1)
	Presence of marine mammals	20 (10)
	Temperature	18 (9)
	Excessively large-sized aggregation	2 (1)
	Continental platform	20 (10)
	Storms	2 (1)

[a]Number of observations in parentheses.

It is rare to observe tuna aggregations around FADs without the presence of other non-tuna (bycatch) species, such as rainbow runner, dolphinfish, wahoo, rough triggerfish, and silky sharks. A total of 56% of the fishers never observed tuna without other species around FADs, and 44% reported that they rarely observe this situation.

When asking about the length of time necessary for a new DFAD to be colonized by fishes, the fishers distinguished between tuna and other species. Non-tuna species seem to begin aggregating to DFADs a short time after deployment (one week, 54% of the answers), and almost all fishers (92%) consider that DFADs are colonized by non-tuna species within 1–3 weeks. The answers concerning tuna species were more variable. The majority of fishers (45%) consider that the time to form an aggregation of tuna under a DFAD is influenced by many environmental factors and therefore cannot be simply predicted. A large number of fishing masters (36%) considered that it usually takes a minimum of 1 month for a DFAD to aggregate tuna, and a few fishers believed that tuna colonize FADs after 2 weeks (9%) or after periods longer than a month (9%).

Retention behaviour

The question regarding the residence time of tuna and other species at DFADs received no response from interviewed fishing masters. Answers to other questions on the retention behaviour are also shown (Table 2). A clear majority of fishers (93%) reported that multiple discrete schools of tuna are usually observed around a single DFAD, instead of a single large school. They believed multiple schools of tuna are segregated only by species (50%) or by both species and size (36%). A few fishing masters (7%) indicated that the order of arrival at the FAD of different discrete schools is responsible for the segregation of schools, and a very small percentage of answers indicated that schools are segregated only by size of tuna (3.6%) or are influenced by the time of day (3.6%).

All fishers clearly indicated that the start time of fishing operations around DFADs in the western Indian Ocean has changed through the years. When the DFAD fishery started in the 1980s, fishers believed that tuna were more abundant around FADs early in the morning. Consequently, they were mainly setting their nets at sunrise. Currently, they successfully set on DFADs throughout the day. Most fishing masters explained that in specific zones, through the use of sonar and echosounders or with binoculars, they commonly observe tuna schools arriving at FADs some hours after the sunrise. This behaviour was not noted 20 years ago.

Departure behaviour

According to fishers, departures of tuna schools from FADs are correlated with changes in currents or FAD drift trajectory (36%), when DFADs drift over shallow areas (20%) such as the Seychellois Plateau (mean depth 50 m, maximum 75 m), or the appearance of marine mammal predators (20%) on the FAD (Table 3). Regarding the presence of marine mammals, a majority of fishing masters pointed out that dolphins, porpoises, and whales do not necessarily cause a permanent departure of tuna from the FAD, but are usually responsible for a temporary disturbance resulting in a short-term departure, especially for those tuna schools that are strongly associated with the DFAD. Fishing masters believe that tuna schools need some time to associate themselves to a certain DFAD and that marine mammals can cause a definitive departure of tuna schools that have recently arrived at a DFAD. Change in sea surface temperature was also identified as an important factor causing tuna to leave FADs (18%) and was clearly identified by fishing masters as an independent factor from changes in FAD trajectory or currents. Finally, other explanations for tuna departure from DFADs included a lack of trophic resources (2%), excessively large-sized aggregation (2%), and storms (2%).

Discussion

Number of DFADs in the western Indian Ocean

This study is the first known published estimate of the number of active DFADs deployed in the western Indian Ocean, which precludes the comparison with other studies to determine the temporal evolution of their numbers. However, it is known that before the 1990s, the fishery was only exploiting natural FADs found drifting in the open ocean, which are still exploited today. Because of present methods of construction and seeding of artificial FADs, the total number of DFADs is likely to be much higher than 20 years ago. Having an estimate of the daily number of FADs used by the fishery is critical to studying the impact of different fishing strategies, calculating effective fishing effort, and modelling the effects of FADs on fish behaviour. DFADs are not evenly distributed in the western Indian Ocean, but are influenced by their initial seeding location and subsequently by surface current patterns, which will affect the number of FADs found at any given time. Monitoring the future evolution of the number of FADs at sea should be a part of international projects in order to study their impact on fish communities and interpret any observed changes in fish behaviours and spatial dynamics.

Attraction behaviour

Most of the interviewed fishers believe the attraction distance of tuna to FADs varies from 0 to 5 n.mi (almost 10 km). From sonic tracking experiments conducted around AFADs, Girard et al. (2004) identified that yellowfin tuna are able to orient towards anchored FADs at a range of 4–19 km. Fishers with no prior knowledge of attraction distance to AFADs provided similar attraction distances to DFADs. The variability of attraction distance from Girard et al. (2004) is also evident in the answers from fishers. They indicated that attraction distance could depend on the area and local productivity, implying possible effects of different environmental conditions affecting the propagation of acoustic and olfactory signals emitted by FADs, which could be employed by tuna during their orientation behaviour towards the FADs. Specific scientific tracking experiments need to be performed on tuna around DFADs, similar to what has been done on AFADs (Holland et al. 1990; Brill et al. 1999; Dagorn et al. 2000*a*). Unfortunately, such operations in offshore waters will be much more complicated and costly than at nearshore AFADs, where small vessels can be safely used. However, fisher's answers suggest to researchers that DFADs might have similar attraction distances compared with AFADs. It has been proposed that AFADs can more easily attract tuna because of the sounds produced by their anchoring chains or the influence of current on the mooring ropes (Fréon and Dagorn 2000), but our results suggest that DFADs can also attract tuna from considerable distances without these structures (DFADs without subsurface structures are also productive). This implies that structure or design of FADs might not play a key role in determining attraction processes, and therefore it is likely that the fish aggregations around DFADs may play a very important role in attracting tuna schools (Itano et al. 2004).

Half (50%) of the fishing masters consider natural floating objects (mainly logs) as the best platforms to aggregate fish. It is difficult to know if the perceived higher efficiency of natural DFADs is due to their morphological characteristics or their length of deployment and movements related to oceanographic features. A high percentage of fishers (32%) think that there is little difference between natural and artificial DFADs in their ability to aggregate fish. In AFAD studies, structure size and vertical profile were found as the most significant factors for attracting non-tuna species, but no major characteristic of AFADs has explained the attraction of tuna species (Rountree 1989; Hall et al. 1992; Nelson 2003). Natural DFAD history may be a more relevant factor explaining their possible higher efficiency. They originate in forested coastal zones and usually spend several months at sea before arriving in the fishing grounds, whereas fishers typically deploy artificial FADs in or near the fishing grounds only a few weeks before starting their fishing operation.

Taquet (2004) observed that the first organisms to colonize the DFADs (a few hours after deployment) were small juvenile fishes of several non-tuna species, usually found hiding in the floating structure. A few days later, larger fishes such as dolphinfish colonized the FADs, but tuna have never been observed in these initial colonization stages (Nelson 2003). The time needed for a FAD to be colonized by non-tuna species seems to be relatively short, whereas the time to aggregate tuna is considerably longer. We hypothesize that the colonization process of FADs by different pelagic fish species plays an important role on their ability to attract tuna schools. In agreement with this hypothesis, fishers clearly indicated that tuna are never found as the sole species aggregated around FADs. The few fishers who said that tuna are occasionally observed alone at FADs explained that these rare events correspond to moving tuna schools that briefly visit a "virgin" FAD that has not yet been colonized by other species. According to fishers, these tuna schools are likely to remain for very short periods at these virgin FADs. Non-tuna species likely influence the attraction and retention behaviours of tuna at FADs, and some of these non-tuna species could first be attracted and retained because of the specific design of the FAD.

The species composition of fish aggregations could also influence the attraction and retention processes of tuna. Fishers report that rough triggerfish play a key role in the attraction of tuna, as this species makes a lot of noise. Behavioural studies of tuna around AFADs mostly observed the movement of individually tagged fish (Holland et al. 1990; Brill et al. 1999; Dagorn et al. 2000*a*), collecting some information on the physical oceanography around the FADs. The characteristics of the forage community around FADs have been acoustically observed on a few occasions (Josse et al. 1998; Dagorn et al. 2000*b*; Doray 2006). Future behavioural studies should therefore consider the role of species composition and biomass of fish aggregations (including tuna and non-tuna species) around DFADs to better interpret observations of tuna attraction and retention behaviours. Experiments to determine if some specific signals are used by tuna to locate FADs should be developed, thus combining physiology and in situ behaviour.

Retention behaviour

Tuna aggregation structure

Scientists working with catch data from purse-seiners usually consider that the catch from a single purse-seine set corresponds to a single school of tuna (Fréon and Misund 1999) and that FAD aggregations are characterized by mixed-species schools of different tuna species (Hallier and Parajua 1992*a*). As several distinct schools of tuna can be caught together around a FAD and become mixed in the net, it is not possible to use catch data to determine tuna school characteristics at DFADs. Most fishers in this study believe that tuna aggregations around DFADs usually consist of several distinct schools of different tuna species, based on visual and sonar observations before setting the purse-seine net. Some of them also suggested that distinct schools of the same species can occur around the same FAD, segregated by size or by their initial time of aggregating to the FAD. Therefore, the idea that a single, mixed-species school of tuna occurs around FADs seems unlikely. Schaefer and Fuller (2005) observed both directional correspondence and directional separation within bigeye and skipjack pairs of individuals monitored by ultrasonic telemetry while in association with an AFAD and with a drifting vessel, suggesting both possible cases, i.e., bigeye and skipjack tuna schooling together and independent schools.

Tuna school characteristics around DFADs should be further investigated by researchers using vessels equipped with sonar to track school movements and scientific echosounders to identify specific composition of the schools, in addition to visual surveys by divers. If distinct tuna schools occur around FADs, it is still unknown if exchanges of individuals between schools occur. The use of acoustic tags could help investigate if FADs are places where schools exchange individual tuna.

Diel dynamics of tuna around DFADs

Fishing time around DFADs has changed in recent years: while fishers originally made sets early in the morning, currently they have changed their fishing practices and set nets throughout the day. Is this the result of a change in fish behaviour or in fishers' knowledge? An analogy with scientific knowledge can provide some valuable inputs to this topic. After the first sonic tracking experiments on tuna around AFADs (Holland et al. 1990), it was believed that tuna would stay at anchored FADs during daytime and would perform excursions away from FADs at night. Information from logbooks of purse-seiners suggested that the behaviour around DFADs was the reverse: fish would remain around drifting FADs during nighttime and would leave FADs during the day (Holland et al. 1990; Hallier and Parajua 1992*b*). When scientists started to collect more data on behaviour of tuna around anchored FADs, they found different patterns (Holland 1996; Dagorn et al. 2000*a*). Purse-seiners began to use long-range sonars a few years ago. These devices allow them to observe tuna schools that could be thousands of metres away from the FAD but not visually detectable with binoculars. The use of these sonars likely has improved the ability of fishers to locate and track tuna schools in proximity to FADs. It should be noted that in other tropical regions, such as in the western and central Pacific Ocean, FAD-related purse-seining takes place before dawn and only free school fishing is carried out throughout the day. This is not because tuna are not present on FADs throughout the day, but because the clarity of the water and the depth of the thermocline allow easy escape of tuna before the net can be pursed close (Habib 1984; Doulman 1987). In the eastern Pacific Ocean, setting during daytime does occur successfully as in the western Indian Ocean, as both areas are characterized by a shallow thermocline and relatively lower water clarity as a result of productivity.

Future studies aiming at resolving diel fine-scale behaviours of tuna around DFADs should combine observations of schools with sonars and echosounders while tracking individual acoustically tagged fish.

Time residency of tuna around DFADs

Fishers usually visit FADs for a short period of time. If they find associated tuna, they set their net, and if there are no tuna present, they simply leave in search of other FADs. On rare occasions, they remain for a few hours in the vicinity of an empty FAD (overnight for instance) waiting for tuna schools to approach, but they never remain more than a day at an unproductive FAD. Although they do not have direct knowledge or experience concerning the amount of time that tuna spend associated with the FADs, indirectly, they provided some interesting information on factors that could help our understanding of residence time. They suggested that several distinct schools of the same species can occur around the same FAD, and a few of them advanced a theory of school segregation by the time of arrival at the FAD. If segregation by arrival order occurs, then the history of each school may determine their residence time and keep it distinct from other schools owing to, for instance, foraging differences. Dagorn et al. (2007), studying spatial behaviour of tuna in a network of AFADs, suggest that FAD-associated tuna aggregations are composed of subgroups that might have different physiological states determining their residence time.

Residence time clearly needs to be addressed by future research projects. To assess the effects of FADs on the behaviour of tuna (e.g., movements, spatial distribution, etc.), a key parameter to measure is the time fish spend associated with FADs. Ohta and Kakuma (2005) and Dagorn et al. (2007) used acoustic tags and listening stations attached to AFADs to measure the residence time of yellowfin and bigeye tuna around anchored, nearshore FADs in Japan and Hawaii, respectively. From both studies, association of yellowfin and bigeye tuna was on the order of a few days, up to a maximum of 64 days. The variability of these values could not be explained, although it seems that abiotic factors were not responsible. More studies (using acoustic tags and receivers) are clearly needed to measure time residency of tuna and other species around anchored and drifting FADs, as this parameter is very important in assessing the impacts of deployment of thousands of FADs on the vulnerability and spatial dynamics of these species.

Departure behaviour

The majority of fishers believe that a change in the speed or direction of a DFAD can cause fish to depart. Other factors mentioned included marine mammal predators or drift over the shallow Seychellois Plateau. A change in the FAD drifting speed or direction would be indicative of a change of the water mass, which could affect oceanographic conditions surrounding the FAD. Researchers have little information on the causes or conditions under which tuna leave FADs. Researchers have generated multiple hypotheses to explain why fish associate with FADs (Fréon and Dagorn 2000; Castro et al. 2002), but none to explain why fish leave. This knowledge could provide a clue about the initial reasons that lead tuna to associate with a FAD. For fishery management purposes, it may be more useful to understand when and why fish leave a FAD, rather than why they aggregate. Future research should focus on the consequences of DFADs subjected to rapid changes in drifting speeds or directions that can be remotely monitored by radio- or satellite-linked buoys and on the consequences of local marine mammal presence on DFAD aggregations. Studying departure processes will require the use of instrumented FADs for long periods to measure tuna biomass and environmental conditions.

Table 4. Main information provided by fishers compared with those known by scientists, with suggestion for research perspectives.

Topic	Information from fishers	Information from scientists	Recommended research
No. of DFADs in the WIO	2100 at any given time in average	?	Regular interviews of fishers
Attraction distance	0–10 km on DFADs	0–10 km on AFADs	Not a priority
Determinism of attraction	Role of non-tuna species on tuna attraction?	?	Research on the role of non-tuna species in the attraction (and retention) of tuna.
Tuna aggregation structure	Several schools, usually separated by species	Thought to be one unique mixed school	Research to determine if individuals move from one school to another while at FADs (acoustic tagging)
Diel dynamics	Tuna can be around DFADs at any time of the day	Tuna can be around AFADs at any time of the day	Not a priority, or can be done using acoustic tagging and acoustics
Time residency	?	A few days around AFADs (up to 64 days)	Measures of time residency at DFADs (acoustic tagging)
Departure behaviour	Situations identified (change in drift, shallow zones, etc.)	?	Research on behaviour to understand the causes, using instrumented FADs

Future research considerations

As recommended by various experts (Le Gall et al. 2000), including the existing regional fishery management organizations (IOTC, ICCAT, IATTC, WCPFC), improved and expanded knowledge on the behaviour of tuna aggregations on DFADs is required to improve management measures on tropical tuna populations. Catches around DFADs have become so important during the last decade that researchers must determine the impacts of FADs on tuna behaviour and associated species. Development of experiments in the open ocean to study the behaviour of pelagic tuna around drifting FADs is a priority. Such studies are time-consuming and expensive. Therefore, research priorities should be determined, and when possible, existent hypotheses should be critically examined and ranked. Interviewing fishing masters of the European tuna purse-seine fleets working in the western Indian Ocean provided an alternate, independent, and previously unutilized source of behavioural information on tuna around DFADs. A great deal of the information given by fishers is in agreement with scientific hypotheses obtained from research activities related to AFADs (i.e., attraction distance to FADs). In this case, conducting experiments at sea might not be an initial priority, as the agreement between estimates from fishers and research on AFADs suggests the validity of both. On the other hand, fishers provided information that was previously unknown to science, such as possible reasons why fish may leave a FAD. We compare the main information provided by fishers with those known by scientists, with suggestion for future research (Table 4).

Calheiros et al. (2000) noted that involvement of the participants (fishers in this case) in research efforts invests them in the process and makes them more likely to accept resulting management and policy changes. Moreover, working in close association with fishers could assist in the timely identification of behavioural changes in fish, which could be indicators of changes in the population size or the environment. Incorporating fishers into the planning and design stages of research projects facilitates collaborative and integrated approaches and can lead researchers toward new and exciting areas of study. Fishers then become active and recognized participants in research while acknowledging their years of experience with the credibility it deserves.

Acknowledgements

The authors sincerely thank all Spanish and French fishing masters of tuna purse-seiners in the western Indian Ocean who kindly agreed to answer our questions. We would like to underscore the fact that they made all possible efforts to facilitate the exchanges, not just answer the questions. Of course, we would like to thank the fishery owners and the associations that represent them (ANABAC, OPAGAC, and ORTHONGEL). The authors are grateful for the useful suggestions of the three anonymous reviewers. We also sincerely thank Deborah Bidwell for revising the discussion of this paper. This study was a part of the European project FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems), funded by DG Research (contract no. QLRT-CI-2001-02773). This paper is contribution no. 374 from AZTI-Tecnalia.

References

Armstrong, W.A., and Olivier, C.W. 1995. Recent use of fish aggregating devices in the eastern tropical Pacific tuna purse-seine fishery: 1990–1994. National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, Calif. Admin. Rep. No. LJ-95-14.

Brill, R.W., Block, B.A., Boggs, C.H., Bigelow, K.A., Freund, E.V., and Marcinek, D.J. 1999. Horizontal movements and depth distribution of large adult yellowfin tuna (*Thunnus albacares*) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes. Mar. Biol. **133**(3): 395–408.

Calheiros, D.F., Seidl, A.F., and Ferreira, C.J.A. 2000. Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland of Brazil. J. Appl. Ecol. **37**(4): 684–696.

Castro, J.J., Santiago, J.A., and Santana-Ortega, A.T. 2002. A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. Rev. Fish Biol. Fish. **11**: 255–277.

Clark, C.W., and Mangel, M. 1979. Aggregation and fishery dynamics: a theoretical study of schooling and purse seine tuna fisheries. Fish. Bull. **77**(2): 317–337.

Dagorn, L., Josse, E., and Bach, P. 2000*a*. Individual differences in horizontal movements of yellowfin tuna (*Thunnus albacares*) in nearshore areas in French Polynesia, determined using ultrasonic telemetry. Aquat. Living Resour. **13**(4): 193–202.

Dagorn, L., Josse, E., Bach, P., and Bertrand, A. 2000*b*. Movement patterns of large bigeye tuna (*Thunnus obesus*) in the open ocean, determined using ultrasonic telemetry. Mar. Biol. **136**: 361–371.

Dagorn, L., Holland, K.N., and Itano, D.G. 2007. Behavior of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna in a network of fish aggregating devices (FADs). Mar. Biol. **151**: 595–606. doi:10.1007/s00227-006-0511-1.

Davis, A., and Wagner, J. 2003. Who knows? On the importance of identifying "experts" when researching local ecological knowledge. Hum. Ecol. **31**: 463–489.

Davis, A., Hanson, J.M., Watts, H., and MacPherson, H. 2004. Local ecological knowledge and marine fisheries research: the case of white hake (*Urophycis tenuis*) predation on juvenile American lobster (*Homarus americanus*). Can. J. Fish. Aquat. Sci. **61**(7): 1191–1201.

Dempster, T., and Taquet, M. 2004. Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies. Rev. Fish Biol. Fish. **14**(1): 21–42.

Doray, M. 2006. L'ágrégation de thons de sub-surface au sein du sytème [DCO ancré–macronecton–environnement–pêche] en Martinique : étude hiérarchique par méthodes acoustiques, optiques et halieutiques. Thèse de Doctorat, L'École Nationale Supérieure Agronomique, Renne, France.

Doray, M., Josse, E., Gervain, P., Reynal, L., and Chantrel, J. 2006. Acoustic characterisation of pelagic fish aggregations around moored fish aggregating devices in Martinique (Lesser Antilles). Fish. Res. **82**(1–3): 162–175.

Doulman, D.J. (*Editor*). 1987. Development and expansion of the tuna purse seine fishery. *In* Tuna issues and perspectives in the Pacific Islands Region. East–West Center, Honolulu, Hawaii. pp. 133–160.

Felt, L. 1994. Two tales of a fish: the social construction of indigenous knowledge among Atlantic Canadian salmon fishers. *In* Folk management in the World's fisheries: lessons for modern management. *Edited by* C. Dyer and J. McGoodwin. University Press of Colorado, Niwot, Colorado. pp. 251–286.

Fonteneau, A. 2003. Prospects for the management of FAD fisheries in the Indian Ocean. *In* Report of the Fifth Session of the IOTC Working Party on Tropical Tunas, Victoria, Seychelles, 3–12 June 2003. Indian Ocean Tuna Commission Document No. WPTT-03-04.

Fonteneau, A., Pallares, P., and Pianet, R. 2000. A worldwide review of purse seine fisheries on FADs. *In* Proceedings of the Conference on Pêche Thonière et Dispositifs de Concentration de Poissons, Martinique, 15–19 octobre. *Edited by* J.Y Le Gall, P. Cayré, and M. Taquet. IFREMER edition. pp. 15–35.

Fonteneau, A., Delgado de Molina, A., and Dorizo, J. 2007. Species composition of FAD and free swimming schools fished by purse seiners in the western Indian Ocean during the period 1991–2006. Indian Ocean Tuna Commission, Victoria, Seychelles. IOTC-2007-WPTT-05.

Fréon, P., and Dagorn, L. 2000. Review of fish associate behaviour: toward a generalisation of the meeting point hypothesis. Rev. Fish Biol. Fish. **10**: 183–207.

Fréon, P., and Misund, O.A. 1999. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Blackwell Science, Oxford, UK.

Girard, C., Benhamou, S., and Dagorn, L. 2004. FAD: fish aggregating device or fish attracting device? A new analysis of yellowfin tuna movements around floating objects. Anim. Behav. **67**(2): 319–326.

Habib, G. 1984. An overview of the purse-seine tuna fishery in the central/western Pacific and development opportunities for island states. *In* Workshop on National Tuna Fishing Operations, Tarawa, Kiriabati, 28 May – 2 June 1984. Forum Fisheries Agency, Honiara, Solomon Islands, Working Paper No. 15.

Hall, M. 1998. An ecological view of the tuna–dolphin problem: impacts and trade-offs. Rev. Fish Biol. Fish. **8**(1): 1–34.

Hall, M., García, M., Lennert, C., and Arenas, P. 1992. The association of tunas with floating objects and dolphins in the eastern Pacific Ocean. III. Characteristics of floating objects and their attractiveness for tunas. Inter-American Tropical Tuna Commission, La Jolla, California.

Hallier, J.P., and Parajua, J.I. 1992*a*. Tropical tuna at sea: what are they associated with? *In* International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects and on Assessment Issues Arising from the Association of Tunas with Floating Objects. *Edited by* M. Hall. Internal Report, Inter-American Tropical Tuna Commission, San Diego, California.

Hallier, J.P., and Parajua, J.I. 1992*b*. Review of tuna fisheries on floating objects in the Indian Ocean. *In* International Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects and on Assessment Issues Arising from the Association of Tunas with Floating Objects. *Edited by* M. Hall. Internal Report, Inter-American Tropical Tuna Commission, San Diego, California.

Hampton, J., and Bailey, K. 1993. Fishing for tunas associated with floating objects: a review of the western Pacific fishery. South Pacific Commission, Noumea, New Caledonia. SPC Tuna and Billfish Assessment Programme Technical Report No. 31.

Hilborn, R., and Medley, P. 1989. Tuna purse-seine fishing with fish-aggregating devices (FAD): models of Tuna–FAD interactions. Can. J. Fish. Aquat. Sci. **46**: 28–32.

Holland, K.N. 1996. Biological aspects of the association of tunas with FADs. South Pacific Commission Fish Aggregating Devices Information Bulletin No. 2. pp. 2–7.

Holland, K.N., Brill, R.W., and Chang, R.K.C. 1990. Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull. **88**(3): 493–507.

Itano, D., Fukofuka, S., and Brogan, D. 2004. The development, design and recent status of anchored and drifting FADs in the WCPO. Standing Committee on Tuna and Billfish, Majuro, Republic of the Marshall Islands. Information Paper No. INF-FTWG-3.17TH.

Johannes, R.E. 1993. Integrating traditional ecological knowledge and management with environmental assessment. *In* Traditional knowledge: concepts and cases. *Edited by* J.T. Inglis. International Development Research Centre, Ottawa, Ont. pp. 33–40.

Johannes, R.E., and Hviding, E. 2000. Traditional knowledge possessed by the fishers of Marovo Lagoon, Solomon Islands, concerning fish aggregating behaviour. South Pacific Commission Traditional Marine Resource Management and Knowledge Information Bulletin No. 12.

Johannes, R.E., Freeman, M.M.R., and Hamilton, R.J. 2000. Ignore fishers' knowledge and miss the boat. Fish Fish. **1**(3): 257–271.

Johnson, M. 1992. Lore: capturing traditional environmental knowledge. Dene Cultural Institute, Hay River, NWT. ISBN: 0889366446 (pbk).

Josse, E., Bach, P., and Dagorn, L. 1998. Simultaneous observations of tuna movements and their prey by sonic tracking and acoustic surveys. Hydrobiologia, **371/372**: 61–69.

Josse, E., Dagorn, L., and Bertrand, A. 2000. Typology and behaviour of tuna aggregations around fish aggregating devices from acoustic surveys in French Polynesia. Aquat. Living Resour. **13**(4): 183–192.

Klimley, A.P., and Holloway, C.F. 1999. School fidelity and homing synchronicity of yellowfin tuna, *Thunnus albacares*. Mar. Biol. **133**: 307–317.

Le Gall, J.-Y., Cayre, P., and Taquet, M. 2000. Mechanisms and effects of the aggregation of tuna by fish aggregating devices (FADs). Aquat. Living Resour. **13**(4): 181–182.

Mackinson, S. 2001. Integrating local and scientific knowledge: an example in fisheries science. Environ. Manag. **27**(4): 533–545.

Moron, J., Areso, J.J., and Pallares, P. 2001. Statistics and technical information about the Spanish purse seine fleet in the Pacific. *In* 14th Meeting of the Standing Committee on Tuna and Billfish, Noumea, New Caledonia, 9–16 August. Standing Committee on Tuna and Billfish Working Paper No. SCTB14.

Neis, B., Felt, L., Haedrich, R.L., and Schneider, D.C. 1999. An interdisciplinary method for collecting and integrating fishers' ecological knowledge into resource management. *In* Fishing places, fishing people: issues and traditions in Canadian small-scale fisheries. *Edited by* D. Newell and R. Ommer. University of Toronto Press, Toronto, Ont. pp. 217–238.

Nelson, P.A. 2003. Marine fish assemblages associated with fish aggregating devices (FADs): effects of fish removal, FAD size, fouling communities, and prior recruits. Fish. Bull. **101**(4): 835–850.

Ohta, I., and Kakuma, S. 2005. Periodic behavior and residence time of yellowfin and bigeye tuna associated with fish aggregating devices around Okinawa Islands, as identified with automated listening stations. Mar. Biol. **146**(3): 581–594.

Parin, N.V., and Fedoryako, B.I. 1992. Pelagic fish communities around floating objects in the open ocean. *In* Fishing for Tunas Associated with Floating Objects, International workshop. Inter-American Tropical Tuna Commission, San Diego, California. pp. 447–458.

Pianet, R., Pallares, P., Norström, V., Hervé, A., Delgado de Molina, A., and Ariz, J. 2004. Statistiques de la pêcherie thonière europeenne et assimilée durant la période 1991–2002. ICCAT Collect. Vol. Sci. Pap. **56**(2): 737–759.

Pianet, R., Pallares, P., Delgado de Molina, A., Nordstrom, V., Dewals, P., and Lukas, V. 2005. Statistics of the main purse seine fleets fishing in the Indian Ocean (1981–2004). Indian Ocean Tuna Commission, Victoria, Seychelles. IOTC-2005-WPTT-23.

Pitcher, T.J. 1993. The behaviour of teleost fishes. Fish and Fisheries Series 7, Chapman and Hall, London, UK.

Poizat, G., and Baran, E. 1997. Fishermen's knowledge as background information in tropical fish ecology: a quantitative comparison with fish sampling results. Environ. Biol. Fishes, **50**: 435–449.

Rountree, R.A. 1989. Association of fishes with fish aggregation devices: effects of structure size on fish abundance. Bull. Mar. Sci. **44**(2): 960–972.

Samples, K.C., and Sproul, J.T. 1985. Fish aggregating devices and open-access commercial fisheries: a theoretical inquiry. Bull. Mar. Sci. **37**(1): 305–317.

Schaefer, K.M., and Fuller, D.W. 2005. Behaviour of bigeye (*Thunnus obesus*) and skipjack (*Katsuwonus pelamis*) tunas within aggregations associated with floating objects in the equatorial eastern Pacific. Mar. Biol. **146**: 781–792.

Silvano, R.A.M., and Begossi, A. 2005. Local knowledge on a cosmolitan fish ethnoecology of *Pomatomus saltatrix* (Pomatomidae) in Brazil and Australia. Fish. Res. **71**: 43–59.

Taquet, M. 2004. Le comportement agrégatif de la dorade coryphène (*Coryphaena hippurus*) autour des objets flottants. Thèse de Doctorat, Océanologie biologique, Université de Paris, France.

Valbo-Jorgensen, J., and Poulsen, A.F. 2001. Using local knowledge as a research tool in the study of river fish biology: experiences from the Mekong. Environ. Dev. Sustain. **2**: 253–276.