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DETERMINATION OF GEOMETRIC PARAMETERS OF THE SARDINE *SARDINA PILCHARDUS* (Walb.), SHOALS USING HYDROACUSTIC TECHNIQUES

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JÓZEF SWINIARSKI — KRZYSZTOF GUŹNICZAK

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INTRODUCTION

Owing to the increasing intensification of sea fisheries, problems of fisheries effect on the state of resources, and those of the optimal catch determination become more and more meaningful. In the present stage of the fisheries development, the basic tasks in this respect are concerned with the quantitative determination of the commercial fish resources, nature of the fisheries influence upon the amount and population dynamics of these resources, and the determination of the fisheries development admissible limits adjusted to the optimal catch; on the other hand. the lines of fisheries regulation and protection are being designed as well. Owing to the above mentioned problems as well as to the fishing gear construction, fishing operation technique and tactics, our understanding of size and concentration types of different fish species in different regions seems to be very important.

A stock structure (an interdependent location of fishes in the stock) depends on the actual situation of this stock. Different variants of stock structures are subjected to continuous changes. However, with a great diversity, some of the variants appear to be the most typical ones for each fish species. The geometric parameters of shoals (width, height, volume) are also typical for each fish species in different periods of its life cycle.

A number of researchers have dealt with the fish shoal structure and size; the works by B r e d e r (1959), C u l l e n, S h a w, B a l d w i n (1965), R a d a k o v (1968) could be mentioned. The technical development, particularly in the field of electronics, provides new and improved equipment for studies on the fish shoal structure and the resources estimation. The hydroacoustic devices and techniques applied to fisheries have created vast possibilities for a direct evaluation of the fish resources as well as structure and size of the stock, based on hydroacoustic methods (Berdičevskij, Jermolčev (1973), Truskanov, Zaferman (1973), Elminowicz (1973), Świniarski, Elminowicz (1974). Informations on the objects tracked are transmitted by echosignals recorded as so-called traces on the echo-sounder recorder. Since echo-signals more or less deform the informations on the object sounded, a proper interpretation and identification of traces are essential when using an echo-sounder.

The aim of the present studies is to determine the geometric parameters of sardine shoals (length, width, height, volume) through the appropriate interpretation of their traces from the recorded echosignals coming from the shoals detected.

MATERIALS

Materials for studies were collected at the North-western African fishery grounds during the fishing cruises of two B29 type vessels: m/t »Langusta«, during the period 11 February 1973 to 9 June 1973, and m/t »Kanaryjka«, during the period 29 March 1973 to 11 April 1973. The region surveyed is determined by the following positions:

m/t »Kanaryjka«	$\varphi = 24°17$ N	$\lambda = 015°48'$W
	25°20'N	015°07'W
	$\varphi = 24°20$ N	$\lambda = 015°55'$W
	24°58'N	015°05'W
m/t »Langusta«	$\varphi = 21°23'$N	$\varphi = 27°40'$N
	$\lambda = 017°30'$W	$\lambda = 013°27'$W
	$\varphi = 27°40,$N	$\varphi = 21°31'$N
	$\lambda = 013°27'$W	$\lambda = 017°30'$W

The hydroacoustic equipment consisted of:

1. vertical fishery echo-sounder SP402
2. net echo-sounder LSE232 RO6.

Data obtained were recorded on the chart (Table 1).

The basic material comprised the vertical echo-sounder records, the haul beginning and its end as well as the haul number being marked according to log-books.

METHODS

Preliminary analysis of the records

Only the echo-sounder records related to sardines (confirmed by the catch) were selected, the records being compact, corresponding to concentrated shoals (usually »day records« since at night sardines dispersed and their geometric parameters could not be calculated in the way shown below). The other criteria of selection comprised: similar amplifications of the echo-sounder in all the records, and an undisturbed work of the fishing gear. The preliminary analysis allowed to select, for further calculations, 14 echo-sounder records of the amount collected by m/t »Kanaryjka« (514 shoals) and 11 ones of those obtained from m/t »Langusta« (199 shoals). The sardine individuals caught showed the gonad maturity stage of 5—6 according to the Mayer scale.

Mathematical analysis of the records

1. Direct measurements of the shoal parameters from the records. The following shoal parameters were measured directly from the record:

Shoal occurrence depth, read from the record with the aid of a frame provided with a scale similar to that of the vertical sunder recorder. The value read related to the upper border of the shoal.

Shoal height, determined in millimeters, as the distance between the upper and lower borders of the shoal (i.e., the shoal trace).

Shoal width, expressed in millimeters, as the horizontal distance between the both ends of the shoal trace.

Intensity of the echo-sounder record was evaluated according to the following scale:

Poor intensity	—1	
intense record but paler than that of the bottom	—2	
very intense record like that of the bottom	—3	
intensity like »2« but the shoal of an »empty inside«*	—2'	(Fig. 4)
intensity like »3« but the shoal of an »empty inside«	—3'	

The paper band shift speed was expressed in mm/min.

Shoal denotation — the shoals were given subsequent numbers.

2. Proper interpretation of the echo-sounder records.

When using a vertical echo-sounder, a proper interpretation of informations on the shoals appearing in the form of »traces« on the records is necessary. The parameters of small and large shoals should be considered separately. A division of the shoals into the small and large ones, based on echo-signals, is relative and depends on the echo-sounder beam angle and on the depth of the shoal occurrence. »The shoals of surface area much greater than that of the beam cross-section at the depth of the shoal sounded will be considered large« (E l m i n o w i c z, 1971).

Owing to the fact that during shoal sounding the lengths of their traces are obtained instead of a surface area cross-section from a given depth, the shoals should be grouped as the small and large ones according to the trace length.

The shoal satisfying an inequality

$$B \geqslant 2h \operatorname{tg} \frac{\Theta}{2}$$

will be considered a large one,
where:

* The shoal was so dense that an impulse could not penetrate inside it.

B — the sounded shoal length, as measured along the vessel path (identical with the trace length for echo-sounders with narrow beams),
h — depth of the shoal occurrence,
Θ — effective beam angle.

The shoals satisfying an inequality

$$B < 2h \operatorname{tg} \frac{\Theta}{2}$$

will be considered small ones.

The shoal width B depends on:
— the shoal trace witdh appearing on the vertical echo-sounder record, the paper band shift speed,
— the trawling speed.

This was determined according to the following:

$$B = \frac{l \cdot v_t}{v_p} \tag{1}$$

where:
v_t — the trawling speed,
v_p — paper band shift speed,
l — shoal trace length on the record.

Shoal width B_w (Fig. 1)

Influence of the beam width on the shoal trace length is taken into account when determining the shoal width B_w. The latter was calculated from the following (Elminowicz, 1971):

$$B_w = B - 2h \operatorname{tg} \frac{\Theta}{2} \tag{2}$$

where:
h — mean shoal depth,
Θ — effective beam angle along the vessel.

Sometimes the sardine shoal widths calculated from (2) assumed negative values (small shoals). The echo-sounder beam width was then corrected; the formula for B_w calculation appeared as:

$$B_w = B - \frac{\pi}{4} 2h \operatorname{tg} \frac{\Theta}{2} \tag{3}$$

In some cases the correction was repeated, the B_w formula assuming the form of

$$B_w = B - \left(\frac{\pi}{4}\right)^2 \cdot 2h \operatorname{tg} \frac{\Theta}{2} \tag{4}$$

Shoal width B_s

Assuming the shoal area being greater than that of the beam cross-section, the shoal width as measured through sounding is not accurate and unequivocal on account of the dependence upon the vessel path above the

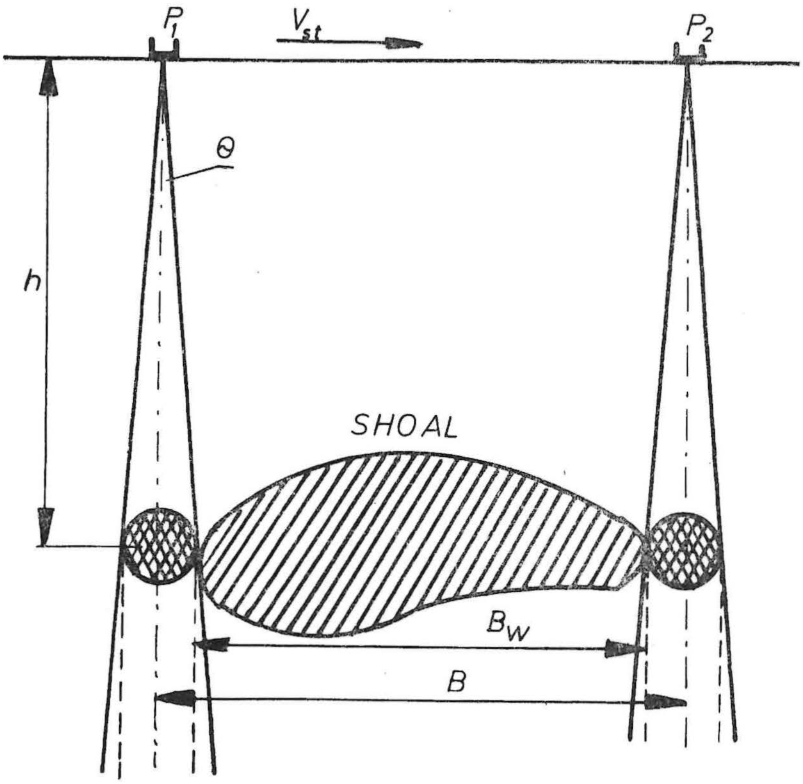

Fig. 1. Echo-sounding the fish shoal width

shoal (the vessel may pass above the centre or the border of the shoal). Considering a statistical correlation between a trace length and an actual shoal width, the latter can be calculated as follows:

$$B_s = \frac{4}{\pi} B_w \tag{5}$$

Shoal height H

The shoal height H was calculated from the following dependence:

H — 0.46 shoal height measured from the record (6)

0.46 — a coefficient determining a real distance (in m) per 1 mm on the recorder scale.

Actual shoal height ΔH

When calculating the shoal height H, an effect of the beam angle width on the accuracy of the sounded shoal thickness measurement is taken into account (Fig. 2). The actual shoal thickness H was calculated according to the following formula (E l m i n o w i c z, 1971):

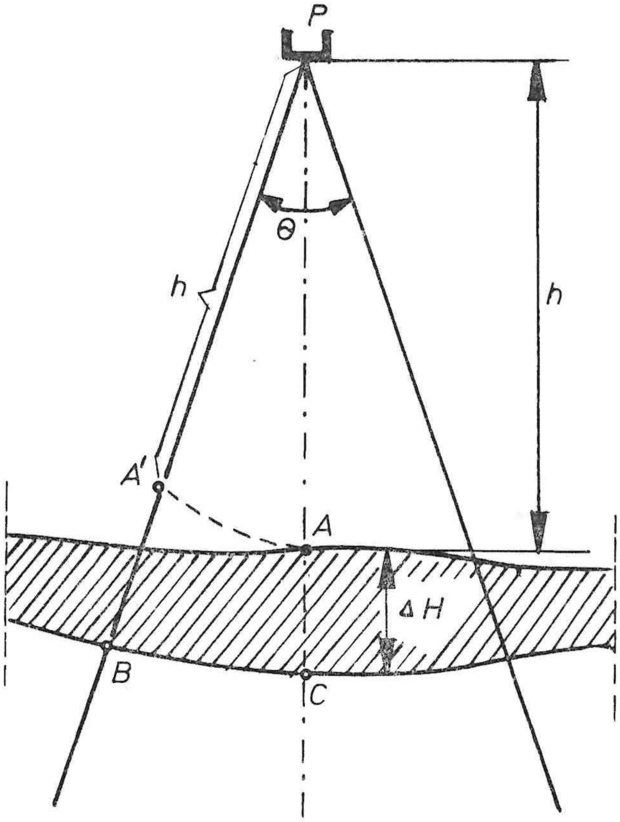

Fig. 2. Echo-sounding the shoal thickness.

$$\Delta H = \cos \frac{\Theta_1}{2} (H + h - v\,T_n) - h \tag{7}$$

where:

ΔH — actual shoal height,
Θ_1 — transducer beam angle,
H — shoal height provided by the record,
h — depth of shoal occurrence,
v — velocity of sound in water,
T_n — length of transducer pulse.

In order to calculate an actual thickness of small shoals, a criterion allowing to place the given shoal into the group of small ones was applied. It is satisfactory when the beam cross-section diameter is greater than the actual length of the shoal, i.e., 2 dw B_w. In this case, the shoal-covering angle of the echo-sounder, Θ_w was applied instead of the effective beam angle. The first was calculated from

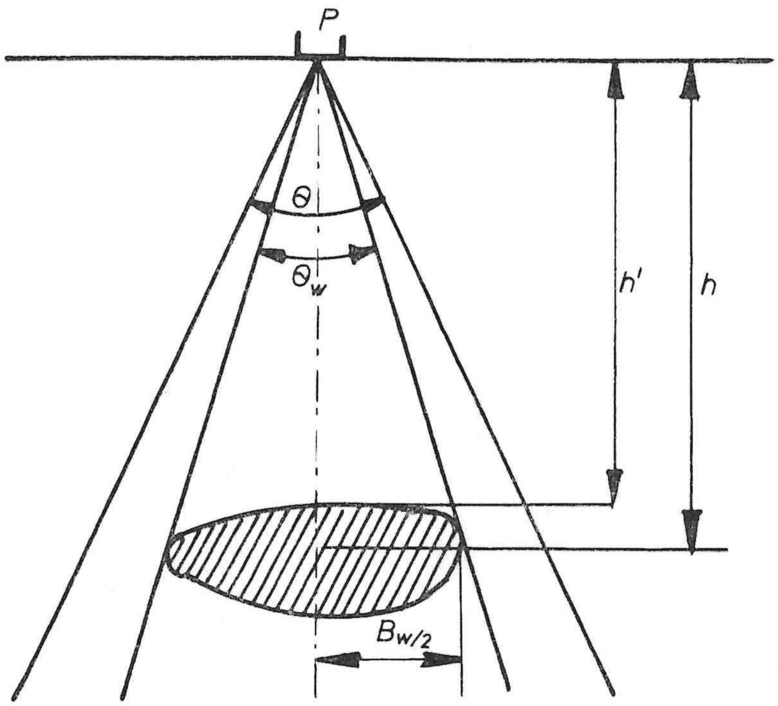

Fig. 3. Shoal-covering angle of the echo-sounder.

$$\frac{\Theta_w}{2} = \mathrm{arc\,tg}\,\frac{\frac{B_w}{2}}{h} \tag{8}$$

Finally the thickness formula of the shoal of length smaller than the beam diameter is

$$\Delta H = [(h + H - v\,Tn) \cos (\mathrm{arc\,tg}\,\frac{\frac{B_w}{2}}{2})] - h \tag{9}$$

assuming the shoal depth at the calculated length level being equal to that of its upper surface $h \cong h'$

Shoal volume V

Assuming the ellipsoidal shape of the shoal with the shoal height ΔH being one of the axis and the remaining two being equal to the shoal width B_s, calculation of the shoal volume can be made from the following expressions:

$$V = \frac{\pi}{6} B_s^2 \Delta H \tag{10}$$

$$V \cong 0.5\, B_s^2 \Delta H \tag{11}$$

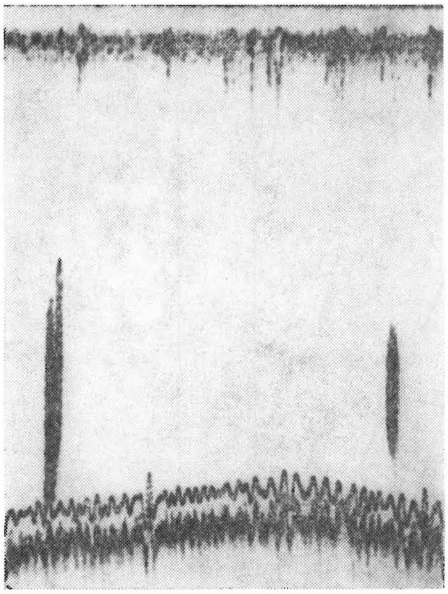

Fig. 4. An example of an »Empty inside« shoal record of the vertical echo-sounder.

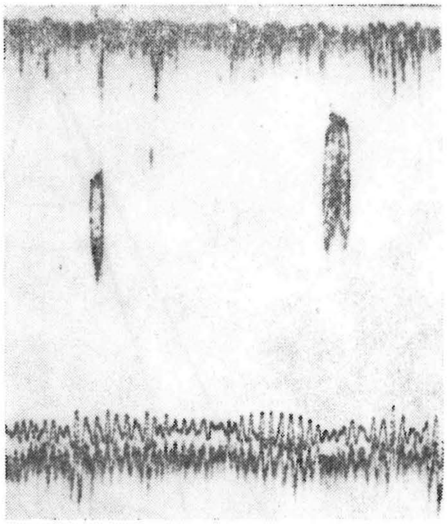

Fig. 5. An example of compact shoal record of the vertical echo--sounder.

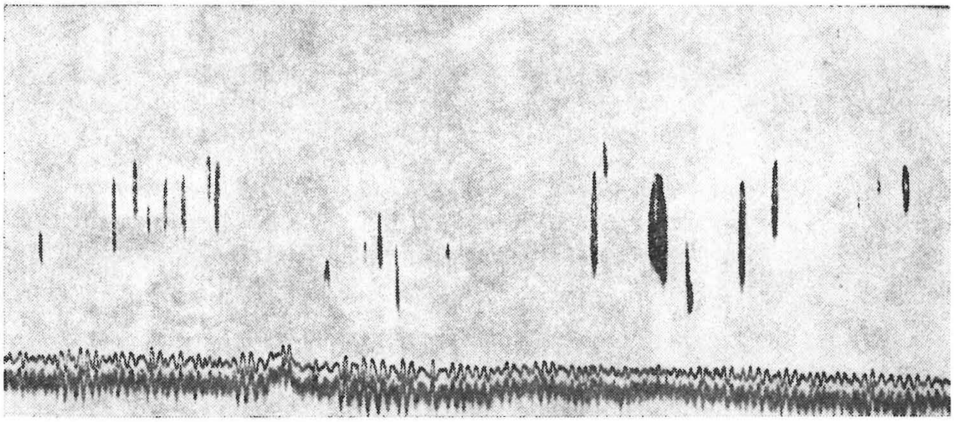

Fig. 6. Echo-sounder record of the vertical echo-sounder for the haul No 127. Position: 24°48'N 015°10'W; hour: 0530—0700; catch: 15 t of sardine.

RESULTS

Auxillary values and those related to the shoal parameters as measured directly on the echo-sounder records are summarized in Table 2 (columns 2—10), whereas columns 12—17 (Table 2) comprise shoal geometric parameters calculated by a proper interpretation of the records.

As a whole, materials collected by m/t »Kanaryjka« and m/t »Langusta« yielded 514 shoals recorded on 14 echo-sounder records and 199 ones on 11 records, respectivelly. Numerical and percentage portions of each distinct length, height, and volume class among the shoals examined are given as follows:
for m/t »Langusta«

Widths

up to 5.0 m	5	shoals making		2.51%	of total amount
5.0— 10.0 m	17	„	„	8.54%	„ „
10.0— 15.0 m	41	„	„	20.60%	„ „
15.0— 20.0 m	23	„	„	11.56%	„ „
20.0— 30.0 m	37	„	„	18.59%	„ „
30.0— 40.0 m	28	„	„	14.07%	„ „
40.0— 50.0 m	9	„	„	4.53%	„ „
50.0—100.0 m	34	„	„	17.09%	„ „
more than 100.0 m	5	„	„	2.51%	„ „
	199	„	„	100.00%	„ „

Heights

up to 3.0 m	21	shoals making		10.55%	of total amount
3.0— 5.0 m	49	„	„	24.62%	„ „
5.0— 8.0 m	49	„	„	24.62%	„ „
8.0—10.0 m	22	„	„	11.06%	„ „
10.0—15.0 m	35	„	„	17.59%	„ „
15.0—20.0 m	17	„	„	8.54%	„ „
more than 20.0 m	6	„	„	3.02%	„ „
	199	„	„	100.00%	„ „

Volumes

15.0— 50 0 m^3	3	shoals making		1.51%	of total amount
50.0— 100.0 m^3	5	„	„	2.51%	„ „
100.0— 500.0 m^3	50	„	„	25.13%	„ „
500.0— 1,000.0 m^3	29	„	„	14.57%	„ „
1,000.0— 2,000 m^3	15	„	„	7.54%	„ „
2,000 — 5,000 m^3	32	„	„	16.07%	„ „
5,000 — 10,000 m^3	26	„	„	13.06%	„ „
10,000 — 20,000 m^3	20	„	„	10.05%	„ „
20,000 — 50,000 m^3	11	„	„	5.53%	„ „
50,000 —100,000 m^3	6	„	„	3.02%	„ „
more than 100.000 m^3	2	„	„	1.01%	„ „
	199	„	„	100.00%	„ „

for m/t »Kanaryjka«

Widths

up to 5.0 m	83	shoals making	16.15% of total amount
5.0— 10.0 m	92	,, ,,	17.90% ,, ,,
10.0— 15.0 m	129	,, ,,	25.10% ,, ,,
15.0— 20.0 m	95	,, ,,	18.48% ,, ,,
20.0— 30.0 m	49	,, ,,	9.53% ,, ,,
30.0— 40.0 m	30	,, ,,	5.84% ,, ,,
40.0— 50.0 m	13	,, ,,	2.53% ,, ,,
50.0—100.0 m	21	,, ,,	4.08% ,, ,,
more than 100.0 m	2	,, ,,	0.39% ,, ,,
	514	,, ,,	100.00% ,, ,,

Heights

up to 3.0 m	206	shoals making	40.08% of total amount
3.0— 5.0 m	150	,, ,,	29.18% ,, ,,
5.0— 8.0 m	101	,, ,,	19.65% ,, ,,
8.0—10.0 m	22	,, ,,	4.28% ,, ,,
10.0—15.0 m	30	,, ,,	5.84% ,, ,,
15.0—20.0 m	3	,, ,,	0.58% ,, ,,
more than 20.0 m	2	,, ,,	0.39% ,, ,,
	514	,, ,,	100.00% ,, ,,

Volumes

up to 5.0 m^3	29	shoals making	5.64% of total amount
5.0— 10.0 m^3	18	,, ,,	3.50% ,, ,,
10.0— 15.0 m^3	13	,, ,,	2.53% ,, ,,
15.0— 50.0 m^3	70	,, ,,	13.62% ,, ,,
50.0— 100.0 m^3	25	,, ,,	4.86% ,, ,,
100.0— 500.0 m^3	172	,, ,,	33.47% ,, ,,
500.0— 1,000.0 m^3	70	,, ,,	13.62% ,, ,,
1,000.0— 2,000.0 m^3	48	,, ,,	9.34% ,, ,,
2,000 — 5,000 m^3	43	,, ,,	8,37% ,, ,,
5,000 —10,000 m^3	12	,, ,,	2.33% ,, ,,
10,000 —20,000 m^3	11	,, ,,	2.14% ,, ,,
20,000 —50,000 m^3	3	,, ,,	0.58% ,, ,,
	514	,, ,,	100.00% ,, ,,

As it is seen from above, shoals of width range of 10—15 m are most frequently met both in m/t »Langusta« and »Kanaryjka« results, their percentages amounting to 20.6 and 25.1, respectively. Although the small-width classes are dominant in both cases, the width class distribution is more uniform for the m/t »Langusta« shoals than for those of m/t »Kanaryjka«.

The same is true for the shoal height classes of m/t »Langusta« which are more evenly distributed. Two classes are predominant here, i.e., shoals of 3—5 and 5—8 height ranges (49 shoals in each group), each group amounting to 24.62% of the total number of shoals analysed. The shoals of 3 m height definitely prevail among m/t »Kanaryjka« records, amounting to 40.08%.

Of the distinct volume classes, in both cases the shoals of volume range of 100—500 m^3 make up a predominant group (50 shoals amounting to 25.13% of total and 172 shoals amounting to 33.47% of total for m/t »Langusta« and »Kanaryjka«, respectively).

Generally it can be stated that the shoals derived from m/t »Langusta« records are of greater volumes than those of m/t »Kanaryjka«. It is evidenced, among the others, by the lack of shoals of volumes below 15 m^3 for m/t »Langusta« while the shoals of that size make up 11.67% of the total amount of shoals examined for m/t »Kanaryjka« as well as by the presence of shoals with volumes up to 100,000 m^3 whereas for m/t »Kanaryjka« the greatest volume class comprised shoals of 20,000—50,000 m^3.

It is suggested that the discrepancies occurring in both heights and volumes between the shoals analysed for the »Langusta« and those analysed for the »Kanaryjka« may be due to the different regions of collecting materials.

m/t »Kanaryjka«	φ = 24°17'N	and	25°20'N
	λ = 015°05'W	and	015°55'W
m/t »Langusta«	φ = 21°23'N	and	27°40'N
	λ = 013°27'W	and	017°30'W

although the sampling periods were similar.

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Table 1.

Chart prepared by					Subsequent No of chart				
No	Vessel type and name, echosound. type*	Date	Gear type	Floats	Loading	Weights	Legs	Bridles	Otter boards
1	2	3	4	5	6	7	8	9	10

Table I

1.
a)
b)
c)

Table II

No	Particulars		Subsequent hauls I	II	III	IV	V
1.	Position						
2.	Cloudiness and precipitation						
3.	Temperatures	p					
		w					
		wp					
4.	Wind direction and force						
5.	Fishery ground depth						
6.	Trawling depth						
7.	Bottom type						
8.	Warp length						
9.	Trawling direction and speed						
10.	Current direction and velocity						
11.	Fishing gear position against vessel axis						
12.	Horizontal gap between doors						
13.	Catch						
14.	Fish shoal movement direction						
15.	Fish reaction to gear						
16.	Trawl directing to shoal						
17.	Fish behaviour in trawl mouth						
18.	Damages of gear						
19.	Gonad maturity state acc. to Mayer scale						

Table III

1.	Echo-sounder record No acc. to haul No	
2.	Record hr	a
		b
3.	Pulse frequency	a
		b
4.	Measurement range	a
		b
5.	Amplification	a
		b
6.	Paper band shift speed	a
		b

* a — vertical echo-sounder
b — net echo-sounder
c — horizontal echo-sounder

Table 2.

Shoal trace parameters as measured directly from echo-sounder records and geometric parameters of sardine shoals calculated through a proper trace interpretation

No	Haul number, catch efficiency, species composition	Recording hr, trawling time	Trawling speed	Vertical echo-sounder working range	Depth of shoal occurrence h (m)	Shoal height (mm)	Shoal width (mm)	Record	Paper band shift speed mm/min.	Shoal denotation	Shoal width B (m)	Shoal width B_w (m)	Shoal width B_s (m)	Shoal height H (m)	Shoal height ΔH (m)	Shoal volume V (m^3)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	24	1325—	3.8	I 0—65 m	15.0—24.0	19.5	2.0	2	8.3333	1	28.15	24.28	30.84	8.97	7.91	3,761.62
	15 t	—1455	117.29		19.0—23.0	9.0	1.0	2		2	14.07	9.91	12.59	4.14	3.09	244.89
	10 t/h	1h 30m	m/min		20.5—24.0	7.0	1.0	3		3	14.07	9.66	12.27	3.22	2.17	163.34
	100%				25.0—32.0	15.0	1.5	3		4	21.11	15.46	19.63	6.90	5.74	1,107.84
	sardine				22.0—27.5	12.0	2.0	3		5	28.15	23.24	29.51	5.52	4.42	1,924.56
					22.0—25.5	7.5	1.0	2		6	14.07	9.36	11.89	3.45	2.37	167.53
					26.0—29.0	6.5	0,5	2		7	7.04	1.58	2.01	2.89	1.87	3.78
					24.0—26.0	4.5	0.5	1		8	7.04	2.08	2.64	2.07	0.99	3.45
					12.5—17.0	10.5	1.0	9		9	14.07	11.04	14.02	4.83	3.86	379.36
					19.0—22.5	7.5	1.0	1		10	14.07	9.95	12.64	3.45	2.41	192.52
					16.5—25.5	19.0	1.5	3		11	21.11	16.94	21.51	8.74	7.67	1,774.38
					25.0—28.5	7.5	1.0	3		12	14.07	8.76	11.13	3.45	2.33	144.32
					29.5—27.0	14.0	3.0	3		13	42.21	37.50	47.63	6.44	5.34	6,057.21
					24.0—29.0	10.5	2.0	3		14	28.15	22.89	29.07	4.83	3.71	1,567.60
					12.5—16.5	9.0	1.0	2		15	14.07	11.90	15.11	4.14	3.08	351.66
					12.0—15.5	7.5	1.0	1		16	14.07	11.34	14.40	3.45	2.51	260.24
					13.5—24.0	22.5	2.0	3		17	28.15	24.43	31.03	10.35	8.95	4,308.80
					12.0—15.0	6.0	1.0	3		18	14.07	11.39	14.47	2.76	1.83	191.58
					10.5—15.0	10.0	3.5	3		19	49.25	46.72	59.33	4.60	3.66	6,465.58
					13.5—17.5	9.5	1.0	3		20	14.07	10.99	13.96	4.37	3.39	330.32
					18.5—24.5	13.5	3.5	3		21	49.25	44.98	57.12	6.21	5.14	8,385.12
					11.5—19.0	16.5	1.0	3		22	14.07	10.95	13.91	7.59	6.60	638.51
					11.0—19.0	17.0	1.0	3		23	14.07	11.09	14.08	7.82	6.83	677.01
					22.0—27.0	10.5	1.0	3		24	14.07	9.21	11.70	4.83	3.74	255.98
					11.5—16.0	9.5	3.0	3		25	49.25	46.63	59.22	4.37	3.42	5,996.98

ODREĐIVANJE GEOMETRIJSKIH PARAMETARA JATA SRDELE, *SARDINA PILCHARDUS* (Walb.) PRIMJENOM HIDROAKUSTIČNIH METODA

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KRATAK SADRŽAJ

Autori su izvršili opažanja o geometrijskim parametrima jata srdele (dužina, širina, visina i volumen) brodovima tipa B-29 m/t »Langusta i m/t »Kanaryjka«, na lovištima sjeverozapadne Afrike. Pri tome su upotrebljeni vertikalni ultrazvučni detektor SP 402 i ultrazvučni detektor LSE 232 R 06 koji se pričvršćuje na mreži.

Obrađivani su samo ekogrami srdele sa zbijenim znakovima koji odgovaraju koncentriranim jatima (to su obično dnevni znakovi). Iz ekograma su se uzimali slijedeći parametri: dubina pojavljivanja jata, te visina i širina jata. Posebno su se analizirala mala i velika jata. Ukupno je analizirano 514 jata s 14 ekograma sakupljenih na m/t »Kanaryjka« i 199 jata s 11 ekograma sakupljenih na m/t »Langusta«.

Intenzitet znakova klasificiran je u pet skupina. Interpretacija znakova vršila se je po Elminowiczu 1971).

U tabeli 2 izneseni su podaci direktnih mjerenja dimenzija jata (stupci 2—10) i podaci o izračunatim dimenzijama jata (stupci 12—17), kao i ostali podaci.

Najbrojniju klasu širine na m/t »Langusti« i m/t »Kanaryjki« predstavljala su jata od 10 do 15 m kojih je udio iznosio 20,60, odnosno 25,10%. Kod jata zabilježenih na m/t »Langusta« dominiraju dvije klase visine: 3—5 m (49 jata) i 5—8 m (49 jata), što predstavlja 24,62%. Na m/t »Kanaryjka« dominantnu klasu predstavljaju jata s visinom od 3,00 m (40,08%).

S obzirom na volumen dominiraju jata od 100 do 500 m^3, i to 50 jata ili 25,13% zabilježenih na m/t »Langusta« i 172 ili 33,47% na m/t »Kanaryjka«. Jata zabilježena na ekogramima m/t »Langusta« imala su veći volumen nego ona zabilježena na m/t »Kanaryjka«.

Znatnija amplituda visine i volumena jata analiziranih na m/t »Kanaryjka« u odnosu na ona s m/t »Langusta« vjerojatno je uvjetovana različitim mjestima istraživanja.