SYMP/1981/004

Col.Vol.Sci.Pap. ICCAT, 17 (2): 458-466 (1982)

SONIC TRACKING EXPERIMENTS WITH TUNAS

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SUMMARY

This report describes some acoustic telemetry experiments conducted with yellowfin tuna in the eastern tropical Pacific during April and May 1981. Depth transmitters were used to obtain three-dimensional records of the movements of the fish. Tuna that seemed to be members of a school made frequent vertical movements in the mixed layer between the surface and the thermocline. Those that we assumed to be alone spent more time in the thermocline. These results with yellowfin are compared with some previously unpublished telemetry experiments with giant bluefin tuna in the Atlantic off Nova Scotia, Canada.

RESUME

Le présent rapport fait état d'expériences de télémétrie acoustique menées sur l'albacore dans le Pacifique tropical oriental en avril et mai 1981. Des émetteurs de profondeur ont été utilisés pour illustrer en trois dimensions les déplacements du poisson. Des thonidés qui faisaient apparemment partie d'un même banc se déplaçaient fréquemment dans la couche mixte entre la surface et la thermocline. Ceux que l'on supposait isolés passaient plus de temps au niveau de la thermocline. Les résultats ainsi obtenus pour l'albacore sont comparés à des données inédites d'expérience de télémétrie portant sur le thon rouge géant dans l'Atlantique au large de la Nouvelle-Ecosse (Canada).

RESUMEN

Se describen algunos experimentos de telemetría sónica efectuados con rabiles durante los meses de abril y mayo de 1981, en el Pacífico tropical oriental.

Se utilizaron transmisores de profundidad para obtener grabaciones tridimensionales de los movimientos de los peces. Los túnidos que parecían pertenecer a un cardúmen realizaron frecuentes desplazamientos en vertical en la zona intermedia comprendida entre la superficie y la termoclina. Aquellos animales que se supuso no pertenecían a ningún cardúmen, permanecieron más tiempo en la termoclina. Se comparan los resultados obtenidos con los conseguidos mediante experimentos telemétricos (sin publicar) llevados a cabo anteriormente con atún rojo gigante, en el Atlántico frente a Nova Scotia, Canadá.

MATERIALS AND METHODS

Transmitters were constructed by Fred Voegeli, VEMCO, Shad Bay, Halifax County, Nova Scotia. The output power was nominally 62 dB at a frequency of 32.7 kHz. A "Biotek" strain gauge pressure transducer caused the 30 msec long pulses to come at a rate which varied from 1 per sec to 3 per sec over a 343 m or 686 m range. Transmitter life was approximately 4 days at a pulse rate of 2 per sec. The transducers were 10.2 cm long x 3.7 cm dia and weighed 145 g in air and 63 g in water. They had a nylon loop at one end for attachment and a reed switch which allowed the device to be turned on at the last minute by removing a magnet.

We tried two methods of attaching the transmitter to the fish. In the first the transmitter was shoved into the stomach using a detachable handle. Inspection showed that the transmitter occupied somewhat more than one-half the volume of an empty stomach for a 90 cm yellowfin. In the second method the transmitter was attached to the fish by threading a nylon "tie-wrap" through the muscle and pterygiophores at the base of the anal fin. A steel needle was used to push the tie wrap through. Use of the "tie-wrap" was suggested by Dotson and Laurs (NOAA-NMFS, San Diego) and the ventral fin attachment had been used successfully by Ichihara et al. (1972) in experiments with yellowtails (Seriola sp.). The fish were handled rapidly and returned to the water in 1.5 to 2 minutes. Yellowfin No. 4 was dropped on deck.

The receivers were Communications Associates, Inc., CR 40's with appropriate crystals for 32.7 kHz. During part of the experiment with No. 3 the audio output from this receiver was fed into a phase-lock receiver - tachometer and displayed on a strip chart recorder as a graph of depth vs. time. Otherwise data were collected manually by timing an integral number of pulses with a 0.01 sec stopwatch and converting frequency to depth with a pocket calculator using a linear regression for the calibration curve (which was a straight line).

The four-hydrophone array used for listening was constructed of 2.8 cm long, 1.06 cm diameter cylinders of Marine Resources TCD5 material. The axes of these cylinders were arranged along the sides of a square in the horizontal plane. The cylinders were covered with epoxy and mounted on a steel frame with the upper, inner, and lower surfaces acoustically shielded with alternating layers of 3 mm thick neoprene-impregnated cork and steel. The resulting array was one of four hydrophones with a broad vertical pattern looking out in four different directions at an approximately 90° sector in the horizontal plane. A set of four matched preamplifers with a frequency response -3 dB from 30 to 40 kHz was located near the hydrophone array.

The hydrophones were carried on a 0.9 m wing span depressor modeled after the ENDECO "V fin" and constructed of 9 mm galvanized steel. The plan view shape approximated an equilateral triangle with a rounded anterior end. Dihedral angle was -22.5° and a 30 cm high vertical stabilizer was used. The tow point was about one-third back from the anterior end which had a 25 kg lead weight to balance the depressor at this point. Weight of the vehicle was 75 kg in air. The hydrophone array was bolted to the lead weight of the depressor with a 3 mm layer of neoprene impregnated cork interposed to help isolate it from acoustic noise. The device towed well, keeping a steep wire angle and easily following the ship. At 10 knots, with 20 m of wire out, wire angles of 50° from vertical were obtained.

The depressor was towed on an 8 mm armored steel multiconductor cable. The cable was faired with 5 cm long tabs of 2.5 cm wide glass fiber tape spaced about 3 cm apart. This fairing prevented strumming of the cable, reducing noise, wear, and drag. The cable was 120 m long and was run through 22 cm diameter steel blocks from the boom forward to a large capstan on the anchor winch, then to the receiver. The depressor was usually towed with 20 to 70 m of wire out.

We were fortunate in our vessel, the MARY K, a 78 ft, 100 ton bait boat out of San Diego, being both acoustically and electricallly quiet. We were able to get useful ranges while towing at 6 to 8 knots, but maximum range was only obtained with the engine throttled back.

XBTs were dropped to measure water temperature vs. depth. Oxygen partial pressure was determined by lowering an oxygen electrode (Carey and Teal, 1965) on a conducting cable. Navigation was by satellite, Omega, and radar bearings. The position of our ship was used to approximate the position of the fish and effort was made to bring the ship near the fish for each position fix.

RESULTS

Yellowfin No. 2 was an 87 cm tuna caught at 7°52'N, 79°24'W in the Gulf of Panama on 24 April 1981. It was part of a school associated with spotted porpoises, Stenella attenuata. The transmitter was placed in the stomach of the fish and followed from 1339 to 2300 hrs over a distance of 55 km (30 n mi) (Fig. 1A). The transmitter was regurgitated after 9.3 hrs. The tuna move rapidly at first, covering 39 km (21.2 n mi) in 5 hrs, a speed of 7.8 km/hr (4.2 kn) or 2.5 body lengths per sec. It made frequent vertical movements, but stayed in the mixed layer with only three brief excursions through the thermocline (Fig. 2A). Its position was deep in the mixed layer during the first three hours, but it moved nearer the surface after 1700 hrs. There were numerous schools of tuna in the area and fish and birds were seen in the direction of the telemetry signal, indicating that the fish we were following was part of a school. Porpoises were heard during most of the experiment and the tuna appeared to rejoin a school of spotted dolphins (Stenella attenuata) at 1750 hours.

Yellowfin No. 3 was an 89 cm fish caught in the Gulf of Panama near 7°59'N, 79°19'W on 25 April. It was taken from a school that was not associated with dolphins. The transmitter was attached to the base of the anal fin and the fish was followed for 46.1 hrs before we abandoned it. It traveled 159 km (87.2 n mi) giving an average speed of 3.5 km/hr (1.9 kts). The tuna moved south from the release point, into deeper water and had reached 200 fathoms by 0200 hrs on 26 April. It then followed a haphazard course to the southwest for the remainder of the experiment. Although there were occasional flocks of birds and porpoise noises in the vicinity, we saw no sign that No. 3 had rejoined a school during the time that we followed it. This tuna oriented to the thermocline. It made frequent short excursions into the mixed layer, but always returned to a position in or below the steep part of the thermal gradient (Fig. 3). This reference position moved to the top of the thermocline after sunset, then down below the steep part of the thermal gradient again at dawn. No. 3 made several brief dives through the thermocline going to 100 m at 2110 hrs, to 135 m at 2155 hrs and to 168 m at 2255 hrs. Oxygen was not measured during this experiment, but would have been 40 to 60 percent of air saturation in the steep part of the thermocline (Forsbergh, 1969). This tuna spent an impressive amount of time in a region of reduced oxygen concentration. Yellowfin No. 3 seemed sensitive to our vessel and appeared to go deeper when the boat was driven over it.

Yellowfin No. 4 was a 98 cm tuna caught from a mixed school of yellowfin and skipjack near Clipperton, Island (10°17'N, 109°13'W) at 0750 hrs on 12 May. A transmitter was placed in its stomach and it swam away from the island on an irregular course to the southwest (Fig. 1B). It regurgitated the tag at 0225 hrs on 13 May, after having traveled 43.7 km (23.9 n mi) in 18.25 hr for an average speed of 2.4 km/hr (1.3 kts). Dolphins and birds were in the area, but we had no sign that this fish had rejoined a school. No. 4 spent much of the time during the first 6 hours at a relatively constant depth within the thermocline (Fig. 2B). The remainder of the record was characterized by many vertical movements into the mixed layer from the thermocline and by some remarkably deep dives below the thermocline, going as deep as 464 m at 0225 hrs. Water temperature at 400 m was estimated to be less than 9°C and oxygen partial pressure less than 20 percent of surface saturation. This tuna frequently returned to the 20 to 24°C isotherm in the thermocline where oxygen concentration was 50 to 75 percent of air saturation. No. 4 was often in an area with reduced oxygen availability.

Yellowfin No. 5 was a 96 cm tuna caught from a mixed school of large and small yellowfin and skipjack near Clipperton Island (10°18.8'N, 109°14.0'W) at 0815 hrs on 14 May. A transmitter was tied to the base of its anal fin and it was followed for 48 hr in an interrupted fashion. Excessive noise from dolphins (Tursiops truncatus) and danger of running aground on the island in the dark forced us to leave the fish on the nights of 14 and 15 May, but we were able to find it again each morning. When first released, the tuna left the island, swimming 13 km off to the east southeast for 5 hrs. It then turned and retraced its course, arriving back at the island at 1700 hrs. During this excursion it swam 29.6 km (16.2 n mi) in 8.65 hr, for an average speed of 3.4 km/hr (1.9 kts). For the remainder of the experiment it stayed close to the beach on the north side of the island. The depth record for this tuna can be divided into two segments (Fig. 4). During the first portion, it held a relatively constant depth of 80 m. After returning to the island it spent much of the time up in the mixed layer with excursions down to the 80 m depth. XBT data were not available, but by comparison with No. 4, it is clear that yellowfin No. 5 was in the thermocline during the first part of the experiment when it was making its excursion to the southeast and was moving between the thermocline and the surface after it had returned to the island. When near the island its vertical range may have often been limited to less than 80 m by shallow water depth. Fish and birds were seen in the direction of the telemetry signal and when we passed over the fish on the final morning, jig strikes and boils indicated that it was with a school.

DISCUSSION

While we recognize that these experiments contain many uncontrolled factors, it is still possible to propose some explanations of the results. The tuna swim mainly in the region between the surface and the lower side of the thermocline. When they are with a school they spend much of the time moving up and down in the mixed layer. When they are alone, they are primarily oriented to the thermocline, but may make frequent excursions into the mixed layer. Yellowfin No. 2 was with a school and moved in the mixed layer. Nos. 3 and 4 were not seen to be with other fish and oriented to the thermocline. Yellowfin No. 5 is an interesting combination. It did not seem to be with a school during the first part of the experiment when it was away from the island. During this time it remained in the thermocline. When it returned to the island, and presumably rejoined the many fish in the area, it moved up into the mixed layer (Fig. 4).

This behavior is similar to that seen in giant (300 kg) bluefin tuna during some tracking experiments done some 12 years ago (Carey and Lawson, 1973; Carey, unpublished data). During some 12 experiments with tuna caught in traps in St. Margarets Bay, Nova Scotia, all but one of the fish left the bay and headed more or less directly out to open sea (Fig. 5A,B). Except in one case there were no surface signs or other indications that these fish were in a school. They usually oriented to the shallow (10 to 30 m) thermocline. In areas where the thermal structure was complex, with temperature gradients at several different depths, the fish woud sometimes move up and down from temperature step to temperature step (Fig. 6A,B). We have seen a number of other instances of fish orienting to the thermocline (e.g., Carey et al., 1982) and have come to associate this behavior with fish traveling, although we have no proof that the fish are not doing something else. In another experiment done on the continental shelf south of Block Island, MA, the tagged bluefin was part of an actively feeding school. The school was frequently seen on the surface and the tagged fish moved rapidly up and down between the surface and the bottom at 35 m, quite ignoring the thermocline (Fig. 6C).

The present yellowfin experiments are consistent with the idea that feeding fish with a school move in the mixed layer, while fish traveling alone orient to the thermocline. Tuna have a strong instinct to school and it seems probable that their behavior will be different when with a school than when alone. In future experiments with yellowfin or any other tunas, it will be most important to arrange to have an adequate sonar on the tracking vessel to allow a positive determination of when the tagged fish is part of a school.

Laurs et al. (1980) have reported that albacore (*Thunnus alalunga*) swim deeper during the daylight hours than at night and make more vertical movements during the day. Swordfish show a very pronounced version of this daily vertical migration (Carey and Robison, 1981). While there is some suggestion in these present experiments that yellowfin may show a daily depth change, the effect is not at all as clear as in the albacore and swordfish.

Weihs (1973) has suggested that a fish with negative buoyancy might progress in an energy-efficient manner by alternately swimming up and gliding down, rather than by swimming continuously at one level. The principle involved is analogous to that which makes the flutter-up, glide-down flight of passarine birds an efficient mode of progression. A clear example of this type of progression was obtained with the automatic depth recording system for Yellowfin No. 3. The angle of climb, +25° to +30° and the -20° glide (Fig. 7) are in the range that Weihs would predict for a fish swimming in this fashion and the sharp turns up and down are similar to those in his diagrams.

The experiments described here and similar ones with albacore, bluefin, swordfish and various sharks described in the references suggest some general features:

1. These pelagic fish may spend a major portion of the day in the sharp temperature gradient of the thermocline.
2. They tend to occur at greater depths during the day than during the night.

3. They make impressively deep dives: Yellowfin No. 4 in this report to 464 m, a swordfish to 617 m and a mako shark to 500 m.
4. They may spend only a small percentage of the time on the surface, yet abundance estimates based on the catches of surface gear are commonly taken by many fishery scientists as indicating true abundance.
5. They usually progress rather slowly with average speeds of 1 to 4 kts.

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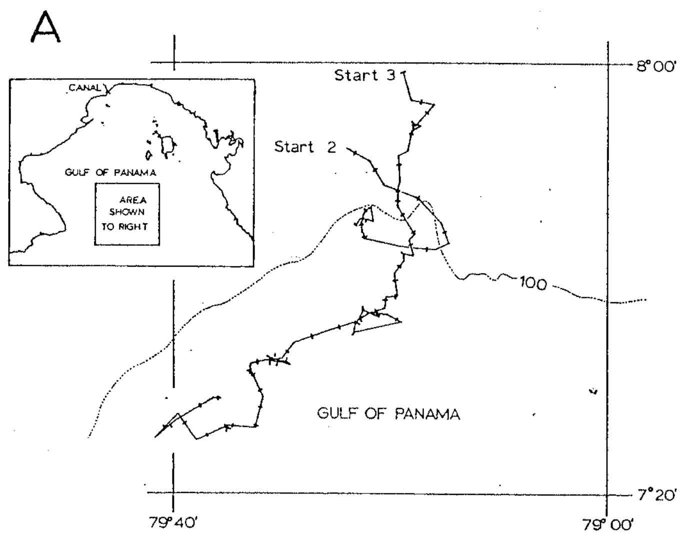


Fig. 1A. Track of Yellowfin No. 2 and No. 3 in the Gulf of Panama. These fish moved rapidly at times, but stopped and milled about at other times. Tics at one hours intervals. 100 fathom curve indicated by dotted line.

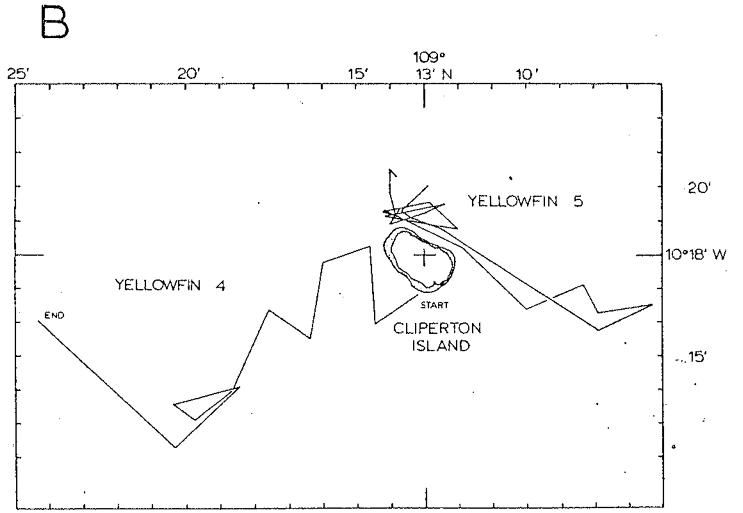


Fig. 1B. Tracks of Yellowfin No. 4 and No. 5 near Clipperton Island. No. 4 was not with a school. No. 5 left the island for an 8 hr period after being tagged, then returned and joined a school of "home guard" fish. No. 5 was actually closer to the north shore of the island than indicated by the course of our vessel. Only a fraction of our cruising back and forth along this coast is shown.

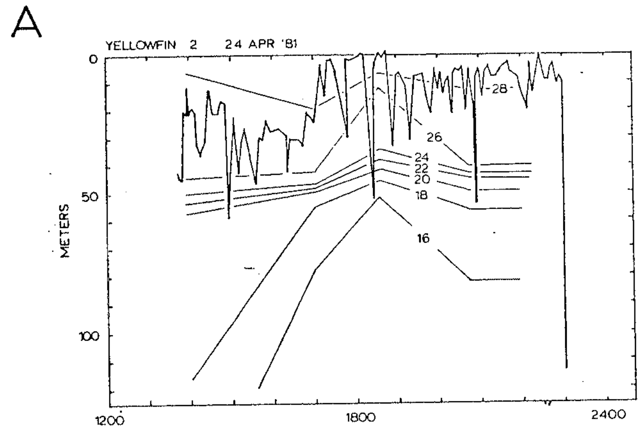


Fig. 2A. Depth record for Yellowfin No. 2 superimposed on an isotherm pattern. This fish stayed with a school of tuna and porpoise. It remained in the mixed layer except for three brief dives through the thermocline. The transmitter was regurgitated at 2300 hrs. Depth in meters. Isotherms at 2°C intervals.

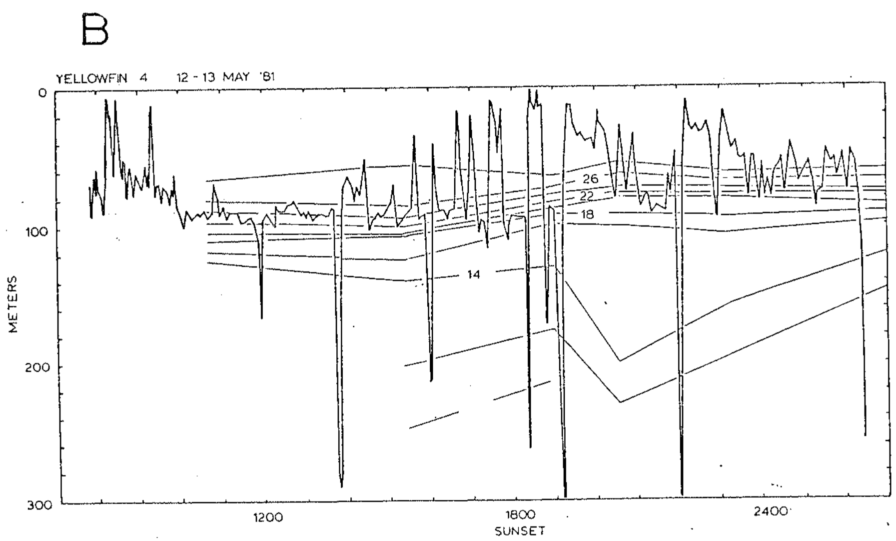


Fig. 2B. Depth record for Yellowfin No. 4. This fish appeared to be alone. It spent much of the time in the thermocline, but made some remarkably deep dives. The transmitter was regurgitated at 0225 hrs.

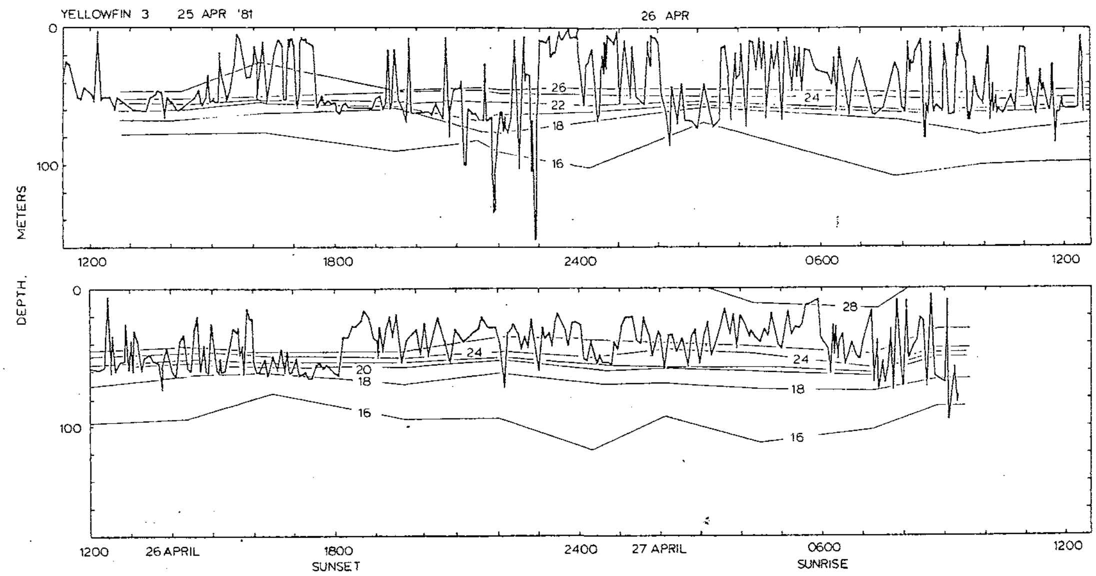


Fig. 3. Depth record for Yellowfin No. 3 superimposed on an isotherm pattern. The transmitter was tied to the base of the anal fin. This fish did not appear to join a school. It spent much time in the steep thermal gradient of the thermocline. Depth in meters, isotherms at 2°C intervals.

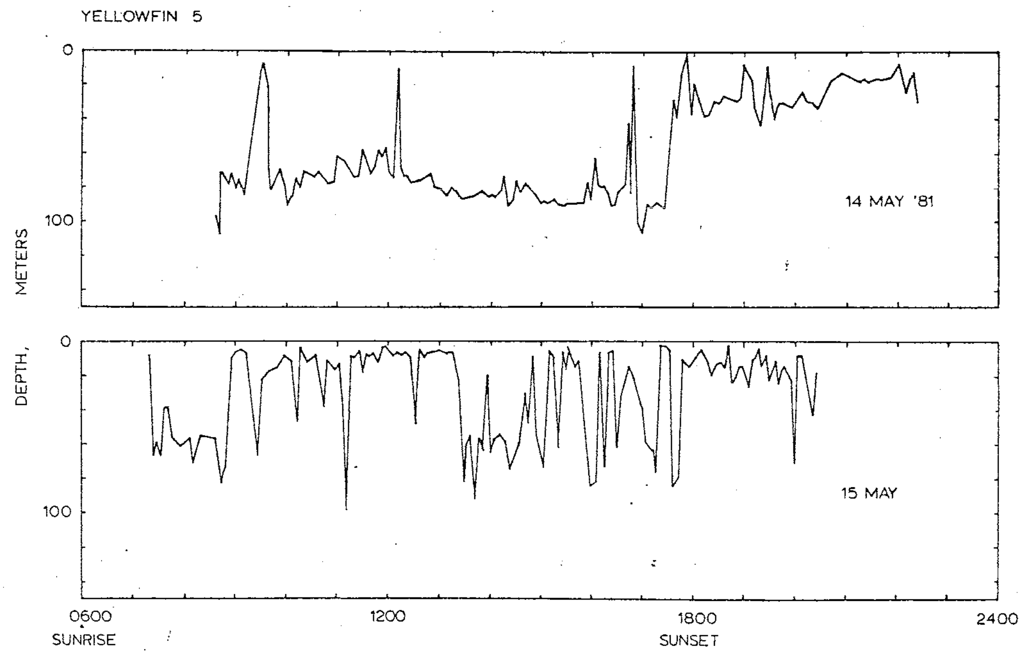
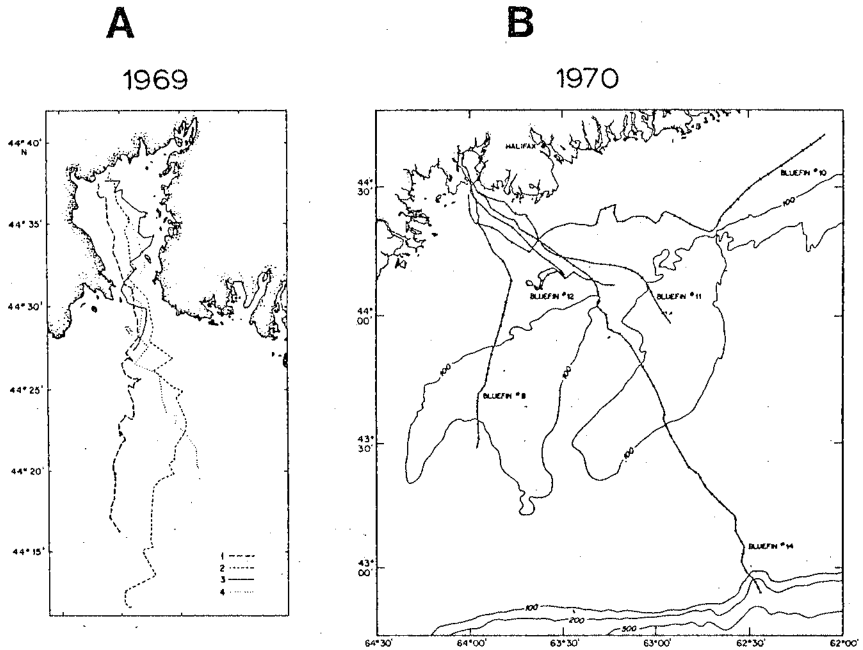


Fig. 4. Depth record for Yellowfin No. 5. The transmitter was tied to the base of the anal fin. When released, this fish swam away from Clipperton Island, then returned at about 1700 hrs. Comparison with temperature data in Figure 2B shows that while swimming away from the island it was in the thermocline, but came up into the mixed layer when it returned. The fish was abandoned at night because of excessive porpoise noise and danger of running aground. When last followed, on the morning of 16 May, it was with a tuna school.



Figs. 5A and B. Tracks of giant bluefin tuna followed out of St. Margarets Bay, Nova Scotia, 1969 and 1970. Most of the fish left the bay and headed out to sea.

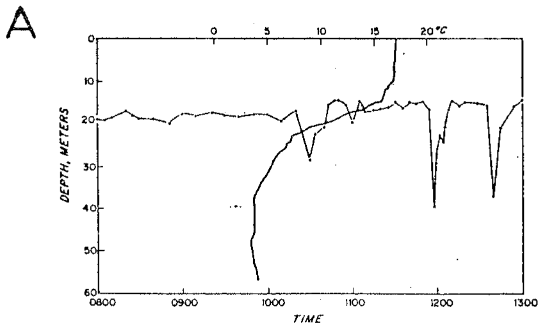


Fig. 6A. Depth record for Bluefin No. 14 with superimposed BT trace. There was one major step in the thermocline and the tuna spent most of the time in the upper part of this thermal gradient.

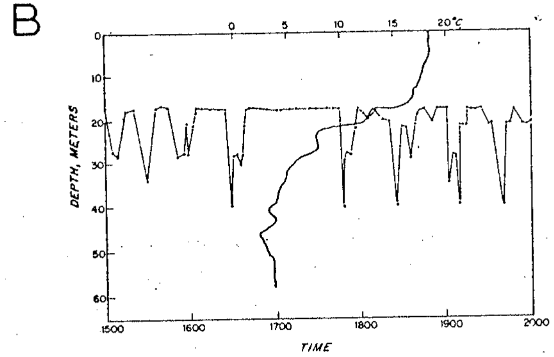


Fig. 6B. Depth record for Bluefin No. 14. The BT trace here shows that there were several steps in the thermocline and the tuna moved up and down between them.

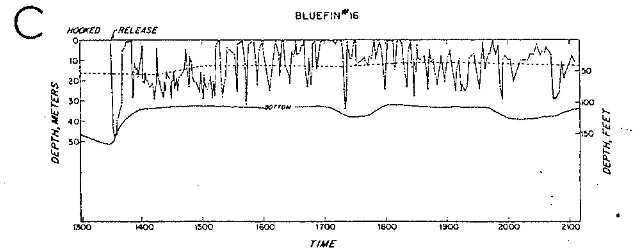


Fig. 6C. Depth record for Bluefin No. 16 with position of thermocline indicated by dotted line. This fish was part of a feeding school followed on the continental shelf south of Block Island. It moved rapidly up and down through the water column without regard for the thermocline.

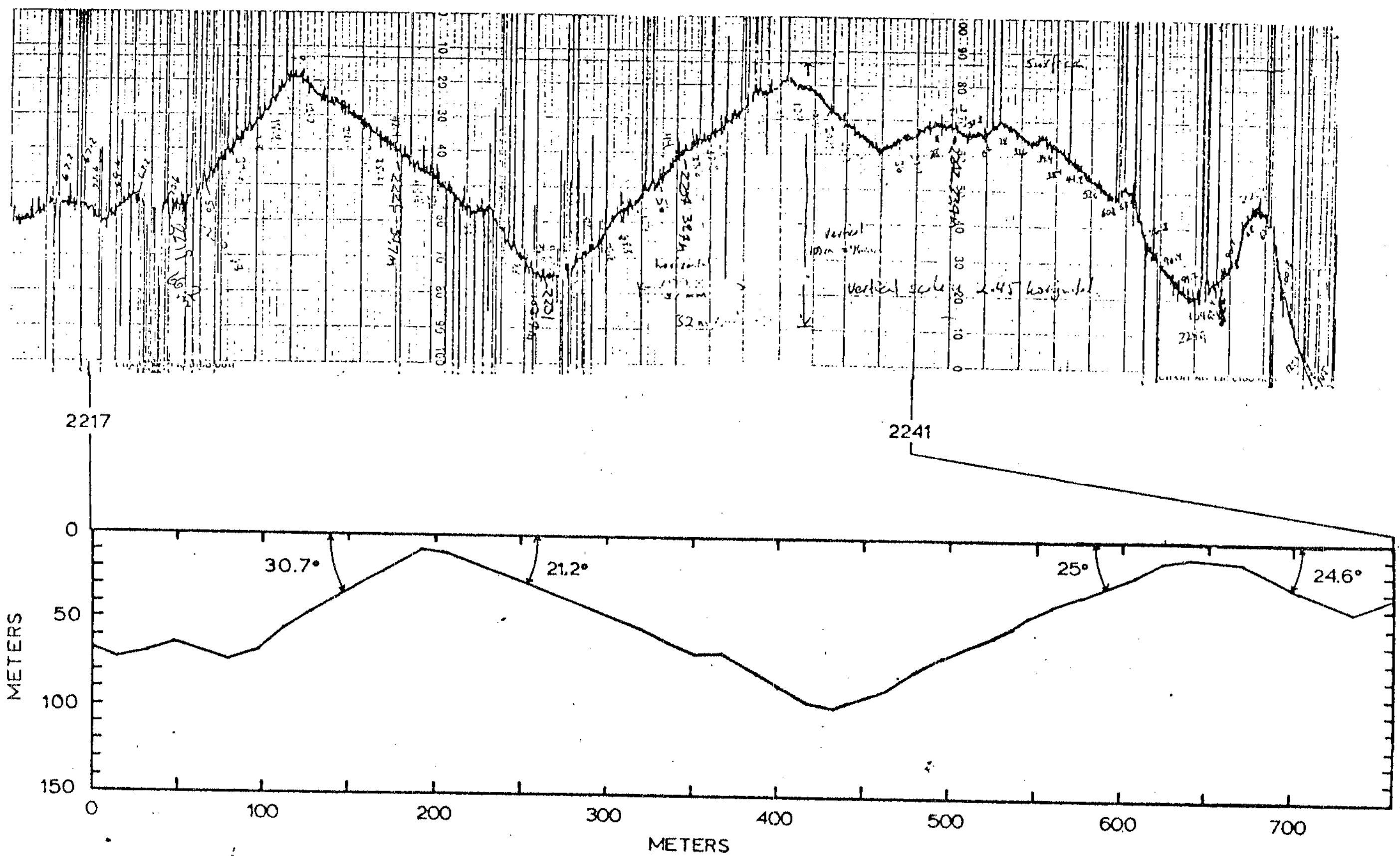


Fig. 7. Part of the automatic recording of depth vs. time for Yellowfin No. 3 was replotted as depth vs. distance (lower panel) to allow the estimation of the angles of climb and dive as the fish moved up and down in the water column.