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THE LOCATION OF SARDINE SCHOOLS BY SUPER-SONIC ECHO-RANGING

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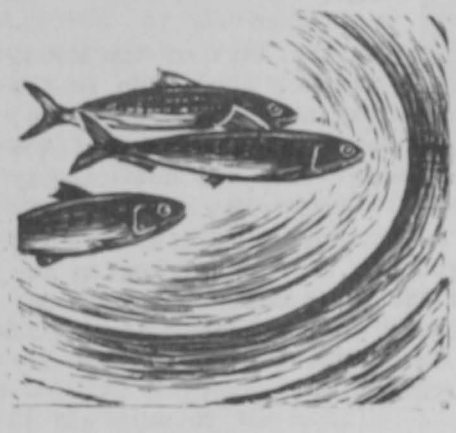

During the California sardine season from August 1, 1944 to February 15, 1945, the Navy cooperated with the Fish and Wildlife Service in conducting experiments to determine the feasibility of using super-sonic echo-ranging equipment to locate sardine schools, for the purpose of increasing the catch of a much needed food during the war.

The echo-ranger is called "sonar" in this country and "asdic" in Great Britain. It should not be confused with radar. The echo principle is the same, but wave frequencies used in radar cannot be used under water.

The sonar, used by the Navy to locate submarines or other under-water objects, operates on much the same general principles as super-sonic echo sounders already in common use on large fishing vessels and used extensively by the Coast and Geodetic Survey for accurately charting submarine topography.

Various types of echo sounders, their uses, and the physics of sound waves in water are thoroughly described in the Hydrographic Manual, U. S. Coast and Geodetic Survey, Special Publication No. 143, Revised (1942).

Super-sonic impulses have less range than sonic impulses, such as those arising from explosions or hammering, but they are more directional. The wave frequency used in echo-ranging is a compromise between the two desirable physical qualities of range and directability.

The ability of high frequency echo sounders to locate fish schools by echo has been demonstrated, notably by the Norwegian research vessel Johan Hjort, that located cod shoals over 10 years ago (O. Sund, Nature, 135 (3423), 953, June 1935) and more recently by experiments on herring schools off British Columbia (Tester, A. L., Fisheries Research Board of Canada, Bull. LXIII, 1943).

The echo-ranging equipment used by the Navy can locate fish schools in much the same way as echo-sounding equipment, but in the case of the former, the beam of high frequency impulses is directed horizontally through the water instead of straight down. Consequently, a vessel scouting with echo-ranging equipment can explore a much larger area. A super-sonic beam may be aimed much like a searchlight, and in this way the bearing and the approximate size of a reflecting object may be measured and any movement detected. The range is derived from the echo-

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time. As with standard echo sounders, the echo from a non-rigid surface, such as fish schools, kelp beds, or a mud bottom, is less sharp than the echo from a hard surface such as rocks, or a ship's hull. This difference can be recognized by either visible or audible electronic signals, or both.

The velocity of sound waves in water varies with the physical properties of the water, the two most important being temperature and pressure. The speed of sound increases with temperature and also with pressure, but the effect of temperature generally dominates in the upper water layers. Hence, a horizontal beam of sound waves may be refracted downward by a sharp temperature gradient or thermocline, sometimes producing echoes from the bottom. A "wall" of different temperature water may also reflect some of the sound waves and produce a faint echo. Both these types of echoes can be distinguished from echoes of fish schools, but they may cause interference or restrict the effective range.

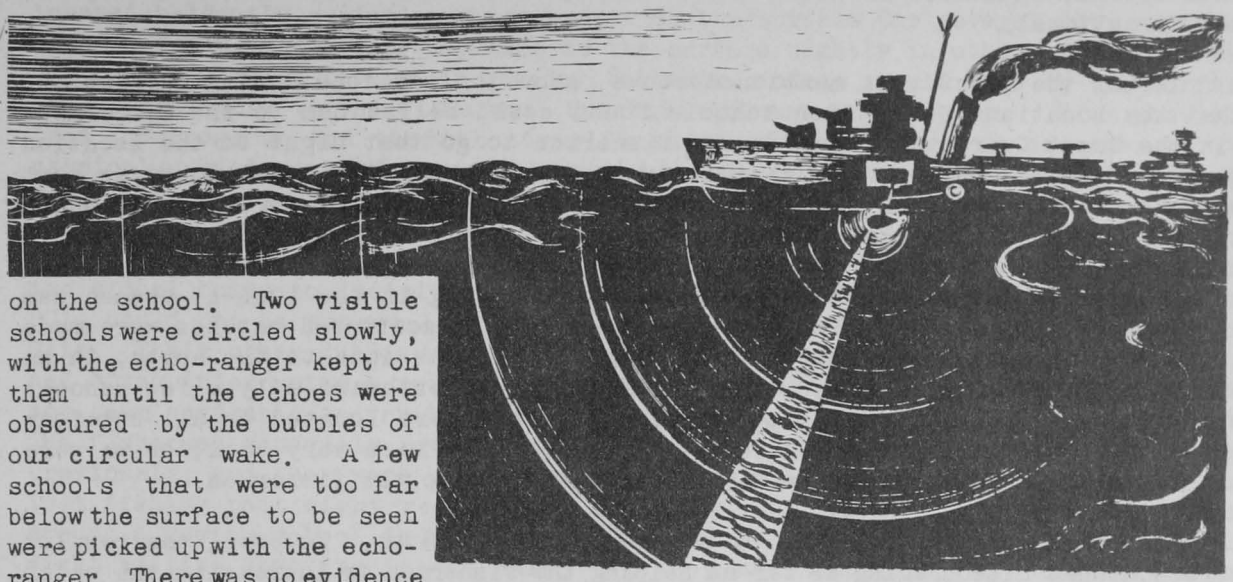
Sardines are caught off the California coast during the dark of the moon, when the dense schools may be found by the luminescent patches they make in the water. The school is circled with a great quarter-mile-long net, or purse seine, and it may yield 150 to 200 tons of sardines, or even more. Sardine schools are apt to occur in groups unevenly distributed along the coast. They are not usually visible at the surface during daylight off California. Anchovies are the only other species commonly occurring in large schools off northern California, and they considerably complicate fishing, as well as scouting with echo-ranging devices, because they are a nuisance and a liability to the fishermen. They may become gilled in the nets by the ton, and may tear or take to the bottom thousands of dollars of netting in one unlucky "set." Even a few anchovies may mean a day of hard work and lost fishing time to remove them from the net.

To test the practicability of aiding the sardine fleet during the past season, Dr. L. A. Walford made two scouting trips on Navy PC's (175 feet submarine chasers) patrolling off San Francisco, and the author went out 12 times. We scouted north to Bodega Bay, west of the Farallon Islands, or south as far as Pt. Montara; the length of each trip being limited by the time that the ship could be spared from her wartime duties.

The first three trips were inconclusive. Sonar contacts were secured during only one of them, and these were too indistinct to be definitely identified as fish.

On the fourth trip (August 8) we obtained many echoes east and northeast of the Farallon Islands, but most of them were very faint, and we could not maintain contact long enough to make a good test. However, salmon caught by trolling from the PC had fresh sardines in them, and also the sardine fleet made catches on the next few nights only a few miles farther south.

On the night of August 16, echo-ranging was tried in the locality where the fleet was fishing. This was done to test the equipment in an area where the schools could be seen by their luminescence. As we approached the fishing fleet of some 60 vessels southeast of the Farallones, sonar contacts became more and more frequent and they were found all around the ship after we were among the fishing boats. Several times an echo was located 700 to 1200 yards dead ahead, and as we approached the spot a typical luminescent sardine school could be seen. Other schools were located with the echo-ranger off the sides of the vessel and seen immediately after. A few small schools were seen first, while the echo-ranger was exploring in another direction, and then the echo was picked up by echo-ranging



on the school. Two visible schools were circled slowly, with the echo-ranger kept on them until the echoes were obscured by the bubbles of our circular wake. A few schools that were too far below the surface to be seen were picked up with the echo-ranger. There was no evidence that the fish were more frightened by the echo-ranger than by the approach of any vessel.

After gaining confidence on this night's scouting trip, we devised a set of criteria for the identification of fish schools. These were: (1) the character and tone of the echo which was described by the sonar operator as "mushy," non-metallic, and much less distinct than the echo received from a submarine or wreck, (2) the size of the echoing surfaces, which were usually larger than a submarine, a wreck, or a whale and yet more distinct and sharply defined than an echo from a sharp temperature gradient or from the bottom, (3) variations in the tone and intensity of the echoes, such as might be caused by the fish heading in different directions and thus offering more or less echoing surface, and especially, (4) by movement of the "target," often in an erratic and irregular manner.

Echo-ranging was also tried on whales, a submarine, schools of porpoises, ships and their wakes, and mine sweeping paravanes for comparison with fish schools. On one occasion, echoes were received from the bottom, in a complete circle about the ship at one range. This apparently was due to a sharp temperature gradient bending the sound path downward. The echoes from all these could be distinguished from fish school echoes.

In addition, each moving "target" made characteristic super-sonic "noises," which could be detected with the sonar listening device. Porpoises clatter like a herd of horses on a wooden bridge, and a school of fish makes a strange conglomeration of clicking, tapping, fluttering, and rumbling noises. One sailor suggested that the fish sounded like activity in a machine shop. It might even be possible to distinguish different kinds of fish by their noises, but this could not be tested. The direction of noises from fish schools checked roughly with the direction of the echoes, though the bearings could not be measured quite as accurately. There are also various "water noises" that cause interference in rough weather or at

high speeds, but these are much like ordinary audible water noises, and they are not directional.

After the night test mentioned above, scouting was done during daylight so that the location of any fish schools found could be radioed to the fishermen, via the Coast Guard, in time for the fishermen to go that night to the location given. Each fishing boat was checked out of the harbor by the Coast Guard as part of their wartime control, and the messages we sent were relayed by the Coast Guard to each boat as it checked out.

It so happened that most of the sardine fishing in the 1944-45 season was done well to the south of San Francisco. Only a few scattered catches were made north of that port. Most of the scouting by PC's was done to the north, in an effort to locate fish nearer port. On most trips northward only a few schools were located. Targets that probably were schools were located on all but four out of the 14 scouting trips made, but if the echoes were very weak, or we were unable to maintain contacts, we did not report them to the fishermen.

Fish schools were reported by radio on five occasions. However, the results were somewhat discouraging as far as helping the fishermen or increasing the catch was concerned. Once, stormy weather and the period of full moon kept the fleet in port. On two occasions the fleet, quite understandably, ignored our reports of fish to the north and all went south, because fish had been caught there the previous night. On one occasion, during the week of the full moon, when the fleet was in port, we scouted south of San Francisco one day and north the next. We found many schools to the south and only a few northward. This situation was reported and all of the fleet went south the following night and made good catches. This checked neatly with our sonar scouting, but as the fleet usually had been fishing to the south during the season, we could not claim to have led the boats to the fish.

On December 3, we located a large group of schools north and west of the Farallon Islands. This was by far the largest group of schools or shoal found to the north, and they met all the criteria of fish schools mentioned above. Twenty-one definite schools were located in an hour and 26 minutes, or about one every 4 minutes, without deviating from our course. These were reported by radio, but only one boat investigated the report. This boat scouted the area on following nights without seeing any fish. It is possible that we located schools of fish that did not come to the surface. It is also possible that the fleet would have found fish in this area sooner if they had scouted it more thoroughly. At any rate, on the night of December 15, 12 days later, the fleet made good catches between Pt. Reyes and the Farallon Islands for the first time in 2 months. After the fishermen had located this school-group, they apparently concentrated on the same fish until December 21, the end of the dark, following them as they moved south as far as Santa Cruz.

DISCUSSION

The tests demonstrated that fish schools can be located with super-sonic echo-ranging equipment, just as they can with an echo sounder. The main difference is that the echo-ranger covers a wider area.

Fish schools below the surface were located on a number of occasions and their positions radioed to the fishing fleet. In most cases the fishermen ignored the report and proceeded elsewhere, where fish had been caught previously, or if a few boats did go to the area indicated they failed to find fish. The scouting by the

fishermen was not thorough enough to be conclusive, but it would appear that schools located below the surface may not appear on the surface for several days or weeks in some areas, while they may come to the surface nightly in other areas. It was our hope that fish located in the day, below the surface, would come to the surface and be available to the fishermen, but this did not materialize. It is possible that knowledge on the thermal stratification of the water, or on other of its physical or biological characteristics might enable one to determine whether schools found at subsurface levels in the daytime would rise to the surface at night.

It was not practical to have the Navy vessel remain in one spot and direct individual boats to individual schools for "blind sets" principally because the PC's could not be spared long enough from their wartime patrol off the Golden Gate. Their other duties restricted both the time and the extent of our scouting and often interrupted a cruise unexpectedly. Faced with this situation, it did not seem advisable to try to break down the natural skepticism of the fishermen. The fishermen generally preferred to scout in areas where fish had been caught previously, and they were afraid of the financial risk or days of hard work and lost fishing that might result from catching anchovies. Furthermore, setting around a moving school is not easy, even when it can be seen, so to set blindly might be like shooting in the dark. If they miss the fish, the men are in for 2 or 3 hours' work just getting the empty net on board again. Aside from the difficulty of circling an unseen and moving school, the fish might easily escape by going out under the net before the purse line has gathered the bottom together, as a draw string closes a bag. Fish are very often lost this way even when the school is found at the surface, so if a school is already 15 or 20 fathoms below the surface, it might easily escape under a net 25 or 30 fathoms deep.

Guiding individual boats would also have raised the problem of distributing any benefits fairly among all fishermen, and might have led to accusations of favoritism. The Navy had been faced with this problem in fish scouting from blimps, and several officers expressed a desire to avoid such a situation.

Taking all aspects of sonar scouting, as carried on during these experiments, it was concluded that the Navy scouting vessel did not increase the efficiency of the sardine fleet enough to be justifiable as a war measure, and the work was discontinued.

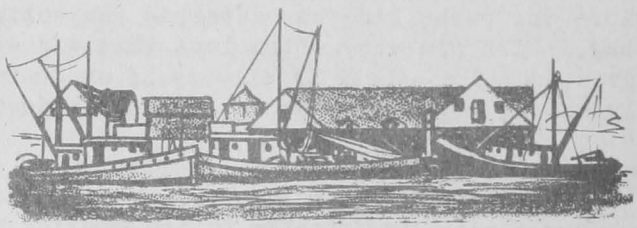
The experiments demonstrated, however, that sonar can locate schools of fish under certain conditions, and sonar may become a valuable tool for commercial fisheries or fisheries research, or both. If echo-ranging devices can be built small enough and cheap enough to be installed on fishing vessels, they might be of considerable value in some cases, especially under conditions of poor visibility. It should be possible to use sonar to locate subsurface schools, and watch their movements so fishing boats could be on hand when the fish come up. In some types of fisheries, sonar might be used to make "blind sets" on subsurface schools.

Probably sonar and listening devices could serve the fishing interests best indirectly, as research aids. For this purpose they should be installed on vessels devoted full time to research on schooling fishes. In this way, if used in conjunction with some sampling method, such as jigs, bombs, or small gill nets, to determine the species of fish located, it would be possible to learn a great deal about the movements, distribution, and perhaps spawning of fish like sardines. Such exploring would help to fill a great gap in the knowledge of both scientists and fishermen. This is especially needed for the California sardine. It occurs

sporadically all the way from Alaska to Baja California, yet most of our present knowledge is derived from waters near a few widely separated fishing ports.

Newer types of echo-ranging and also listening devices, designed for soft objects instead of submarines, probably would be even more effective than the ones tested. The newer ones should also be easier to operate and maintain, according to one electronic engineer. Therefore, super-sonic equipment for fisheries investigation should be modern and, if possible, specially adjusted for the purpose.

PACIFIC COAST SARDINE CANNING



The sardine canning industry of the Pacific Coast utilizes as raw material the California sardine, which is closely related to the species canned as sardine in France, Portugal, and Spain. It is known as pilchard in the British Empire. The range of this fish on the Pacific Coast extends from Vancouver Island south to the Gulf of Lower California. The canning industry is centered at San Diego, San Pedro, Monterey, and in San Francisco Bay, California. While the fish are taken in quantity off Coos Bay, Columbia River, and Grays Harbor area of the Oregon-Washington coast, they are utilized almost entirely for reduction purposes. Some are canned in Astoria, Oregon, and a small quantity is canned in 1-pound tall cans in British Columbia as pilchards. With these exceptions, the sardine-canning industry is located in California. The fishing area covers a radius of approximately 150 miles around each port.

The season when sardines may be taken for canning or reduction purposes varies with the respective areas and is based on the time of year when they are in prime condition. At present, sardines may be taken for packing from August 1 to February 15 in the northern California or the San Francisco and Monterey areas, and in the San Pedro-San Diego district from November 1 to March 30, inclusive.

--Fishery Leaflet No. 81