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Behaviour of yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging

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Abstract

An ultrasonic tagging program for tuna was conducted in 1988 and 1989 within the Regional Tuna Project of the Indian Ocean Commission. Three yellowfin and six skipjack tuna were tagged with temperature or depth sensitive transmitters in the North-western part of the Mozambique Channel (12°S-44°E) around Anjouan island (Comoros Archipelago) where several fish aggregating devices (FADs) were previously moored. The horizontal and vertical movements observed during 8 tracks (3 yellowfin and 5 skipjack tuna) whose duration was between 3 and 24 hours, are analysed in terms of swimming depth, temperature encountered and position of the tracked tuna relative to the FAD or coast line. Comparison between recorded depth of tracked tuna and echosounded fish indicated tracked tuna were schooling.

Two of the 3 tagged yellowfin tuna displayed a behaviour of association with FADs. The optimal distance between 2 anchored FADs, to avoid adverse interference in the attraction of tuna, is estimated as 11 nautical miles. A very small percentage of time is spent by yellowfin tuna near the surface. The mean swimming depths encountered in the daytime by yellowfin tuna are much deeper (70-110 m) than they are at night (40-70 m). The relative homogeneity in the observed behaviour of yellowfin tuna and the fair general agreement with previous results obtained in the Pacific Ocean, should allow application of ultrasonic tagging results to fishing and prospecting purposes in the future.

The movements of the 5 tracked skipjack tuna do not indicate a behavioural association with FADs, and do not present marked differences between the swimming depths encountered by night and during the daytime. The high variability observed in the behaviour of the different tracked skipjack tuna, and the bad agreement with previous results obtained in the Atlantic and in the Pacific Oceans have to be emphasized. A high turnover of the skipjack tuna concentrated around FADs due to an intense and permanent migratory flow through the area of Comoros Islands could partly explain these apparent discrepancies.

Keywords : Tuna, *Thunnus albacares*, *Katsuwonus pelamis*, sonic tagging, behaviour, local movements, fish aggregating devices, Indian Ocean.

Étude du comportement de l'albacore (Thunnus albacares) *et du listao* (Katsuwonus pelamis) *par marquage acoustique autour de dispositifs de concentration de poisson (DCP) aux îles Comores.*

Résumé

Dans le cadre du Projet thonier régional de la Commission de l'océan Indien, un programme de marquage acoustique a été conduit en 1988 et 1989. Trois albacores (*Thunnus albacares*) et six listaos (*Katsuwonus pelamis*) ont été marqués avec des marques acoustiques équipées de capteurs de pression ou de température. La zone d'expérimentation est située dans la partie nord du canal de Mozambique (12°S-44°E) autour de l'île d'Anjouan (Comores) où plusieurs Dispositifs de Concentration de Poisson (DCP) avaient été préalablement mouillés. Les mouvements horizontaux et verticaux enregistrés au cours de 8 opérations de poursuite (3 albacores et 5 listaos) d'une durée comprise entre 3 et 24 heures, sont analysés en termes de fréquence de profondeurs de nage et de températures rencontrées, ainsi qu'en terme de positions par rapport aux DCP ou à la côte. La comparaison des profondeurs atteintes par les thons marqués avec celles de poissons détectés simultanément à l'échosondeur indique que les poissons marqués se déplacent au sein de bancs. Deux des trois albacores marqués ont présenté un comportement d'association avec les DCP. L'espacement optimal à respecter entre DCP, dans le cadre d'une opération d'installation de plusieurs DCP dans une zone donnée, a pu être estimé à 11 milles grâce à ces résultats. Le temps passé dans la couche de surface (0-20 m) par les albacores durant la journée est très court. La profondeur moyenne de nage des albacores au cours de la journée (70-110 m) est significativement plus importante que celle de nuit (40-70 m). La similarité du comportement des albacores observée au cours de ces expériences et la bonne concordance de ces résultats avec ceux issus d'études conduites dans le Pacifique devraient permettre l'utilisation des résultats de marquage acoustique à des fins de prospection et d'exploitation de cette espèce. Aucun des listaos marqués n'a présenté de comportement clair d'association avec les DCP. De même, aucune différence significative n'est apparue entre les mouvements verticaux effectués de jour et de nuit. L'importante variabilité du comportement individuel des listaos marqués et la mauvaise concordance des résultats présentés avec ceux obtenus dans l'Atlantique et dans le Pacifique méritent d'être soulignées. Ces contradictions apparentes pourraient s'expliquer par un taux important de renouvellement des listaos concentrés autour des DCP et par un flux de migration important traversant la zone des Comores, comme semblent l'indiquer des résultats issus d'opérations de marquage classique.

Mots-clés : Thons, *Thunnus albacares*, *Katsuwonus pelamis*, marquage acoustique, comportement, migrations locales, Dispositifs de Concentration de Poissons, océan Indien.

INTRODUCTION

The COI ("Commission de l'océan Indien"), with its Regional Tuna Project conducted within the framework of the "Association thonière", was aware of the necessity for its member countries (Comoros Islands, Réunion Island, Madagascar, Mauritius and Seychelles) to develop simultaneously their tuna fishing capabilities, their knowledge of the target species and their fishery assessment techniques.

The artisanal fishery for pelagic fish such as tuna, is of great importance to the Comorian population. FADs (fish aggregating devices) were deployed to try increasing the efficiency of local fishermen with some apparent success (Cayré *et al.*, 1990).

Following the methods of other ultrasonic tagging experiments (Yuen, 1970; Carey and Olson, 1982; Cayré and Chabanne, 1985; Holland *et al.*, 1990) we attempted to assess the behaviour of tuna in the Comoros Islands. Nine tuna were tagged near Anjouan Island to evaluate the effects of FADs and oceanographic conditions on the diurnal, horizontal and vertical movements of yellowfin and skipjack tuna (*fig.* 1).

METHODS

Equipment

The tracking experiments were performed in 1989 during 3 trips aboard the "M'Hadana", a small 13 meter long vessel of the National Fishing School of Anjouan. The tracking equipment was built by VEMCO, Armdale, Canada ([1]), and installed similar to the description by Holland *et al.* (1985).

The transmitters are cylindrical and measure 75 mm long by 15 mm in diameter. Each tag transmits either a 50 or 80 kHz pulse at a rate that is proportional to either pressure or temperature. The signal is received through a directional hydrophone, and decoded and stored every 20 seconds by a VR-60 receiver/decoder.

The small size of the ship allowed us to fix the directional hydrophone deeper than the keel and pointed forward. The direction to the tagged tuna was then established by orienting the boat to the direction of the strongest signal reception.

Capture and tagging

The tuna were caught by trolling artificial barbless lures to minimize injury to the fish. The tuna to be

([1]) Reference to trade names does not imply endorsement by any Service or Organisation cited as ORSTOM, COI (Indian Ocean Commission), Association thonière (Antananarivo, Madagascar).

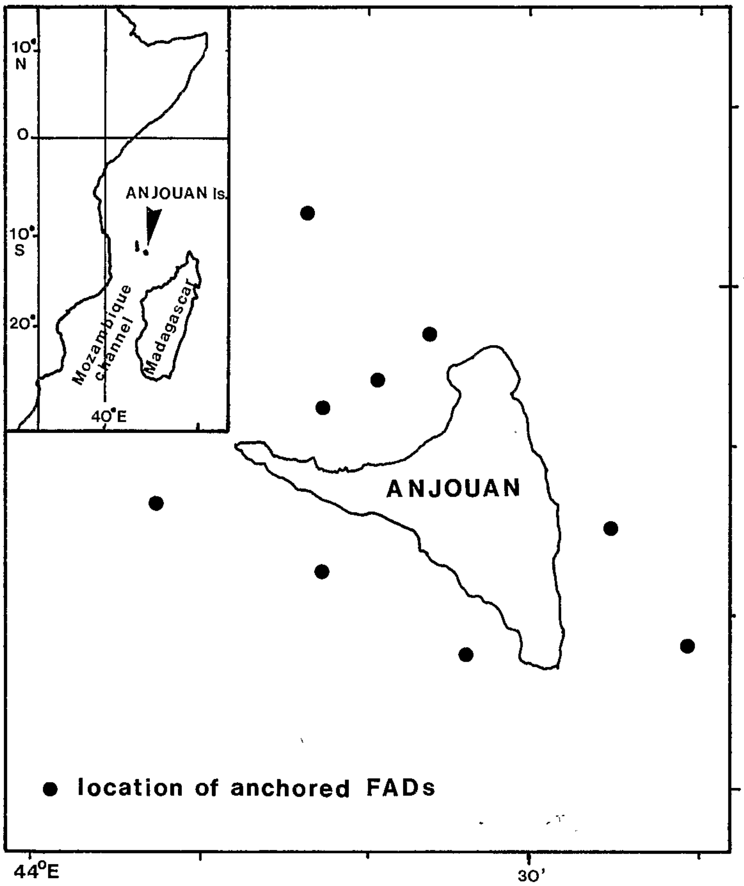

Figure 1. – Location of Anjouan Island (Comoros), where the sonic tagging experiments took place: locations of the 9 moored FADs are also indicated.

tagged was then placed in a "V" shaped graduated cradle, covered with artificial sponge (kept wet for softness), and the head of the fish was covered with a wet towel. The fork length was measured and the sonic tag was attached onto the tuna's back, just behind the second dorsal fin, with two nylon tie-wraps. The tuna was then released and the track began. The on-board tagging operation lasted between 45 and 90 seconds.

Tracking

The receiver/decoder unit was placed in the piloting cabin where one person was piloting the boat and tracking the tuna. Another person was observing the echosounder detection of fish schools and determining the position of the boat which was assessed each 30 minutes using a radar and landmarks. These positions were taken as positions of the tagged tuna itself. Though attempts were made to avoid following too closely and influencing the behaviour of the tagged tuna, the tuna sometimes came close to the tracking vessel. On these occasions if fish were observed on the echo-sounder, their depth was simultaneously compared with the depth of the tracked tuna as given by the transmitter. We chose not to track tuna longer than 24 hours, preferring to track a greater number than fewer for a longer time.

Environmental observations

Just before or after a tracking operation the sea temperature was taken every 10 meters to a depth between 200 and 300 metres by lowering a pressure and a temperature transmitter together on a line. Moreover, mean temperature and oxygen profiles for the second and fourth quarters, in the tagging area, were calculated with data extracted from the TOGA (Tropical Ocean and Global Atmosphere Centre, ORSTOM-IFREMER, Brest, France) database and from the French National Bank of Oceanic Data, IFREMER, Brest.

RESULTS

Temperature and oxygen profiles

The two temperature *versus* depth profiles measured and the mean profiles calculated respectively for the second (*fig.* 2 *a*) and the fourth (*fig.* 2 *b*) quarter are in agreement; the lower part of the mixed layer is located at around 70 m during the second quarter and deeper, though less marked, during the second quarter of the year.

n° 4. No figure was drawn for yellowfin n° 6 because its movements were entirely within a 2 miles^2 area adjacent to a FAD. The yellowfin n° 6 was tagged close by FAD 2 (*figure* 1) and remained within 300 m

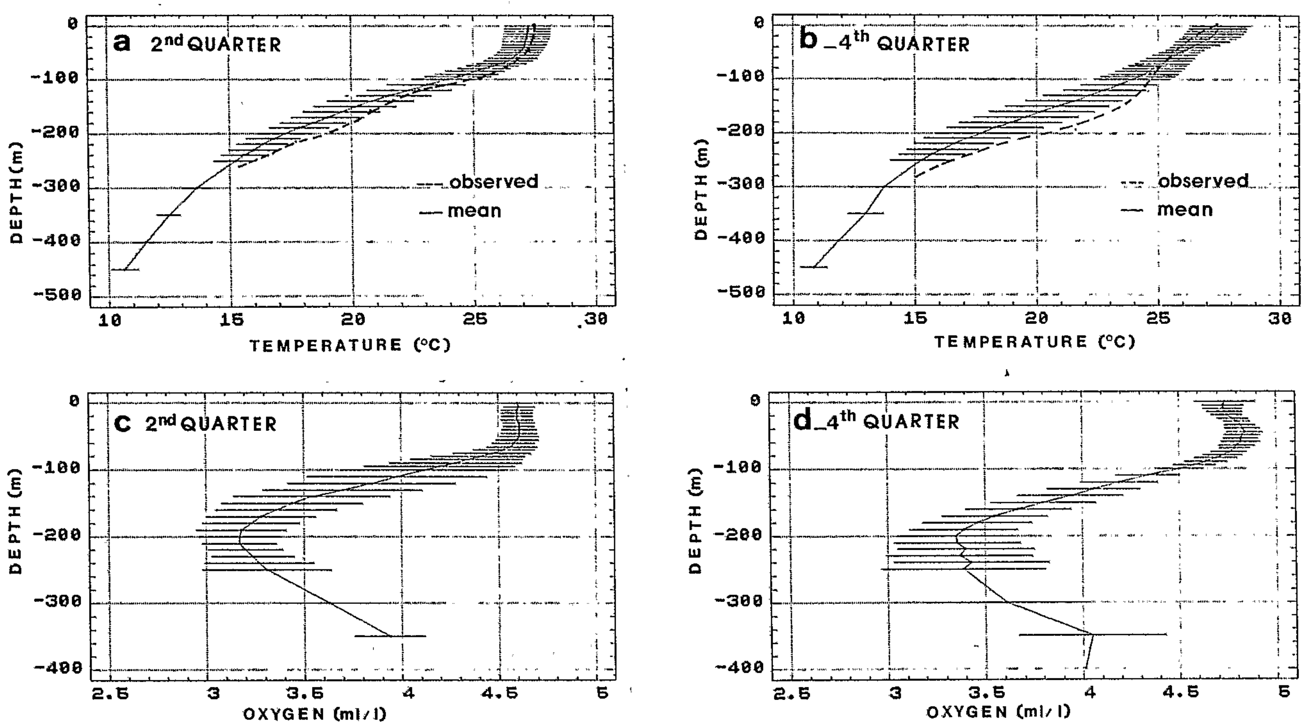

Figure 2. – Temperature (*a* and *b*) and oxygen (*c* and *d*) profiles for the 2nd and 4th Quarters in the area located between 10° South and 15° South, and between 40° East and 45° East. Mean curves were calculated with data extracted from TOGA (Tropical Ocean and Global Atmosphere, ORSTOM/IFREMER, Brest, France) and (National Bank of Oceanic Data, IFRMER; observed temperature profiles were measured by 12°08 S-44°20E on May 15th, 1989 (*a*) and by 11°59S-44°20E on November 13th, 1989 (*b*).

The mean oxygen *versus* depth profiles (*figs.* 2 *c* and 2 *d*) indicate a minimum value of oxygen concentration (3.2 to 3.4 ml/l) occurs at a 200 m depth for both second and fourth quarters.

Tracks

Nine tuna (6 skipjacks and 3 yellowfins) were tracked. One skipjack track was terminated at 55 minutes because the tag was sinking during the whole track; presumably, the fish was dying. The summaries for 5 skipjack and 3 yellowfin tuna are given in *table* 1.

The simultaneously recorded swimming depths of depth transmitter tagged tuna (n° 1, 3, 4, 6, 8) and echosounder detections show that these two sets of data are strongly correlated ($r = 0.81$) (*fig.* 3).

Horizontal movements

Yellowfin tuna

Figures 4 *e* and 4 *f* show the small-scale horizontal movements of the tagged yellowfin tuna n° 3 and

of that FAD during the 13.07 hours track. However, no signal from that fish could be detected when the boat came back the following two mornings to search for it. Yellowfin n° 4 was tagged within 1 mile of a FAD (*fig.* 4 *f*) and did not remain near the FAD, but visited two other FADs in one day and appeared to be returning the next morning toward the FAD where it was tagged.

The mean swimming speed, counted as the total distance made during tracks divided by total duration of tracks, is between 1.6 knots and 4 knots (*tabl.* 1).

Skipjack tuna

Figures 4 a to 4 *d* show the small-scale horizontal movements of the tracked skipjacks tunas n° 2, 5, 7 and 8. No figure was drawn for skipjack n° 1 because its movements were restricted to a 2 miles^2 area. These *figures* 4 *a* to 4 *d* do not indicate any association with the FADs.

The mean calculated swimming speed is between 1.2 knots and 2.4 knots (*tabl.* 1).

Table 1. – Summary of tracking: species (SJ = Skipjack tuna, YF = Yellowfin tuna) date, time (GMT + 3), location and duration of the tracks.

Track n°	1	2	3	4	5	6	7	8
Type of transmitter	Depth	Temp.	Depth	Depth	Temp.	Depth	Temp.	Depth
Species	SJ	SJ	YF	YF	SJ	YF	SJ	SJ
Length (FL)	41 cm	48 cm	80 cm	105 cm	52 cm	73 cm	52 cm	51 cm
Tagging:								
Date	April 16/89	April 16/89	April 18/89	May 14/89	May 16/89	May 17/89	Nov. 11/89	Nov. 13/89
Time (TU+3)	9.23	17.45	13.05	6.06	7.28	6.18	16.47	16.15
Position	12°01,4 S 44°14,5 E	12°15,6 S 44°10,4 E	12°07,8 S 44°25,6 E	12°06,2 S 44°20,6 E	11°59,0 S 44°17,2 E	12°06,8 S 44°20,9 E	11°58,6 S 44°18,0 E	12°56,7 S 44°17,1 E
Duration of the track	2 h 37	14 h 00	22 h 00	24 h 04	9 h 32	13 h 07	24 h 08	17 h 00
Distance travelled (mile)	4	34	89	38	13	*	28	27
Mean speed (knot)	*	2.4	4.0	1.6	1.4	*	1.2	1.6

(*) the distance travelled (or the speed) was too short to be calculated.

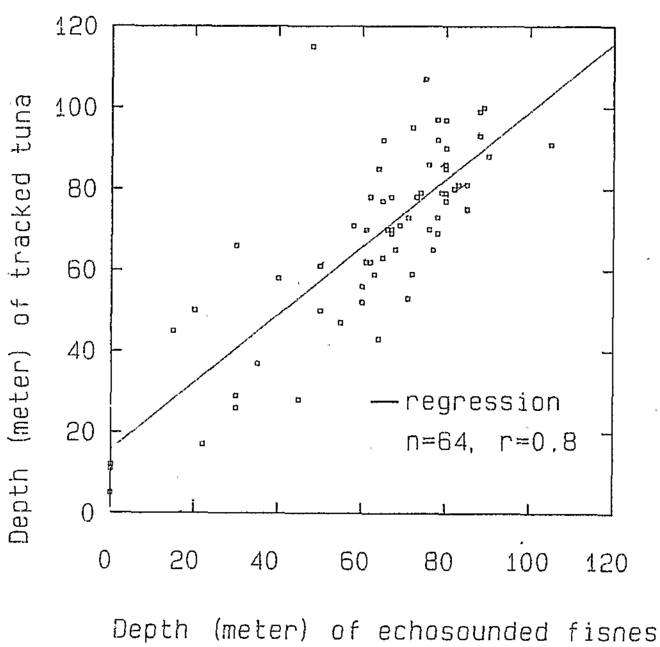

Figure 3. – Relationship (regression) between the simultaneously recorded swimming depths of tracked tuna and free tuna schools (as measured by echo-sounder).

Vertical Movements

Yellowfin tuna

As shown by the raw depth records (*fig.* 5) for the 3 tagged yellowfin tuna and by the frequency of time spent at different depths during the night (*fig.* 6) and during the daytime (*fig.* 7), the swimming depths are deeper during the daytime (mostly between 70 m and 110 m), than during the night (mostly between 40 m and 70 m, *fig.* 8). The 3 tagged yellowfin tuna were seldom near the surface (*i. e.* 0-10 meter depth) during the day: from 0 to 3% of the time (*fig.* 7), and more frequent at night though quite variable from one individual (0%, yellowfin n° 4) to another (15%, yellowfin n° 3), *figure* 6.

Figures 9 and 10 represent the frequency of time spent during the daytime at each temperature. The swimming depths observed during most of the day appear located in the upper part of the thermocline (temperature comprised between 25° and 27°C, *figs.* 2 and 10). During the night the most frequent swimming depth is situated in the warm mixed layer (temperature >27°C, *fig.* 9).

Skipjack tuna

The percentage of the time spent by tagged skipjack n° 1 and 8 at different depths at night and during the day (*figs.* 11 and 12), shows that deeper water layers are visited at night. Incursions into deeper layers were specially undertaken during the first half of the night (*fig.* 13). From *figures* 11 and 12, it appears that the percentage of the time spent in the 0-20 meters layer is greater during the daytime (approx. 45% of the time) than during the night (approx. 25%).

Combining the tracks of skipjacks n° 2, 5 and 7 (tagged with temperature transmitters) with the tracks of skipjacks n° 1 and 8 (having transformed depth data into temperature), indicates that the temperature encountered at night (*fig.* 14) are slightly lower than those encountered during the day (*fig.* 15). This reflects the observed nightly deep dives.

DISCUSSION

Significance of ultrasonic tagging results

The fish detected by echosounding during the tracks (*fig.* 3), although not sampled, can almost certainly be identified as tuna because of the scarcity of other pelagic fish in the area and due to the typical shape of the echo given by tuna on a screen. The fair correlation between the recorded depth of tracked

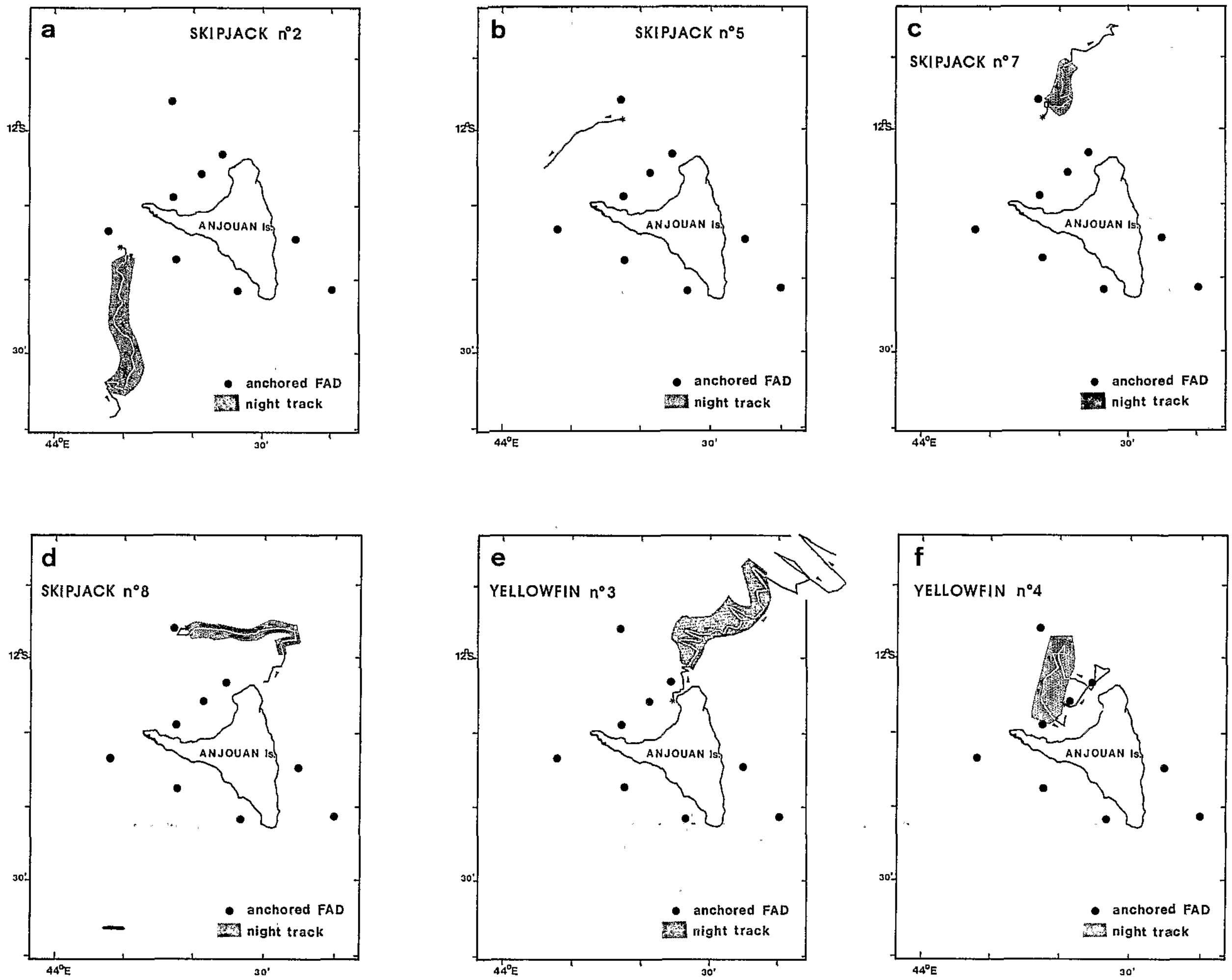

Figure 4. – Tracks of tagged skipjack (A to D) and yellowfin tuna (E and F): *Date and duration of the tracks:* (A) April 16th-14 hours, (B) May 16th-09.30 hours (C) Nov. 11th-24.10 hours, (D) Nov. 13th-17 hours (E) April 18th-22 hours, (F) May 14th-24 hours.

tuna and the depth of echosounded fish (*fig.* 3) indicated that the tracked tuna were schooling.

The raw depth records obtained for the 3 tagged yellowfin n° 3, 4 and 6 (*fig.* 5) show, when superimposed, a remarkable likeness with regard to depth versus time of day. This fact joined to the schooling behaviour of tagged tuna tends to demonstrate that the observations from sonic tracking experiments are not biased and do represent the natural behaviour of the tracked species.

Horizontal movements

The summary of other ultrasonic taggings experiments of yellowfin tuna and skipjack tuna are given in *table* 2.

Yellowfin

Two of the three tagged yellowfin tuna presented a behaviour of association with FAD. The yellowfin n° 6 (*table* 2) remained close to the FAD where it was tagged during the whole daytime. Due to material problems with the tracking boat, it was left at night and was not found the following day, but it may have gone to another FAD, oriented to a depth contour of the island or shed the tag somewhere. Yellowfin n° 4, which returned to the FAD where it was originally tagged after a whole night's long excursion away (*fig.* 4*f*), represents a behaviour quite consistent with the observations made by Holland *et al.* (1990). Combining all the yellowfin tuna they tracked (FAD-associated and coastline-associated ones) they found that 7 of the 11 yellowfin presented the same behavioural pattern (*i. e.* leaving at night the structure, FAD or coastline, with which they were associated during the day, and coming back the next morning to the original starting point or to a similar one in the neighbourhood). The yellowfin n° 3 clearly left the area without presenting any behaviour of association

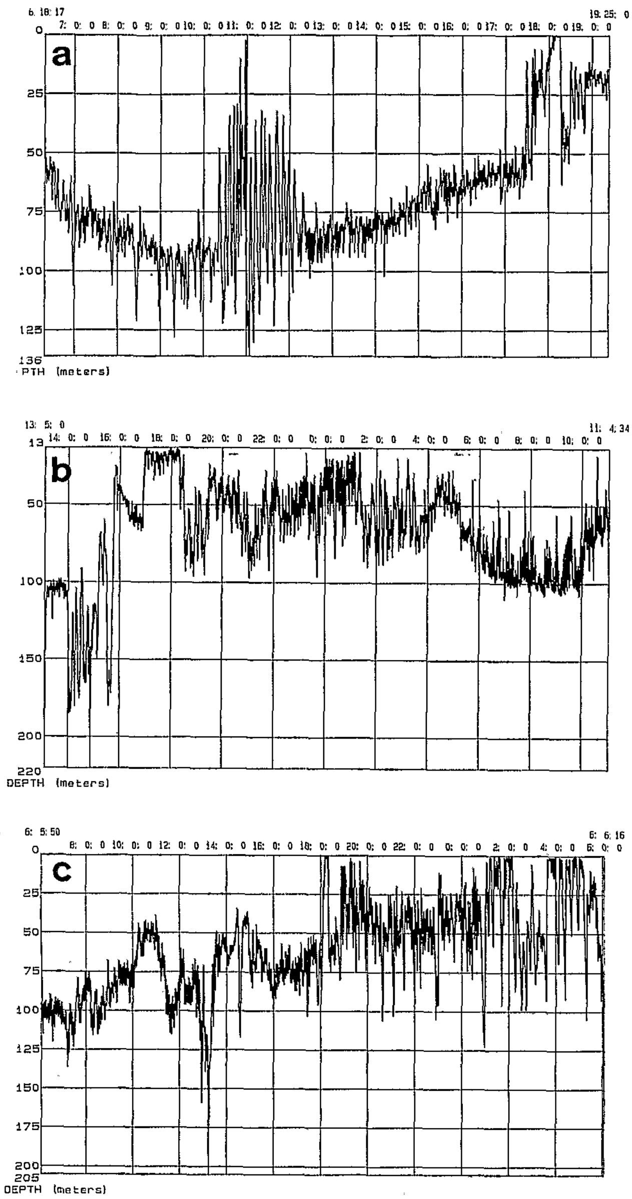

Figure 5. – Depth record for tracked yellowfin tuna n° 3 (*a*), 4 (*b*), and 6 (*c*).

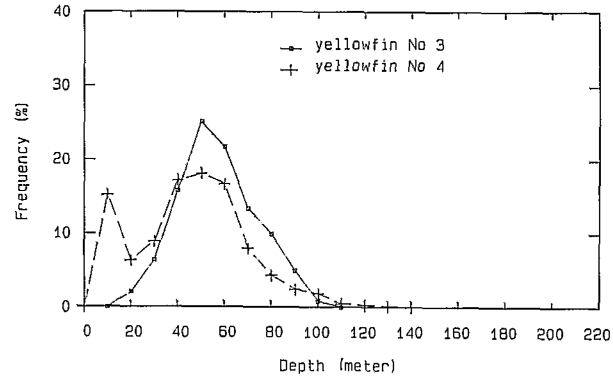

Figure 6. – Night (6.15 pm to 5.15 am) frequency of the time spent by tracked yellowfin tuna at different depths.

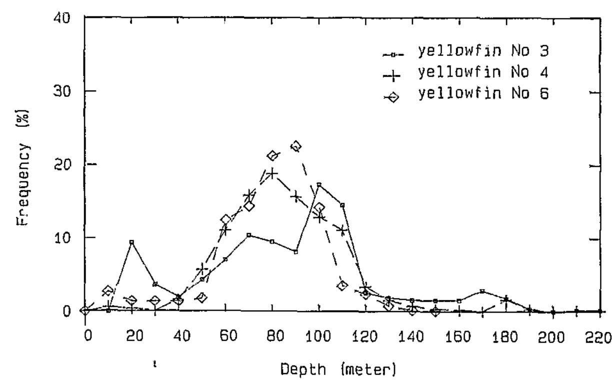

Figure 7. – Daytime (from 5.15 am to 18.15 pm) frequency of the time spent by tracked yellowfin tuna at different depths.

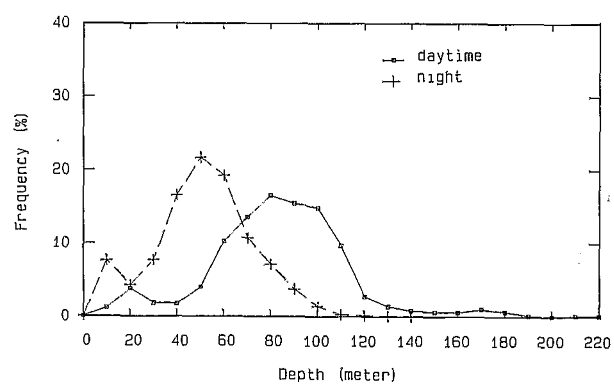

Figure 8. – Mean frequency of the time spent by tracked yellowfin tuna at different depths in the daytime (5.15 am to 6.15 pm) and at night (6.15 pm to 5.15 am).

with FAD or coastline (*fig.* 4 *e*). The present ultrasonic tagging results are not numerous enough to be conclusive on the time of residence of yellowfin tuna around FAD or in the Comoros islands area as a whole. Recent classic tagging experiments (Cayré and Ramcharrun, 1990), conducted around Anjouan island on FAD associated tunas showed a very small tag return though there was a significant fishing effort applied in the area on tuna (Cayré *et al.*, 1990) and fair publicity to support the tagging operation. The few recoveries of tagged tuna made far away from the Comoros islands in the North western part of the Indian Ocean seems to indicate this area to be a place where migrating tuna pass by without stopping for a significant (*i. e.* more than 7 days) period of time. This observation should be confirmed by some additional tracking experiments and classic taggings conducted during the peak fishing season (January, February).

The mean sustained swimming speed calculated from the yellowfin n° 3 and 4 (*tabl.* 1): 2.8 knots (*i. e.*

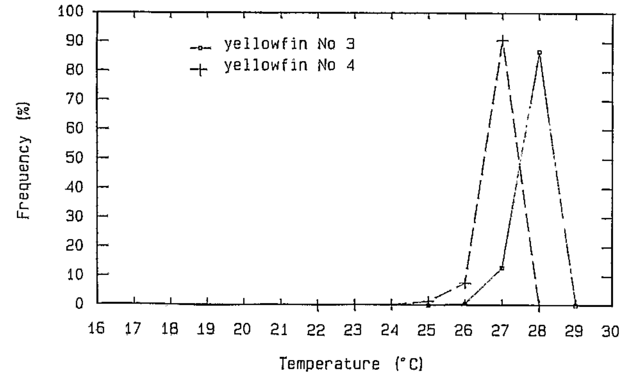

Figure 9. – Night (from 6.15 pm to 5.15 am) frequency of the time spent at different temperatures, converted from depth data, by tracked yellowfin tuna.

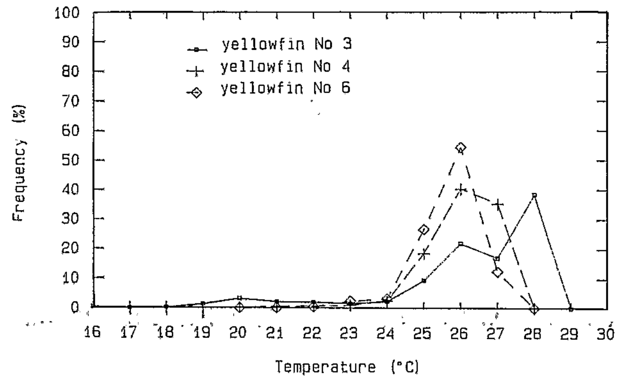

Figure 10. – Daytime (from 5.15 am to 6.15 pm) frequency of the time spent at different temperatures (converted from depth data) by 3 tracked yellowfin tuna.

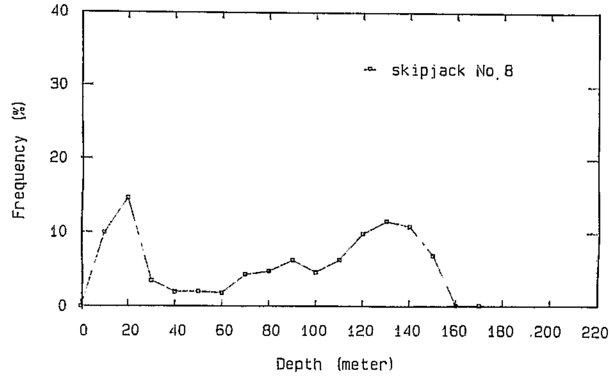

Figure 11. – Night (from 6.15 pm to 5.15 am) frequency of the time spent by a tracked skipjack tuna at different depths.

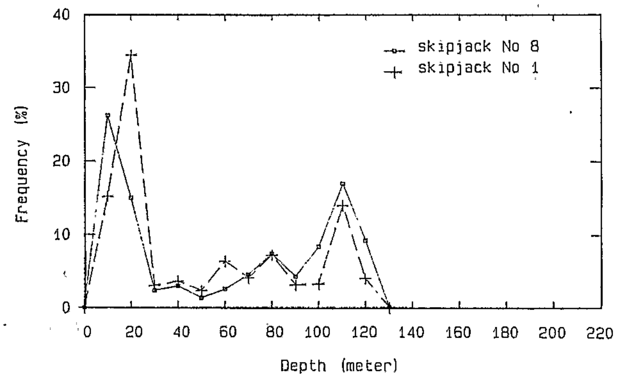

Figure 12. – Daytime (from 6.15 am to 18.15 pm) frequency of the time spent at different depths by 2 tracked skipjack tuna.

5.1 km/h) is consistent with swimming speed previously calculated by Carey and Olson (1982): 4.3 km/h (ranging from 2.4 to 7.8 km/h), by Cayré and Chabanne (1986): 3.9 km/h, and by Holland *et al.* (1990): 4.5 km/h (ranging from 3.2 and 6.5 km/h). Though this swimming speed (5.1 km/h = 1.4 m/s) is much higher than the one calculated following Magnuson's formulae: 0.4 m/s (Magnuson, 1973), the similarity of the swimming speeds calculated in the diverse ultrasonic tagging experiments for yellowfin of quite different sizes tends to demonstrate the accuracy of Magnuson's theory which requires (Magnuson, 1973) that bigger yellowfin tuna do not need higher swimming speeds to increase their buoyancy because of lower density imparted by a larger gas bladder and larger pectoral fin areas.

The question of the radii of attraction of FADs is of major importance when mooring multiple FADs in a given area. *Figure 4f* indicates the behaviour of yellowfin tuna was influenced by FAD at a distance of 7 nautical miles. This result is quite consistent with radii of attraction calculated by Cayré and Chabanne (1986) using ultrasonic tagging data: 6 nautical miles (nm), as well as with the radii calculated by Hilborn

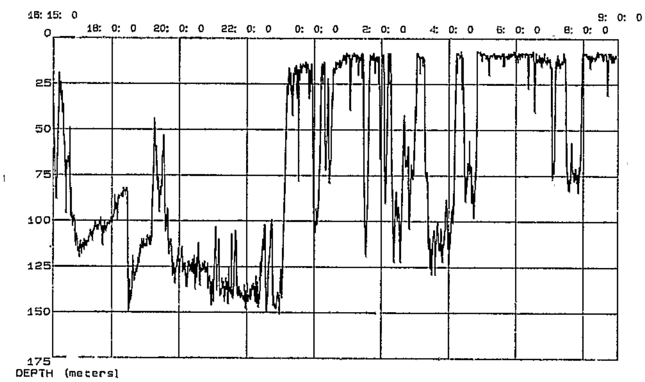

Figure 13. – Depth record for tracked skipjack n° 8 (fork length = 51 cm).

and Medley (1989): 4.3 nm. More recently Holland *et al.* (1990) combining data of 7 tracked yellowfin tuna, calculated that the radii of influence of FAD or depth line (40 fathom or 73 m) was of 5 nautical miles. Combining all these data the mean radii of attraction seems to be between 5 nm and 6 nm. Thus, the optimal

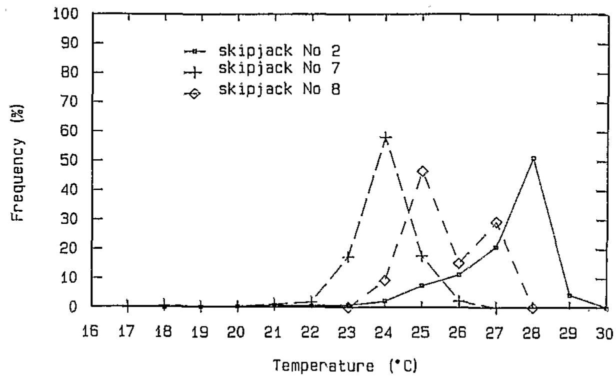

Figure 14. – Night (from 6.15 pm to 5.15 am) frequency of the time spent by tracked skipjack tuna at different temperatures.

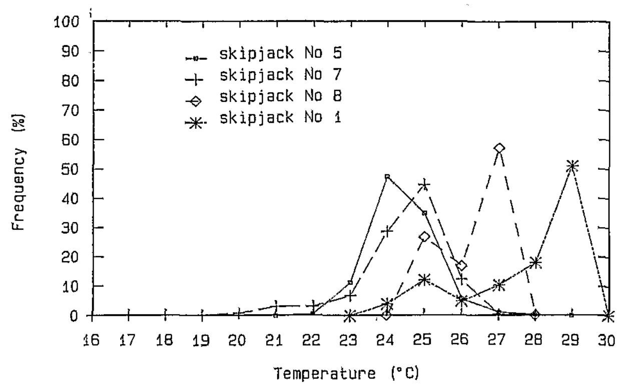

Figure 15. – Daytime (from 5.15 am to 6.15 pm) frequency of the time spent by tracked skipjack tuna at different temperatures.

minimum distance between 2 FADs or between a FAD and the nearest depth line (70 m) should be approximately 11 nautical miles to not have competition between FADs.

Skipjack

The *figures* 4*a* to 4*d* describing the skipjack movements do show a lack of association with the FADs. However, one skipjack does appear to be returning to associate with a depth contour of the island, similar to the findings of Yuen (1970). This apparent lack of association with FADs seems in contradiction with previous studies on skipjack tuna (Yuen, 1970; Lévenez, 1982; Cayré and Chabanne, 1986) as well as observations made on yellowfin tuna which indicate that within the first 24-hour period following the tagging operation a kind of homing behaviour of tuna to FADs or depth contours can be observed. A large turnover of fish in the skipjack tuna schools aggregated around FADs for very short periods could explain the improved catches made by local fishermen (Cayré *et al.*, 1990). This has to be confirmed by additional ultrasonic tagging and classic tagging operations.

The short time of residence at FADs could be due to the fact that the available food within the FAD area is over-exploited by many concentrated tuna, even if some taxonomic groups (*e. g.* Oplophoridae) could become a prey for tuna when they associate with FADs (Brock, 1985).

Vertical movements

Yellowfin tuna

The differences observed between the swimming depths mostly encountered by tracked yellowfin during the day (70-110 m) or at night (40-70 m) is quite consistent with similar observations previously made in the Pacific Ocean (Carey and Olson, 1982; Yonemori, 1982; Cayré and Chabanne, 1986; Holland *et al.*, 1990). Yonemori (1982) tracked four yellowfin tuna around FADs in the Western Pacific and observed, as did Carey and Olson (1982), that before sunset the tagged tuna made an abrupt transition from a mean deep swimming depth (> 150 m) located in the thermocline (22°C) to a shallower depth (50 m) located in the mixed layer (29°C) where they remained during the whole night. Cayré and Chabanne (1986) and Holland *et al.* (1990) made similar observations on yellowfin tuna tagged around FADs in the Central Pacific. Brock (1985) noted that the frequency of empty stomachs was higher among yellowfin tuna caught near FADs than for those caught in the open sea. Thus, the increase in the activity of yellowfin tuna occurring just before sunset, and the observed swimming habits in the mixed layer at night could be foraging activity.

Local fishermen who use handlines and baited hooks to catch yellowfin actually remain by the coast to exploit yellowfin tuna, while trolling canoes exploit FAD areas in the morning (from sunrise to 10.00 am.) and in the late afternoon (from 4.00 pm. to sunset). The above observed differences in mean swimming depths at daytime and at night (*fig.* 8), could allow fishermen using handlines to exploit the FADs and deep water layers (70-110 m) during the day when there is no interference by fishermen using troll lines.

In the area where our experiments took place, oxygen concentration does not seem to be a limiting factor in the swimming depth of yellowfin. The minimum value of oxygen concentration (3.2 to 3.4 ml/l) which occurs at 200 m (*fig.* 2) is well over the lethal limit for this species. Yellowfin tuna are able to maintain arterial oxygen delivery until oxygen concentration as low as 2.1 ml/l, although they are sensitive (decreasing of heart rate) to reduced ambient oxygen value as high as 4.0 mg O_2/l (Brill and Bushnell, 1989).

During the daytime (*fig.* 7) no significant difference can be observed between the vertical distribution of yellowfin tuna tracked away from FADs (yellowfin n° 3 and 4) and the vertical distribution of FAD

Table 2. – Summary of ultrasonic taggings of yellowfin tuna and skipjack tuna.

Author	Species	Size (cm)	Area	Duration of the track (hour)
Yuen (1970)	Skpjack	44	Hawaii	168
	Skipjack	40	Hawaii	12
Dizon, Brill and Yuen (1978)	Skipjack	70	Hawaii	24
	Skipjack	70	Hawaii	11
	Skipjack	70	Hawaii	10
Carey and Olson (1982)	Yellowfin	87	Eastern	9
	Yellowfin	89	Pacific	46
	Yellowfin	98		18
	Yellowfin	96		48
Yonemori (1982)	Yellowfin	63	Western	9
	Yellowfin	68	Pacific	8
	Yellowfin	70		15
	Yellowfin	64		32
Bard and Pinckock (1982)	Skipjack	44	Eastern	3
	Skipjack	45	Atlantic	7
Levenez (1982)	Skipjack	55	Eastern	44
	Skipjack	53	Atlantic	19
Cayré and Chabanne (1986)	Skipjack	57	Tahiti	39
	Yellowfin	54	Tahiti	89
Holland, Brill and Chang (1990)	Yellowfin	51	Hawaii	48
	Yellowfin	47	Hawaii	39
	Yellowfin	55	Hawaii	24
	Yellowfin	44	Hawaii	12
	Yellowfin	62	Hawaii	9
	Yellowfin	64	Hawaii	5
	Yellowfin	74	Hawaii	14
	Yellowfin	75	Hawaii	18
	Yellowfin	70	Hawaii	144
	Yellowfin	47	Hawaii	37
	Yellowfin	57	Hawaii	38

associated ones (yellowfin n° 6); this has to be considered with caution because of the low number of observations and because it appears in disagreement with what was observed by Holland *et al.* (1990). These authors calculated that during the daytime the mean near-FAD swimming depth (59 m) was significantly different from the mean off-FAD swimming depth (85 m); they concluded that FADs tend to make yellowfin swim closer to the surface than they do in other offshore areas of the ocean.

Skipjack

Dizon *et al.* (1978) who tracked 3 skipjack tuna around Hawaii relate that skipjack tuna swim in a shallower layer at night than during the day. Cayré and Chabanne (1986) made the same observation from one skipjack tracked around FAD in Tahiti island and noted that the modal swimming depth shifted from 10-50 m at night to 50-100 m during the daytime. Yuen (1970) makes a similar observation from 2 skipjack tuna tagged around Hawaii. All these observations seem in disagreement with our present results which indicate that the percentage of the time spent swimming in the upper layer (0-20 m) in the daytime (45%) is higher than at night (25%). As a whole, the present results do not indicate marked differences in the swimming depths encountered by night and by day. It would be useful to further test these discrepancies.

As Yuen found (1970), it is important to note that the tracking results indicate that a very small percentage of time is spent by skipjack near the surface. This leads us to question the evaluation of abundance by aerial survey and visual observation of schools on the surface.

Skipjack tuna appears as sensitive as yellowfin tuna to reduction of ambient oxygen concentration and reduced arterial oxygen delivery was observed from oxygen concentration of 3.8 mg/l (Brill and Bushnell, 1989). The time spent by skipjacks at depths over 150 m (3.5 ml/l) during our tracks was very short and rare (*figs.* 12 and 13), and this is consistent with the results of Brill and Bushnell (1989) who stated that "skipjack tuna will not be able to survive long even in ambient oxygen <3.6 mg O_2/l".

CONCLUSION

Ultrasonic tagging experiments necessitate a combination of diverse costly material and optimal natural opportunities (good weather conditions, availability of tuna) to be successfully undertaken. This explains the small number of tuna generally involved in publications (*tabl.* 2). The present study, conducted for the first time within a part of the Indian Ocean, permits confirmation and explaination of previous results obtained using the same techniques on yellowfin and skipjack tuna in other oceans (the Atlantic and the Pacific). Thus, different common features of the small-scale movements and of the behaviour *versus* FADs of yellowfin tuna were outlined (behaviour of association with FADs, sustained swimming speed, radii of attraction of a FAD, night and day swimming depth cycle). On the contrary the skipjack tuna behaviour inferred from the present work does not match with what was observed in the other oceans. Except for confirmation of the role of the limiting factor played by dissolved oxygen in defining the swimming depth of this species, the variability of skipjack behaviour from one individual to another one is striking.

Due to the short time yellowfin tuna swim within the surface layer (0-20 m), the generalised use of sea surface temperature to guide the tuna fishing vessels toward potentially good fishing grounds in areas not characterized by marked gradients of temperature, seems questionable. The homogeneity of the swimming behaviour of the yellowfin tuna should allow use of ocean temperatures to try to predict their habitat and potential abundance.

As shown in this paper, ultrasonic tagging techniques really permit a direct knowledge of the behaviour of tuna. The transfer of the results obtained by this technique can be very fast and efficient on a local basis, as demonstrated recently in the Comorian artisanal fishery. The extrapolation of the results to help in defining a FAD settlement strategy can be undertaken to some extent, but a more extensive and interesting use of these data could be tried if additional tagging experiments are conducted in the future on tuna of different species and sizes within a variety of areas.

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