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Profiling Pelagic Fish Schools Using Airborne Optical Lasers and Other Remote Sensing Techniques

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INTRODUCTION

There is an increasing interest among researchers involved in fishery exploration and stock assessment in the use of airborne techniques to assist in the assessment of pelagic fish stocks. Of particular interest is the development of airborne remote sensing techniques to scan and locate fish schools or school groups, and to examine individual school size in both the vertical and horizontal plane. Rapid real-time assessment of fish stocks is necessary for the management of coastal pelagic schooling species that have a relatively short life span. Real-time data are needed for the management of common pelagic species off the west coast of the United States such as northern anchovy *(Engraulis mordax)*, Pacific bonito *(Särda chiliensis)*, Pacific mackerel *(Scomber japonicus)*, and jack mackerel *(Trachurus symmetricus)*.

Visual detection by commercial aerial fish spotters is one form of remote sensing which has been used for many years to detect fish schools or school groups in both daylight and nighttime conditions; a number of commercial fisheries use this technique to increase the catch of fish (Squire, 1961, 1972). During daylight hours the human eye can detect color, shape of school, and movement of fish within the school as keys to species identification. Visual sightings at night rely on the observation of bioluminescence generated by planktonic organisms as they are disturbed by individual fish within a school. On many occasions differences in the behavior patterns of the various species, resulting in different bioluminescent patterns, make identification more positive at night than during the day. Photographic techniques have also proved valuable in the measurement of fish schools.

These techniques for remote fish detection have limitations. Visual or photographic detection of fish schools during the day relies upon the fish school being relatively near the ocean's surface as illumination, sea state and turbidity can limit visibility. At night, viewing the bioluminescent pattern of a fish school is possible only during periods of very low illumination levels from the moon, or periods of no moon. The bioluminescent characteristics of the phytoplankton and its concentration are also limiting factors.

Airborne electronic remote sensing viewing devices such as low-light level video systems (LLTV) also have many of the same limitations as visual observations. However, the limitation of flight at the low altitudes necessary to visually detect bioluminescent targets is eliminated with the advanced LLTV systems, and this allows scanning a large geographic area from altitudes of 1,300 to 2,000 meters (3,900 to 6,100 ft). Surveys can sometimes be conducted during periods of low level reflected illumination from the moon or shoreline sources, thereby increasing potential survey time.

Airborne remote sensing for fisheries has used image intensifiers and LLTV systems. Some of these are fixed vertical view systems using commercially available electronics (Roithmayr, 1970; Cram, 1974); others are highly specialized LLTV scanning units with electronics specifically designed for viewing targets in the bioluminescent spectral wavelength (470-480 nm). The LLTV system developed specifically for fishery surveys by Zapata Fisheries Development Corporation has been used to evaluate the stocks of anchovy off northwestern Mexico (Figure 1), sardine and mackerel off Chile and Southwest Africa, tuna off Central America and tuna, herring, thread herring and menhaden off the U.S. Atlantic and Gulf of Mexico coastlines.

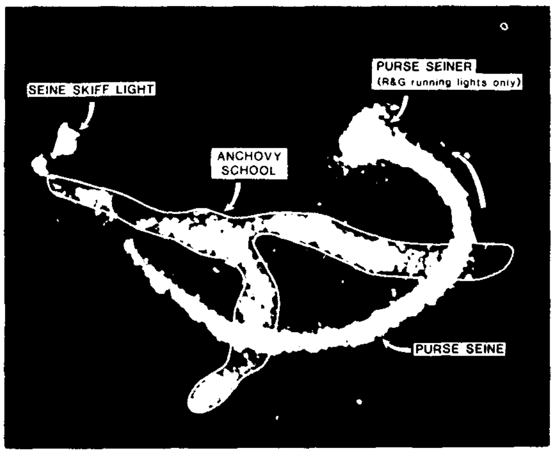

Figure 1. Bioluminescence of an anchovy school, purse seiner, and net recorded by a low-light-level video system. Photo taken by author during anchovy surveys off northwest Mexico, courtesy Zapata Fisheries Development Corporation (altitude - 1,828 meters (6,000 ft)).

The National Marine Fisheries Service's (NMFS) Southwest Fisheries Center has expended considerable effort over the years in the study of detection and profiling of fish school targets using acoustic techniques (Smith, 1970; Hewitt et al., 1976). Studies of the horizontal profiles of fish school targets have been made with aerial photographs and a low-light-level video system (Squire, 1978). Recently underwater laser-radar experiments on fish targets were conducted under laboratory conditions by the Swedish National Board of Fisheries (K. Fredriksson et al., 1978). These studies were preliminary to field tests planned on board a research vessel. The National Marine Fisheries Service has recognized the possibility of using technologically advanced airborne survey aids such as the optical laser, and has conducted a limited amount of experimental studies concerning the reflectance of fish. However the development of such an airborne optical laser system suitable for routine fishery surveys would require funding a research and development expertise currently beyond the capability of the Service.

As in other areas of underwater research, the development of electronic survey equipment for one specific use may find application in other related fields. The observation of a fish school as reported in this paper is an example of a cooperative effort between NAVAIRDEVCEN, Warminister, Pennsylvania, and the NMFS Southwest Fisheries Center, La Jolla, California, relative to making observations of fish school targets intercepted during airborne tests of the ORIC system. Targets such as fish schools were of interest to the ORIC program and records of fish school targets intercepted were made available to the Southwest Fisheries Center.

The mounting of electronic sensors in an aircraft capable of detecting and measuring fish school parameters provides a capability of surveying large areas of the ocean's surface within a shorter time period than can be done from abroad ship. Advanced electronic detection and measuring devices are being developed. Optical laser radar, for example, offers a new capability in the field of fish school detection and evaluation. In 1962, the U.S. Navy initiated a program at the Naval Air Development Center (NAVAIRDEVCEN) to determine the feasibility of sursurface target detection using a pulsed optical laser system. This program was initially identified as the ORAD (Optical Ranging and Detection) program; the acronym ORIC (Optical Ranging, I.F.F., and Communications) was later adopted. The objective of this program was the development of an operationally useful airborne laser radar system capable of detecting submerged targets. In 1963-1965 the feasibility of using a pulsed laser for underwater ranging was demonstrated. Development has continued and more sophisticated optical laser scanning systems have been tested.

RESULTS

Observation #1

In November-December 1976, tests of ORIC system mounted in an SH-3 helicopter (Figure 2) were conducted in the Key West Florida area. During these tests

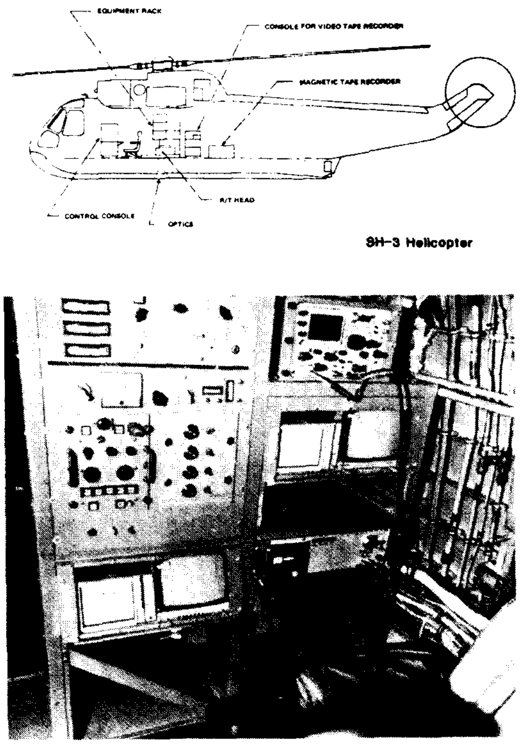

Figure 2. Positioning of ORIC components in SH-3 helicopter and view of operator's console.

possible fish targets were indicated in an area approximately 12 nautical miles south of Key West. During some of the test flights, spurious signals were detected. Since these signals were present only on the backscatter curves, which are a function of water reflectance and exponentially decaying laser power, it is assumed that the signals were due to fish.

A series of oscilloscope photographs was obtained showing laser return signals from fish. This series of photographs (one is shown in Figure 3) was obtained approximately 1 minute before passing over the test

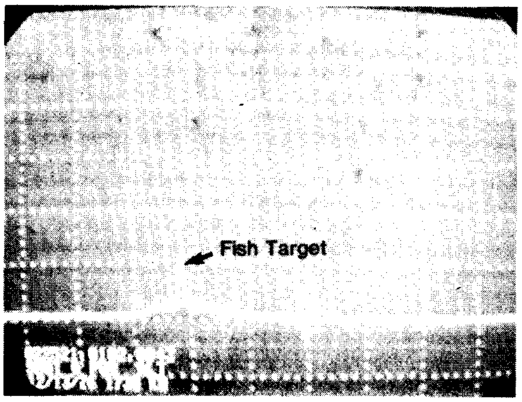

Figure 3. Oscilloscope photograph showing laser return signal from fish near the surface (surface to 11 meters (36 ft)).

target. For a nominal aircraft speed of 60 knots, this places the fish approximately 1 mile from the target. The data block on each photograph contains a shot number, a laser peak power measurement, and aircraft radar altitude. Date and takeoff time as well as oscilloscope scale factors are also given. Laser scan angle and beam divergence are data not indicated on the photographs; the fixed unstabilized scan angle was 45° and beam divergence was 48 mr. Because of this combination, target depth cannot be readily obtained. The range of possible depths, however, is surface to 11 meters (36 ft). Since depth and reflectivity are unknown, it is not possible to determine the size of the target.

Sample calculations show that a target on the surface with a cross section of 1 square foot and a reflectivity of 50 percent would produce a return similar to those in the photographs. The width of the return signals shows little pulse spreading, which is characteristic of targets near the surface. No visual confirmation was possible due to lighting conditions during the flight which was conducted at dusk and during the night.

Observation #2

During tests of the ORIC optical system on December 6, 1977 a small school of fish was detected. This detection occurred near the Five Fathom Bank about 8 miles east of Wildwood, New Jersey. The ground speed of the SH-3 helicopter carrying the ORIC equipment was 60 knots and the altitude was 152 meters (500 ft). The pulse repetition rate of the laser was 15 Hz.

Figure 4 is an intensity modulated record of this detection. This record was made from the flight test magnetic

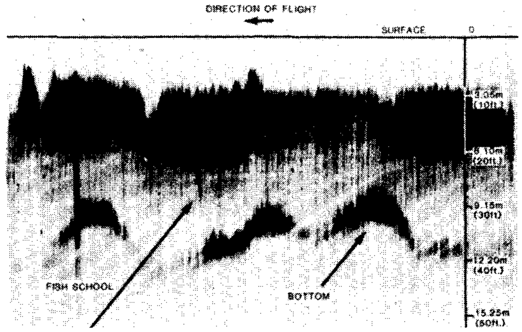

Figure 4. An intensity modulated record of a fish school detected over Five Fathom Bank off Wildwood, New Jersey on December 6, 1977. Arrow indicates direction of fish school plot appearing in Figure 6.

tape recording using a modified Tektronix 4631 hard copy unit. The depth scale shows the bottom depth to range from 9.1 to 12.2 meters (30 to 40 ft). The arrow points to the return signal from the fish school. This return also shows some variation in depth and a shadowing that reduced the return from the bottom.

Figure 5 is a photograph of a pseudo "3D" display showing the same signals. The fish school and the bottom can be readily identified in this photograph.

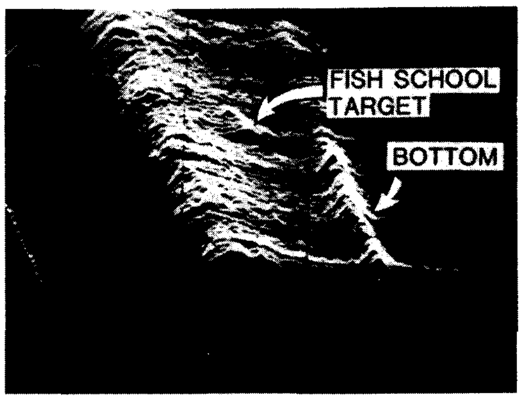

Figure 5. A "3D" oscilloscope display showing the fish school and ocean bottom.

A vertical profile of the fish school target was plotted (Figure 6) based on pulse rate, return width and rate of aircraft movement over the surface (ground speed). The length of the school profile, as measured through a portion of the school by the vertical looking laser beam, was approximately 28.8 meters (87.8 ft) by 2.62 meters (8 ft) at maximum thickness. Thirteen target intercepts were recorded over a 28.8 meter section of the school. The upper and lower boundary of the school was 7.1 meters (21.5 ft) and 9.7 meters (29.5 ft) below the surface, respectively.

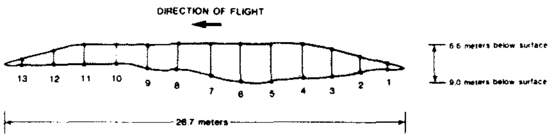

Figure 6. Vertical cross-section of a portion of the fish school directed by the optical laser and plotted from the intensity-modulated record. Length of intercept 26.7 meters (87.5 ft) calculated from a pulse rate of 2.06 meters (6.75 ft) per pulse × 13 pulse intercepts. Arrow indicates direction of plot as observed in Figure 4.

The species of fish intercepted is unknown and no visual observations were attempted. Water clarity in the area was not measured but was reported to be typical of the region. For this area Secchi disk depths are reported to average < 10 meters.

DISCUSSION

Assessment of pelagic near-surface schooling fishery resources requires the detection of fish schools and their measurement in both the horizontal and vertical planes. The photographic and electronic techniques currently in use are capable of profiling in the horizontal plane only. Aerial photos can profile the school in the horizontal plane if lighting conditions are optimum, and the fish school is near the surface and turbidity levels are near optimum for photography. LLTV systems also produce a profile in the horizontal plane. The LLTV system should be capable of providing species identification resulting from the differential behavior patterns displayed when the individual fish are subjected to pulsed light. These systems can detect bioluminescence generated by fish school action on or near the surface and at considerable depths, dependent upon turbidity levels and the concentration of bioluminescing organisms.

Optical lasers offer an unexplored potential because they can profile in both horizontal and vertical plane and are capable of operation during both daylight and darkness. An optical laser can be operated at high altitudes in a scanning mode thereby making it an effective airborne survey device. Airborne optical laser systems are currenlty being developed by the U.S. Navy to provide operational devices to obtain bathymetric data. These systems could be programmed for fish school detection. Detection depths are dependent upon water clarity, and may range to 75 meters (228 ft) or more; in coastal water of reasonable clarity, target detection depths should extend to at least 30 meters (91 ft).

In the future, airborne detection and profiling of pelagic fish schools using an airborne optical laser will play an important part in assessment of pelagic resources. Optical lasers and other airborne detection and identification devices such as LLTV, coupled with surface surveys using acoustical and fish sampling techniques, will contribute to a better understanding of pelagic fish resources.

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Mr. Squire has a BSc from San Diego State University and has conducted graduate research at the University of California at Los Angeles. He is author of over 40 scientific poublications covering the fields of fishery exploration and assessment and application of airborne techniques to the measurement of fish populations and their environmental parameters.