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Measurements of Sardine Schools by Hydroacoustic Apparatus

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ABSTRACT. A method of measuring the geometrical parameters of fish schools and their density, using hydroacoustic apparatus is presented, as are the results of measurements of these parameters for sardine schools along the coast of N. W. Africa.

Introduction

To elaborate effective methods to evaluate the abundance of fish stocks, it is first necessary to know something about fish habits and the character of concentrations formes. This refers in particular, to pelagic schooling fish. So far, methods have been worked out for the evaluation of fish inhabiting the near bottom layers /Cushing 1968. Dowd 1967, Elminowicz 1974, Burczyński and Wrzesiński 1974/ and pelagic fish /Craig and Forbes 1969, Dragesund 1970, Smith 1970, Johannesson and Losse 1973, Burczyński et al. 1973/. The methods of evaluating stocks of pelagic fish concentrated in schools, require further improvement. The difficulties which arise when working out such a method result from the variety of parameters of schools formed by different species of fish, and their continuous changes, not to mention the many factors upon which these depend.

Thus, to elaborate an effective method of evaluation of pelagic fish stocks using hydroacoustic apparatus, the parameters of schools, as well as the character and extent of changes, should first be measured, after which the most suitable apparatus and evaluation method should be chosen.

Measurements of the size of fish schools for the purpose of stock assessment were carried out for the first time in Poland, on the m.t. "Kantar" /Elminowicz 1975/. Density of fish in schools had been evaluated from control hauls, which gave rise to certain reservations. Aimed trawling and the catch capacity of the trawl are essential factors in the estimation of fish school densities. The shortcomings in the methods applied on the m.t. "Kantar" resulted in the adoption of another method of evaluating stocks of schooling fish, eliminating the trawl as an instrument used to estimate the density of fish in schools.

The methods of evaluating this density presented here, is based on measurements carried out by means of hydroacoustic appliances, in particular, the geometrical parameters of fish schools, using a fish concentration counter /Elminowicz 1970/ and an integrator to estimate the density of fish in the schools /Lozow and Suomala 1971, Stepnowski 1974/.

This methods was adopted to measure fish schools during the III scientific survey cruise by the "Profesor Siedlecki". Measurements of 6,500 sardine schools were made in the N.W. African grounds between 25 April and 17 July, 1974.

Method of Measuring Parameters of Fish Schools

The parameters of fish schools include those of a geometrical character /length, height, volume, vertical section areas and depth/ and density of fish in the schools. Knowing the volume and density of fish in a school, the number of fish can be calculated, as can the total biomass - knowing the mean unit weight of fish. The abundance of a species investigated in a given region, can be evaluated on the basis of the biomass of fish in particular schools. During the r.v. "Profesor Siedlecki" III cruise, the following apparatus was used to measure the parameters of fish schools:

- EK-38 /38 kHz/ vertical echo sounder,
- QM-MKII echo integrator,
- 140A type oscilloscope with memory,
- fish concentration counter.

Fig. 1 gives a block diagram of the hydroacustic equipment connections.

The EK-38 echo sounder output signals are introduced to the QM-MKII echo integrator input for initial processing. This consists in the detection of signals, the elimination of noise and interference by means of a threshold system, followed by the choice of signals originating from the water layer sounded, i.e. from the fish schools observed. After this initial processing, the signals are passed to the next blocks of the QM-MKII echo integrator, the 140A type oscilloscope and fish concentration counter. The echo signals for each school are integrated separately and the maximum signal amplitude measured by the 140A type oscilloscope.

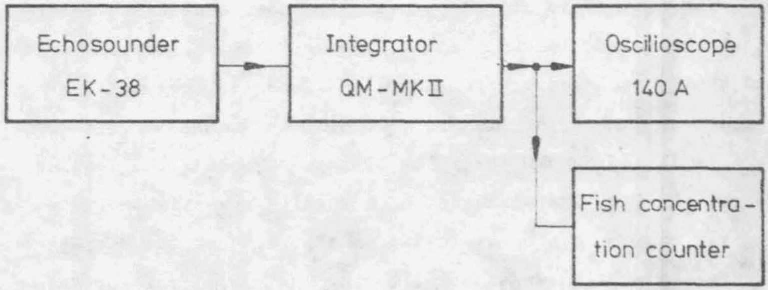

Fig.1. Block diagram of hydroacoustic equipment used to measure fish schools.

The vertical cross section area of the schools and their length along the ship's track are measured by the fish concentration counter.

The mean height of the school can be calculated from the vertical cross section area and length of school along the ship's track, and the volume from the shape of the school. The depth of the school is read from the EK-38 vertical echo sounder echogrammes.

The results of measurements carried out for each school seperately are entered into a special form.

Methods of Elaborating Results

The parameters of schools measured by this method are distorted. This is due to the operating principle of the widebeam acoustic equipment, including the EK-38 echo sounder. The effect echo sounder parameters have on the measurements of schools has been described by Olsen /1969/ and others. The elaboration of results consists in the calculation of the true parameters of schools from the measurements. The length, height and volume of schools are calculated from the formulae given by Elminowicz /1975/.

Calculation of the Density of Fish in Schools

Lozow and Suomala /1971/, Hamilton /1973/ and Stepnowski /1974/ give the following formula relating the target strength of volume scattering with that of single fish and density of fish schools.

$$TS_v = TS + 10 \log \rho \qquad /1/$$

where: TS_v = target strength of volume scattering /dB/,

TS = target strength of single fish /dB/,

ρ = density of fish school /fish/m^3/.

The formula /1/ is true when all the fish are of equal length. Where fish of different length occur, /different target strengths/, and the density of fish changes, the formula /1/ can be written as follows:

$$\overline{TS}_v = \overline{TS} + 10 \log \bar{\rho} \qquad /2/$$

In a certain range of fish densities, formula /2/ can also be applied for fish schools. Multiple reflections in schools can be omitted if the mean density of fish and their mean target strength satisfy the equation:

$$\bar{\rho} \cdot 10^{0.05\, TS} \leqslant \frac{\pi}{4\lambda^2}$$

This inequality is not always satisfied for the operating frequencies of the echo sounders, true lengths and density of fish.

Measurements of volume scattering target strength are carried out by the integration of echo signals of each school separately.

The mean value of volume scattering target strength can be expressed as follows:

$$TS_v = V_o - A + C \qquad /3/$$

where: TS_v = mean value of volume scattering target strength /dB/,

V_o = mean output signal value corresponding to the integrator indices for 1 nautical mile /dB/,

A = integrator amplification,

C = constant depending upon the echo sounder parameters and setting.

The constant C consists of C_1 and C_2, the latter covering corrections which should be introduced where the setting differs from the standard, and C_1 can be expressed by:

$$C_1 = - SL - VR + /20 \log r_o + 2\alpha r_o/ - 10 \log \frac{c\tau}{2} - 10 \log \psi \qquad /4/$$

where: C_1 = constant depending upon the echo sounder parameters /dB/,

SL = source level /dB//1 µbar at a distance of 1 m/,

VR = receiver response voltage /dB//1V ref. 1 µbar/,

r_o = maximum TVG range,

α = absorption coefficient /dB/m/,

c = speed of sound /m/s/,

τ = pulse length /s/,

ψ = equivalent width of beam /dB/.

A source level of SL= + 122.2 dB is attained for an EK-38 echo sounder transmitter with a 1/1 setting, a receiver response of VR = + 4.8 dB is attained for a receiver amplification with a setting of 0 dB, and the factor 20 log $r_0 + 2\alpha r_0$ equals + 64.5 dB. The value of $10 \log \frac{c\tau}{2}$ for τ = 0.6 ms is 3.5 dB. The rectangular transducer transmitter-receiver beam equivalent width expressed in dB relative to 1 steradian is obtained from:

$$10 \log \psi \cong 10 \log \frac{\lambda^2}{4\pi l_1 \; l_2} + 7.4 \qquad /5/$$

where: λ = wave length /cm./

l_1, l_2 = transducer size /cm./.

λ = 3.95 cm and $10 \log \psi = 10 \log \frac{15.5}{4 \cdot 3{,}14 \cdot 45 \cdot 48} + 7.4$

is obtained for the EK-38 echo sounder TR-3 transducer. Therefore:

$$10 \log \psi = -25 \text{ dB}$$

C_1 will be:

$C_1 = -122.2 - 4.8 + 64.5 + 3.5 + 25 = -34$ dB

As an amplifier amplification of 20 dB is applied, then C_2 = +19.5 dB.

Different integrator amplifications were applied during measurements /depending upon the density of fish concentrations/, but the integration result was normalised to 30 dB, but was ten times greater than the accepted normalisation.

Thus:

$$TS_v = V_o - 44.5 \qquad /6/$$

The value V_o was read from the graph given in the QM-MK II integrator instructions. In order to read the V_o, the integrator index for 1 nautical mile and the thickness of the layer containing the fish should be known.

To measure the mean value of volume scattering target strength of a school, the mean height of the school and mean value of the V_o signal should be calculated. For this purpose, a Fish Concentration Counter measuring the surface areas of vertical cross sections of schools and their length, was used. The mean height of a school is calculated from /7/:

$$\Delta\bar{h} = \frac{P}{B_s} \qquad /7/$$

where: $\Delta\bar{h}$ = mean height of school /m./,

P = vertical cross section surface area of a school /m^2/,

B_s = length of school /m./.

To determine the mean signal value from the graph /presented in the integrator instructions/, the integrator indices should be standardised to a width equal to 1 nautical mile. For this, we apply the formula:

$$I_1 = I_L \cdot \frac{1852}{B_s} \qquad /8/$$

where: I_1 = integrator indices standardised for a 1 mile section /mm/,

I_L = integrator indices for the school /mm/.

With a mean school thickness of B_s and I_E, the mean value of volume scattering target strength is calculated as for the layers.

To calculate fish density in schools using the formula /2/, the mean value of the target strength of single fish should be known. Measurement of target strength of single fish is by the method presented by Craig and Forbes /1969/ and Johannesson /1971/.

Prior to the commencement of measurements, the hydroacoustic apparatus was calibrated and the graph for direct read-out of target strength illustrated in Fig.2, was drawn up.

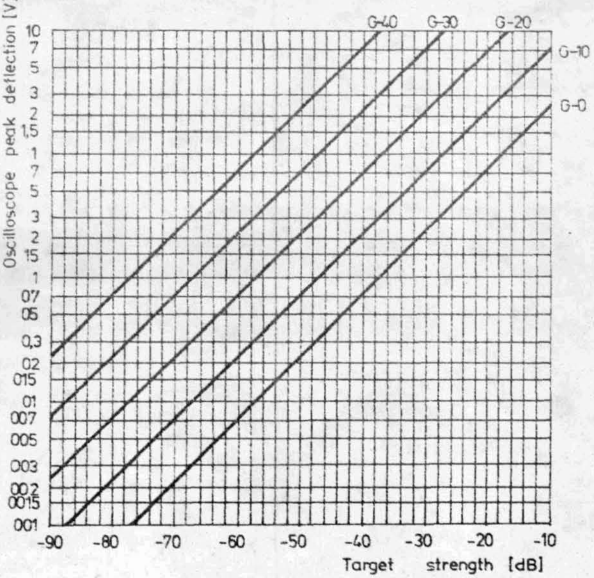

Fig.2. Diagram for the direct reading of target strength in the echo sounder-integrator-oscilloscope measuring system /for the EK-38 echo sounder and TR-3 transducer/.

The graph was drawn in the following manner: A test signal giving 0.3 V at the integrator "Signal" input and with an amplification of G = 20 dB, was fed from the generator to the EK-38 echo sounder input. This result was obtained for the type 20 log R TVG and integrator operation in a 2-metre layer at a depth of 18 m. A signal of 0.045 V was obtained at the EK-38 echo sounder output.

A target strength corresponding to 0.3 V can be calculated for the integrator "Signal" output as follows:

TS = -58 + 19.5 - 9.5 = -48 dB.

The graph in Fig. 2 is essential for the following data:

- transmitter 1/1 output,
- receiver amplification - 20 dB,
- TR-3 transducer,
- type 40 log R TVG
- 3-230 m range.

Other echo sounder settings necessitate corrections after the data listed in "Performance Measurement on Simrad Scientific Sounder EK-38".

During the cruise, measurements of geometrical parameters were carried out on about 6,500 sardine schools.

The true parameters of schools were calculated on the Elliott-905 computer installed on board the R.V. "Profesor Siedlecki", by means of the "PELAG" program. Table 1 gives an example of print-outs from this program. A print-out contains the following ordinal and general data introduced into the program:

Table 1

PARAMETRY LAWIC

DATA 20.05.74 GODZ $8^{00} - 9^{35}$
POZYCJA 24° 32′N 15° 46′

DANE OGOLNE:
PREDKOSC STATKU VST = 5.0
PREDKOSC REJESTRATORA VP = 0.4167
DLUGOSC IMPULSU TN = 0.6
NR OSTATNIEJ LAWICY N = 0
ILOSC LICZONYCH LAWIC K = 23

NR	L (MM)	HB (M)	HC (M)	TS (V)	TSL (DB)	GRUB (M)	DLUG (M)	OBJE1 (M3)	OBJE2 (M3)
1	2.0	17.0	5.0	0.40	-29.1	4.1	9.7	198.3	321.8
2	4.0	28.0	2.0	0.20	-30.8	1.0	21.3	248.4	403.1
3	10.0	20.0	8.0	0.80	-21.7	7.0	58.0	12359.8	20057.3
4	1.0	28.0	1.0	0.10	-36.9	0.1	3.5	0.4	0.7
5	45.0	20.0	10.0	1.20	-18.2	9.0	273.6	352592.4	572179.3
6	8.0	23.0	7.0	0.40	-26.5	6.0	45.7	6606.3	10720.6
7	10.0	21.0	2.0	0.40	-27.3	1.0	58.7	1890.9	3068.4
8	4.0	27.0	6.0	0.90	-18.1	5.0	19.9	1041.0	1689.4
9	1.0	30.0	1.0	0.10	-36.3	0.1	3.3	0.4	0.6
10	12.0	20.0	8.0	0.80	-21.7	7.0	70.4	18180.6	29503.0

Ordinal data

DATA - date,

GODZ - hour,

POZYCJA - position.

General data

VST - ship speed,

VP - recorder speed /echo sounder/,

TN - pulse length,

N - No. of last school,

K - No. of schools counted.

Data from measurements input to the computer are contained in the first five columns of Table 1 and denote:

NR - consecutive number of school,

L - school length /mm./,

HB - school depth /m./,

HC - school height /m./,

TS - maximum amplitude of school echo signal /V/.

The results of calculations are contained in columns six to nine and denote:

TSL - maximum value of "school target strength" /dB/,

GRUB- true height of school /m./,

DLUG- true length of school /m./,

OBJE1- school volume /m^3/,

OBJE2- true volume of school /m^3/.

A "SORT" program was compiled to find the dependencies between school parameters and the break-down of results into classes. Table 2 gives an example of print-out from this program. Data in the form of columns of parameters in between which dependencies will be calculated, are introduced to the computer. The following must be carried out for each cycle of calculations:

- the choice of two parameters between which dependencies are calculated,
- the choice of class break-down of these parameters,
- the choice of the number of parameter classes,
- the choice of the number of pairs of parameters read,
- the choice of a third parameter and range of occurrence

for which the two previously chosen parameters will be read.

The results of calculations comprise:

- correlation table,
- percentage table,
- table of the number of values in each class and their percentage share in the whole /for two parameters/,
- arithmetic mean of parameter values,
- variances,
- standard deviations,
- covariances,
- correlation coefficient,
- regression equation.

The calculation of single fish target strength scattering is by "TARGET" program. Table 3 gives an example of calculation print-outs from this program.

Table. 3.

TARGET STRENGHT CALCULATION

DATE:	14.06.74
SHEET NO:	
HAUL NO:	113/EL
LOG FROM - TO:	595 - 598
HOUR FROM - TO:	23.10
ECHOSOUNDER:	EK-38
TRANSDUCER NO:	3
LAYER FROM - TO:	7 - 28

TS	S	L	L-R	L-%
-43 -40	76	17.0	48.77	9.26
-40 -37	61	32.4	47.74	17.60
-37 -34	47	134.7	134.67	73.14

TS SREDNIE = -36.58

S - number of readings,
L - R - number of fish.

The "TARGET" program print-out contains such ordinal data as: date, No. of sheet, No. of haul, log, hour, type of echo sounder, No. of transducer and depth of integration layer, three-dB class, number of signals in these classes, number of fish of different target strengths, percentage share of fish of different target strengths and mean value of target strength.

Results achieved

Mean heights, lengths, vertical cross-section and density of sardine schools at different times of day were calculated by means of "PELAG" and "SORT" programs.

The results of calculations are givem as graphs in Figs. 3,4,5 and 6. The schools scattered between 21.00 and 04.00 hours, therefore no measurements of parameters were conducted for that period.

It can be seen from the data given in the graphs /Figs. 3,4,5 and 6/, that sardine schools attain maximum size /height, length of vertical section surface area and volume/ between 08.00 and 15.00 hours, the greatest mean height of about 3 m. occurring between 08.00 and 11.00 house, this same period also covering the greatest mean values for school length /about 18m/, vertical section area /24 m^2/ and volume /400 m^3/.

The changes in the volume of schools are very interesting. The mean volumes of schools change depending upon the time of day - Fig.6. They are small during the period from 04.00 to 08.00 hrs and are followed by a substantial increase. This would seem to indicate the initial formation of small schools which later fuse into larger ones. The mean volume of schools remains unchanged during the period between 08.00 and 15.00 hrs. It changes considerably between 15.00 and 19.00 hrs, which would seem to indicate a break-down into smaller schools which become scattered between 19.00 and 21.00 hrs., when the volume of schools increased somewhat as the result of the initial phase of the break-down process of schools into scattered layers still reckoned as schools.

The ratio of integrator indices to vertical section area of the school $/\frac{I_B}{P}/$ may indicate the density of fish in the school as a whole. This index is given in Fig. 7.

The distribution of $\frac{I_B}{P}$ at different times of the day changes considerably. The greatest percentage of high density schools is between 08.00 and 11.00 hrs., that of low density schools - from 19.00 to 21.00 hrs., the mean density of schools forming between 04.00 and 08.00 hrs. being relatively low. Between 08.00 and 11.00 hrs. the density of schools remains stable, decreasing later. There is a further drop between 15.00 and 19.00 hrs., followed by scattering.

Density of fish in schools

In order to calculate the density of fish in the schools /formula 1/, measurements of the target strength of volume scattering were carried out by recording the integrator indices for each school and vertical section area, as well as all integrator and echo sounder settings. Konwing the thickness of schools and integrator indices, the value of the target strength of volume scattering was calculated for each school in the same way as for the layers. The results of measurements of target strength of volume scattering for particular times of day are given in Fig.9, and changes in the mean value of target strength for volume scattering /$\overline{TS}_v$/ during the day - in Fig.8. The mean value of the target strength of sardines - 39.5 dB - was determined from measurements of the target strength of single fish. Konwing the values of the target strength of volume scattering for each school and the mean value of target strength for single fish /sardines/, the density of fish in schools was calculated from formula 1. The results of these calculations is presented in the form of distribution tables of schools with different fish densities at different times of day /Fig.10/.

Table 2a.

PROGRAM SORTOWANIA LAWIC /SORT/

```
WYBOR 2 PARAMETROW OD 1  DO 12:   4   9
PRZEDZIALY KLAS PARAMETROW:       0.6  250
ILOSC KLAS YMAX=12  XMAX=20:      12   20
ILOSC CZYTANYCH PAR PARAMETROW:   861
WYBOR TRZECIEGO PARAMETRU:        1
PRZEDZIAL PARA3 OD....DO....      1    900
```

TABLICA KORELACYJNA /correlation table/

OS POZIOMA Y= 12
4 =GRUBOSC LAWICY
OS PIONOWA X= 20
9 =IAM

60	25	0	7	1	2	4	0	0	0	0	0
33	38	2	12	2	3	4	0	0	0	0	3
5	24	1	5	1	3	2	0	0	0	0	3
9	21	3	19	4	1	4	0	0	3	0	2
2	12	1	11	2	2	4	0	0	1	0	0
3	14	1	10	2	1	5	0	0	1	0	2
2	3	1	6	1	1	5	0	1	0	0	1
6	2	0	11	1	3	7	0	0	0	0	2
0	0	0	3	3	3	2	0	1	0	0	3
0	1	0	0	1	2	5	0	0	1	1	2
0	0	0	0	0	1	3	0	0	2	0	2
0	1	0	2	0	1	1	0	2	1	0	1
0	0	0	0	0	0	1	0	0	0	0	1
0	0	0	0	0	0	3	0	1	0	0	1
0	0	0	0	2	0	0	0	0	0	0	1
0	3	0	1	3	0	2	0	2	0	0	2
0	1	0	0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	2	0	1	0	0	2
0	0	0	0	0	0	0	0	0	0	0	3
3	3	0	6	1	0	1	0	3	0	0	14

Table 2b.

TABLICA PROCENTOWA /percentage table/

11.0	4.6	0.0	1.3	0.2	0.4	0.7	0.0	0.0	0.0	0.0	0.0
6.1	7.0	0.4	2.2	0.4	0.6	0.7	0.0	0.0	0.0	0.0	0.6
0.9	4.4	0.2	0.9	0.2	0.6	0.4	0.0	0.0	0.0	0.0	0.6
1.7	3.9	0.6	3.5	0.7	0.2	0.7	0.0	0.0	0.6	0.0	0.4
0.4	2.2	0.2	2.0	0.4	0.4	0.7	0.0	0.0	0.2	0.0	0.0
0.6	2.6	0.2	1.8	0.4	0.2	0.9	0.0	0.0	0.2	0.0	0.4
0.4	0.6	0.2	1.1	0.2	0.2	0.9	0.0	0.2	0.0	0.0	0.2
1.1	0.4	0.0	2.0	0.2	0.6	1.3	0.0	0.0	0.0	0.0	0.4
0.0	0.0	0.0	0.6	0.6	0.6	0.4	0.0	0.2	0.0	0.0	0.6
0.0	0.2	0.0	0.0	0.2	0.4	0.9	0.0	0.0	0.2	0.2	0.4
0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.0	0.0	0.4	0.0	0.4
0.0	0.2	0.0	0.4	0.0	0.2	0.2	0.0	0.4	0.2	0.0	0.2
0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.2	0.0	0.0	0.2
0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2
0.0	0.6	0.0	0.2	0.6	0.0	0.4	0.0	0.4	0.0	0.0	0.4
0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.4

ILOSC WARTOSCI W KLASIE DLA DANEGO PARAMETRU /table of the number of values in each class and their percentage share in the whole/

KLASA 1=	123	22.65%
KLASA 2=	148	27.26%
KLASA 3=	9	1.66%
KLASA 4=	93	17.13%
KLASA 5=	24	4.42%
KLASA 6=	23	4.24%
KLASA 7=	55	10.13%
KLASA 8=	0	0.00%
KLASA 9=	11	2.03%
KLASA 10=	9	1.66%
KLASA 11=	1	0.18%
KLASA 12=	47	8.66%

....

SUMA = 543

Table 2c.

ILOSC WARTOSCI W KLASIE DLA DANEGO PARAMETRU **/table of the number of values in each class and their percentage share in the whole/**

KLASA 1=	99	18.23%
KLASA 2=	97	17.86%
KLASA 3=	44	8.10%
KLASA 4=	66	12.15%
KLASA 5=	35	6.45%
KLASA 6=	39	7.18%
KLASA 7=	21	3.87%
KLASA 8=	32	5.89%
KLASA 9=	15	2.76%
KLASA 10=	13	2.39%
KLASA 11=	8	1.47%
KLASA 12=	9	1.66%
KLASA 13=	2	0.37%
KLASA 14=	5	0.92%
KLASA 15=	3	0.55%
KLASA 16=	13	2.39%
KLASA 17=	3	0.55%
KLASA 18=	5	0.92%
KLASA 19=	3	0.55%
KLASA 20=	31	5.71%
....		
SUMA	= 543	

SREDNIA ARYTMETYCZNA WARTOSC PARAM. Y = 2.16
/arithmetic mean of parameter values/
X = 1315.61

WARJANCJA VY = 3.96
/variances/
VX = 1765003.85

ODCHYLENIE STANDARTOWE DELTAY = 1.99
/standard deviations/
DELTAX = 1328.53

KOWARIANCJA CXY = 1525.85
/ covariances/

WSPOLCZYNNIK KORELACJI R = 0.57731
/correlation coefficient/

ROWNANIE PROSTEJ REGRESJI Y = 0.00*X + 1.02
/regression equation/
X = 385.52*Y + 483.44

STOP

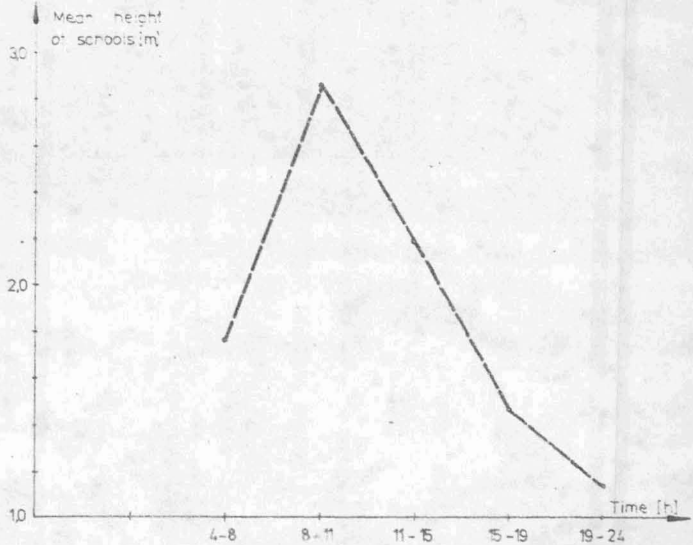

Fig.3. Diurnal changes in the mean height of sardine schools.

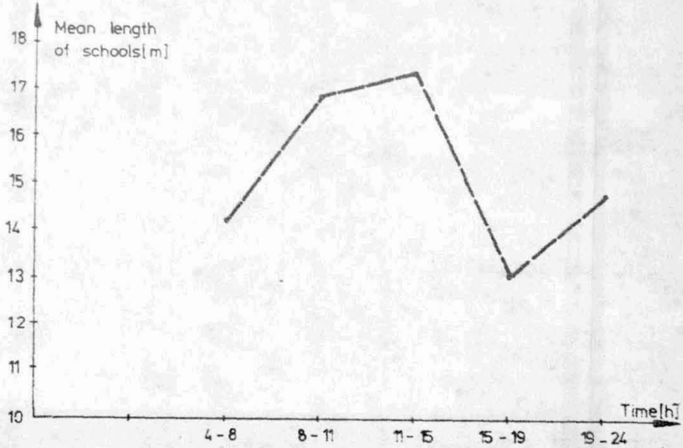

Fig.4.Diurnal changes in the mean length of sardine schools.

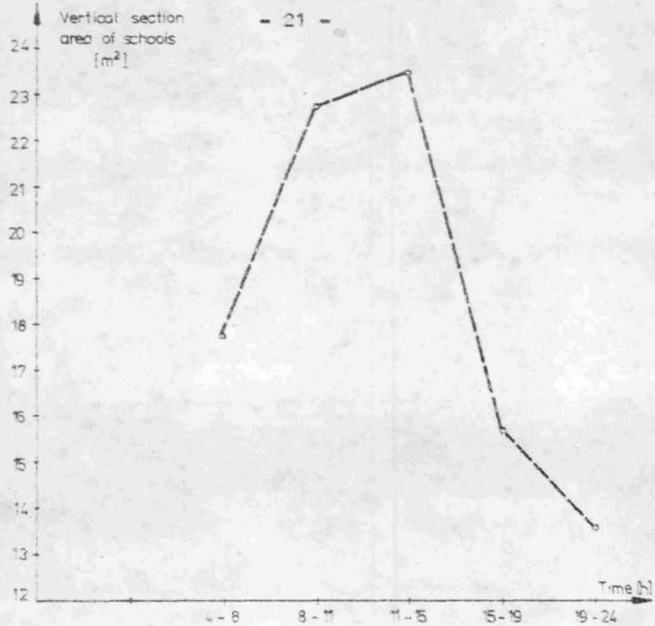

Fig.5. Diurnal changes in the mean vertical section area of sardine schools.

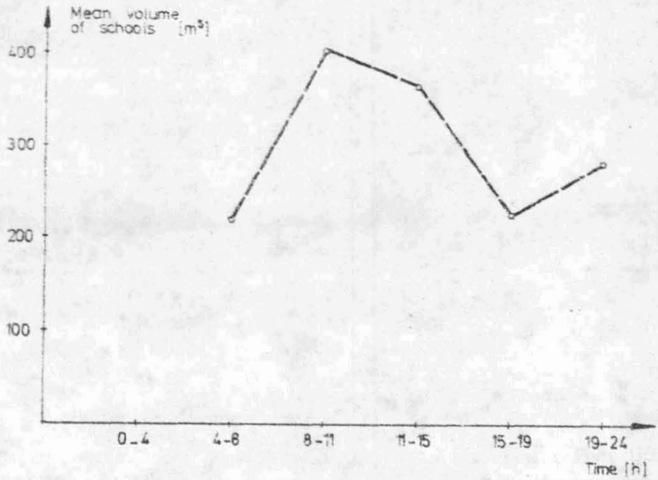

Fig.6. Diurnal changes in the mean volume of sardine schools.

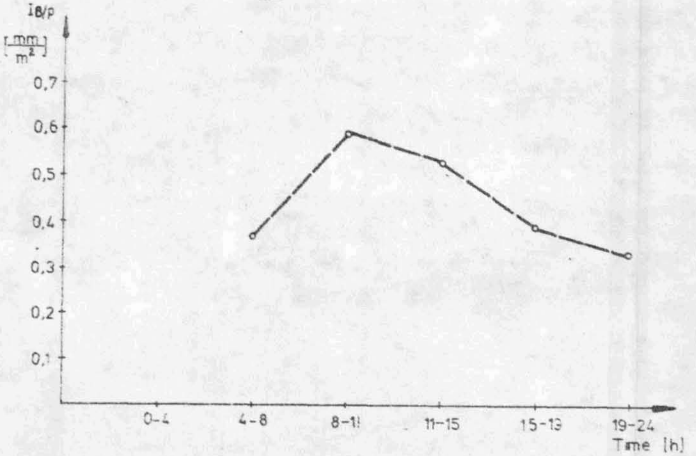

Fig.7. Changes in the fish density index in school I_B/p.

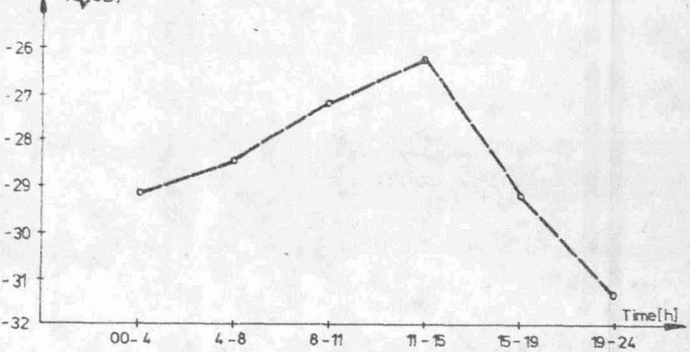

Fig.8. Diurnal changes in the mean value of target strength volume scattering of schools.

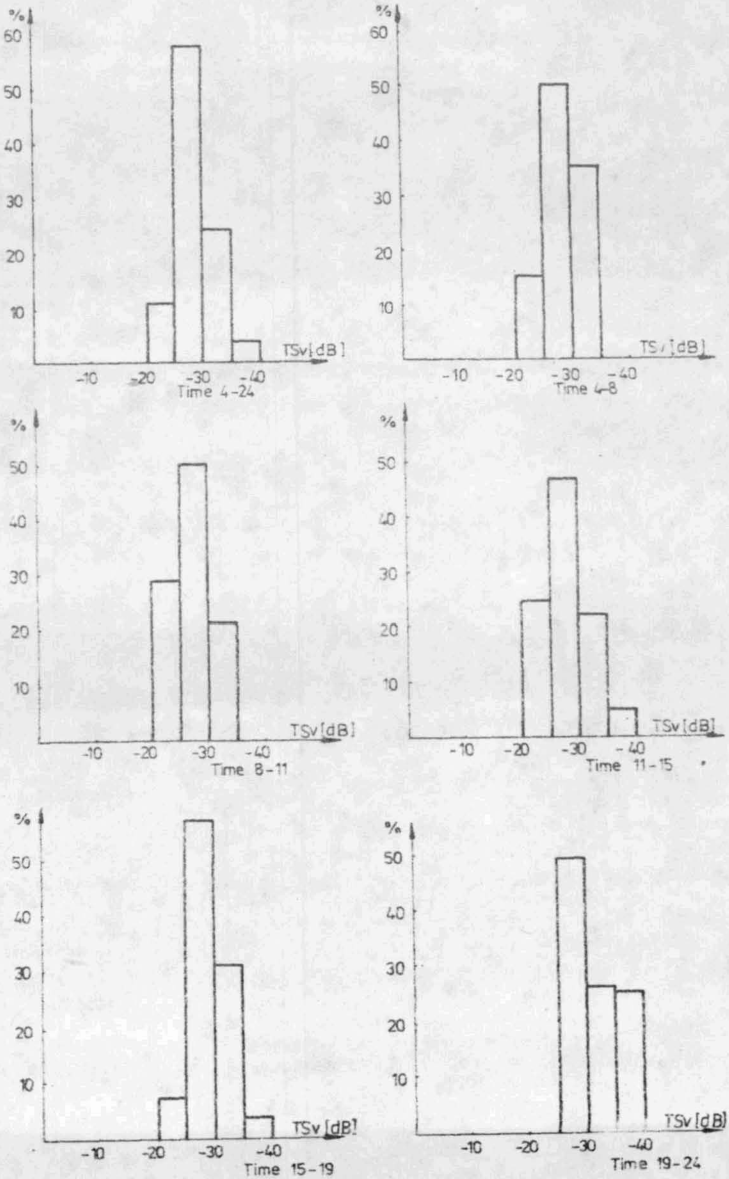

Fig.9. Distribution of target strength of volume scattering of schools at different times of day.

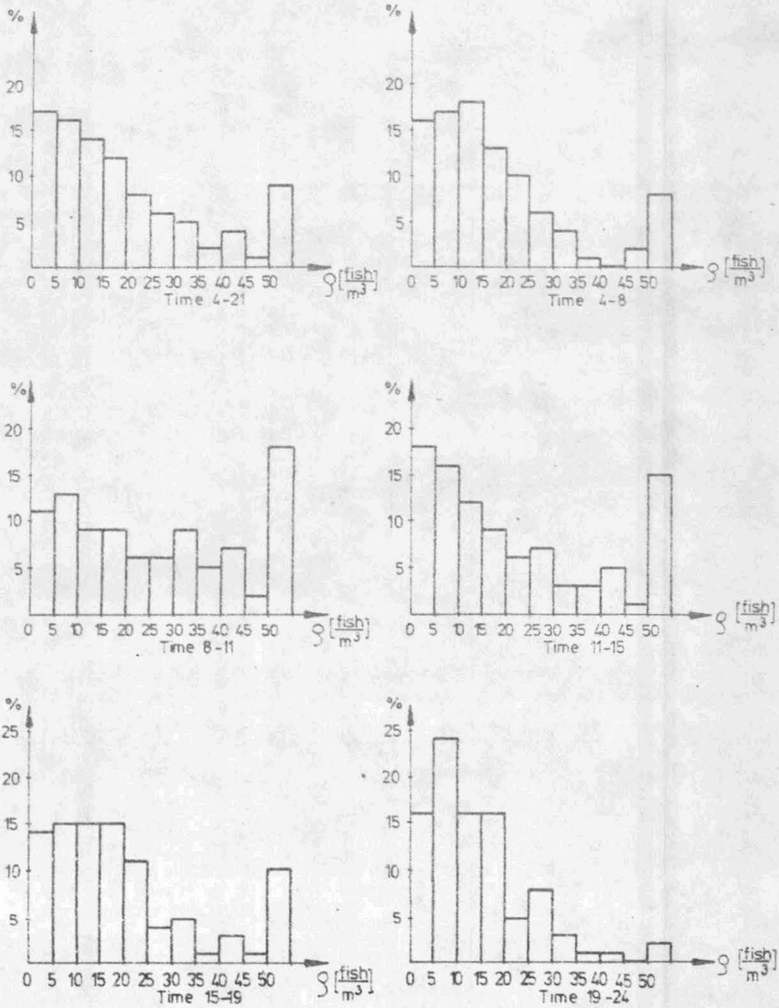

Fig. 10. Distribution of fish density in schools at different times of day.

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