A Small Vessel Technique for Tracking Pelagic Fish

KIM HOLLAND, RICHARD BRILL, SCOTT FERGUSON,
RANDOLPH CHANG, and REUBEN YOST

Introduction

The advent of ultrasonic telemetry techniques for monitoring fish movements in the wild has greatly increased our understanding of the behavior and physiological capabilities of pelagic fish (Carey, 1983). The development of pressure sensitive transmitters has allowed insights into the remarkable pressure (depth) and temperature tolerances of these animals while simultaneously revealing their fine-scale horizontal movements.

Previous tracking studies involving pelagic species have been carried out using large fishing or oceanographic research vessels. Because of the high operating costs of these vessels and the heavy demands on their time, comparatively few fish have been tracked. Also, the tracks that have been made come from widely scattered areas. Thus, although valuable data have been acquired from individuals of several species, only rarely have enough replicate tracks been obtained to give a reasonable indication of the normal daily behavior of a species in a particular location. Pelagic species that have been tracked include skipjack tuna, *Euthynnus pelamis* (Yuen, 1970); yellowfin tuna, *Thunnus albacares* (Carey and Olson, 1982); albacore, *T. alalunga* (Laurs et al., 1977); swordfish, *Xiphias gladius* (Carey and Robison, 1981); blue marlin, *Makaira nigricans* (Yuen et al., 1974); mackerel sharks (Carey et al., 1981); and Atlantic salmon, *Salmo salar* (Westerberg, 1982).

This paper reports on the development of a technique for using a small vessel for the ultrasonic tracking of pelagic fish. Our system produces high-resolution data and is sufficiently adaptable and cost-effective to allow prolonged tracking efforts in a variety of situations. Because of its modest cost, a small vessel can be dedicated to a tracking project for extended periods. This permits acquisition of many replicate multi-day tracks. Thus, sufficient amounts of data can be acquired to yield reliable information about the sequential daily behavior of a target species. Details of our system and methods have been included to allow other workers to adapt our techniques to their own needs.

The impetus for development of our tracking technique began when the Honolulu Laboratory of the National Marine Fisheries Service (NMFS) Southwest Fisheries Center pioneered the modern use of fish aggregating devices (FAD's) by deploying several of these buoys in Hawaiian waters in 1975 (Matsumoto et al., 1981). These deep-water FAD's have proved to be very effective and their use has spread throughout the Indo-Pacific (Shomura and Matsumoto, 1982). However, the influences of FAD's on fish behavior which result in the aggregation of pelagic fishes at these buoys are not understood. Given the importance of FAD's, the high costs associated with FAD deployment, and unanswered questions relating to stock harvesting and management, we initiated a project using ultrasonic transmitters and a small pursuit vessel to document the movements of pelagic species associated with FAD's. To date, our efforts have concentrated solely on yellowfin tuna and bigeye tuna, *T. obesus*, with fork lengths between 50 and 75 cm.

Methods

General

Our two major objectives when equipping the vessel were simplicity and redundancy. The data acquisition and recording systems were designed to emphasize shore-side data processing,

ABSTRACT—Tracking of pelagic fish has previously been conducted from large research or fishing vessels, both of which are expensive to operate. We have adapted advances in ultrasonic tracking technology to permit tracking of pelagic fish from a small (33-foot) vessel. Sportfishing techniques have been successfully employed to capture fish for tracking.

The use of a small vessel has many advantages including maneuverability in congested areas, the ability to work both offshore and close to shore, high responsiveness to changes in fish behavior, and low operating costs. Low operating costs allow the vessel to be utilized over extended periods, thereby permitting replication of experiments. High quality data on the vertical and horizontal movements of pelagic fish have been acquired for periods of up to 6 days. These techniques could be utilized to track fish inexpensively in a wide range of locations.

Kim Holland is with the Hawaii Institute of Marine Biology, University of Hawaii, P.O. Box 1346, Coconut Island, Kaneohe, HI 96744. Richard Brill and Randolph Chang are with the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812. Scott Ferguson is with the National Oceanic and Atmospheric Administration, and Reuben Yost is with the Department of Zoology, University of Hawaii. This work was the result of research project MR/R-25 sponsored by the U.H. Sea Grant College under Institutional Grant NA81AA-0-00070 from NOAA Office of Sea Grant. Major facilities assistance was provided by the Honolulu Laboratory, SWFC, NMFS.

thereby maximizing the use of on-board space and equipment for actual acquisition and storage of high-quality raw data. Secondary objectives were minimizing operating costs and maximizing crew comfort, thus improving our ability to track fish for long durations.

The Vessel

The R/V *Kaahele'ale* is a 33-foot vessel built for the U.S. Navy as a personnel boat. It was acquired by the NMFS in 1979 and modified for nearshore fisheries research, primarily telemetry. As modified, the vessel has an open-stern deck, a semi-enclosed central cabin with engine beneath, and a fully enclosed forward cabin. The stern deck is equipped for fishing and tagging. The central cabin houses the steering console and an instrument rack containing the telemetry equipment, navigation equipment, and radar. The forward cabin is air conditioned and contains two bunks, a work bench, an expendable bathythermograph (XBT) system, and a microwave oven.

The vessel is powered by a single screw driven by a GM-671[1] diesel engine through an Allison hydraulic transmission. Two 120-gallon fuel tanks are backed with a 50-gallon reserve tank. At cruising speed (11 knots), fuel consumption is 10 gallons/hour, at trolling speed (7.5 knots) it is 5 gallons/hour, and during tracking operations fuel consumption is usually less than 3 gallons/hour. The main engine alternator supplies a 24 volt main battery which powers the starter motor, the radar, and autopilot. Radios, tracking instrumentation, navigation lights, and fathometers are powered by a separate 12V DC battery bank. A 7.5 KW 120V AC diesel generator (Onan) is housed below a portion of the stern deck and powers the XBT system, the microwave oven, the forward cabin air conditioner, and an automatic 12V battery charger.

Tracking Apparatus

Transmitters

Pressure sensitive 50 KHz ultrasound transmitters were purchased from Vemco, Halifax, Nova Scotia. Two types of transmitters have been used, one with an expected operation life of up to 22 days and the other with nominal expected life of 3 days. We have found maximum open ocean operating ranges to be about 0.8 miles for the 3-day tags, and about 0.5 miles for the 22-day tags. The transmitters are pressure sensitive such that the pulse frequency of the 50 KHz carrier signal is directly proportional to increasing pressure (depth). Normal operating range is zero (surface) to 500 psi (370 m depth). The 22-day duration transmitters are cylindrical (8.0 cm long and 1.6 cm diameter) and weigh 27.7 g in air and 11.7 g in seawater. The 3-day duration transmitters are of similar specifications. The transmitters are equipped with magnetically operated reed switches for rapid activation and have a nylon loop at one end for use in attachment to the fish (discussed later).

Receivers

The 12V DC amplifier/receivers (CR-40, CAI Co.) are matched to the transmitters with 50 KHz crystal-controlled oscillators. These receivers amplify and convert the telemetered pulses into an audible signal. Two receivers were installed on the vessel in case one of the units failed during a track.

Hydrophone

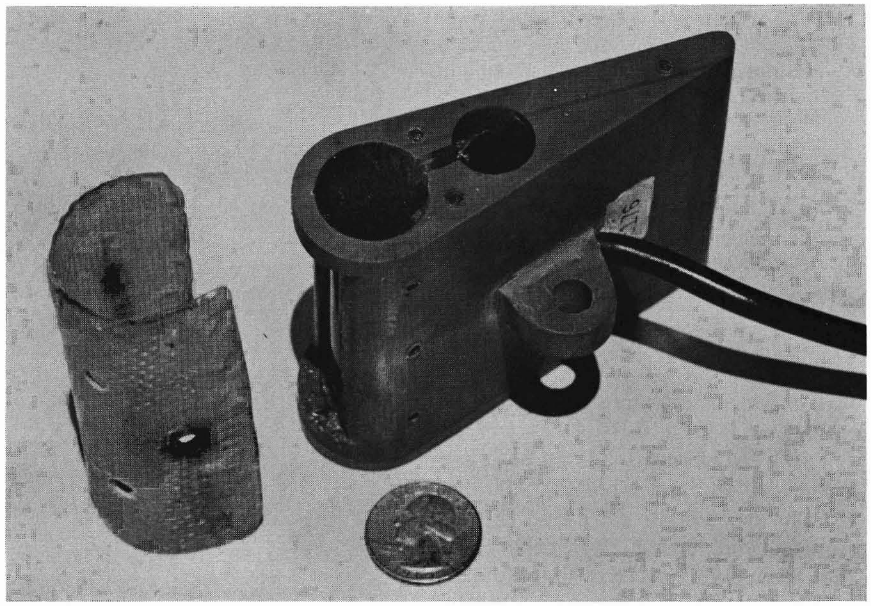

Figure 1.—The directional hydrophone is shown with fiberglass faring removed. Holes in the faring permit attachment to hydrophone body and allow water to flood the space between the hydrophone and the faring. The hydrophone sideplate has been removed to show hydrophone and preamplifier.

The directional hydrophones were also manufactured by Vemco. However, a small but very significant modification was made after delivery from the factory. This modification involved the fabrication and installation of a 2 mm thick fiberglass faring over the leading face of the hydrophone (Fig. 1). This faring serves to protect the actual sensor from physical damage and, more importantly, reduces noise generated by water passing over the hydrophone. The signal/noise ratio is improved to such an extent that usable data can be acquired at boat speeds in excess of 7 knots. We can therefore track and acquire depth data from fast moving fish. The faring also allows the boat to be driven at 11 knots without damage to the hydrophone. No reduction in operating range

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

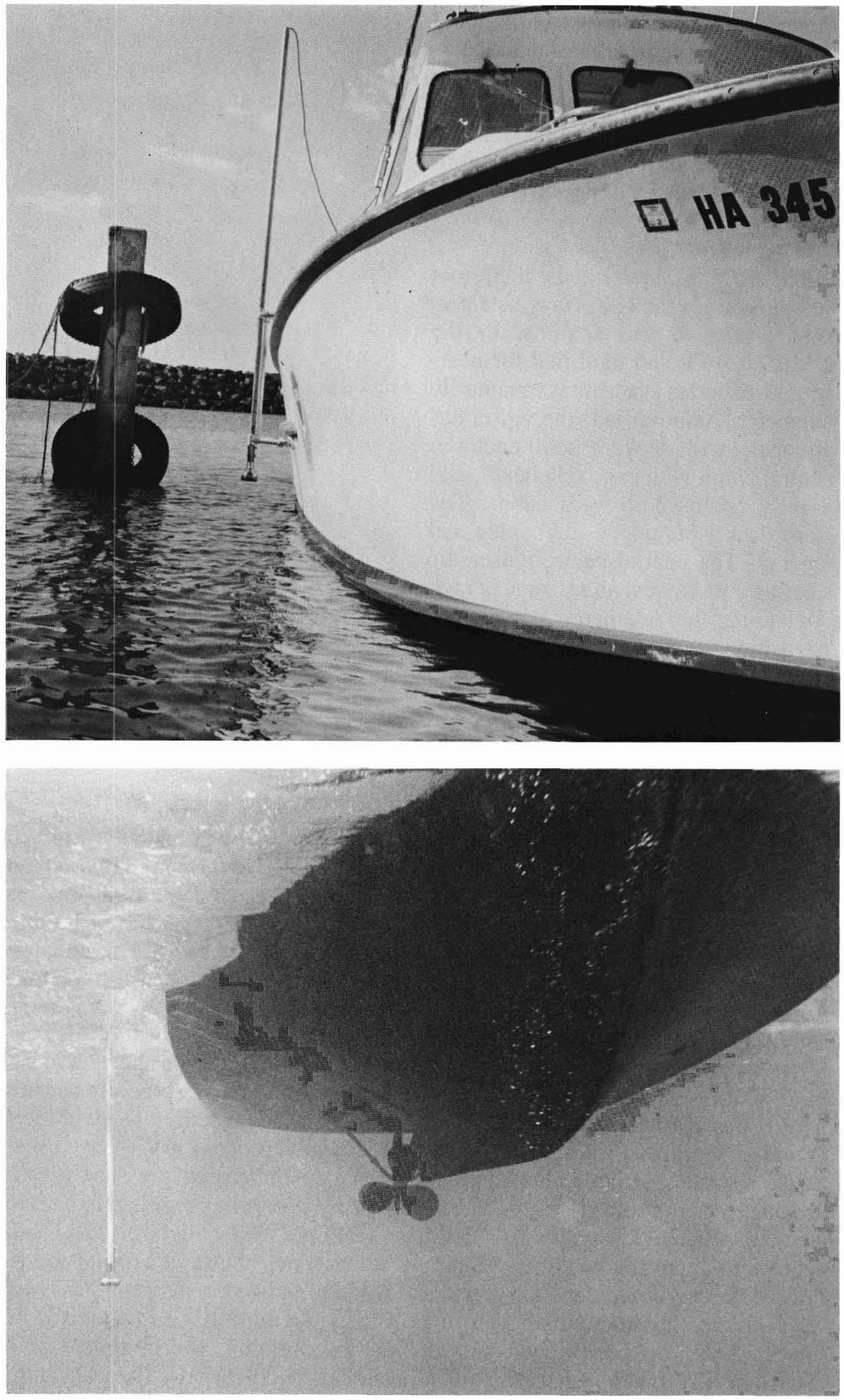

Figure 2.—Hydrophone Mounting. Top: The tracking hydrophone is in retracted position. Two triangular aluminum brackets mounted above the waterline allow the hydrophone to be lifted out of the water when not in use. Bottom: The hydrophone mounting pole is lowered through the support brackets to a position in which the hydrophone is clear of the keel and is unaffected by turbulence from the boat hull.

was observed following installation of the faring.

The hydrophone is braced within a stainless steel bracket bolted to the end of a 10-foot length of 1-inch I.D. galvanized pipe. The shielded cable from the hydrophone to the amplifier is threaded through the pipe. Shielding the cable is necessary to reduce radio frequency interference.

The hydrophone mounting pipe is deployed amidships using two triangular brackets, constructed of 1-inch I.D. aluminum tubing, which are bolted, one above the other, through the hull above the waterline. The pole is free to slide through the brackets and is held in place by thumbscrews. Thus, the hydrophone can be lowered for tracking and raised out of the water when not in use. This outrigger type of mounting allows the hydrophone to run about 5 feet below the surface and 6 feet to the side of the keel where it is unaffected by water turbulence generated by the hull (Fig. 2). During tracking, the hydrophone is secured facing forward in parallel with the keel of the boat, and localizing the transmitter (i.e., the fish) is accomplished by turning the vessel.

Depth Data Logging

A data processor/frequency counter (Telonics, TDP-2) is connected to the audio output of the receiver. This processor unit provides a digital display of the inter-pulse interval which is recorded manually at regular intervals and which gives an immediate indication of the fish depth and any changes in behavior. A cassette tape recorder is also connected to the audio output of the receiver. This provides a continuous record of the telemetered depth data for fine-scale plotting and analysis ashore.

Navigation

Three types of fixes are used to determine the vessel's position during tracking. The primary navigational reference is by Loran C (Furuno LC-80). This unit provides latitude and longitude in-center of the transom. The cradle is a foam-lined, "V"-shaped trough with one side hinged to allow variable gape to accommodate fish of different sizes. The fish to be tagged is lifted aboard, lightly wedged into the cradle and its eyes covered with a wet chamois cloth. These procedures are usually sufficient to immobilize the fish. Once aboard, species identification is verified, the hook removed, and mouth damage assessed and the fish length measured. Handling is performed without gloves which remove large amounts of mucus from the fish's surface.

Using the nylon loop embedded in one end of each transmitter, the unit is attached to the dorsal surface of the fish (adjacent to the second dorsal fin) using nylon "tie-wraps." These are inserted through the dorsal pterygiophores using sharpened hollow brass needles. Two tiewraps are used per fish; one passing through the transmitter loop, the other half way along the transmitter's length to prevent the transmitter from wobbling from side to side. After insertion through the musculature, the tie-wraps are cinched down and trimmed (Fig. 3). The fish is then released. The entire operation requires the fish to be on board between 1 and 2 minutes.

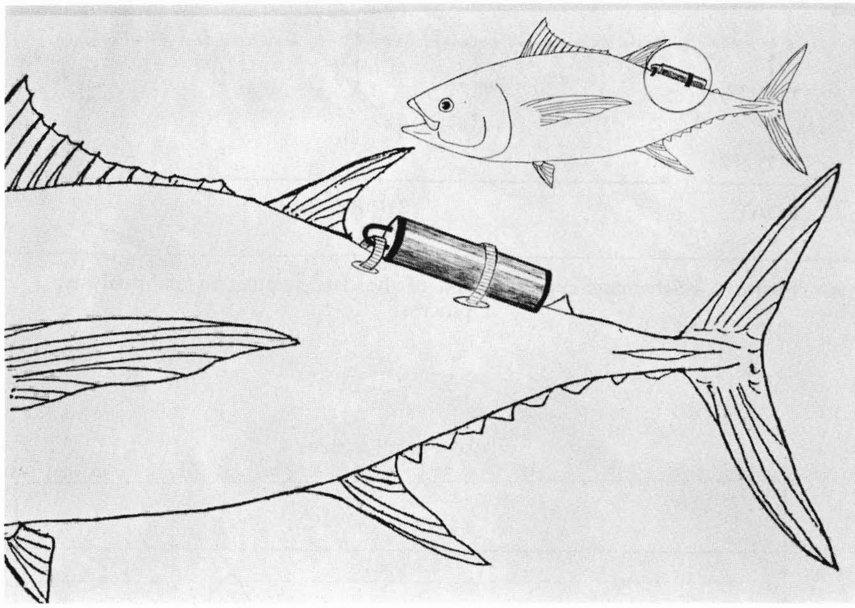

Figure 3.—The ultrasonic transmitter is attached to the dorsal surface using two nylon tiewraps inserted through the dorsal musculature and pterygiophores.

formation and also the vessel's course and speed. These latter data are useful in subsequent onshore analysis of the fine-scale movements of the fish. The waypoint storage capability of this unit also permits instantaneous information about the vessel's current position relative to starting or other important (e.g. FAD) positions. Supplementary visual fixes on charted landmarks are made using a hand-bearing compass or sextant. These visual fixes are made hourly to ensure the accuracy of the Loran C positions. The 24V DC radar unit is used to acquire accurate distances to landmarks or FAD's.

Oceanographic Information

Knowledge of the thermal structure of the ocean is essential to interpretation of the movements of the fish. Temperature data are acquired using a 110V AC expendable bathythermograph (XBT) system (Sippicon, Mass.). The XBT probes are deployed about every 3 hours or whenever the fish being followed moves into new waters (e.g., onshore to offshore). A bucket thermometer is used to verify the accuracy of the XBT surface temperatures.

Water current direction at FAD locations is determined by visual inspection of plastic streamers attached to the FAD's mooring chain. When operating in inshore areas (<100 fathoms) a fathometer is used to record ocean depth and to assist in determining geographic position.

Fishing and Tagging Techniques

The research vessel is equipped for both handline (drift) fishing and trolling. To date, most fish have been caught trolling. Artificial trolling lures tailored to the size of the target species are used with single "J"-type hooks. Large reels (14/0, Penn Reels, Pennsylvania) and 130-pound test line are used so that the fish can be reeled in rapidly to reduce capture stress. The reels are set with very light drag to reduce injury to the fish's mouth. After the initial strike and run, the drags are tightened and the fish brought to the boat as quickly as possible. Occasionally, the fish are towed behind the slowly moving vessel while the remaining fishing gear is retrieved and the stern deck prepared for tagging.

The tagging cradle is located in the

Tracking Techniques

Testing of the transmitter/receiver system has demonstrated that maximum operational range is between 0.25 and 0.8 n.mi., depending on the type of transmitter being used. Furthermore, we have established that maximum deflection of the signal amplitude meter on the CAI receiver occurs when the transmitter is within about 200 m of the vessel. Consequently, during tracking we attempt to keep the fish at just the distance where maximum gauge deflection occurs. This gives us added confidence in the accuracy of our tracks and also that we are not unduly "crowding" the fish. The directional hydrophone (and therefore the boat) is kept pointed at the fish by maximizing the audio output of the receiver. The small size of the vessel permits rapid changes of direction and rapid identification of the direction of the signal. Due to the noise reduction resulting from the installation of the hydrophone faring, a fish can be pursued at up to 7 knots if it appears to be drawing away. At higher pursuit speeds depth data recording must be temporarily suspended because the noise of water rushing past the hydrophone masks the transmitter's signal.

Data Acquisition

During tracking, four types of data are acquired: 1) A continuous tape of fish-depth data from the audio output of the CAI receiver, 2) water depth/temperature profiles (XBT), 3) water depth, and 4) navigational data. Navigational data are recorded every 10 minutes and include: 1) Time, 2) heading/engine RPM, 3) Loran C fixes, and 4) visual and radar fixes (usually taken hourly). When close enough to a FAD, its range and bearing from the vessel are also recorded every 10 minutes. A narrative commentary is compiled to assist in subsequent data analysis.

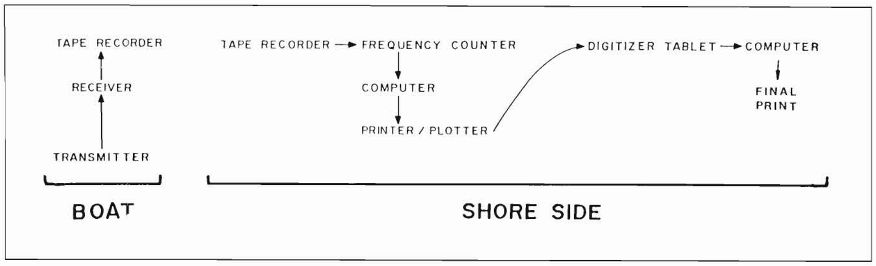

Figure 4.—Schematic representation of the data acquisition and analysis process.

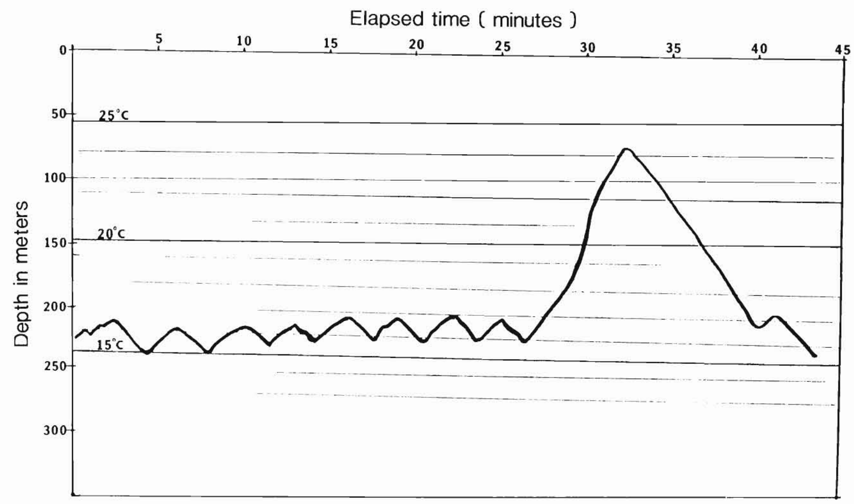

Figure 5.—A 45-minute vertical movement plot. Continuous recording of vertical movement data on cassette tapes allows both fine-scale and large phenomena to be discerned. Superimposing XBT data indicates that the swimming depth of this bigeye tuna is strongly influenced by the 15° and 17° C isotherms. Depth data of this type are recorded for the entire duration of each track.

Data Analysis

Vertical Data

Figure 4 summarizes the system for acquisition and analysis of vertical movement data. Once ashore, the recorded information is played from the cassettes into a Telonics TDP2 Data Processor. This processor is modified to output a +5V DC square wave each time a sound pulse is detected. A Hewlett Packard (HP) frequency counter (HP5308A) is used to time every other pulse interval. An HP 9845 computer with real-time clock converts the pulse intervals to depth and plots a graph of depth versus elapsed time. This original hard copy of the fish's swimming depth contains some erroneous points which are eliminated by tracing the depth-time profile on an Apple computer digitizer pad. This "cleaned" track (where depth is plotted every 10 seconds) is then stored on floppy disks prior to final plotting and analysis. Bathythermograph temperature profiles are superimposed on the final printouts (Fig. 5).

Horizontal (Position) Plotting

Because of the proximity of the tracking vessel to the target fish, no attempt is made to distinguish between the positions of the two. Plots are made on navigation and bathymetry charts based on Loran C positions recorded manually at sea. These relative positions are checked against the visual and radar fixes that were concurrently collected. Where applicable, fathometer readings are used as cross references for the other navigational data. Fine-scale movements of fish in the immediate vicinity of FAD's are plotted using manual records of the buoy's range and distance relative to the vessel.

Results

Since the installation of the tracking equipment in its current form, we have acquired 11 tracks of yellowfin tuna and 2 tracks of bigeye tuna that were caught near FAD's or near the adjacent coastline. The duration of the tracks ranged from 8 hours to 6 days.

All but one of the fish was caught by trolling. The small (6/0) size of hooks and light drag settings result in comparatively minor hook wounds. In only one instance has a fish died immediately upon release. All others have shown rapid recoveries to, what we believe, based on consistency within and across samples, is normal behavior. None of these tracks have been terminated due

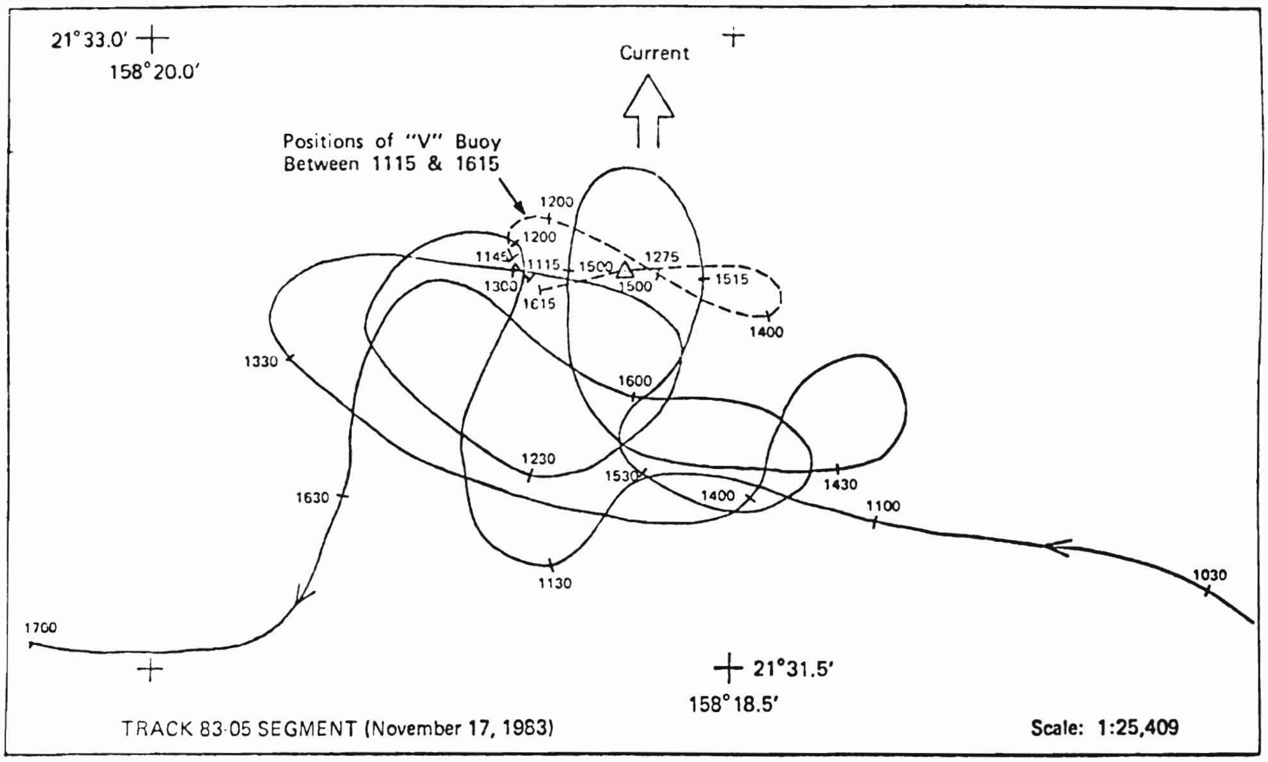

Figure 6.—Fine-scale horizontal plotting. Loran C, radar, and visual fixes allow fine-scale movements to be plotted. After arriving at FAD "V" off of Waianae, Oahu, this 55 cm yellowfin tuna spent about 85 percent of the next 5 hours on the upcurrent side of the buoy. The "Figure 8" movement of the buoy can also be plotted.

to death of the fish.

Captive fish tagged with the "double tie-wrap" method and observed in large tanks at the Kewalo Research Facility of the NMFS Honolulu Laboratory were able to swim normally with the school and appeared healthy after the 2-week observation period ended. In addition, a fortuitous recovery of a tagged fish by a fisherman attests to the suitability of our trolling/tagging technique. This fish was caught by a fisherman trolling near a FAD 3 weeks after we obtained a 36 hour track of it.

Discussion

Although almost all of the technology incorporated in the current research had been previously developed and utilized by others, we feel we have made significant advances in successfully adapting these techniques to a small vessel. Also, the ability to chase pelagic, highly mobile fish at 7 knots in the open ocean and still simultaneously collect vertical movement data is an innovation. We believe that our cassette recording and subsequent plotting of the vertical movement data has produced higher resolution vertical movement data than have previously been published. The continuous depth record has revealed phenomena (such as rapid vertical excursions and small scale oscillations) that manually collected data would have missed (Fig. 5). When the XBT data are superimposed on the tracks, much of the vertical behavior shows correlations with temperature (Fig. 5). Similar temperature influenced behaviors have been observed in bluefin tuna, *Thunnus thynnus* (Carey and Olsen, 1982).

The Loran C system of geographic plotting, when referenced with visual fixes, provides high resolution positioning of both large- and small-scale movements (Fig. 6). When Loran information is used in conjunction with visual fixes and radar ranges, small-scale movements of both the fish and FAD's can be plotted. Knowledge of the relationship between signal amplitude and transmitter distance lends confidence to the precision of the small-scale plots.

The small size of the tracking vessel has proved to have several advantages. For example, while able to pursue fish in the open ocean, the maneuverability of the vessel has also permitted unobtrusive data collection even when in the midst of many other vessels fishing at the FAD locations. Also, fish have been tracked to within 200 m of shore where larger vessels could not safely go. Similar situations occur in other locations such as straits, bays, lakes, and estuaries where tracking studies might be worthwhile but where large vessels would be too cumbersome. A vessel such as ours is capable of continuously following a fish both when it is moving in inshore (e.g., estuarine) waters and also when it moves offshore where it would be beyond the range of fixed hydrophone arrays or of very small vessels such as skiffs.

Of course, small vessels are not suitable for mid-ocean work or offshore locations beyond refueling range. However, they could be used very successfully in association with a larger mother ship which could be performing other tasks while the small pursuit vessel was tracking.

The comparatively low hydrodynamic and mechanical noise generated by our small hull allowed the hydrophone to be attached directly to the side of the boat, thereby precluding the need for complex towed arrays such as have been deployed in some other tracking studies which used large vessels. Similarly, because a small vessel is very maneuverable and can accelerate quickly, the hydrophone can be permanently locked in an orientation parallel with the keel and the entire boat turned to accomplish maintaining contact with the target fish. This high responsiveness eliminates the need for rotatable or multi-head hydrophone systems such as have sometimes been used in the past.

Much of our tracking work has been conducted out of small boat harbors with depths of 2 fathoms or less and which would have been inaccessible to larger fishery research vessels. Each 24 hours of tracking consumes about 70 gallons of fuel. At this rate our vessel can track for at least 3 days without refueling, which can be conducted at any nearby small boat harbor. We have found crews of three sufficient for all phases of the field work. This, combined with the low fuel costs, makes the total operating cost of each tracking expedition extremely modest when compared with the $5,000 to $15,000 daily costs of large research vessels or commercial fishing boats. Our modest expenses enable the vessel to be dedicated to the tracking project for extended periods. This allows replicate tracks of different species from various locations. Also, because the vessel is committed to the tracking project full time, we can take advantage of short term increases in fish abundance and avoid fishing when fish are not abundant. Our ability to use sport fishing techniques to obtain fish for tracking indicates that labor-intensive trapping methods or expensive bait-boat techniques are not obligatory for a successful tracking program.

The small size and modular nature of the actual tracking equipment is such that it could be quickly installed on almost any suitable vessel. The major installation requirement is the bracing of the hydrophone brackets to the hull. However, since the bracket mountings are well above the water line, even this aspect of the installation could easily be repaired when the tracking is completed. The availability of an AC power generator has proved to be essential. Not only does this provide XBT capabilities but also allows improvement in crew facilities such as hot food and air conditioning.

The two major limitations of our system are fuel capacity and crew fatigue. We have solved the former by refuelling during prolonged tracks. However, this technique may be unique to our project because of the proximity of small boat harbors and the rhythmicity of behavior of some of our fish which has allowed us to relocate them after temporary suspension of tracking. Crew fatigue is inevitable with a small vessel after a few days on water. We feel that in our case this could be substantially remedied by using only a slightly larger vessel (e.g., 40-45 ft) which would be somewhat more spacious and comfortable and yet which would retain the desirable characteristics of maneuverability and low operating costs. Another possible technique would be the use of a shuttle vessel to exchange crews on the pursuit vessel.

We are currently unable to be completely sure whether or not the fish being tracked is travelling alone or in a school. We feel this shortcoming will be rectified by the installation of a chromoscopic fish finder.

In general terms, however, we feel that we have developed a cost-effective technique for acquiring high-quality tracking data which could be adapted to a range of small vessels operating in a variety of situations and locations. This, in turn, will result in a significant increase in our understanding of the normal behavior of commercially important fish species about which not much is currently known. Such an increase in our understanding will improve both management and fishing techniques.

Literature Cited

Carey, F. G. 1983. Experiments with free swimming fish, p. 57-68. *In* P. G. Brewer (editor), Oceanography, the present and the future. Springer-Verlag, N.Y.

Carey, F. G., J. M. Teal, and J. W. Kanwisher. 1981. Visceral temperatures of mackerel sharks. Physiol. Zool. 54:334-344.

Carey, F. G., and R. J. Olson. 1982. Sonic tracking experiments with tunas. Coll. Vol. Sci. Papers Int. Comm. Cons. Atlantic Tuna 17(2): 458-466.

Carey, F. G., and B. H. Robison. 1981. Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. Fish. Bull. (U.S.) 74(2):277-292.

Laurs, R. M., H. S. H. Yuen, and J. H. Johnson. 1977. Small-scale movements of albacore, *Thunnus alalunga*, in relation to ocean features as indicated by ultrasonic tracking and oceanographic sampling. Fish. Bull. 75(2):347-355.

Matsumoto, W. M., T. K. Kazama, and D. C. Aasted. 1981. Anchored fish aggregating devices in Hawaiian waters. Mar. Fish. Rev. 43(9):1-13.

Shomura, R. S., and W. M. Matsumoto. 1982. Structured flotsam as fish aggregating devices. NOAA-TM-NMFS-SWFC-22, 9 p.

Westerberg, H. 1982. Ultrasonic tracking of Atlantic salmon. I. Movements in coastal regions. Rep. Inst. Freshwater Res. Drottningholm 60: 81-101.

Yuen, H. S. H. 1970. Behavior of skipjack tuna, *Katsuwanus pelamis*, as determined by tracking with ultrasonic devices. J. Fish. Res. Board Can. 27(11):2071-2079.

Yuen, H. S. H., A. E. Dizon, and J. H. Uchiyama. 1974. Notes on the tracking of the Pacific Blue Marlin, *Makaira nigricans*, p. 265-268. *In* R. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12-72, Part 2. NOAA Tech. Rep. NMFS-SSRF 675.