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Simultaneous observations of tuna movements and their prey by sonic tracking and acoustic surveys

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Abstract

This paper reviews results of some experiments conducted in French Polynesia on tuna behaviour. A method based on the simultaneous use of two techniques, acoustic tracking and acoustic surveys, was used. Experiments were conducted within the framework of the ECOTAP program, a joint program between two national research institutes (IFREMER and ORSTOM), and a territorial institute (EVAAM).

Acoustic tags equipped with pressure sensors were used in order to record horizontal and vertical movements of one yellowfin tuna (*Thunnus albacares*) and two bigeye tuna (*T. obesus*). Trackings lasted between 13 to 24 h. In the same time, echogram data were recorded between the surface and a depth of 500 m on board the tracking vessel. As the maximum range of the acoustic tags is small (a few hundred meters), vessel and tagged fish horizontal movements are therefore treated as equivalent. Echogram data from the sounder and data on the swimming depth of the fish given by the acoustic tag are then considered as having been obtained at the same time at the same place.

Comparison between the swimming depth of the tagged fish and the echogram data from the sounder clearly shows the important role of scattering layers, assimilated as food, on vertical and horizontal tuna movements, during daytime as well as during night-time.

The method used during these experiments allows to observe a new explanatory factor of tuna behaviour: the biotic environment. At small temporal and spatial scales, structure of the biotic environment and its dynamic appear to be a key factor to understanding the vertical and horizontal tuna movements. The simultaneous technique presented here must now be improved by using behavioural activities sensors. By this way, it would be possible to elucidate different tuna foraging phases in relationship with the dynamic of scattering layers.

Introduction

Acoustic telemetry has been applied in a variety of studies on tuna behaviour in the world's oceans. Among the available sensors (pressure, temperature, tail beat frequency, electromyograms from epaxial and opercular muscles, electrocardiogram, body temperature), pressure sensors have been the most used if we consider the literature published on this subject. Horizontal movements have been interpreted in relation to the presence of anomalies in the environment such as Fish Aggregating Devices (Cayré & Chabanne, 1986; Holland et al., 1990; Cayré, 1991; Marsac et al., 1996) and seamounts (Yuen, 1970). Vertical movements detected by pressure sensor have been interpreted in relation to the vertical structure of abiotic variables such as temperature, oxygen, salinity (Laurs et al., 1977; Cayré & Marsac, 1993). Other experiments have examined changes in fish body temperature in relation to vertical movements and the vertical structure of the temperature (Holland et al., 1992).

Except experiments reported in Carey (1990), the biotic environment has been generally ignored as an explanatory factor in vertical and horizontal movements of tuna, as experiments did not produce relevant observations on this environment. This gap was already reported by Cayré & Chabanne (op. cit.): 'La relation éventuelle entre les nombreux déplacements verticaux et l'alimentation des thons est d'autant plus intéressante à explorer que celle entre ces mêmes mou-

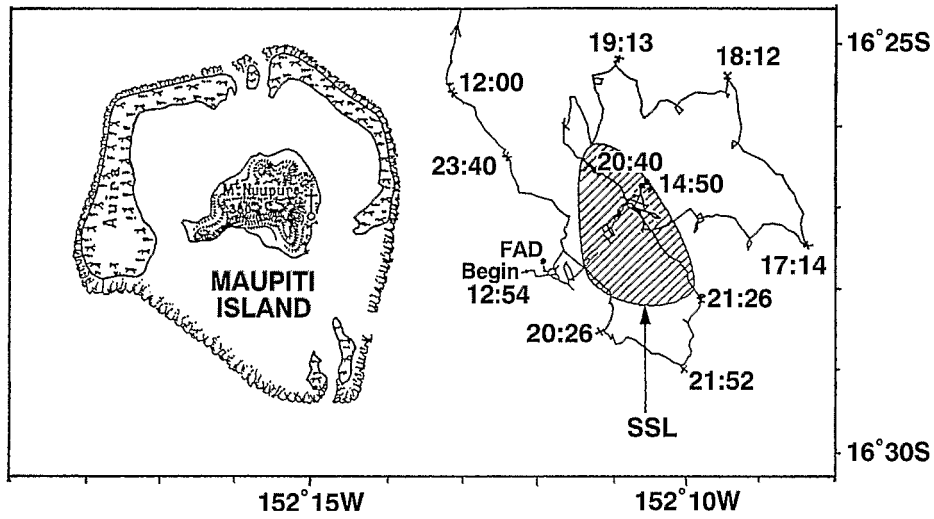

Figure 1. Experiment 1 (27/10/95). Horizontal movements of the tagged yellowfin tuna, with indication of the Sound Scattering Layer (SSL) position (hatched area) and the Fish Aggregating Device (FAD) position, near Maupiti Island (time is local time: UT – 10).

vements et les différents paramètres ou conditions hydrologiques n'est pas claire'. We present here a method based on the simultaneous use of two techniques: acoustic tracking and acoustic surveys. The simultaneous use of these techniques allows the interpretation of the vertical and horizontal movements of the fish in relation to the biotic factors of the environment. Three examples are used to illustrate the new observations on tuna behaviour we obtained with this method.

Materials and methods

Our experiments were conducted in French Polynesia within the framework of the ECOTAP program. ECOTAP (Etude du Comportement des Thonidés par l'Acoustique et la Pêche / Studies of tuna behaviour using acoustic and fishing experiments) is a joint program between EVAAM[1], IFREMER[2] and ORSTOM[3]. The aim of this program is to study the distribution and the behaviour of subsurface tunas, *Thunnus albacares* (Bonnaterre, 1788), *T. obesus*, (Lowe, 1839), and *T. alalunga* (Bonnaterre, 1788), exploited by local longline and drop-stone (Moarii & Leproux, 1996).

Experiments were performed during cruises on board the ORSTOM research vessel 'ALIS'. The tracking equipment used during these experiments is a VEMCO system. Acoustic tags (model V16P, 50 kHz, 500 PSI) are equipped with a pressure sensor. Each tag transmits a 50 kHz pulse at a rate proportional to the pressure. For the first experiment, the signal was received through a VEMCO V10 directional hydrophone fitted on a V-fin towed depressor, then decoded and stored by a VEMCO VR60 receiver/decoder on board the R/V 'ALIS'. For the other experiments, a VEMCO V41 bearing hydrophone connected to VEMCO VR 28 receiver replaced the directional hydrophone. During acoustic survey, a SIMRAD EK 500 scientific sounder was used. This sounder was connected to a hull-mounted transducer SIMRAD ES 38 B Split Beam (frequency 38 kHz).

Fishing operations were conducted on board the R/V 'ALIS' using the drop-stone technique or trolling line, or on board longline fishing units. Two different methods were applied to attach the transmitter on the fish, according to its size. When the fish was small enough, it was pulled up on board without any injury, the fork length was measured and the sonic tag was attached on to its back, just behind the second dorsal fin, with two nylon tie-wraps. The tagging operation lasted between 45 to 90 sec. When the fish was too big, it was not moved out of the water but only drawn alongside the ship. The fork length was then estimated,

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[3] ORSTOM – L'institut français de recherches scientifiques pour le développement en coopération, Centre ORSTOM de Tahiti, B.P. 529, Papeete, French Polynesia

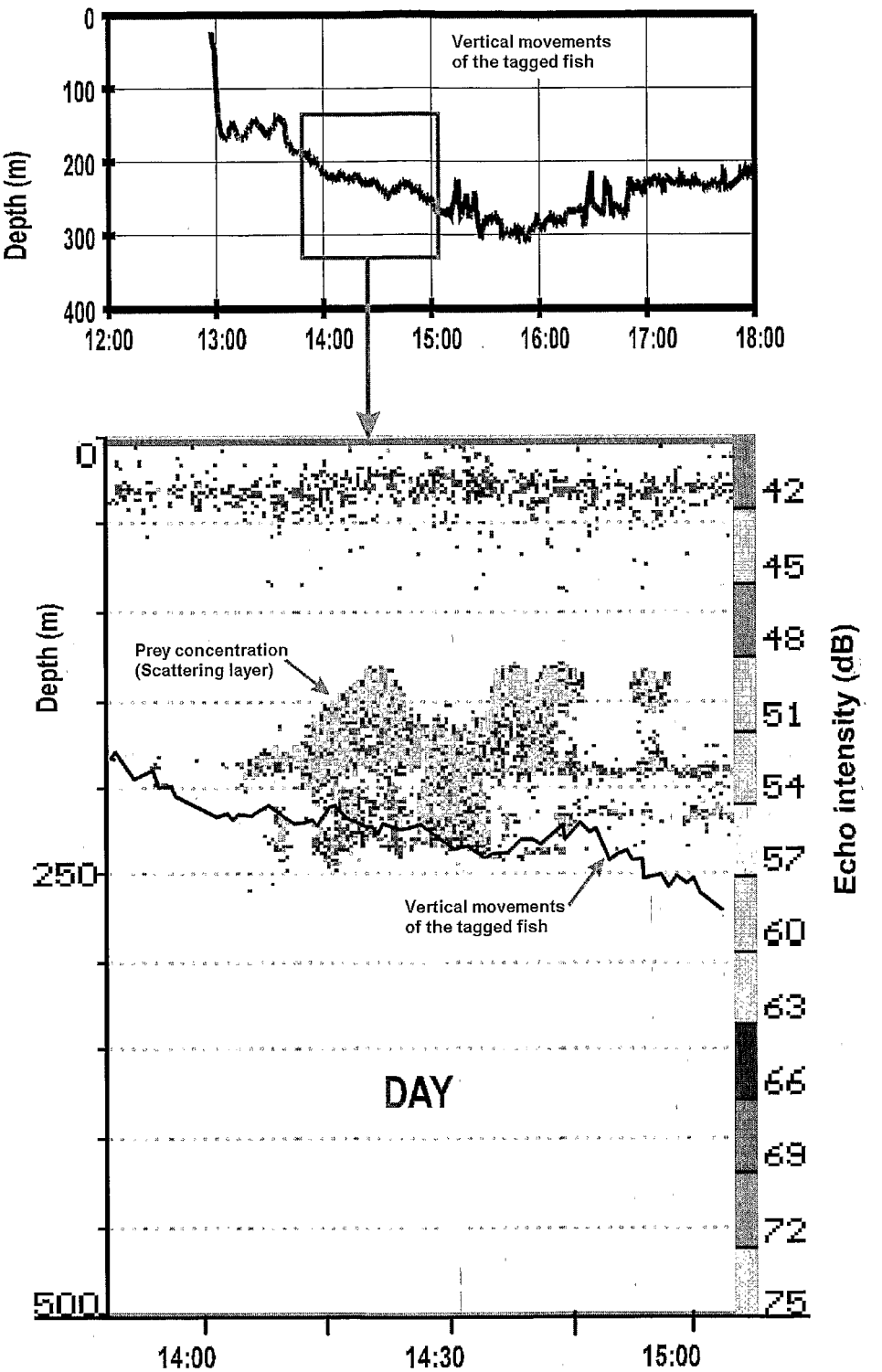

Figure 2. Experiment 1 (27/10/95). Vertical movements of the tagged yellowfin tuna and relation to the Sound Scattering Layer during daytime (time is local time: UT – 10).

and the sonic tag was fixed to the anterior dorsal musculature of the fish using a tagging pole. In this case, the tagging operation lasted about 20 sec. Immediately after the tagging operation, the fish was released at the same place and tracked. During tracking, simultaneous echosoundings were carried out between the surface and a depth of 500 m. The horizontal distance between the tracking boat and the tagged fish is generally short (between 500 and 800 m at the most). So, the horizontal movings of the vessel and those of the tagged fish are considered identical. The EP500 SIMRAD software was used to record echosounding data. At the same time, depth and geographical coordinates (GPS data) of the fish were recorded with a second recording unit using the VEMCO TRACK software. Interferences between the frequency of the tags (50 kHz) and the one used with the sounder (38 kHz) were very low and without effect on the quality of the data recorded.

During the tracking period vertical XBT profiles of temperature were performed between the surface and a depth of 460 m. At the end of each tracking, an hydrological station with a SeaBird SBE 19 probe was carried out. Pressure, temperature, salinity and oxygen were recorded between the surface and a depth of 600 m.

When possible, a fishing operation, using a pelagic trawl, was made before or after the tracking, in order to identify the species composition of scattering layers detected by the sounder.

Results

Experiment 1

A yellowfin tuna (*Thunnus albacares*), 60 cm fork length, was caught by the drop-stone technique at a depth of 120 m at midday, the 27th of October 1995, close to a Fish Aggregating Device (FAD) anchored near Maupiti Island (16°27′ S–152°17′ W), an island of the Leeward Islands of the Society archipelago. This tuna was tracked for 24 h. The results we present here concern only the first twelve hours of this tracking. Four periods can be distinguished for the horizontal movements: (i) a FAD association just after the release, (ii) a free-swimming phase directed offshore between 13:45 and sunset at 17:15, (iii) a progressive return to the FAD until 23:00, (iv) a free-swimming phase near the reef coast between 23:00 and midnight (Figure 1).

Vertical movements can be divided in two periods: (i) below the mixed layer during daytime, (ii) in the mixed layer during night-time.

Inside an oligotrophic area, an isolated Sound Scattering Layer (SSL) was observed in the vicinity of the Fish Aggregating Device (Figure 1).

The yellowfin tuna crossed the Sound Scattering Layer twice, first during daytime (Figure 2) and secondly during night-time (Figure 3). At each crossing, the tuna changed its movements. Horizontally it moved away from the Fish Aggregating Device during daytime although tuna are generally strongly associated with Fish Aggregating Devices during daylight (see experiment 2). Vertically, it swam in the mixed layer during night-time except during visits to the Sound Scattering Layer probably associated with foraging.

Experiment 2

This experiment was realised in the open ocean around an anchored instrumented oceanographic buoy (5° S–140° W), the 20th of January 1996. Repeated echosoundings around this buoy were achieved every 4 h during a 24-h period just before the tagging.

These echosoundings confirmed the regular presence of a tuna school, essentially composed of juvenile bigeye tuna (*Thunnus obesus*), 35 to 84 cm fork length, during daytime (Figure 4). In the afternoon, an individual of this species (77 cm fork length) was caught by trolling line and equipped with an acoustic tag. This tracking lasted 24 h in all. We show here only some observations performed during this experiment.

During daytime, the tagged fish remained in the school. Depth and spread of the school did not seem to change while it appeared that the tagged fish exhibited vertical movements within the school (Figure 5). The maximum depth of the school and vertical movements of the fish seemed to be limited by the presence of a well-defined oxycline (1 ml l^{-1} O_2) at a depth of 200 m. Because of this limit, the Sound Scattering Layer could be inaccessible to tuna during daytime.

At the end of the afternoon, the school structure disappeared and the tagged fish left the buoy. At dusk, the fish swam into the Sound Scattering Layer which migrated to the surface layer. The mean swimming depth of the tuna (60 m) corresponded to the maximum acoustic intensity in the Sound Scattering Layer (Figure 6). The first part of the vertical movements showed on Figure 6 is similar to the movements exhibited in the scattering layer by the yellowfin tuna tracked in experiment 1 (see Figure 3).

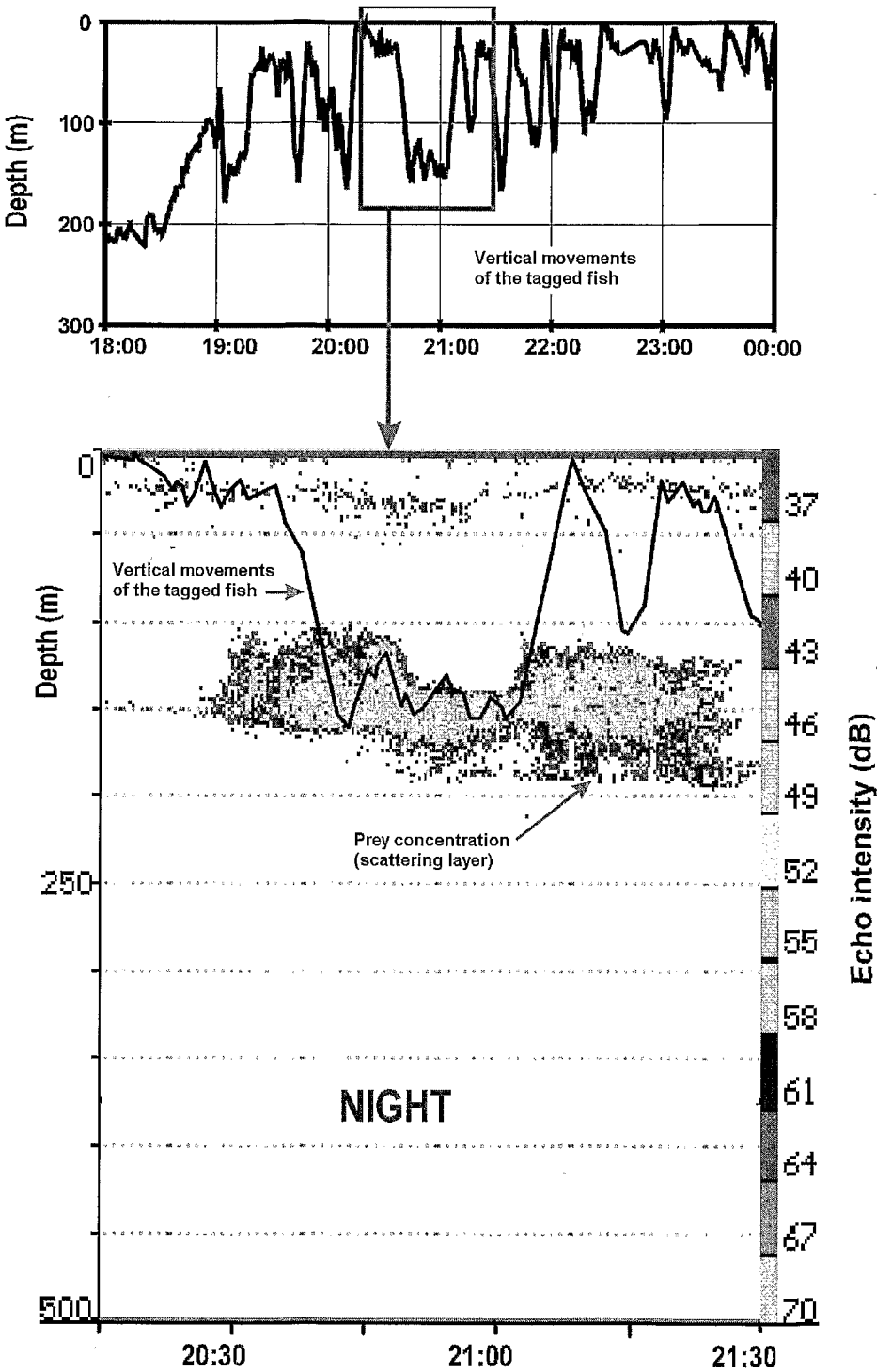

Figure 3. Experiment 1 (27/10/95). Vertical movements of the tagged yellowfin tuna and relation to the Sound Scattering Layer during night-time (time is local time: UT – 10).

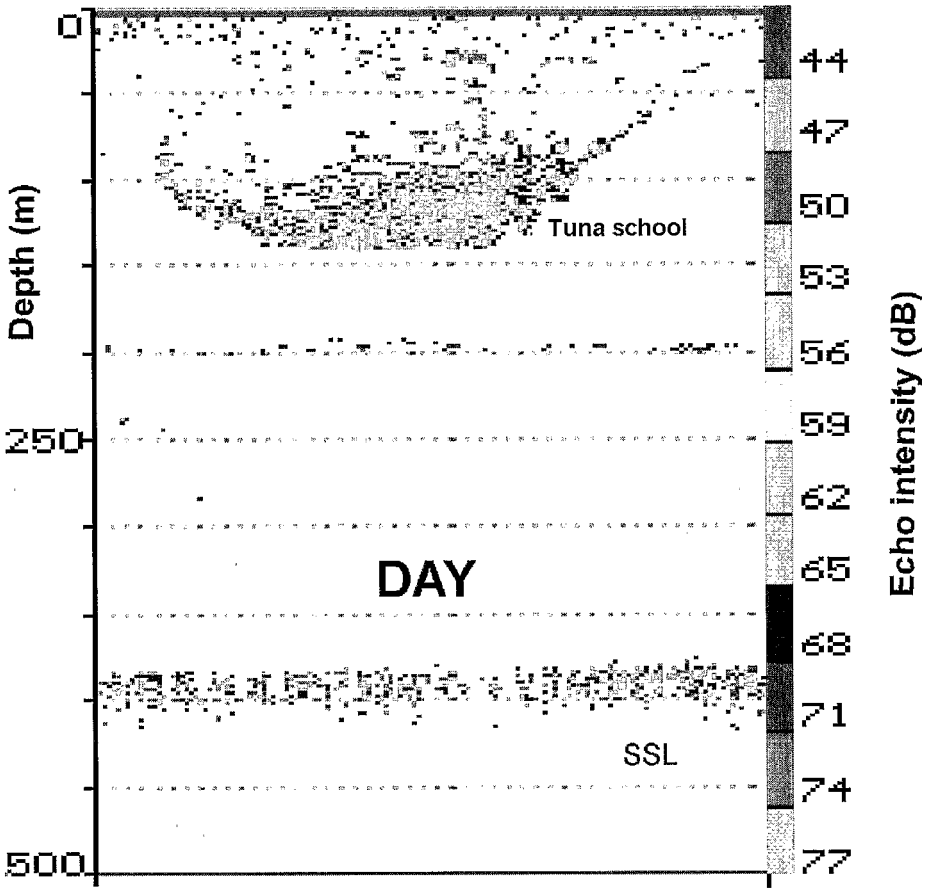

Figure 4. Experiment 2 (20/01/96). Tuna school (mainly bigeye tuna) and its biotic environment with indication of the Sound Scattering Layer (SSL) observed close to an anchored oceanographic buoy to the north (5° S–140° W) of the French Polynesian Exclusive Economic Zone.

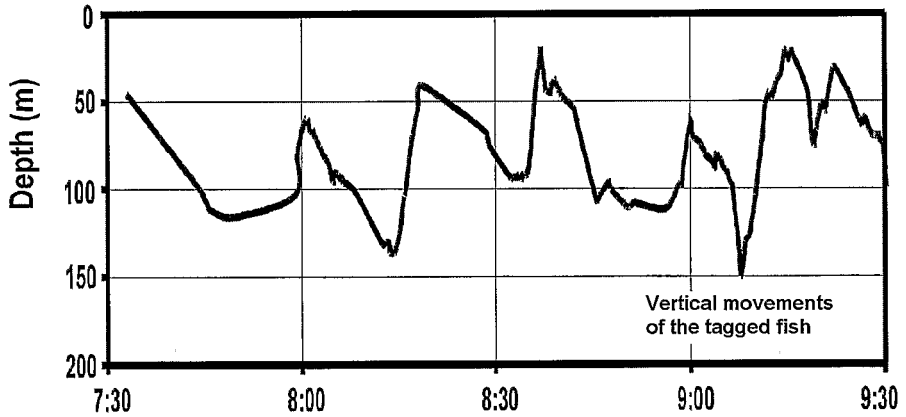

Figure 5. Experiment 2 (20/01/96). Detail of vertical movements of the tagged bigeye tuna inside the tuna school during daytime (time is local time: UT – 10).

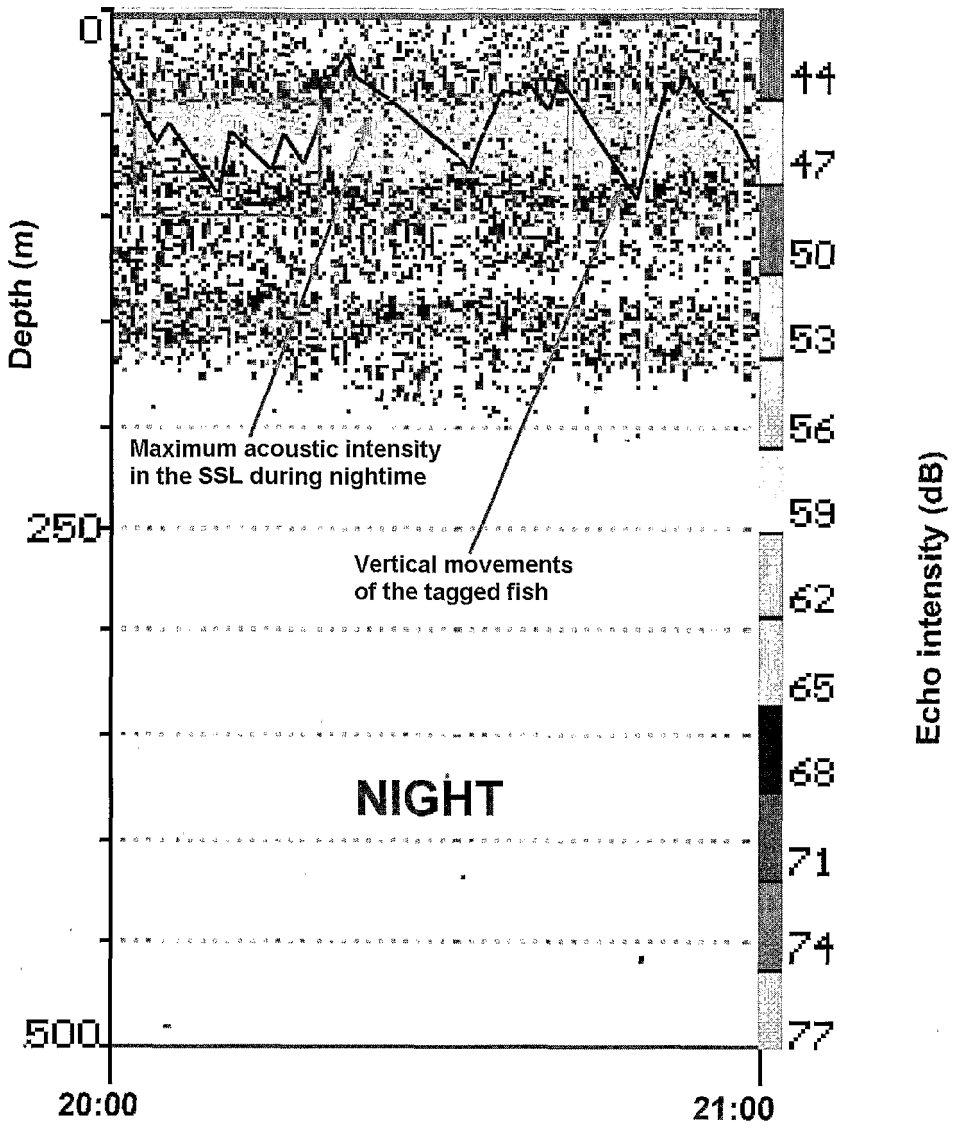

Figure 6. Experiment 2 (20/01/96). Vertical movements of the tagged bigeye tuna in relation to the Sound Scattering Layer (SSL) during night-time (time is local time: UT – 10).

Experiment 3

A bigeye tuna *(Thunnus obesus)*, 100 cm fork length, was caught in the open ocean by a longline fishing unit at 01:00, the 18th of December 1996 off Tetiaroa Island (17°00′ S–149°35′ W), an atoll of the Windward Islands of the Society archipelago. This experiment lasted at all 13 h. After tagging and release, the fish principally remained in the upper part of the Sound Scattering Layer between the surface and a depth of 40 m. Some rapid and small-scale changes in depth were observed down to 110 m deep corresponding to the lower limit of the Sound Scattering Layer (Figure 7).

At dawn (about 05:00), the tagged fish left the mixed layer and swam down slowly until a depth of 350 m. The simultaneous mapping of vertical movements and echosounding records observed during the tracking clearly shows that the tagged fish followed the Sound Scattering Layer migration at first light (Figure 7).

The fish stopped its descent at a depth of 350 m (water temperature: 15 °C) while the Sound Scattering Layer continued its migration to a depth of 550 m.

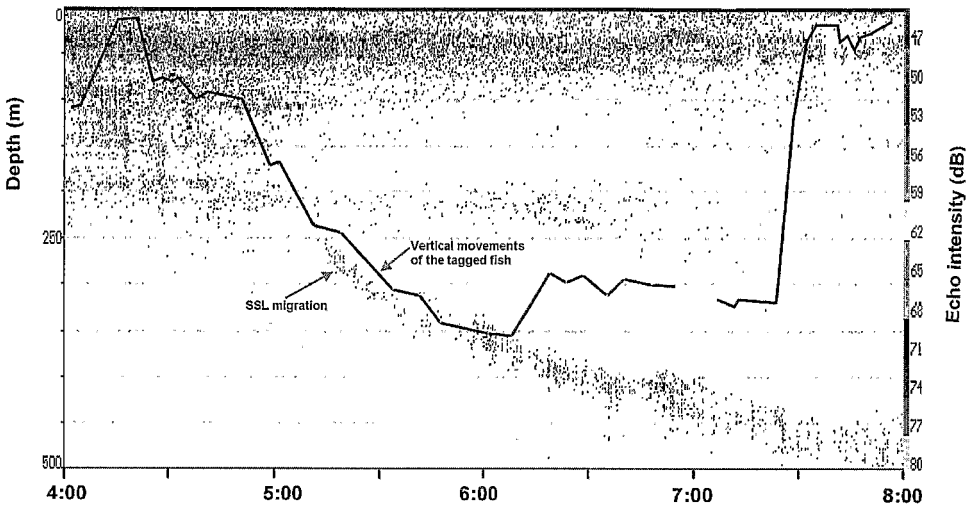

Figure 7. Experiment 3 (18/12/96). Vertical movements of the tagged bigeye tuna, with indication of the Sound Scattering Layer, off Tetiaroa Island (time is local time: UT – 10).

Discussion

It is generally accepted that three-dimensional tuna movements are controlled by abiotic factors which determine habitat limits. Various studies have attempted to delineate the habitat requirements of tuna species, first by studying relationships between catch statistics and oceanographic conditions averaged over time and space (see Sund et al., 1981 for a review), more recently by developing researches on the physiological abilities and tolerances of tunas (see Brill, 1994, for a review).

Only one part of tuna movements observed during our experiments could be explained by limiting abiotic factors. For example during the experiment 2, the presence of a well-defined oxycline at 200 m deep (1 ml l^{-1} O_2) seems to represent an impassable boundary, both for the tagged yellowfin tuna and for the tuna school associated with the anchored instrumented oceanographic buoy. In order to explain another part of tuna movements we observed, the presence of Fish Aggregating Devices must be considered (experiments 1 and 2). However, the structure of the abiotic environment and the presence of Fish Aggregating Devices do not allow to explain all of the observed vertical and horizontal movements of tunas. If we consider experiments 1 and 3, both conducted in the Society archipelago, abiotic factors do not allow to explain the limitation of tuna vertical movements. Oxygen concentrations are between 3 and 4 ml l^{-1} from the surface to a depth of 500 m, whereas temperature (15 °C at 350 m depth) does not either represent a limitation according to the published literature.

Using simultaneous sonic tracking and acoustic surveys, it appears that tuna exhibited movements in relation to vertical and horizontal distributions of prey. Carey (1990) reported similar experiments conducted in the 80's on swordfish (*Xiphias gladius*) where a fish exhibited the same descent made by the bigeye tuna (experiment 3) at dawn with the migration of the scattering layer. Other studies used these two techniques together but not for the same topic (Cayré, 1991; Malinin et al., 1992).

Despite some evidences of the role of the biotic environment on tuna movements, some questions need further detailed observations. In experiment 1 as well as in experiment 3, why did tunas leave the scattering layers? Is it due to a behavioural feature (satiety, patch residence time, social behaviour)? Our experiments do not give us the answer. On the other hand, if tunas visit scattering layers during night-time, are they, for all that, able to eat on them, and with what efficiency? Finally, what are the relationships between scattering layers and tuna diet? This last question is, at the present time, investigated within the framework of the ECOTAP program, using comparative studies between stomach contents of longline tunas and the species composition of scattering layers sampled by means of pelagic trawling.

Conclusion and perspectives

Simultaneous observations of tuna movements and the biotic environment show the important role of prey on tuna movements. At small temporal and spatial scales, and within habitat limits determined by abiotic factors, the three-dimensional structure of the biotic environment and its dynamic (prey density, patchiness, daily migrations, ...) appear to be the key factors in the understanding of tuna movements.

A foraging behaviour hypothesis can be suggested. But the simultaneous technique presented here must be improved by using behavioural activities sensors (existing or to be developed). By this way, it would also be possible to elucidate different foraging phases (search, attack, capture) at small temporal and spatial scales.

A behavioural model could be developed to use such small-scale results to predict large-scale movements of tuna. Then, records from archival tags equipped with behavioural activity sensors could be used in order to validate such a model.

Such results on tuna foraging behaviour would represent an interesting step to improve our knowledge on tuna catchability, and more particularly for longline fisheries studied as part of the ECOTAP program in French Polynesia.

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