AIRBORNE LOW-LIGHT SENSOR DETECTS LUMINESCING FISH SCHOOLS AT NIGHT

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The National Marine Fisheries Service (NMFS) is aware of the need for new and improved methods of assessing fish stocks. Fishery data are inadequate because they have produced wide-ranging population estimates. Systematic appraisals of world fish stocks vary from 55 to 2,000 million metric tons; obviously, this wide range is not suitable for management purposes.

NMFS presently assesses fish stocks from samples caught by research and commercial vessels. The evasive behavior of fish caused by vessels and gear often results in considerable bias of the catch rate. Stock assessment is difficult because the samples are collected with few vessels in a small area over a long period. The most reliable assessments are based on collections over a large area in a short time. Any new assessment method requires more accurate and rapid detection. All indications point toward use of remote sensors to collect the information required to assess and manage the Nation's fishery resources.

Detection of pelagic fish schools from aircraft is well established in the world's commercial fishing. In Florida, spotters often fly as low as 300 feet to detect Spanish mackerel schools that blend with coral bottom and submerged vegetation. In California, night and day operations ranging 125 miles or more offshore are conducted with single-engine aircraft. During the dark of the moon, the fish spotter may remain in the air from dusk until dawn searching for luminescing schools of tuna and anchovy (Squire, 1961 and 1965). Airborne remote sensors are needed that can rapidly detect fish schools day and night.

REMOTE SENSORS

Remote sensors are instruments that extend man's visual abilities far beyond normal range. With radio telescope, he explores objects far out in space. Television cameras mounted in satellites can spot a hundred-foot object on earth from 500 miles. By extending his senses with such devices, man can locate targets that he cannot observe directly.

NMFS scientists at the Exploratory Fishing and Gear Research Base, Pascagoula, Mississippi, in cooperation with National Aeronautics and Space Administration (NASA) Spacecraft Oceanography Project, are testing airborne sensors to detect and identify fish schools in daylight and at night (Peace and Drennan, 1969; Drennan, 1969; Benigno, 1970).

The sensors include aerial cameras (Bullis, 1968; Bullis and Pease, 1968), spectrometers to measure reflectance spectra of fish schools and associated fish oils (Bullis and Thompson, 1970), and low light sensors to detect schools from high altitudes at night. Background information on bioluminescence and the results of tests with low-light sensors are presented here.

BIOLUMINESCENCE IN THE SEA

Bioluminescence is light produced by living animals and plants comprising thousands of species of marine organisms, including plankton. The lanternfishes and euphausiid shrimp that predominate in the deep scattering layer possess luminous organs.

Direct observations and the use of sensitive underwater photometers reveal the universal occurrence of bioluminescence in the oceans. The phenomenon occurs in all temperate seas, particularly during warm season. It occurs more often and with greater intensity throughout the year in tropical and subtropical seas. Studies in the Atlantic and Indian Oceans, and in the Mediterranean Sea, have shown luminescent organisms always present

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where measurements were made with underwater photometer (Clarke and Wertheim, 1956; Clarke and Breslau, 1959; Clarke and Kelly, 1964).

The major concentrations of luminescing organisms are in the upper 100 meters, usually within the lighted zone, and in waters where most pelagic fishes abound. Population densities of luminescent organisms vary considerably. The maximum concentration reported for Phosphorescent Bay, Puerto Rico, was 7,600 cells per liter (Clarke and Breslau, 1960); cell densities as high as 220,000 per liter were found in Oyster Bay, Jamaica, in the West Indies (Seliger, Fastie, Taylor, and McElroy, 1962). The luminous dinoflagellate, Pyrodinium bahamense, is the most abundant organism in both bays.

Most bioluminescence in the sea is caused by dinoflagellates that emit light when stimulated. The light is produced by a biochemical reaction catalysed by a specific enzyme in the presence of water and oxygen. Light-emitting luciferin is oxidized by the enzyme luciferase, and some luciferin molecules absorb energy and thereby reach excited state. When stimulated, each molecule of luciferin releases one photon (unit) of light. If sea water is stirred, the luminous discharges of individual microorganisms look like sparkling crystals. If the water is agitated rapidly, the points of light emitted by dinoflagellates fuse into a bright glow. Turbulence resulting from the swimming motion of fishes provides the mechanical stimulation that outlines their bodies with light, and leaves behind a luminous trail.

What Low-Light Sensor Achieves

Visual observations and feasibility tests using an airborne low-light sensor during moonless periods show that: 1) bioluminescence associated with fish schools makes the schools conspicuous; 2) the perimeter of the school is usually well defined; and 3) the school is detectable to sensor and television camera from aircraft at 5,000 feet.

Potential applications of low-light sensor include detecting herring, sardine, mackerel, and tuna schools at night on traditional grounds where luminescing schools are known to occur; observing the reaction of fish to bioluminescence associated with fishing gear; and to make "real-time" observations as part of a remote sensing system in exploratory fishery-resource assessment.

PRACTICAL SIGNIFICANCE OF BIOLUMINESCENCE IN COMMERCIAL FISHERIES

1. Pacific Sardine (Sardinops caerulea)

Bioluminescence has been used in detection and capture of sardine schools off the U.S. Pacific Coast. Once the most important fishery in the western hemisphere, it is now under a moratorium due to the absence of commercial concentrations. The greatest catch occurred in 1936-37: 790,000 tons landed. It is still fished off Mexico's Pacific coast.

The sardine schools are located by their luminous glow during moonless periods. Before the new moon, fishing occurs from one hour after sunset until moonrise and, during the new moon, from one hour after sunset until one hour before sunrise. Following the new moon, fishing is done from moonset until one hour before sunrise. On the average, 19 nights are fished during each lunar period during sardine season. Before new moon, good catches are made from one hour after sunset until moonrise; after new moon, the best fishing occurs immediately after moonset (Scofield, 1929).

The seiner passes close to the glow to assess school's extent and density. Identification of species is determined by luminescent trails left by individual fish darting from vessel. Sardines show long rocket-like streaks, smelts swim in "S"-shaped curves, and anchovies display short spurts (Higgins and Holmes, 1921).

The lampara seine used is particularly efficient because its webbing stimulates organisms to luminesce as it is pulled through water. The fish, frightened by bright glare associated with fibers, are herded into bag. As wings are pulled in, a "scarer" consisting of several paddles on a long rope is raised and lowered through the water. The luminescence produced by the whirling paddles frightens fish away from net opening, thereby preventing their escape.

2. Skipjack (Katsuwonus pelamis), Yellowfin Tuna (Thunnus albacares), Bluefin Tuna (T. thynnus)

In the eastern Pacific, luminescing schools of skipjack, yellowfin, and bluefin tuna are sighted by spotters aboard tuna purse-seine clippers during dark of the moon.

Table 1. Summary of Commercial Fishes Detected by Luminescence

	East Pacific	West Africa	Gulf of Mexico	Gulf of Maine
Coastal:	sardine (*Sardinops caerulea*)	sardine (*Sardinella aurita*)	thread herring (*Opisthonema oglinum*)	herring (*Clupea harengus*)
	anchovy (*Engraulis mordax*)	herring (*Sardinella eba*)	Spanish mackerel (*Scomberomorus maculatus*)	mackerel (*Scomber scombrus*)
	mackerel (*Scomber japonicus*)	mackerel (*Scomberomorus maculatus*)	bluefish (*Pomatomus saltatrix*)	butterfish (*Poronotus triacanthus*)
	smelt (*Atherinopsis californiensis*)		menhaden (*Brevoortia patronus*)	menhaden (*Brevoortia tyrannus*)
	saury (*Cololabis saira*)		ladyfish (*Elops saurus*)	
	jack mackerel (*Trachurus symmetricus*)		bluerunner (*Caranx crysos*)	
			tarpon (*Megalops atlantica*)	
Oceanic:	bluefin (*Thunnus thynnus*)	yellowfin (*Thunnus albacares*)		
	yellowfin (*Thunnus albacares*)	skipjack (*Katsuwonus pelamis*)		
	skipjack (*Katsuwonus pelamis*)			

	Mediterranean Sea	Caribbean Sea	Australia	North Sea	Indian Ocean	South Africa	Philippine Islands
Coastal:	sardine (*Sardinella aurita*)	sardine (*Sardinella* either *anchovia* or *brasiliensis*)	pilchard (*Sardinops pilchardus*)	herring (*Clupea harengus*)	mackerel (*Rastrelliger kanagurta*)	pilchard (*Sardinops ocellata*)	sardine (*Sardinella fimbriata*)
	mackerel (*Scomber scombrus*)					maasbanker (*Trachurus trachurus*)	

All lights, except for navigation, are extinguished while searching. The spotter in crow's nest periodically flashes a high-powered spotlight over the water. When beam passes over a school, disturbance of the fish causes a bioluminescent glow called a "fireball" (Scott 1969). Generally, the glow is uniform throughout school. "Popper" refers to a fireball school in which brilliant bursts of light are caused by activity of individual fish. Before purse seine is set, the fishermen identify the species--because anchovy and jack mackerel also cause bioluminescence. The large luminescent outlines usually distinguish tuna from other fishes.

More Susceptible to Night Capture

The logbook records of Pacific tuna purse seiners show that luminescing schools of skipjack, yellowfin, and bluefin tuna were more susceptible to capture at night (Whitney, 1969). Only 50 to 54 percent of daylight sets were successful, while night sets ranged from 69 to 77 percent. The average night catch of yellowfin tuna during dark of the moon is about the same as during the day, about 14 or 15 tons per set. Off southern California, spotter pilots rely on bioluminescence to detect tuna schools between September and June. At night, they fly only when moon is dark, before the moon rises, or when moon is overcast. As verified by ship sonar, schools have been seen from aircraft as deep as 35 fathoms.

3. Atlantic Mackerel (Scomber scombrus)

In the Gulf of Maine, bioluminescence helps purse-seine fishermen detect and catch mackerel. Luminescent patches associated with moving schools are visible at depths to 10 fathoms during moonless periods (Sette, 1950). Fishermen scouting at night can identify at least four species according to type of luminescence. Long brilliant streaks indicate Atlantic mackerel, starlike flashes identify butterfish, bright zig-zag lines characterize Atlantic herring, and a dim glowing sphere is recognized as a school of Atlantic menhaden.

4. Atlantic Herring (Clupea harengus)

Maine stop seine fishermen are most active at night when searching coves to locate herring by their "fire". They follow the luminous trails until the school enters a shallow inlet, where it can be trapped.

5. Spanish Mackerel (Scomberomorus maculatus)

During night fishing in Florida coastal waters, the vessel cruises at 5 knots in areas where luminescing schools of Spanish mackerel are likely to be seen. The captain periodically flashes a spotlight, and the fish show the "fire" produced by their sudden movements. Catches of 10,000 to 20,000 pounds per set are not unusual.

6. California Anchovy (Engraulis mordax)

Off California, schools surface at night and are visible as luminous spots (Messersmith, Baxter, and Roedel 1969). The schools expand as dawn approaches. Night catches up to 160,000 pounds per set have been made using purse seines.

7. Thread Herring (Opisthonema oglinum)

Spotter pilots have seen large luminescing schools of thread herring as far as five miles off Florida's southwest coast.

DEVELOPMENT OF LOW-LIGHT SENSORS

Research by the U.S. Army Electronics Command on night-time search and identification of enemy targets has produced the starlight scope. Unlike the infrared sniper scope, it needs no light of its own. It uses only natural light (moonlight, starlight) or the faint luminescence of decaying jungle foliage. It amplifies light 40,000 times and transforms darkest night into day. The heart of the starlight scope is the image-intensifier tube (Fig. 1), which consists of several bundles of very thin glass fibers. Each fiber transmits light in a straight line down length of fiber, which prevents both distortion and leakage. The scope's objective lens focuses the light against a chemical film that discharges electrons. These electrons, boosted by a 15,000-volt electrostatic field, impact onto a phosphor-coated screen whose light then loosens additional electrons. The process is repeated three times. The high-voltage electron acceleration produces a brighter image at the ocular lens. The only power source is a small built-in battery.

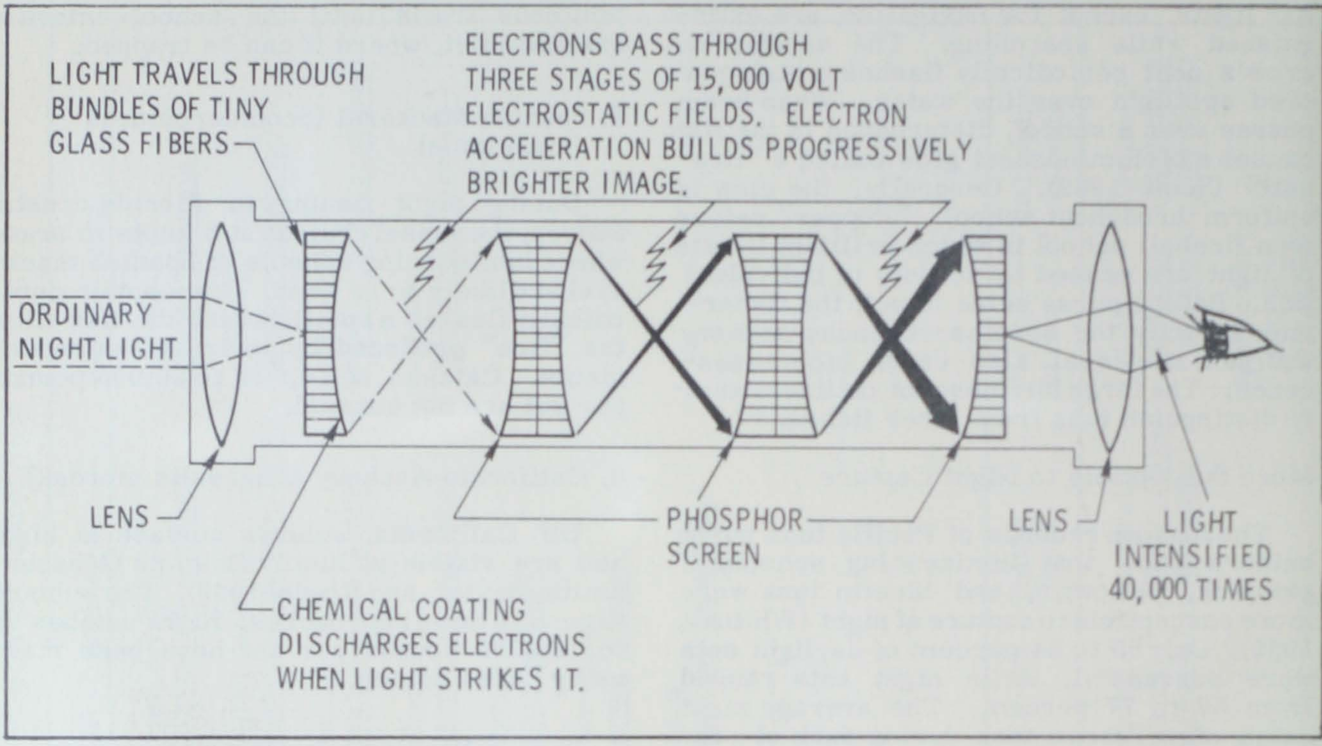

Fig. 1 - Diagram of image intensifier tube of starlight scope.

NMFS PASCAGOULA RESEARCH

During October 1968, tests were conducted at Port St. Joe, Florida, aboard a commercial seiner. The starlight scope was used to detect bioluminescence associated with Spanish mackerel schools during dark of the moon (Fig. 2). With scope coupled to a closed circuit television camera, the image of luminescing school was recorded on video tape (Fig. 3). Figures 4 and 5 show each moving fish outlined by light around its reflective body, which is followed by a luminous trail. The trail is produced by stimulation or organisms in turbulent wake of the fish.

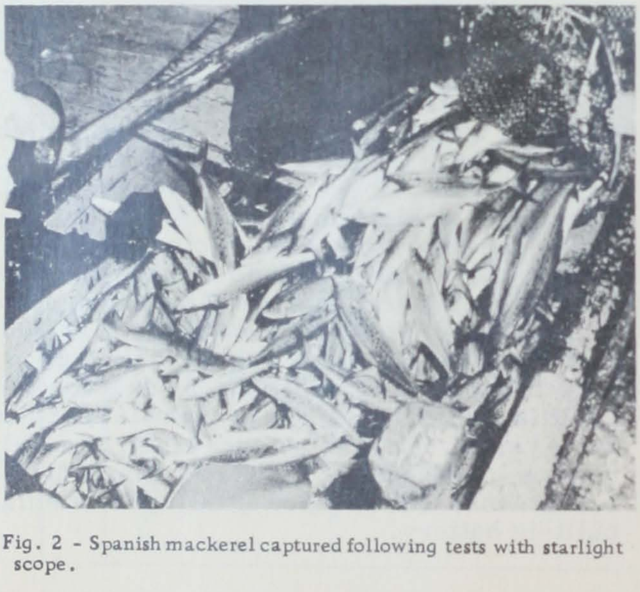

Fig. 2 - Spanish mackerel captured following tests with starlight scope.

During dark of the moon, in January and February 1969, luminescing fish schools were recorded on video tape with SANOS (stabilization airborne night observation system) scope and closed-circuit television. Data were recorded from a Grumman Albatross

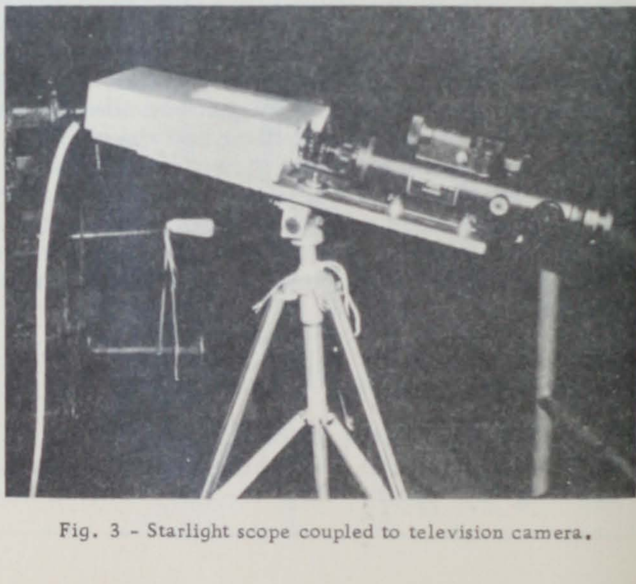

Fig. 3 - Starlight scope coupled to television camera.

Fig. 4 - School of Spanish mackerel showing associated bioluminescence as detected with star light scope and seen on television screen. School is 5 to 10 feet below surface; its distance from sensor is about 50 feet.

Fig. 5 - A Spanish mackerel outlined by definite field of light around body.

and a helicopter stationed at St. Petersburg, Florida, Coast Guard Air Base. A commercial fish spotter was chartered to spot schools of thread herring during daylight over commercial fishing grounds off Sanibel Island, Florida. A search of the same area at night revealed luminescing schools near surface. At altitude of 3,500 feet, a luminescing school was amplified by the low-light sensor before appearing on television screen (Fig. 6). The width of crescent-shaped school was estimated by spotter pilot at 150 feet. Night aerial search near Ft. Myers Beach, Florida, revealed an elliptical school with long axis of about 500 feet (Fig. 7). Sporadic flashes in school probably were caused by nocturnal predators, such as shark or tarpon. Luminescing schools were detected in same general area during three consecutive nights.

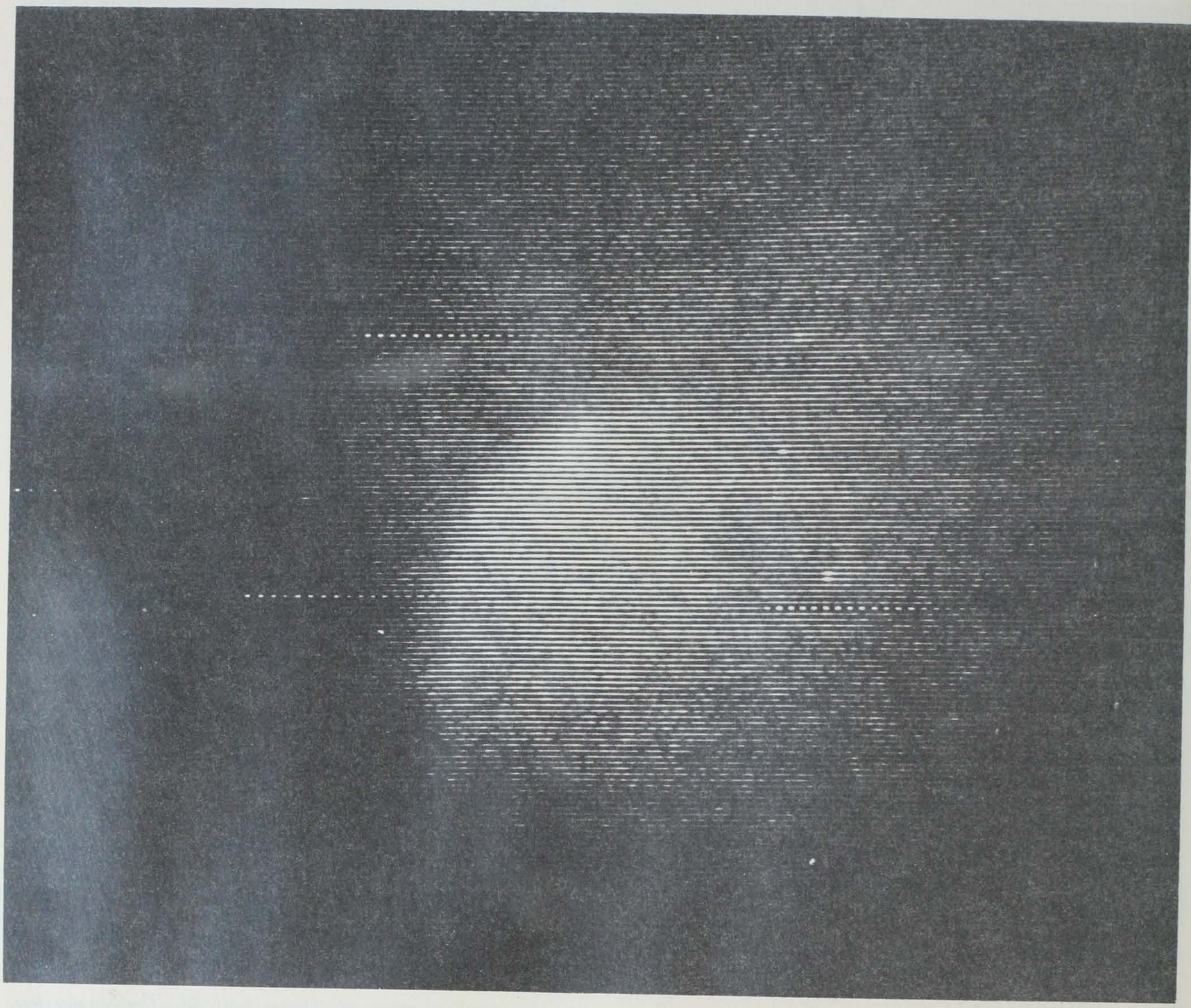

Fig. 6 - A school of thread herring 150 feet in diameter spotted from the aircraft at 3,500 feet. The faint luminescence was amplified by lo-light sensor before appearing on TV screen shown in photo.

With SANOS scope in helicopter (Fig. 8), several schools about 300 feet wide were sighted off Sanibel Island from 500 to 5,000 feet altitude. The luminescence was visually intense from spotter aircraft at 2,000 feet as helicopter videotaped school at 500 feet. The glow was brilliant despite twilight and early morning haze, probably because helicopter noise frightened school.

Visual and low-light-sensor observations during moonless nights show that:

1. Bioluminescence makes school conspicuous.

2. Perimeter of school usually is well defined.

3. The school is detectable to sensor and television camera from 5,000 feet.

Results show that low-light sensors can detect fish schools invisible to naked eye at night.

APPLICATION OF LOW-LIGHT SENSORS TO FISHERIES & RESEARCH

Low-light sensors may be applied in two ways:

1. As direct fishing aid by mounting sensor and television camera in crow's nest of a purse seiner, with television screen in pilot house. Then the captain could detect herrings, sardines, mackerels, and tunas at night where schools are known to occur. Airborne sensors would shorten search time, increase successful sets, increase catch per day, and reduce vessel trip time. For daylight fishing of menhaden, tuna, and thread herring, detecting the schools before sunrise would provide advance information on concentrations. Data indicate that purse-seine sets during early daylight hours produce larger catches than at other times.

2. Probably more important application of low-light sensors would be as a prime sensor in fishery research. Scientists are concerned with schooling behavior at night. Observations of bioluminescence with the unaided eye are insufficient to determine what influence

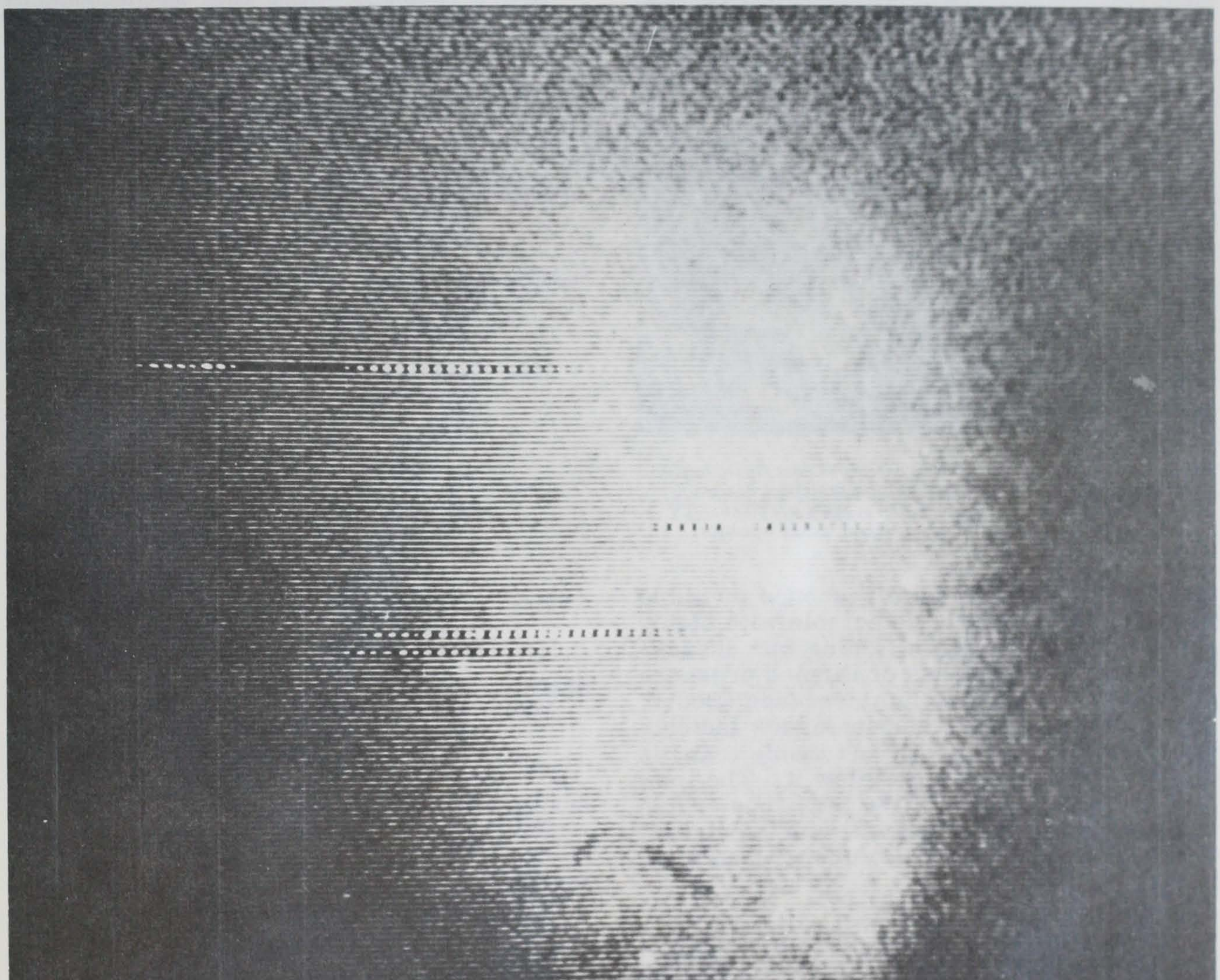

Fig. 7 - A large luminescing school of thread herring 500 feet in diameter amplified by airborne low-light sensor. Flashes inside school may be preadators attacking from below.

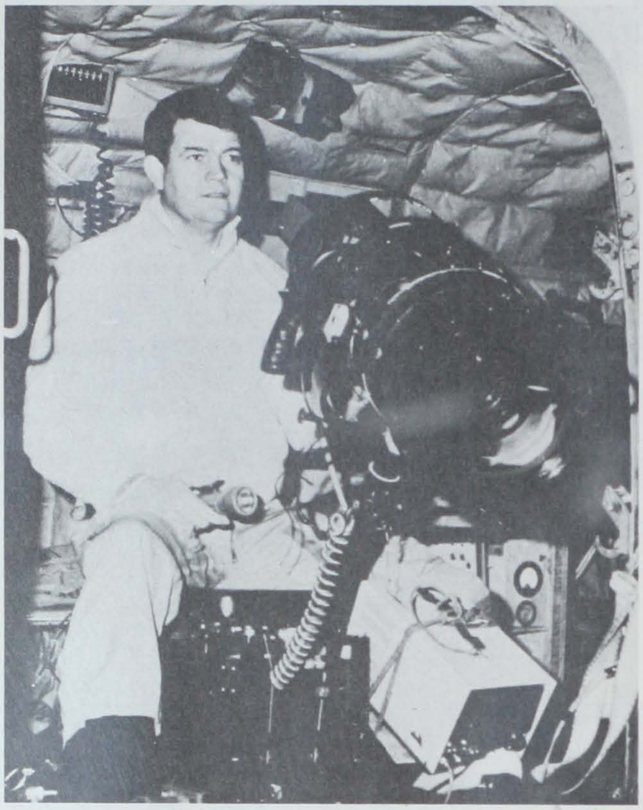

Fig. 8 - SANOS scope mounted in hatch of Coast Guard helicopter used as survey aircraft during fish-school detection tests. TV camera is coupled to the scope's eyepiece. TV monitor is in lower right corner of photo facing operator.

it has on the school. Luminescence invisible to unaided eye would be detectable with highly sensitive sensor. Night fishing with Isaacs-Kidd midwater trawl has confirmed presence of associated cone of luminescence (Boden, 1969). Photometric measurements indicate that amount of light ahead and inside trawl is greater than that above or below it. The low-light sensor can detect the reactions of fish to luminescence associated with the trawl, which also may provide new insights on night midwater trawling.

The airborne sensor can greatly assist in resource assessment by providing "real-time" observations of number and size of schools. Also, it would rapidly record data for analysis and interpretation by computers. This new technology would supply reliable information on status, size, movements, inventory, and forecast of traditional and new stocks in large areas on a time scale not now possible.

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