ANALYSIS OF SMALL-SCALE MOVEMENTS OF YELLOWFIN TUNA AROUND FISH-AGGREGATING DEVICES (FADS) USING SONIC TAGS

F. Marsac

ORSTOM, Seychelles Fishing Authority, BP 570, Victoria, Mahé, Seychelles

P. Cayré

ORSTOM, 213 rue Lafayette, 75010 Paris, France

F Conand

ORSTOM, BP 60, 97420 La Réunion

RÉSUMÉ

Les premiers résultats des expériences de marquage acoustique entreprises dans le cadre de la seconde phase du Projet Thonier Régional de la Commission de l'océan Indien, sont présentés et analysés en fonction des paramétres locaux d'environnement. Seules les observations concernant cinq albacores (sur sept au total) marqués à proximité de Dispositifs de Concentration de Poissons (DCP), au cours des trois premières campagnes de marquage, sont analysées dans cet article.

Les déplacements horizontaux de ces albacores associés à des DCP, présentent des caractéristiques saisonnières marquées: forte association avec les DCP et comportement de « retour au point de départ » pendant la saison de pêche, association plus faible avec les DCP alors que la saison de pêche se termine et que les poissons commencent à migrer.

Les déplacements verticaux sont analysés afin de définir une typologie de leur comportement en fonction de différentes situations (proximité des DCP de jour et de nuit, nage de transit entre DCP de jour et de nuit) et paramètres: stade biologique (juvénile ou adulte), phase lunaire, structure thermique de l'océan).

ABSTRACT

The ongoing ultrasonic experiments of phase 2 of the Regional Tuna Project (Commission de l'Océan Indien) are reported and analysed in relation to the local environmental parameters. Although 7 yellowfin tuna were tagged during the first three cruises of the project, only 5 of them are considered in this paper, as they were tracked around FADs. Seasonal trends affect the horizontal movements associated with FADs: strong association and homing behaviour during the fishing season vs. weaker association when the fishing season comes to an end and the fish start migrating from the area. The vertical movements are analysed in order to provide a typology of the distribution of tuna in relation to different features (FAD association by day and at night, transits between FADs by day and by night) from which other variables are considered: life stage (juvenile or adult), moon phase and thermal structure.

INTRODUCTION

The second phase of the Regional Tuna Project of the «Commission de l'Océan Indien» (COI) started at the end of 1992. One of the research objectives is the improvement of the knowledge and understanding of the behaviour of tuna associated with Fish-Aggregating Devices (FADs). FADs were anchored in the vicinity of many island states of the region in order to enhance the development of the local tuna fisheries. Interest in this is especially strong around volcanic islands like La Réunion or Comoros where bottom fisheries are spatially limited. Moreover, FADs around such islands can be anchored in deep waters even at a short distance from the shore (*e.g.* 1000 m depth 6 to 10 nm offshore), making them accessible to small boats. In 1989-90 25 FADs were anchored off the 200-km coastline of La Réunion Island. The tuna catch by the local fishery has increased from 370 mt in 1988 to 1000 mt in 1994 (Tessier, pers. comm.).

Table 1. Characteristics of the 7 yellowfin tuna tracked. FL = fork length

Fish ref.	*FL (cm)*	*Area*	*FAD*	*Date*	*Track duration*
YF1	110	La Réunion	Le Port	19/02/94	44 h
YF2	49	La Réunion	Le Port	23/02/94	21 h
YF3	60	Seychelles	-	17/11/94	14 h
YF4	60	Seychelles	-	18/11/94	15 h
YF5	104	La Réunion	3 Bassins	27/03/95	19 h
YF6	95	La Réunion	Stella	29/03/95	24 h
YF7	58	La Réunion	Stella	01/04/95	30 h

Small-scale horizontal and vertical movements of yellowfin tuna were investigated using ultrasonic tracking, coupled with accurate measurements of the local hydrological environment. This direct method for studying behaviour has been used in the Pacific Ocean (Yuen, 1970; Laurs *et al.*, 1977; Cayré & Chabanne, 1986; Holland *et al.*, 1990). In the Indian Ocean it was implemented in the Comoros Islands by Cayré (1991) and further analysis of this data set was performed by Cayré and Marsac (1993), with special attention to the relationships with the hydrological environment. The present study shares this objective, and a more comprehensive analysis is scheduled once the experiments are finished. So far, 5 yellowfin tuna caught on FADs were tracked around La Réunion, and 2 in the Admiral Islands (Seychelles), but without any FADs in the vicinity (Table 1). The present analysis will mainly consider the 5 fish tagged and tracked near the FADs (Cayré *et al.*, 1994; Conand and Marsac, 1995).

DATA AND METHODS

The fish were tracked continuously from a 10-m-long large game-fishing vessel after being tagged with an ultrasonic transmitter. The transmitter is cylindrical, 8 cm long and 1 cm in diameter,, with a maximum «life expectancy» of 4 days, depending of the depths encountered during the tracking. The tunas are caught with a handline and hauled aboard. The transmitter is fitted with nylon straps inserted through the pterygiophores of the second dorsal fin; this takes approximately one minute. The fish is gently released to the sea and followed using a directional hydrophone mounted on a subsurface-trolled V-fin. The hydrophone is linked to a VEMCO™ VR-60 receiver, and the depth of the fish is recorded every 20 seconds. Reception is generally fair up to a distance of 500 m. The position of the vessel, given by a GPS, is noted every 10 minutes by a logbook

Figure 1. Location of the FADs off the est coast of Reunion Island.

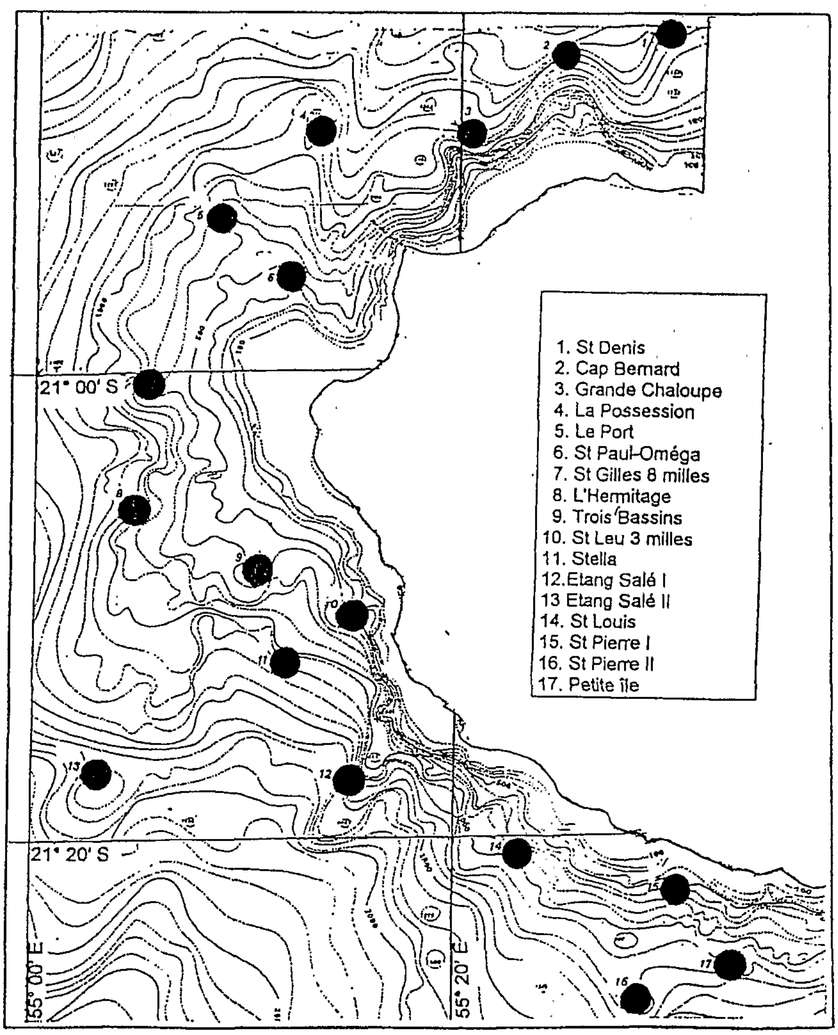
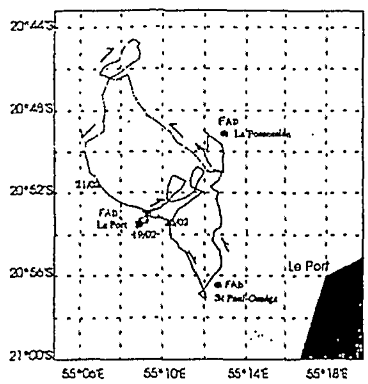


Figure 2. Tracking course of the YF1 (FL=110cm). Feb. 19, 1994, 11:00 am to Feb. 21, 6:30 am.



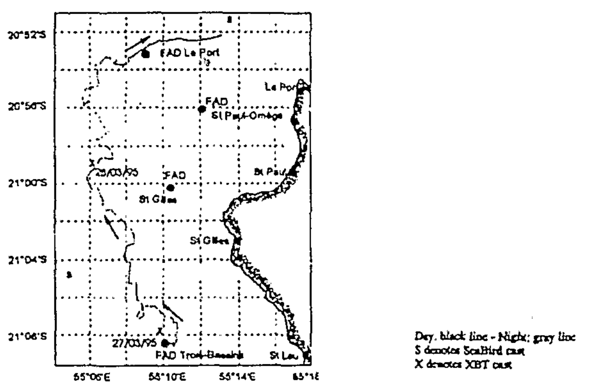


Figure 3. Tracking course of the YF5 (FL=104cm). March 27, 1995, 10:55 am to March 28, 7:33 am.

Oceanographic parameters were measured with two types of instruments, a SeaBird™ SBE19 CTD (conductivity-temperature-depth) probe equipped with a dissolved oxygen sensor, and XBTs (expendable bathythermographs).

For each track two CTDO casts are made, one before tagging and the other at the end of the track, in order to obtain temperature and dissolved oxygen concentration profiles. Casts cannot be made while the boat is in motion. The mean depth interval for each CTDO scan was 3 meters.

XBTs were used to produce temperature profiles while the boat was moving. Afterwards, due to the close relationship between temperature and oxygen concentration within the range of values mostly encountered (Cayré and Marsac, 1993), and using the CTDO casts as a reference, the depth of the oxycline can be deduced from the temperature data. The time interval between XBT casts depended of the distance covered: in the experiments reported below it varied from 5 to 12 hours.

RESULTS

Horizontal movements

As stated above, only the fish tagged on FADs are considered in the present analysis. The experiments were carried out off the west coast of La Réunion Island, which is the leeward side and the sea conditions are better. Several FADs are anchored in this area (Figure 1).

The tracked yellowfin tunas exhibited two different behaviours:

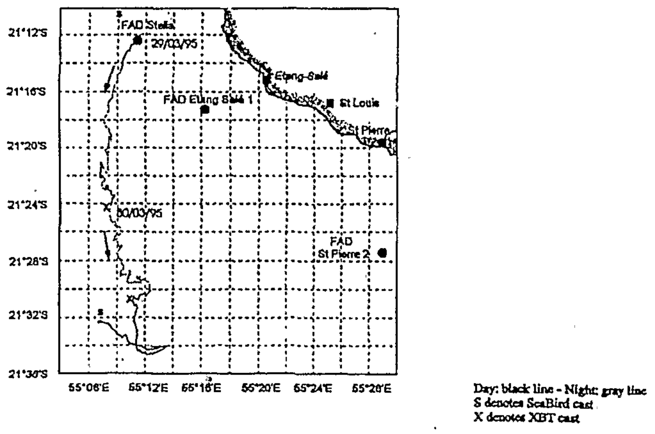
- the 2 fish tracked in February 1994 were clearly linked with 3 FADs in the area.
- the 3 fish tracked in March-April 1995 left the FAD and never revisited it, nor any other, during the tracking period.

The 44-hour track of the fish YF1 (Figure 2) shows the strong link with FADs. Tagged at 11 a.m. at the Le Port FAD, the fish stayed there until midnight. Then, shortly after the moon rise, it made a 5-hour excursion before returning to the FAD immediately after sunrise. Three hours later it left the FAD and swam in various directions for 6 hours before swimming 3.5 miles straight to the St. Paul FAD, at a speed of about 2 knots. It left that FAD after one hour, and swam almost straight to the Possession FAD, covering the 7-mile distance between the two buoys in less than two hours. The fish left the FAD after a very brief visit, at which time night was falling. During the first part of the night YF1 moved slowly, changing direction often, but with a general offshore trend; during the second part of the night it swam gently toward the Le Port FAD, where it had been tagged. At dawn the fish swam straight and fast toward the FAD where it stayed until the track ended.

Two days later YF2 was tagged on the same Le Port FAD at 2 p.m. The track duration was 21 hours. The observed behaviour was similar to that of YF1 (close association with the FAD during daytime, swimming 4 miles away during the night, back to the initial FAD at dawn).

The track of YF5 (Figure 3) lasted 19 hours. Tagged at 11 a.m. at the 3 Bassins FAD, the fish remained extremely close to the FAD until sunset. It left the FAD at night and swam away to the north, following the 500-m isobath along the coast. Just after dawn YF5 passed a few hundred meters away from the Le Port FAD, but did not stop. It was lost during the following hour due to its fast swimming.

Figure 4. Tracking course of the YF6 (FL=95cm). March 29, 1995 12:55 am to March 30, 13:15 am.



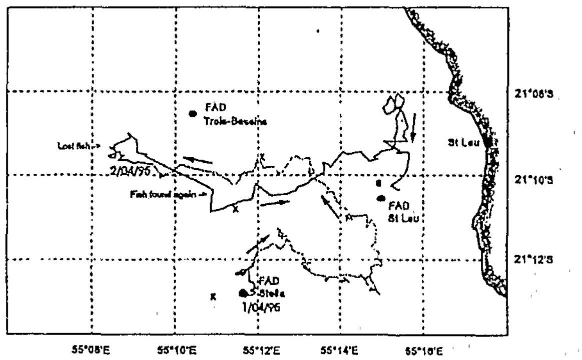


Figure 5. Tracking course of the YF7 (FL=58cm). Apr. 1, 1995, 8:50 am to Apr. 2, 14:50.

YF6 was tagged the day after on the Stella FAD (Figure 4). As with the previous observations, it stayed close to the FAD during the day and swam away to the south and away from the coast at night. It reached a point 22 miles south of the FAD before the track was stopped when the fish headed in an offshore direction.

A much smaller fish, YF7, was tagged at 8:50 a.m. 2 days later at the same Stella FAD (Figure 5). Like the others it remained attached to the FAD during the day and left it before sunset. It swam erratically all night, but never went more than 4 miles away from the FAD. At dawn it swam slowly toward the coast, and stayed less than 2 miles from the shore. At 3 p.m., when the track was stopped, it was in the vicinity of the St. Leu FAD.

Vertical movements

The depth records of the fish, averaged in 1-minute time intervals, are presented in Figures 6 to 10. In addition to the vertical movements, indications relevant to the thermal structure are also plotted. Oxygen levels are excluded since the concentrations measured in the waters of La Réunion are high (> 3.6 ml/l) to a depth of 300 meters., and thus oxygen availability does not act as a limiting factor on yellowfin tuna distribution (Cayré, 1987).

In order to provide a clear view of the thermal structure, three temperature-derived parameters were selected, as described in a previous paper (Cayré and Marsac, 1993): the upper limit of the thermocline, defined as SST-1°C (U), the depth of the maximum vertical gradient (G) and the lower part of the thermocline, defined as the weakest gradient (L). The higher number of casts during the 1995 cruises allows a better definition of these boundaries with time. The following observations can be made:

- the range of vertical movements is mostly delimited by the upper and lower limits of the thermocline;
- within these boundaries, the fish swim predominantly in the lower layer, from the depth of the maximum gradient and the bottom of the thermocline;
- to some extent, the average change in depth of the fish seems related to the vertical dynamics of the water column, depicted by the variable depth of the lower part of the thermocline. This is clear in Figures 8 to 10 (YF 5 to 7);
- some deep dives were observed far below the thermocline, in cool waters (17°C); this might be the due to body temperature regulation behaviour. The time spent at these depths is very short, but probably long enough to cause a positive physiological response.

In spite of these common features, a more detailed observation highlights some striking differences in behaviour. The first is the day-night effect on the swimming depths, when comparing YF1 and YF2 (February 1994) with YF5, YF6 and YF7 (March-April 1995). In 1994, the bigger YF1 drastically changed its swimming depths at sunset and sunrise (above the temperature gradient at night, below it in the at day), and this was repeatedly observed during the two day-night cycles of the track. However, this variable behaviour was not so obvious with the smaller fish (YF2). In 1995, the day-night effect did not play a role in the mean swimming depths of the fish but in the amplitude of the movements, which was very large at night.

Figure 6. Vertical movements recorded by the YF1.

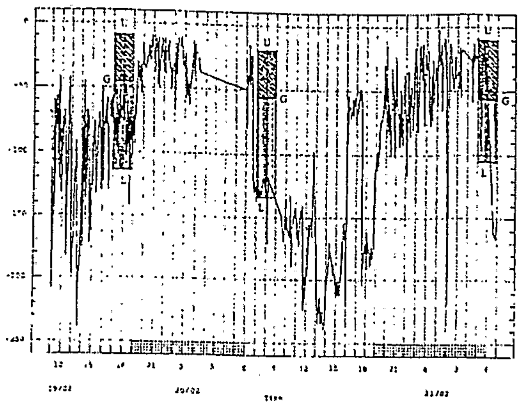


Figure 7. Vertical movements recorded by the YF2.

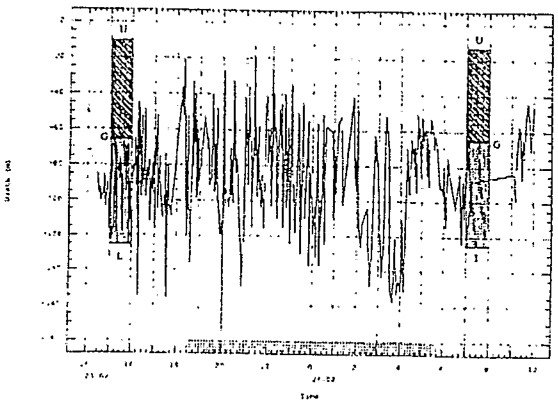


Figure 8. Vertical movements recorded by the YF5.

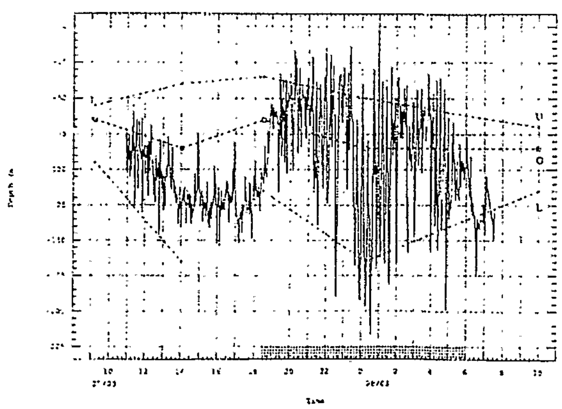


Figure 9. Vertical movements recorded by the YF6.

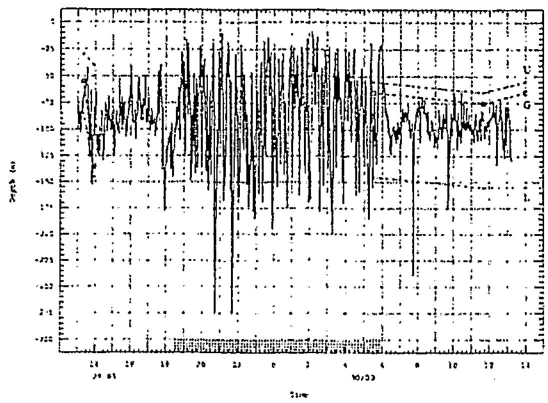
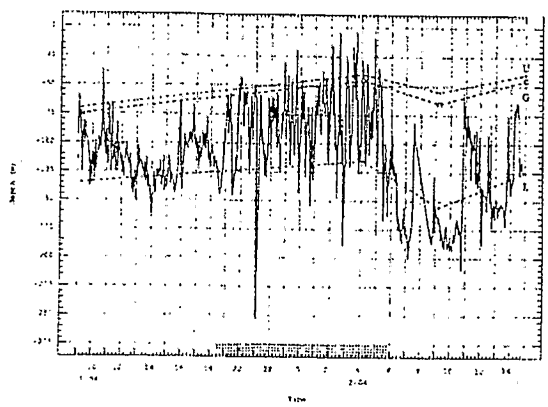


Figure 10. Vertical movements recorded by the YF7.



DISCUSSION

Patterns of FAD attraction

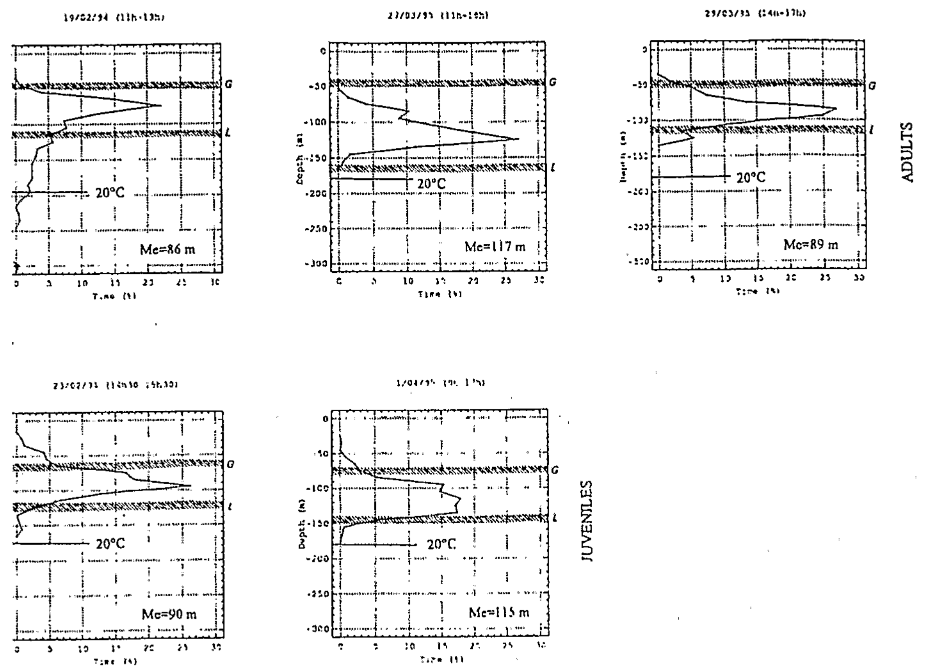
The two basic behaviours, strong association with FADs (YF1 and YF2 in February 1994), and weak association (YF5, YF6, and YF7 in late March-April 1995), have also been observed by Holland *et al.* (1990) and Cayré (1991). It is unlikely that differences in the size of the fish can explain the difference in behaviour, as there were large and small individuals in both situations. One reason could be the seasonal migration pattern: February 1994 was the core of the fishing season, whereas the 1995 tagging was undertaken at the end of the season. We might consider that the peak fishing season coincides with the presence of fish in the vicinity of the island, and that FADs could have an attractive effect on this population. On the other hand, , when the fish start to leave the area, they seem to pay less attention to the FADs and only stop for a short while.

Figure 11. *Relative time at depth on FAD and daytime.*

G = depth of the maximum thermal gradient

L = depth of the lower limit of the thermocline

Me = median of the tuna vertical distribution



More observations need to be made to confirm this hypothesis.

The nature of the attraction of tunas to FADs is still an open question. However, it seems clear that tuna can memorise the location of the FAD, probably for a limited time, ending when the fish migrate out of the area. The visual stimulus is likely to be important in the close vicinity of the FAD, being most effective at daytime or in full moonlight. The tunas tracked never joined a FAD at night, whereas swimming directly toward FADs was observed at sunrise.

Depth swimming behaviour

Clear differences are apparent in depth swimming behaviour, and the diurnal cycle has already been mentioned as a factor. However, an additional source of variability could be an age-dependent behaviour. Finally, we should also consider the fact that the fish are either attached to a FAD, or transiting among FADs, which might also cause a part of the behavioural variability.

For these reasons, and in order to analyse those effects, the observations were divided among 3 «strata» (or situations), with 2 different sub-strata in each case. This typological approach, still provisional, is a basic step for modelling. The strata are:

1. FAD swimming (distance from FAD <1.2 nm) *vs.* transit swimming;
2. Daytime (6:30 a.m.-6:30 p.m.) and nighttime (6:30 p.m.-6:30 a.m.);
3. Life stage of the fish: juvenile or adult (fork length > 90 cm).

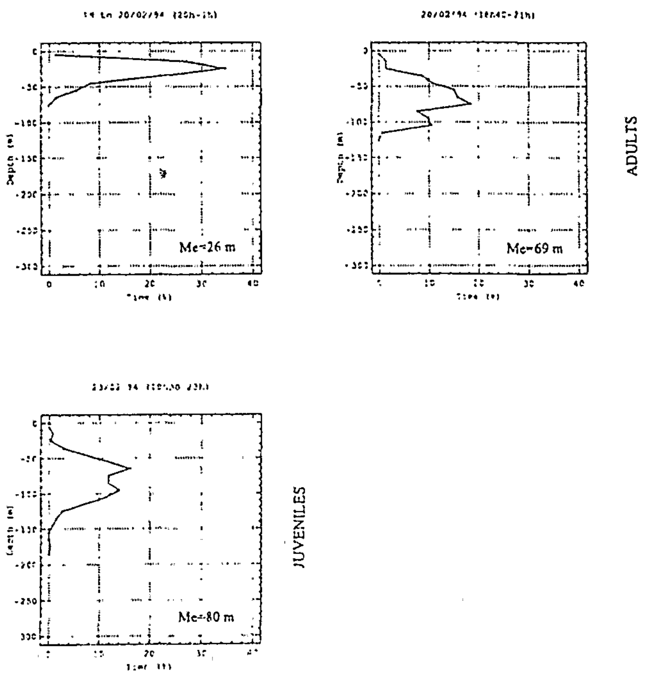
The distribution of the observations into these strata is presented in Table 2. We considered a minimum tracking duration of 2 hours for inclusion within a stratum. Some strata are still empty but should be sampled during forthcoming trips. The data set for each stratum was processed to produce a relative time spent at depth (TD), by 10- meter intervals; these are plotted in Figures 11 to 14 with the temperature boundaries previously defined. The following observations can be made:

- *FAD association in daytime* (Figure 11): for all life stages, TD shows a unique mode, mostly situated between the maximum temperature gradient depth (G) and the lower depth of the thermocline, L (the medians of the distributions are located 25 m above L). When

Table 2 - Distribution of observations within the three-level stratification system.

Life stage	*Fish ref*	*FAD*		*TRANSIT*	
		Day	*Night*	*Day*	
Adult	YF1	19/02/94, 11h-19h	19/02, 20h to 20/02, 1h	20/02/95, 10h-15h	20/02, 21h to 21/02, 5h
Juvenile	YF2	23/02/94, 14h30-18h30	23/02, 18h30-23h	-	23/02, 23h to 24/02, 5h
Adult	YF5	27/03/95, 11h-18h	-	-	27/03, 19h to 28/03, 5h
Adult	YF6	29/03/95, 14h-17h	-	30/03/95, 6h30-13h15	29/03, 19h to 30/03, 5h
Juvenile	YF7	01/04/95, 9h-17h	-	2/04/95, 6h30-15h	1/04, 19h to 2/04, 5h

Figure 12. Relative time at depth on FAD and nighttime.



TD extends below L, the 20°C isotherm acts as the deeper limit.

- *FAD association at night* (Figure12): No temperature profiles are available for this stratum. As in the daytime situation, there are no apparent differences related to life stage. TD is still unimodal, but the swimming depths are generally shallower. Unfortunately, the possible effect of a different thermal structure cannot be assessed.

- *Transit swimming in daytime* (Figure 13): TD is more variable. A significant amount of time is spent in deeper layers, even below L. The 20°C isotherm still plays a role in the depth delimitation, but this is not as clear as it is in Figure 11.

- *Transit swimming at night* (Figure 14): TD distribution shows also some variability but in general the fish (adult and juveniles) swim at shallower depths than in the daytime. Juveniles are distributed between G and L, while adults swim in the shallower layer as well, with a majority of time spent above the thermal gradient.

The main conclusions from the comparison of these different situations are:

a) **Daytime *vs.* nighttime FAD association**: whatever the life stage, the fish swim in shallower water at night. This is in agreement with several previous studies (Cayré and Chabanne, 1986; Cayré, 1991; Holland *et al.*, 1990)

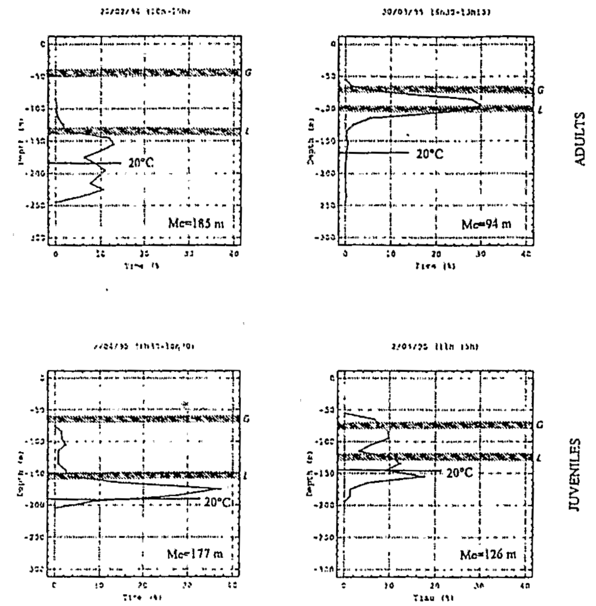
b) **Daytime *vs.* nighttime transit swimming**: whatever the life stage, fishes swim in shallower water at night.

c) **Daytime FAD association *vs.* daytime transit swimming**: whatever the life stage, the swimming depth distribution (TD) of the fish is more variable when transit swimming. Moreover, in general the swimming depth is greater during transit swimming than when FAD-associated.

d) **Night-time FAD association *vs.* night-time transit swimming**: as we do not have the relevant vertical temperature data for FAD association at night (G and L not calculated), we cannot say much about this comparison. The main visible difference is a greater variability in depth distribution during transit swimming.

Another parameter could also act as a key factor in the observed difference of behaviour: the moon phase. The striking difference in behaviour observed between the two sampled periods (1994 and 1995) relates to the behaviour of tuna at night. The moonlight might keep the fish close to the surface because it allows trophic activity. Though tuna are mostly considered day feeders, there are several reports of night feeding in the vicinity of a source of light. On the other hand, a new moon would not allow such a behaviour, and the fish keep swimming while saving energy: physiological models indicate that this is done by alternating downward (passive) and upward (active) movements across the thermocline. A periodogram applied

Figure 13. Relative time at depth for transit swimming at daytime.



to our data indicates a dominant frequency peak at 13 minutes and a secondary one at 38 minutes, which could characterise this energy-saving swimming pattern.

The next tracking operation will be designed to assess this hypothesis, and will add a new stratum for comprehensive analysis.

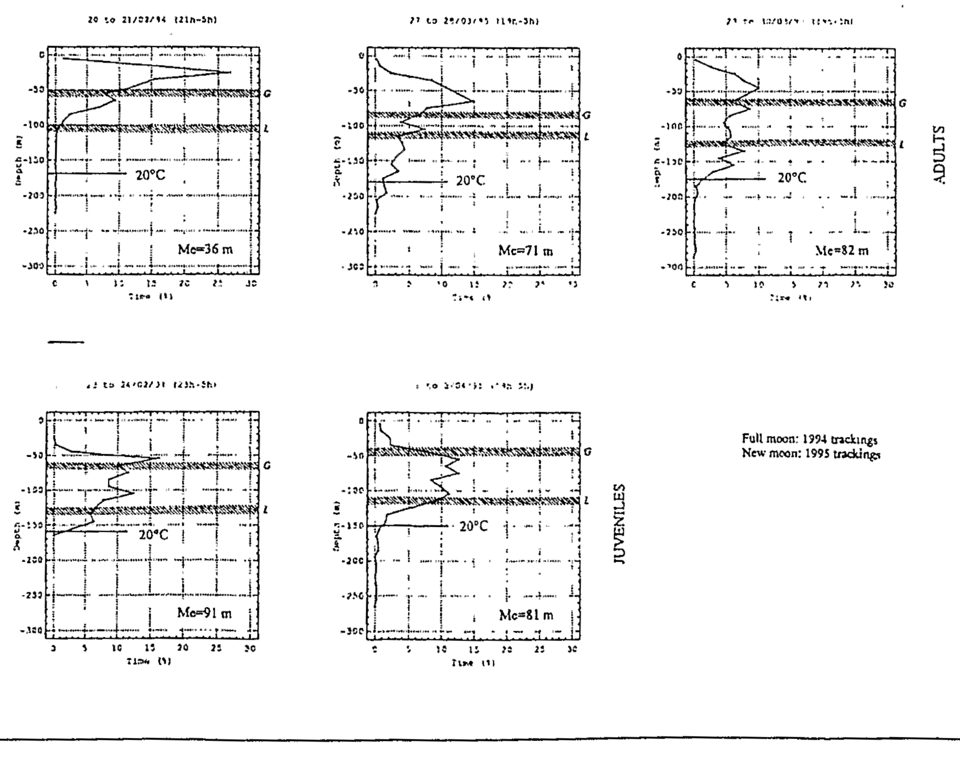
CONCLUSION

This kind of analysis provides practical indications for optimal fishing around FADs. The oriented movements from one FAD to another point to the tunas' ability to memorise some locations.

Under the hypothesis that the local biomass of tuna in the area cannot be increased by immigration of new fishes, if too many FADs are moored in the same place they will enhance the dispersion of the fish and decrease the concentration on any single FAD. The optimal distance between FADs is estimated to be 10 nm (Cayré, 1991). In addition, if FADs are moored at greater distances from the coast, they might also attract tunas swimming offshore. The typology of vertical distribution provides a useful indication of the optimal fishing depth. To some extent, depending on the time, the most suitable fishing gear can be operated, either trolling or drop line.

The present analytical process will, when combined with future additional data collected during future tracking operations, permit improvement of the models described by Cayré and Marsac (1993) and even extending them to other case studies. However, significant sampling effort should be made in accordance with the present proposed stratification, and past data, from the Indian Ocean and

Figure 14. Relative time at depth for transit swimming at night.



operations, permit improvement of the models described by Cayré and Marsac (1993) and even extending them to other case studies. However, significant sampling effort should be made in accordance with the present proposed stratification, and past data, from the Indian Ocean and from other oceans, have to be included.

Other cases to investigate in the near future are behaviours around oceanic seamounts and around drifting logs. Observations of skipjack movements around seamounts (Levenez, 1982; Cayré, 1982) suggest that such hydrographic structures act as FADs. On the other hand, logbook reports by purse seiners indicate that tuna gather at night around drifting logs, which is the opposite of what is observed on FADs.

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