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Jason P. Larese

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
8604 La Jolla Shores Drive
La Jolla, California, USA 92037-1508

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U.S. DEPARTMENT OF COMMERCE
Carlos M. Gutierrez, Secretary
National Oceanic and Atmospheric Administration
VADM Conrad C. Lautenbacher, Jr., Undersecretary for Oceans and Atmosphere
National Marine Fisheries Service
William T. Hogarth, Assistant Administrator for Fisheries

ABSTRACT

Beginning in 1992, the National Marine Fisheries Service investigated the feasibility of using airborne lidar to detect tuna in the eastern tropical Pacific as an alternative to setting on dolphins in the purse-seine fishery. Research by the agency and contractors has been sporadic with limited field trials of various lidar systems. Initial results to determine the feasibility of using lidar to detect yellowfin tuna were inconclusive. However, other research groups have continued lidar development and improved systems are currently being used to detect other species of fish. Several obstacles remain and must be resolved before lidar could be used to supplement or replace using dolphins to find tuna.

INTRODUCTION

In 1992 the National Marine Fisheries Service's (NMFS) Southwest Fisheries Science Center (SWFSC) began its Dolphin-Safe Research Program (DSRP) with the purpose of reducing dolphin mortality in the eastern tropical Pacific (ETP) yellowfin tuna purse-seine fishery through changes in fishing methods. One of several goals outlined in a strategic plan[1] was to develop and evaluate methods of purse-seining that do not involve chasing or encircling dolphins. Airborne lidar (LIght Detection And Ranging) was identified as equipment which might improve the efficiency of locating and capturing yellowfin tuna that are not associated with dolphins in the ETP. Investigating and evaluating the feasibility of using lidar was listed as one research objective[2]. This report summarizes past research by the DSRP and others concerning the use of lidar to locate fish schools and also reviews the current status of the technology.

LIDAR TECHNOLOGY

Lidar is similar in principle to radar but uses light instead of radio waves. A pulse of laser light is transmitted out to a target. Some of this light is scattered and some is reflected back from the target and detected by a receiver. The elapsed time from transmission to detection enables calculation of the distance to the target whereas return signal attributes are indicators of target properties.

There are several different forms of lidar systems used for assessments in air, on land, and underwater. They are applied to such tasks as creating topography or bathymetry contours, analyzing atmospheric properties, or locating and identifying objects underwater. Fisheries biologists may use lidar to measure chemical changes in the water,

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[1] Demaster, D. P. 1992. Strategic plan to develop and evaluate "dolphin-safe" methods of fishing for yellowfin tuna in the eastern tropical Pacific, Southwest Fisheries Science Center Admin. Rpt. LJ-92-16. Southwest Fisheries Science Center, La Jolla, CA 92038.

[2] DeMaster, 1992.

observe and count large objects in the water, and measure changes in the concentrations of small particles (Gauldie et al., 1996).

Researchers have adapted lidar technology in order to detect fish schools four to six times deeper than can be seen by eye[3]. The resulting output is similar to an echosounder, indicating depth, size of fish schools, and possibly fish size. The advantages of using airborne lidar compared to slower ship based methods include improved spatial and temporal coverage and the ability to perform assessments under adverse surface conditions.

PAST STUDIES

Gauldie et al. (1996) discusses several studies of lidar application in fisheries research that have been conducted over the past three decades. More recent studies include modeling performance of a lidar survey system[4] (Lo et al., 2000), measuring reflectivity of live sardines in a seawater tank and subsequent deployment of a ship mounted lidar system in the Southern California Bight (Churnside et al., 1997), and estimating laser safety thresholds for cetaceans and pinnipeds (Zorn et al., 2000). Airborne lidar systems have been used to measure salmon in Alaska (Churnside and Wilson, 2004), capelin in the North Pacific (Brown et al., 2002), fish schools off Florida (Churnside et al., 2003), and plankton, squid, and marine mammals in the Southern California Bight, Puget Sound, and off Spain (Churnside et al., 2001).

Several tests of lidar systems have focused on locating tuna. Research has primarily been conducted by NOAA's Environmental Technology Laboratory (ETL) in conjunction with the SWFSC using ETL's lidar system (named FLOE for Fish Lidar, Oceanic, Experimental). Other lidar systems by contractors have been tested as part of the DSRP. The Pelagic Fisheries Research Program (PFRP) at the University of Hawaii at Manoa has also investigated using lidar to measure tuna.

The following attempts to chronicle research and progress in lidar systems used to locate tuna, some of which are associated with the DSRP.

1991 - The NMFS lidar system known as OSPREY-1, designed and built by Remote Sensing Industries (RSI), was field tested in a helicopter off southern California (Oliver et al., 1994). Several adjustments led to profiling surface schooling fish and bottom profiles to 25 meters in depth.

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[3] Hunter, J. R., and J. H. Churnside. 1995. Airborne fishery assessment technology: a NOAA workshop report. Southwest Fisheries Science Center Admin. Rpt. LJ-95-02. Southwest Fisheries Science Center, La Jolla, CA 92038. 33p.

[4] Lo, N. C. H., J.R. Hunter, and J. H. Churnside. 1999. Modeling properties of airborne lidar surveys for epipelagic fish. Admin. Rep. LJ-99-01. Southwest Fish. Sci. Ctr. NMFS, NOAA. P.O. Box 271, La Jolla, CA 92037.

1992 - RSI improved the OSPREY-1 design and renamed it OSPREY-2 (also called OSPREY.C). The system was installed in a helicopter and tested on the ground; however funding was not available for flight tests (Oliver et al., 1994).

1992 - The OSPREY-2 system was further modified and the new LIDAR.C was tested off Panama first from a land based helicopter and then from a helicopter aboard the tuna seiner Capt. Vincent Gann (Oliver et al., 1994). Operated by Grams Environmental Labs, the system was used for approximately 160 hours over 30 sea days before it failed. Slow fishing allowed only 7 overflights to profile tuna encircled in the net. Fish were detected down to 17m.

1993 - The NMFS lidar system was sent to NOAA's ETL for modification[5].

1994 – SWFSC and ETL organized the LIDAR cruise I where the FLOE lidar system was hung over the side of the NOAA vessel David Starr Jordan while the ship passed over fish schools. The system was reported to have worked well after adjustments and calibrations[6].

1994 - Kaman Aerospace Corporation flew its lidar system at 800-1000ft and detected anchovy at a depth of 55ft. Other unsubstantiated images were obtained for tuna, manta ray, dolphins, and sunfish at depths of 10-30 ft[7].

1994 - Arete' Associates flew their Airborne Streak Tube Imaging Lidar system (ASTIL) and imaged calibration targets and dolphins. Improvements were made to the multispectral processing algorithms which reportedly reduce surface features while enhancing subsurface features[8].

1995 - Prior to the LIDAR cruise II, the FLOE system was tested at the Scripps Institution of Oceanography deep tank containing live fish (Churnside et al., 1997). Lidar measurements in southern California waters aboard the David Starr Jordan totaled more than 280 hours. Data on several species of fish were collected to compare with sonar readings[9].

1996 - PFRP and Science Application International Corporation (SAIC) tested reflectivity of artificial targets (representing tuna and swordfish) in a deep tank using their lidar system. Fish were identified down to 76ft in turbid waters (corresponding to 205ft in blue water) and it was possible to distinguish between tuna and swordfish targets. Detection of fish down to 109+ft (294ft in blue water) and data extrapolation showed possible detection to 450ft in blue water (Schoen and Sibert, 1996).

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[5] Oliver, C.W. and Edwards, E.F. 1996. Dolphin-Safe Research Program progress report II (1992-1996). Southwest Fisheries Science Center Admin. Rpt. LJ-96-13. 91p.

[6] Oliver and Edwards, 1996.

[7] Oliver and Edwards, 1996.

[8] Oliver and Edwards, 1996.

[9] Oliver and Edwards, 1996.

1997-1998 - Arete' Associates flew their ASTIL system off Australia, Hawaii, and Massachusetts to image various species of tuna and improve the design (Griffis, 1999). In the Australia experiments, captive southern bluefin tuna in a net were detected at depths down to 10 meters in the turbid waters. No yellowfin tuna schools were detected off Hawaii after 30 hours total flight time; however, data on other schooling species was gathered and analyzed. One school of giant bluefin tuna was detected off Massachusetts before weather ended testing.

1998 - Computer modeling of a FLOE-type lidar system predicted tuna detection in the ETP down to 40 meters under typical conditions and down to 60 meters under ideal conditions (Churnside et al., 1998).

CURRENT LIDAR SYSTEM STATUS

It is unknown if any commercial fisheries are currently utilizing a lidar system. It is possible that Russian fishermen were, at one time, using airborne lidar to find fish in the Sea of Japan but very little has been publicized.

The following information on the current capabilities of an operating lidar system and specific requirements for one focused on detecting tuna is based upon several personal communications in October of 2004 with Jim Churnside at the ETL in Boulder, Colorado. He is the primary researcher/developer of the FLOE and has collaborated with the SWFSC on many experiments.

The laser for the current lidar system in use at the ETL has the approximate dimensions 1 ft. x 1 ft. x 2.5 ft. In addition, there is a 4 ft high electronics rack. The entire system weighs approximately 400 lbs and requires a 1500 W power source. A new, cheaper, lighter, smaller, and more robust laser is due on the market soon.

The lidar system is built in two configurations with the recommended version generating a profile similar to an echo sounder. It is estimated to detect fish down to approximately 50 m in ETP waters. Detection probability can be calculated given values for fish size, school size, school density, school depth, school spacing, and search area. Values for some parameters (e.g. school spacing and density) are not well known and can only be estimated.

ETL lidar systems have not been built to operate on tuna boat helicopters; however, they can be redesigned to improve weight, space, power requirements, and reliability necessary for operation in the harsh conditions present on a tuna seiner. A rough estimate for research and development costs of the first lidar system are on the order of $300K - $400K. Development time including testing would last approximately 1 - 2 years. Purchase price per system after that would be around $200K - $250K. A primary concern is whether a replacement can be found for the receiver amplifier/digitizer that is currently in use but is no longer manufactured.

FUTURE RESEARCH NEEDS

In 1999, at the end of the SWFSC lidar research program, future research needs were identified[10]. Lidar signatures from known fish targets need to be collected, along with measurements of environmental conditions to provide a baseline for designing system software and training operators to identify targets. Software upgrades would provide accurate and automated target recognition as well as providing information in a manner understandable to expected users.

Lidar might be capable of detecting tuna in the ETP but it is unknown whether yellowfin could be distinguished from skipjack and bigeye. This would be critical if lidar is to locate unassociated large yellowfin tuna as an alternative to setting on dolphins. Fish reflectivity studies might detect characteristics of each species that would allow identification.

Oliver and Edwards[11] also noted that research of fish school characteristics such as packing density, depth, distribution, and shape would guide decisions in which type of lidar system would work best and its development. For example, the depth of a school determines the laser power necessary to detect it and while lidar penetration depth can be increased by increasing the laser power there are trade-offs. Achieving increased detection depth necessitates a corresponding increase in weight, expense, and power requirements. Ultimately, design specifications for a usable lidar system must take into account the size, weight, and power output capability of small tuna vessel helicopters.

Finally, Oliver and Edwards[12] identified the need to discuss the requirements of a lidar system to identify whether the design should be able to detect a fish, part of a school, or the whole school. In broad terms, the operating scale of the system should be defined by whether the system would be required to locate an area of the ocean where fish were present or be capable of providing the 3-D location and number of fish in a specific school, or something in between.

Studies by the Inter-American Tropical Tuna Commission (IATTC) have also provided useful for identifying future research needs. Relatively little is known about the abundance and distribution of large (>90cm) unassociated yellowfin in the ETP. Observers for the IATTC record the number of sets made by and the quantity of retained catch by tuna purse-seine vessels in the ETP. Data for 2003 show that of the number of sets made on tuna approximately 43% were on fish associated with dolphin, 19% on fish associated with floating objects, and 38% on unassociated schools (IATTC, 2004). Data on retained catch for yellowfin in 2003 show that 68% were on fish associated with dolphin, 8% were on fish associated with floating objects, and 23% were on unassociated schools. Numbers are approximate however, as observers must make a subjective

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[10] Oliver, C. personal communication. 12/2/04.

[11] Oliver and Edwards, 1996.

[12] Oliver and Edwards, 1996.

judgment as to whether a tuna school near a floating object is actually associated or not. Regardless, significantly fewer yellowfin tuna are retained from unassociated sets as compared to dolphin sets. Under the scenario of a moratorium on catching tuna by setting on dolphins, Punsley et al. (1994) used data from 1980-1988 to estimate the potential tuna catches in the ETP. They estimated that yellowfin catches would be reduced by an average of about 25%. Lidar was not considered in their analysis however. Future work should focus on determining the abundance and distribution of large unassociated yellowfin tuna.

Contrary to previous short-term ultrasonic telemetry studies where tagged yellowfin tuna in the ETP remained primarily above the thermocline (~50 m), the results of tagging studies conducted in 2002 by the IATTC were markedly different (IATTC, 2003). A fish was tagged close to Magdalena Bay in Baja Mexico and data was collected until it was recaptured 287 days later. Early on, the yellowfin remained primarily within the mixed layer with occasional deeper dives below the thermocline. However, once the fish moved farther offshore, it began repetitive diurnal diving from about 50 m down to around 250 m (IATTC, 2003, see their Figure 6b). More research is necessary to determine whether this behavior is representative of all offshore yellowfin tuna, or at least a significant fraction. If so, it would dramatically decrease detection rates as fish would be well below the detection depth limits of a lidar system.

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