USE OF ULTRASONIC TELEMETRY TO DETERMINE THE SHORT-TERM MOVEMENTS AND RESIDENCE TIMES OF TUNAS AROUND FISH AGGREGATING DEVICES

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I. The importance of fish aggregating devices

The ability of floating objects to attract fish in the open ocean has long been recognized (reviewed by Seki, 1983). This phenomenon is now being exploited throughout the Pacific by the use of anchored buoys (referred to as fish aggregating devices or FADs) which are specifically designed to attract commercially important fish species (Shomura and Matsumoto, 1982). Pioneering work by the Southwest Fisheries Center Honolulu Laboratory of the National Marine Fisheries Service (NMFS) has clearly demonstrated the benefits (e.g., increased catches, less travel time, and reduced fuel consumption) FADs provide to commercial and recreational fishermen (Matsumoto et al., 1981).

There has been research to determine effective FAD designs with respect to maintaining FADs on station for long periods (Boy and Smith, 1983) and increasing the ability of FADs to aggregate targeted species (Wickham et al., 1973; Wickham and Russell, 1974). There have also been studies on the feeding habits of FAD associated tuna and the changes in tuna feeding habits caused by FADs (Brock, 1984). However, little is known about the optimal placement of FADs with respect to oceanographic or bathymetric conditions, or to each other. Also, there is little or no direct information available on the true effects of FADs on the behavior of commercially important fish species or the ultimate impact of FADs on fishery resources. We therefore decided that much could be learned about the optimal placement and effects of FADs by using ultrasonic telemetry techniques to determine the short-term (1-12 days) behavior around FADs of commercially important fish species such as tunas. Yellowfin tuna, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*, are the primary FAD associated target species in the Pacific (Matsumoto et al., 1981; Shomura and Matsumoto, 1982).

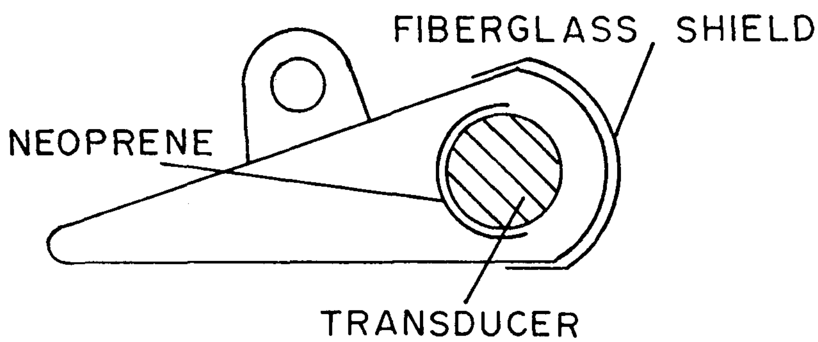
II. Description of the telemetry system

To monitor the fish's swimming depth, as well as their daily movements and residence times around FADs, we decided to employ depth sensitive ultrasonic transmitters. Transmitters, purchased from VEMCO[1] (Shad Bay, Halifax County, Nova Scotia), were 1.6 cm in diameter and either 7.4 or 8.0 cm long. The former weighed 28.8 g in air and 14.0 g in seawater and had a battery life of 2.2-3.7 days. The latter weighed 27.7 g in air and 11.7 g in seawater and had a battery life of 14-24 days. The 50 kHz carrier signal was 153-158 dB (re 1μ Pascal at 1 m), which gives the transmitters a working range of approximately three-fourths nautical mile in our system. Depth (water pressure) is measured with a strain gauge mounted on one end of the transmitter. The strain gauge controls the frequency of the transmitters' pulsed output, which ranges from approximately 1 per second at the sea surface to approximately 3 per second at 400 m. The transmitters are designed such that pulse frequency is linearly proportional to depth.

The directional hydrophone employed was also from VEMCO. The transducer and a preamplifier (50 dB gain) are mounted in a PVC housing. The hydrophone has a sensitivity of 144 dB (re 1 V/μ Pascal at 1 m), a horizontal acceptance angle (beam width) of 30°, and a vertical acceptance angle (beam width) of 150°.

Because of the high speed swimming abilities of tuna (Yuen, 1966), the pursuit boat has to intermittently travel at 7-8 knots for short periods while tracking. The directional hydrophones, however, are designed and are usually used for tracking much slower species. Therefore, the hydrophone had to be modified for our purposes. Directionality in the hydrophone is attained by a sheet of sound absorbing neoprene placed around a portion of the hydrophone's transducer element (Fig. 1). However, water pressure on the face of the transducer element, when the hydrophone is being rapidly moved through the water, compresses the neoprene and allows the transducer element to rotate. This can sever the wires connecting the transducer to the preamplifier in the body of the hydrophone. We lost a yellowfin tuna that we had been tracking for 5 hours before we discovered this weakness in hydrophone design. This problem was corrected by simply gluing the neoprene in place.

FIGURE 1 Side View of the VEMCO Directional Hydrophone Showing the Relative Positions of the Transducer, Sound Absorbing Neoprene and Fiber Glass Shield



In addition, a fiber glass shield was fitted over the face of the hydrophone (Fig. 1). The shield was made by impregnating fiber glass cloth with resin and then draping it over a PVC pipe of the proper diameter as the resin hardened. If care is taken so that no air bubbles are trapped in the fiber glass cloth, the shield is

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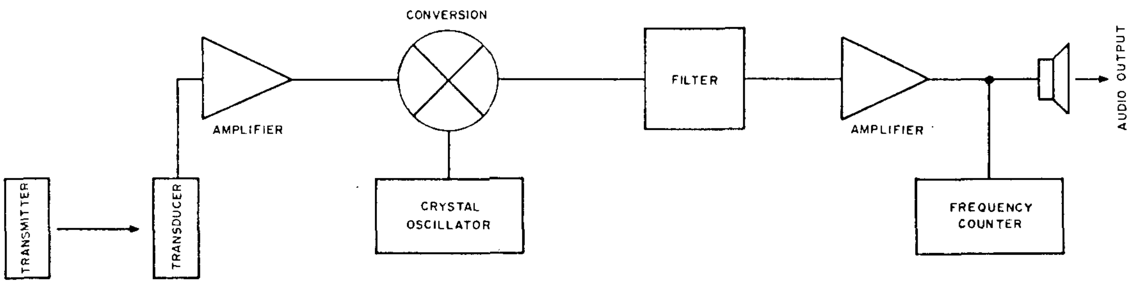
[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

acoustically transparent. The shield improves the performance of the hydrophone at high boat speeds because it reduces water turbulence at the face of the transducer and increases the signal-to-noise ratio.

The ultrasonic receivers employed were Communication Associates (Huntington Station, NY 11746) model CR 40. The hydrophone-receiver system functions as follows. The hydrophone detects and amplifies the ultrasonic transmitter's signals plus background noise. In the receiver, a crystal controlled oscillator (designed to match the crystal controlled oscillator controlling the 50 kHz carrier frequency of the ultrasonic transmitter) is used to select the frequency to be converted to the audible signal. The strength of the audible signal is used by the boat operator to keep the directional hydrophone pointed at the fish. In other words, when the hydrophone is pointed directly at the fish the audible signal is louder than when the hydrophone is pointed in a slightly different direction. We recorded the audible signal with a Sony TCS-310 tape recorder and also fed the signal to a Telonics (Mesa, AZ 85201) TDP-2 frequency counter. This latter device displays pulse interval which, as stated, is inversely proportional to the fish's swimming depth. This swimming depth data were also recorded manually every 15 min. The Sony tape recorder was chosen because recorders of this type are designed for playback of recorded music and generally exhibit wow and flutter (a measure of the accuracy of tape speed) of approximately 1°/₀₀. Therefore, the tape recorder introduces no significant error with respect to shoreside analysis of the telemetered depth data. The entire telemetry system is shown schematically in Figure 2.

FIGURE 2 Diagram of the Ultrasonic Receiver System. The Tape Recorder (Not Shown) Is Connected Directly to the Audio Output



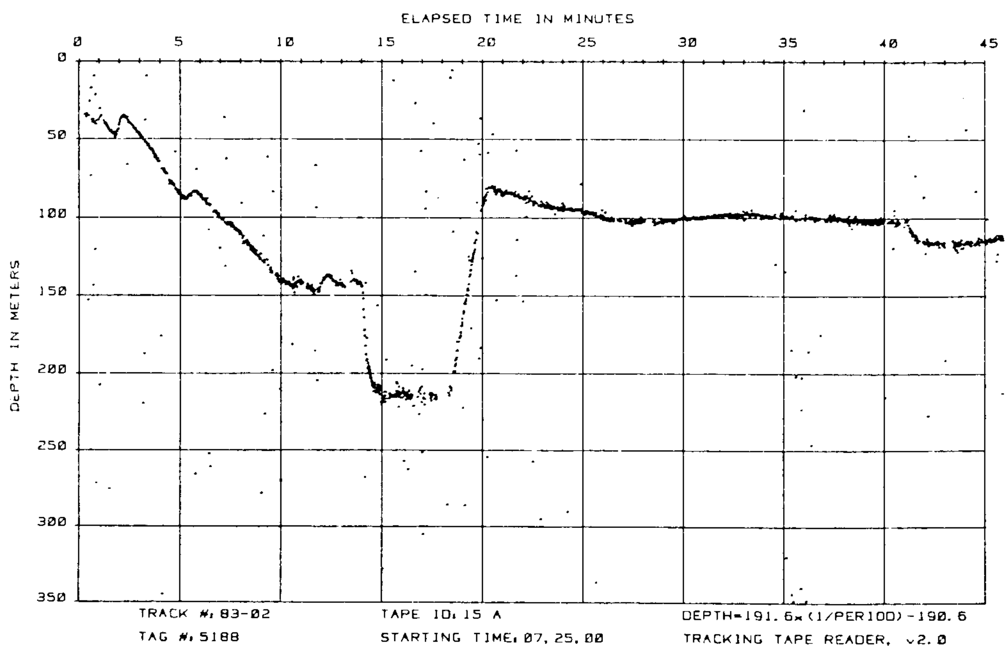
We employed a relatively small boat (11 m long) as a pursuit vessel, rather than the larger NMFS's research vessel that had been used for previous telemetry studies (Dizon et al., 1978). A small vessel has several advantages. First, it is relatively inexpensive to operate and it can be dedicated to this one project. Therefore, tracking can be attempted whenever conditions are optimal. Second, a small vessel is maneuverable enough so that the hydrophone can be fixed-mounted in one direction. Therefore, instead of turning the hydrophone to determine the location of the fish, the whole boat is turned. This greatly simplifies the mounting of the hydrophone on the boat and makes the whole structure more reliable. Third, and perhaps the most important, our 11-m boat is about the same size as the majority of the other vessels fishing around FADs in Hawaii. Our vessel, therefore, does not interfere with other vessels fishing near the FADs, as would a large fisheries research ship. Finally, the small boat is ideal for catching the relatively small tuna 50-70 cm fork length) that are suitable for tracking.

Small boats do have disadvantages. First, 120 V a.c. must be supplied by a small generator which is generally unstable with respect to alternating current frequency. This makes it difficult to operate computers and other sensitive digital electronic devices. Also, an 11-m vessel is subject to far more motion than is a large fisheries research ship and all areas of the boat are exposed to salt and moisture corrosion. A small boat is therefore not a suitable environment for sensitive digital electronic equipment. Finally, an 11-m vessel can only support a three- to four-man crew. Therefore, it is limited to a maximum tracking duration of approximately 48 hours before the crew must be exchanged. Our vessel does carry 290 gal of fuel, which at speeds used during tracking, provides enough fuel to track a fish for at least 3-4 days.

Because of the limitations of an 11-m vessel, the data acquisition system was designed with a philosophy of simplicity and (whenever possible) redundancy with respect to all critical and automated data acquisition equipment. Because of the amount of data that can be collected on the fish's swimming depth, automated data collection and computer analysis are needed. However, real time computer collection and analysis with a shipboard computer is not practical on a small vessel.

As described, we recorded the audible signal from the ultrasonic receiver with a Sony tape recorder. The tapes are then played back at our shoreside laboratory and every other pulse interval is plotted as a point on a depth-time graph. A Hewlett-Packard (HP) 9825A computer, an HP 5312A timer-counter (to measure pulse intervals), and an HP 7245A plotter-printer are used. This system permits one to determine spurious data points within the swimming depth data. Spurious depth data points can easily be seen in an example of the plotted depth data (Fig. 3).

FIGURE 3 Forty-five Minute Record of the Swimming Depth of a Yellowfin Tuna, *Thunnus albacares*. The Data Were Plotted by Computer Directly From the Tape Recorded Signal From the Depth Sensitive Transmitter



This system was chosen to get rid of spurious data points rather than a computer algorithm, such as that developed by Westerberg (1983), because our system requires the investigator to look at the data and forces the use of human judgment.

Furthermore, if the transmitter's signal begins to get out of range, although still audible to the boat operator, the signal-to-noise ratio can be insufficient to trigger the HP counter-timer. As shown in Figure 3, even when data plotting is intermittent, the fish's swimming depth pattern can easily be determined by eye and the missing data points filled in. Totally automated data processing would not permit this. We are in the process of developing computer programs to digitize and manipulate this plotted depth data by tracing the depth-time plots on a digitizer tablet.

Navigational data are collected in two ways. The first is by use of standard loran-C receiver (Furuno, model LC80) aboard the pursuit vessel. However, loran-C navigation is not consistent near the main Hawaiian Islands. Because tuna can be caught relatively near shore in the Hawaiian Islands, we are also able to determine vessel position by taking hourly fixes on landmarks using a hand-held compass. These land fixes are used to adjust the position information determined by loran-C. The tracking vessel's course is plotted by hand using both sources of position information.

III. Horizontal and vertical movements of yellowfin tuna around fish aggregating devices

Fish to be tracked are caught by trolling feather and plastic and rubber jigs. Heavy rods and reels are used to bring the fish to the boat as quickly as possible. The fish are then wedged in a trough lined with foam rubber which does not allow the fish to struggle excessively. A wet cloth is used to cover the fish's eyes which also helps to quiet the animals.

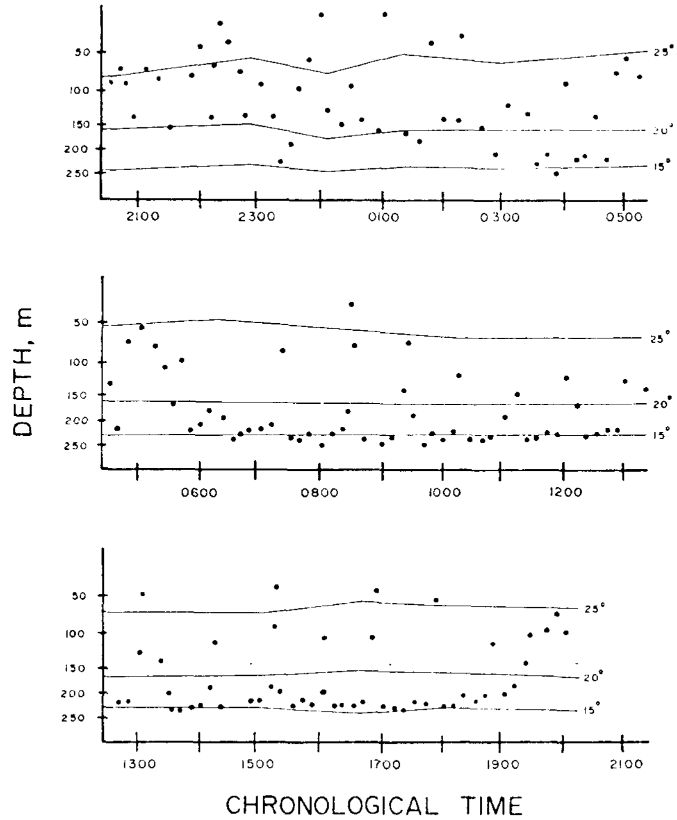
The transmitters are attached to the dorsal surface of the fish, posterior to the second dorsal fin. Plastic "tie wraps" are inserted through the muscle with the aid of hollow brass needles. One tie wrap is placed through a plastic loop on one end of the transmitter. A second tie wrap is used to hold the body of the transmitter to prevent it from flopping as the fish swims. Using this attachment method, dummy transmitters were placed on kawakawa, *Euthynnus affinis*, held at the Kewalo Research Facility of the Honolulu Laboratory, NMFS. These fish were able to carry the dummy transmitters for several weeks and swam, fed, and behaved normally.

So far we have been able to track three yellowfin tuna and one bigeye tuna, *T. obesus*. The use of a small dedicated pursuit vessel and a three-man crew has proven to be overwhelmingly successful. As Figure 3 shows, we are able to get long-term, yet fine scale, records of the fish's swimming depth.

Analysis of the data collected so far has revealed remarkable diurnal changes in both vertical and horizontal movements of tuna. A striking example of the former is shown in Figure 4, which is a plot of the swimming depth of a bigeye tuna recorded at 10-min intervals. The animal tended to remain nearer the surface at night and to descend to the depth of the 15°C isotherm (200 m) during daylight hours making only occasional forays to the surface during this time. The fish returned to its shallower swimming depth as the sun set (1900).

We have also observed instances of predictable diurnal rhythmicity in the horizontal movements of tunas. On one occasion this rhythmicity allowed us to relocate a yellowfin tuna on two separate occasions over a 5-day period. Similar behavior has been shown for skipjack tuna (Yuen, 1970). The practical advantage of these predictable horizontal movement patterns is that it is feasible to get extended tracks of tuna using a small pursuit vessel which can rapidly return to the nearest small harbor, refuel, exchange crews, and then return and relocate the fish carrying the transmitter.

FIGURE 4 Twenty-four Hour Record of the Swimming Depth of a Bigeye Tuna, Thunnus obesus. The Fish's Swimming Depth Was Recorded Manually Every 10 Min.



IV. Conclusions

Because of the rapidly increasing deployment of FADs throughout the Pacific, the cost of their deployment, and the use of and increasing dependance upon FADs by commercial and recreational fisheries, an understanding of the optimal placement and the true effects of FADs on fish and fishery resources is needed. Ultrasonic telemetry appears to us to be a rapid and relatively inexpensive way to gather some of the required information.

We have shown that with appropriate equipment, a small pursuit vessel can be used for open ocean tracking studies. We feel our system is both effective and efficient. We plan to continue our telemetry work for at least several more years and eventually we hope to track other pelagic species such as skipjack tuna and mahimahi (dolphinfish, Coryphaena hippurus) around FADs.

Acknowledgments

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