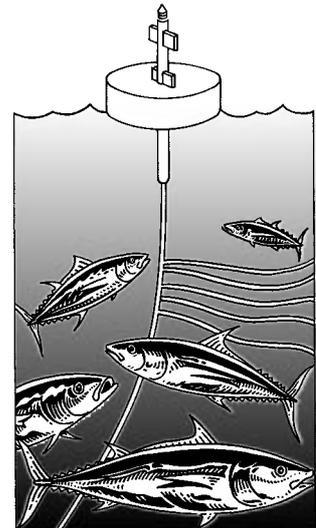Secretariat of the Pacific Community

FAD

Fish Aggregating Device

Number 3 — March 1998

INFORMATION BULLETIN

Editorial

'Why do tuna gather around FADs? How long do tuna stay near FADs? Why do some FADs seem to attract more tuna than others?' These are some of the many questions which interest researchers working for the ECOTAP (Tuna Behaviour Study through Acoustics and Longline Fishing) programme in French Polynesia. Pascal Bach and six other scientists participating in the programme summarise (p. 3) the preliminary results obtained during experimental fishing carried out in the vicinity of FADs. Through concurrent use of ultrasonic telemetry to track tuna and acoustic surveys to observe the surrounding environment, these researchers have demonstrated the important effect which the biological environment has on horizontal and vertical tuna movements.

A large-scale study was carried out by Jean-Philippe Detolle and four other scientists in La Reunion Island in the Indian Ocean for the purpose of optimising FAD costs and lifespans. In addition to the technical options proposed following an analysis of all the critical points in the fabrication of mooring lines, the authors address FADs' importance to the continuation and development of artisanal fishing activities on the island. The extract selected for this publication (p. 19) covers the social and economic aspects of FADs through a study of their effects on the number of working fishermen, catches and income. Oddly enough, few studies of this kind exist, although they are, in fact, essential when it comes to convincing governments and possible institutional donors of the merits of continuing FAD programmes.

Again in the same region, Michel de San, one of the designers of a type of FAD which uses a surface array of small trawl buoys, summarises experiences with FADs in the Western Indian Ocean on page 24. In that part of the world, the FADs deployed are simple to make and costs are kept down to the bare minimum. Fishing techniques there are very similar to those used in the

Inside this issue

Pacific. Readers from the Pacific area will be surprised to learn that FADs may first have been used in the Mediterranean and not in the Philippines as they had always thought.

After the Pacific and Indian Oceans, we could not neglect the Atlantic. The news comes from the island of Martinique, where Marc Taquet, Paul Gervain and Alain Lagin (p. 30) present a very original technique used for recovering lost FADs. This technique made it possible to analyse the mooring lines of the FADs recovered and identify the causes of failure. The results confirmed that most problems occur in the upper part of moorings, which is where most of the efforts for improvement should therefore be concentrated. What's more, the success obtained in Martinique with ultra-light, very low-cost FADs (about one-tenth the price of FADs used in the Pacific) should raise a lot of interest among those countries in our region whose FAD programmes have been put on hold for lack of resources.

Finally, Max Palladin, a consultant for SEPIA International, presents a security system for FADs developed in Sao Tome (p. 35). A brilliant idea which is simple to implement.

In Alain Fonteneau and Jean-Pierre Hallier's article '*La pêche aux thons sous objets flottants*' ('Fishing for tuna around floating objects') published in the November 1992 issue of *La Recherche* and translated for the second issue of this bulletin, the authors conclude by noting: 'The potential impact of artificial floating objects on tuna resources and the environment will (…) require careful appraisal, to make sure that the development of this fishing technique (which appears very attractive initially) does not have negative consequences on the ecological balances of the ocean.'

Five years later, it must be noted that development of this technique by the fishing industry has been much more rapid than assessment of its impact, particularly as concerns bigeye tuna stocks (see the article from *Fishing News International* on p. 37). According to the latest news, following expressions of concern by scientists, the fishing companies themselves have decided to implement a three-month moratorium on the use of this technique in some parts of the Atlantic Ocean. Close attention should be paid to developments in this area.

Scientific discoveries, new techniques, a social and economic approach, ideas, inventions, not to forget concerns . . . FADs certainly aggregate lots of discussion!

Happy reading.

Aymeric Desurmont

Workshop in preparation

A workshop on FADs and the aggregation of large pelagic fish around floating objects is being planned by our colleagues in the Caribbean (IFREMER-IRPM) for 1999. The main topics addressed would be:

1. FAD technology (e.g. lifespan, cost, new materials).
2. Economic, social and cultural aspects of FADs.
3. Study of aggregation behaviour.
4. FADs and fishery management: impact and limits.

Such a workshop would only be worthwhile if it brought together a large number of scientists, technologists and fishing-sector professionals from many countries and indeed included representatives of manufacturers able to put forward new technological options (part 1).

If you are interested in this workshop, please send a message by e-mail or postal mail to:

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Experimental research and fish aggregating devices (FADs) in French Polynesia

by P. Bach[1], L. Dagorn[1], E. Josse[2], F.-X Bard[1], R. Abbes[3], A. Bertrand[2] & C. Misselis[3]

Introduction

Floating natural or man-made objects are often encountered at sea. Fishermen themselves deploy such devices because they know that small or large pelagic fish are likely to gather around them and that fishing there is likely to be productive. Artisanal fleets in South-east Asia have been using this technique to catch small pelagics for many years. Where the larger pelagics are concerned, purse-seine fishing around floating objects has intensified over the past 20 years in all the world's oceans. Fonteneau (1992), in a review of tuna fisheries, wrote that the main area in which fishing is carried out around floating objects is the western central Pacific, where catches associated with such devices account for approximately 50 per cent of landings. In 1995, 42 per cent of the French purse-seine catch and 65 per cent of Spanish purse-seine landings in the Atlantic Ocean came from fishing around floating objects. These figures rise to above 70 per cent in the Indian Ocean (Stretta et al., 1996).

Fish aggregating devices (FADs) moored near the coast are an aid to artisanal fleets targeting large pelagics such as tunas in many island states. Historically, the FAD testing area of the 70s was the Pacific, with the guidance of the South Pacific Commission. As was stressed by Holland (1996) in this bulletin, FADs are now used world-wide to support or develop artisanal or sport tuna fisheries.

French Polynesia began its FAD deployment programme in 1981. Technological progress on materials, giving moorings a longer lifespan, has had an impact on the programme. The latest type of FAD used in French Polynesia was recently discussed (Leproux & Desurmont, 1996) in this bulletin.

Scientists have been recording observations on tuna behaviour near FADs for about the past 10 years (Cayré & Chabanne, 1986; Holland et al., 1990a, 1992; Cayré, 1991; Cayré & Marsac, 1993; Marsac et al., 1996). Whatever the merits of observing, however, understanding is better. Despite the extensive experimental work already carried out in all the world's oceans and consequent wealth of available information, Holland (1996), concluded that a great deal remain to be learned on the mechanisms (including the role of biological factors) affecting the relationship between tunas and FADs.

Why do tunas aggregate around FADs? How long do tunas remain near FADs? Why do some FADs seem to be more effective in attracting tunas than others? These are some of the questions facing scientist from EVAAM[4], IFREMER[5] and ORSTOM[6], who are working together in the ECOTAP[7] programme in Tahiti.

These issues affect the resource at various levels of perception (individual specimen, school, aggregation) and on various time-scales from one day to

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5. Institut Français de Recherche pour l'Exploitation de la Mer (French Institute of Research for Ocean Development)
6. Institut français de recherche scientifique pour le développement en coopération (French Institute of Scientific Research for Cooperative Development)
7. ECOTAP: Étude du Comportement des Thonidés par l'Acoustique et la Pêche (Tuna Behaviour Study through Acoustics and Fishing)

several months. To find the answers to these questions, science needs to call upon a range of tools and methods: sonic tagging, active acoustics, coupling of sonic tagging and active acoustics, Artificial Life modelling.

Initially, this paper will discuss the two main tools used by the ECOTAP programme: ultrasonic telemetry and acoustic surveys. These tools were either used separately or together depending on the goals of the activities concerned. The second part of the paper will address implementation methods, with some comments on the initial results being given in each case. Lastly, some planned analytical and experimental work will be discussed.

Tools used as part of the ECOTAP programme

Sonic tagging

The first fish tracking by sonic telemetry was carried out in the late 50s (Trefethen, 1956 in Yuen, 1970). Much more research has been carried out for the purpose of describing fish movements in their natural environment since that time, through the rapid development of telemetry, in other words, the distant transmission of a signal carrying the result of measurement work, which has been made possible by technological progress achieved in electronics and in particular the miniaturisation and improvements in the range and lifespan of transmitters.

Since the work carried out by Yuen (1970) on tunas, many sonic tagging experiments have been performed out in all the oceans. Holland (1996) has produced a synopsis of the results so far published of tuna tagging near FADs (Cayré & Chabanne, 1986; Holland et al., 1990a, 1992; Cayré, 1991; Cayré & Marsac, 1993; Marsac et al., 1996).

Under the ECOTAP programme, tuna tracking by sonic telemetry was performed using two different devices.

The first, which was used in the first series of experiments, comprised a VEMCO V-10 bearing (directional) hydrophone fitted to a paravane towed by the boat. This hydrophone was connected to a VEMCO VR-60 decoder which converted the value of the raw signal transmitted by the tag into the value of the variable measured (depth, in the case of our experiments). The boat position was recorded on a global positioning system (GPS) receiver every five minutes.

Concerning the second, which has been in use since 1996, signal reception was by the "VEMCO V-

41 Bearing Hydrophone" system fitted to a towed paravane. In this case, four basic hydrophones, each having its own listening angle, were used. Four zones were defined for the horizontal plane: forward, rear, port and starboard. All the hydrophones were connected to a VEMCO VR 28 receiver by an electromechanical cable. This receiver was equipped with a control module making it possible to select which of the four areas was to be listened to. The receiver was connected to a micro-computer through an RS232 link. This micro-computer was also connected to a GPS through a second RS232 link.

The "TRACK" software package used on the micro-computer made it possible to record:

- signals transmitted by the tag and decoded by the receiver every second, and

- GPS data every five seconds.

Two methods were used to attach the tag to the fish. The most widely used method for tunas, which has been described in this bulletin by Holland (1996) involves attaching the tag using two nylon straps inserted through the muscle behind the dorsal fin. This method is difficult to use on specimens weighing over 30 kg. In such cases, it is preferable to tag the fish in the water in the same way as with billfish (Holland et al., 1990b; Brill et al., 1993). The sonic tag is attached to a flexible tag developed as part of a billfish tagging experiment. A pole with a stainless steel arrowhead is used. The hydroscopic nylon head of the hollow flexible tag is pushed through the fish's muscle by means of the arrowhead. A ring fitted to the pole two or three centimetres behind the tip acts as a stop, preventing the nylon head from penetrating too far. A rubber band secures the tag to the pole to prevent it being misplaced during preparations for tagging (Figure 1).

Active acoustics

There are two different main acoustic survey methods:

- active acoustics where the basic information comes from the echoes returned by the targets from a signal generated by the sonic equipment, and

- passive acoustics performed by analysing noises spontaneously emitted by organisms or the environment.

The use of active acoustics to detect fish (acoustic surveys) was first referred to in the scientific literature in 1929 (Kimura, 1929 in Johannesson &
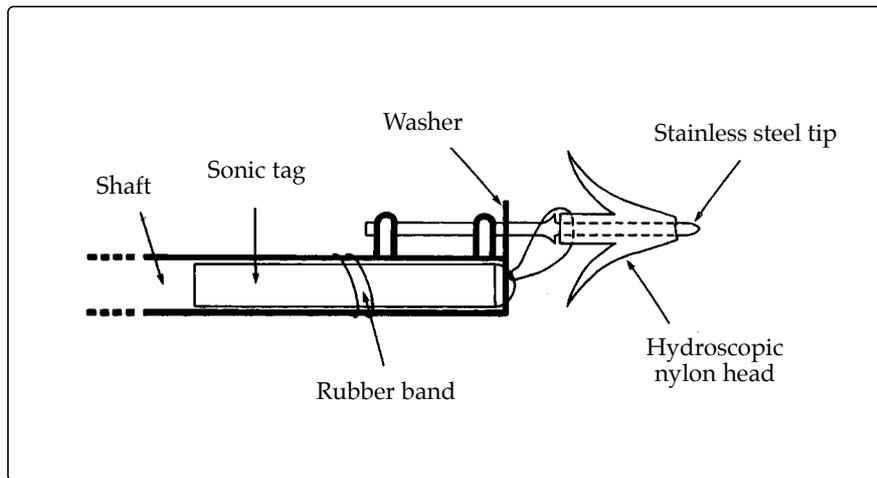
Figure 1

Sonic tag attachment device for specimens weighing over 30 kg

Mitson, 1993). Not until the 1960s did the first electronic integrators appear, making it possible to process fish echoes (echo-integration). Quantitative fish stock estimates then made rapid progress (Johannesson & Mitson, ibid.). There are various types of sounders which differ in their operating principles and the kind of information they collect.

Only vertical sounders were used in the ECOTAP programme. The Biosonics 102 model, using two frequencies, 38 kHz and 120 kHz, was used first either in normal mode (single beam) to make quantity assessments or in dual beam mode to determine the target strengths (TS) of individual subjects. The echo-integration data collected with the Biosonics sounder were analysed using the INES-MOVIES software package (Diner, 1990). From 1995 onwards, observations were carried out with a SIMRAD EK500 sounder, operating on two frequencies, 38 kHz and 120 kHz. This is a compact sounder including an echo-integration module and a TS analysis system. The 120 kHz transducer is a single beam transducer whereas the 38 kHz is a split beam transducer.

Results of some experiments

Movements of tunas tagged near FADs

Tuna tagging experiments near FADs in French Polynesia began in November 1985 (Cayré & Chabanne, 1986) and continued in 1992 as part of the EVAAM FAD programme, in 1993 as part of the

ECOTAPP experimental programme (Abbes et al., 1995) and then in 1995 under the ECOTAP programme. Nine tunas have been tagged near FADs since 1992 (8 yellowfin, *Thunnus albacares* and 1 bigeye, *Thunnus obesus*), four of which are the subject of this report. Three involved conventional ultrasonic tagging while the fourth was an association of acoustic survey and ultrasonic tagging.

Yellowfin tagged on 2 September 1992

A yellowfin tuna 48 cm in fork length was caught by trolling near a FAD located 20 nautical miles (nm) east-south-east of the Tahiti peninsula (see Figure 2 on next page). Tagged in the morning (09:11, local time), this fish was tracked for almost 28 hours. After being tagged, this fish stayed close to the FAD for approximately four hours before heading south (between 12:30 and 16:30) then south-west (from 16:30 to 18:00). At sunset, it was located 1.5 nm from the FAD and then veered west and subsequently north. It then started swimming back towards the FAD, which it swam past at a distance of 0.5 nm, before exploring the zone to the north of the device.

From the middle of the night to dawn, this animal's horizontal movements were not very extensive in an area which it would again favour in mid-morning, after a period of rapid movements towards the FAD. The fish was lost at 11:11 and then relocated two hours later at the FAD. During the tracking period (28 hours) the fish did not move more than 2.1 nm away from the FAD.
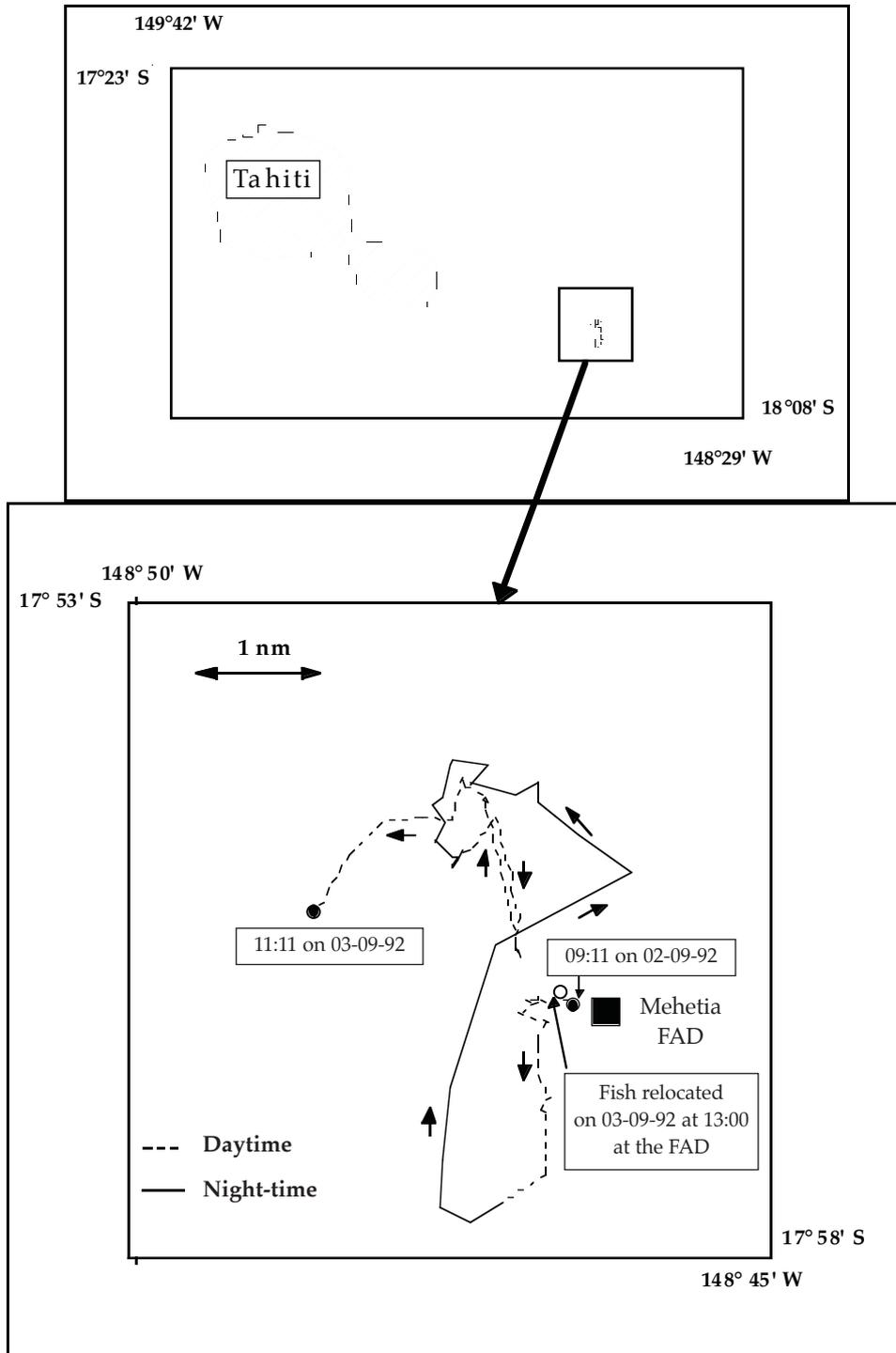
Figure 2

**Horizontal movements of the 48 cm fork-length yellowfin tuna
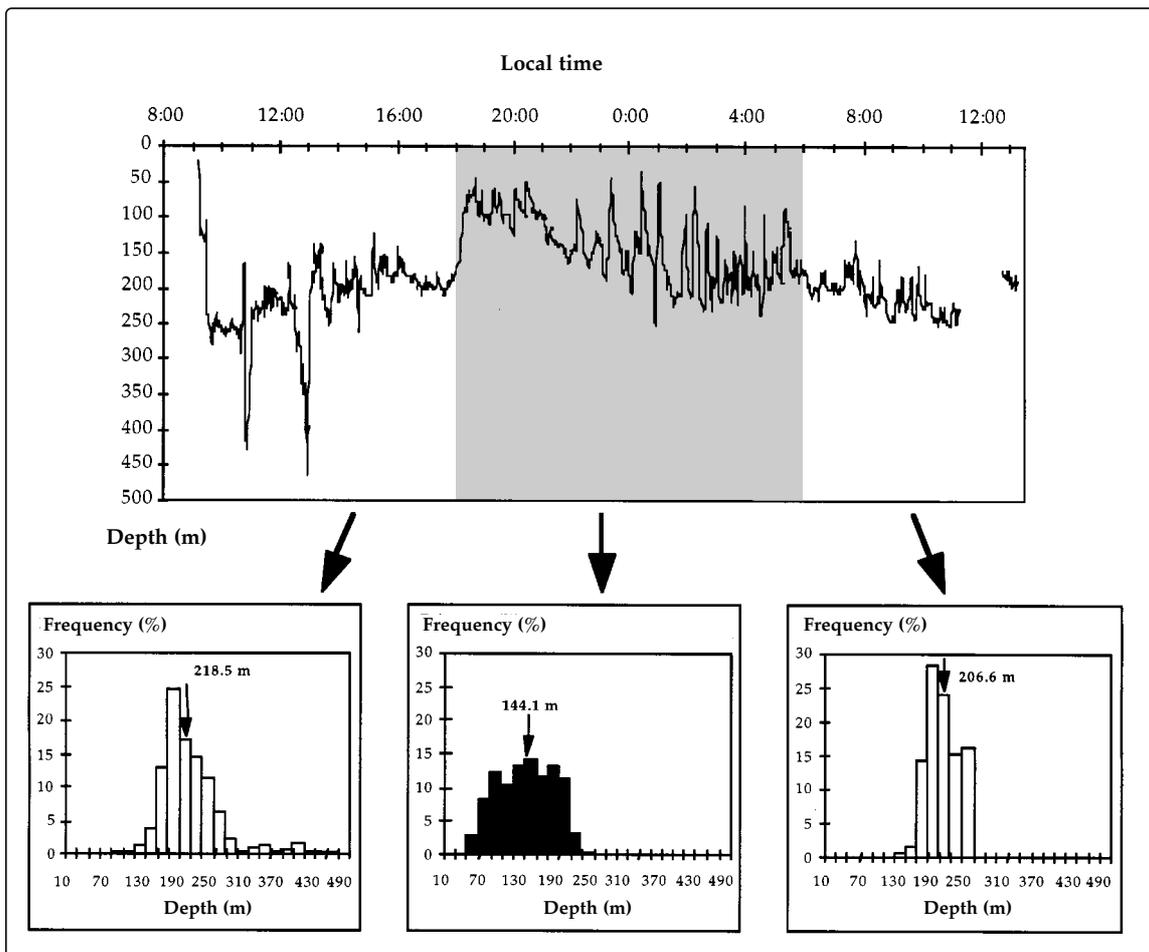tagged on 2 September 1992 and tracked for 28 hours**

Vertical movements during the diurnal phase were mostly limited (between 180 and 260 m) except two brief deep dives to 430 m in the morning and 470 m in the afternoon (Figure 3). The fish moved up nearer the surface early in the night (50–120 m) before commencing a phase of wide depth variations (50–250 m). During the morning of the second day, the fish remained between 150 and 250 m, in an identical manner to the first day.

Yellowfin tagged on 2 March 1993

A yellowfin tuna 51 cm in fork length was caught on a trolling line near FAD no. 165 (Punaauia FAD) located 5.2 nm from Tahiti's west coast (see Figure 4 on next page). This specimen was tagged at 18:35 (local time) and tracked for approximately 64 hours. It left this FAD just after being tagged and swam parallel to the coast for the first night towards FAD no. 179 (Paea FAD) located 6.4 nm from the previous one. Little movement was

recorded between 09:30 and 12:30, and the fish remained within a semi-circle 1.5 nm in radius from the FAD. In the middle of the day, its movements turned southwards towards a third FAD (FAD no. 170, known as the Papara FAD) located 9.2 nm from the second and 15.6 nm from the first. It continued swimming towards this FAD all night to reach a point approximately 0.8 nm from it at first light. During the day and in the early evening, it remained relatively far from the FAD, returning towards it in the middle of the night (maximum distance from the FAD = 7.8 nm).

Early in the morning (07:00 local time), it was located under the FAD and remained there until 09:30 when tracking ended. A synopsis of these results reveals that the fish swam between the FADs on the first two nights and came back to the third FAD during the third night, having swum away from it at the end of the second day. The diurnal phases were spent in areas close to FADs.

Figure 3

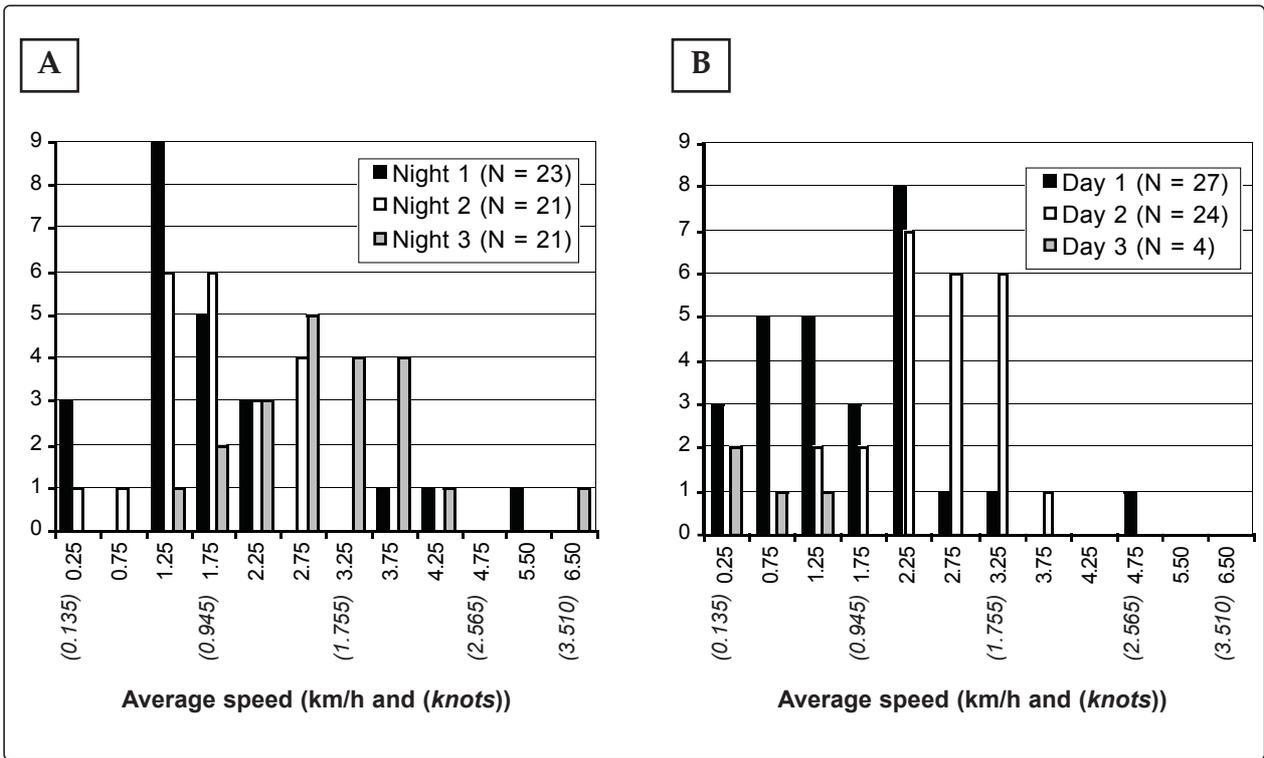**Vertical movements of the 48 cm fork-length yellowfin tuna tagged on 2 September 1992**
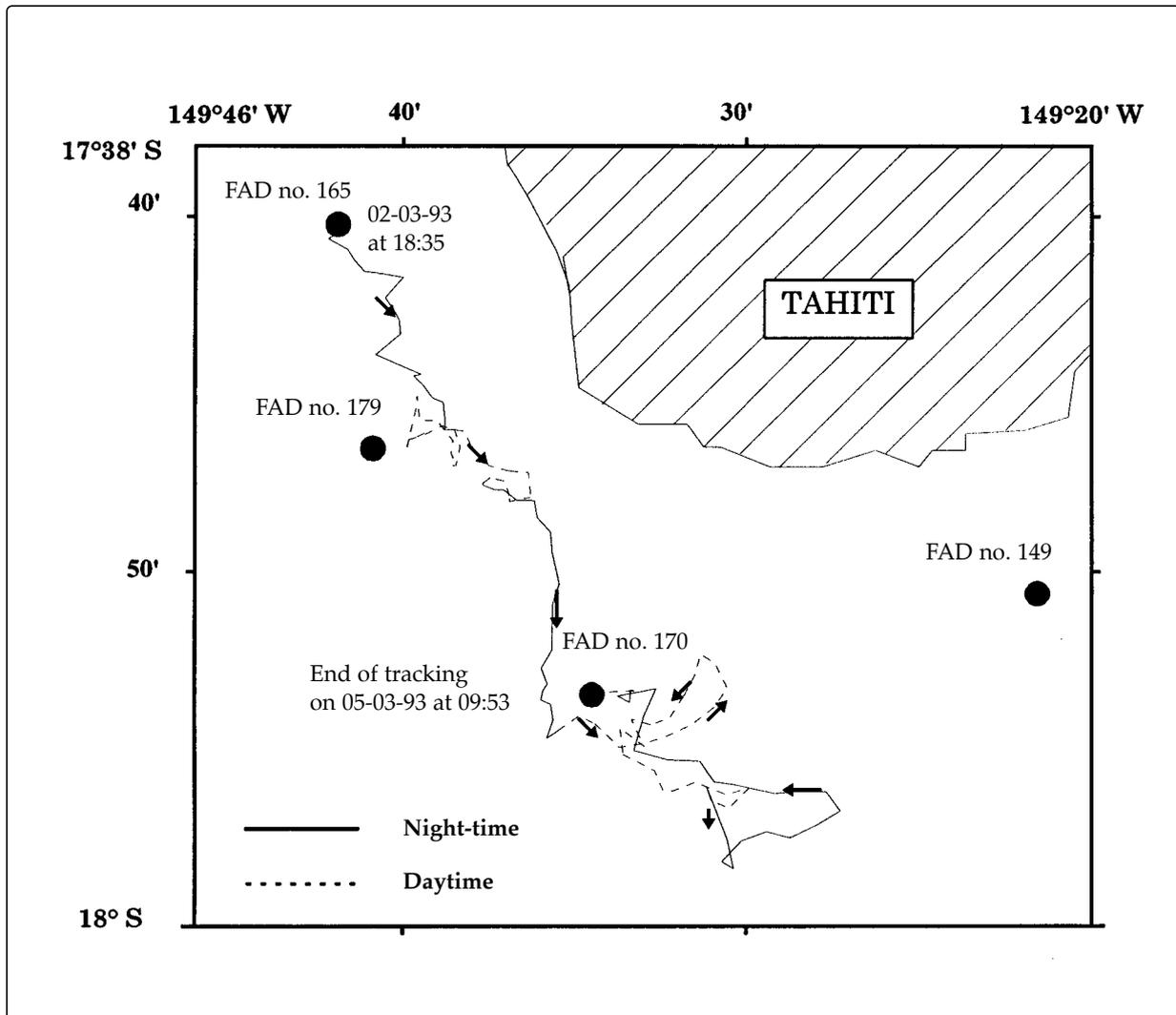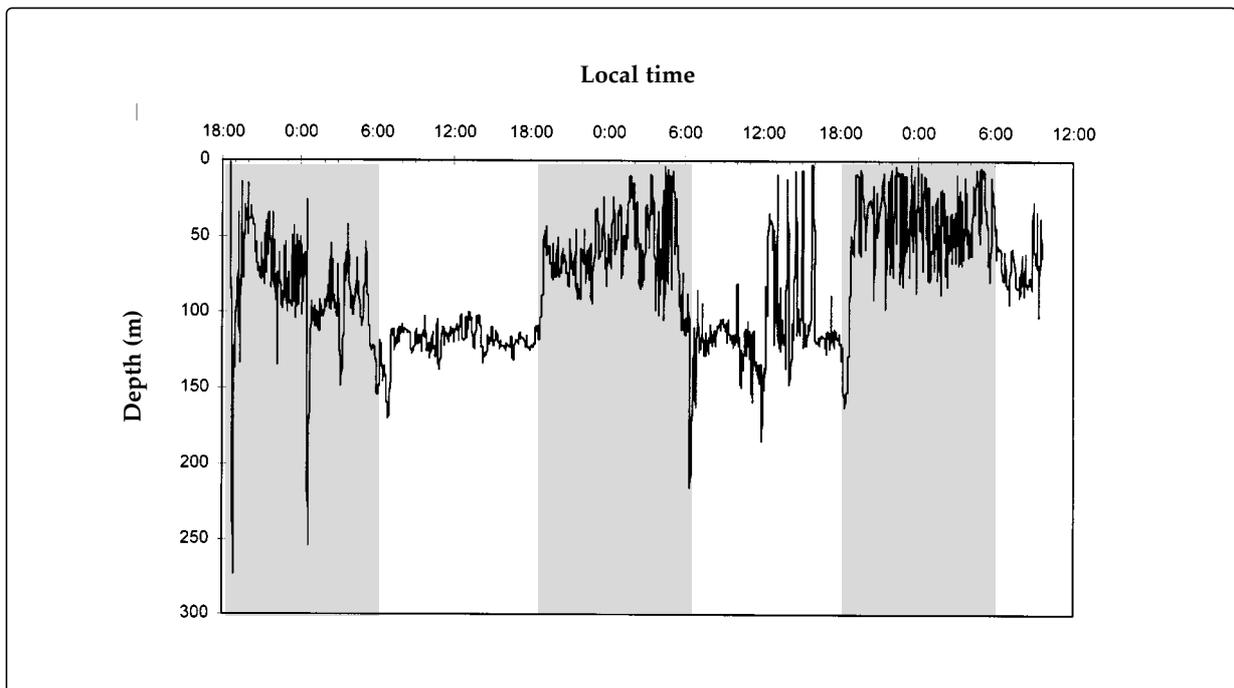
Figure 4

**Horizontal movements of the 51 cm fork-length yellowfin tuna tagged on 2 March 1993
at FAD no. 165 (Punaauia) and tracked for 64 hours**

The average speed-frequency distributions per thirty minute period calculated during the nights and days of tracking show that these speeds fluctuated over time (Figure 5). From being relatively stable over the first two nights and the first day of tracking (average speed approximately = 0.9 knot or 1.7 km/h), they increased during the second day (average = 1.4 knots or 2.6 km/h) and the third night (average = 1.6 knots or 3 km/h) to reduce at the beginning of the third day when the fish was near the FAD (average = 0.4 knot or 0.7 km/h).

The vertical movements show that on the first night, the fish occupied the water layer between the surface and a depth of 120 m with a dive to 250 m in the middle of the night (Figure 6). On the other hand, during the next two nights, it mostly remained in the top 80 m. During the first diurnal phase, the fish showed a preference for depths of between 100 and 140 m while swimming between the surface and 210 m during the second. This difference in diurnal vertical movements was in both cases observed when the fish was swimming close to a FAD.

Figure 5

Average speed-frequency distributions per 30-minute period observed at night (A)
and during the day (B) in the course of tracking

Figure 6

Vertical movements of the 51 cm fork-length yellowfin tuna tagged on 2 March 1993

Yellowfin tuna tagged on 2 March 1996

A 90 cm fork-length yellowfin tuna was caught on a vertical longline (drop-stone fishing, Moarii & Leproux, 1996) near FAD no. 204 (Papeete FAD) located 14.2 nm off the northern coast of the island of Tahiti (Figure 7).

During tracking, which lasted almost 81 hours, the fish always remained at a distance of less than 1 nm from this FAD. This tagging experiment shows that the fish did not leave the FAD for at least 81 hours or approximately 4 days.

The vertical movements oscillate between the surface and 165 m (this depth interval corresponds to a temperature interval between the 28.5°C and 23°C values). No significant difference between diurnal and nocturnal movements was recorded (Figure 8).
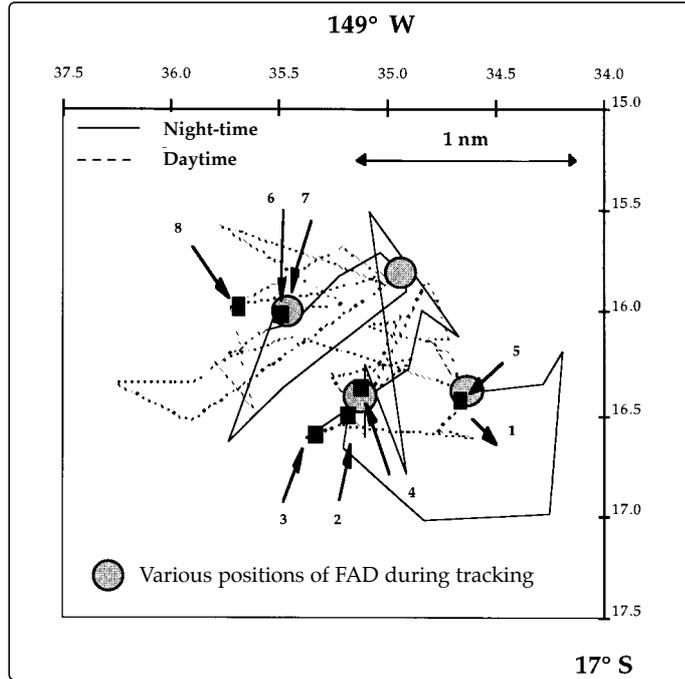
Figure 7

Horizontal movements of the yellowfin tuna in the vicinity of the Papeete FAD from 09:13 on 2 March 1996 to 18:00 on 5 March 1996
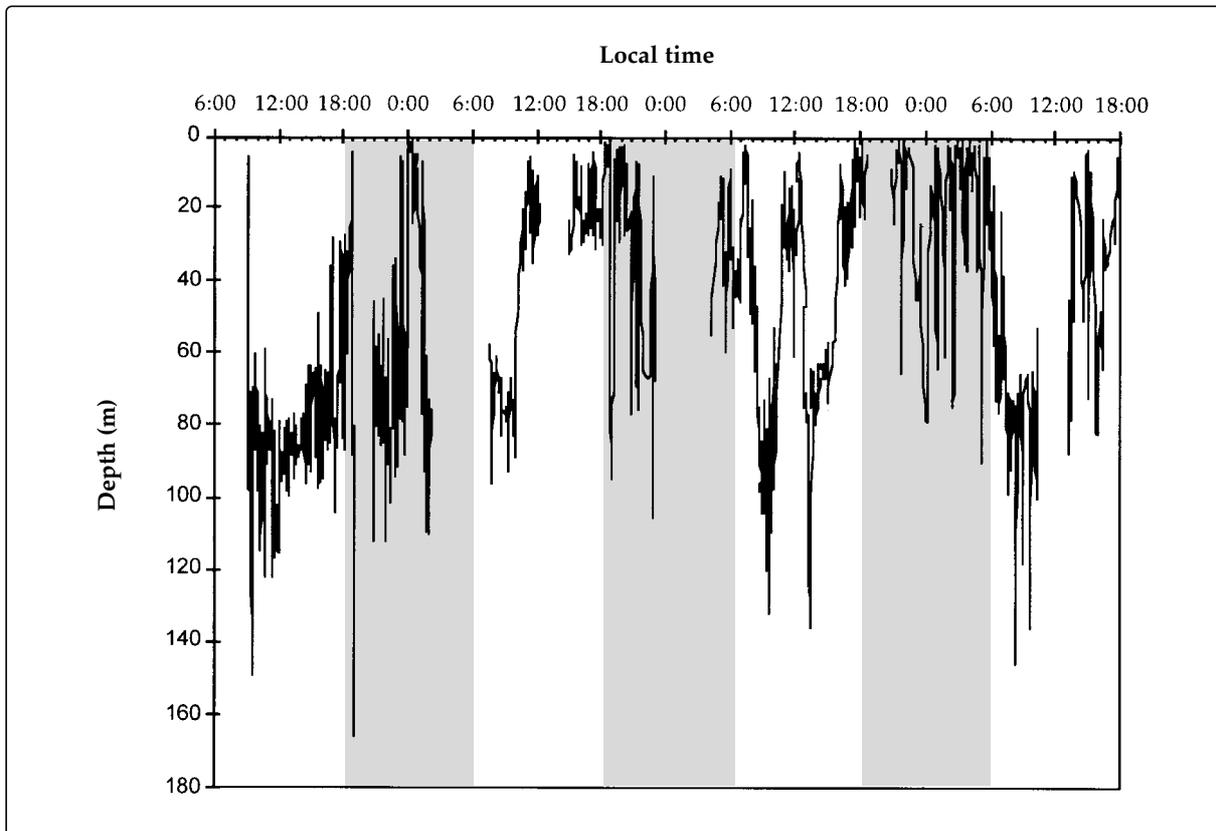
Figure 8

Vertical movements of the 90 cm fork-length yellowfin tuna during the 81 hours of tracking

Coupling of acoustic surveys and ultrasonic tagging

The use of active acoustics together with a sonic tagging experiment made it possible to observe the biological environment inhabited by the tracked fish. In the same way as with the physical environment (temperature, dissolved oxygen) it becomes possible to consider this biological environment as an explanatory factor for vertical and horizontal tuna movements (Josse et al., 1997). The tagging experiment described below illustrates the wealth of information that such a dual method can provide.

Yellowfin tuna tagged on 27 October 1995

A 60 cm fork-length yellowfin tuna was caught by vertical longlining near FAD no. 177 (Maupiti FAD) moored near the island of Maupiti (16°27'S and 152°17'W), (Figure 9). This fish's horizontal movements can be divided into four periods:

(i)   association with the FAD just after tagging;
(ii) gradual movement away from the FAD until sunset (the maximum distance from the FAD was 3.3 nm at 17:14);
(iii) gradual return to the FAD until 23:00; and
(iv) gradual movement away from the FAD parallel to the coast from 23:00 onwards.

Two periods characterise the vertical movements :

(i)   under the mixed layer during the day, and
(ii) in the mixed layer for the nocturnal period observed.

Within an oligotrophic environment, a sound scattering layer (SSL) was observed (Figure 9), using the SIMRAD EK500 sounder. SSLs were sampled several times during pelagic trawling, revealing that they are formed of tuna prey. The fish crossed this layer a first time during the day (see Figure 10 on next page) and a second time at night (see Figure 11 on next page). During the second crossing, this fish changed its vertical movement: it swam in the mixed layer at night and left to enter the prey aggregation, probably for feeding purposes. The horizontal movements would appear to be more due to the attraction exerted by this layer than by an association with the FAD.

Synopsis of the four taggings described in this document

The last tagging experiment coupled with an acoustic survey revealed the need to observe the biological environment in the same way as the physical and chemical environments in order to better understand the behaviour of tunas near FADs.
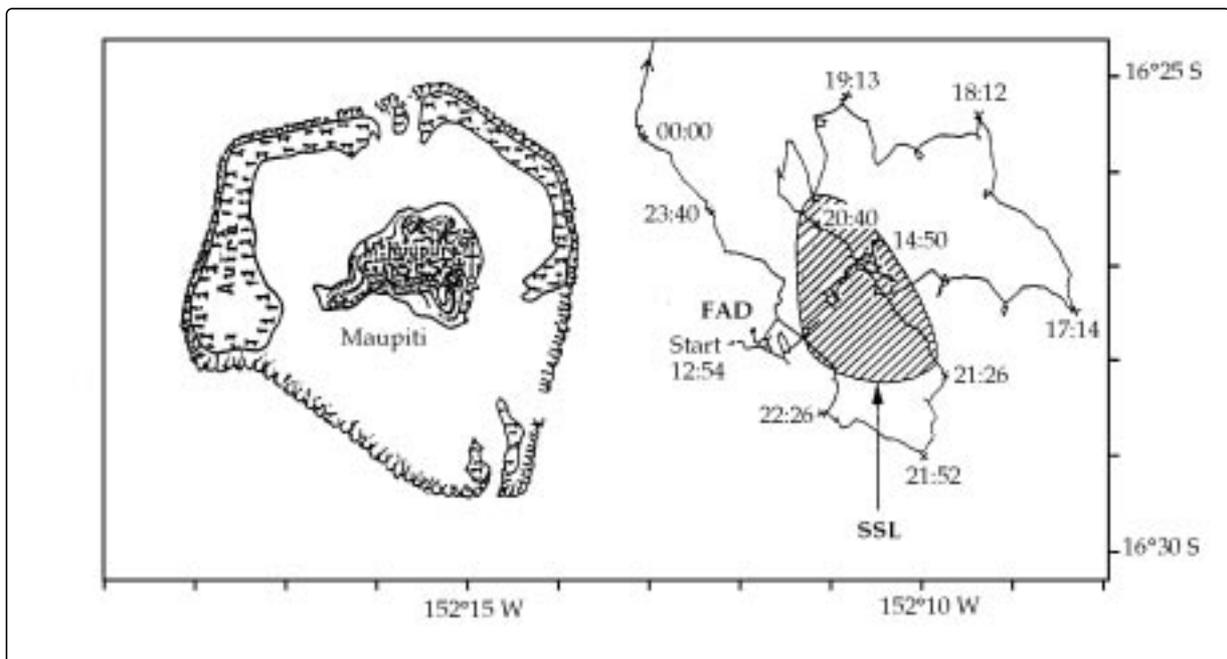
Figure 9

**Horizontal movements of the 60 cm fork-length yellowfin tuna caught
and tagged at a FAD moored near the island of Maupiti.
Superimposition of the sound scattering layer (SSL) on the horizontal movements**
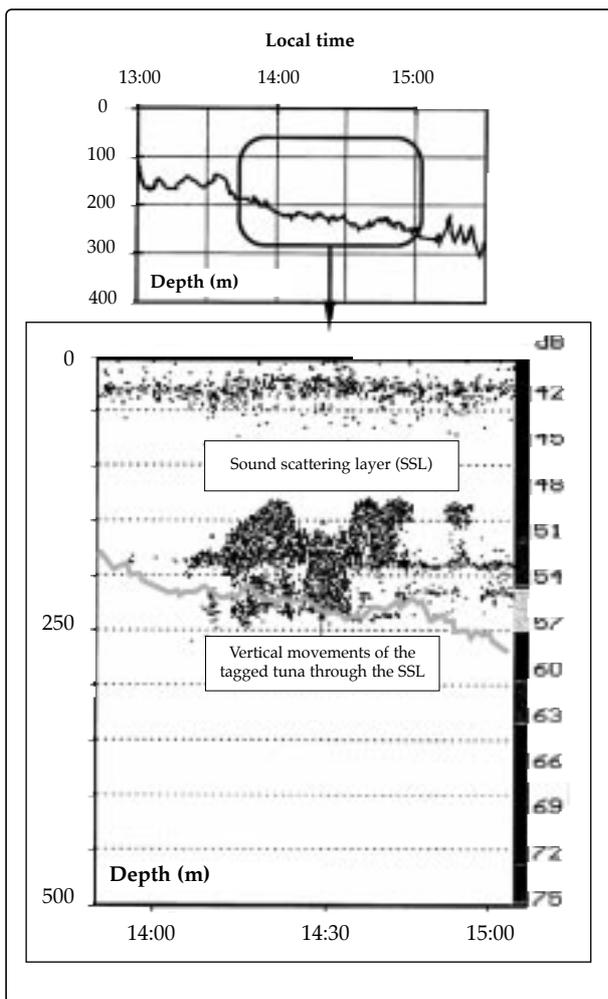
Figure 10

Vertical movements of the yellowfin tuna in the daytime between 13:30 and 15:00 (local time) and relationship with the sound scattering layer (SSL)
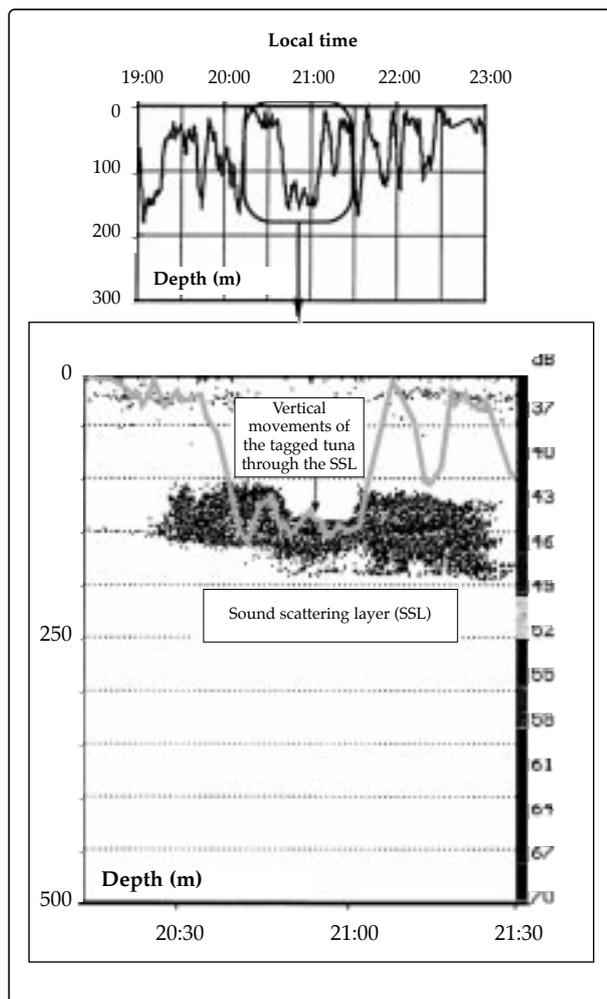
Figure 11

Vertical movements of the yellowfin tuna in the night-time between 20:15 and 21:30 (local time) and relationship with the sound scattering layer (SSL)

In addition, these four taggings showed that it is not possible to define a single kind of association (in term of duration or horizontal and vertical movements). The first and third tunas remained near the FAD during tracking whereas the second and fourth tunas left the FAD close to which they had been caught to visit other FADs or follow the outline of the coast. Similarly, the vertical profiles did not make it possible to show any particular trend as to vertical movements near FADs.

Use of acoustic survey methods to study the daily variability in aggregations

In analysis of tuna-FAD relationships, sonic tagging with tracking only yields information on these relationships at the level of the individual fish. Multiple ultrasonic tagging (up to 20 specimens) with a network of receivers installed on neigh-

bouring FADs makes it possible to analyse the group's degree of cohesion, the strength of its relationship with a FAD and the exchange mechanisms between FADs on a time scale which will be determined by the lifespan of the transmitters (Klimley & Holloway, 1996).

Acoustic surveys around FADs make it possible to consider the associated aggregation. The purpose of the experiments carried out in Tahiti (see Depoutot, 1987 and Josse, 1992, for some initial results) was to study the horizontal and vertical extensions of aggregations and their variations on a one-day time scale. Acoustic surveys, in a star formation around the FAD (Figure 12) were carried out several times per day in order to do so.

The results presented here concern a series of acoustic surveys performed with the Biosonics 102

sounder in July 1993 around a FAD moored off the island of Nuku Hiva in the Marquesas Group (FAD moored 1.5 nm from the coast at a depth of 450 m). These are preliminary results and take into consideration overall acoustic response values irrespective of individual target strengths (TS). Six operations were carried out over a 24-hour period but only the results of three of them will be presented here for clarity reasons.

Acoustic density values were calculated by depth stratum (10 strata each 25 m in width between the surface and 250 m) taking into account distance from the FAD (4 distance strata of 0.2 nm).

During the night-time acoustic surveys (Figure 13A), the high acoustic responses in the first 50 m (strata 25 and 50) are due to the presence of a nocturnal deep scattering layer (DSL). Under this layer, some strong response values correspond to detections of single fish situated between 75 m and 150 m. The first daytime trip (Figure 13B) reveals the disappearance of the night deep scattering layer which had migrated deeper, beyond the echosounder's vertical range. Small schools of fish are present vertically beneath the FAD to 125 m, as are isolated fish at greater depths (between 175 m and 250 m), 0.3 nm from the FAD. Early in the afternoon (Figure 13C) the aggregation would appear to be more compact close to the FAD. Detections are also observed at greater depth (125 m and 150 m) further from the FAD.

An appraisal of the previous results made it possible to reveal the high response to nocturnal acoustic surveys associated with the presence of a deep scattering layer in the top 50 m. At night, if the 0–250 m water layer is considered in its entirety, the intensity of this response thus creates background noise which masks any vertical variations in acoustic response dependent on other organisms such as tunas. In order to discriminate between these two sources of acoustic response (DSL, and predators apart from DSL) two depth strata were considered individually, a 0–50 m stratum and a 50–250 m stratum.

Figure 12

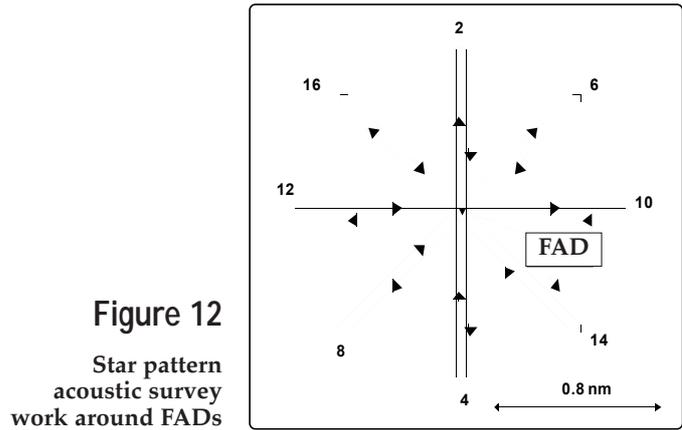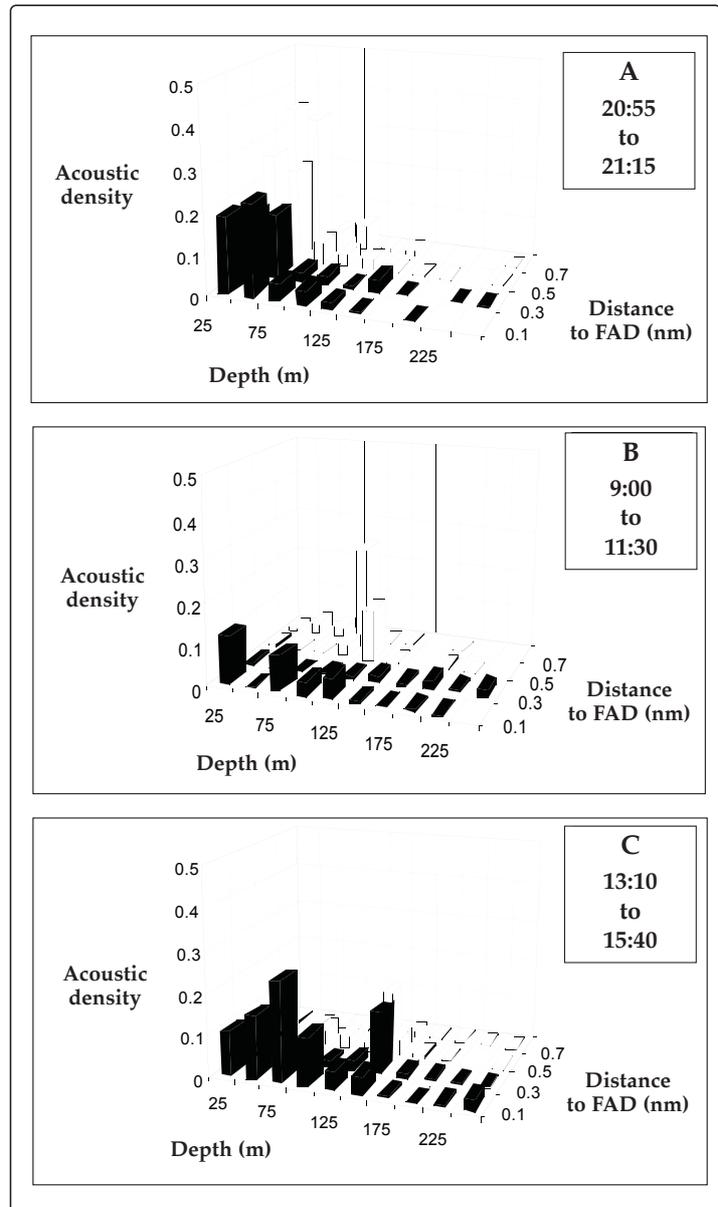**Star pattern acoustic survey work around FADs**

Figure 13

Acoustic response density distributions by depth stratum (25 m stratum) according to distance from FAD (0.2 nm stratum) observed during successive acoustic surveys around the Nuku Hiva FAD (Marquesas Group).

During the night-time, between 0 and 50 m, acoustic responses are high and located offshore rather than close to the coast (Figure 14A). In the daytime, the acoustic response densities observed in this layer are low with the exception of some areas located near the FAD and, in this case, the highest values are located between the FAD and the coast (Figure 14B and C).

The spatial distribution of acoustic responses between 50 and 250 m differs from that observed for the upper layer (Figure 14D, E and F). Where night-time acoustic surveys are concerned (Figure 14D), no particular trend can be noted as to the orientation of acoustic response intensities. On the other hand, this trend does appear with day-time surveys. In the same way as for the 0–50 m stratum, high acoustic densities are recorded near the FAD, as well as along certain radials

(Figure 14E and F). These radials are always located between the FAD and the coast (north-east and east radials of Figure 14E, south-east radial of Figure 14F). The high values near the FAD correspond to two small schools located in the top 100 m and to some isolated fish echoes identified to a depth of 250 m and a distance from the FAD of 0.45 nm (Abbes et al., 1995). Vertical longlining over these isolated echoes yielded young yellowfin tuna at depth of between 100 and 150 m.

This spatial heterogeneity could be due to the fish positioning themselves in relation to a current. The acoustic responses recorded at the greatest distance from the FAD are thought to be able to be attributed to detections close to the sea floor which is at a depth of approximately 200 m at the end of the east radial. These detections probably relate more to the demersal than to the pelagic fish resource.
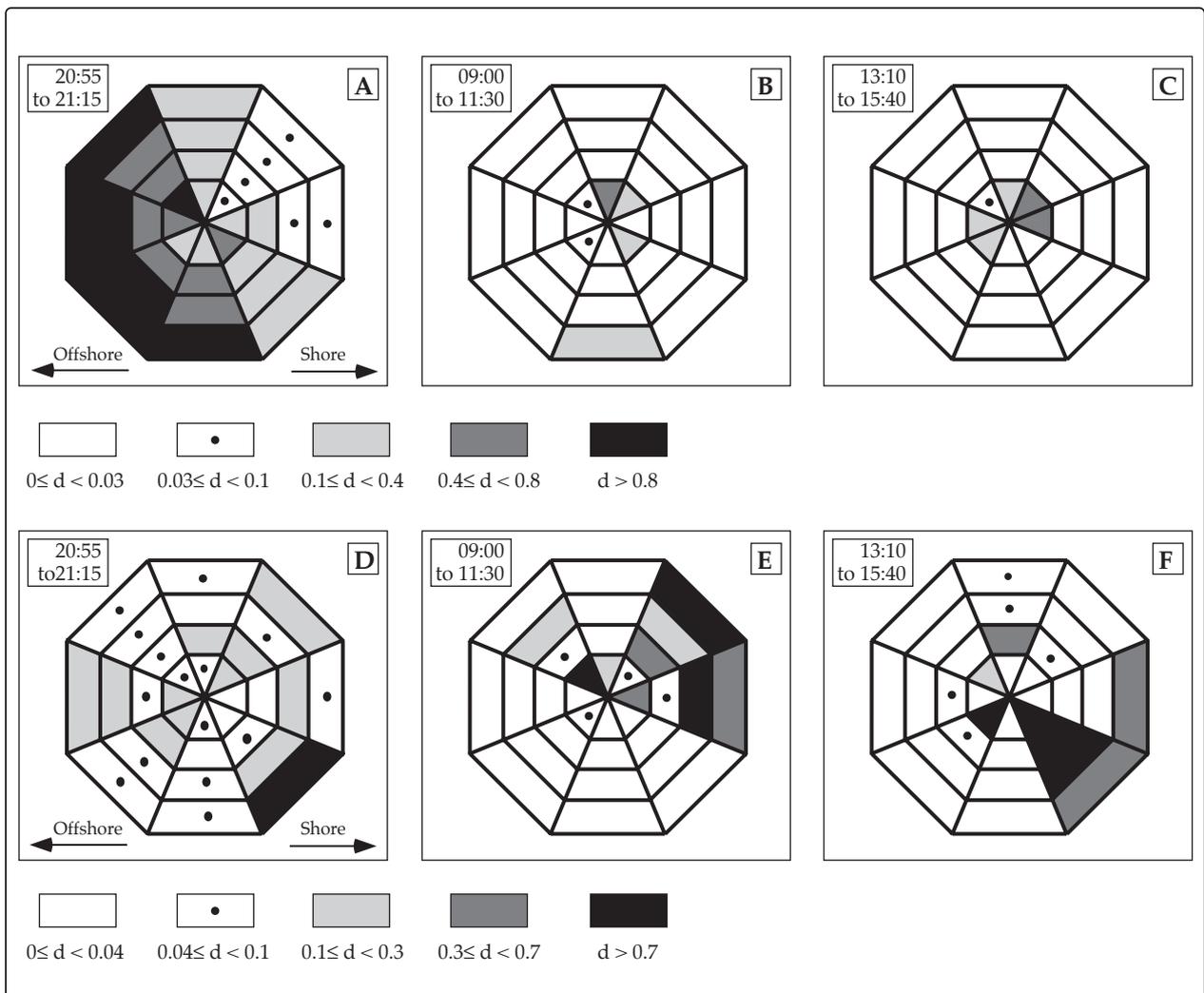

Figure 14

Spatial distributions of acoustic response densities by 0.2 nm intervals as observed in the 0–50 m stratum (A, B, C) and in the 50–250 m stratum (D, E, F) during a series of acoustic surveys carried out around the Nuku Hiva FAD (Marquesas Group).

Discussion

The results presented in this paper and those under analysis show that no real trends exist which would make it possible to define the behaviour of tunas in relation to FADs in simple terms.

At the scale of the individual specimen, the published results (Cayré & Chabanne, 1986; Holland et al., 1990a; Cayré, 1991; Marsac et al., 1996; Marsac & Cayré, 1997) as well as those presented in this document demonstrate the variability of tagged tunas' horizontal and vertical movements in the vicinity of FADs. Concerning horizontal movement, tunas assumed to be associated with a FAD swim at a variable distance from it, up to 5 nm in the daytime and 7 at night (Marsac & Cayré, 1997). Tracking for several successive days showed that some tunas remained under the FAD all the time, while others stayed close to the FAD in the daytime and swam away from it during the night, returning towards the FAD on the following day or leaving it in a horizontal movement pattern tied to the coast, or offshore, or attracted by other objects such as a new FAD. In other cases, a tuna could return to a FAD several months later after an initial association with it (Klimley & Holloway, 1996).

Tagged tunas' vertical movements close to a FAD vary in a given geographical area. The only constant factor in these movements concerns the nycthemeral variation, with movements generally taking place close to the surface at night rather than in the daytime. This trend would appear to be independent of the tuna's relationship with the FAD, since it is observed with specimens not associated with FADs. However, some authors (Holland et al., 1990a; Cayré & Marsac, 1993) have shown the influence of FADs on tunas' vertical movements.

One piece of information which makes it possible to justify the heterogeneity observed in the behaviour of tunas near FADs can be provided by our observations as represented on Figure 9. This result suggests that the spatial structure of the biological environment could be one of the explanatory factors in the diverse ways in which the relationships of tunas to FADs express themselves, a theory which have not yet been put forward.

It is difficult to draw conclusions about the structure and spatial organisation of FAD-generated aggregations. Also, results differ regarding fauna composition determined from the observation of FAD-related catches. This difference should be related to the diversity of fishing techniques used. Skipjack (*Katsuwonus pelamis*) and small yellowfin tuna, generally swimming in mixed schools, (Depoutot, 1987; Cayré et al., 1991; Sims, 1992;

Cillauren, 1994) account for the major proportion of catches from trolled aggregations. In French Polynesia, handlining has almost entirely replaced trolling around FADs (Josse, 1992). The albacore (*Thunnus alalunga*) accounts for approximately 80 per cent of catches and is taken with lines 140 to 270 m in length (Asine, pers. comm.). When artisanal fishermen target yellowfin, they usually use shorter lines (approximately 90 m long). These handlines are set at random around the FAD within a radius of approximately 0.5 nm and their success would not appear to be connected with distance from the FAD.

Current knowledge does not make it possible to deduce the specific composition of schools from acoustic responses. However, with results recently obtained on target strength of tunas (Bertrand et al., 1997), future analysis of acoustic surveys carried out around FADs should make it possible to characterise aggregation composition more accurately.

The results gained from acoustic surveys around FADs provide a partial image of the aggregation in its vertical and horizontal extensions. These results depend on the sampling methodology (means used and protocol). Depoutot (1987), using acoustic survey techniques sampling the top 100 m of the ocean, demonstrated that aggregations showed major spatial and temporal variability, with acoustic responses diminishing during the day and increasing during the night. During the diurnal phase, the acoustic responses increase with decreasing distance from the FAD without a clear trend as to their orientation in relation to the FAD. At night, the acoustic responses are higher and increase with distance from the shore.

These results concur with those presented in this paper for the 0–50 m stratum. In contrast, we have shown that fish echoes were identified down to a depth of 250 m and up to a distance of 0.3 nm from the FAD. In the case of sonic tagging, fish echoes could be recorded at a distance of 5 to 7 nm from the FAD and at depths of over 250 m. Maximum echo distance corresponds to the length of the radials carried out : 0.6 nm for Depoutot (1987) and 0.8 nm for the observation described in this paper, which shows the limits of this kind of experiment for addressing the aggregation in every dimension.

It can be seen therefore that the issue regarding tuna aggregation dynamics around FADs, often addressed by scientists, has not for the moment found a satisfactory response. This answer is nevertheless the one the most keenly awaited by fishermen and coastal fishery managers using FADs to maintain and develop both artisanal and sport fisheries. This situation can be explained by two main reasons.

The first, as we have seen, is connected with the spatial and temporal limits of ultrasonic tagging operations and acoustic surveys. In this connection, Kleiber and Hampton (1994) stressed that: 'These tracking studies deal with individual animals perhaps in the vicinity of one or a few FADs. They typically cover a time scale of days and a spatial scale of tens of kilometres. It is not clear how to extrapolate the findings to longer term movements within a population of tunas in a large area occupied by a given spatial arrangements of many FADs.' Multiple-tagging with listening stations (Klimley & Holloway, 1996) improves the coverage in space and time of the results of tuna-FAD relationship studies.

The second reason is connected with the restrictions imposed by the issue of the relationship between an aggregation and a FAD. To provide answers supposes that all the mechanisms governing a relationship between the two factors should be taken into consideration. In particular, it is essential that the spatio-temporal observation scale should be higher than or equal to that in which these mechanisms act.

We believe that it is essential to distinguish between two spatio-temporal windows for fish likely to gather around FADs (Figure 15): firstly, a window corresponding to the FAD's radius of attraction (window A); secondly, a window which can be referred to as a comfort window (Postel, 1966; Legett, 1977; Balchen, 1979; McKeown, 1984) which is defined by the biological quality of the environment (window B). The results of ultrasonic tagging show that a FAD attraction radius is approximately 5 nm in the daytime and 7 at night (Marsac & Cayré, 1997), which could correspond to the size of window A. The edges of the comfort window (window B) will be determined by the environment's capacity to meet fishes' needs, in particular their food needs. One B window could contain several A windows (a number of FADs). In this way, a fish can satisfy its needs within a given A window, which would explain their back-and-forth movements close to a FAD or why they remain associated with a FAD. If a fish cannot meets its needs within an A window, it leaves the A window, while remaining within a B1 comfort window (see Figure 15), where it may meet other FADs (A windows). If this B1 window does not enable it to satisfy its needs, it may go to a B2 window and be able to associate itself with FADs if these are present in that window (Dagorn, 1994). Thus, when Klimley and Holloway (1996), observe a time interval of 114 days before a tuna returns to a FAD, this tuna might have remained, during the period in question, within the same comfort window, while it might or might not have

associated itself with other FADs, swum within another comfort window—with or without an association with FADs—and then again returned to the FAD where it was tagged.

This working hypothesis is under test in the ECO-TAP programme. A modelling tool has been selected and the approach used calls upon recent developments in the sphere of Artificial Life modelling.

The tridimensional biological environment (window B = comfort window) of the tunas in the model, comprises various A windows (FADs) 10 to 12 nm apart. This biological environment corresponds to a prey environment based on acoustic observations carried out during ECOTAP.

Tuna's movements are modelled by using artificial neurone networks. In fact, an artificial tuna consists of variety of internal and external sensors and interprets the data from these sensors over time, which makes it possible to determine its behaviour (swimming speed, direction and depth) on the basis of stimuli perceived around itself (prey, FADs).

This model is still under development. However, the initial results obtained concur with the results of movements observed during ultrasonic tagging (Dagorn et al., 1997). This approach therefore makes it legitimate to study the relationships between tunas and FADs at space and time scales superior to those conventionally used so far. This kind of simulation, which calls upon the results of acoustic surveys and ultrasonic tagging is an avenue of work which is currently being developed in order to propose a fishery management plan based on FAD deployments (distance from the coast and FAD network density).
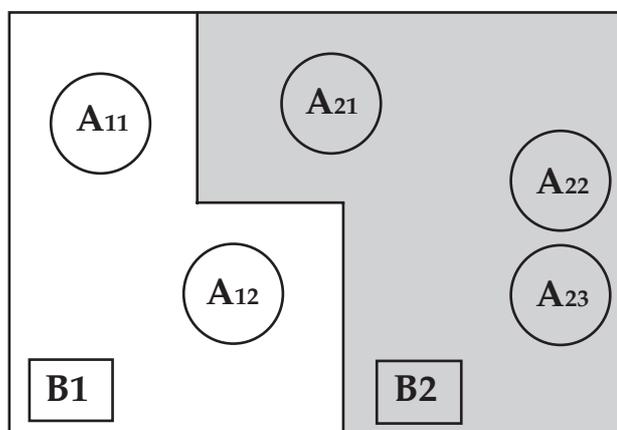

Figure 15

Example of FAD window layouts (Aij) around two different Bi comfort windows.

Conclusion

Research on the theme of the relationships between tuna aggregations and FADs has made considerable progress over the past ten years. A range of tools has been developed within the ECOTAP programme to improve knowledge in this area.

The results obtained from ultrasonic tagging agree with those already published. The use of acoustic surveys and sonic tagging in a coupled arrangement has made it possible to reveal the important role played by the biological environment on tunas' horizontal and vertical movements. A similar association has made it possible to carry out the first target strength measurements for tunas and thus future acoustic survey analysis will make it possible to qualify and quantify aggregation more accurately.

Acoustic observations of the biological environment played a determining role in all our experiments. They lead us in particular to address the relevance of the scale of study of the relationship between an aggregation and a FAD. Thus, we believe that issues such as tunas' 'faithfulness' to a FAD, exchange mechanisms between FADs and the attraction of a FAD should be considered on a scale taking into account a spatio-temporal window which can be referred as a comfort window. The edges of this window correspond to the environment's capacity to satisfy the needs of the resource. This working hypothesis is currently being tested using an artificial life modelling approach.

On the experimental level, future observations within the study of the relationship between tunas and FADs will need to take into consideration space and time scales greater than those so far used. In addition, then, to the instruments described in this paper, those used in future will need to make it possible to include the following scales: network of echo-sounding buoys, network of listening posts, pop up tags, conventional tagging and high-definition satellite station.

At a time when the exploitation of tuna resources around floating objects is expanding considerably without it being yet possible to evaluate the consequences of this type of fishing on stocks, research on the relationships between tuna and drifting and anchored floating objects is becoming more important than ever.

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The dynamics and effects of FADs in La Reunion Island

by J.-P. Detolle[1]*, E. Tessier*[2]*, D. Roos, F. René & J. Sacchi*

The following article has been translated from a French document entitled 'Study designed to optimise the costs and lifespans of fish aggregating devices in Reunion Island: A technical and economic approach'[3]*. This sudy was prepared by the main author to pass* a DESS Génie et Gestion de l'Environnement *(Higher Tertiary studies in Environment Engineering and Management), at the University of Paris VII. In the following extract, the authors study the effects of FADs on the artisanal fisheries of La Reunion.*

Effects on fishing results: number of fishermen, landings, prices and turnover

To determine the social and economic impact of FADs in Reunion Island, as well as the ways in which they are used (Nguyen-Khoa, 1990 and 1993), a survey form was designed during the study and will subsequently be used systematically with the maximum number of fishers. During the preliminary stages of this study, it became apparent that, without FADs, many fishermen would have abandoned their profession.

FADs have, therefore, played an important role in the development of artisanal fisheries in Reunion Island as the number of fishermen and the quantities caught have increased constantly since their introduction.

This has, however, had some adverse effects on the Reunion Island fish market. Relatively small in size (600 000 inhabitants and an annual consumption of 11 kg of fish per inhabitant, compared to 22 kg in metropolitan France), this market mainly consumes bottom fish like snappers and groupers. Pelagic fish such as tuna and mahi-mahi are therefore difficult to sell, as the market rapidly becomes oversupplied. The creation of an export trade is difficult, especially as Seychellese and Mauritian artisanal fishermen and Reunionese longliners have inundated the Indian Ocean and French markets with their much lower prices.

Effect on prices

FAD fishing may, along with longliners, be partially responsible, for the drop in tuna prices from US$ 5.5/kg[4] or even 6.5/kg in 1988 to US$ 4.5/kg or even 3.5/kg today, which is the break-even point for artisanal fishermen whose costs are high (use of motor launches[5]). But it is difficult to get a more precise idea of their role in this drop in prices. On the international market, where only the competition with imports has to be taken into consideration, the highest price for tuna is about US$ 2.9/kg.

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2. CRPMEM, 238 rue du Maréchal Galliéni, 97820 le Port, La Réunion, France. E-mail: etessier@oceanes.fr
3. DETOLLE, J.P., E. TESSIER, D. ROOS, F. RENÉ & J. SACCHI. (1996). Étude en vue d'optimiser le coût et la longévité des dispositifs de concentration de poissons de l'île de La Réunion, approche technico-économique. IFREMER/ RIDRV n°94.14 RH/La Réunion. 73 p.
4. Original figures are in French Francs (FF), a conversion factor of US$ 1.00 = FF 5.50 has been used for this translated document.
5. Note from the translator: in this English version, the term 'skiff' means a small open motorised fishing boat and the term of 'launch' a bigger boat with a superstructure.

On the other hand, pelagic fish catches have more than doubled since 1988.

Effect on landings

A study by the regional fisheries committee (CRP-MEM) (Tessier, 1995) determined the overall quantities caught on Reunion Island near and around FADs. In 1987, professional artisanal fisheries production was 330 t. Today, it is 916 t of fish, 702 t of which are large pelagics (i.e. 77%). Of this production, 560 t come from fishing around FADs (80% of large pelagic fish and 61% of the total). In eight years, the increase in landings has been 143 per cent, with 171 t of demersal species (an increase of 28%) and 159 t of pelagic fish (an increase of 112%), as a result of the introduction of FADs (Figure 1).

Effect on employment and the fishing fleet

The number of jobs created by the deployment of FADs is difficult to quantify. For the production sector, the number of professional fishers, registrations went up from 350 in 1988 to 450 in 1994. But subsidies from local governments (up to 60% of the price of the boat) and the various financial advantages (e.g. payment of a portion of the relevant fisher's social security contribution by the local government, partial relief on fuel) mask the influence of FADs on these developments. Similarly, the number of pleasure boats has increased slightly, if the number of registered vessels, which went from 598 in 1987 to 637 in 1994, is an indication.

The newly-registered fishers, are, for the most part, former sport fishermen who have decided to take up fishing for various economic reasons. Some come from the public service (e.g. primary and secondary school teachers or others), and in this case, take one or more years of leave to be able to register; others maintain a second job (e.g. in a company), while still others retired from another profession and so receive retirement payments. However, 90 per cent of boat owners working around FADs have fishing as their only source of income. The percentage of new fishers who did not have any declared job before will have to be determined by a more in-depth sociological study to find out the number of jobs (seamen included) directly created since 1988. This, however, will still not give the number of jobs created due to FADs.

Since the appearance of FADs, the number of fishing boats, professional or otherwise, has increased by 14 per cent (from 779 to 888), mainly accounted for by launches which use FADs the most frequently, and their numbers have gone from 19 in 1987 to 65 today, i.e. a 242 per cent increase.

Effect on yields

Yield per unit effort is a good indicator for monitoring developments in any economic activity. Calculated here by fishing trip days and by boat, a comparison can be made between the yields obtained by the two types of vessels in 1987 and 1994 (Table 1).
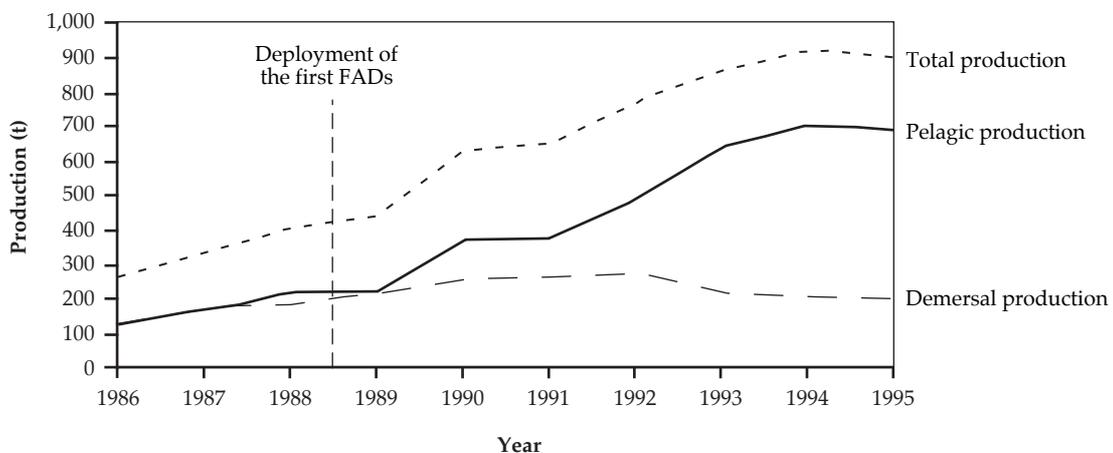
Figure 1

Developments in production from the artisanal fisheries (1986–1995)

Table 1: **Comparison of average daily yields during the second quarters of 1987 and 1992 for skiffs and launches (according to E. Tessier, 1995)**

	Average daily yields		Average number of fishing-trip days	
	Skiffs	Launches	Skiffs	Launches
Second quarter 1987	18 kg	50 kg	23 days	28 days
Second quarter 1994	21 kg	85 kg	24 days	29 days

Table 2: **Changes in production and turnover for launch and skiffs between the second quarters of 1987 and 1994**

	Second quarter 1987	Second quarter 1994	
	Yield/boat (kg)	Yield/boat (kg)	Change %
Pelagic species/skiff	60	150	+150.0
Demersal species/skiff	354	354	0.0
Total/skiff	414	504	+21.0
Pelagic species/launch	1 153	2 218	+92.0
Demersal species/launch	247	247	0.0
Total/launch	1 400	2 465	+76.0
	Turnover/boat (US$)	Turnover/boat (US$)	Change (%)
Pelagic species/skiff	311	611	+96.0
Demersal species/skiff	4 538	4 190	–7.6
Total/skiff	4 849	4 801	–1.0
Pelagic species/launch	5 975	9 033	+51.0
Demersal species/launch	3 166	2 924	–7.6
Total/launch	9 141	11 957	+31.0

Yields have therefore clearly increased, especially for launches which are the principal users of FADs and which catch 90 per cent of their production there. It would seem that FADs have played a vital role in the development of both production and the fleet.

The number of fishing trips annually, especially as weather conditions are the same for both types of boats, have, on the other hand, remained fairly constant, for both categories of boat (Table 1).

Effect on turnover

Bearing in mind that the average price of fish per kilo for pelagic species went from US$ 5.20 in 1987 to US$ 4.00 in 1994 (a drop of 21.4%) and from US$ 12.8 to US$ 11.8 during the same period for demersal species (decrease of 7.6%), the turnover for skiffs has been subject to a negligible decrease of 1 per cent, while for launches, it has increased 31 per cent. Table 2 shows this evolution, assuming that demersal landings have remained constant, as

the distinction between skiffs and launches was not made in the 1987 statistics.

For those skiffs which fish for both pelagic and bottom-dwelling fish, FADs did not have much effect. The mooring of FADs allowed launches to increase their turnover by 31 per cent, in spite of an increase in costs.

Effect on costs

Fuel

FAD fishing techniques (drift methods and longlining) generally use less fuel (about 3 times less) than traditional trolling, as less engine power is used. Since there is less search time, the effective fishing time is, in principle, increased (5 out of 10 hours per day instead of 2 hours as before) and the amount of fuel used per trip is consequently lower. However, the practise of visiting several FADs a day (up to 7), has limited these effects.

For the record, it should be noted that the prices of high octane petrol and diesel are respectively only US$ 0.42 and US$ 0.33/l for fishermen, due to the tax incentives they benefit from; the cost incurred is therefore negligible. It can consequently be estimated that consumption has been reduced by 30 per cent for launches and by an insignificant amount for skiffs.

Investments

FADs have, in contrast produced extra costs linked to investment in bigger boats. At the beginning, this involved tourist launches, but a few years ago, medium-sized boats of local manufacture appeared which had lower operating costs and were more suitable for fishing around FADs than launches.

Registration as a fisher

For professional fishers, this covers both health insurance and retirement scheme contributions. These costs are very high for professional fishers and do not exist at all for sport fishers. They have increased slightly since 1988, but without any con-

nection to the implementation of FADs. In Reunion Island, fishers have the choice of either paying full contributions or half-payments to limit costs, thereby decreasing their number of retirement points.

Social Security payments

Skiff fishers are registered between the third and fifth category. Half-payments are:

- US$ 2145 for a skipper in the third category,
- US$ 2273 for a seaman in the third category,
- US$ 2545 for a skipper in the fifth category,
- US$ 2673 for a seaman in the fifth category.

Fishers in launches are in the sixth category and seamen in the third. Their half-payments are:

- US$ 2545 for a skipper,
- US$ 2768 for a seaman.

This covers 360 days of professional activity annually.

The total annual fees for a skiff fisher are on average between US$ 1636 and US$ 10 000 for one and up to US$ 16 364 for two. For a launch fisher, fees are between US$ 3636 and US$ 36 363. These fees include maritime social security (ENIM), family allowance payments, maintenance, insurance, fishing gear and financial costs. In fact, the increases in fees due to FADs were only felt by those skiff fishers who decided to invest in a launch. Except for such cases, costs have remained unchanged overall for skiff fishers. For launch fishers, it can be estimated that there was a drop in fuel consumption due to FADs of 20 to 30 per cent, which is a very negligible sum if you take into account the low cost of fuel in overall operating costs.

Effect on profits, or gross operating surplus (GES)

Gross operating surplus = turnover – costs

To calculate profits per quarter shown in Table 3, average costs have been estimated at US$ 9090 per year for a skiff and US$ 21 820 per year for a launch.

Skiffs, which had been more profitable before FADs due to limited costs, are today far behind launches in this area, as launches can make up for higher costs by much higher yields near FADs.

Table 3: **Changes in profits from 1987 and 1994 for skiffs and launches**

	Profit/boat (US$)		Change
	2nd quarter 1987	**2nd quarter 1994**	
Skiff	2 582	2 527	-2%
Launch	1 818	4 673	+157%

Other effects: sociological, big game fishing, environment (protection of bottom-fish resources) . . .

Another adverse effect of FADs is that pelagic species are not necessarily more abundant in the area where the FAD is located. They do however gather around the devices and are thus more accessible to fishers. One of the consequences is a decrease in catches in areas located away from the FADs. While around FADs, the most common fishing technique is drift fishing, in areas away from the devices, the only possible technique is trolling. This has resulted in a decrease in this activity which is mainly used by sport fishermen (big game fishing), even if only in order to avoid clients becoming seasick as drift line fishing is very difficult to support. Sport fishing, which used to be a feature of Reunion Island, is now losing some of its attractiveness for enthusiasts. FADs could therefore have a negative effects on the island's tourism industry.

Beside increases in pelagic species catches, one of the reasons for mooring FADs was to relieve bottom-dwelling resources from the excess pressure exercised by traditional coastal fisheries. This goal has only been partially achieved. Due to lower investments, and assured sales, older, more-traditional fishers have remained faithful to bottom fishing. Younger fishermen have, for their part, been attracted by the possibilities of profit offered by fishing around FADs. In fact, although tuna was sold for US$ 6.40/kg instead of the US$ 18.20/kg paid for bottom fish, the fact that the tuna could weigh up to 80 kg gave them hopes of high earnings more rapidly. Unfortunately, as the price of tuna has now dropped to less than US$ 4.5/kg, due to sales difficulties, this fishery is today attracting fewer new fishers.

Exploitation of bottom resources has thus not been reduced by the introduction of FADs. The number of fishers living off these resources has simply stabilised while the number of fishers targeting pelagic resources has greatly increased. Young fishers are increasingly turning towards diversified activities while trying to reconcile the high yield prospects offered by FADs and the high prices for bottom fish, crustaceans and molluscs.

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Social and economic impacts of FADs

Positive impacts

- Increase in fishermen's turnover and in total landings

- Development and modernisation of the fishing fleet

- Development of local boat-building

- Improvement of work conditions and safety

- Possible creation of jobs (non quantifiable)

- Decrease in search time and fuel use

- Stabilisation of bottom resources exploitation

- Increase in the number of days covered by social welfare for fishermen

Negative impacts

- Drop in the price of fish

- Negative impact on tourism i.e. big game fishing

- High costs for local governments

- Possible conflicts between pleasure boats and professional fishermen

- Risk-taking by skiff fishermen who venture to distant FADs

FADs – The Western Indian Ocean experience

by Michel de San[1] & Alain Pages[2]

Definition and description

Fish aggregating devices (FADs) are used to gather large pelagic species, particularly tuna.

Fish generally congregate at nightfall, gradually leaving the FAD after daybreak.

So, nightfall and daybreak are the best times for fishing. Tuna eat about 5 per cent of their body weight each day—juveniles even more—requiring them to spend the day hunting within a radius of 10 to 20 miles from the FAD.

The floating parts of FADs are generally made of bamboo, drums, arrays of trawl floats, other metal or plastic buoyancy components in various shapes—in short, anything which can float and support the appendages attached to the first 50 metres of line below the surface.

Two types of FADs are used:

- fixed FADs anchored to the bottom which become regular fishing sites, and

- drifting FADs, natural or artificial, which are used particularly for industrial purse-seine fishing[3].

Background

It is generally acknowledged that anchored FADs originated in the Mediterranean region, where they were first recorded in Malta during the 17th century.

They have always been used in traditional fishing in Tunisia during the tuna season.

The systematic use of FADs started in the early 20th century in Indonesia and the Philippine Islands.

They spread through the Pacific in the 1970s and first appeared in the Indian Ocean through FAO and European Union projects early in the 1980s.

The Western Indian Ocean experience

Array FADs
(string of pressure-resistant buoys)

The use of arrays of trawl buoys for the floating sections of FADs was first developed in the Indian Ocean. This system allows the top part of the FAD to be deeply submerged (–600 m) without suffering damage due to water pressure. This is their principal advantage, as they require reduced buoyancy of only 250 to 300 l, compared to double or triple this buoyancy for FADs which must stay on the surface.

Consequently, there is much less tension on the mooring and these FADs last for an amazingly long time, on average more than two years, excluding boat accidents and vandalism.

In Mauritius, FADs of this kind lasted for over four years, but their reduced buoyancy (150 l) caused them to disappear under water for six months each year, clearly hindering fishing. A satisfactory compromise had to be found.

Technical aspects

Figure 1 (on page 27) shows the FAD commonly used in the Indian Ocean. The following remarks and design details concerning these FADs are interesting:

- In areas where there is a possibility of theft or conflict between fishermen, the array is threaded onto a 35 m long steel cable sheathed in a plastic tubing.

- The region's technicians have decided to eliminate shackles wherever possible and to replace them with a direct thimble-swivel connection.

- In La Reunion, the use of stainless steel for the shackles, thimbles and swivels is experimented. However, care must be taken not to mix different types of metal due to very rapid electrolysis (about one month). This solution is feasible on the upper part of the FAD (if there is no cable) but must be avoided on the lower section where, very often, engine blocks or concrete blocks with normal steel ring are used.

- Nylon rope is used on the upper part of FADs (≈ 20% of depth) due to its negative buoyancy which keeps it from floating to the surface where it would be likely to be cut. Also, the end of the mooring lead is made of polypropylene so that its positive buoyancy keeps it from dragging on the bottom.

- The net weight of the mooring, not counting chain, is estimated at 700 kg.

- The total length of the mooring lead is approximately 20 per cent more than the depth.

Costs

Table 1 (on page 26) shows the cost of the materials needed for a FAD and their technical specifications.

Shallow-water FADs in the Indian Ocean

Shallow-water FADs appeared in the Comoros around the island of Anjouan as a result of the Regional Tuna Project of the Indian Ocean Commission funded by the European Community. These FADs are moored in 200 to 600 metres of water at the edge or beginning of the continental slope.

By combining the Reunionese deep-sea fishing (200 to 400 m) technique using live bait (see *SPC FAD Bulletin #2*), and the traditional Comorian drop-stone technique using 'chum' (minced fish), real success has been obtained with these shallow FADs, leading to catches of large yellowfin and albacore tunas weighing 10 to 80 kg.

Their success is also due to the short distances to be covered for non-motorised fishermen to reach them.

Rigging is similar to that of deep-water FADs, but only 10 to 15 buoys, a single 12 mm chain mooring and 250 to 300 kg of ballast are used.

Location and mooring methods

It is important to remember that the FADs are best placed in areas where there is the combination of tuna, fishermen and marketing opportunities.

FADs aggregate all tuna present within a radius of 10 to 20 nm for the night.

Until recent years, it was thought that FADs should be moored 2–3 nm from the edge of the continental slope at a depth of 1000 to 2000 m. But experience in the Comoros with shallow-water FADs opens up other possibilities.

The commonly accepted minimum distance between two FADs is 6 to 7 nm.

In this region, we rarely have deep echo-sounders available and when we do, they are not often in working order. Once the site and location have been found by GPS, deployment is carried out using an extra 800 to 1000 m of rope which is later removed. Beginners should know that first the floating part is released, then the mooring line and only when well positioned, the anchor. Proceeding in any other order carries a risk of damage to components and crew.

It is difficult to predict how profitable a FAD will be. There must therefore be a reliable system to monitor catches and visits by fishers to determine the most effective spots to re-anchor FADs after the original ones have been lost. In this way after a few years of trial and error, an effective and well-positioned FAD system can be established.

Of the 10 FADs moored at new sites, two are very good, three or four are average and the rest are not worth being replaced once they are lost.

Fishing techniques around FADs

The fishing techniques used around FADs in the Western Indian Ocean are artisanal in nature. They are used by boats ranging from traditional paddle or sailing canoes to small dory-type boats with outboard motors, and small 10 m fishing boats. Three types of technique are used for fishing around FADs: trolling, drift fishing and fixed gear.

Table 1: **FAD materials and cost (FOB prices)**

	FAD materials (depth 1800 m)	Unit price (US$)*	Quantity	Total price (US$)*
1	Pressure-resistant float (600 m); ø 280–300 mm; ø 19 mm central hole	8.10	35 + 3	308.0
2	6 x 19 preformed steel wire; ø14 mm; 9+9+1 wire strands; hot-dip galvanised (HDG); interior and exterior greasing	2.15 /m	35 m	75.3
3	Cable clamp (HDG); ø 19 mm	0.88	9	7.9
4	PVC tube; interior diam. 15–16 mm and exterior 18–19 mm (The 14 mm steel wire must be able to pass through this tube)	0.51 /m	35 m	17.8
5	Thimble (HDG) for ø 19 mm wire rope.	0.99	3	3.0
6	Thimble (HDG) for ø 18 mm wire rope.	0.99	2	2.0
7	Anchor-type safety shackle (HDG); ø 16 mm; square head bolted pin; cotter pin; high-quality carbon-steel pin.	3.31	1	3.3
8	Shackle; ø 14 mm	3.19	2	6.4
9	Shackle; ø 12 mm	3.01	10	30.1
10	Swivel (HDG); ø 18 mm; eye-and-eye	15.14	2	30.3
11	Rubber separator; outside diameter 110 mm; central hole 30 mm; thickness 20–25 mm; origin: rubber tyres with multi-textile threads without steel	0.71	40	28.4
12	Polypropylene rope; 3 strands; 20 mm free diam.; ø 18 mm under tension (ref.: iso); anti-UV treatment; 148 g/m; breaking strength: 4450 kg; 200 m roll	0.35 /m	1800 m	621.8
13	Nylon rope; 3 strands; 20 mm free diam.; ø 18 mm under tension (ref.: iso); 210 g/m; breaking strength 8300 kg; 200 m roll.	1.44	200 m	287.3
14	Polypropylene rope; 3 strands; ø 6 mm; anti-UV treatment	0.05	200 m	9.5
15	Chain (HDG); ø 12 mm; interior range 78 x 24; central passage 16 mm; 2.55 kg/m; breaking strength: 4220 kg	6.36	30 m	190.8
16	Chain (HDG); ø 16 mm (in 20 m pieces); interior range 48 x 20; 5.71 kg/m; test load 3,950 kg; breaking strength 9900 kg	8.84	20 m	176.8
17	Plastic strapping; width 12 mm; 2000 m roll.	17.23	1 roll	17.2
18	1 kg roll of woven nylon; ø 1.5 mm; for splice whipping	12.73	1 kg	12.7
			Total	**1828.5**

* Original figures are in French Francs (FF), a conversion factor of US$ 1.00 = FF 5.50 has been used for this document.

Thimbles (ø 18 mm)

35 pressure-resist. floats (ø 300 mm)

Cable clamps (ø 19 mm)

Rubber separator between each float
(20–25 mm thick)

PVC tube (inside ø 16 mm)

Wire cable (ø 14 mm)

Cable clamps (ø 19 mm)

Thimble (ø 18 mm)

Swivel (ø 19 mm)

Thimble (ø 19 mm)

Nylon rope (ø 20 mm, 3 strands)
(length = 20% of depth)

Appendages made of plastic
strapping (12 mm width)

Nylon–polypro. splice

Polypropylene rope (ø 20 mm, 3 strands)
(length = depth)

Thimble (ø 19 mm)

Swivel (ø 19 mm)

Safety shackle (ø 16 mm)

20 m of chain (ø 16 mm)

2 shackles (ø 14 mm)

15 m of chain (ø 12 mm)

15 m of chain (ø 12 mm)

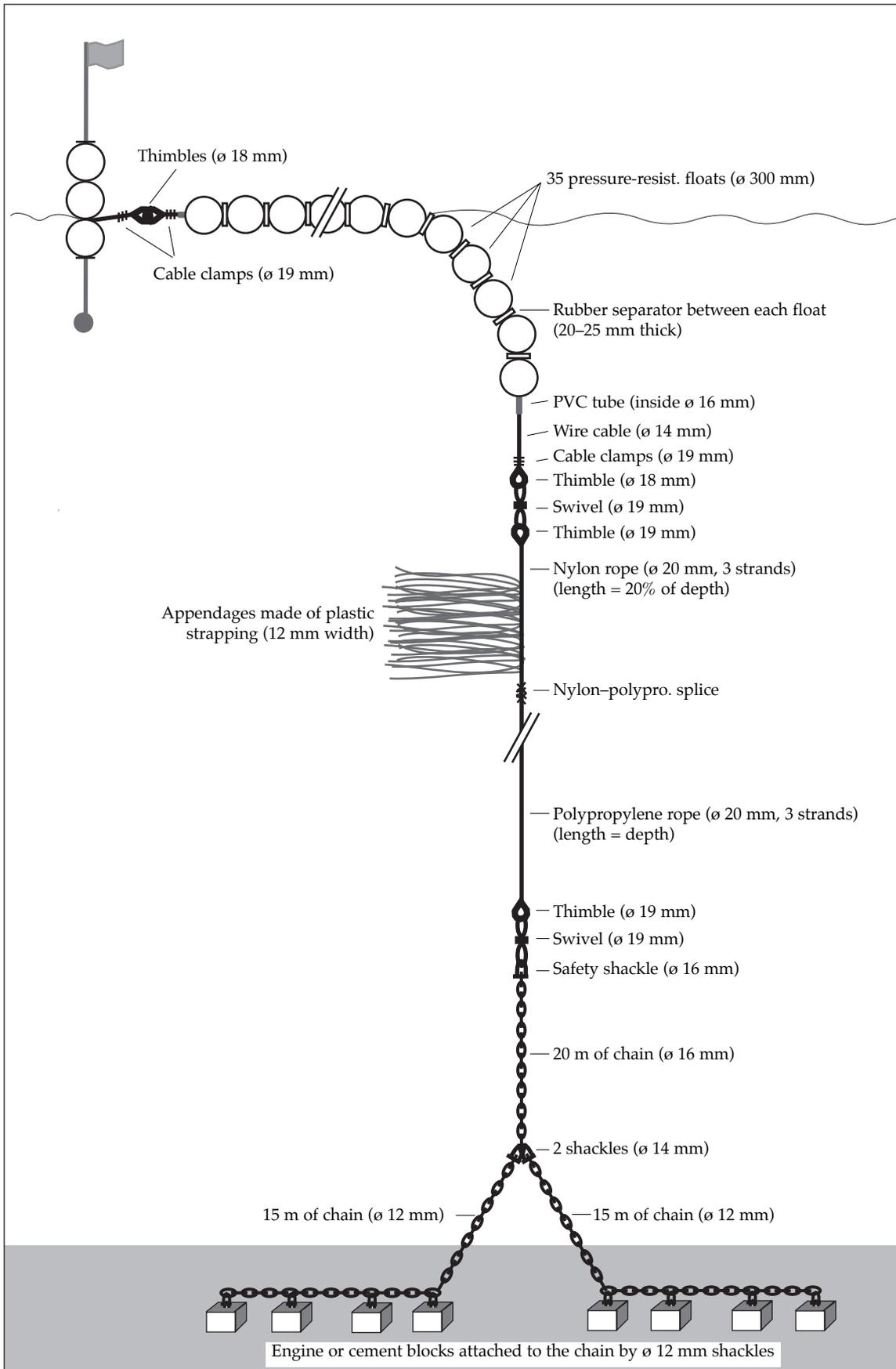Engine or cement blocks attached to the chain by ø 12 mm shackles

Figure 1

Commonly-used Indian Ocean FAD

These techniques vary depending on the means and the stage of development of artisanal fisheries in the countries concerned. The recent development of night fishing (La Reunion and Comoros) can be noted; its results are quite encouraging using the same techniques as are used in the daytime.

Trolling

Rapid lure trolling

We will not go into rapid trolling as it concerns sport fishing and is a very heavy fuel-user.

Slow lure trolling

The slow trolling technique involves trailing a plastic squid-type lure at a distance of 100 m while giving it lifelike movements by pulling and releasing the line. This type of fishing can also be done with dead bait (e.g. squid or scad). The lines used are 90–140/100 monofilament lines.

Slow trolling with live bait

Slow trolling with live bait is very effective with predators like tuna and dolphinfish (mahi-mahi). The most spectacular form is sportfishing for marlin with live bait 5 to 10 kg in weight.

Drift fishing (handline)

Drift fishing with dead or live bait

Drift fishing takes place up-current from the FAD. One or more lines baited with pieces of fish, squid or live bait are allowed to drift in the current. This technique makes it possible to target deep-water tuna (yellowfin or albacore), which are often larger in size than those caught at the surface.

Drop-stone with chum fishing technique (Comoros)[2]

This unusual technique involves dropping the bait to the desired depth (100 to 200 m) using two stones, between which is held some chum (minced fish) and the baited hook.

When the bait reaches the desired depth, a quick jerk on the line frees the rocks which are attached to the line by a loop and a quick-release knot.

The stones drop to the bottom while the baited hook emerges in the middle of a cloud of minced fish which attracts tuna and whets their appetites.

Fixed gear

Horizontal drifting longlines or mini-longlines (see Figure 2)

Vertical tuna longlines (see Figure 3)

Fishing for, storing and using live bait

Live-bait fishing

This is essentially done at night using a lamparo—often a gas or petrol lamp or sometimes even a simple petrol torch. The live bait are caught with multi-rig type line to which are attached small fluorescent octopuses or multicoloured silver wool flies. The diameter of the line rarely exceeds 30/100.

Storing live bait

After being caught and carefully removed from the hook, (as wounded live bait die very quickly) the live bait is placed in a tank of water (at least 100 litres), in which the water circulates or is changed by bucket. In the Comoros, a woven basket attached to the outside edge of the canoe is often used. Bait can be stored several days in a fishtrap.

Use of live bait

The live bait is taken from the tank with a scoop net. It is generally hooked through the nostrils and only rarely in the back (above the lateral line). The forward position of the hook will help it to swim during slow trolling. The hooks used are always relative to the size of the live bait and must be very sharp and strong.

It is possible, after positioning the boat up-current from the FAD, to scatter a few baitfish as far as possible from the boat; they will try to swim back to the boat as quickly as possible for safety and attract predators, particularly dolphinfish (mahi-mahi).

Artisanal pole-and-line fishing around FADs

Artisanal pole-and-line fishing has been attempted without success by a Maldivian crew in Anjouan, Comoros. This activity involves two techniques: live-bait fishing and pole-and-line fishing. Traditionally, Maldivians fish for bait in the coral heads at daybreak. Sticks and divers are used to herd the fish into nets set by a coral head. The bait for the day is kept on-board in a tank and fishing is a daytime activity.

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2. Note from the editor: a very similar technique used in French Polynesia was described in details in the *SPC FAD Bulletin #1.*
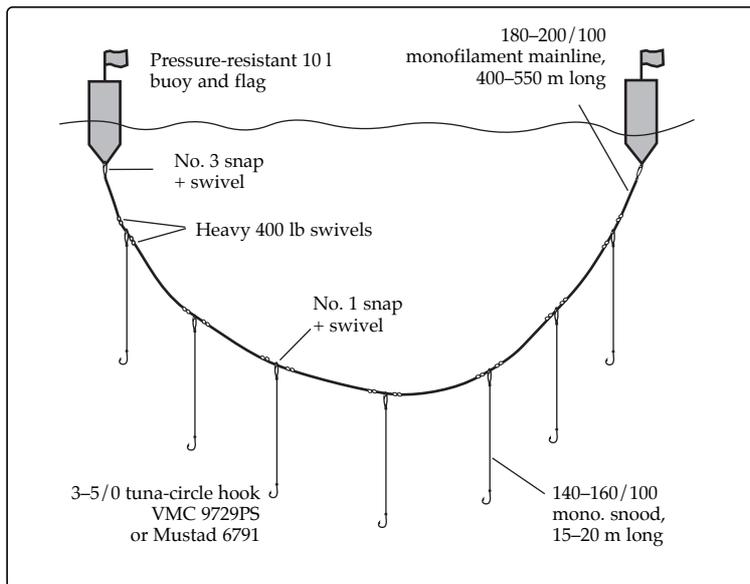
Figure 2

Horizontal drifting longline
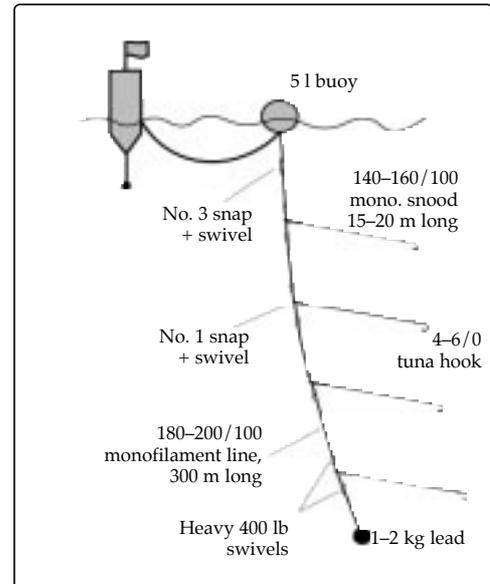
Figure 3

Vertical drifting longline

In the Comoros, which are volcanic islands with few coral heads, very few of these fish were found. Fishermen turned without much success to lamparo night fishing. The bait was stored in floating cages.

As for pole-and-line fishing itself, even when the problem of bait had been partially resolved, it did not have any success during our two-month stay in the Comoros. Consequently, given the need to teach the fishermen three techniques, i.e. bait capture, bait storage and pole-and-line fishing, and especially given the small size of catches, we decided to cut the experiment short.

An identical operation was carried out without success by the FAO in Zanzibar in 1970. In contrast, in Western Samoa, a similar operation was successfully carried out using bait raised by aquaculture (tilapia and mullet).

Fishermen's involvement

One constant worry for fishery officers is maintaining the FAD networks and getting users to take responsibility for them. To date, only partial success has been achieved. Very often, the equipment remains the responsibility of the government with donor support. Fishermen sometimes take part in anchoring the devices and very often they participate in their up-keep. In Anjouan, in the Comoros, a set of 30 shallow-water FADs has been made the responsibility of village chiefs and fishermen at 10 different sites. They are responsible for maintaining and replacing the devices off their villages.

For deep-water FADs, the government and projects most frequently assume this role. In La Reunion, fisheries organisations, in collaboration with the marine school, are responsible for the FAD network. In Mauritius, all the work is carried out by the government. In the Philippines, FADs maintenance is, in some cases, carried out by the private sector. Private operators inform fishing companies of the existence of tunas around one or more of these FADs, and in return, are paid a catch-related fee.

In the area of artisanal fisheries, fishermen must be educated and gradually obliged to organise themselves at the very beginning of the design of a FAD programme and become independent as far as equipment, mooring and maintenance of their FADs are concerned.

Conclusion

The setting-up of a FAD network is a real revolution for artisanal and sport fishing. Beginning a FAD operation and making it sustainable for fishermen requires regular activity over a period of several years, a major stock of equipment, and often outside expertise for construction, deployment, maintenance and operating methods. The social and economic context and future marketing problems must be taken into consideration. Neither must conflicts between fishermen and different fisheries be neglected. But there is a strong possibility that the results will exceed your expectations.

Recovering FADs lost at a depth of 2000 m

by Marc Taquet[1], Paul Gervain[2] & Alain Lagin[1]

In Martinique, the first fish aggregrating devices (FADs) were deployed off the Atlantic coast in 1983 (Sacchi & Lagin, 1983). These heavyweight devices comprised a large floating component in order to provide as much shade as possible under the FAD. At that time, shade was often referred to as one of main aggregating factors for large pelagic species. These initial trials rapidly demonstrated the usefulness of such devices for small-scale local fishing and were naturally followed by other deployments. Between June 1983 and February 1997, 53 FADs were set around Martinique by IFREMER (French Institute of Research for Ocean Development) as part as of various research programmes. Over this period, the experience acquired in Martinique and other tropical regions established certain rigging principles, thereby improving FAD performance. In spite of the progress made, however, losses are still too frequent. Technological research on FADs was therefore included in IFREMER's programme on large pelagic species around Martinique (1995–1997). Two research topics have been selected:

• modelling FAD behaviour under the influence of currents, and

• identifying the devices' weak points.

Theoretical modelling work was supplemented by a series of measurements carried out at the IFREMER test site in Boulogne-sur-mer. These experiments made it possible to study the drag coefficients of the various types of FAD raft currently in use (e.g. single floating part, string of buoys). In order to facilitate the use of the model, a more user-friendly computer interface on Windows will be designed during the second phase of the study, to begin in early 1998.

To increase the lifespan of these devices is one of the common goals of all fisheries development teams responsible for building, deploying and maintaining a group of FADs. A choice must first be made among the three major types of devices depending on the buoyancy required: heavyweight FADs (more than 300 l), medium-weight FADs (between 150 and 300 l), and light-weight FADs (less than 150 l). All the components of the device will be determined by this initial choice: e.g. the weight of ballast, the breaking strength of ropes, chains, and connecting pieces, the amount of appendages.

Without any clearly-established correlation between the size of the device and that of its associated aggregations of fish, it can be assumed that the choice of the type of FAD is entirely guided by a concern for a long lifespan. A comparison of two types of devices as different as the 'Nirai' of Okinawa (Kakuma, 1997), which costs a million dollars, and the ultra-light FADs of Guadeloupean fishermen, which consist of 6 mm rope and some empty detergent containers, costing about 3000 French Francs (≈ US$ 550), well illustrates the range of technical options available for probably comparable aggregating effects.

The cost of a group of FADs and their maintenance depends on:

• the type of FAD,

• the materials chosen (e.g. the choice between different qualities of rope or buoys, or between stainless and galvanised steel for connecting pieces, can make the cost vary by up to a factor of 10), and
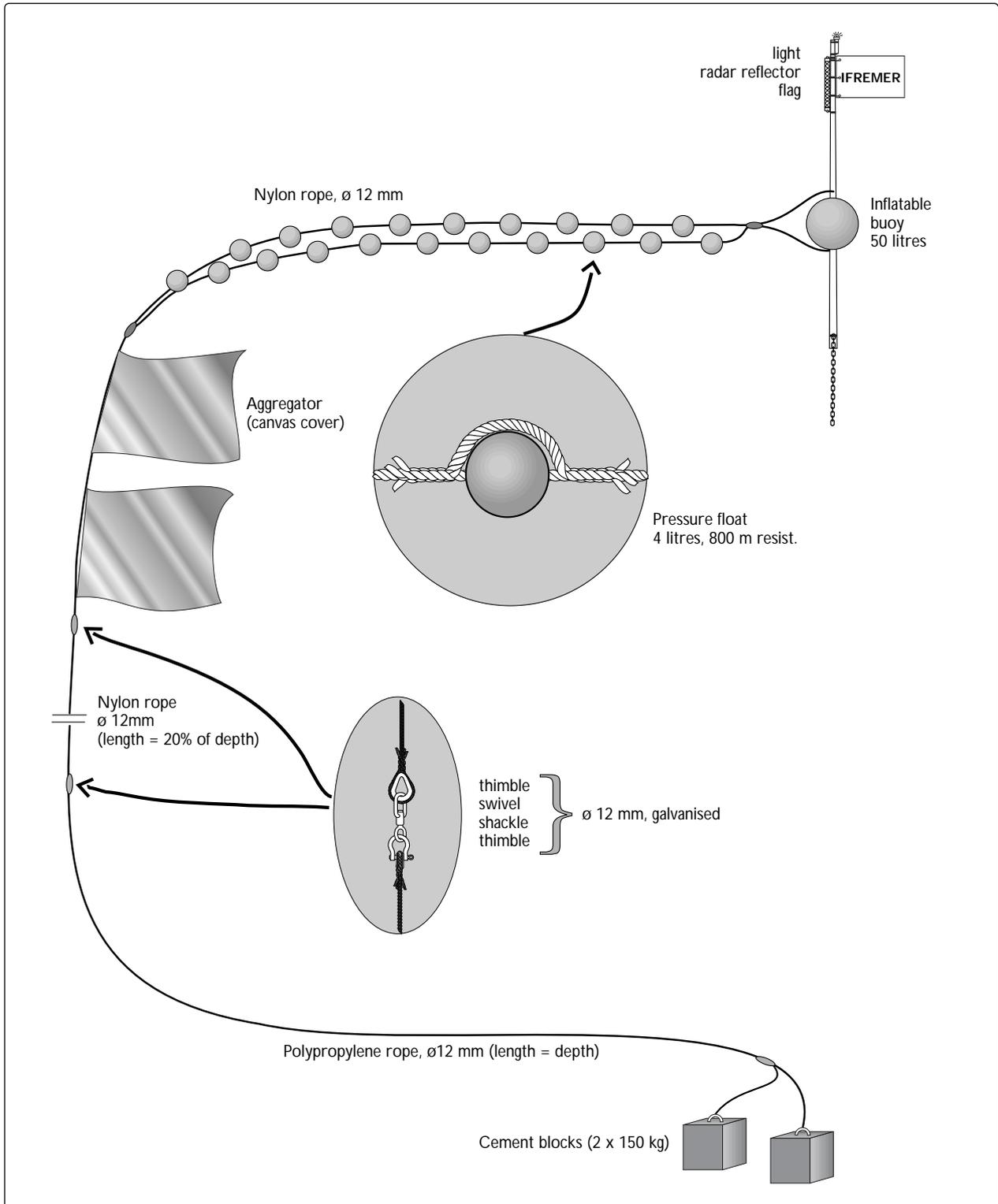
• the devices lifespan.

It is therefore very important to identify accurately weaknesses and the consequences of the failure of any one component on the survival of the device (Detolle et al., 1996).

1. IFREMER (French Institute of Research for Ocean Development), Laboratoire de ressources halieutiques (Fisheries Resources Laboratory), Pointe Fort, 97231 Le Robert, Martinique (France). Marc Taquet's e-mail: Marc.Taquet@ifremer.fr
2. POLKA, Navire océanographique et travaux maritimes, Rivière-sens, 97100 Basse-Terre, Guadeloupe (France)

Martinican managers preference quickly turned towards lightweight devices (Figure 1). The Regional Marine Fisheries Committee manages a group of about 20 devices for professional fishermen. This programme, designed to assist fisheries development, is funded by the Martinique Regional Council. These devices have generally given very satisfactory results. Their use by professional fishermen, particularly off the Caribbean coast, is increasing. Very large aggregations of certain species, like blackfin tuna (*Thunnus atlanticus*), are frequently observed during the fisheries cruises

light
radar reflector
flag

IFREMER

Nylon rope, ø 12 mm

Inflatable
buoy
50 litres

Aggregator
(canvas cover)

Pressure float
4 litres, 800 m resist.

Nylon rope
ø 12mm
(length = 20% of depth)

thimble
swivel
shackle   ø 12 mm, galvanised
thimble

Polypropylene rope, ø12 mm (length = depth)

Cement blocks (2 x 150 kg)

Figure 1

Design of the Martinican FAD

which IFREMER carries out on a monthly basis as part of their study of large pelagic species around Martinique. To avoid disturbance of professional fishing practices, all technical or biological work is being conducted around experimental devices, specially deployed for the purposes of the study.

To make a device more reliable, direct observation to assess the causes of failure of the various components is necessary. While these observations are relatively simple to carry out on the upper part of the device, the same cannot be said for the mooring line. Some damaged drifting FADs have been
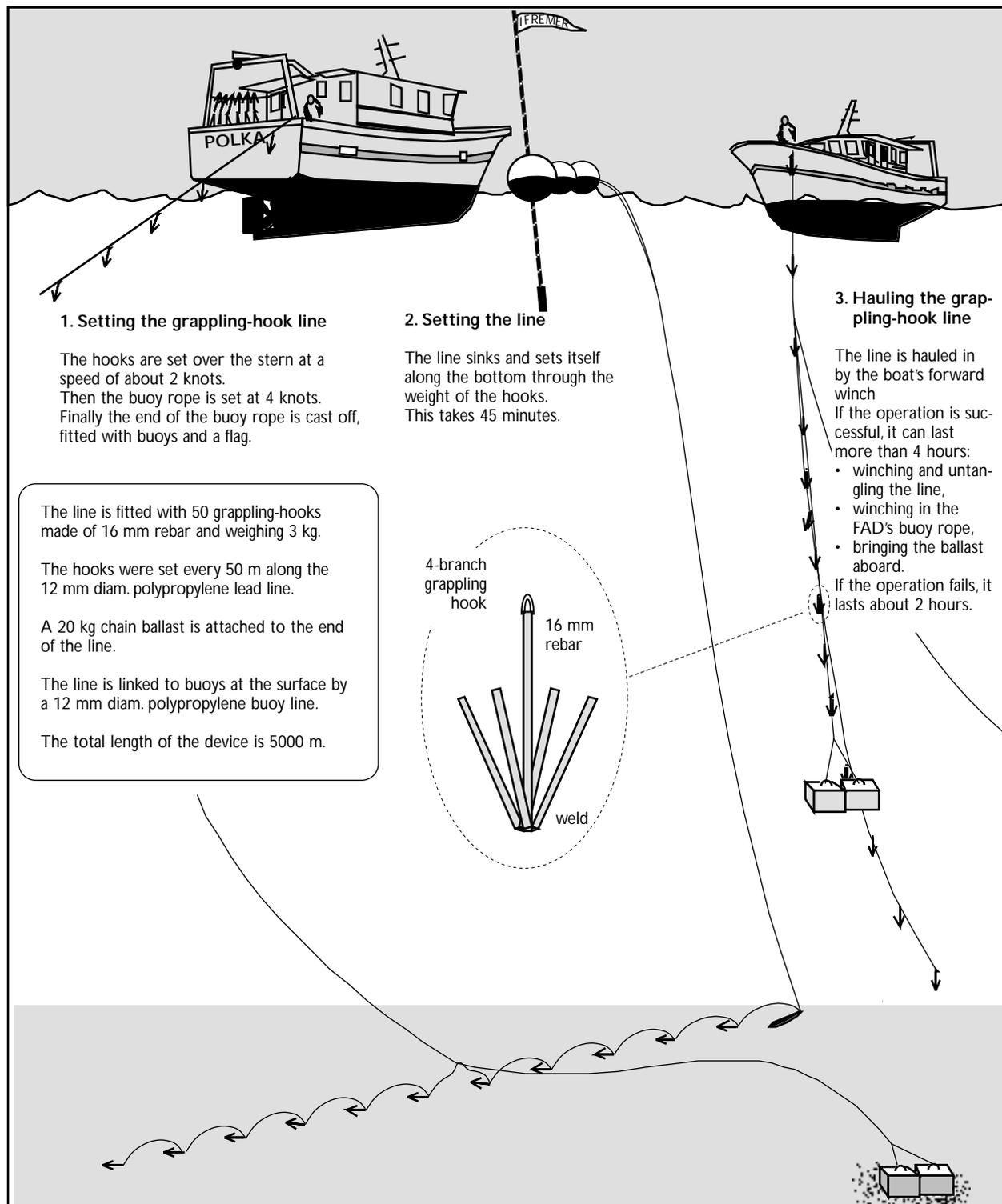
1. Setting the grappling-hook line

The hooks are set over the stern at a speed of about 2 knots.
Then the buoy rope is set at 4 knots.
Finally the end of the buoy rope is cast off, fitted with buoys and a flag.

The line is fitted with 50 grappling-hooks made of 16 mm rebar and weighing 3 kg.

The hooks were set every 50 m along the 12 mm diam. polypropylene lead line.

A 20 kg chain ballast is attached to the end of the line.

The line is linked to buoys at the surface by a 12 mm diam. polypropylene buoy line.

The total length of the device is 5000 m.

2. Setting the line

The line sinks and sets itself along the bottom through the weight of the hooks.
This takes 45 minutes.

4-branch grappling hook

16 mm rebar

weld

3. Hauling the grappling-hook line

The line is hauled in by the boat's forward winch
If the operation is successful, it can last more than 4 hours:
• winching and untangling the line,
• winching in the FAD's buoy rope,
• bringing the ballast aboard.
If the operation fails, it lasts about 2 hours.

POLKA
IFREMER

Figure 2

Recovering FADs from a depth of 2000 m

found by fishermen, in these cases, inspection of the recovered part is of particular interest. In most cases, the cause of failure can be identified. Around Martinique, these recoveries have confirmed the theory that accidental loss due to boats and wire leaders is common. Problems due to the use of certain materials or to design faults have been identified and corrected. Unfortunately, many devices are never found again and so doubt persists on the location and cause of failure.

The theory that most FAD losses are accidental naturally implies that mooring line failures either occur very close to the raft (when caused by boats) or in the upper 200 m (when caused by fishing lines). The parts of the FAD which remain on station after failure deserve attention for two reasons: i.e. identification of the causes of loss and observation of the state of wear and tear of the deep-water parts. Encouraged by the results obtained by the *Polka* during the recovery of lines of fishing traps lost at a depth of 500 m last May, we initiated a campaign to recover lost FADs.

The tool used was a line of grappling hooks 5000 m long (Fig. 2). At the depth at which the grappling hooks must work, it is not possible to drag the gear, because the movement of the boat would raise the

grappling hooks instead of dragging them along the bottom. Also, the power required to drag the gear would make it very difficult to be sure whether or not the line had hooked the FAD. There would be a risk of not hooking the device if the grappling hooks slipped over the rope and a risk of breakage if the hooks did catch. The technique selected was to lay the line on the seafloor at the presumed location of the FAD's mooring line, then to slowly haul in the line using a winch. A stabilisation period of 45 minutes is allowed between setting and hauling to be sure that all the hooks have settled onto the bottom.

The success of the operation is closely linked to the accuracy with which the FAD's position is known. In fact, in order to lay the line at the right spot, the exact position of the anchor must be known and an educated guess about the position of the remaining part of the FAD's mooring line must be made. This position can depend on how the FAD was built. If the rope is buoyant and has no dense intermediate parts , it will probably stretch out in the direction of the current.

During this cruise, we decided to lay the grappling line perpendicular to the general current by staying at less than 1000 metres from the supposed position of the anchor. We worked on two sites, at each of which two FADs were moored between August 1995 and February 1997. In the interests of data comparability, we generally kept the same mooring site when replacing a lost FAD. The line-setting trajectories were determined using a computer-generated map prepared with the Karto software (Y. Cadiou, 1994) (Figure 3). During the monthly cruises, GPS checks are carried out on a regular basis in order to obtain a scatter of points representing the various possible positions of the FAD, depending on the currents. These checks facilitate the search for FADs which have a swing radius of about 1500 metres.

The 13 attempts carried out during the cruise allowed 3 of the 4 FADs present in the work zone to be recovered in their entirety. Examination of the material recovered
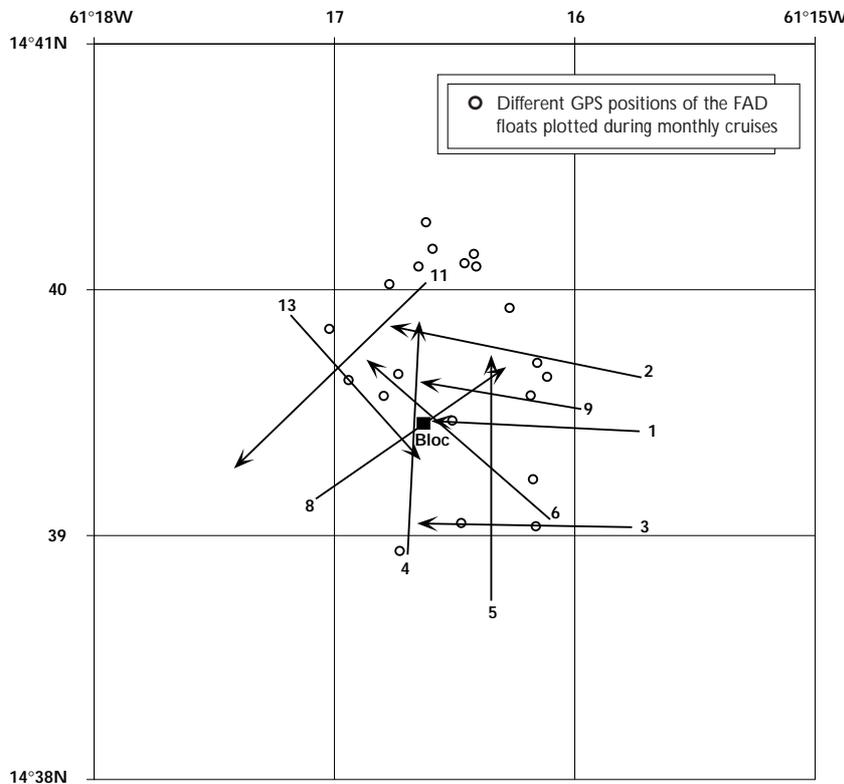
Figure 3

Directions of the grappling-hook line settings on the main site

resulted in the causes of failure being identi-fied. One FAD had been torn away from its mooring by a boat as the stretching of its rope was characteristic of very strong traction (Photo 1). The stainless steel wire leaders from fishing lines tangled at the exact loca-tion of the breakage point of the other two devices, leave no doubt about the reason for their loss (Photo 2).

This confirms the theory based on observa-tions of FAD rafts recovered while adrift. In addition, many devices were lost between December and February when weather condi-tions were good. This period corresponds to the time of the year when maritime traffic is at its heaviest (cruise ships) as well as the fishing season for pelagic species, when FADs are more heavily used. The use of steel wire lead-ers is considered in French Polynesia to be one of the main causes for the loss of FADs.

On one of the FADs recovered (deployed in 1995 and lost in 1996), we were able to exam-ine in detail the deep-water components. The ropes had not been subjected to any damage (Photo 3). Below the first 200 metres (from the surface), no sign of aging, fouling or kinking was observed. The splices were in perfect con-dition and the whippings were in place. The shackles and swivels located on the deep part showed little corrosion and were in very good condition. The anchor was in its original con-dition (Photo 4). The thimbles which had not been secured by whipping were, however, badly damaged, but part of the damage was due to the strain exercised during recovery because of the weight of the anchor. Galvanised thimbles, nevertheless, constitute the weak point of every connection, and a simple alternative must be implemented without delay.

For the deep-water section, the materials used to construct FADs in Martinique are therefore of sufficient quality to ensure a lifespan over two years as long as care is taken with rigging (e.g. splices, whipping). Care must be taken to protect and strengthen the first 200 metres of mooring line. The use, for the upper part of the device, of protective tubing and materials resistant to damage caused by fishing lines should restrict losses. However, the lifespan of FADs can be improved significantly through better visibility of the devices (radar reflectors and more efficient lighting) to limit damage due to boats. Information campaigns directed towards seafarers, shipping compa-nies and fishing groups can also reduce acci-dental losses.
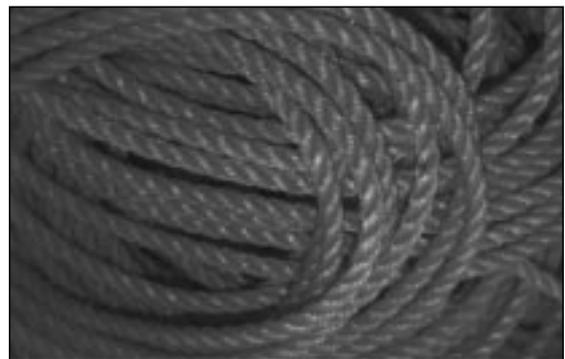
Photo 1

Photo 2

Photo 3

Photo 4

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Safety system developed for light FADs[1]

by Max Palladin[2]

Between 1994 and 1996, the French Co-operation Fund (FAC) supported a light FAD development project as part of an artisanal fishery development programme in Sao Tome and Principe, started by FIDA in 1995.

This programme was managed by the French company SEPIA (fisheries and aquaculture consultants) and supervised by Master Fisherman Joël Diquelou. With the benefit of experience from 26 coastal and deep-water FAD deployments, this programme made it possible to design a type of FAD suitable for local conditions, which was economical to make and set and could be managed and maintained by the fishers themselves.

In addition to the usual problems encountered in programmes of this kind, the use by the fishers of very long drift gillnets added a further constraint by causing the loss of many devices. These nets, 1000 to 2000 m in length and with a 2 m drop, are widely used to catch flying fish from October to May. When the nets drift and become entangled around a FAD, the fishers often have no alternative

but to cut the mooring, leading to the irretrievable loss of the FAD.

In order to solve this problem, the project developed an original safety system which makes it possible to recover severed moorings and replace the upper part.

The FADs concerned consist of the following components: an anchor consisting of a lorry tyre filled with concrete from which extend straps similar to car safety belts, to which the mooring line is fixed. This line consists entirely of 10 mm diameter polypropylene rope (length equal to 1.5 times depth). At the surface, a set of 10 buoys each of 4 l of buoyancy, plus a 60 l plastic float fitted with a wooden mast, form the visible part of the FAD.
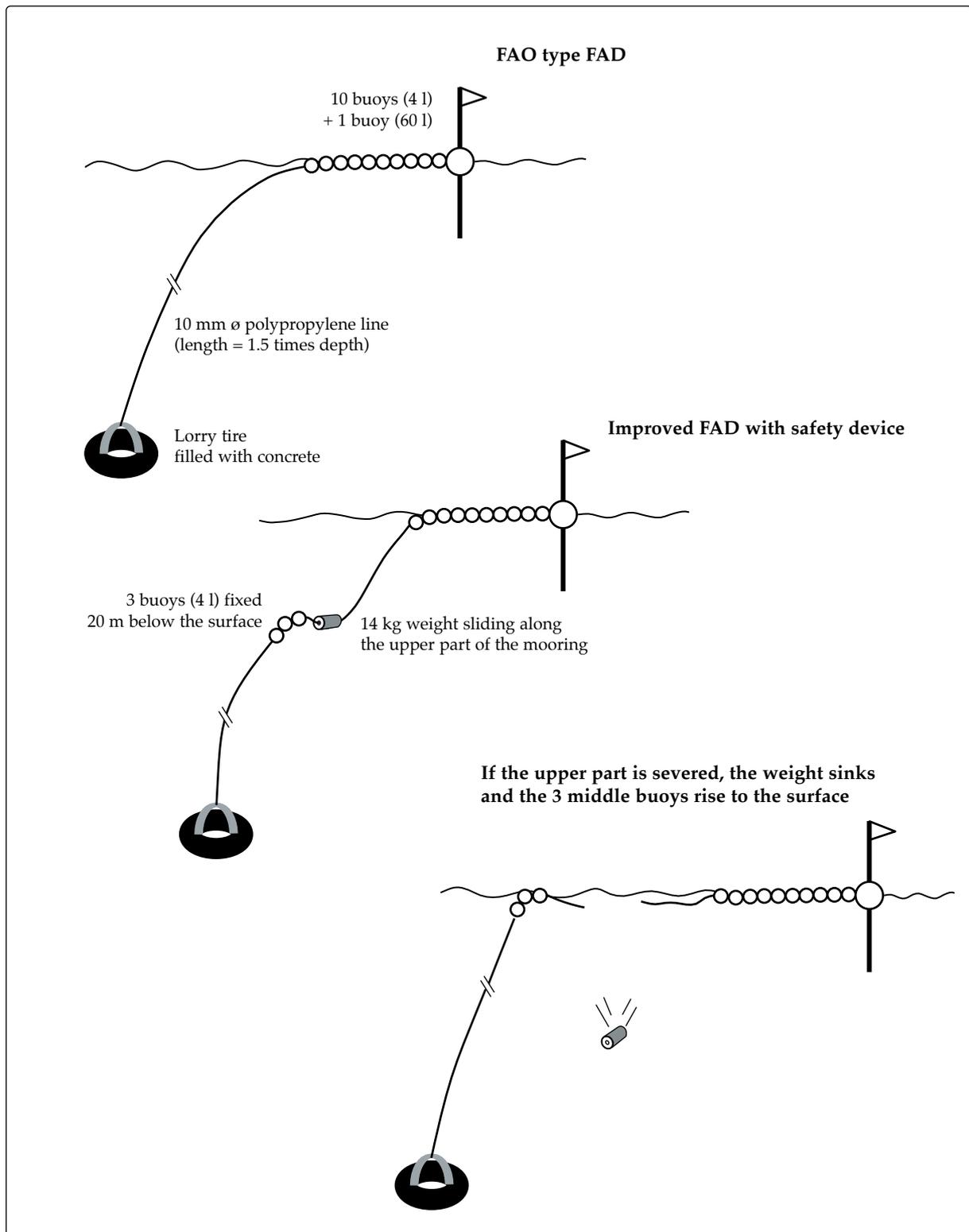
At approximately 20 m below the surface, three 4 l buoys have been attached to the line followed by a weight of approximately 14 kg which can slide along the mooring line. This weight consist of a cement block with a centre hole made by inserting a PVC tube to protect the rope from chafing

directly against the cement. Should the line be severed, the weight drops and releases the line, which comes back up to the surface and floats. The fishers can then rebuild the upper part of the mooring, not forgetting of course to include another safety system.

This project has just been extended for a three year period (1997 to 2000) with funding from *Caisse française de développement* to pursue the goal of setting 25 new FADs around the islands of the group and transferring their management to the fisher communities.

FAO type FAD

10 buoys (4 l)
+ 1 buoy (60 l)

10 mm ø polypropylene line
(length = 1.5 times depth)

Lorry tire
filled with concrete

Improved FAD with safety device

3 buoys (4 l) fixed
20 m below the surface

14 kg weight sliding along
the upper part of the mooring

**If the upper part is severed, the weight sinks
and the 3 middle buoys rise to the surface**

Figure 1

Diagram of the safety system developed on FADs in Sao Tome and Principe
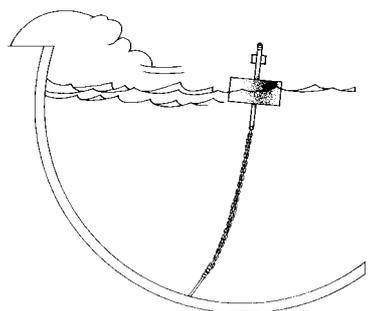
Readings

Huge rise in bigeye catch in the Atlantic

Bigeye are financially the most important of the tunas fished in the Atlantic and are worth US$ 600 million on the Japanese markets. The introduction of deep-water longliners and freezing systems enabled Japanese vessels to catch bigeye in large quantities in the Atlantic. The Taiwanese fleet, which previously focused on albacore, has also switched largely its attention to bigeye due to high prices in Japan.

Dr Joao Gil Pereira, professor at the Azores Institute of Oceanography, is a specialist in tuna and he gave details of the Atlantic fishery at the 16th Fisheries Week of the Azores conference held in Horta in March 1997.

Catches of bigeye taken with longlines have increased significantly in recent years to 60 000 t in 1994–95. 'Bigeye are caught in shoals close to the surface, by baitboats and purse seiners. But they go into deeper waters as far down as 500 m—and this had led to the development of deep longline gear specifically for bigeye.' Dr Pereira said.

Bigeye are fished extensively by tuna seiners working off west Africa and this fishery is becoming increasingly associated with FADs.

'Since 1991 the use of FADs by tropical purse seiners has been increasing and tens of thousands of floating objects are drifting in the tropical Atlantic.' Dr Pereira said.

Floating objects such as logs and rafts were used in the past as these attracted small fish. Specially designed buoys were then used for the same purpose and these were equipped with radio transponders which could be traced using direction-finder (DF) equipment.

More recently these have been replaced largely by buoys fitted with satellite positioning devices. Seiners shoot around the FADs—and this has increased to the extent that seiner fleets are relying increasingly on FADs. Therefore, they need to spend less time actively searching out for tuna.

Bigeye is taken as a by-catch in this fishery, which targets yellowfin and skipjack tuna, but the catch of juvenile bigeye by purse seiners has increased from 10 000 t before 1991 to 30 000 t in 1994. This is primarily because of the increased use of FADs as bigeye form schools with skipjack and juvenile yellowfin tuna.

An additional juvenile bigeye fishery takes place in west African waters with a live-bait fleet based in Ghana. One other live bait fleet, targeting medium-size bigeye, is based in Dakar.

The technique consists in fishing in schools associated to the fishing boat itself, effectively using the boat as a FAD. This technique is also used by the Spanish (Canary island) fleet. The Portuguese (Azores and Madeira) and Spanish (Canary Islands) pole-and-line fishery further north takes larger fish.

Catch levels of Atlantic bigeye are estimated to stand at around 100 000 t annually.

FADs 'take too many juveniles'

'The International Commission for the Conservation of Atlantic Tunas (ICCAT) feels that catch levels of 100 000 t annually for bigeye cannot be maintained,' Dr Joao Gil Pereira told the ICCAT Azores conference.

'Mortality is calculated at being above the optimum level. This is overexploitation of the reproducing stock and overfishing of juveniles. Millions of bigeye are caught at 2 to 3 kg and so it will be necessary to reduce use of FADs'.

'If no measures are taken, catches will drop to low levels and a total of decline of the stock could result. ICCAT wants catches reduced to the levels of 20 years ago, which is a drastic reduction.'

He went on to say that the Standing Committee on Research and Statistics (SCRS) has proposed an intensive research programme, which would include wide-scale tagging, to see if catch levels are sustainable.

'The high value of the catch justifies this research into bigeye,' Dr Pereira said. He criticised ICCAT Commissioners for ignoring the research proposed by scientists and their failure to adopt the necessary management measures.

He pointed out that the Europeans have a major responsibility in tuna research. 'Tuna research was over-looked by Brussels for many years. It was seen as a distant water fishery. But the situation is changing. Europe is now the biggest exploiter of tuna resources in the Atlantic and Indian Oceans.'

Source: *Fishing News International*, May 1997

Note from the editor:
Following expressions of concern by scientists, three fishing companies (ORTHONGEL in France, OPTUC-ANABAC and OPAGAC in Spain), which operate the majority of European purse-seiners, have decided to implement a three-month moratorium on the use of this technique in some parts of the Atlantic Ocean known as spawning sites.

Effect of fish aggregating devices (FAD) for gathering juvenile Japanese horse mackerel, *Trachurus japonicus*

by Seong Wan Hong[1], Mineo Okamoto[2], Takehiko Imai[3] and Shigeru Fuwa[3]

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The gathering behaviour of juveniles *Trachurus japonicus* towards fish aggregating devices (FADs) was studied using an outdoor water tank (5 x 5 x 3 m) and different scale-model FADs (0.4 x 0.4 x 0.2 m).

The distribution pattern of juveniles *Trachurus japonicus* changed with light intensity. In the daytime, the gathering behaviour to the FAD was apparent, but not in night-time. The results evidently indicated that juvenile of *Trachurus japonicus* are independent of FAD in night-time. In order to determine the gathering behaviour quantitatively, an index, related to the length of the time spent close to the FAD, was introduced. The ratio of gathering index varied with the shape and depth of the different scale models. However, the results showed small index value in all experiments.

It is suggested that localisation by visual stimulation may in some cases play an important part in the taxis of fishes toward FAD. A visual stimulation must be one of the factors but not the only factor which attracted juvenile *Trachurus japonicus* to the FAD. Further studies into the factors are necessary.

Source: *Bulletin of the Japanese Society of Fisheries Oceanography*, Vol. 60, No. 4, 356–362 (in Japanese).
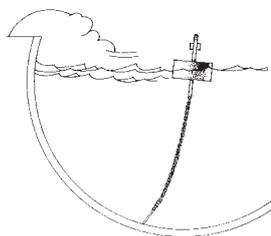
Tuna and trees: a reflection on a long-term perspective for tuna fishing around floating logs

by John F. Caddy & Jacek Majkowski

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A significant portion of tuna catches is taken in the vicinity of floating objects like large pieces of floating wood. Recently, there has been strong pressure to abandon another mode of fishing tuna in eastern Pacific that is associated with dolphins because of social concerns. This pressure may lead to an increased reliance of fishermen on fishing around floating wood. Most such timber comes from watersheds containing tropical forests. Deforestation in the vicinity of water courses will eventually lead to a gradual decrease in the influx of natural timber to oceans. The considerations raised in this note are preliminary and speculative to stimulate discussion and further research rather than to make any definitive judgements or conclusions.

Source: *Fisheries Research* 25 (1996): 369–376

Fish telemetry applied to behaviour analysis of yellowfin tuna movements in a fish aggregating devices network

by Francis Marsac[1] & Patrice Cayré[2]

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This paper analyses acoustic tagging of 8 yellowfin tunas (*Thunnus albacares*) undertaken around Fish Aggregating Devices (FADs) in La Reunion island (Indian Ocean). Emphasis is laid on the horizontal movements and thus completes previous studies on vertical movements around the same FADs. The first result of the present study deals with the relative dwelling time of yellowfin over the distance to FAD where tagging was made, considering 0.5 nautical mile (nm) intervals. Typical distributions of the dwelling time are described, which are different from day to night. At daytime, the fish remain in the close vicinity of the FAD (mostly within a 1 nm radius), whilst a drastic disassociation from the FAD occurs at night. During the day, the attractive influence of the FAD disappears 5 nm away; this finding leads to the suggestion that a minimum distance of 10 nm between neighbouring FADs should be applied in La Reunion to avoid overlapping the influence radii. The second group of results points out the potential use of the vertical and total swimming speeds as indicators of the foraging activity of the fish and of the type of movements (behaviour of tight association to FAD, transit among FADs or offshore migration, away from the area of FADs). The day–night change affects the vertical activity, with large magnitude of vertical movements exhibited at night. The total speed during the offshore movements is estimated about 1.2 m/s: the shift from a phase of tight association to FAD toward a phase of transit movement characterised by an increase of the total speed. A typology of the relationship between swimming speed and feeding activity is proposed and discussed.

Source: Document presented at: 'Second Conference on Fish Telemetry in Europe' (La Rochelle, 5–9 April 1997)
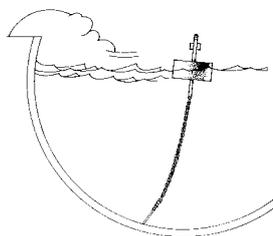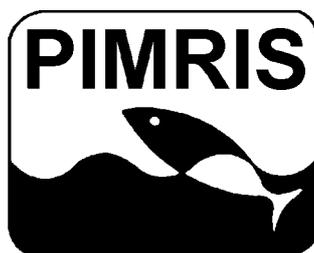
A preliminary bibliography of FAD-related literature. . . continued

Following our publication of a preliminary bibliography of FAD-related literature in the SPC FAD Bulletin #2, *we have received the following additions and corrections. Please, keep submitting all references that you would like to include, we will publish them in the next issue of this bulletin.*

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