Association of yellowfin tuna (*Thunnus albacares*) with tracking vessels during ultrasonic telemetry experiments

Laurent Dagorn
Institut de Recherche pour le Développement (IRD)
BP 5045
34032 Montpellier
Cedex 1, France
E-mail address: dagorn@ird.fr

Erwan Josse
Institut de Recherche pour le Développement (IRD)
BP 70
29280 Plouzané, France

Pascal Bach
Institut de Recherche pour le Développement (IRD)
BP 5045
34032 Montpellier
Cedex 1, France

Abstract—Three yellowfin tuna (*Thunnus albacares*) carrying ultrasonic depth-sensitive transmitters developed a strong association with the tracking vessel, following it at speeds up to 5 knots (2.6 m/s). Two fish associated with the tracking vessel during daytime, and the other fish during day and night periods. Swimming behavior appeared to depend on the speed of the vessel. The tuna remained within a few meters of the surface when the vessel was traveling at high speeds but moved deeper when the vessel drifted. The behavior of these fish is compared to those of other yellowfin tuna tracked in other situations (associated with fish-aggregating devices or unassociated with devices). The reasons for these associations are not known but some hypotheses are advanced.

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Tunas associate with floating objects, such as logs, anchored man-made fish-aggregating-devices (FADs) (see Fréon and Misund, 1999, for a review), and fishing boats (Fonteneau and Diouf, 1994). Numerous ultrasonic telemetry experiments have been conducted (Cayré and Chabanne, 1986; Holland et al., 1990; Cayré, 1991; Cayré and Marsac, 1993; Marsac et al., 1996; Bach et al., 1998; Josse et al., 1998; Marsac and Cayré, 1998; Brill et al., 1999) to determine the behaviors of tunas associated with anchored FADs, but no published studies have examined fish associated with drifting objects. Moreover, during ultrasonic telemetry experiments, the assumption is that neither the transmitter nor the tracking operation alters the behavior of the fish. Some yellowfin tuna, however, have developed associations with the tracking vessel—a rare behavior previously observed on two occasions (Cayré et al., 1996; Brill et al., 1999). In other words, in these situations, the vessel is not following the fish but the fish is following the vessel.

In our study, we examined the movements of three yellowfin tuna, which clearly followed the tracking vessel during ultrasonic telemetry experiments. Our objective was to characterize these associations and to compare them with other types of association behavior. We discuss these observations in relation to some hypotheses on the nature of tuna associations with floating objects and propose ideas for future studies.

Materials and methods

Fish movements were monitored with acoustic telemetry techniques from the research vessel RV *Alis*. Tracking operations were conducted between October 1995 and April 1996 in French Polynesia. The depth-sensitive acoustic transmitters carried by the fish and the ultrasonic receiving equipment were built by VEMCO (Shad Bay, Nova Scotia, Canada), and are described in detail in Dagorn et al. (2000).

Fish were caught on vertical longline gear and transmitters were attached externally with either nylon tie-wraps (as described by Holland et al., 1990) or a stainless steel dart (as described by Brill et al., 1993).

During tracking operations, simultaneous acoustic data were collected be-

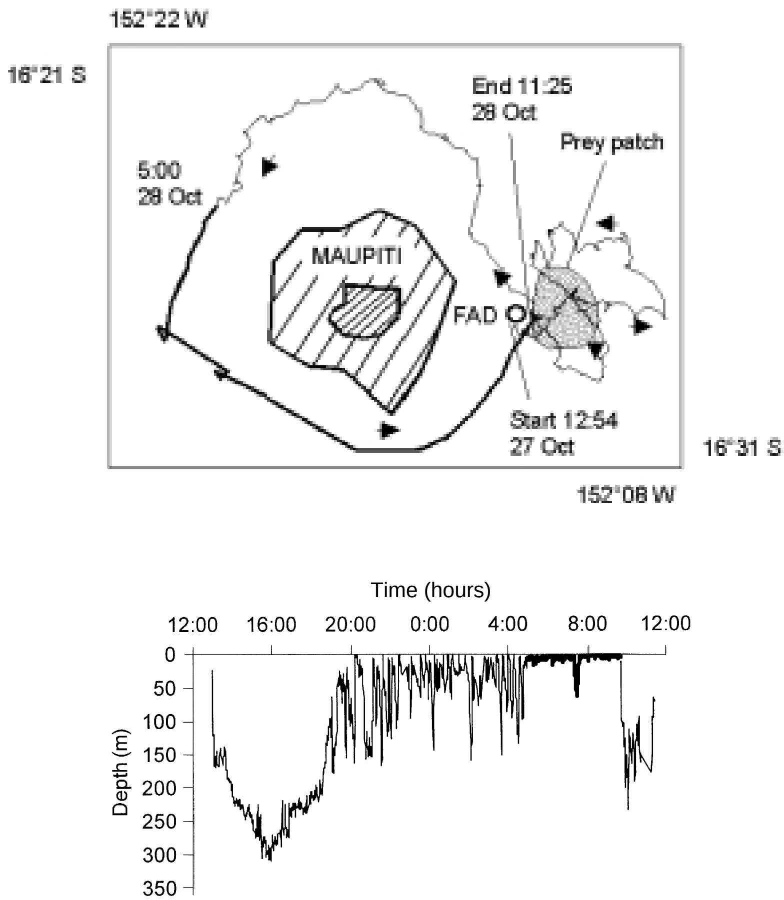

Figure 1

Horizontal (upper graph) and vertical (lower graph) movements of yellowfin tuna 1, 60 cm FL. Tracking lasted 22 h (October 1995). The period of association between the fish and the tracking vessel is shown by the bold line. Arrows indicate the direction of horizontal movement in the upper graph. The light gray patch represents a prey patch observed by the echo sounder.

tween 10 and 500 m depth with a SIMRAD (SIMRAD, Horten, Norway) EK500 scientific sounder connected to a hull-mounted SIMRAD ES38B split-beam transducer (frequency 38 kHz, beam angle 6.9°). Acoustic data, along with vessel position, were simultaneously logged on a personal computer running SIMRAD EP 500 software (Simrad, 1994). Vessel speeds were estimated from straight-line calculations by using positions of the tracking vessel based on data from the Global Positioning System for the first two fish. Speeds were taken directly from the knot meter of the vessel for fish 3, which provided a greater volume of data on real-time movements of the tracking vessel.

When the crew suspected the fish had become associated with the tracking vessel, experiments were developed to test the association (complete turns, changes in vessel speed and direction, etc.). Fish that clearly followed the vessel during such tests were considered to be associated.

Results

Of the fourteen yellowfin tuna that were tagged and tracked in French Polynesia from 1985 to 1997, three individuals clearly exhibited strong and lengthy associations with the research vessel.

Tuna 1 (60 cm FL) was caught at a depth of 120 m at midday close to a FAD anchored near Maupiti Island, located within the Leeward Islands of the Society Archipelago. The fish was tracked for 22 h as indicated in Figure 1. This fish associated with the FAD immediately after release but shifted to a free-swimming (unassociated) phase directed offshore (eastward movement) until 17:14 h, crossing for the first time a patch of mid-water prey observed on the echo-sounder. After crossing the patch for the second time (beginning of the night), the tuna returned to the FAD but did not re-associate; rather it began a cir-

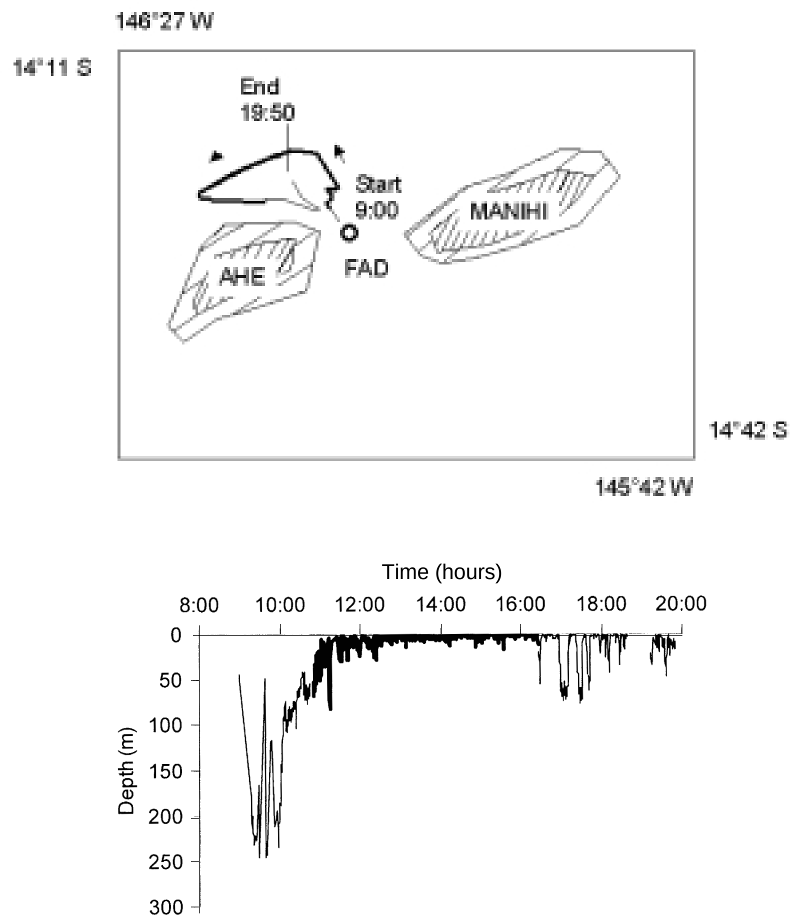

Figure 2

Horizontal and vertical movements of yellowfin tuna 2, 100 cm FL. Tracking lasted 11 h (December 1995). The period of association between the fish and the tracking vessel is shown by the bold line. Arrows indicate the direction of horizontal movement in the upper graph.

cular movement around the island. The fish became associated with the tracking vessel after traveling half-way around the island. The association occurred simultaneously with a change in its vertical movement pattern, shifting from a movement pattern between the surface and 150 m to a surface oriented behavior that kept the fish within a few meters of the surface (Fig. 1). As the boat continued to move around the island, the fish maintained the association and swam within 10 m of the surface, except for an excursion to 50 m around 07:30. However, this dive occurred simultaneously with a XBT (expendable bathythemograph) launch and the fish may have followed the instrument as it went down, a behavior also observed by Block et al. (1997). When the tracking vessel reached the FAD where the fish had been caught the day before, the fish broke its association with the ship and dove, likely to join a small tuna school observed on the echo-sounder under the FAD at around 150 m depth.

Yellowfin tuna 2 (100 cm FL) was captured at 9:00 while it was associated with a FAD off Ahe Island (Tuamotu Archipelago) and after being followed for 11 h. Immediately after its release, the fish returned to the depth at which it was caught (between 200 and 250 m) and left the FAD heading northwest (Fig. 2). Before 11:00, the fish rose to the surface and became associated with the boat; the main engine was then shut down and the vessel drifted. Around 11:15, the boat began to move and the fish followed. The fish remained strongly associated with the moving vessel, swimming within the first 10 m below the surface until 16:25, when it began to break off the association, making some rapid dives to 70 m. Contact was lost at 18:38, after a sudden departure of the fish during a heavy rain squall. The fish was briefly relocated at 19:14.

Yellowfin tuna 3 (108 cm FL) was caught at 07:38, close to a FAD located off the island of Tahiti (Fig. 3). After release, the yellowfin tuna returned to the depth where

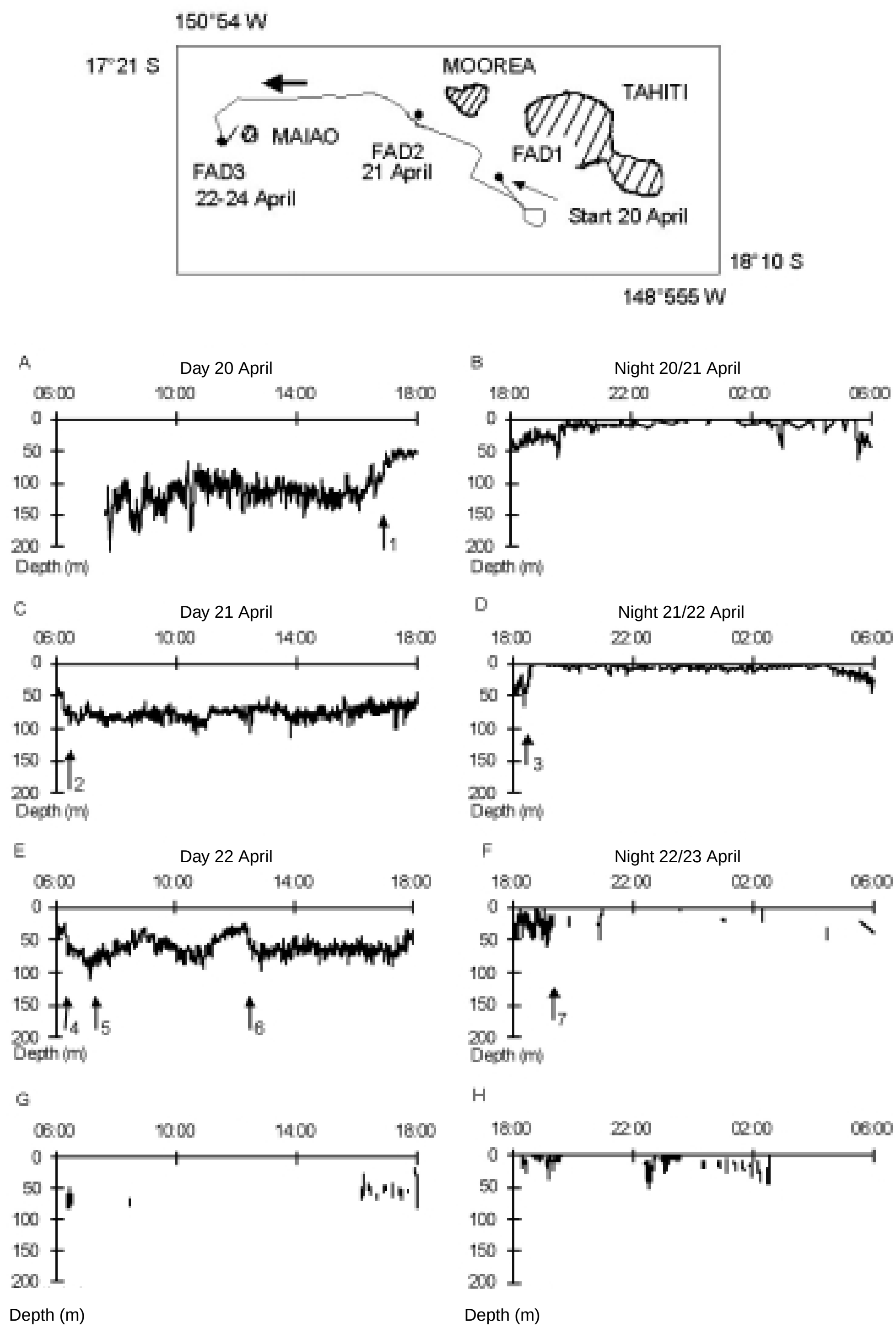

Figure 3

Horizontal and vertical movements of yellowfin tuna 3, 108 cm FL. Tracking lasted 91 h (April 1996). This fish was always associated with the tracking vessel. Arrows indicate the direction of horizontal movement in the upper graph. Changes in the movements of the tracking vessel are represented by vertical arrows on the graphs representing the vertical movements of the fish. 1 = the vessel left FAD1 to move to FAD2 during the night; 2 = the vessel arrived at FAD2; 3 = the vessel left FAD2 to go to FAD3; 4 = the vessel arrived at FAD3. 5 = the vessel left the FAD to go close to the Maiao island; 6 = the vessel came back to FAD3 and start drifting; 7 = the vessel moved away from FAD to conduct trawl and acoustic survey operations.

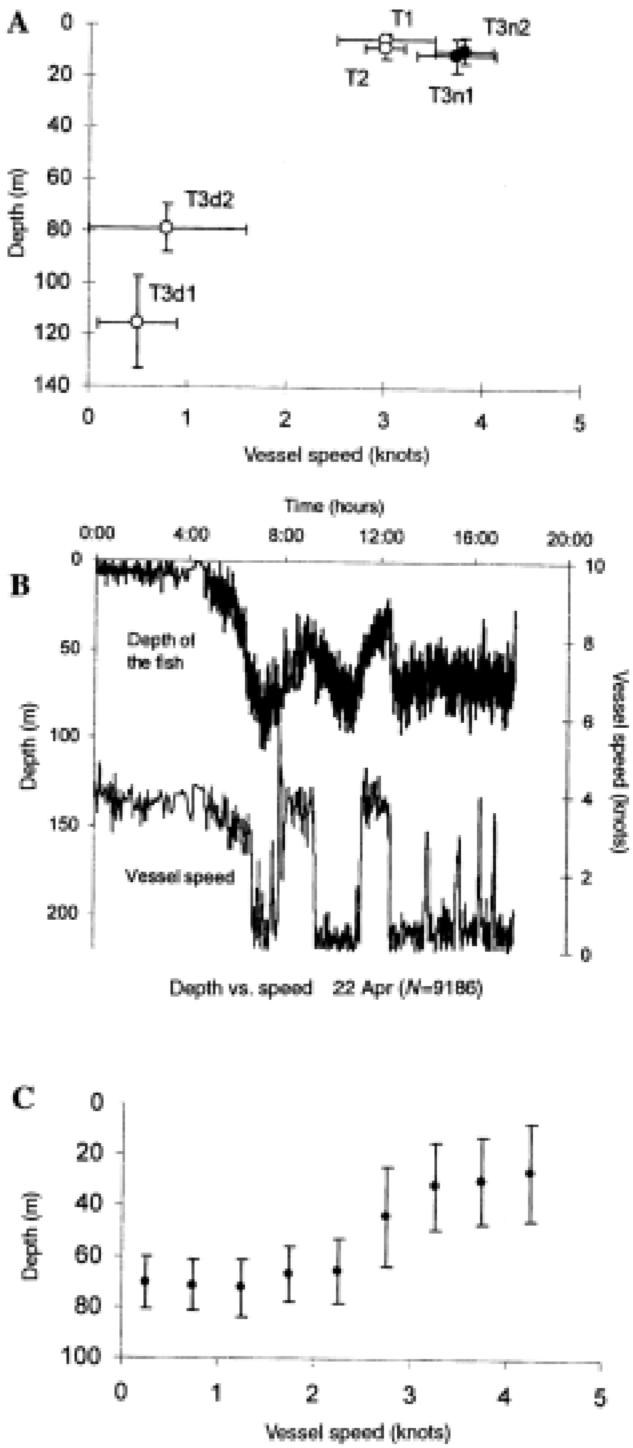

Figure 4

Relationships between swimming depths of the fish and the speed of the tracking vessel during associations. (**A**) Mean values (±SD) corresponding to each association: T1, T2, T3 for tunas 1, 2, 3; d1, d2, representing day times (white dots) and n1, n2 representing night times (black dots) of the first two 24-h cycles of the track of tuna 3. The two other graphs represent details of the association between tuna 3 and the tracking vessel during the third day (22 April 1996) where many changes in the vessel speeds occurred: (**B**) vertical movements and vessel speeds in relation to time; and (**C**) depth versus vessel speed (mean value ±SD).

it was captured (approximately 150 m) and immediately became associated with the tracking vessel. It remained at a depth between 80 m and 150 m while the vessel drifted close to the FAD. When the ship left the FAD (FAD1) at 16:20 to go to an other FAD (FAD2 South of Moorea Island), the fish moved closer to the surface and followed in a similar manner to that exhibited by yellowfin tuna 1 and 2. It remained within a school of other yellowfin tuna (individual size ranging from 20 to 50 kg) that could be seen from the ship, swimming just below the surface. During the second day (21 April), the fish remained associated with the ship as it drifted close to FAD2. Mean swimming depth was 75 m. During the second night (21–22 April), the vessel moved from FAD2 to FAD3, southwest of Maiao Island, and the fish followed, swimming close to the surface as during the first night. When the vessel and the fish arrived at FAD3 in the morning of 22 April, the fish left the surface and came under the ship. Around 07:45, the vessel left the FAD to shelter close to Maiao Island to find better sea conditions, with the tagged yellowfin tuna and the school following closely. The fish remained associated when the vessel returned to the FAD at 12:30. In the afternoon, the vessel drifted close to the FAD until 19:00, after which it made rapid accelerations away from the FAD to break off the association. The strategy was successful, and the fish remained associated with the FAD. During the fourth day (23 April), trawl and acoustic survey operations were conducted away from the FAD. The fish did not associate with the vessel during this period, but its presence at the FAD was regularly observed. Attempts to reassociate the fish with the tracking vessel were not successful because the fish returned to the FAD when the ship moved 0.5 nmi from the FAD. The fish remained associated with the FAD until operations terminated.

Figure 4 shows the relationships between swimming depths and the speed of the vessel during all observed associations. Shallower swimming depths were observed when the vessel was moving at higher speeds, both during daytime (tuna 1 and 2) and nighttime (tuna 3) associations. Figure 4 also shows in detail the response of tuna 3 to rapid changes in vessel speed during the third day (22 April), when the vessel was moving between FAD3 and the Maiao Island, or drifting close to the FAD or to the island. This day represents an example of frequent changes in vessel speed and corresponding changes in swimming depths of the fish.

Discussion

Individual yellowfin tuna have been documented associating with tracking vessels in the Indian Ocean (a 108-cm yellowfin tuna, Cayré et al., 1996) and near the main Hawaiian Islands (a 167-cm yellowfin tuna, Brill et al., 1999). However, these authors merely noted the occurrence of the associations without providing further analyses or comments on this striking behavior. It is noteworthy that all these fish were yellowfin tuna. It seems, however, that this behavior is not size dependent (sizes ranged from 60 to 167 cm FL) nor is it related to the size of the tracking vessel: 12-m vessel for Cayré et al. (1996), 20-m and 53-m vessels for Brill et al. (1999), and 28-m vessel in our study.

Horizontal movements

The horizontal movements of fish associated with tracking vessels duplicated the horizontal movements of the tracking vessel. Therefore, the observed paths are not comparable with horizontal movements of tagged fish that were not associated with tracking vessels. Our results, however, give information on the duration of associations and possible "competition" between FADs and tracking vessel to attract the tagged fish.

Considering the different patterns of movements of tunas observed at anchored FADs, Holland (1996) proposed three horizontal patterns: 1) fish that leave the FAD and show no tendency to return to it over the duration of the track; 2) fish that spend the entire duration of the track (day and night) within a few hundred meters of the FAD, and 3) fish that spend daylight hours at the FAD site, leave at night and return to the same or an adjacent FAD the next day. Fish 1 and 2, as well as the 167-cm yellowfin tuna tracked by Brill et al. (1999) near the main Hawaiian Islands, associated with the tracking vessel during daytime, which corresponds to the third class defined by Holland (1996). Conversely, Cayré et al. (1996) reported a nighttime association between a 108-cm yellowfin tuna and the tracking vessel. Moreover, fish 3 remained associated with the tracking vessel for more than two 24 h (continuous day and night cycles) which corresponds to the second pattern defined by Holland (1996). Although our sample size was small, the three fish of our study, and the two other yellowfin tuna that exhibited such association (Cayré et al., 1996; Brill et al., 1999), exhibited different lengths of associations, at different periods of the diurnal cycle, all of which also correspond to the variety of patterns observed for fish associated with anchored FADs. These features, however, cannot be used to determine if tuna treat drifting and anchored floating objects differently, as first proposed by Holland et al. (1990).

The possible competition between FADs and the tracking vessel to aggregate tuna is an interesting feature of our results. The three tuna were caught close to and were considered associated with a FAD. Yellowfin tuna 1 and 2 left their FADs after release and did not associate immediately with the tracking vessel, whereas yellowfin tuna 3 associated with the tracking vessel after release. In the last part of their track, yellowfin tuna 1 and 3 clearly abandoned the vessel to associate with FADs. The presence of yellowfin tuna 2 was also noticed close to the FAD a few hours after the end of the tracking. Attempts to reaggregate yellowfin tuna 3 while associated with the third visited FAD were not successful. However, it is noteworthy that this tuna chose to associate with the tracking vessel rather than to FADs 1 or 2 on the previous days, showing a different motivation than those exhibited toward FAD3. Cayré et al. (1996) attempted to abandon the associated 108-cm yellowfin tuna by rapid vessel accelerations, trying to make the fish associate with a FAD, but without success. We cannot determine the reason for a possible preference of fish toward vessels or FADs. We can only propose that tuna regard the vessel and FADs in a similar manner, or that the choice in aggregating between these two structures depend on factors (external or internal stimuli) that we could not record during our experiments.

Vertical movements

It is known that the swimming depth of yellowfin tuna is controlled by the diurnal cycle: surface swimming at night and deep swimming at daytime (Carey and Olson, 1982; Cayré and Chabanne, 1986; Holland et al., 1990; Cayré, 1991). However, besides this diurnal behavior, it seems that fish travel closer to the surface when associated with a moving vessel: yellowfin tuna 1 and 2 swam very close to the surface (mean swimming depth=5.3 m ±2.9 for tuna 1 and 8.4 m ±4.5 for tuna 2) when they were associated with the moving vessel during daytime. Yellowfin tuna 3 also exhibited very shallow swimming depths when associated with the tracking vessel, but during nighttime (mean swimming depth=11.3 ±6.6 and 9.3 ±4.8 for the first two nights). Cayré et al. (1996) and Brill et al. (1999) did not report any relationship between the swimming depth of the fish and the speed of the tracking vessel. Figure 4 indicates definite relationships between fish swimming depths and the speed of the vessel during the associations. However, while this vertical reaction of the associated fish to the different vessel speeds have been observed during daytime, we should mention that no observations were made to examine the response of the fish to low vessel speeds during nighttime, which should have been deeper than the depths exhibited by yellowfin tuna 3 during the first two nights. This association behavior is similar to that observed by Holland et al. (1990), in that fish tend to be closer to the surface when associated with FADs. We propose that floating objects generally induce the fish to swim closer to the surface and that this tendency increases when floating objects are moving fast.

In addition to the shallower swimming of yellowfin tuna when associated with moving vessels, the amplitude of vertical oscillations are drastically reduced. We suggest that when fish are associated with a vessel, they reduce the amplitudes of their vertical oscillations, and that the mean swimming depth is partly controlled by the speed of the vessel (i.e. the distance from the fish to the tracking vessel decreases when the vessel speed increases). The reasons for this change are not known. More data are clearly needed to examine the exact effects of a floating object (including its speed) on the vertical pattern of associated fish and to distinguish these effects from those due to the diurnal cycle, thermoregulation, or foraging behavior.

Hypotheses to explain why tunas associate or disassociate with tracking vessels

The reasons why pelagic fish associate with floating objects are still not known conclusively (Fréon and Misund, 1999).

Tagging operations certainly represent a stress for the fish, especially when performed after a traumatic capture and removal from the water to attach the tag. If we assume that a fish considers this particularly large floating object (the tracking vessel) to be a shelter against the stress or possible injury caused by tagging procedures, the association with the vessel could then be interpreted as an antipredator behavior (shelter from predator hypothesis, Suyehiro, 1952, cited in Fréon and Misund, 1999). In fact, Block et al. (1992) and Brill et al. (1993) did observe badly injured fish swimming within a few meters of the surface (one Indo-Pacific blue marlin and one striped marlin, respectively), which corresponds to the swimming pattern exhibited by our fish when following the moving tracking vessel. If an injury or significant stress occurred during the capture or tagging operations, one could expect to see post-tagging antipredator behavior. The time delay between release and the onset of association behavior differs from one fish to another and ranges up to 16 hours after release (tuna 1), which argues against a stress-related association caused by the tagging operation. Moreover, observations of a school of yellowfin tuna exhibiting the same association as yellowfin tuna 3 prove that nontagged and apparently noninjured and nonstressed tuna develop the same association. Our observations thus do not support the "shelter from predator" hypothesis as an explanation for the attraction of tuna to the tracking vessel.

The role of social behavior to explain the association of fish with floating objects has been expressed in the "meeting point" hypothesis (Dagorn, 1994; Dagorn and Fréon, 1999; Fréon and Misund, 1999). This hypothesis proposes the enhancement of fish aggregation by floating objects through improving the encounter rate between small schools or between isolated individuals, or both. According to this hypothesis, tuna associate with various floating objects (drifting logs, anchored FADs, boats) to increase their chances of encountering conspecifics. Yellowfin tuna 1 and 2 seemed to be isolated during the tracking, whereas yellowfin tuna 3 was a member of a school. Yellowfin tuna 1 broke its association with the tracking vessel, joining individuals (observed by the echo-sounder) located under a FAD. It is not possible to know if the fish left the tracking vessel because of the FAD or because of the conspecifics. This observation, however, appears to support the "meeting point" hypothesis: this tuna and those of the aggregation benefited from their respective associations to find more conspecifics. Yellowfin tuna 3 was visually observed to be with a school during nights when the school swam close to the boat, and acoustically observed when it was associated with FAD3. The school was estimated to be composed of 80 individuals while associated with FAD3. Our observations were not precise enough to determine if new individuals joined the school during the 4-day experiment, nor if the school broke its association with the boat to join a group already aggregated to FAD3, in a manner similar to that shown by yellowfin tuna 1. However, we believe that the present observations do not reject the meeting point hypothesis.

Yellowfin tuna 1 and 3 left the tracking vessel to stay close to anchored FADs. It is difficult to know, however, if they broke the vessel association to associate with FADs or to join conspecifics located close to the FADs, or both. Contact with yellowfin tuna 2 was lost owing to a heavy rain. We do not know if the fish voluntarily broke off the association with the vessel or if it simply lost contact with the vessel. For instance, if the fish used the sound of the vessel to stay close, it is possible that the sound of the vessel was masked by the rain.

Because it is very important to know why tuna associate with floating objects (or vessels in the present case), it is also essential to understand why tuna leave floating objects. Although the sample size of our study was very small, it seems that the presence of other floating objects, conspecifics, or bad sea conditions can be responsible. Understanding the reasons why tuna form and break off aggregations is of major importance when studying the consequences of aggregation on tuna movements and distribution (Dagorn and Fréon, 1999).

Future studies

The objective of a sonic tagging experiment is to observe movements of a fish in its natural environment. The variety of experiments conducted throughout all the tropical oceans (Cayré and Chabanne, 1986; Holland et al., 1990; Cayré, 1991; Cayré and Marsac, 1993; Marsac et al. 1996; Bach et al., 1998; Josse et al., 1998; Marsac and Cayré, 1998; Brill et al., 1999; Dagorn et al., 2000) have contributed to a considerable increase in knowledge on the behavioral ecology of tropical tunas. Nevertheless, when a fish associates with a tracking vessel, although a very rare event, this objective has been violated. Among the tracking experiments on 14 yellowfin tuna in French Polynesia, the distinction between vessel-associated and unassociated individuals was very obvious. Moreover, this striking behavior has never been observed on other tuna species during tracking experiments (i.e. bigeye tuna, *Thunnus obesus*, and skipjack tuna, *Katsuwonus pelamis*). We consider that there is no possible doubt on the nature of the movements exhibited by a tagged individual (free movements or patterns associated with the vessel), which insures the validity of the interpretations of sonic tagging results. However, these rare events can be used to study the associations of fish with floating objects in a general sense. Rather than interrupting the tracking operation, we propose to develop particular experiments to improve our knowledge on tuna behavior. During the associations with vessels described in this paper, fish sometimes followed the vessel at speeds of up to 5 knots (2.6 m/s). It could be useful to use this behavior to study *in situ* the relationship between endurance time and velocity. Moreover, it is important to collect data on the duration of associations. Observations of the biological environment of the associated fish would also be very useful to test the validity of certain concepts, such as the "meeting point" hypothesis. During our experiments, we observed the biological environment (i.e. both prey and conspecifics) using an echo-sounder. The sounder assisted us to observe patches of prey (for yellowfin tuna 1) and the tuna aggregation joined by yellowfin tuna 1, and also helped to determine the size of the school that yellowfin tuna 3 was drawn away from. However, the use of a multibeam sonar that can observe the few meters below the surface could provide complementary information, especially for such close observations. Similar sonar units have been successfully used to observe the structure and the behavior of small pelagic fish schools (Gerlotto et al., 1999) and would be particularly appropriate for the observation of both tuna schools and prey in the vicinity of a tracking vessel. A long-range multibeam omnidirectional sonar could also provide useful information on the horizontal distribution and spatial dynamics of tuna schools around the vessel.

Rather than disregarding tuna aggregations around tracking vessels, we propose to continue collecting information on such events. The tracking vessel represents a useful and fully instrumented, mobile floating object adapted to conduct detailed ethological observations to improve our knowledge of the behavior of tuna aggregated around floating objects.

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