A Literature Survey on the Subject of

# THE USE OF ACOUSTICS IN FISH CATCHING AND FISH STUDY

by

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13. ABSTRACT

This paper traces the history of the use of acoustics in fish catching and fish study and briefly describes the present state of the art, gives a comprehensive bibliography of the relevant papers and books, and presents summaries of some of the significant papers. It also lists the problems to be solved. It is hoped that fishermen, fisheries biologists, and others concerned with the application of acoustics to fishing and fish study will find this report useful as a literature survey.

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## Preface

In the humdrum of our urban life, where availability of food means a walk or a drive to the nearby grocery store, we tend to forget that two thirds of the world's population is either afflicted with hunger or suffers from protein malnutrition.

While a humane stabilization of the world population is definitely a problem which needs very urgent consideration, the search for food, the war against hunger and malnutrition are problems which ought to be uppermost in the minds of the administrators in most parts of the world. Food from the sea offers a potential solution.

The present harvest of the ocean is roughly 64 million tons annually. The United Nations Food and Agriculture Organization estimates indicate that a well-managed world fishery could yield 3 to 5 times the current output[A4]. In the U.S. alone, fishermen harvest just one tenth of what the Bureau of Commercial Fisheries estimates the coastal areas around the U.S. could yield. This is not because of low domestic consumption. In fact, the U.S. fish consumption has trebled during the last three decades and in 1969 about 60% of the total U.S. supply of fish products came from imports[A4].

The main constituent of the food from the sea is fish. The present contribution of fish to the world's food supply is 1%. The contribution of fish to the world's animal protein supply is 10%[A20]. "Although finding the fish is only a part of the problem associated with using fish to feed the starving people of the world today and in the future, it must be the first part of the solution"[118].

Only about three decades ago fishermen were, so to say, groping in the dark for fish. The introduction of acoustical devices to fish catchers and fish researchers could be compared to giving eyes to the blind. This equipment has proved to be a boon for fishermen and marine biologists.

This paper traces the history of the use of acoustics in fish catching and fish study and briefly describes the present state of the art, gives a comprehensive bibliography of the relevant papers and books and presents summaries of some of the significant papers. It also lists the problems to be solved.

It is hoped that fishermen, fisheries biologists, and others concerned with the application of acoustics to fishing and fish study will find this report useful as a literature survey.

PART I

## Summarized Remarks

### 100. History

Most of the development in the use of acoustics in fish study and fish catching has taken place during the last three decades. In fact, most of the science of Marine Bioacoustics developed during and after World War II.

Since prehistoric times fish have been known to be capable of sound production. Aristotle (384-322 B.C.) in his work "Historia Animalium" has reported descriptions of fish sounds[3]. Duffose (1874), Moreau (1876) and later on Burkenroad (1930) also reported descriptions of fish sounds[146]. These descriptions were based upon sounds that could be heard when fish were pulled out of the water. Von Ihering (1930) and others reported having heard sounds of large choruses of drumfish and similar forms that appear to produce sounds in association with spawning. Such sounds can often be heard out of water or by the simple expedient of placing one's ear against the hull of a boat. To this day many fishermen still use this technique to locate good fishing grounds for some of these sonic species[146].

Before World War II, the publications concerning noise made by marine life were sporadic and rudimentary in nature. During World War II, the widespread use of acoustical devices (e.g., active and passive sonar gear) for detecting the presence of submerged enemy submarines made it necessary to study the background noises in the ocean on a more professional basis. The performance of these acoustical devices is inherently limited by the signal to noise ratio[102]. Therefore, to ensure proper functioning of the acoustical devices, a precise knowledge about the background noises likely to be found in a certain locality became necessary.

Fish noise forms an important part of ambient biological noise in the sea. The other sources of biological noise are the invertebrates and the Cetaceans.

Proudfoot and Loye (1942-43) made an early study of ambient noise in coastal waters[102]. With the postwar development of sophisticated instruments for detecting and recording sounds, bioacousticians were able to differentiate and define various underwater noise sources. Spectrograms and oscillograms have been mainly used for these purposes[55]. The component parts of sounds are analyzed and measured from the spectrograms and the oscillograms. Fish, Kelsey and Mowbray (1952) and Fish (1954) undertook a cataloguing procedure in which sounds from identified individual fishes were recorded under captive conditions. Comparison of these sounds with field recordings was considered as a method for the identification of unknown underwater sound sources heard while at sea[146].

In the field of fish catching, use of acoustics has made several changes in the fishing industry. Acoustical devices, e.g., echosounders and sonars, are used for detection, location and catching of fish. Recorded sounds are also used to lure fish and drive them into a net.

While echosounders and sonars have found increasing use on fishing vessels only after World War II, various sounds to attract fish have been produced and used by fishermen since quite a long time ago. Fishermen of a number of maritime countries have been known to listen to fish sounds in a calm sea, especially at night, and to infer from them the location and kinds of fish producing sound and whether there are many or not. Further, they have been known to frighten away the fishes by producing certain types of sounds and to lure fishes by sound imitations and direct them into schools at places favorable for catching.[144]

The sounds for luring fish were produced by beating the surface of the sea with bamboo poles, by tapping the side of a boat with sticks and by throwing into the water objects such as a small lead bell-shaped instrument named "Boko"[104].

Hashimoto and Maniwa (1963) undertook the frequency analysis of sounds of marine animals with a view to detect and identify the sources of sound[76]. They also recorded the swimming and bait-eating sounds of various species of fish for subsequent playback in order to attract the fish.

Echosounders for location of fish became popular with fishermen after World War II. Although the equipment had already become standard on large North European distant water trawlers before 1939, still the gear was only used for depth soundings. The improvement of acoustical underwater equipment during World War II paved the way for electronic fish detection and after the war recording echo sounders were speedily adopted in medium and large fishing vessels.

Apart from fish detection, echo sounding has contributed to a great extent in various other ways to the field of fisheries. It has been used to study the performance of midwater trawling gear and thereby help improve its design[129]. Echo sounders can indicate whether to use a trawl of high gape and limited spread or of widest possible spread and limited gape.

In the case of pelagic fishing, transducers attached to the headline or the footrope of the net have also been used as depth telemeters, to determine exact depth of the trawl net. (This need arises because in the case of midwater trawling experience has shown that few, if any, fish are caught by "blind" towing. For good hauls it is necessary to locate concentrations of fish, determine their depth and devise some accurate means of positioning the trawl net.) These transducers show the exact depth of the trawl net, the vertical opening of the trawl and the fish entering the trawl mouth or evading above or below it.

Echo sounding has also been used for the estimation of fish population. The recording echo sounder was first used for the fish population estimation in the early 1950's[22]. This was further improved upon by the use of electronic signal processing which helped eliminate the subjective errors involving human decision as to whether a trace was sufficiently dark or not or whether a mark represented one target or two targets. Three types of electronic signal processing systems have been developed. The first one was described by Mitson and Wood (1961). The second one, the echo integrator was described by Dragesund, Olsen and Hoff (1965).

The third one has been described by Carpenter (1967)[152]. All the three systems have some advantages and disadvantages, but Echo Integrator has a slight edge over the other two. Echo sounding has also been used for mapping distribution of fish in relation to environmental factors.

During World War II, horizontal echo ranging sonar was used for locating submarines. But it was not until the early 1950's that the sonar was used for the first time in fish catching and fish study, on a Norwegian ship, "G. O. Sars". After 1958 its use became fairly widespread, particularly for shooting purse seines around deep swimming schools.

The use of horizontal sonar results in an increase in the area and speed of search, as compared to an echo sounder. Also the echo sounder equipped fishing boat has to cross over a school once or twice to ascertain its extent and depth. But with ahead-looking sonar, school size can be determined before the boat's arrival over the school and so a net can be placed around the school rather accurately.

The ordinary non-scanning broad beam type of sonar mentioned above had limitations as regards its power of resolution and its use in demersal fishing. To make it more useful in demersal fishing and to increase its power of resolution, the acoustic beam was narrowed down. With a narrow beam the speed of search had to be slowed down. In order to increase the speed of search, an electronic scanning type of sonar was developed. It became popular in the field of fisheries after 1958, when it was first used on Great Britain's Royal Research Ship "Discovery II"[158].

The range of detection of the scanning sonar is less as compared with a non-scanning sonar of the same beamwidth; still it has become more popular than the ordinary non-scanning type of sonar. It is so because of its other advantages, viz.: 1) higher power of resolution, 2) increased speed of search, 3) a live display can be seen by means of the cathode ray tube information presentation technique.

The statistics given in Table I support this view (see page 6). The scanning type of sonar system referred to above is in fact the "pulse electronic sector scanning sonar" discussed by Tucker[158]. Another type of sonar system that has recently found application in fishery work is the FM (Frequency Modulated) or CTFM (Continuous Transmission Frequency Modulated) sonar. In this case there are separate transducers for transmission and echo-reception. The projector transmits continuously so that all the targets within its beam are insonified at all times. By scanning with the receiving hydrophone, these targets can be detected immediately without waiting (as is the case with a pulsed sonar) for the sound to make a round trip.

CTFM sonar systems are best suited for fishery problems that require rapid information flow, e.g., in the deployment of purse seines and the tracking of fast swimming fishes[123].

## 101. PRESENT STATE OF THE ART

In 1969 the U. S. fish catch has been reported to have been approximately four billion pounds. Half of this catch may be conservatively estimated as resulting directly from the use of acoustical devices aboard fishing vessels. In most cases the acoustical device used is an echo sounder. In excess of 90% of U. S. fishing vessels are equipped with echo sounders. On some fishing vessels the echo sounder is used to locate and delineate fishing areas or to locate concentrations of fish; while on some other fishing vessels it is used solely as an aid to navigation. Only about 2% of the U. S. fishing vessels are equipped with horizontal search sonar[A7].

Regarding the use of echo sounders and sonar aboard fishing vessels of other countries, one can say that in general, all fishing vessels of over 20 or 30 tons in Northern Europe, Canada and Japan (and also in the U. S. A.) have echo sounders; while all purse seiners in Norway and Iceland have sonar units. Some of the larger fishing vessels in Norway and Iceland have two sonar units and two to three echo sounders. Sonar is beginning to be used in Germany and France on trawlers that fish with midwater trawls and high opening bottom trawls for herring. Sonar is also widely used in the big Japanese purse seine fishery for horse mackerel and mackerel. Netzsonde is used on midwater trawls in Japan, Germany, France and Canada[A12].

Some of the statistics on the use of sonar and echo sounders in other countries are as follows:

TABLE # I

| Country | Number of fishing vessels | Number equipped with echo sounders | Number equipped with sonar units |
|---|---|---|---|
| Australia[A14] | | all 30' or more long | 10-12 boats (all S type) |
| Denmark[A19] | 3987 (all vessels greater than 5 gr. tons) | all vessels above 15 gr. tons (about 2370 vessels) | 10-15 boats (all NS) |
| Germany[A10] | 1129 | all vessels longer than 10 m. | 79 (all S) |
| Iceland[A16] | 700 (those greater than 10 gr.t.) | 700 | all vessels greater than 70 gr.t. (about 280 vessels: all NS) |
| Japan[A18] | 20,551 (greater than 5 gr. tons) | 12,460 (11,514 fixed, 946 portable type) | 2116 (statistics not available) |
| Norway[A11] | | 5500 | 500 (statistics n. a.) |
| U. K. [A13] | 6314 | 5000 | 12 (10 S, 2 NS type) |
| U. S. A. [A15] | 12,874 (greater than 5 net tons) | almost all vessels greater than 5 net tons | approx. 2% of the domestic fleet |
| India[A21] | | 125 | 10 (statistics n. a.) |
| Peru[A22] | | 1500 | 85 (All S type) |

Notes:

1. S - scanning
2. NS - non-scanning
3. Statistics not available - Statistics as to scanning and non-scanning type not available
4. It appears that the majority of the listed Japanese vessels have scanning sonars.

TABLE # 2

The following statistics[A3] pertain to fishing vessels (of over 50 gross tons belonging to some of the countries not mentioned in Table 1) which fished in the ICNAF (International Commission for the North West Atlantic Fisheries) Convention Area in 1968:

| Country | Total number of fishing vessels (in the ICNAF Convention area only) | Number of vessels equipped with echo sounders | number of vessels equipped with sonar |
|---|---|---|---|
| Canada | 623 | 479 | 135 |
| France | 35 | 33 | 4 |
| Poland | 84 | 0 | 84 |
| Portugal | 63 | 63 | 0 |
| Romania | 2 | 2 | 2 |
| Spain | 171 | 171 | 0 |
| U.S.S.R | 586 | unknown | unknown |

Research Work in England and Russia

Efforts are being made in England to identify different fish species by correlating a particular fish species with its wide band frequency response and with the resonant frequency of its swim bladder. If successful, this would enable the sonar to be used for the identification of a particular fish species, in addition to its detection and location by sonar[158]. As of this writing remote identification of fish by acoustic means is still in the research stage. It may become practically feasible for short ranges by the use of high resolution short-ranged sonar.

Remote identification of the patterns of fish school shapes (in three dimensions) is within limits of present day technology. Different species have different and characteristic patterns of swimming and schooling. Thus the knowledge of fish school shapes could lead to identification of species.

Remote identification of sound producing fishes by analyzing the sound made is feasible. Research work on this aspect is being carried out in Japan. (See also Reference # 76.)

As regards the research work in Russia, among other things the Russians have been doing research on what is called the "acoustical herding" of fish. By using acoustical herding, they claim to have increased their catches from 300 to 500%[1].

Acoustical herding of fish is carried out by playing in water either predator sounds (sounds of mammals and fish which prey on smaller fish) or low frequency non-biological sounds. (The original experiment involved transmitting a signal of about 1000 Hz. for a period of about 15 seconds; the signal strength at 1 meter from the microphone was 2000 bars and the signal was non-directional.) The Russians have discovered that schools of cod and herring are driven towards ocean beds by low frequency sounds. The fish try to go farther away from predator sounds.

These ideas for aggregating fish can be utilized to increase harvest efficiency of catch by increasing the density of fish within the influence of the harvesting device.

The Soviets also seem to be ahead of the U. S. A. in the field of acoustical counting procedures. They have developed a technique that allows study of fish close to the sea bed. Unlike the conventional "White Line" technique, it completely blocks out the bottom echo[1].

## 102. PROBLEMS TO BE SOLVED OR AREAS WHERE RESEARCH IS NEEDED

1. There is a need for studying the variations of target strength of fish with frequency and with size. Also the swim bladder resonant frequencies of different species of fish should be determined. Based on this we can evolve a means of identifying the fish before catching it.
2. There is a need for research work in non-linear (underwater) acoustics. This

could make feasible, for instance, a highly directive, low frequency sonar, or a wide band transducer. The former can be used for determining resonant frequencies of swim bladders of fish or for underwater communication over long distances, while the latter can be used for studying wide band frequency response of fish, and thereby help remote identification of fish.

3. Better methods of electronic processing of received signals are needed: e.g., digital sonar systems, so that the range of electronic scanning sonar can be increased.

4. There is a need for studying and recording the sounds (e.g., the bait-eating and swimming sounds of fish) which can lure fish, if played back to certain fish species. These sounds can be helpful in identifying as well as in catching fish.

5. A more definitive knowledge about fish sounds in various environmental and behavioral contexts is needed. A thorough study of sensor physiology of fish is also important, side by side. This can be helpful in predicting the reaction of the fish towards a fishing gear. Hence, measures can be taken beforehand to prevent the fish from evading the fishing gear or the net.

6. Further research is needed in the use of predator sounds and low frequency non-biological sounds for aggregating the fish and thereby increasing the catch efficiency.

7. There is scope for refinement in sonar equipment for detecting the direction and speed of fish by the use of Doppler sonar and in high resolution, short range equipment for identification of targets (by studying the three dimensional patterns of fish school shapes which are characteristic of species).

8. There is a need for giving vocational training to operators of sonar units and echo sounders. According to an official of the Simonsen Radio A/S, Norway, only about 10% of the echo sounder and sonar users obtain more than 90% efficiency from their instruments while more than 50% of all fishermen obtain

only half of what the equipment can do for them[121]. Such vocational training is already given in the United States at a few places: e.g., University of Rhode Island, Rhode Island, and Clatsop County Community College, Oregon, but there is a need for more such centers.

## 103. CONCLUSIONS

In the foregoing pages, it has been established that acoustics and acoustical devices have a very definite and a very significant role to play in modern fishing. In some cases some of the acoustical devices have become indispensable to fish catching and fish study. The following conclusions in this regard are noteworthy:

1. The contribution of sonar to the success of herring fishery in Norway and Iceland is 100%; although the very high yields would not have been possible without the use of a power block (which facilitates the handling of large catches). Sonar is also the prime search tool in cases of midwater trawling by the German fishing fleet[121]. In other countries, too, most of the purse-seiners would have sonar units installed on them.

2. Net-sonde is also of considerable value to the midwater trawling sector and in conjunction with sonar allows the net to be towed at optimum depth for catching the most fish. It is thought by many German experts that 40% less fish would be caught by vessels fishing without Net-sonde[121].

3. The Net-sonde has also been used to study the behavior of fish towards the fishing gear and thereby help improve the design of the fishing gear.

4. The utility of the echo sounder for purposes of searching for and locating fish depends entirely upon the skipper of the fishing vessel. It appears that in the majority of cases, the echo sounder is used as a depth-finder. Some of the top skippers use it for locating fish, while others rely on their previous experience with certain fishing grounds. The echo sounder is also used as an aid to the sonar in finding out the extent and depth of the fish shoal and

helping to shoot the seine accurately[121].

5. The recording echo sounder in conjunction with electronic processing of signals has been used for estimation of fish population and studying migratory habits.

6. Over the years since they were first used for fish detection, location and study, acoustical devices have undergone continuous improvement and refinement. Out of this have come electronic scanning sonar, CTFM (Continuous Transmission Frequency Modulated) sonar, stabilized beam echo sounder, the echo integrator, etc. In addition, the manufacturers of sonar and echo sounders continuously seek to increase the reliability and extend the range of their instruments. But there seems to be a limit beyond which it will be impossible to detect marine animals in the sea with the help of sonar (in its present form). In this context Alverson and Wilimovsky in "Modern Fishing Gear of the World - Two" write:

> "The technological development of sonar has apparently reached an asymptote and it appears unlikely that any major breakthrough will permit detection of biological populations at ranges of greater than 15 nautical miles."

The above-mentioned range also dictates a limit on the passive reception of animal sounds by sonar.

7. Research is being carried out to develop methods which would allow the scientists to identify fish acoustically[A15]. These methods may involve the frequency spectra analyses of fish sounds themselves or these may involve the study of the patterns of fish school shapes in three dimensions. (Each species has a characteristic pattern of schooling.) Also the way with which target strength of the fish varies with frequency may be characteristic of fish size or fish species. By using a wide band sonar we can come to know the manner with which the target strength varies with frequency.

Also, since the frequency spectrum of the sound produced by a marine animal is characteristic of the species, these sounds can be used for detecting, attracting or repelling fish schools[76].

8. Fish may be aggregated by projecting non-biological sound in water or by using predator sounds (which are the sounds of the big fish or mammals which prey on smaller fish). This is also known as acoustical herding. This may be helpful in increasing the harvest efficiency of the catch[1].

9. The study of fish sounds which forms an important part of ambient biological noise in the sea is not just important for its own sake or for purposes of fishcatching. It is of extreme strategic importance inasmuch as it is necessary for the proper detection of submerged enemy submarines. The Navy maintains listening posts at various points along the coastline which mainly consist of passive sonar gear. (These might be sonobuoys or hydrophones suspended in water.) To ensure proper functioning of this equipment, it is imperative to study the ambient noises around these devices. These studies might involve the differentiation and definition of underwater noise sources; spectrograms and oscillograms have been mainly used for these purposes.

10. Bioacousticians have tried to interpret the biological significance of fish sounds. The important conclusions regarding this are:

i) Different species emit different sounds which differ from one another qualitatively.

ii) The fish sound varies in seasonal and diurnal cycles.

iii) External stimuli, e.g. playback of sounds, can elicit different responses in fishes.

iv) Evidence indicates that fish could convey different information by temporal patterning of signals.

v) The amplitude and frequency characteristics of most acoustic signals from fish do not seem to carry enough information.

vi) Different sounds may be produced in different behavioral contexts.

vii) There is more sonic activity during the reproductive season[171].

## 104. GLOSSARY

1. Asdic - An English word coined in World War I which stands for the more popular American acronym SONAR (SOund Navigation And Ranging).
2. B-Scan Display - This is an information presentation technique. It yields a two dimensional picture of the sea bottom profile as would be obtained from a cross sectional view of the sea bottom.
3. Beam Trawl - It consists of a bag-shaped net, called a trawl, fitted with a beam placed across the head of the net. The beam helps to keep open the mouth of the net when it is dragged by the trawler. These days the beam trawl is used only on a few small fishing craft.
4. Bunt - The central or bagging portion of a fishing net.
5. Cod End - The closed sac-like terminal part of a trawl in which fish are trapped.
6. CRT - Cathode ray tube.
7. Demersal Fishing - Catching of fish which are within two to three fathoms above the sea bottom.
8. Demersal Species - Bottom dwelling species.
9. Digital Sonar System - This type of sonar system works on a numerical basis for processing of the received signal, in order to differentiate between a true signal and noise. It uses a binary system of electronic counting and for information relies on phase relationship of signals.
10. Doppler Sonar - This type of sonar utilizes the Doppler effect to study the direction and speed of movement of the target. It does so by comparing the frequency of the received echo with that of the transmitted pulse.
11. Drift Net - The same as Gill Net. A drift or a gill net is attached either to a floating buoy or to a drifting ship (hence the name) and moves with the buoy or the ship under the influence of the wind or tide. This type of net catches fish by the gills as they attempt to pass through the netting.

Drift nets are used for catching herring, mackerel, pilchards, sprats and salmon.

12. Drifting - This is a passive method of catching fish, using a drift or a gill net.

13. Echogram - Record traced on electrosensitive paper by the moving stylus of the echo sounder. An echogram is read upwards from the bottom of the paper.

14. Echo sounder - It is essentially a vertical beam sonar in which the transducer is fixed in a vertical position.

15. Fish finder - Echo sounders and sonars used in conjunction with a recording system (a CRT system or a paper recorder) for detection and location of fish and fish shoals are commercially known as fish finders.

16. Fish tagging - This may also be called fish marking. This is used to study migration of different species of fish underwater. Fish may be marked ( or tagged) by removal of one or more fins, by subdermal injection of colored liquid, by attaching a metal or plastic subcutaneous tag or by attaching a miniature transducer. Transducers used thus are called "Sonic tags".

    One of the best ways of following the migrations of fish is to study changes in the distribution of the recoveries of marked or tagged individuals. The sonic tag emits a high frequency signal which is picked up by an automatic tracking device. The tracking device aims an asdic at the target.

17. Floatline - The upper line of the seine net to which floats are attached to prevent it from sinking.

18. Floats - These are buoyant hollow spheres, made up of aluminum or glass, or some other material, and are attached to the headline of the trawl or the floatline of the seine net. These may also be similar to kites in shape in the case of trawl nets. In the case of trawl nets these help keep the net mouth open, while in the case of seine nets they keep the net afloat.

19. Footrope (also called groundrope) - The lower rope at the mouth of the trawl. It is just a chain or a wire rope attached to the sidelines of the trawl and may be weighted.

20. Gape - Vertical opening of the trawl net.

21. Gill - The respiratory apparatus of a water breathing animal.

22. Gills - The respiratory apparatus of a fish together with supporting bronchial arches, bronchial clefts, gill covers and associated structures.

23. Gillnet - See drift net.

24. Gillnetting - See drifting.

25. Groups - These denote age of fish. Age of a fish (and also its length, for a particular species) can be judged by knowing the age group in which a fish falls. For instance, 0-group fish means fish which are one year or less than one year old; 1-group fish means fish which are two years or less than two years old, and so on.

26. Handlining - This is a passive method of fish catching. In this case line and baited hook are used. The line is drawn in by hand as soon as the fish is felt.

27. Headline - The upper line at the mouth of the trawl. This is made of wire rope. Floats are attached to the headline to keep the mouth of the trawl open.

28. Kite - This is a net spreading device. A kite is attached to the headline to increase the vertical opening of the trawl mouth.

29. Leadline (also called sinker line) - The lower line of a seine net which is weighted with lead.

30. Lining - These are methods of catching fish. The term implies fishing with lines and baited hooks. There are three methods of lining, viz.: handlining, longlining, and trolling. See individual names for meanings.

31. Longlining - It is a passive method of catching fish. In this case the line is shot out and left unattended until hauled in. A longline is fitted with

a great number of hooks (sometimes as many as 5500) attached to the main line by thin lines of some strong material.

32. Lampara net - It is a type of net used in seining. It is used in pelagic fisheries. In case of seining the shoal of fish is first surrounded with a wall of netting that is buoyed at the surface and weighted at the bottom. The lampara net has its central portion shaped in such a way that when hauling the wings a bag can be formed and the sinker line closed thus preventing fish from escaping downwards.

33. Midwater trawling (also called pelagic trawling) - It is an active method of catching fish, i.e., the net is brought to the fish. The trawl net is towed by the fishing vessel in midwater--a zone which extends from the surface to the near bottom.

34. Net-sonde - It is a device which is specifically designed to provide information of trawl depth when midwater trawling for pelagic species. It enables the trawl to be towed at optimum depth to catch most fish.

It is essentially an echo sounder with the transducer (transmitter-receiver) installed in the headline of the trawl net. The trawl transducer is connected with a recorder on board the ship through a cable. The beam of the transducer is directed towards the sea bed, so that the distance of the trawl from the sea bed, the height of the trawl mouth, fish entering the trawl and those passing below are indicated. When the water is very deep, the transducer can be mounted on the footrope and is arranged to radiate in the direction of the surface.

35. Otter board (also called trawl board) - This is a net spreading device used with the trawl net. Two such boards are attached to sides of the trawl mouth to keep the net spread out horizontally while it is being towed.

36. Otter trawl - It consists of a trawl net fitted with otter boards. This is employed on all the big trawlers and is the most effective device for taking

demersal fish.

37. Pair fishing (also called pair trawling) - This is an active method of catching fish. In this case the trawl net is towed by a pair of ships, as opposed to fishing with an otter trawl, in which case one ship is used. The pair of ships keeps the net spread out horizontally. It is an efficient method of catching hake and herring off the bottom.

38. Pelagic trawling - See midwater trawling.

39. Purse seining - This is an active method of catching fish. In this case the purse seine, which is an improved form of lampara net, is used. (See also - Lampara net.) It lends itself better to mechanical handling than the lampara net. The distinctive feature of the purse seine is the presence of special purse rings attached to the sinker line (lead line). A purse line is lead through these rings. After surrounding a fish school the purse line is hauled up on board the vessel by means of a winch, thus constricting the sinkerline like a tobacco pouch. The fish thus enclosed are then removed by a brail or or pumped aboard the fishing vessel. Purse seining is carried out using either a single boat or two boats. The dimensions of the seine may vary for different species of fish and the conditions of shooting. In one case a tuna purse seine measured 1050 m long by 212 m deep while in the other, one for horse mackerel measured 750 m by 75 m.

40. P.P.I. - Stands for Plan Position Indicator. This is a method of recording of echo-ranging signals. It yields a two-dimensional plan view showing the distribution of targets relative to the vessel. On a P.P.I. display the bearing of a fish echo may be shown relative to the ship.

41. Ring-net - It is a type of seine very similar to the purse seine (see Purse seine).

42. Seining - It is an active method of catching fish. The fish are gradually encircled with a net in the center of which is a bag to collect fish. The

types of seine used most frequently in pelagic fisheries are the lampara net, the purse seine and the ring net (for meanings, see individual names).

43. Sector Scanning Sonar (also called electronic scanning sonar or scanning sonar) - This is used to increase the speed of coverage of an area using a sonar with a narrow beam. This is achieved by arranging the receiving beam to sweep across a wide sector at high speeds by electronic means so that it can collect echo signals from all the objects in water within that sector.

44. Shoal (also called school) - According to Webster's Dictionary, a shoal is a "group especially of fish or animals of one kind, a multitude; a large number of one kind of fish or other aquatic animals swimming or feeding together". Not all species of fish form fish schools. Prominent amongst the commercial species which school are sea herring, menhaden, alewife, blueback herring, mackerel, tuna, anchovy, pilchard and sardine. It is their schooling habit which facilitates their capture in bulk by use of trawls, purse seines, etc. The schools range in size from a few hundred of individuals to tens of millions of individuals. A typical school of Pacific sardine may measure 50 meters in diameter, horizontally.

45. SNR - Stands for Signal To Noise Ratio.

46. Sonar - An acronym for SOund Navigation And Ranging. It essentially consists of a transducer which can project an acoustic beam in water. The transducer operates horizontally and can be trained in any lateral direction. Any object or an inhomogeneity in water reflects the acoustic beam. The reflected beam is received by the receiving transducer. The time elapsed between the transmission and reception of the acoustic beam gives an estimate of range at which the object or the inhomogeneity is located in the water.

47. Sonic tag - See Fish tagging.

48. Spread - The horizontal opening of the trawl.

49. SRR - Stands for Signal to Reverberation Ratio.

50. Stern trawling - A method of catching fish in which the trawler is arranged for handling trawl gear over a ramp at the stern.

51. Target strength - This is the ratio of the echo intensity ($I_2$) at 1 meter from the center of the target to the incident intensity ($I_1$). Expressed in decibels it is T.S. = 10 $\log_{10} I_2/I_1$ dB.

52. Time varied gain - Time varied gain system is incorporated in some echo sounders. This is helpful in discriminating between different types and sizes of fish when they are distributed throughout a considerable depth range. T.V.G. system compensates for the reduction of the sound field intensity with depth so that the effects on the received echoes of distance from the transducer are eliminated.

53. Trawl - A large conical net that is dragged in the sea by a fishing boat to gather fish.

54. Trawler - A fishing boat equipped with a trawl gear for catching fish.

55. Trolling - This is an active method of catching fish. Single lines with one or more barbed hooks at the free end are used. These are dragged by a boat. A natural or artificial lure is used as a bait attached to the hook. This is towed at the required depth by varying the speed of boat or by varying the weight attached to the line. The lines are hauled in when the fish are caught.

56. Two boat trawling - See Pair fishing.

57. Wake - According to Webster's Dictionary it is the "track left by a ship or other body in water". In the context of this topic it is significant because small air bubbles get entrapped in the wake of the fishing vessel and if sonar is aimed at it the air bubbles give false echoes.

58. Warps - These are wire cables attached to trawl net bridles and are used for hauling the trawl net.

59. White line technique - This is a technique of recording adopted for fish which

are very near to the sea bottom; the traces due to the stronger bottom echoes overlap the traces due to the weaker fish echoes. To make the fish echoes distinguishable from the bottom echo traces, white line recording is adopted. This is done by introducing a gating circuit into the amplifier which operates only in response to signals which lie between certain values of amplitude. The gating circuit thus cuts off the amplifier for about 0.01 sec. on receipt of the stronger bottom echo; so that the bottom echo is followed by a white gap whereas the fish echo is not. The white gaps add up to form a white line, hence the name.

60. White noise - A sound which contains all the audible frequencies at equal intensities simultaneously is called white noise.

61. Wide band sonar - A sonar which covers a very wide band of frequency (e.g., a ten to one ratio of upper to lower frequency).

62. Wings - These are the lateral extensions of the trawl mouth. They tend to drive the fish into the net.

63. Zero line - The zero line represents the ship's bottom in the trawler's echogram. In the Net-sonde echogram, it represents the headline of the trawl.

# PART II

## The Literature Survey

### 200. Nature, Categorization, Source & Arrangement of Bibliography

#### Nature, Categorization and Source of Papers

The references given in the bibliography represent a wide cross-section of papers collected from various sources. The author has excluded from the bibliography the papers on bioacoustics which pertain to functioning of sound producing mechanisms of fish.

The papers have been broadly classified into four categories, viz.:

1) Instrumentation, Fish Catching, Fish Detection and Fish Location
2) Fish Counting (fish population estimation and echo surveys)
3) Fish Sounds
4) General Nature, Research and Experimentation (which includes papers on acoustical devices, e.g. sonar and the echo sounder, measurement of target strength of fish, identification of fish by acoustic means, etc ).

One can say that in general category 1 concerns itself with fish catching and would be useful to fishermen; categories 2 and 3 both contribute to fish study and would be of use to the fishery biologists and the bioacousticians, respectively. Category 4 would be of interest to the research workers in the field of acoustics pertaining to fish study and fish catching. Bioacousticians are also advised to refer to the bibliography given at the end of Tavolga's "Review of Marine Bio-acoustics: State of the Art, 1964"; see also Ref. # 146.

As the above-mentioned categories are quite broad in themselves, their domains might overlap and therefore some of the references appear in more than one category. The following references pertain to different categories mentioned above.

Category 1: 5, 14, 17, 18, 19, 27, 29, 31, 36, 37, 41, 42, 44, 45, 52, 56, 57, 61, 65, 59, 68, 69, 73, 74, 76, 86, 87, 89, 90, 91, 92, 97, 100, 103, 104, 107, 119, 122, 123, 127, 129, 130, 134, 135, 136, 137, 138, 142, 150, 151, 152, 158, 161, 164, 165, 173, 174.

Category 2: 12, 16, 21, 22, 23, 24, 25, 26, 33, 34, 35, 42, 43, 99, 109, 110, 123, 125, 153, 154, 156, 157, 175.

Category 3: 3, 8, 9, 10, 20, 32, 38, 46, 47, 48, 49, 50, 51, 53, 54, 55, 76, 93, 96, 98, 102, 113, 116, 117, 120, 124, 131, 132, 140, 144, 145, 146, 147, 148, 149, 166, 172.

Category 4: 1, 2, 4, 6, 7, 11, 13, 15, 27, 28, 30, 32, 35, 36, 37, 39, 40, 41, 42, 45, 58, 60, 62, 63, 64, 65, 66, 67, 68, 70, 71, 72, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 88, 89, 94, 95, 96, 98, 101, 102, 105, 106, 108, 111, 112, 113, 114, 115, 117, 118, 121, 123, 126, 127, 128, 129, 133, 139, 141, 142, 143, 155, 158, 159, 160, 161, 162, 163, 166, 167, 168, 169, 170, 171, 176, 177.

(For the above references please refer to the bibliography.)

Regarding the sources of the above-mentioned papers, some of the important papers on fish catching and on the practical use of acoustical devices have been published by Simonsen Radio A/S, Norway. But by far the most prolific publisher of books and magazines concerned with fisheries is the Fishing News (Books) Ltd., at London. A separate alphabetical list of periodicals and books which appear in the bibliography with the addresses of their publishers and subscription rates has been given in Appendix B.

Arrangement of Bibliography

The bibliography has been compiled with the last names of the authors arranged in alphabetical order. In some cases where the names of the authors are not mentioned or a whole series of articles which contribute to the study of fish catching or fish study appear in one cover, the names of the publishers appear in the alphabetical order. In some cases the names of the editors are given and in one case (see Ref. # 174) the name of the magazine in which the article was published is given in the alphabetical order. At the end References 175 and 176 have been written by unknown authors and so are listed as anonymous.

An asterisk appearing at the end of a reference denotes that that particular paper has been referenced in this report. Two asterisks at the end of a reference denote that a summary or an abstract of that paper is contained in this report. Papers without any asterisks denote that they have neither been referenced in this report nor have their summaries appeared in this report.

In Appendix A are listed the books which as a whole are not related to the use of acoustics in fish catching and fish study but significant portions of which are relevant to the afore-mentioned topics and are referenced in the bibliography. Appendix A also lists the personal letters which have been received by the author (in response to his enquiries) and which contain statistical and other information which has been given in the History, Present State of the Art, or elsewhere in this report.

Appendix B, as has been mentioned earlier, contains an alphabetical list of periodicals and books mentioned in the bibliography with the addresses of their publishers and their subscription rates, etc.

## 201. Tabulation of Specific References by Number

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## Appendix A

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A14. Letter from A. G. Bollen, Asst. Sec'y, Fisheries Division, Canberra, Australia.

A15. Letter from Martin O. Nelson, Chief, Resource Assessment Program, Exploratory Fishing and Gear Research Base, Seattle, Washington.

A16. Letter from Jakob Jakobsson, Marine Research Institute, Reykjavik, Iceland.

A17. Letter from L. W. Proctor, Department of Fisheries and Forestry, Ottawa, Canada.

A18. Letter from M. Morimoto, Ministry of Agriculture and Forestry 1-2-1, Kasumigaseki, Chiyoda Ku, Tokyo, Japan.

A19. Letter from K. Popp Madsen, Danmarks Fiskeri-Og Havundersogelser, Charlottenlund Slot, Denmark.

A20. Letter from Bureau of Commercial Fisheries, Arlington, Va. 22209.

A21. Letter from Central Institute of Fisheries Technology, Kerala, India.

A22. Letter from Director de Invgs, Technologicas, Ministerio de Pesqueria, Peru.

## Appendix B

List of Periodicals which have been Referred to in the Bibilography.

with the Addresses of their Publishers

1. Aegir 1905, s-m; subs. $4 (text in Icelandic; summaries in English), ed. Mar Elisson, Fisheries Association of Iceland, Box 20, Reykjavik, Iceland.

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3. Biological Bulletin (U.S.) 1898, bi-m, subs. $9/vol.(two volumes a year), ed. W. D. R. Hunter, Woods Hole, Massachusetts, 02543.

4. British Journal of Applied Physics; see Journal of Physics, D. Applied Physics.

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6. Commercial Fisheries Review 1939 m.; subs. $7, U. S. Bureau of Commercial Fisheries, 1801 N. Moore St., Room 200, Arlington, Va. 22209. Subscribe to Superintendent of Documents, Government Printing Office, Wash., D. C. 20402.

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8. Copeia, Washington D. C., publication ceased.

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10. Elektroteknisk Tidsskrift (now called Elektro-Elektroteknisk Tidsskrift) 1888 32/yr, subs. $10 (summaries in English), Ingeniorforlaget A/S, Kronprinsensensgt 17, Oslo 1, Norway.

11. FAO Fisheries Technical Papers, published by Food and Agriculture Organization of the United Nations, Via delle Terme de Caracalla, 00/00 Rome, Italy.

12. Fishery Investigations, published by Her Majesty's Stationery Office, 49 High Holborn, London, W.C.1.

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22. Journal of Physics D; Applied Physics (old name - British Journal of Applied Physics), Institute of Physics and Physical Society, 47 Belgrave Square, London, S.W.1.

23. Marine Bioacoustics Vol. 1, 1964, and Marine Bioacoustics, Vol. 2, 1967, ed. W. N. Tavolga, Pergamon Press, 122 E. 55th St., New York 10022.

24. Modern Fishing Gear of the World # 1, 1959, Modern Fishing Gear of the World # 2, 1964, Modern Fishing Gear of the World # 3 (to be published 1971), Fishing News (Books) Ltd., 110 Fleet Street, London E.C.4.

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27. Physiological Zoology 1928, g, subs $10, ed. Thomas Park, University of Chicago Press, 5750 Ellis Ave., Chicago, Illinois 60637.

28. Priroda 1912, m, subs 6 rub., ed. D. I. Shcherbakov (contents page in English) ul. Osipenco 52, Moscow, Tzentr, U.S.S.R.

29. Radio and Electronic Engineer 1926, m, subs. $20, ed. Frank W. Sharp, Institute of Electronic and Radio Engineers, 9 Bedford Square, London, W.C.1.

30. Science, 1880, w, subs. $12, ed. Philip H. Abelson, American Association for Advancement of Science, 1515 Mass. Ave., N.W. Washington, D. C. 20005.

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36. Underwater Science and Technology Journal, g, subs. $20, Iliffe Science and Technology Publications Ltd., address as in # 35.

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## 202. Summaries of Certain Significant Papers

### 202.1 "Sonar in Fisheries--A Forward Look"

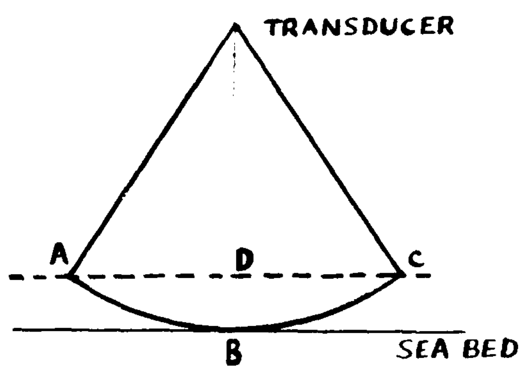
(Ref. # 158)

By D. G. Tucker

Earliest form of sonar equipment used in fishing boats and still by far the commonest is the echo sounder. The echo sounder is essentially a sonar with a vertical beam. It has been found a most useful detector of fish in midwater and to a much smaller extent, of fish on or very near sea bottom. As a matter of fact, most of the equipment used up until now is quite effective for midwater fish detection but has been inefficient for detecting fish very near the sea bed. (This is due to the fact that the sea bed echo is stronger than the weaker signal from the fish; and on a paper recorder their traces become indistinguishable.)

An ordinary echo sounder essentially consists of a generator of pulses of electrical oscillation, a transmit transducer, receiving transducer, receiving amplifier, a means of display and a time base. Beams used were wide, in the range of 30°, and pulse lengths in the range of 1.5 meters. As such, it has the following shortcomings:

1. Its power of resolution is limited depthwise as well as horizontally. Individual fish can be detected when they are separated from one another and from other targets by at least one pulse length in depth and at least one beam width horizontally.




A fish at edge of beam, e.g., at A or C gives an echo at the same range as part of bottom echo, e.g. from B. Therefore fish echo cannot be detected. Also if distance BD is greater than one pulse length, then individual fish are detectable on echo trace. If distance BD is less than one pulse length, then bottom echo trace merges with fish trace.

2. In case of a sloping bottom, fish may be recorded as being within a certain distance of the bottom when in fact they are higher and might be missed by the trawl.

These defects have been almost completely removed. The equipment is still basically a vertical beam echo sounder with the following changes:

1. Larger transducers and higher acoustic power for transmission are used. The beam has been made narrow and pulse durations shortened to give better resolution. Typical figures would be beam width = 1° and pulse length = 15 cms.

2. Devices, e.g., "Bottom Lock" and "White Line" have been used to make fish echoes clearly detectable from the more powerful bottom echo.

3. Cathode ray tube A-scan display came to be used with the chemical paper recorder to enable users to make speedier time base traverses.

4. High frequency echo sounders were used. Use of high frequency made possible small transducers having narrow beams and high directivity. (This is due to the fact that beam width of a transducer is approximately inversely proportional to the linear dimensions of the transducer in units of wave length.)

It may be noted here that the higher the frequency the greater the attenuation of the sound intensity and the less the range of detection. This sets a limit on the high frequency which may be used.

## Sonar Systems with Non Vertical Beams

Non vertical beam systems were developed in the nineteen-fifties. Their main advantages over the vertical beam echo sounders are

1. Use of non vertical beams enables detection and location of fish at some distance from the boat horizontally (ahead of boat's arrival) so that nets etc. may accurately be cast over the fish.

2. Horizontal sonar helps increase the area and speed of search. These points are very useful in cases of mid-water fishing with drift nets, seine nets and mid-water trawls.

However, in cases of demersal fishing where only those fish within two or three fathoms above the bottom are of concern, these (non-vertical beam) systems are of questionable value. This is due to the fact that fish echoes from fish within 2 to 3 fathoms of bottom are received simultaneously with the returns from the sea bottom. As the latter are stronger than the fish echoes the fish can't be detected. This disadvantage of non-vertical beam sonars for use in demersal fishing has been overcome by narrowing the beam in either one axis or both axes (vertical as well as horizontal).

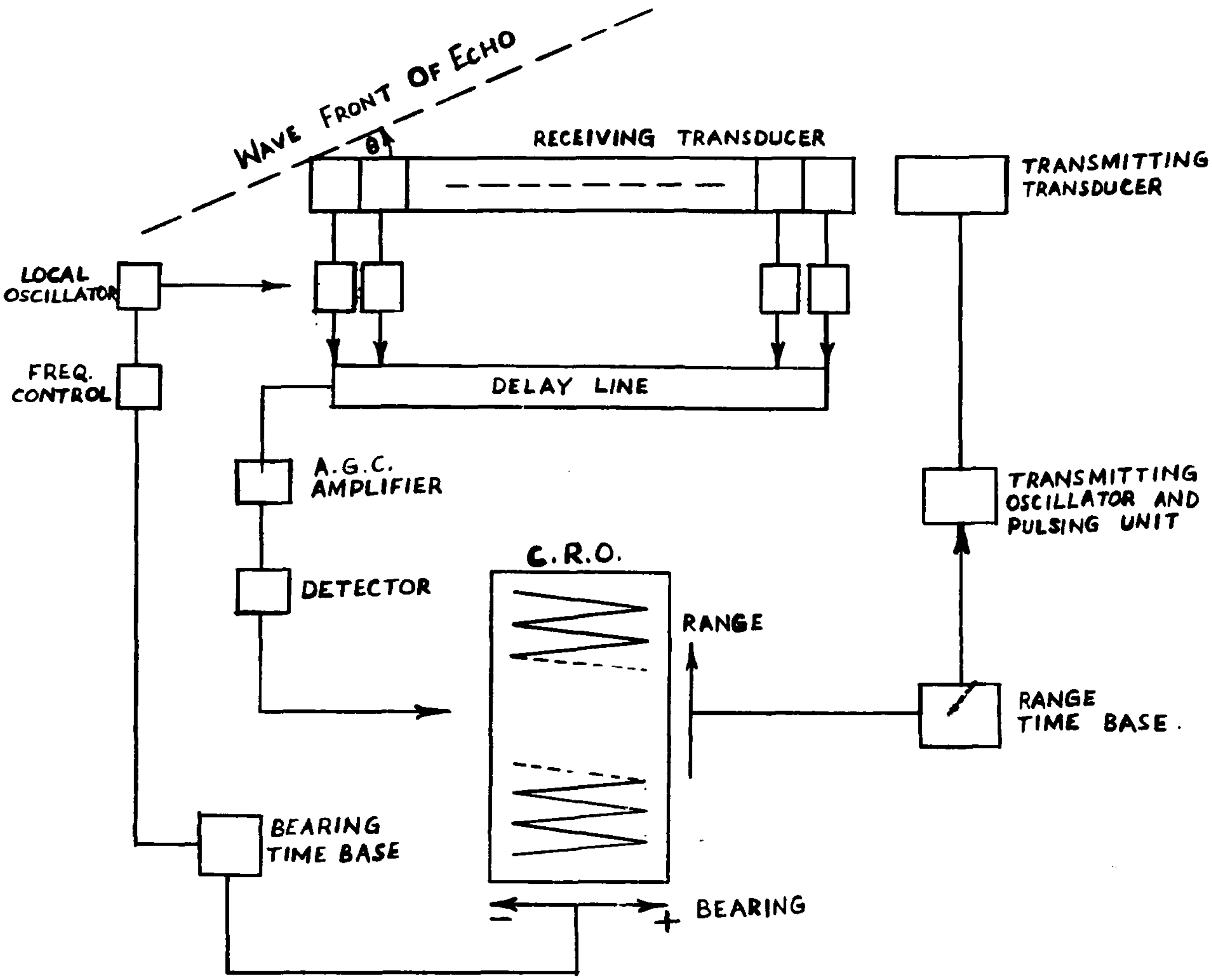
But narrowing the beam results in serious reduction of search effectiveness of sonar. This is due to the fact that for a given depth and a given angle of tilt of the beam (from the horizontal) the area of the intercept of the beam at the sea bottom gets reduced as one reduces the beam width. Thus in a given time we are only able to cover a fraction of the area we would cover with a wide beam.

## Electronic Scanning Sonar

To increase the speed of search using a narrow beam, electronic scanning sonars have been developed.

Principles of electronic scanning sonar:

The system consists of an array of n sectional transducers. These n sections are connected to n corresponding taps on a delay line. The sonar beam can be deflected by an amount dependent on the phase shift in the delay line. If an echo is received from a target on a bearing of $\theta$ relative to the perpendicular axis of the transducer,




Schematic Diagram of Electronic Sector-Scanning System

then the wave front of the echo pulse lies parallel to the line shown in the figure. The echo is received by the first transducer section before it reaches the second, and so on, so that the echo signal received by other sections gets delayed in phase depending on the inclination of the wave front to the transducer array. If a peak output is to be obtained for this angle of arrival, then the delay line is required to insert compensatory phase-shift so that all the components of the combined output are in the same phase. Frequency changer equipment is inserted between the transducer sections and the delay line. A local oscillator feeds all the frequency changers. It is swept in frequency by the bearing time-base, so that the signal frequency received by the delay line varies over a range during every sweep of the bearing time base. If now the delay line is made to have a phase shift which varies over this frequency range from negative values to positive values, the beam will be swept from left to right during each sweep of the bearing time base. The latter also deflects the spot on the cathode-ray tube from left to right, so that signals received on any particular bearing are recorded on that bearing in the display. The range time base measures the range by measuring the time elapsed between transmission of pulse and reception of echo from the target. The position of the echo-spot on the cathode ray tube can thus show both bearing and range on rectangular axes. If the bearing scan is so rapid that it is completed within the duration of the pulse and is immediately repeated, no information is lost and all directions in the sector are effectively looked at simultaneously, but with the angular resolution corresponding to the beam-width of the receiving transducer.

Advantages of electronic sonar:

1. The ship can afford to move at a greater speed without greatly affecting the search effectiveness of the sonar.

2. A narrow beam can be used giving a good angular resolution.

3. Instead of the picture being built up bit by bit as in an ordinary sonar (with the result that moving fish may appear blurred or may be lost altogether, merged with fixed objects) the movements of fish are conveyed almost instantaneously Displayed on a cathode ray tube, moving fish may be observed (with movement relative to ship) against a background of fixed objects, e.g., rocks, stones, etc. As a result, electronic scanning sonar has been much used in the study of fish behavior e.g, their reaction to light and darkness, their reaction to a low frequency vibration source, their behavior towards nets, etc.

4. In demersal fishing, where the bottom reverberation has higher target strength

than the target strength of an individual fish and thus the echoes from the bottom overshadow the fish echoes, and where it is advisable to use a narrow beam in the vertical plane, we can use electronic scanning sonar with advantage (of higher speed of bottom coverage) by scanning in the vertical plane.

Signal to Noise Ratio and Signal to Reverberation Ratio in Electronic Scanning Sonar

The detection performance of the sonar systems is limited by the above mentioned ratios. Noise is undesired background against which the target signal echo has to be detected. Reverberation is the reradiation of acoustic energy (called back scatter) from the transmitted pulse, at the sea bottom or at various other inhomogeneities. Signal to noise ratio could be improved by raising the power level of the transmission but signal to reverberation ratio cannot be improved by this method because signal and reverberation are equally dependent on the transmitted power level.

In case of within-pulse electronic sector scanning the transmitted energy is spread over a wide sector of n times the angular width of the receiving beam. Thus the power level or acoustic intensity at any given range is 1/n times as compared to the intensity in narrow beam width non scanning sonar. The receiving noise level is not affected by scanning so that signal to noise ratio is worsened by 10 log n db. However, the rate at which information is obtained is increased by a ratio n. This offsets to a great extent the loss of signal to noise ratio and also results in a more interpretable display.

Signal to reverberation ratio is unchanged by scanning. Now as the signal to noise ratio is worsened due to scanning it is advisable to increase signal to noise ratio by increasing the transmitted power level so that conditions in respect of signal to noise ratio and signal to reverberation ratio at least equal those in a non scanning sonar. Moreover we have clear additional gain over the non scanning sonar in that data rate is increased by n, resulting in a better display.

At present the range of detection in an electronic scanning sonar is less as compared with a non scanning sonar of the same beam width. This is because the transmitted power is spread out over a large number of beamwidths. Better methods of electronic processing of the received signal may restore this loss.

## A Forward Look

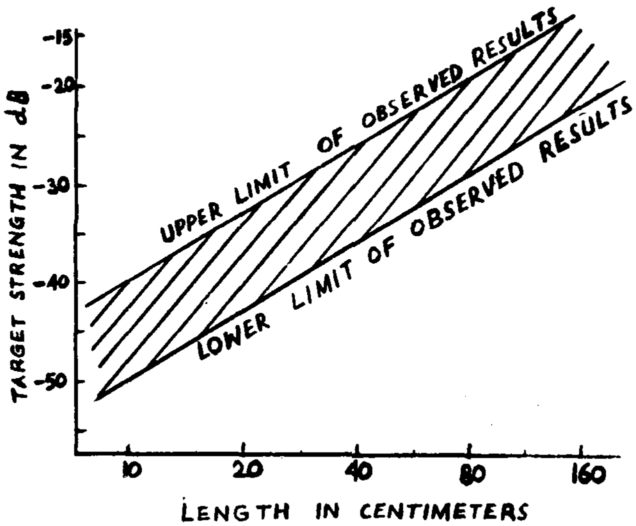
Some new possibilities in the field of "Sonar in Fisheries" that look very promising are

1. Wideband sonar systems
2. Systems exploiting non linear acoustic wave interactions
3. Digital sonar systems.

In addition to these, research is being conducted on high-power low-frequency systems, very low frequency systems, high frequency image forming systems using an acoustic lens or mirror with acoustic/electronic image convertor, etc.

Wideband sonar - Some experimental evidence indicates that the target strength of fish depends on frequency and that the way target strength varies with frequency may be characteristic of the size and/or species of fish. If we have a sonar which covers a wide range of frequency (e.g., a 10:1 ratio of upper to lower frequency) it can in addition to giving the range and bearing of fish, show us the manner in which its target strength varies with frequency, so that we could come to know the range, bearing, size and species, of the fish before catching it. For this purpose we require transducers which can operate in a wide band and yet give a constant beamwidth over this band. This latter requirement is contradictory to the fact that the beamwidth of a transducer does depend on the frequency, i.e., it varies with frequency.

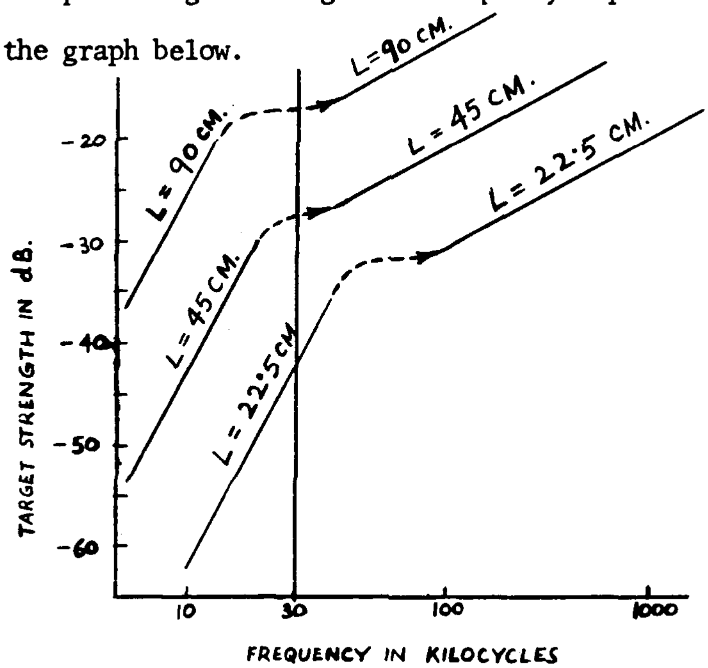
Experiments carried out in two establishments in England (at Fisheries Laboratory at Lowestoft and at Kelvin Hughes) have shown that the target strength of a fish (in its dorsal aspect) is related to the length of the fish at a fixed frequency of 30 Kc/s as shown in the graph. Fish used were cod, herring, perch and plaice. The measured values all lie within the hatched area.




(Graph shows the dependence of target strength of fish in dorsal aspect on length Fixed Freq. of 30 kc/s used)

Graph based on Experimental Data

Based on experiments with scale models and theoretical analysis it has been suggested that the relationship of target strength to frequency depends on size roughly in the manner shown in the graph below.




Graph shows the general trend of the dependence of target strength of fish in dorsal aspect on frequency, L = Length of fish.

At low frequencies (where fish size is small compared with wavelength) there is a steep dependence of target strength on frequency, while at higher frequencies the target strength dependence on frequency is less steep. In between there is a region (joined by dotted lines) where the target strength varies in an indefinite manner with frequency.

It can be concluded from these two graphs (ordinate drawn at 30 Kc/s frequency for purposes of comparison) that experimental and theoretical results compare favorably, that target strength does depend on frequency, and that the shape of a wideband frequency response should give a lot of information about the size of fish.

Because of these factors research work on wideband sonar has been directed mainly towards getting wideband operation over the frequency range 5 -100 Kc/s. But frequency response from fish at a lower range of 200 c/s to 2 kc/s may also be quite important because it is within this range that swim-bladder resonance occurs and resonance frequency together with size of fish may help us to identify the fish species.

"Wideband Receiving and Transmitting Transducers"

It is not essential to have the same constant beamwidth on transmission and reception. The bearing accuracy of the wideband sonar system may be allowed to depend mainly on the receiving transducer, as the signal to noise ratio is determined by the transmitted acoustic power level relative to the sea noise and is largely independent of the ratio of signal level to the noise generated in the receiver. In cases where this is true we can use receiving transducer elements which have their resonance (normally they show a marked resonance at a particular frequency) right outside the frequency band of the sonar. The variation of sensitivity with frequency can then be relatively small.

Normally beam width is approximately inversely proportional to the frequency. To obtain beamwidth which is reasonably constant over the frequency band, the author had put forward a scheme in which a line transducer was used. It was divided into sections and connected to a series of delay lines ( or phase shifting circuits). Each of the latter has a phase shift which increases with frequency so that at each end the signals correspond to an effective directional pattern which is deflected by an amount which increases with frequency but at the same time becomes narrower due to the increasing number of wave-lengths in the length of the transducer. After phase corrections, the outputs are added together.

This arrangement tends to keep the overall beamwidth constant in one axis.

In case of a wideband transmitting transducer, more efficiency is needed so that signal intensity above the noise intensity at the end of transmission path is obtained. In this case, therefore, it was proposed to have a series of resonant ring type transducer elements mounted on a common axis with resonant frequencies (and therefore sizes) forming a tapered sequence. The spacing of resonant frequencies between adjacent elements is such that the frequencies at which the response was 3 dB below the peak coincided so that a reasonably smooth response over the band was ensured.

The exploitation of Non-linearity in underwater acoustics--

Non-linearity arises when the acoustic intensities involved are large and the density and compressibility of the medium change as a result of propagation of waves through it. For smaller intensities (for smaller amplitudes) non linearity is negligible.

For instance, if two different frequencies are applied to a transducer, the source waveform shall be the sum of wave of frequencies, say 3f and 2f. The two component waves, (a) & (b) and their sum is shown in the figure. The waveform (c)

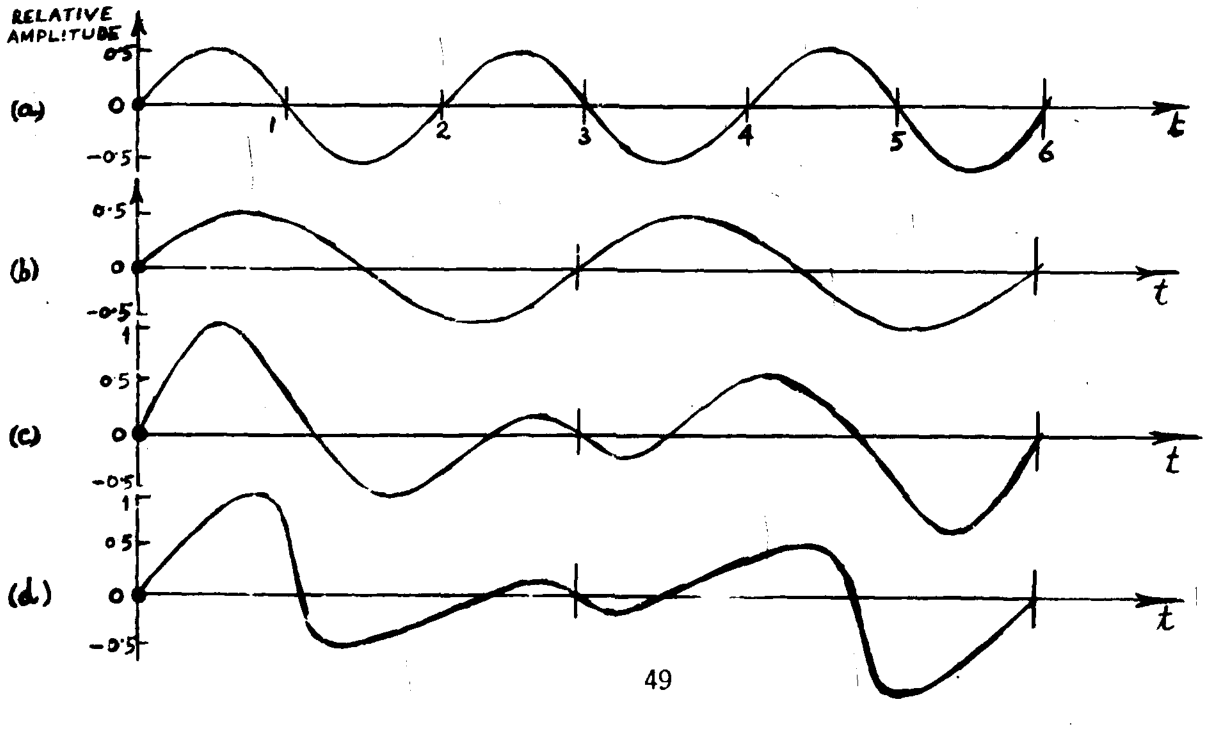



FIGURE SHOWS THE PRODUCTION OF SUM AND DIFFERENCE FREQUENCIES DUE TO NON-LINEAR PROPAGATION.

represents the wave at the source. Now at a point of observation at some distance from the transducer there will be a different arrival time for the different amplitudes due to acoustic nonlinearity; so that at the point of observation the waveform will be, as shown in (d). Nature of the distortion can be observed by subtracting (c) from (d).

If we draw the sum frequency of the two applied waves, i.e., 5f, and the difference frequency of the applied waves, i.e., f, and add these to our source wave (c) we get a wave form quite similar to (d). This shows that distortion due to nonlinear propagation has introduced among other products the sum frequency of the applied waves and difference frequency of the applied waves.

## The Proposed Uses of Acoustic Nonlinearity

The distortion of the wave increases as it propagates through the medium and thus the amplitude of the difference frequency wave which is generated, increases; so also does that of the sum-frequency wave. In practice, however, due to absorption losses in the medium and due to turbulence and inhomogeneities, amplitude of source wave will decrease as it propagates and thus the rate of increase of distortion will decrease. Beyond a certain distance from the source there will be no further growth in the amplitude of the difference frequency wave, and it will then start to decrease.

The energy in the difference frequency wave as it propagates remains confined to a parallel sided beam over some distance and then it begins to diverge. The difference frequency wave, as such, propagates on a highly directional basis. Its directivity is practically the same as that of the original source wave. The significance of this is considerable. For instance, if we take the source frequencies as 100f and 99f and take the size of the transducer to be large enough in wavelengths at 100f to give a narrow beam, we will have a wave of frequency f generated with a full directivity of 100 f. Of course its intensity will be very small compared to that of the source waves. To obtain the same directionality directly would require a huge transducer.

Another advantage of nonlinear systems is that the transducer can transmit a wide band of frequencies effectively. For instance, difference frequency wave can be varied over 10:1 range by merely varying the source frequencies by 10% (assuming they are as high as 100 times the difference frequency).

The difference frequency beam can also be made to deflect by using phase shifters with the high frequency transducer sections.

To sum up, nonlinear systems can find applications in:

1. A fish finding sonar operating in the frequency band 7-30 kc/s, with a range of 2 km on a single cod, angular resolution of 2 degrees, range resolution of 25 cms., transducer only 35 cms. long using peak power of 50 KW and mean power of less than 1 KW.

2. A sonar system having a wide bandwidth and thus able to display the frequency response as well as range and bearing of targets.

3. A highly directive very low frequency system operating over 500 to 2000 c/s with constant beamwidth. It can detect the resonances of the swim bladder of fish. It can also be promising for communication of information over long ranges underwater.

Digital Sonar Systems--

For processing of the received signals, most sonar systems depend on a conventional type of electronic circuitry, which are often called analog circuits. Equipment based on these elements occupies several cubic feet and costs several thousand dollars. To reduce the volume and the cost a different type of electronic circuit system called the digital system is used. In this system, everything is done on a numerical basis and instead of the conventional ten, a binary system of counting is used.

The basic principle is to do away with all the amplitude information and to rely entirely on the phase relationship of signals.

If we have a sectionalized transducer with the wave coming from a direction other than normal to the array, than the signal received on successive sections will be shifted in phase relative to its neighbor. In practice the signal will be disturbed by noise, and these combined waveforms can be represented graphically with a phase shift in successive transducer sections. These are amplified and chopped off so that we only see the zero-crossings of the waveforms. By means of counting circuits the time intervals between corresponding pulses (of the zero-crossings of successive waveforms) can be measured and recorded on digital counting circuits. If we find that these time intervals (which represent phase differences between the input waves) are equal on the first count, we may assume there is a strong signal coming in. If this condition is repeated at subsequent counts, we become quite certain of it. On the other hand, if there is no signal and only noise is being received, we will find that all these time intervals will be different. If it is repeated we become certain that there is no signal being received.

This can be expressed symbolically and a threshold value set for the average difference between average of time intervals on first count and the second count. If the value of the average difference falls below threshold value, we retain the measurement; if the average difference exceeds threshold value, we assume there is no signal and we reject the measurement. Now all the arithmetic measurement and determination of whether the thresholds are satisfied is done by the digital circuitry quite automatically. If the various criteria are satisfied, so that the system "decides" that a signal is present, then the direction from which it has arrived is readily determined, and a bright mark is put on the B-scan display at the correct bearing. The range is determined by the time elapsed since transmission. So we have a sector scan display just like the earlier systems except that all targets displayed have the same brightness, much of the random background has been removed, and the operator is required to exercise much less judgment.

Some preliminary experiments with the laboratory equipment at a reservoir have given very promising results.

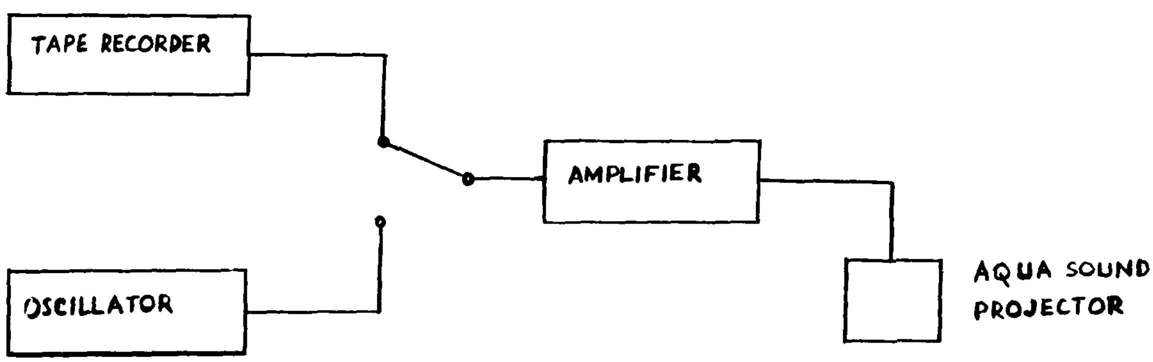
### 202.2 "Recorded Sound Lures Fish"

Ref. # 104

Dr. Yoshinobu Maniwa

To increase the efficiency of fish catching, acoustical equipment has been used to lure fish schools into fish nets. The idea of using sound to lure fish is not a new one. Fishermen have produced sound by beating the surface of the sea with bamboo poles or by tapping the side of a boat with a stick to attract fish. In Senegal and in Nigeria fish schools in fresh water are gathered by the sound produced from the rubbing of an instrument.

Analysis of tape-recorded sounds of numerous fish schools shows that certain species of fish produce characteristic sound spectra. It was determined experimentally that fish are attracted if they hear the sound of their own species eating bait. Experiments were carried out using tape recorders (or oscillators), amplifiers, and aqua sound projectors.



Experiments were carried out in Japan on fresh water fish and sea fish schools. Bait of flour was used, and the sound of carp swimming and eating bait was detected by a hydrophone and recorded. This was played back into the water through the aqua sound projector. Fish gathered in a group came to about 3 meters of the projector. In another case they swam to a vicinity of about 1.5 meters from the projector.

Experiments were also carried out for luring yellowtails at sea by recording their bait-eating and swimming sounds and playing it back through a projector. The sound pressure was approximately the same as when recorded. Yellowtail responded to the sound and swam close to the projector.

Experiments were also made in conjunction with a fish finder to observe behavior of fish. Before emission of sound the fish swam at greater depths, but after emission of sound they ascended toward the projector. Sound is also successful in luring mackerel and jack mackerel schools.

Certain kinds of fish schools are startled by dolphin's sound. So dolphin's sound was used and was emitted from near a stationary net. The objective was to drive fish into the stationary net. Big catches of barracuda, young mackerel and young jack were made this way.

In this way the aqua sound projector can be used to lure fish schools making it easy to enclose them in purse seines, or it (projector) can also be used in gill net fishing. As fish are attracted by sound and ascend upwards, fishing by hook and line can be made easier.

### 202.3 "Sonar Instruction Courses for Fishermen"

Ref. # 165

By G. Vestnes

After World War II echo sounders and sonars came to be used on Norwegian fishing fleets. At first echo sounders became popular and then sonar became very popular with commercial vessels.

Because of inadequate operational knowledge of sonar by the skippers of commercial vessels, sonar equipped vessels were not very successful in the beginning. Hence a need was felt to give instructional courses to fishermen in sonar operation.

As the average age of fishermen participating in the course was about 40 years, more stress was laid on audio-visual methods of imparting instructions. It was an 8 day course.

After discussing basic principles of sound propagation in sea water, search procedures using sonar were taught. At first location technique was explained. This consists of various search patterns which involve turning of the transducer from "side to bow" or from "side to side" or from "side to side and back", and it was explained how the different patterns differed in their efficiencies in obtaining complete coverage. For instance, in the searching pattern "side to bow" the transducer is turned to between 70° or 90° port or starboard. A sound pulse is transmitted and the transducer quickly turned 5° forward and kept in this position to allow sufficient time for possible echoes to come in. With a scale range of 3000 meters the transducer must be kept pointed in the same position for 4 seconds to allow the sound waves to travel back and forth (sound velocity in water 1500 m/sec). In addition a dead period of approximately 0.5 seconds is required before the next transmission. At a range of 3000 meters the sonar therefore will need 19 x 4.5 seconds or 85.5 seconds to search from 90° to directly ahead while within that time the ship would have covered some distance. The transducer is then quickly turned to the opposite side and the program is repeated.

The catching technique used with sonar depends on the type of gear the vessel is equipped with. For pelagic trawl fishing the technique is to point the ship towards the fish concentration. When the concentration is below the ship the echo sounder will show the depth and the trawl depth can be adjusted accordingly. In the case of a stern purse seiner when the fish concentration has been located the ship moves toward the concentration. The contact with the concentration is

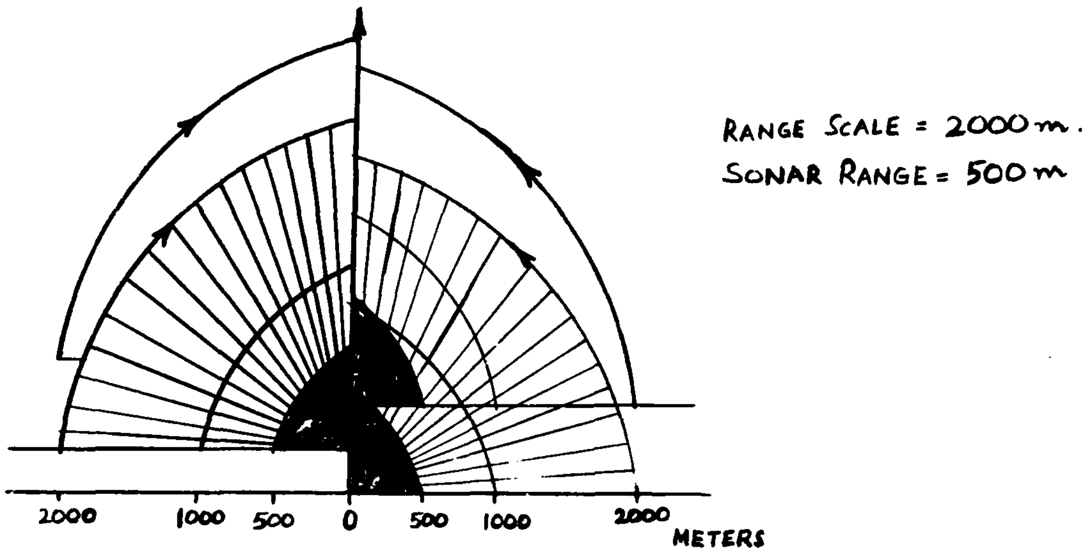



Figure shows "Side to Bow" search pattern.

maintained until the distance has narrowed down to 40 to 70 meters when the setting of the seine is begun. With the aid of sonar the skipper keeps the same distance from the concentration while it is being surrounded.

As the oceans contain large numbers of objects from which echoes may be obtained (e.g., air bubbles, bottom topography, plants, surface echoes, waves) and which may be mistaken as having been obtained from fish, the fishermen are told about other echoes which are classified as 1), bottom echoes, 2), reverberation, 3) stratal echoes, 4) surface echoes, 5) shore echoes, 6) wave echoes, and 7) wake echoes. This is followed by practical training at the sea with a dummy target suspended from a marked buoy.

### 202.4 "Recent Developments in Icelandic Herring - Purse Seining"

Ref. # 91

By Jakob Jakobsson

Since 1958 the annual yield of the Icelandic herring fishery has increased rapidly after a lean period of several years. Apart from the natural fluctuation in stock strength, this increase in catch is partly due to organized fish searching by the use of asdic (sonar) and a new technique in asdic guided purse seining for deep (submerged) swimming schools.

Previously from 1904 to 1944 the Icelandic fishery was an inshore one. For purse seining, the American two dory system was used. But after 1944 the migration and behavior pattern of the North Coast herring changed altogether. Good schools were not found in waters near the shore. Low catches forced change to the one dory system of purse seining. Most of the Icelandic fleet changed to a one dory system for 1946 to 1960. This changeover enabled experimentation with asdic guided shooting.

Aerial scouting was not helpful because schools of fish in waters offshore surfaced very infrequently and irregularly. Echo sounding was also not much help because fish schools once spotted could not usually be relocated owing to the limited vertical spread.

Asdic became popular on Icelandic fishing boats after its use on a Norwegian research ship proved to be very successful in locating herring in the area.

Vestnes has described (see paper by Vestnes) the use of asdic for organized fish search.

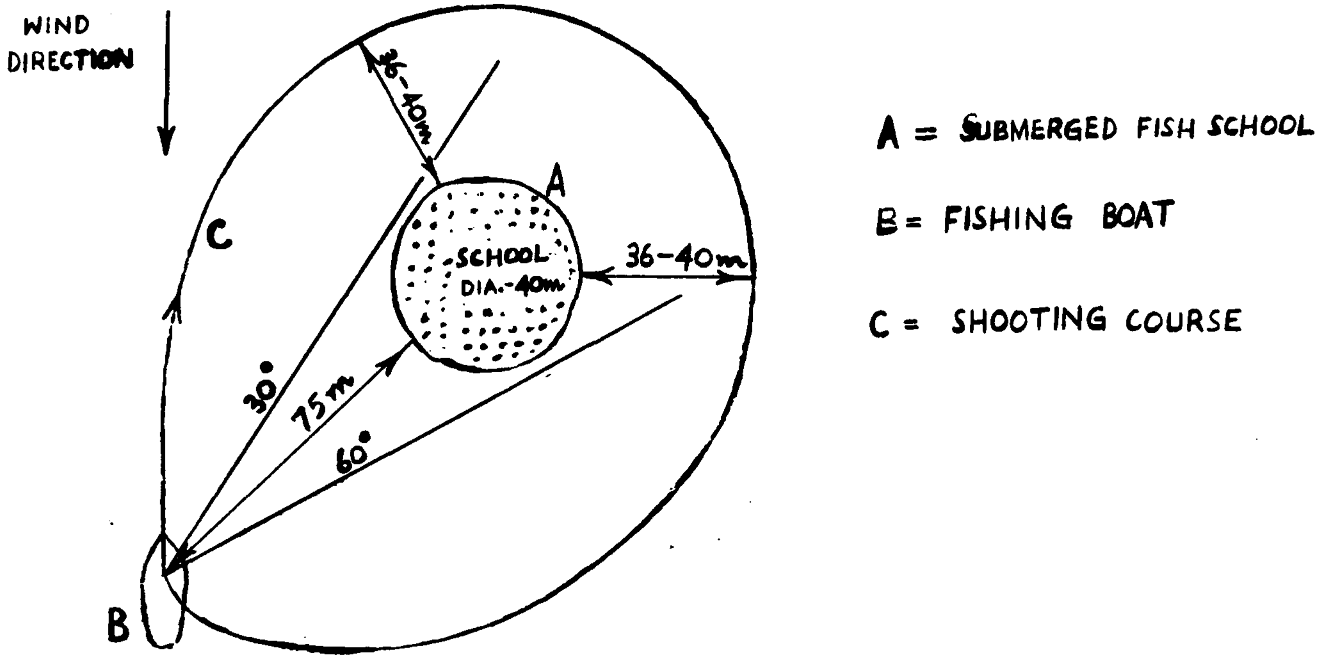
For using asdic for netting submerged schools the principle of the method used is quite simple. Let us first assume the school is circular in shape and that the net has to surround it like a ring, forming two concentric circles. The diameter of the submerged school can be estimated by trailing the edges of the school with the asdic. Let us suppose the diameter of the fish school is 40 meters and that the purse seine is 400 meters long. Then we can come to know the distance of the boat from the school at which it should start shooting the net. This will simply be $400/2\pi - 20 = 45$ meters. If this worked strictly in practice, the method would be to get the school 90° to starboard at a distance of 45 meters and then maneuver the ship through this distance with the school always at 90° to starboard until the ring is closed.

But this is not used in practice because the bag end of the net is not as deep as the rest of the net and as a result the purse seine will not prevent the escape of a school in that area as effectively as elsewhere. It has therefore been more advantageous to shoot in an egg shaped manner than in a circular fashion. The shooting starts and finishes at the pointed (narrow) end of the egg. If we refer to figures in the above example this would be accomplished by starting to shoot at a distance greater than 45 meters and with the center of the school considerably less than 90° to starboard. For determining bearing of the center of the school at the small ranges just prior to shooting, the edges of the school are trailed carefully with the asdic and the center is taken as the average of the two bearings.

Using a 400 meter net it has been found best to have the center of the school approximately 45 to 50° on the starboard and a distance about 75 to 85 meters. At that distance a school of 40 meters diameter should disappear at just over 30° from the starting course. Also before shooting the net the captain must determine whether the school stands high enough in the sea for his particular net. This is done by previously relating the distance at which the echoes of the school disappear from a given horizontal beam. Then the net is shot (if the school stands high enough in the sea for the net) in only a very slight curve until the school is approaching 90° to starboard. Now a constant distance of about 36 to 40 meters is kept from the school until the boat has made a U-turn and is again heading for the buoy.

The course of the boat and the shape of the net as shot will be as shown in the figure on the following page.

In practice this method will catch fish schools if the boat and the school are not subjected to any appreciable force due to any current or wind. The above method of starting when the school edge is just 30° to starboard may have to be changed to suit the conditions of prevalent wind and current. For instance, in very strong head currents, cases are known where shooting has been successful only if the school




Starting position and subsequent course of asdic guided shooting. The dimensions refer to a 90 to 100 ft. boat, 400 m. long purse seine net and a school 40 m. dia.

is already more than 90° to starboard when the operation begins. The captain should have complete understanding of the interaction of wind and current on both the ship and the net. The best method is perhaps when approaching the school and at a distance of about 150 to 250 meters from the school to go at a dead slow speed, or even stop with the school slightly to starboard and heading into the wind. At such a distance the relative movements of the boat and the school can be detected; yet there is enough space to maneuver into the best starting position.

In practice, precautions should be taken not to mistake the echo from the ship's wake (which acts as an air bubble and blocks all echoes from the school) as having been received from a fish school.

202.5 "Underwater Noise Due to Marine Life"

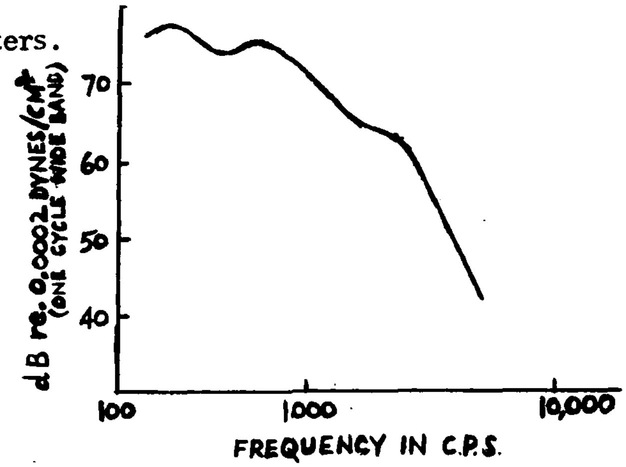
Ref. # 102

By Donald P. Loye and Donald A. Proudfoot

Several acoustical devices were used during the second World War to detect the presence of submerged submarines. As the performance of such systems is limited by the signal to noise ratio, it became necessary to obtain precise information about the ambient noise conditions in the sea. For this purpose a number of hydrophones regularly spaced and connected to a submarine cable were used. A study of the output records of the hydrophones showed that far from being constant, the noise possessed a distinct diurnal cycle (in addition to variations caused by passing ships) with a period of higher level invariably occurring during the evening or night-time hours. As judged by listening from the shore station, the noise at its higher level seemed to consist of a large number of separate sources, as with choruses of frogs or crickets. One source having somewhat the character of a rapid drumming would ocasionally stand out from the background quite strongly. These individual sources could sometimes be heard simultaneously on two adjacent hydrophones 150 feet apart but never more than two at the same time.

The diurnal cycle and local origin of noise ruled out any possibility of its being connected with shipyard riveting or movements of water. So it was concluded that the noise was associated with some form of marine life. To further confirm this, when the noise had risen to its night time maximum some charge was exploded underwater. The effect of the explosion on the noise was immediate. Instantly the cacophony was hushed. The noise resumed only after a few seconds. A few more explosions were caused. Their effects duplicated those of the first. Enquiries from local fishermen ascertained the presence of croakers, the name evidently arising because of a peculiar noise made by these fish. Thereupon a live croaker was listened to by means of a hydrophone suspended in a bucket of water and this dispelled any last doubt as to the ability of the fish to make the noise underwater.

With the source of interfering noise established it remained to determine its acoustical magnitude and characteristics with a view towards devising a means of eliminating or minimising its masking of ship signals. For this purpose measurements of underwater sound were made. A number of frequency analyses were made using overlapping octave band filters.

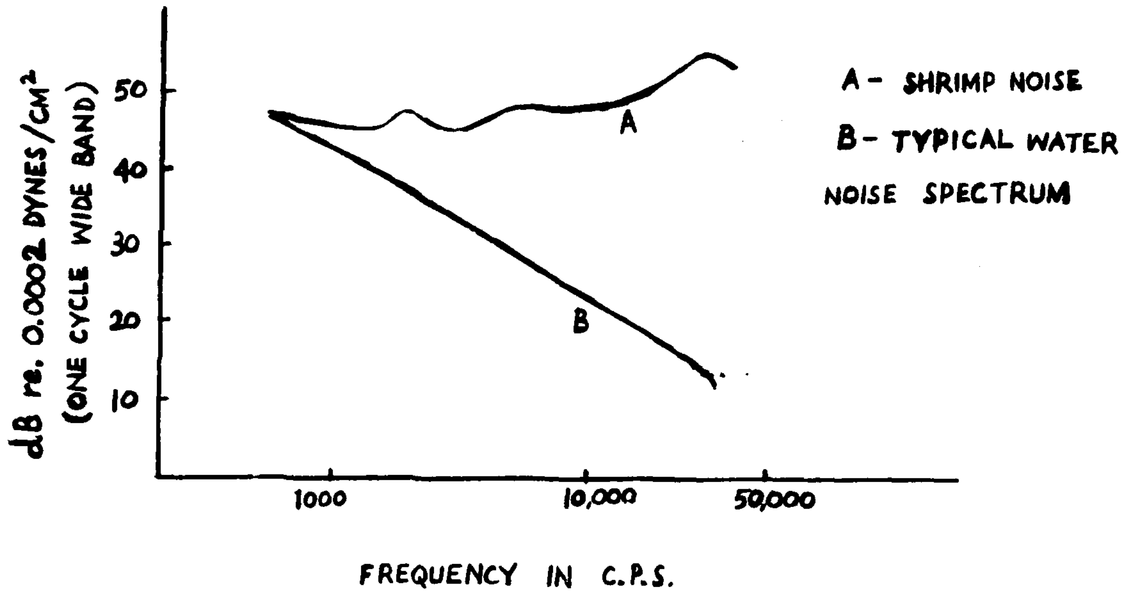



Frequency characteristics of Croaker Noise in Chesapeake Bay May 1942

It can be seen that most of the energy of the croaker noise is confined to frequencies below about 2500 cps. During a second measurement taken in July it was found that the croakers' voices had matured, as the curve now indicated very little energy above 1000 cps.

Investigation of Chesapeake Bay noise was hardly over when reports were received from the Pacific coast regarding another type of underwater disturbance of considerably different character than the croaker noise.

Investigators found the noise was due to snapping shrimp; due to its vigorous snapping of the claws. The study of the character, noise intensity and living habits of snapping shrimp from the viewpoint of submarine detection was considered important in World War II. So frequency analyses of its sound were made. The shrimp live in tropical and shallow waters where the bottom offers them such cover as coral, broken shells or stone.




Frequency characteristic of snapping shrimp noise as compared with typical water noise characteristic

A frequency characteristic of snapping shrimp noise is compared with typical water noise characteristic of a moderately quiet location. In case of snapping shrimp, energy is largely concentrated above 2,000 c.p.s.

202.6 "Review of Marine Bioacoustics. State of the Art: 1964"

Ref. # 146

By William N. Tavolga

Before World War II not much research had been undertaken in the field of marine bioacoustics. The unaided ear was used in hearing such sounds. People would sometimes hear large choruses of drumfish during the spawning season by placing an ear against the hull of a boat. To this day many fishermen still use this technique to locate good fishing grounds for some of these sonic species.

In the 1940's underwater sound detecting and recording apparatus was developed and scientists began to analyze underwater sounds of biological origin. Fish, Kelsey and Mowbray in the early 1950's undertook a cataloging procedure in which sounds from identified, individual fishes were recorded under captive conditions.

Comparison of these sounds with field recordings was considered an approach towards the identification of unknown sound sources encountered in water.

Oceans are considerably noisier than the terrestrial environment. Sound propagated in water will be transmitted farther and faster than in air. In water, sound levels are expressed in terms of decibels with respect to a reference level of 1 dyne/cm$^2$ (= 1 microbar). In air, the corresponding reference level is 0.0002 microbars. The average sea ambient noise is roughly comparable to a busy office with typewriters clattering and telephones ringing, etc. The activity of marine animals alone may add as much as 20 db to the ambient noise level. The marine animal noise is often in frequency ranges that can interfere with sonar gear, acoustic mines, and underwater listening equipment.

The characteristics ascribed to marine sound are duration, pitch and quality. The quality of sound depends on the combination of the harmonics present.

A sound spectrograph is used to analyze the sounds produced by marine organisms. It produces a graphic record of a sound in which the frequency is plotted against time and the relative intensities at various frequencies can be estimated by the intensity of the black on the paper. The instruments can also take a section of a few milliseconds of a sound and plot the frequency against the intensity. Any given sound can be pictorially represented in this way and its component parts analyzed and measured.

The marine animals that are commonly recognized as sound producers can be broadly divided into three groups -

1. The invertebrates, e.g., crustacea (crabs, shrimp, lobsters), molluscs (oysters, clams, squid, octopus, etc.), and sea urchins.

2. The cold blooded vertebrates, e.g., the fishes.

3. Warm blooded mammals, e.g., cetaceans (porpoises, dolphins and whales).

Sounds of marine invertebrates -- crabs, shrimp and lobsters are capable of producing various clicking rasping sounds with their claws, mandibles and many other parts of their bodies. Snapping shrimp (which possess a modified claw) produce a considerable static-lil background noise in all of the warm seas of the world. The individual click of a snapping shrimp is quite powerful and at a distance of a yard may attain an intensity of over +50 db. (This click is a short sound pulse of duration 1 millisec.) Noise may also be produced during feeding or in shallow water zone when large beds of oysters or mussels close their shells.

Sounds of Marine Fishes

Three general types of sounds are emitted by fishes:

1. Stridulatory (rubbing or rasping)
2. Swim Bladder Vibrations
3. Hydrodynamic Sounds.

1. Stridulatory Sounds -- are produced when one rough surface rubs against another. Many species of fish produce such sounds by gnashing their teeth or rubbing patches of denticles in the pharynx. Usually these sounds are produced during the course of feeding. These stridulatory sounds are generally not specific for any particular species of fish and identification of sound source is extremely difficult or impossible.
2. Swim Bladder Vibrations -- Many species of fishes are equipped with a set of specialized muscles attached to or surrounding the swim bladder. These drumming muscles are capable of vibrating and the swim bladder with its enclosed air acts as an underwater loudspeaker. Prominent in this group are members of the drum fish family, including croakers, sea trouts and sea drum. Important sound producers are marine catfish, toadfish, squirrel fish. The sounds are basically harmonic, with a fundamental frequency varying from about 100 to 500 cps, depending upon the species. Some of the sounds

are short grunt-like pulses of a duration of about 0.1 sec. and these can be rapidly repeated in groups of 5 or 10 to produce rattling or hammering effect. Often a particular species can be recognized on the basis of the patterning of these pulse groups, e.g., drumfish and croakers. Toadfish are recognized by their "boat whistle" sound (up to 0.5 sec. duration - fundamental freq. 200 or 300 cps.) Sounds have mostly behavioral and biological significance.

3. Hydrodynamic Sounds - The physical movement of a fish through the water produces a displacement and a pressure wave. This noise is generally low in frequency ranging down to the subsonic, aperiodic and is produced when fish changes speed and direction.

Sounds of Cetaceans (Marine Mammals).

These produce two classes of sounds

1. Echo locating clicks
2. Harmonic whistles or lower pitched cries

1. Echo locating clicks are given out by almost all the members of the order of toothed whales. The click is a white noise* pulse of less than 0.01 sec. in duration. They can occur as single clicks or in trains with a repetition rate of well over 200 per sec. This rate varies with target distance.
2. Porpoises, dolphins, pilot whales, etc. (of the order of toothed whales) also emit high pitched whistles whose pitch varies from 1000 to 10,000 cps. There is some evidence that the contours of the whistle might be characteristic of a species.

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* A sound which contains all the audible frequencies at equal intensities simultaneously is called a white noise.

202.7 "The Biological Significance of Fish Sounds"

Ref. # 172

By H. E. Winn

It was known from a long time back that fish produce sounds but little was known about the functional significance of these sounds. Pioneering studies by Fish and recent studies by other bioacousticians have established that 1. Species emit different sounds which differ from one another qualitatively. 2. Sounds may be produced in seasonal and daily cycles. 3. Different sounds may be produced in different behavioral contexts. 4. Sounds can also stimulate courtship activities, aggressive and escape behaviour and serve as warning signals to produce escape and investigatory activities. 5. Sound production may be restricted to one sex, usually the male.

Properties of acoustical signals from some fishes may be classified in five categories:

1. Variable time interval signals
2. Fixed time interval signals
3. Unit-Duration Signal (Duration of any unit of sound is lengthened)
4. Time length signal (Amount of time during which units of sound are produced is varied)
5. Harmonic Frequency Signals.

Sounds from fish may also be classified as exogenously driven sounds and endogenously driven sounds according as they are produced as a response to external stimuli or they are produced spontaneously, respectively. In the latter case the fish itself is in the required physiological state and environment.

Different species utilize the above types to a variable degree. An example is the grunt sound of oyster toadfish given off as variable interval signals which may grade into a fixed interval type signal, when produced at the maximum rate. The boat whistle call of oyster toadfishes (produced by other toadfishes also) is an example of harmonic frequency signal. Holocentrus rufus has a variable interval grunt-like signal and an entirely distinct fixed interval staccato call.

There is a strong probability that fish convey information to one another, or warn others or react against predators or in courtship or territorial defense, by changing temporal patterning of signals. Information can be graded by varying the intervals and length of time over which units are emitted. Amplitude and frequency characteristics of most acoustic signals do not seem to carry enough information. Notropis Analostanus might be using frequency and amplitude characteristics to differentiate its own sounds from other sounds of the environment. Similarly, high frequency stridulatory sounds and other signals given by different species tend to be temporally patterned in a way which serves to convey information to other species or appears to be response to external stimuli.

There is also a cyclic nature of sound production in the fish. Sounds rhythmically change during the 24 hour period varying with the passage of day and with passage of night. For instance some fish produce sounds only during the day and some fish produce sounds only during the night. In one specie under study drumming started at noon and increased until mid-afternoon, then decreased until at sundown only a few fish could be heard. Also peaks of sound activity by croakers were correlated with tidal changes and feeding activity.

Similarly, there are seasonal cycles of sound production. Sound varies cyclically during the time of the year and also it changes during spawning season. For instance, toadfish boat whistle is restricted to a few months from late May through early August at the dock of Solomon's Island Lab., Maryland.

There is more sonic activity in fish during the reproductive seasons. Sound production is restricted to male sex and it acts as an aid to problems of aggregations, synchronization and stimulation of reproductive activities. In some species only the females also produce sounds during the spawning season.

In non-reproductive behavior, sounds have been reported during competitive feeding, territorial defense, aggregating behavior, new stimulus situations, escaping and during migration. In new stimulus situations the sounds are produced as aggressive sounds, startle sounds, fear sounds and warning sounds.

Similarly during reproductive behavior of various species sounds are produced during defense of nest, chasing, various phases of courtship, etc.

The correlations between sound and behavior show that sounds are an integral part of complex stimulus situations which are used to communicate information for the solution of problems that relate to individual and population survival. Orientation to the source of sound is controversial at this time.

Behavioral value of Stimulus - This external stimulus may be provided from outside, e.g., playback of sound or it may actually be produced from another member of the specie to elicit a particular behavioral response from another member or members. The playback of the recorded sound in some cases caused no response, while in other cases there was increased activity and in some cases movements away from source of sound. There are a large number of parallelisms between the development of certain alarm calls by birds and the alarm call (staccato) system of the longspined squirrelfish.

It is presumed, but not adequately demonstrated, that sounds produced by territorial fish outside of the breeding season are part of the effective stimulus pattern causing dispersal of intruders.

The functional significance of other types of fish sounds, e.g., sounds produced by territorial males of Notropis Analostanus, the toadfish boatwhistle and the toadfish grunt have also been analyzed. Toadfish boatwhistle seems to attract females to the nest. The introduction of males to nest guarding males has the highest stimulus value for production of grunts.

The simplest responses to stimuli involve an increase in activity, inhibition or decrease of activity, change in attentive level, and orientation to the stimulus. These all can be involved with the various types of adaptive behavior such as feeding, escape, migration and phases of reproduction. Sounds can function as possible orientational cues only when the fish are very close to each other. Theoretically, the fish ear cannot localize a source of sound underwater, (though this has not been confirmed) and it appears that the sensory world of fishes is spatially more limited than that of land-dwelling vertebrates.

There is a lack of adequate evidence in fishes for many of the functions of sounds found in birds and mammals. Some of these are echo location, confusion choruses, young parental sound relation, all clear signals, recognition of individual call differences and many others. It is clear that sounds by fishes are not as finely organized and only major moods and responses can be obtained. The use of acoustical signals in species isolation is yet to be studied adequately.

202.8 "Acoustic Techniques of Fish Population Estimation"

Ref. # 153

By Richard E. Thorne and Henry W. Lahore

Practical fishing industry and management agencies need numerical estimates of fish stock. The methods of test fishing and recovery of previously marked stock are subject to limitations and sources of error. Acoustic techniques appear to be a promising means of direct population estimation for pelagic and semi-pelagic fishes.

At first (in the early 1950's) unmodified echo-sounder was used and estimates were made by counting the number of echo-traces on paper. This had the following disadvantages:

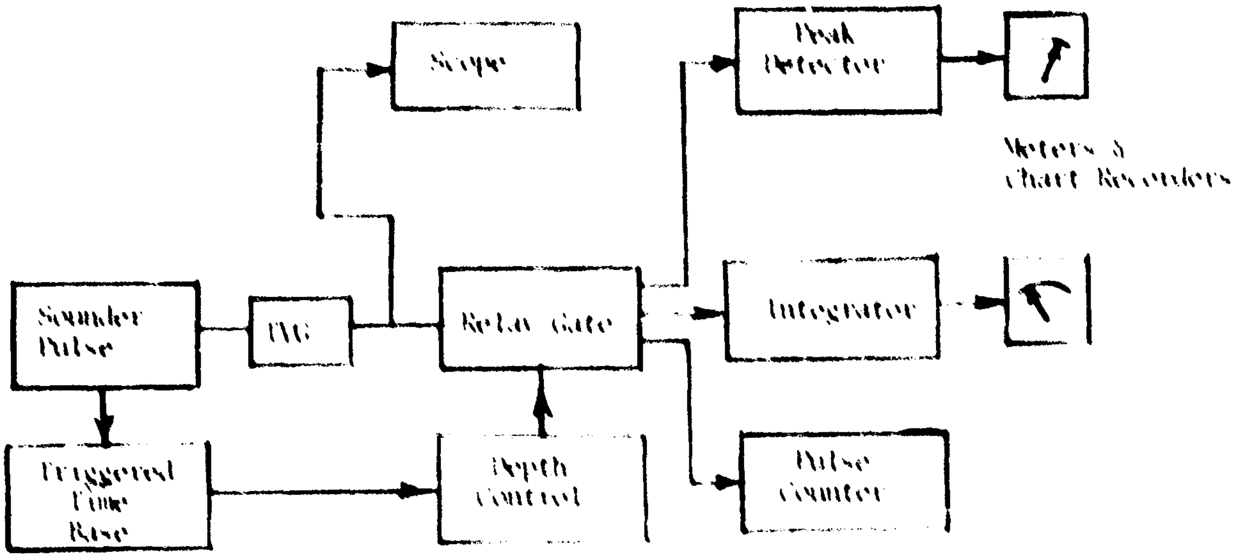
1. Subjective errors involving human decision were introduced.
2. The echo sounder being not specially suited for the purpose did not take into consideration factors which modify the return signal, e.g., depth, frequency and pulse length of sounder and the amplification of receiver.

Subjective errors involving human decision have been eliminated by use of electronic signal processing equipment. There are three types of electronic apparatus for quantifying the returning signals.

1. The relatively simple pulse counter, which counts the number of resolvable targets of more than a minimum threshold level.
2. The pulse length counter which analyzes both the number and length of the returning pulses.
3. The echo integrator which, measures the total strength (voltage) of echos within a given depth interval and sums these voltages over time.

The Echo Integrator - The echo integrator measures the summed echo strength of all targets rather than the number of targets.

A block diagram of echo integrator electronics is as shown below. The time base is triggered by a pulse from the echo sounder. Using this time base, the circuit is able to turn on the relay for the depth interval to which it has been set. The signal from the sounder receiver goes into the time varied gain circuit, is rectified and put through the relay contacts to the integrator peak detector and pulse counter. The electronic integrator is a device that has at its output




Block Diagram Showing the Principle of the Echo Integrator

terminal the integral over time of the voltage that has been applied to its input. In this case we can say it sums up the echo amplitude times the duration. For uniformly sized fish the integration is proportional to the number of fish since the voltage level should be the same for each fish independent of depth. The peak detector indicates the maximum amplitude of the signal in the gated time interval. This serves to allow the adjustment of the input to a good voltage range and is a record of echo density of a surveyed area. The pulse counter indicates the number of pulses in the gated interval that have been over a certain amplitude. For low densities it serves as a count of the fish that have been in the examined depth intervals.

Comparison of Acoustic Techniques

General. At high densities, if two fish occur in the sampling cone approximately the same distance from the transducer, the echo pulses will arrive at the transducer nearly simultaneously. On an echo recorder these targets will be merged and may not be resolvable into two targets. This is the multiple target effect and at high densities this may cause underestimation of fish population. Of course, these can be resolved by increasing the frequency and reducing the pulse length but increased frequency causes greater attenuation.

1. It has been shown that the amplitude of the return from multiple targets is proportional to the square root of the number of targets. If we consider four fish tightly schooled within a depth interval less than one half the pulse length of an echo sounder, the pulse counter and the pulse length counter would count only a single fish. But the echo integrator would count two fish (because of square root relationship).

2. Where there are mainly a single species of a uniform size, and where there may be insignificant number of multiple targets, results from all three electronic survey techniques can fairly well compare with the net catch.

3. When a survey is concerned with a large depth interval, echo integrator has advantage over other counters, because it can be adjusted for use over any depth interval, within range of its echo sounder. (Because of the bias in case of greater depth intervals, more than one counter should be used to increase coverage) or the echo integrator can survey over a wider depth interval with single channel output. Where multiple targets are significant more than one echo integrator should be used for surveying large depth intervals.

4. With all three electronic survey techniques, difficulties are faced in a situation where the species and size distribution are complex, i.e., they are not uniform or nearly uniform.

202.9 "Application of Echo Sounder to Great Lakes Fishery Research"

Ref. #66

The paper mainly deals with the interpretations of echo traces from fresh water fish . Echo traces were obtained using Kelvin and Hughes M.S. 29 recording echo sounder aboard the B. C. F.'s research vessel Kaho. Particulars of Echo Sounder:

Transmitting Freq. 50 kHz

Pulse lengths - 0.5 m. sec. or 1.0 msec.

Pulse repetition rate - 200 soundings/min.

Cone shaped beam of sound with an apex angle of 28° is produced

Electrosensitive dry paper is used for records.

The researcher should understand the various peculiarities and limitations of sound transmission in water in order to interpret accurately the echo trace. Some of these are as follows:

Measurement of Sound -- Accurate measurement of depth to within 3 ft. requires measurement of the transit time of sound within 0.6 msec. To obtain depth accuracy within 4 inches requires measurement of time within 0.07 msec. This establishes the need for a very accurate measurement of time. Also, it should be borne in mind that velocity of sound varies with variations in temperature, depth and salinity of water.

Attenuation -- It is caused by absorption and scattering of signals. Concentrations of air bubbles at the surface and strong currents cause high absorption while suspended matter, plankton, etc., cause beamed energy to scatter.

Reflection -- Sound waves reflect when they strike something they cannot penetrate. Lake bottom provides such a surface. The strength of the useful echoes changes with changes in shape or slope of the reflecting surface.

Refraction -- It may occur where water is separated into layers having different temperatures, sound waves bend at the interface and this affects the accuracy of echo-sounder.

Fish detection depends on both frequency of sound waves used by echo-sounders and on vessel speed. Sounders designed for fish detection use frequencies between 20 and 200 kHz. The best conditions for fish discrimination exist when the wavelength of the sound used is not much longer than the greatest width of the fish. Still higher frequencies (over 50 kc/s) are used when even greater discrimination is desired, as in locating shrimp and plankton.

Transducers can be constructed more easily for ultrasound than for sonic sound because dimensions of transducer are inversely proportional to the frequency used. On the other hand, higher frequency causes greater attenuation and range of sounder is reduced. That is why deep sea sounders use sound in the sonic range.

Interpretation of Bottom Recordings -- Type of echo signal received varies with nature of bottom. Hard bottoms reflect more of sound signal and therefore, echoes received from these make sharp, strong marks on the recorder while soft or muddy bottoms reflect less sound and echoes appear as broad lines. A rock bottom can be identified by the appearance of a large number of multiple echoes which are caused by repeated reflections of the sound signal between the hard bottom and surface.

Interpretation of Echoes from Fish -- The appearance of the echo trace given by different species depends on following factors:

1. Absence or presence and size of swim bladder
2. Frequency used in the Echo Sounder (In this particular case, a fixed freq. of 50 kc/s was used. Hence, it is not discussed below)
3. Size and density of fish school
4. Pulse length used.
5. Experience of the operator.

Among these, the first factor is most important. The swim bladder occupies only 5 to 8% by volume in freshwater species; still it contributes 40 to 80% of the reflected signal. This is because of the fact that acoustic reflectivity of air is 100% while those of fish flesh and bone are 46% and 26%, respectively.

Secondly, it is quite obvious that echo obtained from a smaller or lone fish will be weaker as compared to a larger fish or when a group of fish are present.

Long pulse length (2.5 msecs.) (in this case) improves the markings in deep water or in adverse weather conditions. Short (0.5 m sec.) and medium (1.0 m.sec.) pulse lengths are employed for detection of fish schools near lake bottom in shallow water and for detection of schools in midwaters, respectively. "White line" recordings are used when echoes from fish on or near the bottom merge into the stronger bottom echo trace if conventional recording methods are used.

Finally, echo traces from fish also depend on experience of operator. He can adjust the sensitivity control in rough seas or in bad weather to facilitate interpretations of echoes from fish.

It should be borne in mind that we cannot always relate the quantity of fish echoes that appear on the recorder with the quantity of fish in the catch. This is partly due to the ambiguity in the recorded depth of fish because fish at the edge of the sound beam will be recorded but not at their true depth. The fish will, therefore, appear to be closer to the bottom than they actually are.

Echo sounder is useful in the study of the movement and distribution of fish and plankton. Studies of paper records of echo soundings from the North Sea show that identification of species depends on differences in behavior which are fairly constant in a limited area. Over more extensive areas species probably could not be identified by behavior pattern. Cushing et al. (1952) recognized different species by echo trace and grouped fish traces into four types--the spot, the comet, the plume and the layer. Each type (these are for fish in the ocean) is an index of how much of the sound pulse is interrupted by the fish, irrespective of the depth. In the same way, fish in the Great Lakes can be categorized. The comet trace or slight variations are usually chubs; the the plume or steeple are generally alewives; the layer is mostly smelt and the spot is a combination of other species. Best results are always obtained while the vessel is at anchor or drifting on a calm surface. Concentrations of plankton often appear on the echo sounder when excessive amplification is used. In general, the uniform layers (in echo traces) can be attributed to plankton whereas the less uniform or scattered probably are fish.

202.10 "Characteristics of Echo Records"

Ref. # 127

By G. Saetersdal and G. Vestnes

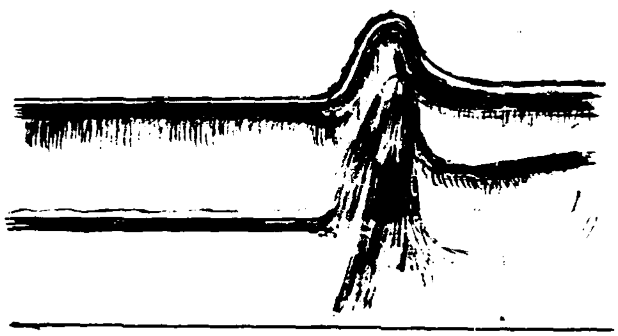
Echo traces are recorded on paper by Echo Sounders and Horizontal Echo Ranging Equipment. This paper describes different types of traces we get in practice and how we can deduce relevant information, e.g., location of fish schools, nature of sea bed, distinction between various types of echo traces, etc.

ECHO TRACES IN CASE OF ECHO SOUNDERS--

Shape of Echo records in case of Echo Sounders depend primarily on speed of paper, pen speed and speed of vessel. Their shape also depends on characteristics of instruments, e.g., beam shape, pulse length, sensitivity, transmitting power, "white line" effect, etc. The effect of varying paper speed, pen speed and vessel speed is to distort the horizontal or vertical scale of echo records which may for instance represent a fish school. At normal cruising speeds the vertical scale of echo records will be about 20 times the horizontal scale.

From the echo traces we can come to know whether the sea bed is hard or soft and smooth or rough. The echo from the soft ground is comparatively weaker than the one from hard ground. Therefore, trace on the paper from soft ground will be narrower as compared to the one from the harder ground.

In shallow waters one may obtain several echoes. This is because the sound after having been reflected from the sea bed back to the ship is reflected down again by the sea surface, thus producing a second sea bed echo. Figure below shows double and triple echoes obtained.



Double and Triple Echoes Obtained with an Echo Sounder in Shallow Waters

When we use a sensitive echo sounder for depths beyond the depth scale set on the sounder we may get traces which are called "Ghost Bottom". This is because the pen returns to the zero position before the sea bed echo returns and we get a true sea bed echo trace recorded at an incorrect scale. Ghost Bottom record can be recognized by the fact that the echo passes the zero line and there is no white line effect on the echo trace.

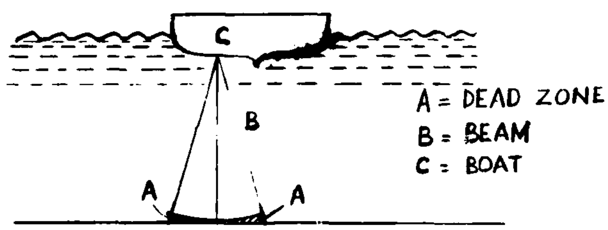
In case of Fish records if the vertical distance between two fish is less than about half pulse length their echoes will overlap. Similarly horizontally Fish records may show individual fish or echoes from adjacent fish may overlap and give a multiple echo trace Horizontal resolution depends on the beam angle; the narrower the beam, the greater the resolution. Resolution in vertical direction depends on pulse length used The shorter the pulse length, the greater the vertical resolution. The longer pulse, in most instruments increases the transmitted energy and it is recommended for use in sounding at great depths and when high resolution is not needed.

In case of echo traces of single fish these are recorded as continuous line traces if the vessel is stationary. If the vessel is moving at a slow speed, the line echo traces shorten and are recorded as curved lines. At high vessel speeds the traces merely appear as dots and points.

In case echo record of single fish is required the beam angle, the sounding rate, the paper speed and the cruising speed should be adjusted. In case we have to discriminate between or make target strength measurements of individual fish throughout a depth range we should use a time varied gain system on the echo sounder.

When fish density in a school exceeds the power of resolution of the echo sounder, we would obtain a multiple echo trace, which will be in the form of a layer or a distinct solid trace. In a layer type trace, traces of individual fish at the borders of layer are also obtained. But in case of echo traces of dense concentrations of smaller organisms, e.g., fish larvae and other plankton organisms whose individual target strength is below the detectable level of instrument, there are no individual traces at the borders.

When fish are near to the sea bed they are difficult to detect because the more powerful bottom echo traces overlap the weaker fish echoes from fish located in Dead Zone as shown in figure.

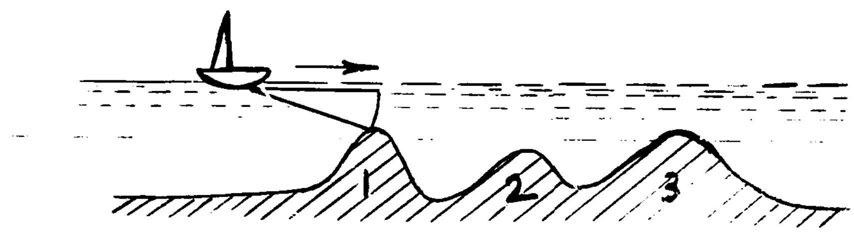



In this case we should use a "White line" system of presentation. We can also

the beam width

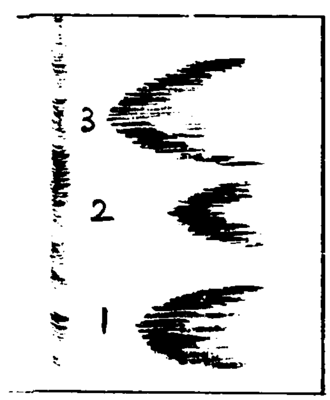
HORIZONTAL ECHO RANGING SONAR RECORDS.

In case of sonar, area covered by search can be much greater than that covered by echo sounder. Also echo traces differ as we train the sonar beam at different angles.




A vessel with echo ranging sound beam fixed in forward direction.

In the figure are shown echo traces of the area shown above. A characteristic of these traces is that the slope of the traces represents the speed of approach of the ship towards the target.




Echo ranging record with sound beam fixed at 90° to the port or starboard.

In contrast to the echo sounder the horizontal echo ranging sonar does not give much useful information about the sea bed.

Fish records on the sonar differ with the type of search pattern that is followed. Records obtained when passing a number of fish schools with a side to side sweep is shown as follows. Traces are produced as the beam passes the schools in 5 degree steps.

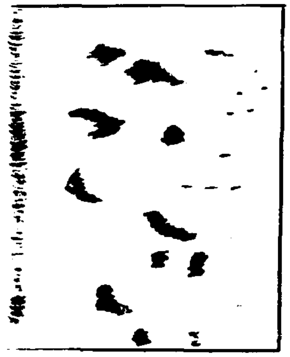


Figure shows the records obtained when passing a number of fish schools with a side to side sweep by the sonar.

Under favorable conditions schools of fish close to the sea bed can be detected by sonar. Echo ranging signals can also be presented on a P.P.I. (Plan position indicator) screen.

Finally, the range of detection of sonar may be affected if the sound beam undergoes refractions due to the presence of vertical temperature gradient. Ideal conditions are when there is no vertical temperature gradient.

DISTURBING ECHO SIGNALS--

Various types of disturbing signals may affect the echo ranging and echo sounding records, or may even prevent the proper functioning of these instruments. In case of echo sounder, the transducer should be properly located and installed.

"Propeller noise" may affect both types of records. Sound is also reflected by air bubbles in rough sea due to breakers or in ships' wake. Their traces may be mistaken for fish schools.

202.11 "Practical and Tactical Use of Sonar"

Ref. # 136

For the successful use of sonar the operator should:

1. Have a knowledge of the principles of sonar and echo ranging.
2. Be able to distinguish between unimportant and essential noise, stray echoes and real echoes.

3. Know how to interpret an echogram correctly.

4. Know the factors which attenuate the sound waves and the variations which the sound velocity undergoes with changes in temperature, salinity and pressure and the accompanying refractions and reflections which tend to limit the range of the sonar.

5. Have knowledge of the fact that all life objects, surfaces and sea conditions (e.g., temperature discontinuities, air bubbles and wakes of the ships) give echoes.

Generally, sonar is most suitable over deeper waters where there are less bottom echoes to cause confusion.

## Tactical Hints

When beginning to use sonar, first of all, actual sonar range of the day should be appraised. If the sonar range is small (e.g., 500 m) one must slow down and cruise in a closer grid pattern over a certain area if a complete coverage of that area is desired. If two or three ships are equipped with sonar, they can cooperate by cruising side by side at a distance of approximately two times the sonar range of the day.

While fishing in fjords it is recommended that the sound beam be fixed in a direction about 45° from the bow and the ship sail alongside of land so that danger of receiving bottom echoes is reduced.

While cruising over any fish school fish may be frightened by propellers. With the sonar it is possible to avoid cruising over any fish school. The ship could stop at a distance from the schools while in constant touch with the school by sonar. The seine boats are then launched. These should move in on the target by a round-about route in order not to put wakes between the mother ship and the target. Net drifters may also use sonar. By stopping the ship at a distance from the school and by keeping the sonar beam on the edge of the school; the direction in which fish are moving can be determined. Then the nets could be set about 200 to 300 m ahead of school.

While hunting tuna and whales, doppler effect could be utilized for judging whether the target is moving towards the ship or away from the ship.

## SONAR FOR FISH [176]

Anonymous

Nature 212, No. 5063, 660-661 (November 12, 1966)

The current trend in sonar is to use narrow beams of sound, generally less than 1 degree wide in at least one axis. The narrow sound beam , together with the use of pulses as short as 0.1 msec., increase resolution. However, this combination also decreases the rate of search because only a small volume of water is reached by each pulse and it is necessary to scan with the beam.

Two instruments proposed as solutions to this problem are described. Both instruments are designed to work through a 30 degree sector and to scan this sector electronically from side to side with a receiver having narrow beam acceptance. As the range and bearing of objects are continually changing with time, the display of such a system must necessarily be three dimensional. A film of the oscillograph display from a sector-scanning transducer mounted on a pier clearly showed fish shoals moving with the tide.

Acquiring more information about targets by using different frequencies of sound raises the problem of generating beams of constant width over a wide range of frequencies. At low frequencies this implies physically large transducers. One solution may be in the way in which an acoustic wave of sufficient magnitude affects the density and bulk modulus of the medium in which it is propagated. The velocity of propagation is a function of acoustic pressure and the crest of the sound wave travels more rapidly than the null point while the trough is retarded. If two waves are superimposed and subjected to this effect, new frequencies can be generated. It is then possible to emit narrow beams of low frequency from comparatively small transducers. The constancy of beam width can be maintained over a 10:1 range in frequency. The drawback of this system is that the power density applied to the transducer is inevitably high and up to 40 watts per square centimeter may be used.

At the present time, electronic circuitry implies high cost and bulk in the transmitting and receiving systems. There is little immediate prospect of these developments becoming useful aids to the fisherman. Nevertheless, with the micro-miniaturization of circuits and the application of digital techniques, it may not be long before the fish have little chance of avoiding detection, identification, and capture.

## ECHO SOUNDING AND FISH DETECTION [14]

R. E. Craig
Marine Laboratory, Aberdeen, Scotland

The tendency of echo sounder manufacturers has been to work on a frequency of about 30 kc. for fish detection but for fishing, there is no such thing as the ideal type. For example, for locating fish a fairly narrow sound beam, without side-lobes, is needed, but if fishermen want to study the nature of the seabed a wide beam and frequencies somewhat lower than 30 kc. have certain advantages. A narrow beam used from small ships may be neutralized by aeration and the motion of the ship and some sort of stabilization, such as mounting the oscillator in gimbals, is called for. In searching for fish, though not for use during fishing, the oscillator could be mounted in a streamlined housing (which the author calls a shark) and towed at a suitable depth. This would provide a stable sound beam and would eliminate or reduce aeration. For studying the seabed, frequencies in the lower range, 10-15 kc. give a clearer picture than the more usual higher range. The future trends in the science of echo sounding are discussed, and it is suggested that the recording of signals as presented on a Cathode Ray Tube might be done photographically although, notwithstanding certain limitations, the recorder is likely to remain an essential feature of echo sounders of the future.

## DIRECT ESTIMATION OF A FISH POPULATION ACOUSTICALLY [21]

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A method is described of estimating fish stocks by length-groups acoustically. Hake off southern Africa were recorded as individuals on the paper record of a Kelvin Hughes "Humber" echo sounder down to 350 fath. Signal strengths of single fishes were observed on the cathode ray tube and the target strengths of fishes are known; estimates of fish sizes were made. The signals were considered as being received from a mean angle (to the axis of transmission) and the heights above the sea bed were calculated.

The echo survey made between Cape Town and Walvis Bay was expressed as numbers of fish/unit volume in a range gate of 1 or 4 fath above the sea bed. A length distribution of the hake stock was derived.

## THE QUANTITATIVE USE OF THE ECHO SOUNDER FOR FISH SURVEYS [26]

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The use of echo sounders for fish finding is now almost universal, and in this paper the author shows how, by the use of Cathode Ray Tube presentation, an approximate correlation between "catch" and "amplitude" of the returned signal can be obtained.

The total signal amplitude, counted during a trawl haul, was multiplied by the square of the depth to correct for dissipation of energy and this was compared with the square root of the number of baskets of fish taken during the haul. In fig. 1 the catch/signal relationship in 1955 and 1956 is shown, but in three cases out of 40 observations the relationship broke down. These cases were of high signal strength and no catch, and it is considered that the error was due to fish swimming above the headline of the trawl, although the returned signal apparently suggested that they were actually below this level, which, the author points out, is quite possible.

The value of C.R.T. observations as a means of surveying a fishing area is shown by three successive runs over the grounds between Bear Island and Spitzbergen, and during a ten day period the movement of the cod on to the Bear Island Banks was clearly shown.

## BIO-ACOUSTICAL DETECTION OF FISH POSSIBILITIES AND FUTURE ASPECTS [57]

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The possibility of using acoustical indications for locating fish has only been investigated during recent years. The conductivity of sound in water is about 3,200 times higher than in air and sound waves propagate 4.5 times faster. Modern hydrophones connected to recorders are now used to study fish sounds. Listening-in is done from boats or from permanent stations ashore connected to outlying devices such as the Japanese "Sonobuoy". The paper then discusses the sounds produced by sea animals and their sound mechanisms, such as those made by the air bladder, stridulatory and swimming movements. The intensity of fish sounds can be correlated to the internal motivation state of the animals; in pre-spawning and spawning periods the animals produce much stronger sounds than at other periods. Experiments to date have obtained some results in attracting and repelling fish and investigations in this direction are continuing, although little is known as to the effective range of fish sound patterns. The main present objective of sea acoustical studies is to establish standard sea animal sounds, leading to full recognition of the species producing such sounds.

## A NEW SONAR SYSTEM FOR MARINE RESEARCH PURPOSES [60]

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A complete "search installation" comprises two combined sounder/sonar sets working on 11 kc/s and 30 kc/s and two additional sounders on 38 kc/s and 18 kc/s. The remote controlled sonar transducers are housed in a retractable 18 knots dome. The transmitters have variable pulselength and an output power of 8.5 kw. The receiving equipment is calibrated and comprises special circuits for TVG, RCG and White Line features. Display and recording equipment includes range/depth recorders, tape recorder, loudspeaker and an oscilloscope for detailed echo studies and play back of tape recordings. The whole installation, including two additional sounders, is manned by a single operator.

## THE DEVELOPMENT OF ECHO SOUNDING AND ECHO RANGING [68]

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One of the most exacting problems facing the designer of echo-sounding equipment is the detection of fish within a few feet of the seabed. The use of the scale expander which enlarges the picture as presented on the Cathode Ray Tube, has helped to clarify the situation, for by this means, fish very close to the bottom are presented as having a brighter trace than the seabed itself. The C.R.T., unfortunately, lacks a memory which the recorder has. In order to get the best of both worlds the manufacturer must produce, in a single display an instrument having both qualities. Owing to the limited number of gradations or "tones" that can be produced on the recording paper, fish on the bottom may pass unnoticed because their echo merges with that of the bottom and to overcome this limitation, an ingenious and simple gating circuit has been devised. This operates only on receipt of the bottom echo and has the effect of cutting out the amplifier for about 1/100 sec., thus producing a white line which follows the bottom contour of the paper, dividing the fish echoes from the bottom echoes. The author deals with the problems and limitations of echo-ranging and stresses the need for the training of fishermen by experts in the use of modern electronic equipment, for only by the correct use of the instruments can complete liaison be maintained between the fishermen and the manufacturer.

## UNDERWATER TELEMETERS FOR MIDWATER TRAWLS AND PURSE SEINES 69

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Since 1957 the authors have worked on the development of a wireless net depth telemeter for commercial midwater trawling. The general principle and some technical details are given of the five types of instruments built and tried so far in the course of this work. The net depth is measured by determining the hydrostatic pressure and the measured data are coded into ultrasound signals transmitted to a sound receiver towed by the trawler. They are converted into electrical signals and led by a 25 m long cable to the depth indicator unit in the wheelhouse. The depth indication was first only by pointer on a scale, as well as acoustical. Later a paper-recording system was developed to write the depth in correct scale on the echogram of the trawler's echo sounder. For the first four instrument types the depth measurements were converted into signals consisting of ultrasound impulses (impulse rate 40 per sec) the duration of which was in linear relation to the depth. Instruments of this kind could not be made light, cheap and rugged enough and continuous depth indication could not be achieved. Then a system of frequency modulation was adopted, i.e., the frequency of a continuous ultrasound signal was changed according to the measured depth. The frequency of the transmitted impulses or signals for all types is approximately 200 kc. The depth-measuring range is 0 to about 250 m with an accuracy of about ± 1.0 m at about 100 m depth. The transmission range from net to trawler is about 1,000 m for the first four models and about 2,000 m for the last model. The last model, which is completely transistorized, was found to be satisfactory and is available on the market. Already in 1961 about 70 units were in commercial use, mainly in conjunction with midwater trawling for shrimp in the East China and Yellow Seas. Such depth telemeters are also suitable for measuring the behaviour (sinking speed) and fishing depth of purse seines.

## ECHO-SOUNDING THROUGH ICE[80]

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and

Yoshinobu Maniwa and Osamu Omoto and Hidekuni Noda
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The echo traces of the bottom of, and fish schools in, a frozen lake could be obtained with ease and speed by determining positions on and by sounding through the surface ice. The transducers were brought into good contact with the ice by removing the snow and pouring a cup full of water. Using 200 kc and 400 kc transistorized recording echo sounders, it was possible to obtain echo traces of pond-smelt, a very slender fish about 11 cm long, through surface ice. The transmission loss of ultra-sound in ice was almost linear with the thickness of ice. In artificial ice it varied from 0.25 db/cm at 20 kc to 0.60 db/cm at 200 and 400 kc, while in natural ice on the surface of the frozen lake studied it was 0.40 db/cm at both 200 and 400 kc. The sound velocity through ice was found to be 3.120 m/sec. The results for natural ice are claimed to be valid only under the conditions of the experiments reported.

## FREQUENCY ANALYSIS OF MARINE SOUNDS [76]

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As fundamental data preliminary to the development of methods for detecting, luring or driving away fish schools with sounds of marine animals and ambient noises in the sea have been studied and analyzed. The frequencies of sounds made by whale, dolphin, drumfish, spotfish, croaker, gurnard, lobster and shellfish, and swimming sounds of yellowtail, squid, surf-perch and filefish were analyzed. Each sound showed a spectrum characteristic of the species. Recorded sounds of risso's dolphin are in the range of 150-5,000 c/sec; drumfish gave a maximum pip at 500 c/sec; spotfish 650 c/sec; croaker 250-800 c/sec; and gurnard 100-400 c/sec. Drumfish, spotfish, croaker and gurnard, etc., produce their sounds with their air bladders. Yellowtail gave pips in the range of 150-3,000 c/sec. The swimming sound of squid schools was at 1,000-2,000 c/sec. Lobster produces sounds at the base of its antenna with maxima at 180-4,000 c/sec, with intensive components in the ultrasonic range. Ambient sea noises of Aburatsubo Bay and Kurihama Bay, Kanagawa Prefecture, Izu Ajiro and Shimoda Shizuoka Prefecture, Choshi Kurohae, Chiba Prefecture and others were analyzed. The spectra differed with the areas and depth of water.

## AN ATTEMPT FOR DETECTING THE SWIMMING COURSE OF FISH SCHOOLS AT A SET NET FISHING GROUND BY FISH FINDER (PRELIMINARY REPORT) [151]

Saburo Kawada and Yozo Tawara

It is important for improving the catching efficiency of set nets to detect the swimming course of fish schools in fishing areas. For this purpose the experiments were carried out at Yoshihama Bay, Iwate Prefecture during November to December, 1954 (Table 1).

Two survey boats, each installed with a vertical type of fish finder, sailed back and forth along the detecting course selected as shown in Fig. 1. A number of points where we encountered with fish schools, were plotted on a chart to calculate the encounter index. The swimming course of fish schools was estimated as follows.

The fish schools which entered the northern part of the bay, at a speed of 0.5~2 m/sec (Tables 3 and 4), swam to the south along the isobath of 40~60 meters and reached at the front of the set net. According to our observation they were expected to fall into the set net on their way out of the bay (Figs. 3 and 4).

Further studies are under way to obtain better results by using simultaneously a vertical type and a horizontal type of fish finder.

## IMPROVED ECHO SOUNDING EQUIPMENT FOR THE DETECTION OF SHOALS OF BOTTOM FISH [97]

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In the trawl fishery, the fish are usually caught within a few feet of the seabed, so that it is most important that recording echo sounders should be able to discriminate between these bottom fish and the sea bottom itself.

The resolving power (picture quality) of a conventional echo sounder allows a fish to be recorded just clear of the seabed, if it is at least 75 cm. above the bottom. As it is not practical to increase this resolving power, a special receiving amplifier has been made which records the strong bottom echoes in a black tone, and the weaker fish echoes in a grey tone, thus making the discrimination between fish and seabed possible. This "Grey-Black Amplifier" should be of great help in the trawl fisheries.

### WE MIGHT LEARN TO SPOT FISH BY THE SOUNDS THEY MAKE[103]

Alan P. Major
Fishing News International 7, No. 5, 37, 90 (May 1968)

The development of suitable underwater-listening apparatus in recent years has made possible the adequate description of the sounds that fish make and an assessment of their use and importance.

In the head of the majority of bony fishes are two flattened bones that respond to vibrations. The fish receive sound waves on these bones, making it possible for them to "hear" and "talk" through the water. Several members of the cod family have striated drumming muscles associated with their gas-filled swim bladder. These muscles contract and produce a sound as part of the fishes' behavior in relation to their own species and other fish. The noises are made as part of their self defense, are connected with aggression, or possibly are part of the reproductive behavior of male fish. Other fish make sounds by forcing air out of their air bladders, gnashing their teeth, quickly opening and closing their mouths, or vibrating their gills against the sides of the head. Such communications give warnings, scare off enemies, show pleasure and anger, and are mating signals.

The sounds have been described as varying from a noise like a soft-shoe dance on a sandy floor, a saw cutting metal, lumps of coal rattling down a chute, and an engine stalling. Haddock produce sounds that are either repetitive knocking sounds or short volleys heard as grunts. Cod make short grunting sounds of a higher intensity than those of haddock. Gurnards produce knocking sounds and growing noises. The total range of sounds produced by other fish is very wide.

The equipment used to pick up sounds from fish is complicated and extremely difficult to use. A sensitive sound detector is a calibrated hydrophone that was specifically designed for this use. Along with the associated pre-amplifier and amplifier, the detector is lowered into the water for working at considerable depths. Recording is done with a tape recorder and a frequency analyzer; an oscilloscope is used for acoustic analyses.

The various echo-sounding devices in use for fish detection on fishing vessels all work on slightly different principles. In modern sonar systems, pulses of sound are sent out in different directions to build up a three-dimensional picture of the sea beneath and before the ship. Even with this equipment, it is difficult to identify the different species of fish shown on an echo sounder. There are, however, differences in the reflectivity or target strength of fish of different sizes and species. Work is being done to improve present techniques in distinguishing between the different types of echo. Research recordings of fish voices at depths from the surface to over 2 miles are being made. This research might make it practical for fishermen to seek shoals of fish and to learn the identity of those species of commercial value.

## REACTION OF HERRING TO FISHING GEAR REVEALED BY ECHO SOUNDING 111

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For successful midwater trawling, the behaviour of the fish towards the gear is of particularly great importance because fish have a better chance to evade midwater trawls than, for instance, bottom trawl gear. Fish behaviour studies are therefore of great value for the improvement of midwater trawling. All the different means of observing fish behaviour, such as diving, television, filming of actual conditions, or aquarium experiments, have their advantages and disadvantages. For the present studies which were made along with German midwater trawling trials in recent years, the echo soundings taken by the trawler's echo sounder and the "netzsonde" were utilized. The "netzsonde" is a recording echo sounder on board the trawler, connected by cable to a transducer mounted on the headline section of the trawlnet. By sounding vertically downwards, the "netzsonde" records the distance of the net from the sea bottom, the opening height of the net mouth and fish in and below the net opening. It was found that herring (Clupea harengus) is easier to catch when spawning because it then occurs in dense schools and it does not react strongly to the gear. Otherwise, the herring is much more active and may evade midwater trawls, particularly when dispersed. Relatively small one boat midwater trawls have therefore been reasonably successful in catching spawning herring on some occasions, although much inferior to the larger two-boat midwater trawls for catching non-spawning herring. Since such active herring usually keeps at several metres distance from lines and netting in the netmouth, the difference in the size of the "effective net opening" is even more pronounced, and this is to the disadvantage of smaller nets. Sprat (Clupea sprattus), which otherwise showed similar schooling and migration patterns, proved to be much easier to catch than herring. Mackerel (Scomber scombrus) reacts to midwater trawls in a way similar to non-spawning herring. Dogfish (Acanthias vulgaris) does not seem to react to midwater trawls at all.

## ECHO-DETECTION OF TUNA [119]

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To fish for tuna scientifically, one must know tuna behaviour, swimming depth, speed and school density. Many methods have been used to gather these data, but have not offered sufficient conclusive evidence. In this paper, the author proposes use of an echo sounder. After many experiments, it has been established that an echo sounder can effectively detect tuna schools and contribute to tuna fishing. First, the author discusses the properties of an echo sounder able to detect tuna at a depth of 200 m, and concludes that the instrument must have a sounding depth of bottom of more than 3,000 m to operate efficiently. Secondly, data are mentioned on swimming depth, speed and school density, procured by echo sounders in the seas around Japan and in the South Pacific Ocean. These data establish that the swimming depth depends on the degree of illumination of the sky. The relationship between the shape of the banks in the grounds and the distribution of tuna is also explained. Finally, some examples of swimming speed and density of school are mentioned.

## ECHO-SOUNDER MEASUREMENT OF TUNA LONGLINE DEPTH [95]

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Efficient tuna longline operation requires a thorough knowledge of the behaviour of tuna and the ability to gauge the depth at which the hooks operate. The depth of individual parts of a longline can be obtained by pressure gauge

recording, but this does not enable the operator to form a clear idea of the shape of the longline as a whole.

The authors compared the echo-sounder recordings of longlines in operation with the data simultaneously obtained by pressure gauges and ascertained that a true configuration of the shape of the longline can be obtained by high-frequency echo sounding. Three types of echo sounder were used having frequencies of 28 kc, 50 kc and 200 kc. All parts of the gear were clearly recognizable on the records, as well as the difference in shape due to the use of different material in longline construction. The experiment further showed that a high frequency (200 kc) gives much better recordings than low frequency (28 kc).

## STUDY OF ACOUSTICAL CHARACTERISTICS OF FISH[133]

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For designing hydro-acoustical instruments useful for commercial fisheries, as well as for surveys aimed at assessing fish populations, more information is required regarding the attenuation of the strength of signals between emission and reception of the echo. The Research Institute of Marine Fisheries and Oceanography of the USSR has conducted a study of the acoustic characteristics of fish and fish schools, and this paper gives in some detail the method of approach to the problem, the mathematical treatment and some of the results obtained. It is stated that while the individual echo signals of a school of fish are strengthened by reflections from the fish, the total echo strength is nevertheless attenuated by absorption of the ultrasonic energy by the fish bodies. The formulae expressing the attenuation of the echo signals are provided. The reflection capacity differs of course between fishes and depends not only on the form of the fish body but also on the presence, or absence, of a swim bladder. The author found that the coefficient of reflection depends on the frequency of the ultrasonic sound. The investigations showed that the intensity of the echo signal is proportional to the pulse length so that echo signals returned by fish schools were not only increased in amplitude but also prolonged. This results in records of fish schools being over-estimated in the vertical direction and may even some time show an extension to beyond the bottom line. A diagram based on acoustical measurement during the investigations shows that the coefficient of attentuation of the echo signal increases with an increasing concentration of fish. A considerable part of the energy of a sonic wave reaching the fish school is scattered so that only a small part of the energy transmitted returns to the receiver. This loss of propagation increases with the frequency.

## SECTOR-SCANNING SONAR FOR FISHERIES PURPOSES [160]

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Research at the Electrical Engineering Department of the University of Birmingham has led to the development of electronic sector-scanning sonar systems which can be valuable in fisheries work. Early experiments at sea demonstrated that such a system was very effective in delineating schools of fish either ahead of the ship or below it. The latest development in the equipment itself, its performance (particularly with respect to angular resolution), and its manner of use have led to the possibility of the accurate detection and location of fish very near to the sea bottom. Moreover, the receiving part of the equipment has been developed in a universal form which can be used with any acoustic frequency within a wide range, and thus without difficulty and with great saving of cost can provide a general-purpose sonar suitable for high resolution at short ranges or lower resolution at longer ranges, using different transducers but the same electronic system. It seems clear that the equipment is now ready for commercial exploitation in fisheries.