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Methods of Direct Calculation of Fish Concentrations by means of Hydroacoustic Apparatus

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Every method is in the long run determined by a complex of means and facilities available at the disposal of the investigator. New technical means of research provide a possibility of working out the new methods. Hydroacoustic fish detection techniques is one of them. At present, various countries with developed oceanic fisheries have designed perfect hydrolocation gears of high resolving power which provide a dependable means of fish detection at any depths open to fisheries.

Since 1957, the authors have been engaged in designing a hydroacoustic method of determining the numbers of fish in both dense and dispersed concentrations.

Since 1961, this method has been formally adopted for assessment of stock condition of the Atlanto-Scandian herring.

The hydroacoustic method of determining numerical strength of fish is a method of direct calculation of the number of fish in the shoal and it is largely free from the defects of other earlier methods of direct calculation of numerical strength. Earlier methods had one big disadvantage: for determining the abundance of any stock of commercially important fish, data were used that only indirectly characterized the quantitative composition of a given stock.

Accuracy of such methods depends on a great number of factors which very often cannot be quantitatively assessed. The hydroacoustic method of determining fish abundance is a direct method of allowing information to be obtained on the numerical strength of fish in a given area of the sea by means of hydrolocators and electronic apparatus.

Commercially important fishes are known to form concentrations of different density. The range of density varies widely: from one specimen per hudreds and thousands of cubic meters of water to a score or two in one cubic meter.

Pelagic fishes as a rule form denser concentrations than bottom fishes. It was generally observed that the density of a fish concentration is inversely proportional to the size of the specimens making up the concentration. It is also known that the density of concentration of the various species of commercially important fishes depends on the season. Thus, spawning shoals are almost always denser than feeding shoals, etc.

When dense local concentrations are formed on the spawning or wintering grounds, the same number of specimens may become rather evenly distributed over a very great area of sea during the feeding period.

In this connection all echograms can be divided into two categories:

a) echograms of scattered concentrations which permit visual calculation of the number of fish within the range of operation of the echo sounder (Fig. 1);

b) echograms of dense concentrations which do not permit visual calculation of the number of fish within the range of operation of the echo sounder, although, in this case, the echo traces also provide some information on the number of objects of dispersion, i. e. fish (Fig. 2).

Numerous commercially important species assemble in certain areas of the sea during certain periods in their lifetime and their concentrations may be patterned accurately enough by means of hydrolocators, i. e. it becomes possible to calculate the number of fish in the shoal, by assessing their size and density by means of echometric surveys.

Depending on the density of concentration of various species of commercial fish, the authors used different methods of echo surveying either for dense or for scattered concentration.

A short description of such methods is given below.

Method of determination of the number of fish in scattered concentrations

Systematic observations with the application of hydroacoustic and underwater apparatuses showed that bottom fish rising off the bottom scattered making favourable conditions for calculating the number of fish. During this period, the density of fish is so low that a usual fish detection echo sounder can record individual specimens.

Sometimes, when a denser shoal is found in a scattered concentration (Fig. 3), it is necessary to apply a high-frequency echo sounder, the working frequency of which is from 150-200 kc/sec.

There are four stages in the method of calculation of the number of fish in dispersed concentrations:

The first stage

Preliminary echo sounding is conducted to determine the range of operation of the echo sounder and its resolving power by distance and angle, as well as for ascertaining the area of stock distribution. Control trawlings are conducted during the day and night time to determine the number of fish keeping off the bottom and the size composition of fish under investigation.

It is known that individual specimens are recorded on a ribbon as special signs (hyperbola). This is due to the fact that every echo sounder has its own direction, and when the vessel moves the ultrasonic rays strike the fish from different distances.

Analysing the results of recordings of individual specimens of fish, it is possible to determine "the area of action", i. e. the area similar to the direction chart of the transceiver system, but unlike the latter, it showed the area under the vessel's keel, which is controlled by the echo sounder.

The area of action of the apparatus in its longitudinal plane is determined by analysing the records of individual specimens. Then, data received are converted in order to determine the elements of the area of action in its diametral plane. This is done by means of a conversion factor obtained for different kinds of echosounders. The area of action for a given echo sounder and an object investigated is calculated and plotted on a chart (Fig. 4; Kiseljev, Truskanov, Scherbino 1962).

Resolving power of the apparatus is mainly characterized by the duration of the impulse and is calculated by a formula as follows:

$$\delta = \frac{c\tau}{2}$$

where S - is a resolving power in meters

τ - duration of the impulse in seconds

c - velocity of sound in water is 1500 m/sec

The knowledge of the resolving power is required to judge the possibility of recording separate objects in a vertical plane.

The area of action and the resolving power should be determined by all vessels engaged in echo surveying.

The second stage

During the main echo survey, a recording of the whole concentration is made by means of the echo sounders installed on board the vessels.. (It is advisable to have two echo sounders, one with a working frequency from 25-30 kc/sec, the other from 150-200 kc/sec). The area of distribution of each shoal is ascertained by means of a grid of tracks covering the location of the shoal, and each track is intermitted 5-7 minutes after the termination of the recording of fish by the echo sounder. All tracks are recorded by each vessel on a detailed chart-board with special mark at the beginning and the end of recorded tracks. By combining all the points of the beginning and the end of the recording, we get patterns of the shoal. The area of the concentration is ascertained on the chart-board by means of a planimeter.

The third stage

The echograms obtained are then treated and analysed. Diametral extent of the range of operation of the echo sounder in deep waters near the upper and lower edges of concentration, the course run by the vessel, and the number of specimens of fish per unit of the course traced by the echo sounder, which were taken from the diagram of the area of operation of the echo sounder, all this makes it possible to determine the density of concentration by the formula:

$\rho = \dfrac{N}{U}$ number of fish/m^3, where

ρ - density of fish in some areas of concentration in number/m^3.

U - volume of water (m^3) with fish examined by the echo sounder

N - number of fish.

Volume of water with fish, in turn, may be calculated as follows:

$V = t.H \left(\dfrac{D_1 + D_2}{2}\right)$, where

υ - speed of the vessel in m/sec.

t - time in sec.

D_1, D_2 - size of the area of action in diametral plane of the vessel at the upper and lower edges of concentration

H - thickness of concentration (vertical range) in meters

It is desirable to determine the density for each mile of course. When these densities do not differ from each other, the intervals between the echo surveys can be longer (up to 2 minutes) with the speed of the vessel being from 6 to 8 knots.

Values of density which are obtained are then plotted on a chart (Fig. 5). There are areas of equal density. The size and volume of the areas are determined. From the data on density obtained for some parts of concentration and on volume for each area, one can determine the number of fish in a shoal by the following formula:

$$N_{total} = \sum U\rho = U_1\rho_1 + U_2\rho_2 + \dots + U_n\rho_n$$

where $U_1, U_2, \dots U_n$ - the volumes of areas of different density

$\rho_1, \rho_2, \dots \rho_n$ - density of areas

The fourth stage

The analysis of errors is then made. When the fish are partially keeping near the bottom, the calculations must be corrected for an obscuring effect of the bottom. If the ground is very rough and most of the specimens of a scattered concentration are keeping close to the bottom, it is necessary to resort to some special measures, e.g. to use different types of echo sounder selectors of bottom traces: "the white line", "differential chain", "fish filtre" types etc.

This is greatly assisted by an electronic fish-tracer, which allows us to distinguish fish from the bottom and to record a quantitative estimation of the specimens.

The echo survey, conducted in the inshore area of the Barents Sea, in August 1962, can serve as an example. This echo survey was made in two stages. During the first stage, the area of work was investigated, the area of fish distribution was ascertained, control trawlings and experimental work such as underwater observations for determining the relation between the incoming signal and the number of haddock were conducted. Observations were made at depths from 100-180 m. Control trawlings showed that haddock about 30-35 cm were in this area. The second stage of the echo survey was aimed at determining the number of haddock in a limited area between the Islands, Bolshoy Oleny and Harlov. A total of 27 tracks were made over an area about 143.8 sq. miles in size and 32 miles in extent.

Observations were made using the hydrolocator "Lodar" working within a range of action of the echo sounder (working frequency up to 20 kc/sec), using the echo sounders "Atlas-658" (working frequency up to 30 kc/sec) and "F-805" (working frequency up to 200 kc/sec).

From the data obtained, it was found that there were 72.95×10^3 fish in the shoal. The area of 143.8 sq. miles may be divided into several zones of different density. Thus, the first zone (the zone of the least density) was 74.5 sq. miles, the extent of the second zone 53.2 sq. miles, that of the third zone 9.4 sq. miles. The density of fish in these zones was 0.8×10^{-5}, 1.6×10^{-5}, 3.8×10^{-5}, 26.8×10^{-5} specimens/m^3 respectively.

High frequency echo sounder recorded individual specimens in the shoal. Density was 40.0×10^{-5} to 60.0×10^{-5} specimens/m^3.

The electronic fish-tracer helped to give better records of specimens keeping near the bottom and to estimate the near-bottom concentration.

The method of determination of the numerical strength of scattered concentrations was tested in different parts of the Barents Sea. Surveys were conducted on concentrations which due to vertical migrations were scattered throughout the depth of the water. As a result of ten echo surveys, the numerical strength of separate local concentrations was defined. For instance, the concentration in shallow waters near Murmansk area numbered about 200,000 specimens of average-sized cod that were keeping in the near-bottom layer. The density was 3.2×10^{-5} specimens/m^3. The distance between specimens was 25-30 m.

Table I gives the data obtained during the surveys.

Table I.

N	Investigated specimen	Density of fish specimens/m^3 minimum	maximum	Number of fish in local concentrations (in specimens)
1.	Small-size cod, shallow waters, Murmansk area	0.20×10^{-5}	4×10^{-5}	39,100
2.	Small-size haddock, inshore area	0.60×10^{-5}	50×10^{-5}	72,950
3.	Average-size cod Rybatchya Bank	0.2×10^{-5}	3.3×10^{-5}	102,300
4.	Average-size cod, shallow waters, Murmansk area	0.2×10^{-5}	3.2×10^{-5}	200,000
5.	Large cod, Finmarken Bank	0.08×10^{-5}	1.2×10^{-5}	307,800
6.	Large redfish, Rybatchya Bank	0.8×10^{-5}	5.5×10^{-5}	500,000

Method of determination of the numerical strength of dense concentrations

As a rule, pre-spawning and spawning shoals of pelagic fish form quite compact concentrations in a small area in comparison with the area occupied by the schools of these fish during the other periods of their life. Such peculiarities in behaviour of pelagic fish is the main factor in determining the method, which can be used to calculate the numerical strength of these concentrations by means of the echo surveying.

The method used in this survey includes five main stages:

First stage

A preliminary echo survey covering the area larger than that occupied by concentrations of fish was conducted by some vessels. Based on the results of this survey, it is possible to define the area of concentration and the sizes of fish schools most characteristic for this period. At the same time a hydrographic survey of the investigated area is made from one of the vessels. The geometrical range of the hydrolocator apparatus may be calculated from hydrological data on the area surveyed. From the least size of the school, the energetic distance and turning angle of the vibrator can be determined.

Knowing these two values, one can determine the actual distance of the echo ranging of the schools.

From the size of the sea area occupied by a school, and from the given actual distance of the echo ranging, it is possible to calculate the required frequency of the echo tracks and the number of vessels needed for the survey.

The character of the schools and their depth serve as the factors determining the working range and the optimum coefficient of the amplification of the echo sounder.

Second stage

The main echo survey of fish concentration is conducted in as short a period as possible; otherwise, changes in distribution of separate schools within the main concentration may take place during the survey. This is extremely undesirable.

Vessels conducting the main survey should be equipped with the following apparatus:

a) hydrolocator apparatus intended for determining the school in depth as well as horizontal range;

b) echo sounder for obtaining vertical sections of located schools and for determining their depth and density;

c) navigation equipment;

d) radar for additional orientation to take tracks and drawing radiolocation charts of position of fishing vessels in relation to the distribution of shoal;

e) automatic submarine camera or deep-water gear for observing the fish (hydrostate, submarine boat etc.).

This survey requires a higher degree of navigational skill in order to gain the greatest accuracy from this method. That is why a receiver type "Loran" or "Decca" is also desirable.

When the main survey is carried out, a detailed chart-board with a grid of tracks is drawn up by each vessel, where all the shoals and their sizes, obtained by means of the hydrolocator and the echo sounder, are recorded. The horizontal range of each shoal is determined by means of hydrolocator, the number of tracks is considerably reduced, and thus, the number of vessels participating in the surveys. It is, therefore, possible to survey a zone of 3000-4000 m in width along the course of a vessel.

When a chart-board is drawn, the time serves as the main synchronous criterion. The size of separate schools, as well as total size of the concentration, are determined by means of the chart-board, and the vertical sizes of the concentration are determined from records received by the echo sounder (Fig. 6).

Third stage

The density of schools, i.e. the number of fish per unit of volume, is determined. Since the accuracy of determination of the density of schools is of great importance, the authors worked out three different methods of determining the number of fish per unit of volume, which supplement and define each other.

The first method of determination of the absolute density is based on the combined use of an automatic under-water camera and a ship's stationary echo sounder. By calculating the number of fish in one still photograph and having estimated in advance the volume of water, where specimens are recorded, one can calculate the density with sufficient degree of accuracy (Fig. 7).

In practice, it is done as follows: the underwater camera is lowered into the same layer occupied by schools of different density, and serves to measure the amount of re-echoing material from the shoal.

From the data so obtained the relation of the amplitude of the incoming echo received by the echo sounder amplifier to the amplitudes of the stock is determined.

The second method is based on placing the transceiver system on the ship's echo sounder directly in the concentration of fish. This greatly improves the angular discrimination of the echo sounder, owing to the lesser number of objects within the operational range in comparison with the method of operation from the surface.

In practice, this is done as follows: the vibrator of an additional echo sounder, in a special installation or without it, is lowered directly into the mass of a shoal in different layers. This allows us to apply the method used for dispersed concentrations and to determine the density.

Simultaneously with an additional echo sounder the ship's stationary echo sounder equipped with an electronic fish-tracer is operated. Their indices are used for determining the relation of the amplitude of the incoming echo received by an amplifier to the density of the concentration.

The third method is based on density determination by means of the echo sounder, calibrated in advance with standard equi- models that had been selected on the basis of experimental data and the data derived from calculations.

In this case the degree of dispersion, the area of reflecting surface and the coefficient of fish reflection are taken into account. In density determinations, especially during the first echometric surveys, it is advisable to use the data obtained by all three above-mentioned methods. These data are used for calculating the relation of the value of the incoming signal to the density of fish concentration by means of the following formula:

$$U_{inc.} = K\sqrt{\rho}$$

where $U_{inc.}$ = amplitude of the incoming echo received by the amplifier of the echo sounder.

ρ - density of fish concentration

K - coefficient, the value of which depends on concentration of the echo sounder and the aspect of the object of survey.

After determining the dependence of "$U_{inc.}$" and "ρ", it is possible to determine the density of the school, while taking tracks in every point of concentration.

Fourth stage

This stage includes the treatment of the data obtained with sufficient degree of accuracy. The detailed analysis of possible errors is made taking into account the accuracy of the angular echo ranging, errors in distance determination, errors made during the echo sounding and in determining the length of the school in following tracks by means of the echo sounder. Filling (?) coefficient is taken into account and errors during navigation are also taken into account.

The volume of each shoal located is calculated according to the size of shoals and their vertical range. Then a total volume of concentration is determined. The next stage is a precise treatment of the data obtained which is done along the following general line: horizontal and vertical sections of fish concentrations are plotted and the density values are entered after the corrections were made for navigation and instrumental errors. Then, zones of equal density are plotted and the size of each zone is calculated separately. Then the number of fish is determined first in each zone, then in the shoal, and, finally, in the concentration as a whole. Size and age compositions of the concentrations are obtained from control trawlings. Finally, the number of fish is converted into weight units. This is a general outline of the sequence of operations of the hydroacoustic method of calculation of stock abundance in dense concentrations.

It can be illustrated by a description of echo survey of the wintering shoal of Atlanto-Scandian herring in the area of the East Icelandic Current (to the south-east of Iceland) in December 1964, which was conducted by the authors from BMRT GOGOL.

The survey began at Lat. 64°57'N; Long. 10°40'W and moved southward during the night (2130 hours) of 9-10 December, 1964. A shoal was found 8 minutes after the vessel started to move. The size of this shoal was determined when the vessel moved along it. Its density was the greatest and at different points amounted to 5 specimens/m^3. Its size was 17.76×10^6 sq. metres and its volume was 3.53×10^9 m^3. Then, the second shoal was found and examined. As a result of the following twelve tracks, 8 more shoals were found and examined. This stage of work was followed by an hour passage, after that 4 more shoals were investigated. A great shoal was also found farther to the south and investigated by making 5 tracks. The extent of the shoal from north to south was about 6 miles. The average density of the shoal was about 1.27 specimen/m^3, size of shoal was 42.5×10^6 sq. metres. A chart-board of the echo survey is given in Fig. 6.

The results of echo surveys of a wintering shoal of the Atlanto-Scandian herring during 1958, 1961-1964, conducted by the authors using the methods developed by them are given in Table II. The wintering stock represented the bulk of a spawning stock of this species.

Table II. Results of echo surveys of herring

N	Indices	1958 (31 Dec)	1961 (12-13 Dec)	1962 (18-19 Dec)	1963 (13-14 Dec)	1964 (9-10 Dec)
1.	Length of echo recording per unit of way (%)	85	53	50	32.5	80
2.	Average thickness of concentrations (m)	70	85	107	114	116
3.	Total size of concentration (km^2)	260	142	267.2	218.5	239.5
4.	Total volume of concentration (km^3)	18.5	15.5	21.3	20.5	23.7
5.	Density (specimens in 1000 m^3)	950	450	680	785	1166
6.	Total stock of herring in millions of specimens	17,575	6,975	14,485	16,092	27,640
7.	Average weight of one specimen (gr)	344	359	196.5	202	246
8.	Total stock of herring (thousands of centners)[x]	60110	25040	28475	32565	67995

[x] Estimation of the total stock was made by summarizing the number of fish in each shoal in accordance with the method described. Values of thickness, size and volume of the total shoal, which are given in the table, characterize the total stock in the different years.

Conclusions

In conclusion it is necessary to dwell in more detail on the possibilities and prospects of this method. While the other methods of direct determination of numerical strength are based on the theory of random sampling and are limited by the number of samples (possible number of experimental trawlings or purse seine hauls), the number of samples in the hydroacoustic method is very great (a few score per minute), because every impulse of the echo sounder is, in a sense, a sample by itself. While, in determining the density of a concentration by means of experimental trawlings, the result may depend on a large number of factors, e. g. on the selection of the area of fishing, on the design and catching capacity of fishing gears, which, often, are not calculated, in our case, it is possible to determine quite accurately the density and the limits of each concentration throughout the area occupied by the concentration. Based on the result of this work, it seems possible to determine the numerical strength of any concentration with no less degree of accuracy than 10-15%, if the number of vessels available is sufficient and, if the echo survey is made thoroughly enough.

As this method requires the synchronous survey, increase in the duration of the survey may result in errors that cannot be taken into account. The survey must be completed within one or two days.

The method does not require too much effort except for a rather complicated process of treatment of the data obtained. The process of collection and treatment of material in echo surveying has now been automized by the authors. A method of automation of the surveying of dispersed concentrations is also being developed.

The experimental echo surveying in the Barents and Norwegian Seas showed that this method can be successfully applied in determining the numerical strength of a number of pelagic and bottom fishes in different fishery basins. In particular, it is possible to determine the numerical strength of herring or silver hake on Georges Bank in pre-spawning and spawning periods. The abundance of pre-spawning cod concentrations remaining in the pelagic layers in 200-400 m depths off Southwest Greenland from March-May can be calculated.

It is also possible to calculate the numerical strength of pre-spawning cod concentrations in 300-500 m off North Labrador.

Introduction of hydroacoustic methods of calculation of commercial fish stocks can improve long-term and short-term forecasts of fish resources.

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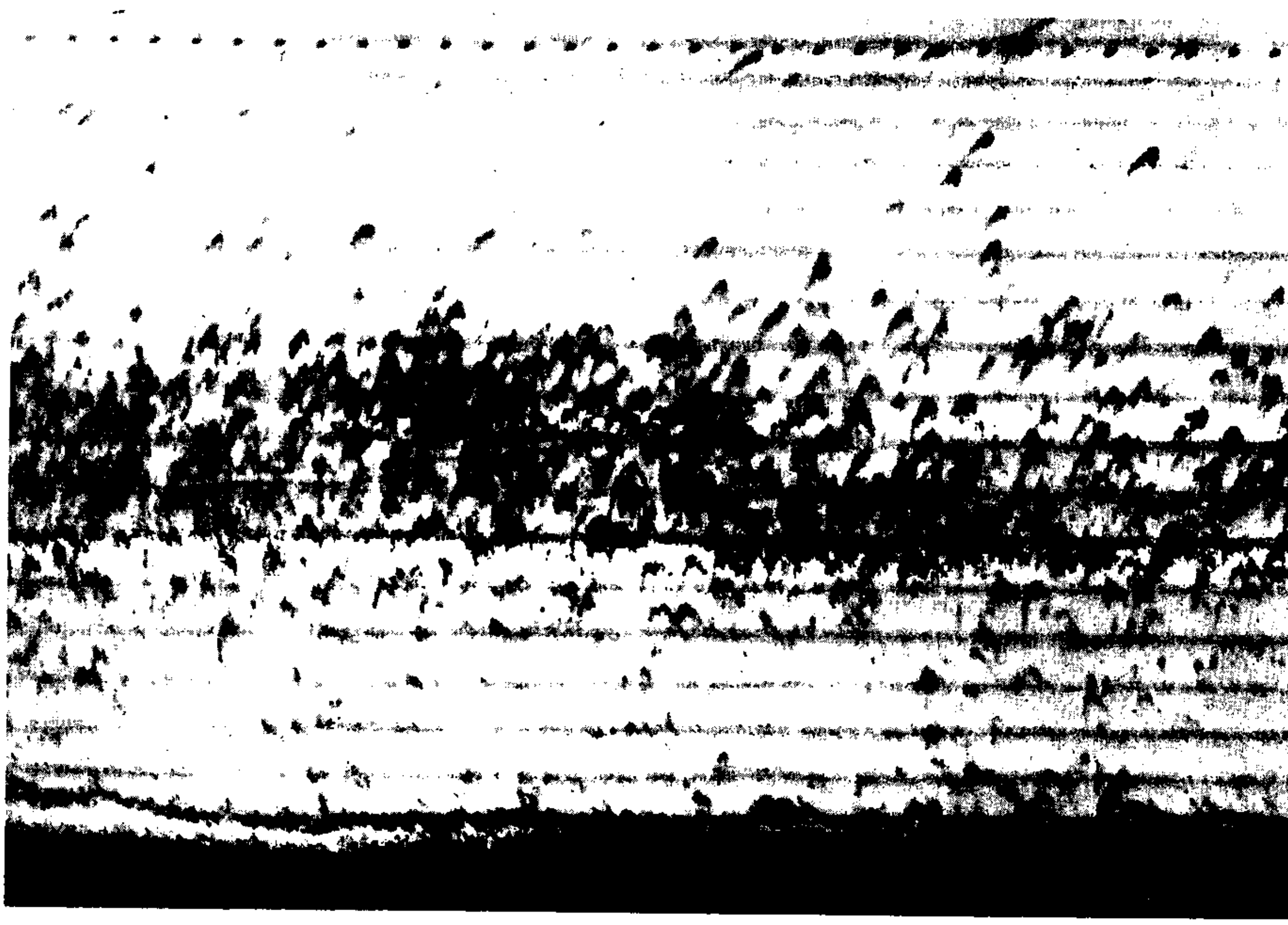

Fig. 1. Typical echotrace of dispersed cod concentrations.

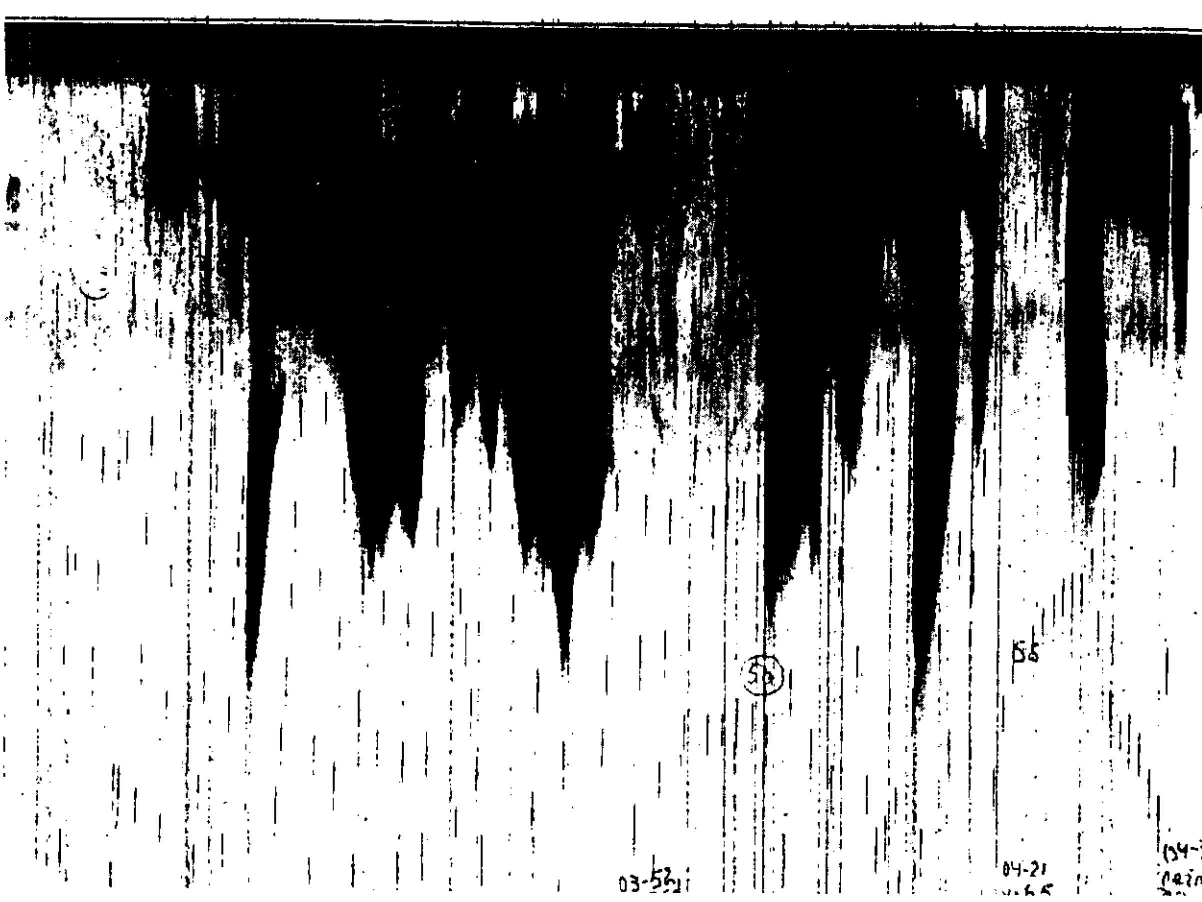

Fig. 2. Typical echotrace of dense concentrations of herring.

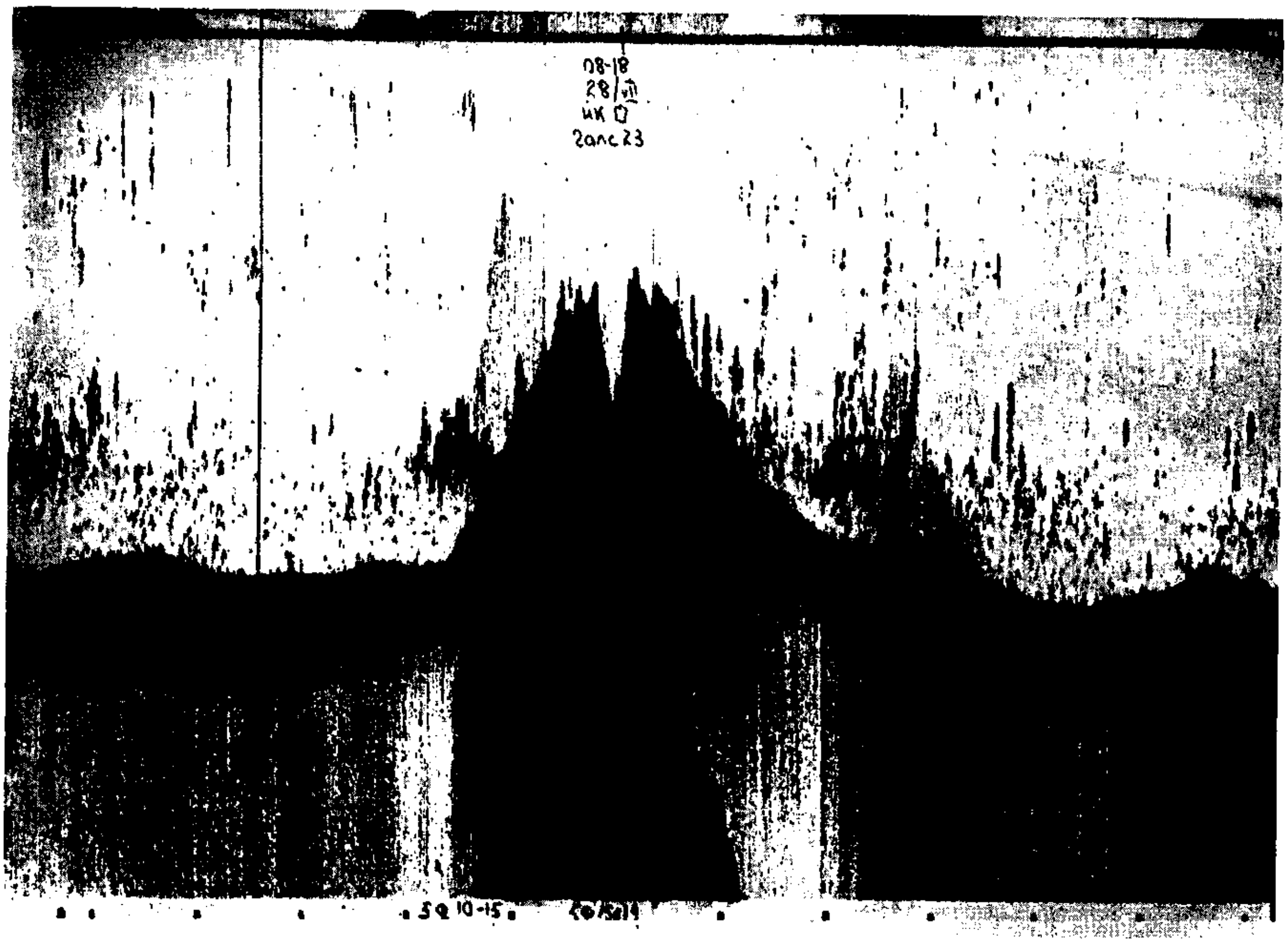

Fig. 3. Dense shoals in dispersed concentration.

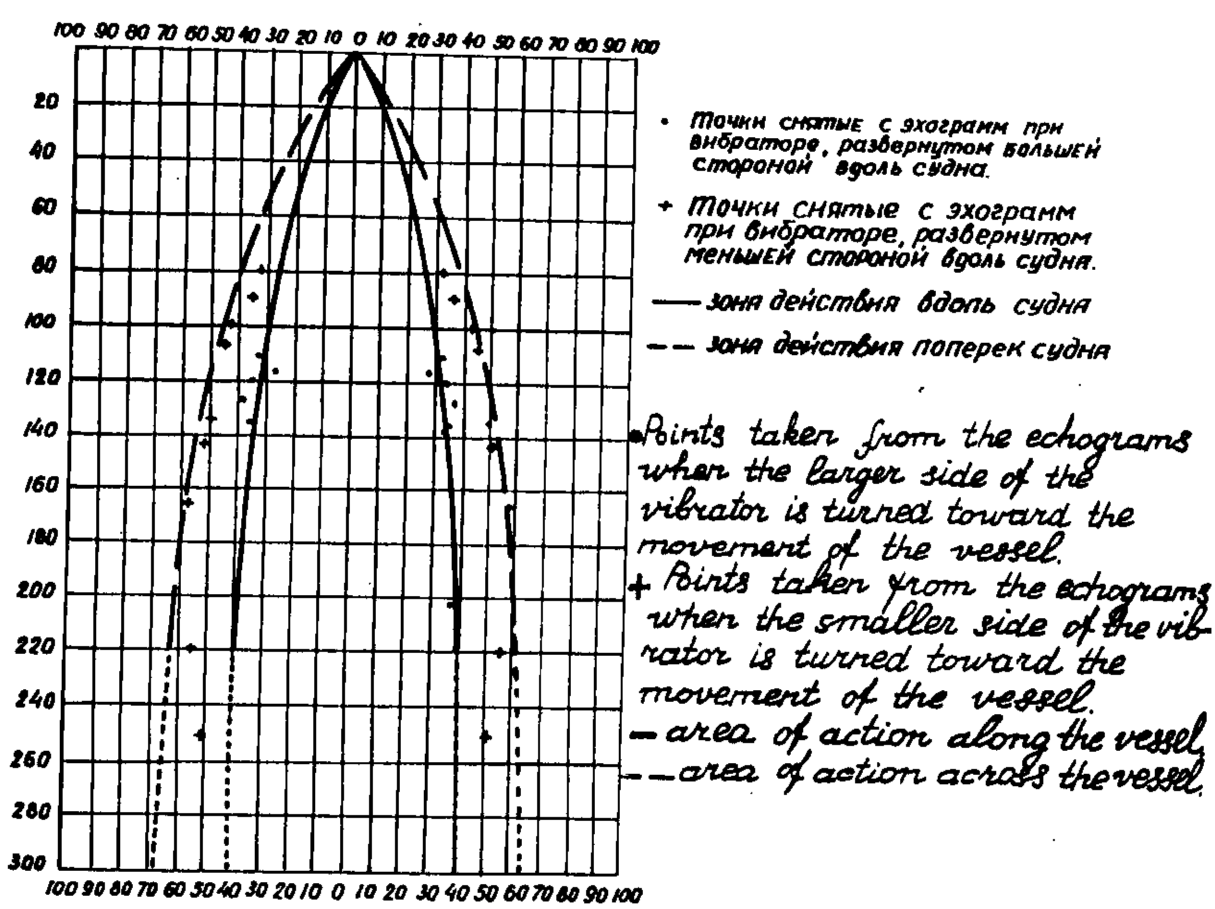

Fig. 4. Range of action of the hydrolocytor " Paltus ".

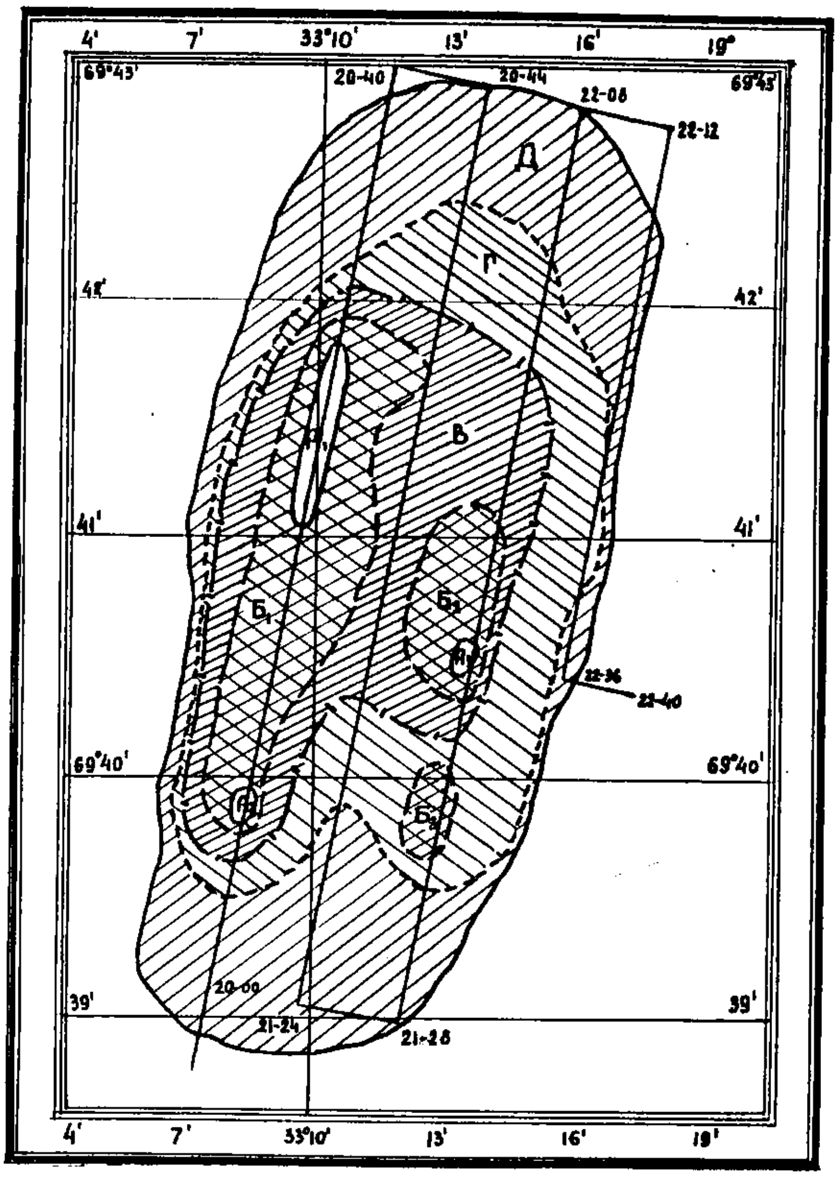

Fig. 5. Chart board of dispersed concentrations.

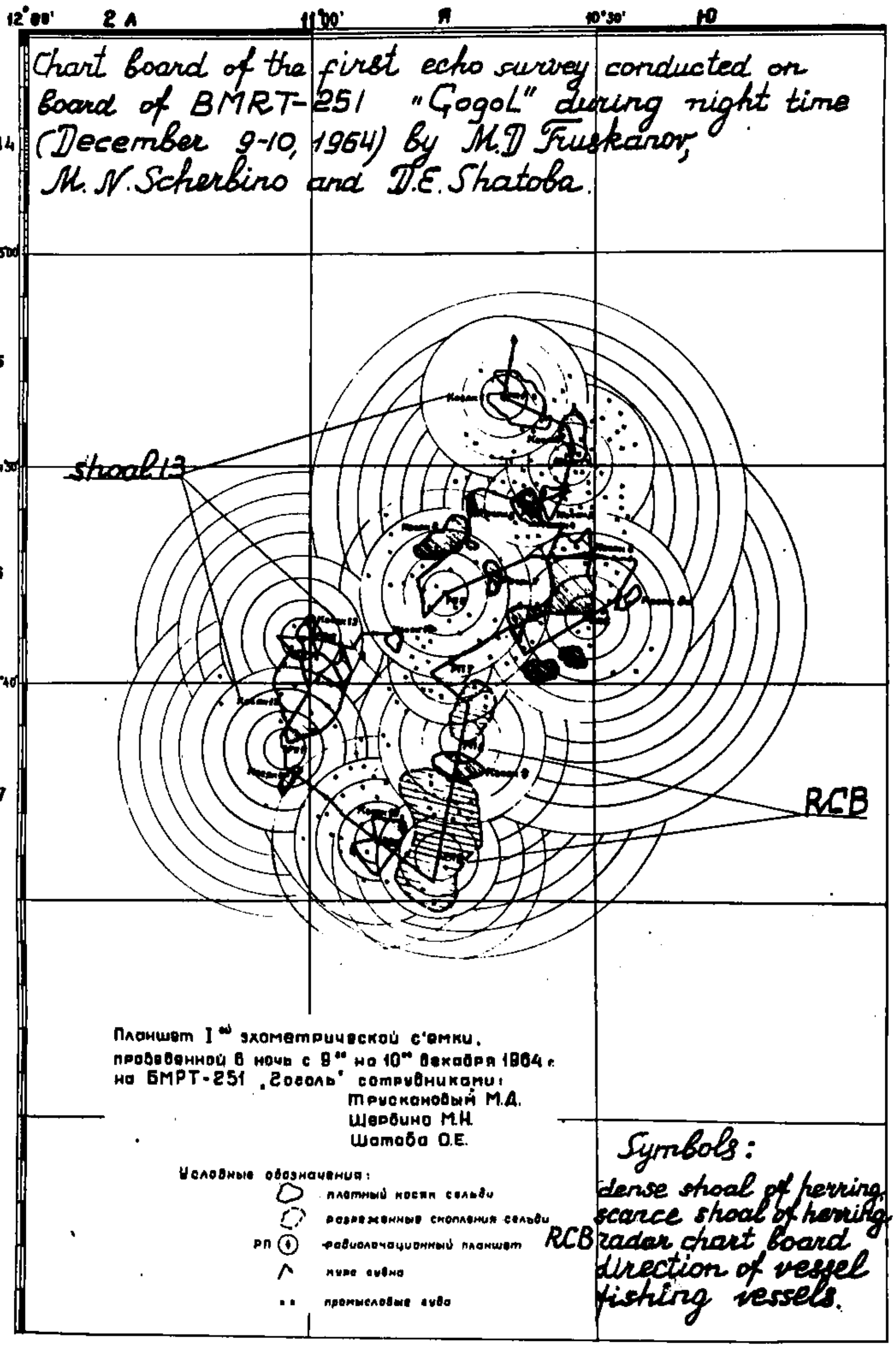

Fig. 6. Chart board of dense concentrations.

Fig. 7. Underwater photo of herring.