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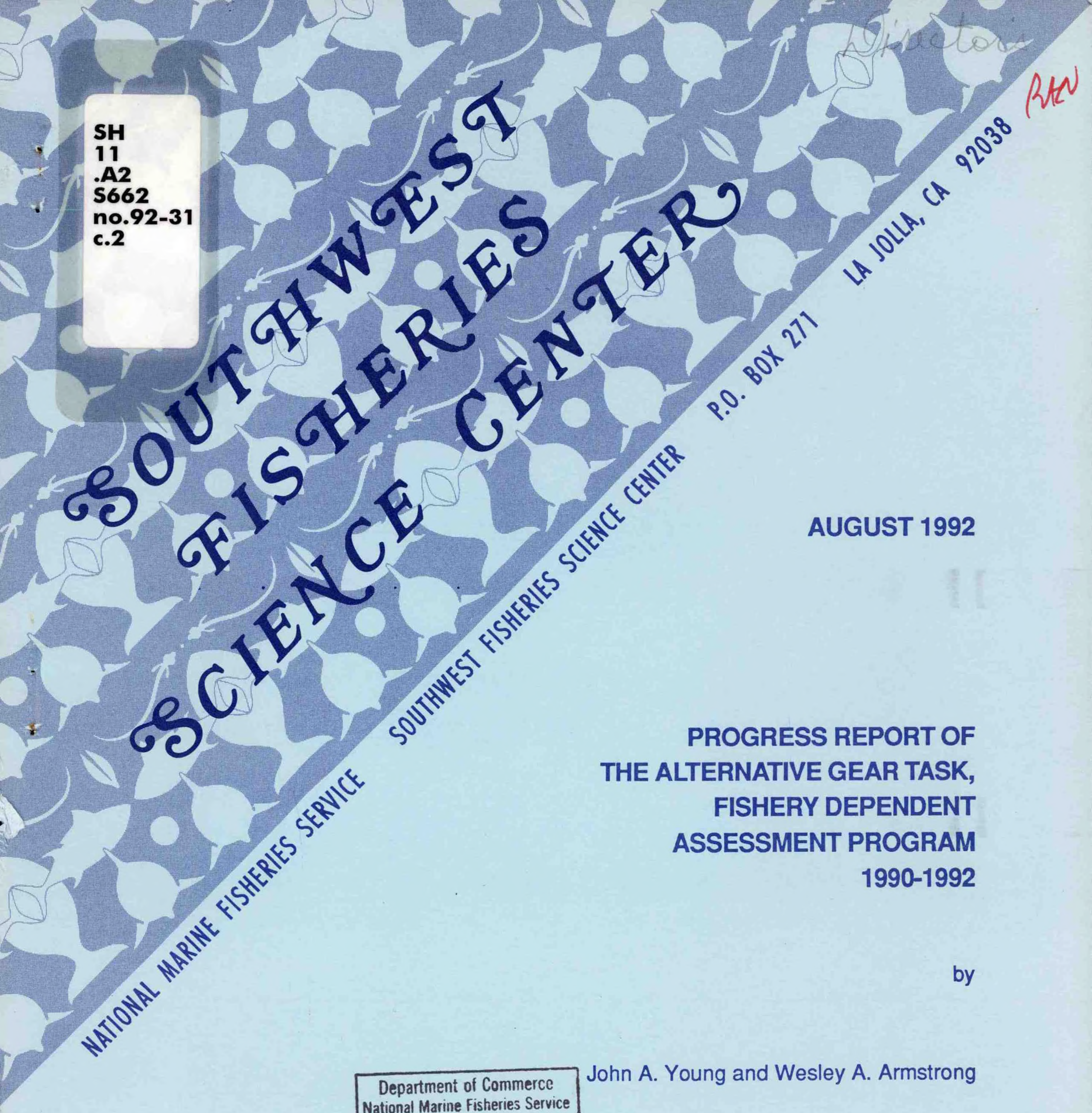

SOUTHWEST FISHERIES SCIENCE CENTER

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES SCIENCE CENTER P.O. BOX 271 LA JOLLA, CA 92038

AUGUST 1992

PROGRESS REPORT OF THE ALTERNATIVE GEAR TASK, FISHERY DEPENDENT ASSESSMENT PROGRAM 1990-1992

by

John A. Young and Wesley A. Armstrong

ADMINISTRATIVE REPORT LJ-92-31

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July, 1992

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PROGRESS REPORT OF THE ALTERNATIVE GEAR TASK, FISHERY DEPENDENT ASSESSMENT PROGRAM
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John A. Young and Wesley A. Armstrong

BACKGROUND

The amendments to the Marine Mammal Protection Act of 1972, passed by Congress on 23 November 1988, direct the National Marine Fisheries Service (NMFS) to develop methods of reducing or eliminating the incidental take of dolphins involved in the eastern tropical Pacific (ETP) tuna purse seine fishery. The Fishery Dependent Assessment Program and the Alternative Gear Task have been established for this purpose.

The most direct method of eliminating the mortality of marine mammals during fishing operations is to avoid encircling dolphins with the seine. Aggregating tuna, separating the yellowfin tuna (*Thunnus albacares)* that associate with dolphins, locating the yellowfin when they are not associated with dolphins, or investigating fishing procedures other than purse seining are possible methods for eliminating cetacean mortalities. Refinement and/or modification of fishing procedures that involve the intentional capture of tuna and dolphins may result in a further reduction of dolphin mortalities, but are not likely to eliminate them entirely.

The National Academy of Sciences (NAS) prepared a detailed report, "Dolphins And The Tuna Industry," which identified scientific and technological innovations that showed promise in reducing dolphin mortality from tuna purse seine fishing (National Academy Press, 1992). The Southwest Fisheries Science Center (SWFSC) subsequently prepared a "Strategic Plan To Develop And Evaluate *Dolphin-Safe* Methods Of Fishing For Yellowfin Tuna In The Eastern Tropical Pacific."[1] Both documents stipulated that methods to reduce or eliminate dolphin mortalities can be considered successful if they result in the long-term economic viability of the ETP tuna purse seine fleet and do not adversely affect the tuna resource or other species. In this report a review of progress towards developing methods of reducing dolphin mortalities, while maintaining the current level of production in the ETP, is presented. Efforts to date have focused on the use of FADs to aggregate tuna, examination of schooling behavior and attempts to separate associations of tuna

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[1] DeMaster, D. 1992. SWFSC Admin. Rpt., La Jolla, LJ-92-16, 21 p., unpublished report.

and dolphins, and the adaptation of laser technology to locate tuna not linked to dolphin schools.

IATTC/NMFS/BUMBLE BEE SEAFOODS, INC. FAD PROJECT

INTRODUCTION

Fishermen and scientists alike have long been aware that objects floating in the ocean attract various species of fish. Fish aggregating devices (FADs) have been utilized to attract commercially important species of fish in many ocean areas. Yellowfin tuna and skipjack tuna (*Katsuwonus pelamis*) are two commercially important species of fish commonly attracted to floating objects. Floating objects may be organic materials such as trees, kelp, and dead cetaceans, or they may be discarded man-made objects such as fishing floats, derelict buoys, ropes, wooden packing crates, etc. Little is known about the attraction of tuna to floating debris in the pelagic habitat. Hunter and Mitchell (1968) thought there to be a connection between schooling behavior and attraction to flotsam. Gooding and Magnuson (1967) concluded that many fish gathered around floating objects at sea because the objects provide shelter from predation. A more recent notion is that although food and shelter may be important factors in attracting some of the species comprising the biological community around flotsam, they may not be the primary attractants. Instead, floating debris may function as links between oceanic features by providing visual cues in the optical void of the pelagic environment. Flotsam may orient tuna to the enriched water masses that flow westward from coastal areas of Central America (Arenas, Hall, and Garcia, unpub. ms.).

Although the precise mechanisms involved in the attraction of fish to floating objects are unknown, it does occur with sufficient regularity to justify research into the use of FADs to enhance fishing efforts in the (ETP). The goal of the Inter-American Tropical Tuna Commission/National Marine Fisheries Service (IATTC/NMFS) joint research project is to explore mechanisms of attracting mature tuna to FADs in sufficient quantities that fishing activity on tuna in association with dolphins can be decreased.

BACKGROUND

Drifting FADs have been deployed in the ETP by the IATTC and NMFS, with major funding provided by Bumble Bee Seafoods, Inc. The goal of this cooperative project is to aggregate mature yellowfin, skipjack, and bigeye (*Thunnus obesus*) tuna in areas of the ETP traditionally fished by the international tuna purse seine fleet. Since the early 1970s the majority of tuna landed by the purse seine fleet in the ETP has been yellowfin caught in association with dolphin herds (IATTC, 1989). If catches of tuna on drifting FADs can significantly supplement the landings of dolphin-associated tuna caught by the international tuna purse seine fleet, then fishing effort on tuna associated with dolphins and the resultant incidental dolphin mortality related to purse seine operations can conceivably be reduced.

METHODS

During the 1990 fishing season NMFS and the IATTC provided four U.S. flag and one foreign flag tuna purse seine vessel with materials to construct FADs for opportunistic short-term deployment during fishing operations. The participating vessels used their own radio buoys. Launching of the FADs was at the discretion of the captain.

During January of 1991, two identically designed FADs were deployed by the crews of the U.S. flag tuna purse seine vessels *Atlantis* and *Pamela Ann*. These first two FADs were put to sea offshore of Costa Rica (Fig. 1) and were intended to drift westward with the prevailing currents in the region (Fig. 2). Objectives of this preliminary experiment were to test the durability of FADs at sea, determine our ability to track FADs by satellite, and evaluate the efficacy of providing FAD position information to vessels at sea.

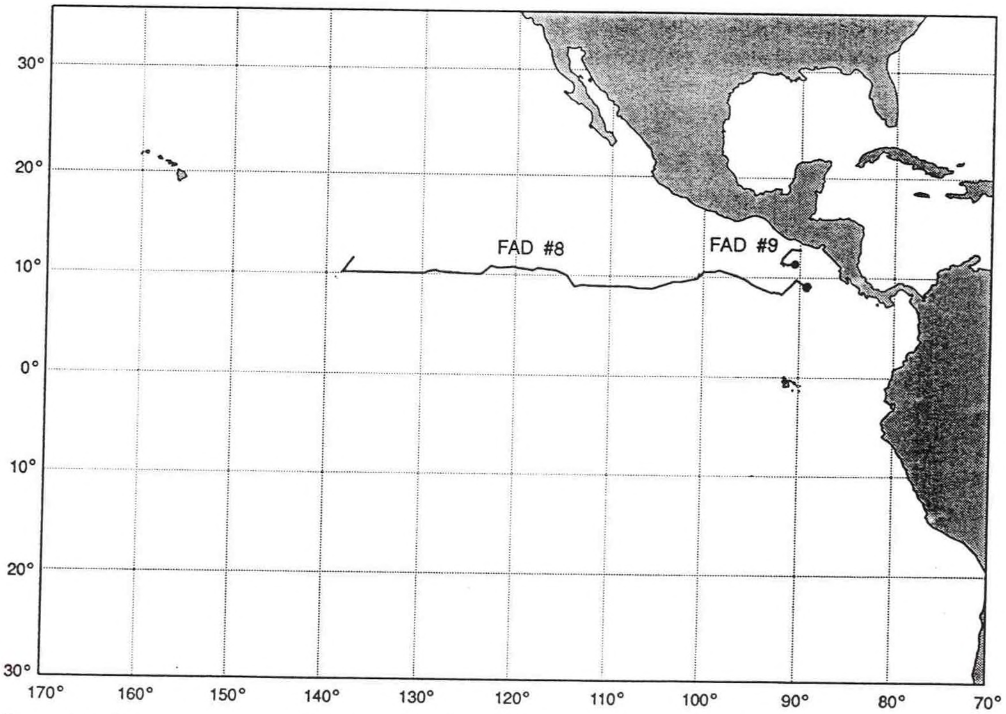

Figure 1. Deployment positions and drift tracks of long-term drifting FADs - preliminary phase.

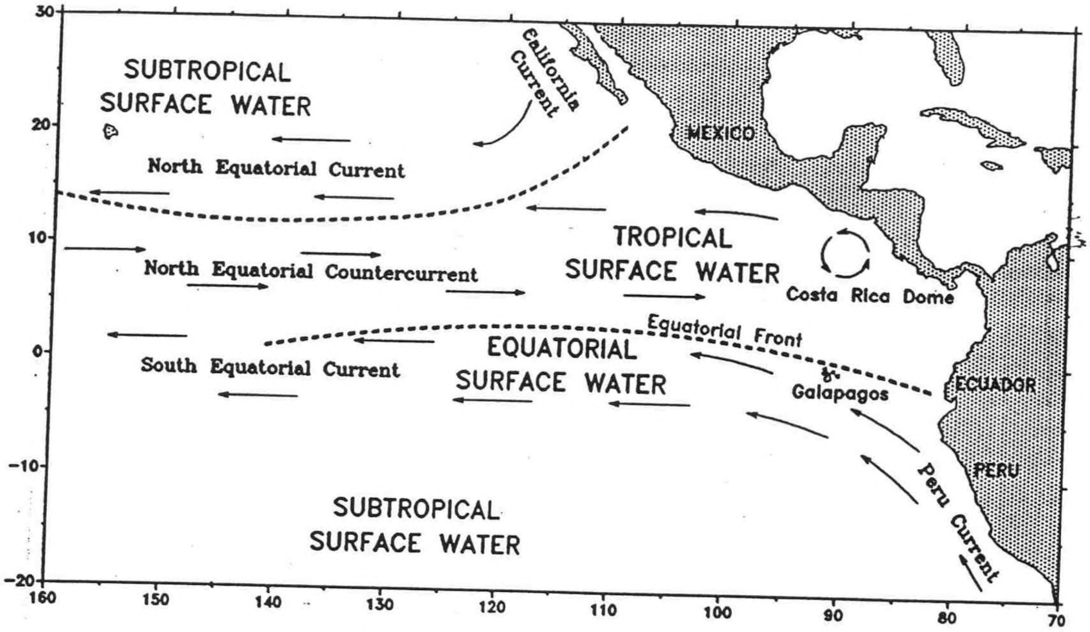

Figure 2. Schematic diagram of ETP surface currents (Fiedler *et al.* 1991).

In July of 1991 thirty FADs were positioned approximately 1,000 miles offshore of Mexico, in an area from 9°N to 11°N between 121°W and 124°W (Fig. 3). This area and the region to the west, where the FADs were expected to drift, have been established as traditional fishing grounds for large yellowfin tuna in association with dolphins. Deployment was carried out by the staff of the IATTC, with assistance from the crew of the *Altair*, a Mexican research vessel. The thirty FADs were arranged into ten groups of three identical units each. The design and construction of surface buoys and subsurface arrays differed for each of the ten groups. One FAD in each group was equipped with a satellite transmitter that provided position information through the Service ARGOS satellite system, and the other two were equipped with selective-calling (SELCALL) medium wave radio buoys. SELCALL buoys operate only when activated by a vessel's signal generator, which extends their battery life. The satellite transmitters provide positions that are accurate to within a few kilometers or less. The SELCALL radio buoys can be located by vessels at distances approaching 200 kilometers. Several FAD surface platforms were also fitted with strobe lights or radar reflectors to enhance detection by fishing vessels.

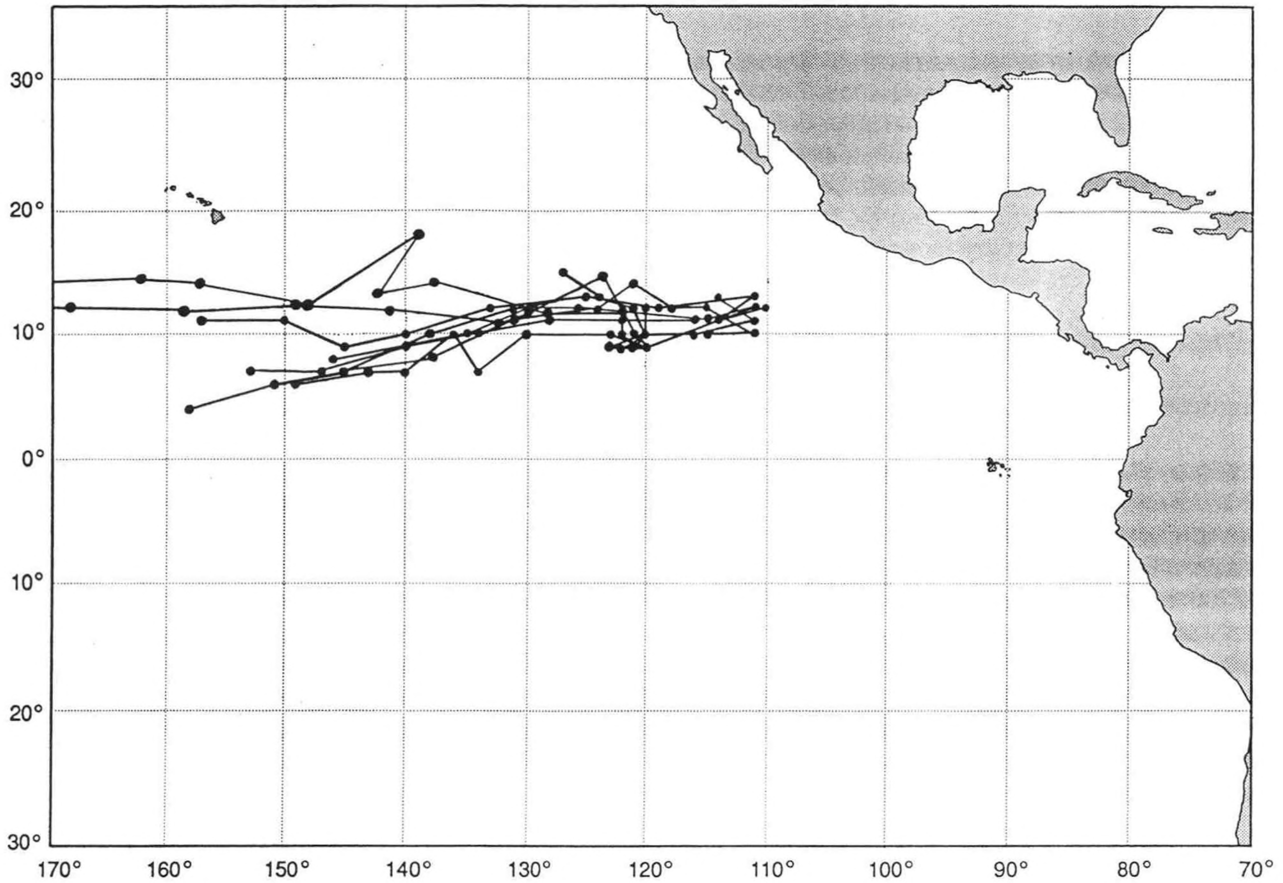

Figure 3. Deployment positions and drift tracks of long-term drifting FADs - phase one.

The three FADs within each group were deployed within a few hundred yards of one another. FADs of identical surface and subsurface construction were expected to drift at similar rates and in similar directions. Hence, even using data several days old, and given an anticipated average drift rate of less than one knot, a skipper using position information from the satellite transmitter-equipped FAD could expect to locate his vessel well within the 200 kilometer range of the radio-equipped FADs.

The FAD positions, drift directions and drift rates were tracked by NMFS and IATTC staff at the Southwest Fisheries Science Center in La Jolla, California. Daily positions were provided to vessel managers and IATTC field offices throughout Latin America. Although some vessels received this information directly from their managing offices via telex or FAX, advisories in English and Spanish were also issued from NMFS radio station KHU in San Diego and from vessel management offices in Ensenada, Mexico.

Positions of drifting oceanographic current-measuring buoys were also provided to interested members of the purse seine industry. The buoy positions were furnished by Don Hansen of the Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, Florida. Position and drift direction of oceanographic buoys are indicative of current patterns and of areas of log accumulation and concentration.

DESCRIPTION OF FADS

Shipboard FADs For Short-Term Deployment

The materials provided for the construction of subsurface arrays consisted of monofilament line, stainless steel hardware and "sea kites". Sea kites are pyramidal structures, measuring six feet on a side, and are constructed from a fiberglass pole frame and yellow "rip-stop" nylon (Fig. 4). A number of these kites are attached at regular intervals to a weighted monofilament mainline suspended into the water from a surface buoy. The pyramid shape of the kite is efficient in providing a relatively large surface area as potential habitat for smaller organisms which, in some cases, may be the only permanent residents on floating debris (Hunter and Mitchell, 1968; Arenas *et al.* 1992).

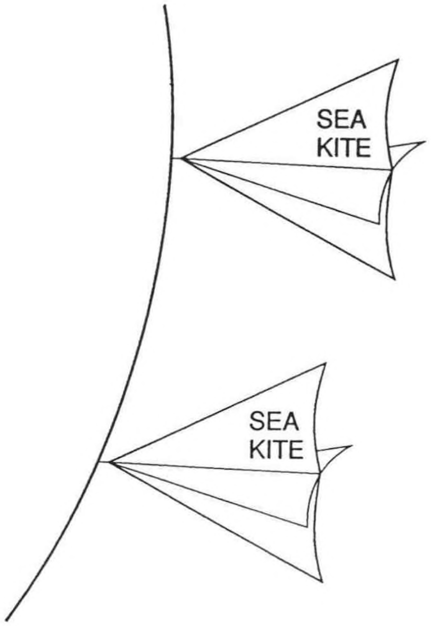

Figure 4. Schematic drawing of sea kite array.

Long-term Drifting FADs - Preliminary Deployment

The two FADs used in the preliminary deployment were designed and constructed by Coastal and Offshore Pacific Corp., Walnut Creek, California under contract to NMFS (Fig. 5). The surface platform configuration for both FADs was a blue octagonal buoy, six and a half feet in diameter, made of 8" diameter foam-filled PVC pipe. Two vertically-mounted PVC tubes on opposite sides of the platform housed the xenon strobe flasher unit with photocell controllers and the ARGOS satellite electronics and battery supply. The subsurface arrays for both FADs consisted of four polypropylene lines tied onto the surface platform at equal intervals, and connected to a 60-pound lead ballast weight at a depth of 25 feet. Thirty-inch cable ties were attached to the lines at regular intervals to increase the surface area of potential habitat for smaller organisms.

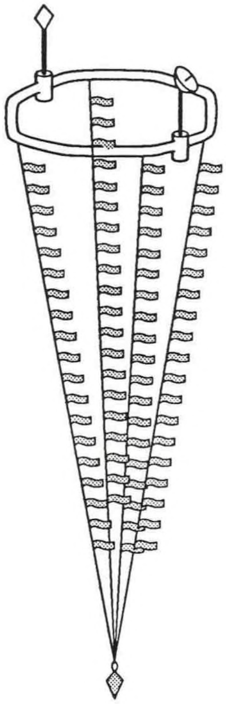

Figure 5. Schematic drawing of preliminary deployment FAD.

Long-term Drifting FADs - Phase One Deployment

FAD surface platforms were constructed in four basic configurations (Fig. 6). Groups one and two consisted of octagonal buoys six-and-a-half feet in diameter, built under contract by Coastal and Offshore Pacific Corp. They were made of foam-filled, eight-inch diameter PVC pipe, and were painted bright orange to aid in visual detection at sea. A radar reflector was mounted on the surface platform. Two vertically mounted PVC tubes on opposite sides of the platform housed the photocell-controlled xenon strobe flasher unit, the SELCALL or ARGOS electronics, and battery supply components.

Groups three, four, five and six FAD surface platforms were built under contract by the Porpoise Rescue Foundation. They consisted of a surface buoy constructed of water-sealed plywood and foam, four feet square, and six inches deep. The surface unit was painted a bright yellow. A radar reflector was mounted at the center of the platform. The SELCALL or ARGOS transmitters were housed in a standard Ryokuseisha[2] SV-CL3B buoy, modified with a flotation collar of purse seine corks. The buoy was attached to the surface platform by a stainless steel tether line jacketed in a heavy rubber hydraulic hose casing.

Groups seven and eight consisted of a foam filled aluminum buoy approximately nine feet-tall and three feet across at the widest point. These buoys, provided by AOML, were designed so that only the upper three feet of the buoy would project above the water. The upper section of the buoy housed the radio or satellite electronics and power supply.

Surface units for groups nine and ten were standard Ryokuseisha SV-CL3B buoys modified with flotation collars made from purse seine corks.

To ensure uniformity of construction within FAD groups, the ARGOS satellite transmitter packages were designed to be interchangeable with the SELCALL radio buoy electronics packages in all of the surface buoys.

The subsurface arrays were attached to the surface platforms in several configurations and extended to various depths (Fig. 6). The subsurface arrays for group two consisted of four polypropylene lines with 30 inch plastic cable ties attached at regular intervals. The lines were tied to the surface platform and terminated at a single weighted point (sixty-pound lead ball) 25 feet below the surface. The arrays for group one were the same as for group two, except that a single weighted monofilament line descending to a depth of 25 fathoms was attached below the weighted polypropylene configuration. This line had five sea kites attached at descending intervals.

The arrays for group three consisted of a single weighted monofilament line descending to a depth of 25 fathoms, with five sea kites attached at descending intervals. The upper portion of

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[2] Use of brand names or models does not imply endorsement by the National Marine Fisheries Service.

the arrays for group four were patterned after the upper arrays of groups one and two. Four polypropylene lines attached to the corners of the square surface buoy met at a depth of 25 feet. At this point a single weighted monofilament line extended to a depth of 50 fathoms. Five sea kites were attached at intervals along this line.

Subsurface arrays for group five were the same as for group four, without the descending single line of sea kites. Group six FADs were surface units only, with chain added to serve as ballast. The chain hung less than a meter below the surface buoy.

The subsurface arrays of group seven were similar in construction to group four, except that the configuration of polypropylene lines and cable ties were attached to an octagonal platform suspended eight feet below the surface buoy. This underwater suspension platform was made of three inch PVC pipe with holes drilled to allow the water to weight down the octagon and provide a substantial sea anchor.

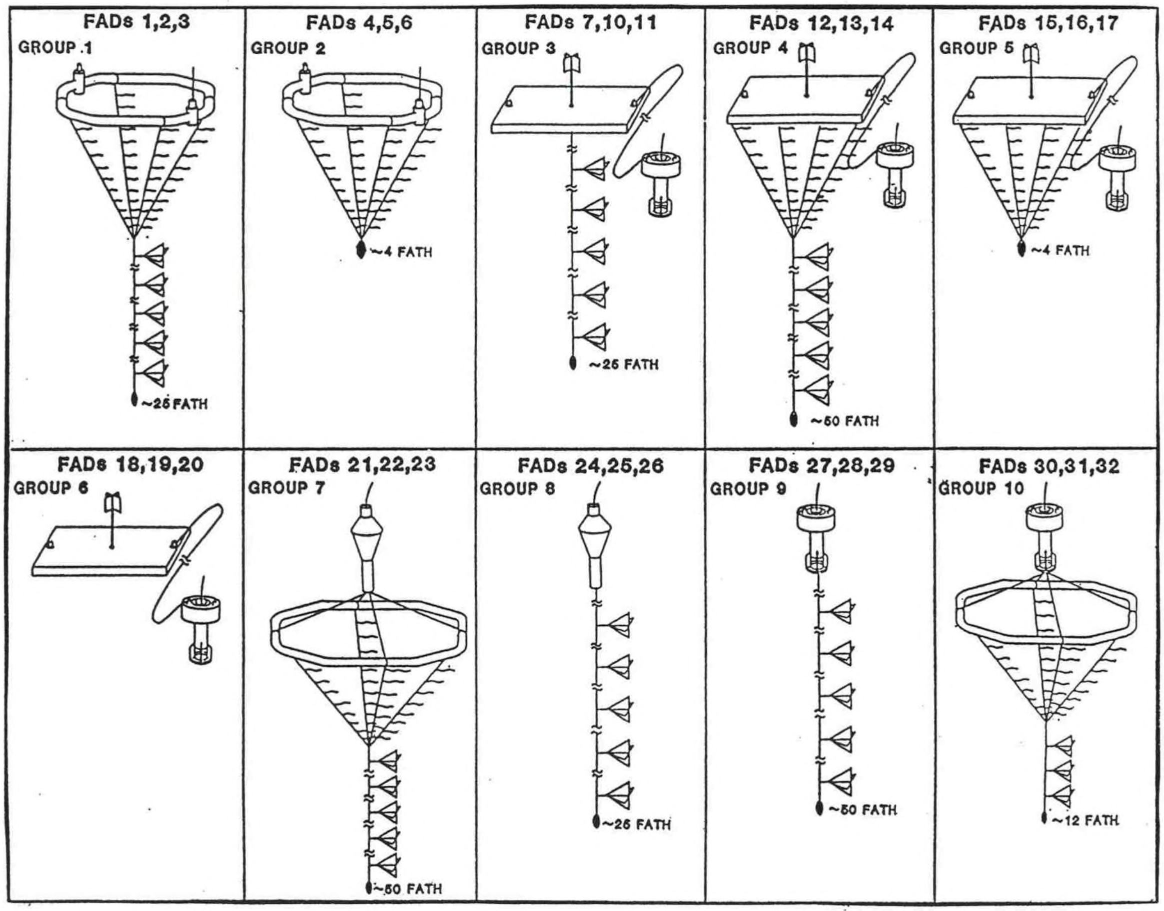

Figure 6. Schematic drawing of phase one FAD designs (IATTC sketch).

The arrays of group eight were a simple weighted 25 fathom monofilament line with five sea kites attached at descending intervals. Group nine arrays consisted of a 50 fathom weighted line with five sea kites attached. Group ten's arrays were the same as for group seven, except the line extended only to 12 fathoms and held only three kites.

Drifting Oceanographic Buoys

The buoys are constructed of a simple PVC cylinder, white in color, and they are unmarked. Descending from the buoy is a 30-foot cable and a 30-foot sea anchor of circular canvas that is weighted at the bottom (Figure 7).

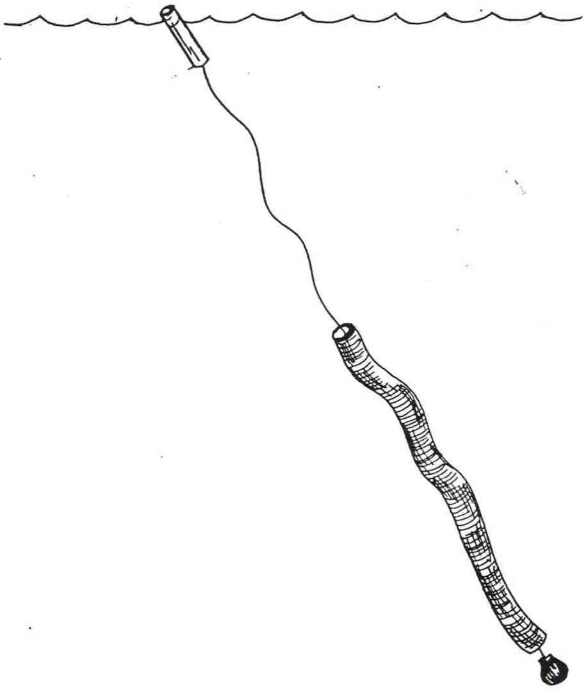

Figure 7. Schematic drawing of AOML buoy.

RESULTS

Short-term Deployment of Shipboard FADs

Subsurface arrays were attached to SELCALL radio buoys in various configurations. Three of the vessels did not release FADs. Two vessels reported a lack of concentrations of fish sufficient to warrant using FADs. Another vessel's direction finder was not functioning, making deployment of FADs with radio buoys useless because they could not be relocated. Two vessels launched a total of seven FADs which were in the water for periods of a few hours to 19 days. Several of these FADs attracted dolphin, various unidentified "baitfish", sharks, and seabirds (common and scientific designations are equated in Appendix 1). Accumulations of barnacles and pelagic crabs were also reported on the surface buoys. There were several small unidentified polyps attached to many of the sea kites. No tuna were reported in association with the FADs and no sets were made.

Long-term Drifting FADs - Preliminary Deployment

FAD #8 was deployed on 1/4/91 at 9° 00'N, 88° 05'W. It drifted in a westerly direction for 175 days and travelled approximately 2,900 miles before the satellite transmitter ceased operating. FAD #9 was deployed on 1/31/91 at 11° 21'N, 90° 35'W. It drifted on a northeasterly course for only 34 days before it ceased transmitting at 12° 44'N, 89° 53'W, near the coast of El Salvador (Fig. 1).

Observers sighting the FADs described them as being intact and in good condition. One observer's report indicated that FAD #8 may have been fished on in the interval between the two documented sets. His description confirmed the presence of only three descending lines, and reported a chain hanging from the FAD. Originally it had four descending lines and no chain. The modifications may have been made by an unknown fishing vessel.

Positions and estimations of drift transmitted to vessels searching for the FADs appear to have been fairly accurate. A set on FAD #8 was within 3 km of the position provided by Service ARGOS. The position data was three hours old when the set was made. A sighting of FAD #9 was within 30 km of the position provided. The position data was about 96 hours old at the time of the sighting. Sets and observations are summarized in Tables 1, 2, and 3.

Long-term Drifting FADs - Phase One Deployment

The thirty FADs were launched within a 24 hour period in roughly a 2° x 3° area (Fig. 3). The deployment around the 10° N latitude appeared to overlap the north equatorial countercurrent and the north equatorial current, as several of the FADs drifted in a northwesterly direction, while others, positioned a short distance away, drifted to the southeast. Those drifting to the northwest eventually turned to the west. Those drifting to the southeast circled around to the northeast, and then to the west as they encountered the westerly current near 12° N latitude (Figure 3).

Soon after the FADs were launched a series of tropical storms and hurricanes developed near the deployment site. At least four hurricanes passed directly over the FADs. Satellite transmissions were received on a regular basis throughout this period. Failure of a satellite transmitter was recorded on 11/6/91, 106 days after deployment, followed by another failure on 11/8/91. The other eight satellite transmitters continued functioning for more than 10 months. Three radio buoys also failed to respond to interrogation. It is not known whether the electronics had failed, or if the FADs had drifted more than 200 km away from their respective groups and out of range of the calling vessel.

Problems with the integrity of several of the FAD units were also experienced. Four of the tethered radio buoys were found without the FAD attached and were returned to port for examination. The tether line had broken in the same location on all four buoys, indicating a weak point in the design. The cable leading to the underwater array on FAD #30 had also broken.

The sighting position of FADs have been compared to the known satellite buoy positions for each group. All of the platforms were sighted within 110 km of the satellite buoy position for their respective groups, with only one exception (Table 4). By July 1, 1992 eight of the satellite transmitters were still functioning. The FADs had drifted steadily westward with longitudinal positions ranging from 145° W to 165° E. All but the most easterly of the FADs had drifted beyond the traditional fishing areas of the ETP. However, two of the satellite transmitter-equipped FADs apparently encountered the north equatorial countercurrent and began drifting eastward again by late June, 1992.

Sightings and catches made around the thirty FADs were similar to those made in association with the two FADs that were put to sea earlier. Sets and observations are presented in Tables 1, 2, and 3.

Drifting Oceanographic Buoys

These buoys have been designed as low profile, wave-resistant and wind-resistant drifting platforms. The low profile makes them difficult to detect at sea. However, the buoys themselves have occasionally served as effective FADs, accumulating substantial quantities of tuna around them (Table 5).

Anchored Oceanographic Buoys

Anchored buoys have been set out in the equatorial regions of the Pacific as part of NOAA's Thermal Array for the Ocean (TAO) monitoring project. Although not in any way involved with the FAD study, it is interesting to note their ability to aggregate fish. Concentrations of tuna have been sighted in association with these anchored buoys (Jim Gilpatrick, NMFS, pers. comm., 1991; Alan Parker, San Diego, pers. comm., 1992) and one set for a substantial catch of skipjack tuna has been recorded (Table 6).

DISCUSSION

The limited results with FADs fielded from purse seine vessels that were designated for short time deployment would seem to indicate little promise for this approach. However, examples from two fishing trips provide a distinctly different impression of this FAD deployment strategy.

During the fall of 1991, two U.S.-flag tuna purse seine vessels made successful dolphin-safe fishing trips in the ETP that illustrate the opportunistic approach that may be necessary to stay competitive without fishing on dolphin-associated tuna. The techniques included fishing on free-swimming schoolfish, organic flotsam, man-made flotsam, and modifying flotsam before fishing, as well as deploying FADs in areas where flotsam is scarce. The FAD data are particularly interesting because none of the FADs were left in the water longer than 27 days. The successful catch data (Table 7) indicates the importance of the choice of area and time of year when considering FAD placement.

These FADs were deployed in areas where widely scattered fish aggregations had been spotted. In many cases they were fitted with buckets of chum (fish parts) in a further attempt to concentrate tuna. Many of these FADs were successful in aggregating fish over a short period of time, and supplemented a low number of schoolfish and natural log sets that were available to the vessels. The size and species composition of the tuna were similar for all types of sets in the area for the time period when the two vessels were fishing (Table 8).

The study involving drifting FADs deployed for the long term was, on the whole, successful because the FADs remained afloat, the electronics packages functioned over a long period of time, and, according to the limited data, they were moderately effective in attracting tuna. Designing FADs to withstand lengthy deployment periods on the open ocean with their electronic apparatus functioning must be considered as one of the key factors in the overall success of the project. Only one FAD was lost shortly after deployment. The others drifted more or less as predicted. Results indicate that structuring groups of radio buoy-equipped FADs around a single satellite transmitter-equipped FAD can be an appropriate deployment strategy. There are a number of possible causes for the anomalous positions of the single FAD that was found well away from the satellite transmitter of its original group. First, it may have encountered a different current than the other FADs in the group despite the close proximity of deployment. Second, it may have lost all or part of the sub-surface array, causing it to drift at a different rate than the other units in the group. Third, tethered radio and satellite electronics appear to be susceptible to breaking away from the FAD buoy itself. There is also a possibility that the FAD may have been picked up by a vessel and re-deployed without our knowledge.

The surface circulation of waters in the ETP vary in response to shifting of the dominant wind patterns in the region (Wyrtki, 1965). There has been speculation that an El Niño event in 1992 may have influenced the position of the equatorial counter current (F. Miller, IATTC, pers. comm., 1992). Future FAD placements will similarly be based on general knowledge of drift patterns, subject to annual variations that are difficult to predict. Another option is to use anchored FADs, a fairly difficult task in the deep waters of the ETP. Expenses in terms of the FADs themselves, maintenance of the FADs and ship time necessary to conduct specialized deployment and maintenance operations necessary to support anchored FADs are important fiscal limitations to their use.

The size range of the yellowfin tuna caught in association with FADs to date has been similar to the size range of tuna historically caught on logs. Generally, the majority of yellowfin caught in association with floating objects are under 60 cm. in length and weigh less than 6.5 kg. (IATTC, 1989). As has been documented in previous studies, tuna caught in association with flotsam are highly variable in size (Greenblatt, 1979). Larger fish were occasionally caught in association with FADs, but the majority of the yellowfin catch was of immature fish. The skipjack catch consisted of substantial amounts of immature fish as well. The efforts to deploy FADs in traditional dolphin-fishing grounds where mature yellowfin are caught have not led to sets that yielded catches of large yellowfin, although the number of sets was small and not sufficient to warrant any final conclusions.

The by-catch of non-commercial species in association with FADs is also representative of log fishing in general. While at times highly successful, fishing on floating objects clearly has more direct impact on a greater variety of species than does fishing on dolphin-associated tuna. The consequence of a large-scale shift to FAD fishing in terms of harvesting greater quantities of immature fish and associated non-commercial species deserves consideration.

The importance of increased fleet involvement with the FAD project cannot be overemphasized. In order to accurately assess the effectiveness and economic viability of FAD fishing in the ETP, it is essential to expand vessel involvement and associated collection of detailed and accurate information on the location, species sighted, the size range and the species composition of catches made on FADs.

The future plans for the project include the deployment of Phase 2 long-term drifting FADs in equatorial waters in November 1992. The IATTC is considering an expansion of the present FAD project to a much larger program. This could mean a greater number of FADs deployed, more direct involvement of IATTC member nations, and possibly, scheduled visits to the FADS by purse seine vessels.

CRUISE REPORT, M/V *HORNET III*
27 May, 1991 - 12 July, 1991

INTRODUCTION

An opportunity to investigate the potential for the separation of tuna and dolphins was provided by Mr. Roland Virissimo, the owner of the tuna purse seine vessel *Hornet III*, with the financial support of the U.S. Tuna Foundation and cooperation from NMFS. Mr. Virissimo's interest was in investigating the possibility of using dolphins to locate yellowfin tuna, but his goal was to separate the dolphins and the associated tuna school just prior to the set and to encircle only the fish. In this way the tuna resource could be utilized in the traditional manner of finding mature yellowfin tuna by locating dolphin herds, but it would eliminate associated dolphin mortalities and the subsequent rejection of such tuna from U.S. canneries. This idea was based on a single experience he had while on a fishing trip aboard the M/V *Hornet III* during which some approaching killer whales (*Orcinus orca*) apparently frightened an aggregation of spotted and spinner dolphins. Mr. Virissimo proposed that NMFS work with his vessel to experiment with killer whale sounds broadcast underwater as a means to disperse dolphin herds so that only the fish would be captured by the purse seine. The incident referred to occurred on February 18, 1988 during NMFS cruise #1123 and is documented by observer data. The set was made on an estimated 30-40 tons of yellowfin tuna which remained in a compact schooling configuration after the dolphin herd, apparently reacting to the approaching killer whales, disintegrated as individual animals swam away in all directions in an attempt to escape. The seiner approached the fish and they stayed together long enough for a set to be made.

During this cruise, NMFS cruise #1418, attempts were made to alter the close behavioral association of yellowfin tuna and northern offshore spotted dolphin (*Stenella attenuata*) and whitebelly spinner dolphin (*Stenella longirostris*) by (1) acoustical broadcasts intended to alter the behavior of the tuna and dolphins; (2) the chumming of squid to induce feeding behavior in tuna; (3) the use of a commercial fish attractant recently introduced and being promoted by the manufacturer to the U.S. tuna purse seine fleet; and (4) various combinations of acoustics, attractant and chumming. Ancillary work included opportunistic underwater behavioral observations of tuna and dolphins in the net and the collection of stomachs of dolphins, yellowfin tuna and skipjack tuna for comparing prey species taken.

The cruise was originally scheduled to operate in the coastal areas of central America so that experimental efforts could be directed toward herds of "untouchable" dolphins. Although, as the name implies, these herds are notoriously difficult to keep inside the net, they are generally easy for the seiner to approach initially. Spotted dolphins in these areas are even known to approach vessels and ride the bow, a behavior which is very rarely observed in offshore areas. It was reasoned that the closer the seiner was to the tuna-dolphin aggregation, the more effectively any pre-set separation achieved could be exploited. Delays in shipyard maintenance, however, put the departure of M/V *Hornet III* out of phase with optimum fishing opportunities nearshore, and a trip farther offshore was planned. Despite this change of strategy, a decision to proceed with the experimental portion of the fishing trip was made.

The *Hornet III* departed from Ensenada, Mexico on May 27, 1991 and it arrived to unload in Panama City, Panama on July 12, 1991. The vessel headed directly for the fishing grounds "outside the line,"[3] and fished in the area from 8°N to 11°N between 130°W and 140°W.

VESSEL AND EQUIPMENT

The *Hornet III* was built in 1971 and is 220 feet in length. Depending on the size of fish and the manner in which it is packed, the vessel can carry 900-1075 short tons of tuna. All fishing gear was conventional in comparison to the current U.S. tuna purse seine fleet, except that a new brailing system was installed and modified during the course of the cruise. This brailer was positioned atop the purse davit, and was completely controlled from the seiner, with no involvement from the seine skiff in the traditional method. The capacity of the brailer, depending on the size of fish, was 4-5 tons, as compared to 1-3 tons for a standard brailer operated from the skiff. The net on this trip was 760 fathoms long, 18 strips deep, with 180 fathoms of porpoise safety panel (1 1/4-inch mesh), two strips deep.

The research equipment and materials assembled for this cruise included Hodgson's "Fish Frenzy" fish attractant (compressed grain in the form of small logs treated with unspecified chemicals), frozen market squid purchased in Ensenada, and a waterproof buoy containing a Realistic Minisette tape player, Orion 250SX amplifier, Kenwood TM-241 "2 meter" radio designed to be remotely activated from the radio in the helicopter, Powersonics PS-12260 battery, and a Dacor DF-3 Xenon gas strobe light for remote verification of proper system operation. Completing the system was a USRD type J-9 transducer suspended from the bottom of the buoy, and a collar of net corks to ensure upright flotation of the buoy (Figure 8). A series of playback tape recordings were assembled for use during the cruise. The recordings were made on 12 minute continuous loop tapes to simplify operation.

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[3] Refers to the IATTC regulatory area for yellowfin tuna.

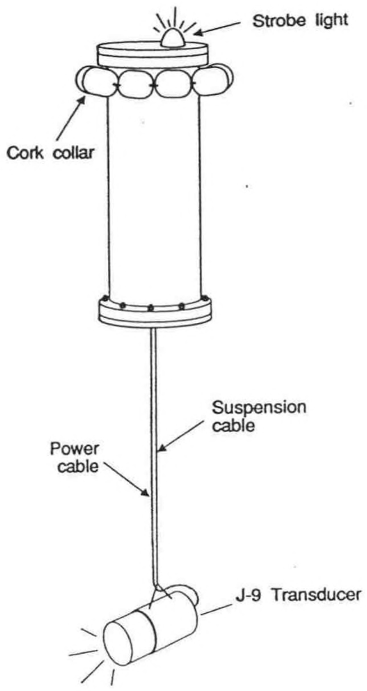

Figure 8. Schematic drawing of the acoustical broadcast buoy.

CRUISE STATISTICS

An estimated 14,600 dolphins were pursued and 13,300 were encircled and captured in 29 sets on tuna associated with dolphins. An estimated 969 tons of yellowfin and 34 tons of skipjack tuna were loaded aboard (Table 9). Acoustic tests were conducted on five sets, chemical stimulant was used on three sets, chemical stimulant together with squid chum was tried on two sets, and underwater behavioral observations were recorded for twenty-eight sets (Table 10).

TUNA-DOLPHIN SEPARATION EXPERIMENTS

Several researchers have reported evasive or avoidance reactions from dolphins and other marine mammals in response to playbacks of killer whale vocalizations (Perrin, 1971; Fish and Vania, 1971; Cummings and Thompson, 1971; Dahlheim, 1987). Aggressive behavior of false killer whales (*Pseudorca crassidens*) towards dolphins and avoidance reactions by the dolphins has been recorded by tunaboat observers on occasion (Perryman and Foster, 1980). Accordingly, playbacks of these two predators were prepared. Because it has been shown that different geographic stocks of killer whales differ in their vocal characteristics (Awbrey, Thomas, Evans and Leatherwood, 1982; Ford and Fisher, 1982; Moore, Francine, Bowles and Ford, 1988), an attempt was made to acquire playbacks from several different areas, including, when possible, those from the ETP. Vocalizations from Icelandic stocks, from Prince William Sound, Antarctica, British Columbia, and from the Sea of Cortez were obtained. For false killer whales, only recordings from the ETP were prepared. In addition to the predator vocalizations intended to disperse herds of dolphins, recordings of tuna (provided by Hubbs-Sea World Research Institute) and a recording of an ETP tuna-dolphin aggregation (a sonobuoy recording from a SWFSC Monitoring of Porpoise Stocks cruise) were prepared. These were obtained with the hope that they might help to serve as an attractant to the tuna.

For a variety of reasons, the opportunity to attempt pre-set separation of tuna and dolphins was not realized on this cruise. The inability of the seiner to approach dolphin herds closely in the offshore areas fished and periods of rough weather were the primary operational difficulties. Another contributing factor was the long delay that the vessel had in the shipyard, with the resultant atmosphere aboard being that "making a trip" was a priority, while the research project was secondary to the capture of tuna. However, efforts to attract tunas within the net after encirclement of the dolphin-tuna aggregation were made, with the weather, the time of day and the presence of sharks as the only limiting factors.

REACTION OF DOLPHINS AND TUNA TO INTRODUCED STIMULI

Set #4

The acoustical buoy was deployed and activated at 1729 hours, during pursing. The buoy was tied to the corkline 21 fathoms beyond the outboard bow bunch. Tuna sounds, consisting of a series of "pops" and "clicks", were broadcast throughout pursing and net roll. The broadcast was audible to the observer at a distance of at least 10 meters even in the presence of the noises produced by the speedboat, skiff and seiner during the set. It is not known whether the tuna could discern the sounds. However, observations of sharks approaching the transducer from beyond the visual range of the observer indicates that they could detect the broadcast from greater distances. Utilizing a mask and snorkel, observations were made from a life raft tethered to the corkline adjacent to the buoy. Nothing was seen for several minutes. At 1731 periodic slow passes by yellowfin tuna and 1 unidentified marlin began. These were repeated every 1-2 minutes. During these passes many of the yellowfin would roll on their sides within 2-4 meters of the transducer and the observer. The dolphins were only rarely visible from this position and they approached no closer than approximately 10 meters.

From the vantage point of the observer at the surface it was not clear whether the tuna were influenced by the broadcasts, or if they were simply passing near the transducer as a result of their periodic forays around the net. The skipper, observing from the bridge, felt that just prior to and during backdown the tuna abbreviated their typical "pacing" behavior up and down the backdown channel, ostensibly in reaction to the broadcasts. His comment was that they tended to "swirl" and remain relatively stationary in the vicinity of the buoy. This could not be verified with any certainty from the water. The skipper was encouraged and felt that this perceived "stationing" of the tuna would be helpful in the backdown process.

The broadcast was terminated at 1819, just prior to the end of backdown.

Set#5

The observer entered the water with the raft and 5 "logs" of fish frenzy, and approximately one kilo of thawed squid just prior to "rings up"[4]. The observer tethered the raft to the corkline at the stern end of the porpoise safety panel at 1335 and deployed two free floating corks with two logs of the fish attractant attached to each. Squid was slowly chummed in the same area as the dissolving logs. No fish of any kind were seen for a period of 15 minutes. At 1350 the observer paddled the raft and one free floating cork with attractant attached to the vicinity of dolphins in the area of the 1/2 net buoy. The tuna were observed swimming near to and under the dolphins. A fifth log was thrown into the water without a flotation device, but floated on its own initially. Chumming was resumed for another 12 minutes. As backdown approached, the raft and attractant were re-positioned on the bow side of the backdown channel, and then chumming resumed. All of the logs continued to dissolve during the course of the set and pieces of the dissolving compressed product could be seen at various depths. On several occasions individual fish were observed to approach fragments of the attractant or the squid for inspection. Fish were not observed mouthing or eating any of the offerings, and no gatherings or movements of groups of fish were observed. Observations from the tethered raft during this set resulted in fewer sightings of tuna than on the previous set. One possible reason for this is that only about 28 tons of tuna were encircled as opposed to 40 tons of tuna encircled on set #4.

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[4] A point in the set sequence when the rings through which the purse cable runs are hauled up along the side of the seiner signalling the closing of the bottom of the purse seine.

Set #6

The acoustic buoy was deployed and activated at 1040 during net roll. The position of the buoy was the same as in set #4. The tuna feeding broadcast was again used. At 1042 the tuna school was sighted passing about seven meters from the buoy. Two yellowfin tuna left the school and swam directly toward the transducer, followed closely by an unidentified shark. The tuna turned and swam away after coming within one or two meters of the transducer; the shark remained in the area for 15-20 seconds and then swam in the same direction as the tuna. At about 1044 another unidentified shark approached the transducer, but this time from outside the net. After lingering near the transducer for thirty seconds or so, it too swam away. After four or five additional nearby passes by the schooling tuna a group of five unidentified sharks approached from inside the net and lingered near the transducer for about 45 seconds before swimming away. During backdown the skipper again noted what he interpreted as a lessening of the pacing behavior of the tuna relative to the broadcast. The broadcast was switched off during the backdown maneuver at 1055. At this point, the backdown channel was collapsed and the movements of the tuna were relatively restricted.

Set #8

The acoustic broadcast buoy was tethered in the same position as before on the bow side of the backdown channel and activated just after rings up. The tuna feeding sounds were employed once again. No tuna were sighted until 0953, 18 minutes after the tape was switched on at 0935. Four separate passes by the entire tuna school swimming within about 10 meters of the buoy and observer were noted. The tuna, about 12 tons of fish were encircled this set, stationed themselves directly under or within two or three meters of the vertical plane of the dolphin herd for the rest of the set until the backdown procedure started. The broadcast was terminated at 1005, midway through the backdown operation as the channel was collapsing.

Set #11

The observer entered the water at 1051, just before rings up. The observer paddled the life raft towards the dolphins and located the tuna which were swimming directly under and nearby to the tightly aggregated herd of dolphins. Three logs of "Fish Frenzy" were thrown directly into the water, where they floated within a few feet of the surface as they slowly dissolved. Two additional logs were tied to the raft, and one log was soaking in the raft and intermittently swirled in the water to disperse the dissolving particles. A total of two kilos of squid was chummed as well. After 40 minutes, the choppy seas and the motion of large swells had completely dissolved the logs of fish attractant. Nothing more than behavior characterized as mild curiosity by the tuna was observed. Tuna did approach floating and sinking pieces of the fish attractant product and squid, but no mouthing or eating behavior was observed. There were no concentrations of fish, appearance of feeding bars, or other evidence of arousal or attraction by the tuna.

Set #15

The acoustic buoy was deployed 21 fathoms beyond the outboard bow bunch and activated at 1326 during the pursing process. The recordings of an ETP spotted dolphin-tuna aggregation was broadcast. In this recording, all that was audible to the human ear were the whistles and clicks of dolphins and the occasional ripple of water against the sonobuoy itself. There did not appear to be any reaction to the broadcasts from the dolphins or the tuna during this set. Although there was significantly more fish in the net than on previous sets, none of the fish were observed passing near the transducer. No fish were visible from the observation position near the buoy until the net roll had considerably reduced the volume of the net, and then the fish were visible only when the dolphins also came into view. There were no observations or comments by the crew that indicated the tuna reacted in any way to the broadcasts during this set.

Set #17

The observer entered the water with the raft and the chemical attractant at 1135, just after rings up. On this occasion the logs of attractant were broken up into small pieces which were about two inches square so they could be scattered over a wider area. After the observer approached the dolphins and visually located the tuna, the attractant was dispersed. The same curious reaction by the tuna to the objects floating or descending slowly through the water was observed. Once again the tuna did not seem to be aroused, they did not congregate near the fish attractant, and they were not observed to eat the fish attractant particles dispersed in the water. They continued to school near to and under the dolphins, occasionally venturing away as a group and returning once again to the area close to the dolphins.

Set #18

The acoustic buoy was secured to the corkline 21 fathoms outside of the outboard bow bunch. The recording of ETP spotted dolphin-tuna aggregation was activated at 1410, just before rings up. At 1412 an oceanic whitetip shark (*Carcharhinus longimanus*) and an associated pilotfish (*Naucrates ductor*) appeared from inside the net and headed straight for the buoy. After three direct passes within a few inches of the transducer the shark moved off and was not seen again. At 1434 and again at 1435 what appeared to be the entire school of yellowfin tuna passed within about eight meters of the buoy. From 1438-1441 schooling skipjack tuna made continuous passes within six or eight meters of the transducer. The groups of yellowfin tuna and the smaller skipjack tuna were observed to be separate and segregated by species and/or size.

BEHAVIORAL OBSERVATIONS

Behavior of captured tuna and dolphins was observed on 28 sets. Observations were conducted underwater inside the net using a two man raft, mask, fins and snorkel. Generally, the observer entered the net during pursing operations, proceeded towards the region of the net where the dolphin school was aggregated, and remained in the water through the entire backdown procedure.

Dolphins

Captured spotted dolphins were aggregated as one group in all of the observed sets. The spinner dolphins were somewhat segregated from the spotted dolphins or were observed to form a subgroup within the spotted dolphin group. Dolphins were never observed to come into contact with the corkline or webbing, except during the backdown operation. Captured tuna oriented themselves away from the corkline, either below or to the side of the dolphins. Dolphins would often "raft"[5] as small groups momentarily, but the majority of the dolphins remained constantly in motion. In contrast to previous reports (Bratten *et al.* 1979), the dolphins did not appear to fear swimming in close proximity to the fish, and were often seen diving amongst 20-150 pound yellowfin tuna. On one occasion a mother and calf were observed swimming at the same level, about 20 feet deep, but in the opposite direction to an estimated 40 tons of yellowfin. Their behavior was relaxed and unhurried as the school of large fish parted and moved closely by them.

During backdown the dolphins grouped together in an even tighter aggregation, apparently in reaction to the decreased circumference of the corkline. Only in the confines of the backdown channel did the dolphins exhibit any perceptible avoidance behavior to the tuna. This may have been due to the scarcity of swimming space when many tons of large tuna are packed into a relatively small space with several hundred dolphins. During this trip it was observed that even in the confined quarters of the backdown channel the tuna only occasionally came into contact with a human swimmer (a few light bumps were experienced over 28 sets). Similarly, tuna were not observed to come into contact with the dolphins except when swimming space was reduced during backdown.

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[5] Rafting is a behavior where the dolphin orients itself perpendicular to the surface with the beak and melon out of the water, displaying little or no motion.

On most sets the majority of dolphins were backed out in a few large groups over the course of a few minutes. In every set it was necessary to hand release animals that were not backed out successfully. Often a group of 15-20 spotted dolphins would form a "cone" from the surface to the bottom of the backdown channel and immediately adjacent to the apex. The cone consisted of a greater number of animals near the surface and a decreasing number descending down to the bottom of the backdown channel. These groupings did not appear to be age specific; spotted dolphins of all color patterns (neonates, two-toned, speckled, mottled, and fused) were involved on various sets. Spinner dolphins were not observed to exhibit this behavior. However, spinner dolphins were not present on every set, and when present were always in the minority. These cones of spotted dolphins appeared disoriented and exhibited passive behavior. Although the corkline was often submerged a meter or more, they acted oblivious to the opening at the apex of the backdown channel or to the rest of the herd escaping and swimming away from the net. When this type of assembly occurred at the apex of the backdown channel aggressive herding and hand release by swimmers was necessary to release the dolphins. "Sleepers" (animals exhibiting passive behavior and positioned lifeless near the bottom of the net) (Norris, Stuntz and Rodgers, 1978; Coe and Stuntz, 1980) often had to be retrieved from the bottom of the backdown channel and pushed beyond the submerged corks or over the corkline on the surface. Once brought to the surface these sleepers would again display active behavior.

The importance of two rescuers during backdown, one actively hand releasing dolphins from the net and one herding animals from a position between the apex of the backdown channel and the vessel, was a critical factor in reducing dolphin mortality in many of the sets. The entire herd or, more commonly, smaller groups of dolphins would often turn away from the apex and swim towards the vessel. At these times it was important to drive them toward the apex by paddling the raft back and forth across the width of the backdown channel. Working with only one rescuer or no rescuers would severely decrease the efficiency of dolphin release procedures.

No reactions by the dolphins were observed in response to the various stimulants introduced into the water. The dolphins never approached the observer in the net, and would calmly avoid contact as they were approached by swimmers.

Tuna

The skipjack and yellowfin tuna appeared to orient themselves near the dolphins within the net. They often ventured 20-30 meters away during their passes around the net, but the fish always returned to the vicinity of the dolphin herd. Most of the time the tuna could be seen within an estimated 10-15 meters of the surface.

Occasionally they were observed to be rising up from greater depths after disappearing from sight for a short period of time. Smaller (<70 cm.) yellowfin tuna and skipjack tuna, when they were present, appeared to form their own group in the net separate from the larger yellowfin. The school as a whole had similar movements, but the smaller fish consistently swam in a subgroup. When the fish were concentrated in the backdown channel the larger yellowfin invariably occupied the upper layer near the surface and positioned themselves away from the mesh floor of the backdown channel. The smaller yellowfin tuna and the skipjack tuna swam below and/or behind the large yellowfin tuna. Tuna of all sizes were observed to display greater movement just prior to and during backdown than did the tightly grouped and relatively stationary dolphins. Tuna consistently swam up and down the backdown channel as though pacing in a confined area. This pacing at times took them 30-40 meters away from the dolphins and well out of sight of the observer stationed near the apex of the backdown channel. The relative ease with which the tuna and the dolphins could be physically separated by means of a net shield of some sort during backdown was clearly apparent on many occasions. Prior to backdown it did not appear that an opportunity to separate the tuna and dolphin would present itself with any degree of predictability, as the tunas movements before backdown seemed to be more random and circular with the dolphins used as a general point of bearing.

Despite the observations of the captain, the observer could not definitely attribute any behavior of yellowfin tuna or skipjack tuna to the underwater broadcasts of dolphin-tuna aggregations or tuna feeding sounds. A likely explanation for the fish passing close to the transducer was the shrinking volume of the net as it was rolled aboard. On some of the sets during which the broadcasts were employed there did seem to be a greater number of passes of schooling tuna in the immediate vicinity of the observer than when compared to sets without broadcasts. However, no conclusions can be drawn because of the small sample size and absence of controls. On set #18 it was interesting to note that the yellowfin tuna and skipjack tuna swam by the transducer repeatedly in separate groups, each of substantial tonnage. The only animals that appeared to be unquestionably attracted to the broadcasting transducer were the various species of sharks. In all cases observed their behavior seemed to indicate a short period of interest, which soon subsided. As has been demonstrated in previous studies (Bratten *et al.* 1979) the reaction of captured tuna to chemical attractants or non-living food items was either short lived or non-existent.

During this cruise tuna and dolphin were never observed escaping through the towline or out of the bottom of the net prior to pursing. The only tuna that were observed avoiding capture were those in association with dolphins that evaded the net circle and those that escaped over the lowered corkline during backdown.

On several sets tuna were observed to be gilled from the outside of the net facing inward. Given the consistent avoidance of the net exhibited by the tuna after encirclement, it seems likely that they can clearly detect the mesh. One might question why they would gill themselves from the outside. A possible explanation would be that their instinct to maintain a link with the school, and/or the bond with the dolphin herd during the chase, surpasses their wariness of the net.

STOMACH CONTENTS

Stomach contents of yellowfin tuna, skipjack tuna, spotted dolphins and spinner dolphins were collected during set numbers 3, 6, 9, 10, 16, and 21. There were a total of 12 spotted dolphin stomach samples, 7 spinner dolphin stomach samples, 9 yellowfin tuna stomach samples, and 7 skipjack tuna stomach samples. The analysis of stomach contents will be done in conjunction with an IATTC study on the food habits of tuna, dolphins, and associated species.

DISCUSSION, RECOMMENDATIONS & QUESTIONS FOR FUTURE RESEARCH

The difficulties of conducting a complete research effort aboard a working tuna purse seine vessel surfaced again on this cruise, much as they have in the past. Although a tuna seiner is ideally suited for locating, capturing and observing tuna and dolphins, the economics of a vessel worth several millions of dollars which is outfitted with hundreds of thousands of dollars worth of fuel and supplies, and the added pressure to provide a living for the fishermen and their families places certain demands on the daily activities aboard. The resulting limitations on research efforts that do not support, and sometimes conflict with, fishing operations are unavoidable unless the costly option of dedicating vessel time strictly to research can be arranged. Additionally, although crew assistance was invaluable, the limitations of a single investigator working alone became increasingly apparent as the cruise progressed.

During the time period preceding this cruise, the application of Hodgson's "Fish Frenzy" had been advocated by several prominent members of the U.S. tuna purse seine community. It had been tested during fishing operations by a few skippers based on optimistic declarations of its effectiveness on tuna, but it had not been scrutinized in an organized manner. The problem of affecting the behavior of an active fish such as tuna in an environment of very large volumes of water, unpredictable currents, and the resultant dilution of any chemical attractant suggests problems in effective application. Therefore, experimental application within the relatively controllable confines of a purse seine where extended observations of behavior could be conducted was a practical necessity. Conversely, the artificial confinement provided by the net itself precluded observations in an entirely natural setting. No perceptible reaction of yellowfin tuna, skipjack tuna, dolphins or sharks to the attractant was observed on this cruise.

Strong reactions from sharks both within and outside of the purse seine indicated that they were aware of the acoustical broadcasts and, at least initially, were attracted to them. This attraction occurred despite the presence of many extraneous sounds emanating from the fishing operation, i.e., main engine noise, skiff engine noise, speedboat motor noise and hydraulic pump noise. Reactions from the tuna to the broadcasts employed were more ambiguous. A previous study indicates that underwater broadcasts of prey organisms have had some effect in attracting predators (Yoshinabu, 1975). Recordings of bullet or frigate mackerel (*Auxis* spp.) or other important prey items (Perrin, Warner, Fiscus and Holts, 1973) of yellowfin tuna might be worth testing as an attractant to tuna associated with dolphins or in attempts to enhance tuna aggregation around logs and FADs.

The importance of hand release in reducing dolphin mortalities has been known for some time. Several very skillful skippers in the U.S. fleet have utilized extensive hand release efforts to further reduce their individual incidental dolphin mortality rates. As previously described in the report, every set observed on this trip required varying degrees of hand release to achieve zero or reduced mortality. However, the limitations of rescuers with masks and snorkels was also evident on several occasions. Entering the purse seine during a set on the high seas to rescue dolphins can be dangerous, but because it is an effective method to reduce incidental dolphin mortality most skippers employ hand release as a standard practice during fishing operations. Methods of reducing the danger and increasing efficiency of hand rescue are desirable. Use of portable SCUBA gear could make hand rescue safer and more effective. Compact SCUBA equipment with 15-20 minute breathing capacity is commercially available for under U.S. $200.00. A compressor for filling the tanks so that they could be used on successive sets would have to be purchased by the owner of the purse seiner, or compressors already used aboard the ship for other functions could be modified to suit this purpose.

Observation of captured tuna and dolphins leads to other questions that may be meaningful factors in describing this behavioral association:

- Why do some sets on tuna-dolphin associations result in catches of only yellowfin tuna, while similar sets yield yellowfin and skipjack tuna?

- Why do skipjack and small yellowfin partition themselves from the larger yellowfin? (or large yellowfin from small yellowfin and skipjack?)

- Why is there consistently a group of dolphins that refuses to swim out of the backdown channel voluntarily even when the majority of the herd has escaped over the lowered corkline?

- Does the behavior of the tuna in the net in relation to the dolphins in the net resemble the behavior of tuna and dolphins that are not encircled by a purse seine?

- Occasionally a single fish was observed turning away from the school and swimming far enough away to be out of visual range of the observer. How acute is tuna vision? How do individual tuna come to associate with other tuna and/or dolphins in the open ocean. Are other sensory organs are used?

- Why do tuna associated with dolphins rarely escape through the open bottom of a purse seine or through many yards of towline where there is no net barrier? (Tuna that are not associated with dolphins or floating objects are notorious for swimming out through the towline, swimming under the boat between the open purse cables, and even over a partially submerged corkline resulting from rapid pursing).

- Tuna reportedly have excellent vision and are observed to carefully avoid coming into contact with the net after capture. Why do they sometimes gill themselves from the outside of the net (facing in) as the net is being dropped around a dolphin herd?

- Why do similar sized, single-species dolphin herds in the same geographical area have extremely varied amounts of associated tuna?

DEVELOPMENT OF AN AIRBORNE LIDAR SYSTEM FOR DETECTING TUNA

INTRODUCTION

Most of the tuna located by purse seine vessels are detected by visual cues that fishermen observe at or near the surface. Deep swimming tuna are caught by longline vessels using baited hooks. Longline fishing is labor intensive with lower catch rates in comparison with purse seine fishing, and therefore is less lucrative.

Tuna are often attracted to naturally occurring logs or other floating debris. Tuna also swim in association with various species of whales, sharks and dolphins. Birds are commonly associated with all types of surface schooling behavior exhibited by tuna and provide one of the most reliable cues indicating a feeding aggregation that includes tuna. Although tuna are often found with other species or floating objects, they are sometimes found alone, as free-swimming schools. Such schools can occasionally be seen finning at the surface, disturbing the water by swimming close to the surface, or actively breaking the surface when feeding. Tuna swimming deeper are rarely detected unless a surface cue provides evidence of their presence below. In this report progress towards the application of light detecting and ranging (lidar) technology to improve searching efficiency for tunas that are not in association with dolphins or other surface cues is presented.

CONCEPT

Efforts to develop techniques for probing of the environment with lasers have been made since the advent of the laser. Lidar systems use a laser to generate a short pulse of light. As the pulse of light travels through the atmosphere or water backscattered light, reflected from objects encountered by the laser, is collected by a receiving telescope, then collimated, filtered, measured and recorded. Vertical probing of the atmosphere with a lidar has been used to detect clouds and aerosol layers (Fioco and Grams, 1964). Downward-directed lidar has been used as a bathymeter (Banic, Sizgoric and O'Neil, 1987). Airborne lidar systems have potential application in profiling sub-surface schools of pelagic fish (Squire and Krumboltz, 1981), and may be useful for species identification as well (Churnside and McGillivary, 1991).

A downward-directed laser on a moving aircraft can repeatedly emit short flashes of light to illuminate subsurface water with columnar areas of light. As each light pulse passes through the water, objects suspended in the water will reflect a small amount of the laser light back to the aircraft. This light can then be collected by a small telescope, detected by an appropriate photodetector and then digitized, recorded and analyzed in real time with a computer.

DESCRIPTION OF THE LIDAR PROTOTYPE

Earlier airborne lidar systems have been too heavy and too large for most commercial fishing operations. Fish spotters generally use single-engine fixed-wing aircraft or, as in the tuna purse seine fishery, small helicopters. Recent developments in solid-state lasers and small computer systems have significantly reduced these problems.

In September, 1990 NMFS initiated the development of an airborne lidar system for use aboard tuna purse seine vessels. The prototype system is now being tested. Its total weight is 245 pounds. It fits in the aft passenger area of a Bell Jet Ranger helicopter, a model which is currently used aboard many of the U.S. flag tuna purse seine vessels operating in the ETP (Fig. 9 and Fig. 10).

Figure 9. Installation of the lidar prototype in a Bell Jet Ranger helicopter. Prototype components occupy approximately 1/2 of aft seating area.

Figure 10. Installation completed, door and window installed. The beam directing mirror assembly (A) is the only external component.

The major components of the lidar system (Fig. 11) include a frequency-doubled Nd:YAG laser operating at rates of up to 20 pulses/sec. The pulse length is less than 20 ns. Each pulse transmits energy at both the fundamental near-infrared wavelength (1064 nm) and the frequency-doubled visible (green) wavelength (532 nm). The pulse energy at the green wavelength is approximately 50 mJ. Only the green light is useful for application to underwater detection of fish; the near-infrared light will be absorbed by the water within a few meters. Therefore, a dichroic beamsplitter is used to eliminate the 1064 nm radiation. The optical axis of an eight inch receiving telescope is adjusted parallel to the direction of the laser beam.

As the beam is pulsed downward the light is absorbed, refracted, and reflected by all media and media interfaces in its path (i.e., air, sea surface, undersea objects). A small fraction of the green wavelength light is backscattered from the surface and any underwater objects encountered. The telescope collects the backscattered light. This light is collimated and directed through a 1 nm narrow-band interference filter and then directed onto the face of a half-inch diameter photomultiplier tube.

Signals from the photomultiplier pass through a preamplifier (to convert current to voltage) and are then amplified and digitized by an 8-bit analog-to-digital converter (oscilloscope) which digitizes the signals at rates of up to one sample every 4 ns (corresponding to lidar range resolutions of 0.45 m in water).

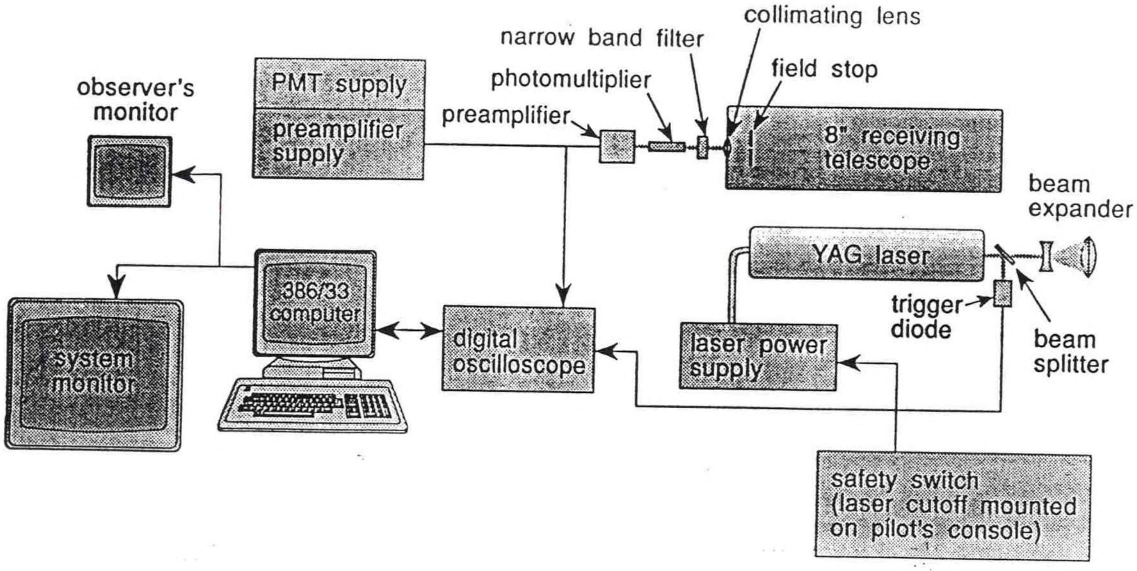

Figure 11. Schematic diagram of prototype lidar apparatus.

A computer controls the operation of the data system, provides real-time displays of the lidar echoes, and stores the digitized data. One monitor is located in the aft compartment of the helicopter with the lidar components to enable the lidar technician to assess system operation and make in-flight adjustments in response to changing environmental conditions. The other monitor is in the forward compartment so that the fish spotter can compare his observations with data being collected. Real-time comparisons of data displays with observations of an expert fisherman will be invaluable to the process of data interpretation and system adjustments during field testing operations.

The entire system is controlled by a menu-driven interactive computer program. The operator is able to select from a variety of functions, including the ability to observe a real time display of the lidar echoes as a two-dimensional color-coded plot of signal versus depth below the ocean surface. These plots have initially been set up to highlight any region of high reflectivity from the surface to a depth of just below 50 m. A separate display simultaneously provides a two dimensional plot of the geographic coordinates of the position of the helicopter. Coordinates of data displays of interest can easily be marked and saved for later review by pressing a key on the computer keyboard. The lidar technician can also toggle the geographic coordinates display to show instead the trace of a single pulse. The single trace is useful in analyzing the quality of the laser pulse. The program provides the means to review and re-display all of the digitized records during or after the flight.

METHODS

Two series of tests were conducted during helicopter flights over the coastal waters of southern California, May 26-28, 1991 and September 10-20, 1991. A crew of three, consisting of a pilot experienced in tuna purse seine fishing operations, a spotter/data recorder, and the project engineer, who operated the lidar system and made mid-flight and post-flight adjustments to the hardware components, accompanied each flight. Flights were made at an average altitude of 500 feet.

Testing consisted of operating the lidar and attempting to record bottom contours as well as profiles of schooling fish that were visually spotted. Bottom contours were recorded as a preliminary baseline for making adjustments to system components.

RESULTS

A combination of problems early in the testing of the lidar system resulted in poor or no data for several of the test flights. These problems included variable strength laser pulses, and finally, the complete failure of the first laser unit. Adjustments to the system led to several successful test flights.

The first goal was to record bottom contours and investigate what adjustments would be necessary to compensate for expected backscatter from the surface of the water. Figure 12 shows a portion of data collected on a flight over a rocky bottom in the vicinity of Catalina Island.

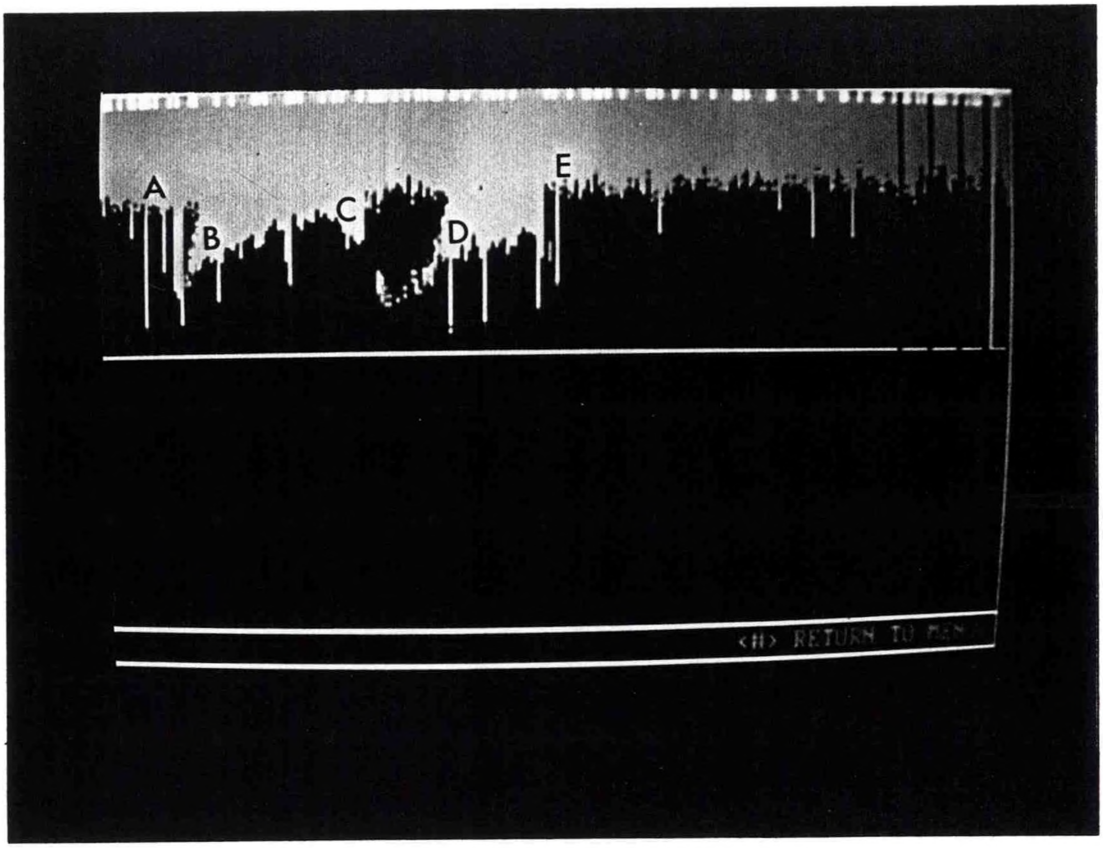

Figure 12. Black and white reproduction of color bottom contour display.

On this early flight the bottom of the display is indicative of a depth of 100 feet (Fig. 12). As the helicopter proceeds, data is recorded from left to right. In this case the helicopter was flying over a shallow area near a cove. The helicopter approached the cove over shallow water (A), the depth increased at the inlet to the cove (B), decreased as the aircraft moved to the opposite side of the inlet (C), increased as the helicopter moved away from the cove (D), and finally decreased again as the aircraft moved away over coastal shallows (E). On this flight the surface backscatter problem was particularly evident, resulting in saturation of the system's amplifier. The saturated signals occupy the upper portion of the display, to a depth of some 30-40 feet. The relatively flat display indicated for shallower depths are artifacts of the saturated layer and do not portray the actual bottom contour. Only depths greater than the saturated layer are distinguishable in this display. On the left side of the display, signals from depths of some 60-75 feet have been recorded. As the depth decreases, the return signals move closer to and finally disappear into the saturated signals associated with the surface backscatter. (Single descending lines in the displays are anomalous electronic aberrations caused by a combination of power fluctuations and bursts of saturation to the amplifier and should be ignored.)

Figure 13 represents a sample of data collected over schools of fish visible on the surface. The display shows a single lidar trace on the left side and a two dimensional (2-D) color display showing lidar echoes received as a function of time with signal intensity indicated by a color code display below the single trace (in the black and white reproduction intensity is indicated by a longer and deeper uninterrupted white pattern). A vertical scale showing lidar range lies between the single-pulse display and the 2-D display.

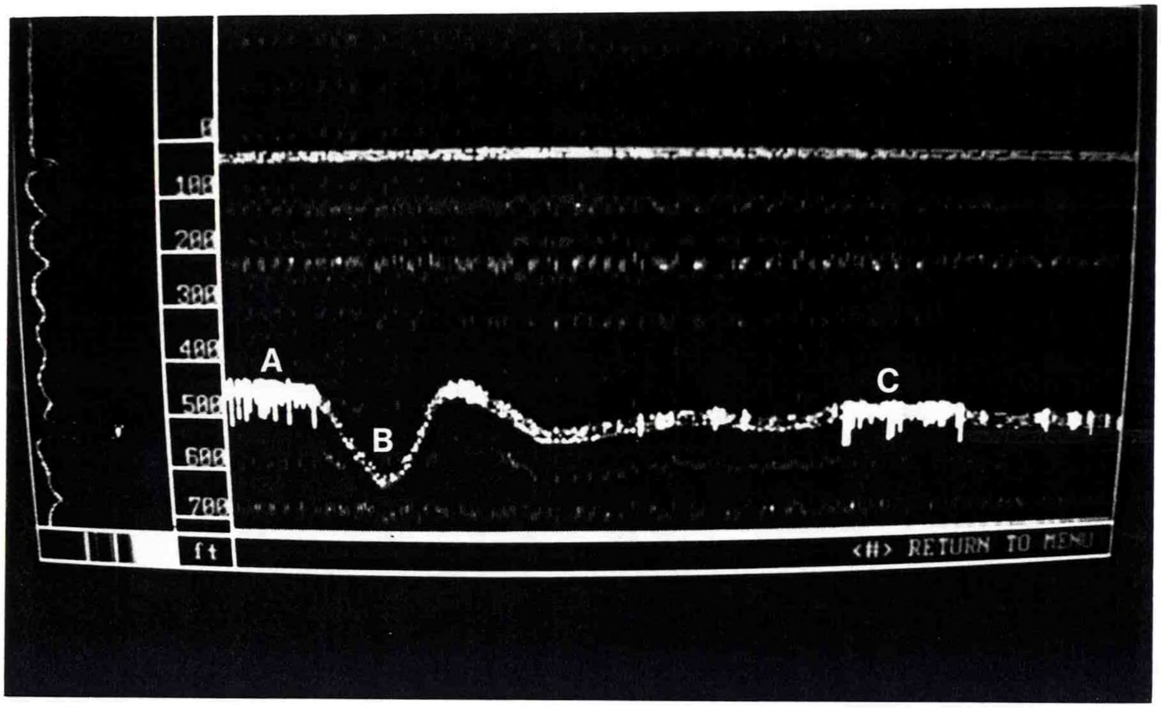

Figure 13. Surface-schooling fish observed from the helicopter are recorded at the extreme left (A) and, again, near the right side of the display (C). (Black and white reproduction of color display.)

A strong echo of atmospheric return as the laser pulse exits the helicopter occurs in both the single trace and 2-D displays. The strong atmospheric return is indicated by the "blip" near the top of the single trace, and as a horizontal pattern of moderate intensity reflection running from left to right on the 2-D display. At about 430 feet below the aircraft the strong signal from the ocean surface was encountered. A large spike on the single trace and a continuous band of these surface reflections on the 2-D are apparent. The considerable amount of white, shown at the left side of the 2-D display, indicates strong reflective signals received from a school of fish (A). These fish were observed from the helicopter at the time the plot was recorded. The dip immediately to the right of the area of high reflectivity (B) is indicative of the helicopter banking and turning, then leveling out to pass over the school again. To the right of the display the school is again indicated (C) by an area of intense reflectivity (the band of white in this black and white reproduction of the color display).

Figure 14 shows another set of data collected during test flights. The single trace at the left, indicative of the quality of the laser pulse, again exhibits the characteristic spikes as the beam exits the aircraft (A) and at the water surface (B). The 2-D display was reprocessed to show only the area from the ocean surface downward. The continuous line at the lower limit of the display is the 100-foot level. Also, in this display the software has been manipulated to represent different signal levels received by different colors for rapid interpretation during flights. In the color display viewed on the monitor, a magenta band indicates high reflectivity. In this black and white reproduction high reflectivity from a fish target is indicated by an area contrasting with the white surface backscatter and darker areas of little reflectivity. A strong return from a school of fish observed from the helicopter is shown at the left of the 2-D display (C).

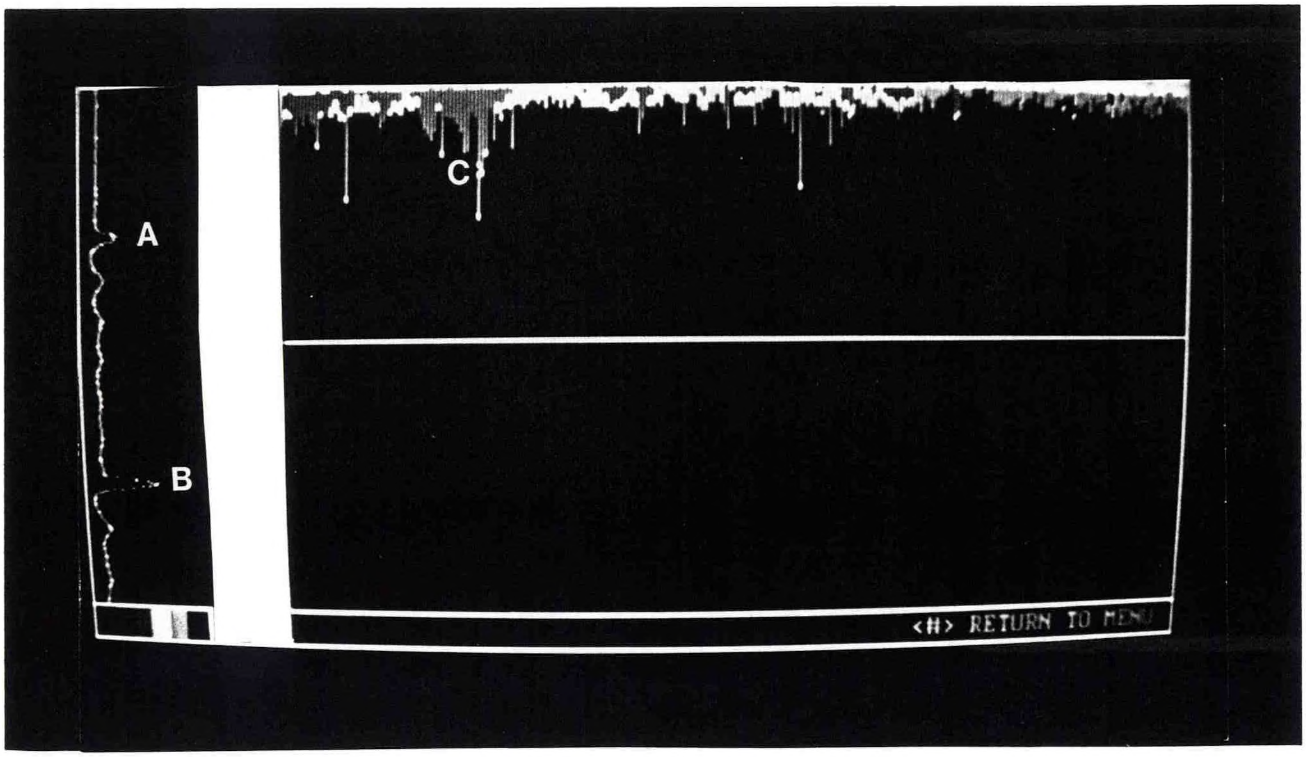

Figure 14. Display of ocean surface downward with fish school observed from the helicopter evident at the left side (C). (Black and white reproduction of color display.)

The depths at which the school was recorded can be estimated by comparing the broad reflective bands with the 100 foot limit at the bottom of the display. In these preliminary tests no vessel was available to conduct surface verification of observations and data recordings made from the helicopter. It is therefore not known whether the recording indicates the true depth of the school of fish. Further work is planned to document depth penetration limits in relation to schooling tuna aboard a purse seine vessel.

DISCUSSION

Supplementing visual searching efforts with sub-surface electronic surveillance using airborne lidar could expand the effective searching field beyond the ocean surface layer, would not be affected by the limits of human vision, and would be applicable day or night. Enhanced searching capacity would improve the economic efficiency of tuna purse seine vessel operations in terms of time and fuel savings, and could contribute towards a reduction of fishing effort on tuna associated with dolphins.

Three initial applications to conventional tuna purse seine fishing procedures are envisioned:

(1) Rapid assessment of logs or other floating debris from the helicopter. Typically, logs are visually inspected for signs of tuna. The helicopter provides an ideal vantage point for observing indications of near-surface fish because adjustments in altitude and angle are easily accomplished. However, observations are still restricted to the limits of visibility. Deep swimming fish may not be discernable. In many cases a promising log may be sighted, but the presence of tuna cannot be confirmed. The vessel is often summoned to scan the area with echo sounding equipment. As a helicopter may be from 5-30 miles away from the vessel when searching, considerable time could be invested in approaching the target of investigation at average speeds of 11-15 knots. Additionally, tuna associated with floating objects are known to range from several hundred yards to several miles away during periodic forays (A. Rodrigues, San Diego, Calif., pers. comm., 1991; Holland, Brill and Chang, 1990; Shomura and Matsumoto, 1982). The problems of assessing the presence of tuna, either visually or with the aid of echo sounding equipment aboard the seiner, are compounded under these circumstances.

(2) Tracking of "school fish". Tuna not associated with floating objects or other species that orient themselves near the surface are difficult to detect. Typically, these "school fish" are sighted only when they are feeding, and often aggregations of multi-species schools are found in a relatively small area. Presumably, these areas of dense concentrations of tuna are rich in feed. A school or series of schools that exhaust the source of food or become, for whatever reason, disinterested dive. Depending on the depth, they are usually lost to the fishermen until they re-surface. If they do not surface within visual range of the vessel they can only be located again by random search. Application of lidar to track the horizontal and vertical movements of a school that disappears beneath the surface would be advantageous in preparing for the next set, as well as following the general direction of movement of the entire aggregation of fish.

(3) Supplementing random searching efforts. The ability to detect schooling tuna in the absence of surface cues, during periods of poor sighting conditions, and as a supplement to the finite effectiveness of extended visual searching would enhance the searching process and could be beneficial in increasing the ratio of catch to searching effort.

The ETP tuna purse seine fishery appears to be particularly suited for the application of lidar technology. The unresolved problem of dolphin by-catch, which can only be averted completely by a cessation in the encirclement of tuna associated with dolphin herds, necessitates the need to increase catches of tuna in other schooling modes. Furthermore, the shallow thermocline depths of the ETP (Figure 15) are similar to the estimated limits of effectiveness of lidar. Much of the ETP has average thermocline (20°C isotherm) depths of 60 m or less (Fiedler, Philbrick and Chavez, 1991). Yellowfin tuna in particular are thought to spend substantial periods of time in the mixed layer above the thermocline, with intermittent trips into deeper and colder water (Carey and Olson, 1982; Holland *et al.* 1990). Lidar has been shown to be effective at depths of 40 m (Banic *et al.* 1987), and is projected to be effective to depths of 75 m (Squire and Krumboltz, 1980).

Further testing of the airborne lidar prototype aboard a tuna purse seine vessel is planned. Data collected will be compared with the observations of expert spotters and with the catch to verify system capabilities and limitations. The seine itself will provide an expansive enclosure for assessing the effectiveness of lidar in delineating various types and sizes of tuna and associated species of fish, as well as providing a comparative measure of functional depth penetration by the laser.

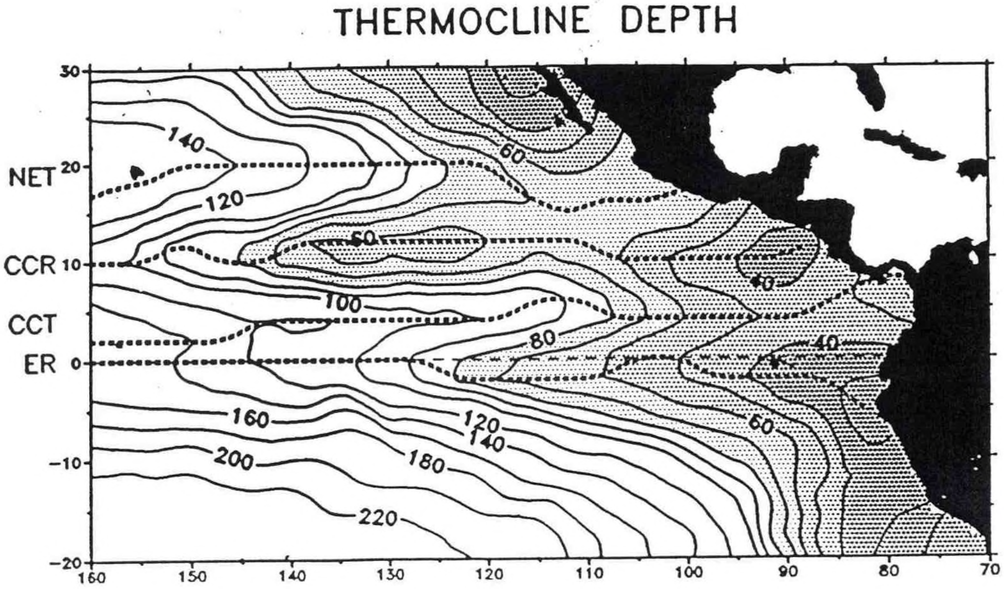

Figure 15. August-November climatology of thermocline (20°C isotherm) depth (Fiedler *et al.* 1991).

Safety

The operation of the prototype lidar system was conducted according to the American National Standards Institute (ANSI) criteria for safe operation of lasers. The laser safety officer (LSO) was present during laser operation to ensure that proper procedures were followed.

The Laser Photonics doubled YAG (YQL 102D) laser utilized in the prototype lidar field tests generates 250 mJ at 1064 nm and 50 mJ at 532 nm, with a pulse length of approximately fifteen ns. The 1064 nm energy is trapped and there is no external emission of this wavelength. A beam expander is employed to expand the 532 nm wavelength so the emitted beam will not burn the thin aluminized coating of the transceiver mirror. The two lenses used to expand the beam are uncoated, resulting in a 10% loss in power at each lens, reducing the output to about 40 mJ.

With the helicopter flying at 80 knots and a laser pulse rate of 20 pulses/sec., individual pulse spots will be about four feet apart at the ocean surface. The possibility of an individual pulse striking a life form at the surface or in the air is unlikely. Moreover, a single pulse will not damage the skin of an animal. Because the aircraft is moving, it is doubtful that an animal would come into contact with more than one pulse. Conceivably, damage might result from looking directly into the oncoming beam. This is unlikely, given the fact that the aircraft is moving rapidly. Additionally, animals in and over the tropical marine environment are oriented and conditioned to look downward or to the side as they respond to predators, prey, and others of their species. The likelihood of an animal that is exactly in line with an oncoming laser pulse looking directly upward at an aircraft passing over at high speeds would be remote.

Safety standards require that the lidar prototype will not be powered up until the helicopter is beyond a minimum safe distance from the ship, as advised by the LSO. A control switch that can stop the laser output is easily accessible to the lidar technician or the pilot. The laser output is to be switched off in the vicinity of other vessels or marine mammals.

There is no advantage in using lidar technology to locate dolphin herds or to assess the amount of tuna in association with dolphins. Dolphin herds are relatively easy to locate visually and the quantity of fish is generally quite evident when viewing a tuna-dolphin surface aggregation from the air (A. Rodrigues, pers. comm., 1991).

PLANNED BEHAVIORAL RESEARCH

There are two major areas of research recommended by the National Academy of Sciences report "Dolphins and the Tuna Industry". The first proposes developing promising new techniques for reducing dolphin mortality in the existing ETP tuna purse seine fishery. The second suggests research and development of new methods for harvesting ETP yellowfin tuna not in association with dolphins. In response to the latter recommendation three projects are being initiated by NMFS and IATTC researchers: 1) simultaneous tracking of tunas and dolphins to study the tuna-dolphin behavioral bond in the ETP; 2) a study of the feeding habits of tuna and dolphins; 3) an investigation into the oceanographic correlates of capture of large yellowfin tuna in the ETP.

Staff of the Alternative Gear Task are working with the office of NOAA Corps Operations to arrange for the charter of a purse seine vessel to assist the NOAA R/V *McArthur* during research operations planned for November of 1992. Both IATTC and NMFS scientists will be participating in the simultaneous tracking of tuna and dolphins. In order to attach tracking devices to spotted dolphins and yellowfin tuna the chartered vessel will make sets on tuna-dolphin associations. Radio tags will be attached to the dorsal fin of spotted dolphins and sonic tags will be attached to yellowfin tuna. Some of the yellowfin tuna tags will have a pressure sensitive transmitter attached to them in order to track their vertical movements. The tuna and dolphin will be released and tracked by the *McArthur*, auxiliary launches from the *McArthur* equipped with tracking gear, the purse seine vessel's helicopter equipped with tracking gear, and the purse seine vessel itself. The process will be repeated as many times as possible in the thirty day charter period. The purpose of the tracking study is to determine the strength and duration of the tuna-dolphin association. Some questions to be asked are: Is there a point during the day or night when the bond weakens or breaks down that could allow exploitation of large, mature yellowfin tuna by purse seine fishermen without involving dolphins? How do tuna and dolphins orient themselves spatially when they are associated with each other? Does their orientation infer something about feeding strategy?

Food habit studies will begin on the research cruise and continue with specimens collected by observers on board vessels in the international tuna purse seine fleet. Stomachs will be collected from tuna, and on an opportunistic basis from dolphins and other high trophic level predators which are involved in purse seine fishing operations. There will be two approaches to stomach content analysis. The first approach will examine stomach contents in order to determine short-term dietary overlap and resource partitioning between species. The second approach will analyze stable carbon and nitrogen isotopes assimilated in muscle tissue to indicate long term relative trophic interrelationships of the species.

The oceanographic correlates study will involve an in-depth review of the tuna purse seine fishery data base from the last several decades. The objective of the study is to evaluate the feasibility of predicting the distribution of large yellowfin tuna in the ETP and elsewhere with oceanographic data.

The information derived from these studies will contribute towards elucidating the tuna-dolphin association and further describing the behavior of mature yellowfin tuna. It is hoped that the results of these investigations will lead to refined application of current fishing techniques and enhance the application of new fishing methods for targeting tuna not in close association with dolphins.

ACKNOWLEDGMENTS

Bumble Bee Seafoods, Inc. provided funding support for most of the FAD research. The Mexican Government provided critical logistical support for FAD placement. Pablo Arenas of the IATTC made arrangements to enlist the cooperation of the Mexican government. Casamar Net Manufacturing Company provided materials used in FAD construction. Don Hansen of AOML provided position data for drifting oceanographic buoys and donated the surplus buoys used in the construction of FADs. The owners and skippers of the tuna purse seine vessels *Pamela Ann* and *Atlantis* provided their vessels for deployment platforms.

Participation on the cruise aboard the *Hornet III* was made possible due to the support of the United States Tuna Foundation and Mr. Roland Virissimo. Recordings of killer whales, false killer whales and feeding tuna were provided and edited by John Francine and Mark Kinsey of Hubbs-Sea World Research Institute. Sonobuoy recordings were provided by Scott Benson. Additional killer whale recordings were provided by Marilyn Dahlheim and Greg Silber.

Progress on the lidar project has been in large part possible due to the support of Ed Gann of Caribbean Marine Service Co., Joe Leavitt of Helicopter Management Company, and Laser Phototonics, Inc. Technical interpretation and descriptions were reviewed and edited by Gerry Grams and Clyde Wyman.

Al Myrick, David Demer and Doug DeMaster reviewed the materials and provided useful suggestions and guidance.

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FAD	DEPLOYMENT			SET			DAYS
#	DATE	TIME	POSITION	DATE	TIME	POSITION	AT SEA
8	1/4/91	NR	9° 00'N 88° 05'W	1/30/91	0659	8° 32'N 93° 01'W	(25)

Species	Tons	Numbers	Range
Skipjack	2 6		1 - 3 lbs 3 - 6 lbs
Yellowfin	3 11		1 - 3 lbs 3 - 5 lbs
Black Skipjack			1 - 5 lbs
Dolphin		3	25 - 30 lbs
Triggerfish		50	1 - 2 lbs
Unidentified Shark		3	1 - 2 m
Wahoo		5	10 - 15 lbs
Bullet Tuna		6	1 - 3 lbs
Rainbow Runners		20	3 - 6 lbs
Unidentified Shark		1	2 m
Unidentified Stingray		2	3 - 4 lbs

FAD	DEPLOYMENT			SET			DAYS
#	DATE	TIME	POSITION	DATE	TIME	POSITION	AT SEA
8	1/4/91	NR	9° 00'N 88° 05'W	4/11/91	0917	10° 32'N 118° 18'W	(90)

Species	Tons	Numbers	Range
Skipjack	5		1.5 - 4.0kg
Yellowfin	2		1.5 - 4.0 kg
Black Skipjack	10		1.0 - 5.0 kg
Triggerfish	1		0.15- 0.3 m
Wahoo		10	0.5 - 2.0 m
Bullets	1		0.5 - 1.0 kg
Rainbow Runners		200-300	1.0 - 7.0 kg
Other Unidentified Fish		15-20	0.5 - 1.0 kg
Olive Ridley Sea Turtle		1	0.7 m

Table 1. Catch data from preliminary long term deployment of drifting FADs.

FAD	DEPLOYMENT			SET			DAYS
#	DATE	TIME	POSITION	DATE	TIME	POSITION	AT SEA
16	7/23/91	NR	9° 40'N 123° 10'W	8/16/91	0827	9° 11'N 121° 11'W	(24)

Species	Tons	Numbers	Range
Yellowfin	0.06		6.75 kg
Black Skipjack	1.0		3.0 - 3.5 kg
Dolphin		20	.75- 1.5 m
Triggerfish		low	small
Unidentified Shark		25	0.5 - 1.5 m
Wahoo		10	1.0 - 1.25 m

On this set the captain reported an estimated 15 tons of tuna, species unknown, escaped under the boat during pursing.

FAD	1991 DEPLOYMENT			1991 SET			DAYS
#	DATE	TIME	POSITION	DATE	TIME	POSITION	AT SEA
4	7/22	NR	9° 34'N 121° 57'W	10/21	0919	10° 37'N 111° 47'W	(91)

Species	Tons	Numbers	Range
Skipjack	0.5		1 - 2 lbs
Yellowfin	2.0		1 - 2 lbs
Black Skipjack	1.0		1 - 2 lbs
Dolphin		30	4 - 6 lbs
Triggerfish	1.0		1 - 2 lbs
Unidentified Shark		5	10 - 20 lbs
Wahoo		20	8 - 10 lbs
Bullet Tuna	1.0		1 - 2 lbs
Yellowtail	0.2		2 - 3 lbs
Rainbow Runners	0.2		1 - 3 lbs
Other Small Fish	0.2		0.5 - 1 lbs
Unidentified Marlin		2	1 - 1.5 m
Unidentified Sea Turtle		2	NR
Unidentified Barnacles	40% of buoy surface area		

The vessel brailed about five tons of small yellowfin, skipjack tuna, and assorted by-catch species which were discarded. An estimated 20 tons of weight was dumped by releasing the ortza.
Captain reported that he sighted a 20 ton spot of jumbo skipjack near the FAD before the set.

Table 2. Catch data from phase-one long term deployment of drifting FADs.

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
9	2/2/91	NR	11° 21'N 90° 35'W	2/23/91	NR	11° 36'N 92° 07'W	(21)

Species	Tons	Numbers	Range
Dolphin	1		2.0 - 10 kg
Unidentified Sharks		50	1 - 2 m
Triggerfish	1		1 - 2 kg

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
13	7/22/91	NR	9° 47'N 121° 10'W	8/6/91	0954	9° 25'N 121° 03'W	(14)

No fish or birds reported near FAD.

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
14	7/22/91	NR	9° 47'N 121° 10'W	8/6/91	1451	9° 25'N 121' 12'W	(14)

Species	Numbers
Dolphin	low
Unidentified Fish	low

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
2	7/22/91	NR	10° 27'N 121° 00'W	8/19/91	1700	10° 27'N 119° 45'W	(27)

Species	Numbers
Dolphin	low
Unidentified Sharks	low
Triggerfish	medium
Unidentified Fish	medium

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
*	7/23/91	NR	10° 15'N 122° 06'W	8/22/91	1057	9° 48'N 120° 42'W	(30)

No signs of fish or birds near FAD
* FAD number unreadable.

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
31	7/22/91	NR	10° 07'N 121° 05'W	9/19/91	0555	9° 40'N 115° 32'W	(57)

Species	Numbers	Range
Unidentified Fish	80	0.1 - 0.2 m
Unidentified Crabs	medium	
Unidentified barnacles	20% of buoy area covered	

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
21	7/23/91	NR	10° 00'N 123° 05'W	9/23/91	0854	9° 50'N 117° 08'W	(61)

Species	Numbers	Range
Dolphin	25	NR
Unidentified Shark	1	NR
Unidentified Boobies	2	
Unidentified Shearwaters	5	

FAD #	DEPLOYMENT			SIGHTING			DAYS AT SEA
	DATE	TIME	POSITION	DATE	TIME	POSITION	
30	7/22/90	NR	10° 07'N 121° 05'W	10/14/91	NR	11° 44'N 109° 23'W	(84)

Species	Numbers
Unidentified Boobies	1
Unidentified Barnacles	15% of buoy area covered

Table 3. Summary of FAD sightings.

Date	FAD#	Grp	Sighting position	Satellite position
8/6/91	13	4	09° 25′N and 121° 03′W	09° 53′N and 121° 05′W
8/6/91	14	4	09° 26′N and 121° 12′W	09° 34′N and 121° 11′W
8/16/91	16	5	09° 11′N and 121° 11′W	09° 53′N and 121° 05′W
8/17/91	23	7	10° 16′N and 120° 55′W	10° 24′N and 121° 17′W
8/19/91	2	1	10° 14′N and 119° 45′W	10° 14′N and 119° 47′W
8/22/91	15	5	09° 29′N and 121° 23′W	09° 40′N and 120° 56′W
9/19/91	31	10	09° 40′N and 115° 32′W	10° 30′N and 115° 42′W
9/23/91	21	7	09° 50′N and 117° 08′W	12° 39′N and 120° 21′W
10/14/91	30	10	11° 44′N and 109° 23′W	12° 13′N and 109° 43′W
10/17/91	12	4	12° 10′N and 110° 21′W	11° 08′N and 110° 38′W
10/17/91	15	5	12° 25′N and 110° 14′W	12° 09′N and 109° 55′W
10/17/91	16	5	12° 04′N and 110° 24′N	12° 09′N and 109° 55′W
10/21/91	4	2	10° 37′N and 111° 47′W	11° 08′N and 111° 42′W

Table 4. Comparisons between shipboard sighting positions of long term drifting FADs and documented satellite positions of FADs.

DATE	SET TIME	SET POSITION
1/23/91	1513	6° 24'N 87° 43'W

Species	Tons	Numbers	Range
Yellowfin	10		0.5 - 7.0 lbs
Skipjack	5		0.5 - 5.0 lbs
Bullet Tuna	5		0.1 - 0.5 lbs
Unidentified Marlin		1	150 lbs
Wahoo		5	35 lbs
Yellowtail		2	4 - 8 lbs
Triggerfish		low	small
Unidentified Shark		low	3 - 6 lbs

DATE	SET TIME	SET POSITION
12/10/91	1105	5° 54'N 85° 21'W

Species	Tons	Numbers	Range
Yellowfin	10		1.5 - 2.5 kg
Skipjack	40		1.5 - 2.5 kg
Skipjack	10		<1.5 kg
Bullet Tuna	2		0.2 kg
Blacktip Shark		25	0.75 - 1.5 m
Dolphin		8	0.5 kg
Rainbow Runner		10	0.5 - .75 kg
Unidentified Frigatebird		4	
Unidentified Storm Petrel		2	

DATE	SET TIME	SET POSITION
12/11/91	0619	6° 12'N 84° 57'W

Species	Tons	Numbers	Range
Yellowfin	5		1.5 - 3.0 kg
Skipjack	35		1.5 - 3.0 kg
Skipjack	12		<1.5 kg
Frigate Mackerel	3		0.3 kg
Blacktip Shark		10	1.0 - 1.75m
Dolphin		15	.75 - 1.25m
Triggerfish		30	0.5 kg
Wahoo		1	1.0 m
Rainbow Runner		15	0.3 - 1.0 kg
Unidentified Sea Turtle		1	1.0 m
Unidentified Storm Petrel		2	

Table 5. Summary of catch data from sets on drifting oceanographic current measurement buoys.

DATE	SET TIME	SET POSITION
2/10/91	1135	5° 00'N 110° 00'W

Species	Tons	Numbers	Range
Yellowfin	1		2.5 - 10.0 kg
Skipjack	65		0.5 - 3.5 kg
Dolphin		6	3.0 kg
Rainbow runner		2	3.0 kg
Whitetip Shark		20	40.0 kg
Unidentified baitfish		300	0.1 kg
Unidentified Barnacles	50% of buoy area covered		

Table 6. Summary of catch data from a set on an anchored NOAA Thermal Array for the Ocean (TAO) oceanographic buoy.

VESSEL	SCHOOLFISH CATCH/SET	NATURAL LOG CATCH/SET	MAN-MADE LOG CATCH/SET	MODIFIED MAN-MADE LOG CATCH/SET	FAD CATCH/SET
6	n/a	n/a	80 tons (643 tons in 8 sets)	51 tons (408 tons in 8 sets)	35 tons (178 tons in 5 sets)
7	18 tons (55 tons in 3 sets)	75 tons (75 tons in 1 set)	72 tons (720 tons in 10 sets)	42 tons (380 tons in 9 sets)	28 tons (285 tons in 10 sets)

Table 7. Breakdown of catch from two dolphin-safe U.S. tuna purse seine fishing trips in the ETP.

VESSEL	NATURAL LOG	MAN-MADE LOG	MODIFIED MAN-MADE LOG	FAD
6	N/A N/A	SJ .5-12 kg YF .5-15 kg	SJ .5-12 kg YF .5-30 kg	SJ 1-12 kg YF 2-3 kg
7	SJ 2-10 kg YF 2-3 kg	SJ 1-10 kg YF 1-20 kg	SJ 1-12 kg YF .5-20 kg	SJ 1-12 kg YF .5-25 kg

Table 8. Comparison of the weight range of catch by fishing mode between two dolphin-safe U.S. tuna purse seine trips in the ETP.

Set#	#dolphins captured	% spotted	%spinner	tons YF	tons SJ
1	250	100%		1	
2	325	100%		22	
3	350	70%	30%	35	
4	750	90%	10%	40	
5	200	99%	1%	28	
6	800	65%	35%	110	4
7	550	100%		40	
8	150	98%	2%	12	
9	400	99%	1%	50	3
10	1100	85%	15%	100	1
11	525	99%	1%	45	
12	200	96%	4%	15	
13	350	80%	20%	25	
14	500	90%	10%	15	
15	800	98%	2%	80	
16	600	100%		50	4
17	400	99%	1%	33	3
18	200	100%		32	10
19	250	90%	10%	10	
20	1000	95%	5%	30	
21	300	97%	3%	15	2
22	300	95%	5%	18	
23	550	95%	5%	18	
24	450	92%	8%	35	2
25	350	94%	6%	8	
26	650	100%		35	
27	400	98%	2%	20	2
28	80	100%		12	1
29	550	100%		35	2

Table 9. Set composition sumary, NMFS cruise # 1418.

Set #	Acoustical broadcasts	Chemical attractant	Squid chum	Behavioral observations
1				
2				X
3				X
4	X			X
5		X	X	X
6	X			X
7				X
8	X			X
9				X
10				X
11		X	X	X
12				X
13				X
14				X
15	X			X
16				X
17		X		X
18	X			X
19				X
20				X
21				X
22				X
23				X
24				X
25				X
26				X
27				X
28				X
29				X

Table 10. Set summary of introduced stimuli and underwater behavioral observations.

APPENDIX 1

Common name	Scientific name
Scombrids	
Yellowfin Tuna	*Thunnus albacares*
Skipjack Tuna	*Katsuwonus pelamis*
Black Skipjack Tuna	*Euthynnus lineatus*
Frigate/Bullet Mackerel	*Auxis* spp.
Other species	
Dolphin/Dorado	*Coryphaenae hippurus*
Triggerfish	Balistidae
Unidentified Marlin	Istiophoridae
Wahoo	*Acanthocybium solandri*
Rainbow runners	*Elagatis bipinnulatus*
Yellowtail	*Seriola lalandi*
Oceanic Whitetip Shark	*Carcharhinus longimanus*
Unidentified Requiem Sharks	Carcharhinidae
Unidentified Stingray	Dasyatididae
Olive Ridley Turtle	*Lepidochelys olivacea*
Unidentified Shearwaters	*Puffinus/Pterodroma* spp.
Unidentified Storm Petrels	*Oceanodroma* spp.
Unidentified Booby	*Sula* spp.
Unidentified Frigatebirds	*Fregata* spp.

Appendix 1. List of common and scientific designation of fauna associated with FADs.