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Biomass variability of krill in the South Shetland Islands region (BIOMASS III, October 1986 — January 1987)

ABSTRACT: Results of hydroacoustic investigations of krill biomass carried out in the South Shetland Island region between October 1986 and January 1987 are presented. A considerable difference in the krill biomass between Antarctic spring and summer was recorded. Initially observations were conducted close to Elephant Island, in the period just after the retreated of compact ice cover. Krill then aggregated only in swarms, the density of which frequently exceeded 100 t nM^{-2}. In the region of Polygon I (30—31 October 1986) the total estimated biomass was 26899 t, in the region of Polygon II (6—10 November 1986) it was 25827 t. Investigations were repeated in January 1987 obtaining 112372 t in the Bransfield Strait and 390309 t in the region of Elephant Island. The results are presented in tables and maps.

Key words: Antarctica, krill stocks, BIOMASS III.

1. Introduction

Investigations of krill stocks covered by the BIOMASS Project have been carried on since 1981. They comprised a number of national expeditions in various areas, the South Shetlands area being the object of particular interest. Krill biomass was estimated with various methods, but hydro-acoustic equipment was the basic kind of instruments employed.

In 1981, as a part of the FIBEX experiment, a complex assessment of *Euphausia superba* Dana stocks was made in all Antarctica and its results were presented at the PostFIBEX Acoustic Workshop in 1984. Results of Polish research, covering the region of the South Shetlands were additionally included in the papers by Kalinowski (1982) and Kalinowski (1984a). Siegel (1985) presented the estimate of krill biomass based on control hauls made on 2—23 February 1982 in the region west of the Antarctic Peninsula as far as to the Bellingshausen Sea. Another part of the BIOMASS Project, the so called SIBEX I and SIBEX II, was carried out in the seasons 1983/84 and 1984/85. Poland participated in the former one, SIBEX I, and the results of the krill stocks investigations are included in the papers by Kalinowski (1984b) and Kalinowski, Godlewska and Klusek (1985). West Germany took part in both of these experiments (Siegel 1986; Nast 1986; Klindt 1986). Subsequent expeditions were organized in the season 1986/87, in which Poland also participated.

The aim of the present paper is to present the estimates of krill stocks made with the hydroacoustic method, paying particular attention to changes taking place over a single season.

2. Methods

Investigations were carried out in 24-hours cycle of hydroacoustic watches. The echosounder Simrad EK-120 connected to the analogue echo integrator Simrad QMMK II were the basic instruments. The echosounder Simrad EK-38 was employed to monitor the water layer down to the depth of 500 m. The working parameters of the echosounder EK-120 were following:

— working frequency	— 120000 Hz
— source level SL	— 219 dB/1 μPa ref. 1 m
— voltage response VR	— −109 dB/1 volt/μPa
— pulse duration	— 0.0006 s
— receiver bandwidth	— 10000 Hz
— mode	— normal.

Echo was integrated in the layer down to 190 m but for range below 110 m, i.e. the range of the correct TVG (− time varied gain) operation, suitable coefficients were applied.

Krill biomass was calculated on the basis of the mean target strength of volume-back-scattering S_{r} for every mile of ship's penetration. For the analogue echo integrator S_{r} might be obtained from the equation (Simrad 1972):

$$S_{r} = \bar{V}_0 - A + C \tag{1}$$

where:

$\bar{V}_0$ — the average value of the input signals that caused the recorder deflection obtained over each nautical mile (dB),

A — echo integrator gain setting (dB),

C — constant factor depending on the echosounder performance data and control settings (dB).

The calculation was made on the basis of echo integrator readings. After transformations the result was:

$$S_v = -75.81 + 10\log I \qquad (2)$$

where:

S_v — mean volume-back-scattering strength (dB),
I — integrator reading for 1 nM (mm).

The mean biomass density per unit of area was calculated from the formula:

$$\bar{\sigma} = 10^{\,0,1(S_v + 10\log \Delta R - TS)} \qquad (3)$$

where:

$\bar{\sigma}$ — mean biomass density (amount of krill m^{-2}),
ΔR — width of the integration layer (m),
TS — mean target strength of individual krill (dB).

Calculations of krill target strength were made according to the recommendations of the Post-FIBEX Acoustic Workshop, Frankfurt 1984:

$$TS = 19.9 \log L - 95.7 \qquad (4)$$

where:

TS — krill target strength,
L — krill mean body length (mm).

Mean body length of krill was taken after Kittel and Rakusa-Suszczewski (1988) obtained for the nearest krill trawling.

The mean biomass density per unit of area was calculated from the following formula:

$$\bar{B} = 3.43 \cdot \bar{\sigma} \cdot \bar{w} \qquad (5)$$

where:

$\bar{B}$ — mean biomass density per unit of area (t nM^{-2}),
$\bar{\sigma}$ — mean krill body weight (g).

The mean krill weight was calculated from the equation used during the Post-FIBEX Acoustic Workshop, Frankfurt 1984:

$$w = 0000925 \cdot L^{3,55} \cdot 10^{-3} \qquad (6)$$

where:

w — mean krill body weight (g),
L — mean krill body length (mm).

To calculate krill biomass, particular study areas were divided into square, as it is shown in Figs. 2, 3 and 4. On the basis of formula (5), the mean arithmetic biomass density was calculated in each of the squares and the obtained value multiplied by the square area. The sum of biomasses of all the squares was the total biomass in a given study area. The results obtained are presented in Tables 1, 2 and 3.

3. Material

Investigations were carried out during two periods: spring and summer. In the first period following legs were distinguished:

21—29 October 1986 — penetration of the shelf around Elephant Island (Fig. 1);

30—31 October 1986 — study polygon west of Elephant Island, the so called Polygon I (Fig. 2);

6—10 Nov. 1986 — study polygons mounth of King George Island, the so called Polygon II (Fig. 3).

Totally, 3000 nautical miles were echosounded. Due to the difficult ice conditions part of Elephant Island's shelf could not be echosounded, hence the total biomass of E. superba was not estimated in this area and only biomass density distribution along the ship's route, in the manner shown in Fig. 1, is included. The arbitrarily accepted width of the band was 2 nM. The results obtained, limited by the presence of ice cover as they are, still prove that aggregations of krill do occur in this region in various seasons of the year, in contrast to the South Georgia region, for example, where as late as in December this year no E. superba aggregations were encountered by the echosounder in the course of fishery studies.

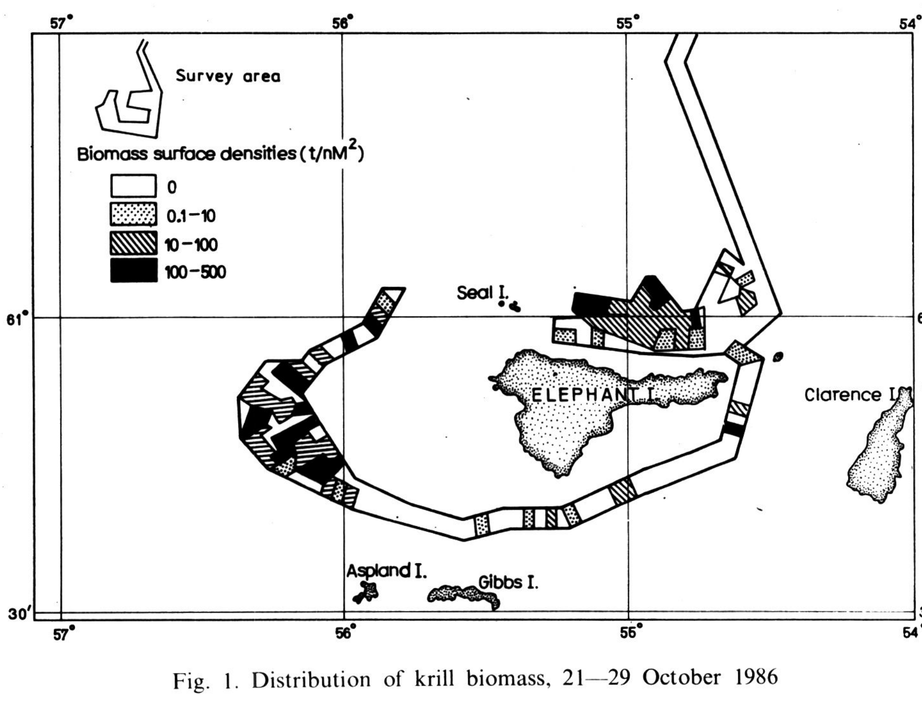

Fig. 1. Distribution of krill biomass, 21—29 October 1986

The second part of the investigations comprised the echosounding in the Bransfield Strait and of the areas around Elephant Island, along previously established profiles. It was carried out from 2-nd to 12-th January 1987, and the basic hydroacoustic cross-section comprised 1260 miles, 400 of which were in the Bransfield Strait.

4. Results

Krill biomass estimated for the Polygon I (30—31 October; Fig. 2, Tab. 1 amounted to 26899 t, that for the Polygon II (6—10 November; Fig. 3, Tab. 2 amounted to 25827 t. The area of Polygon I was twice smaller than that of Polygon II but its biomass density on the average twice higher than that of the latter. Biomass density value were particularly low in Polygon II, sometimes only several tons per 1 nM^2, being at the same time highly variable. This may be illustrated by the situation observed in the square B1 — 6.2 (Tab. 2) where the ship was twice. On the first

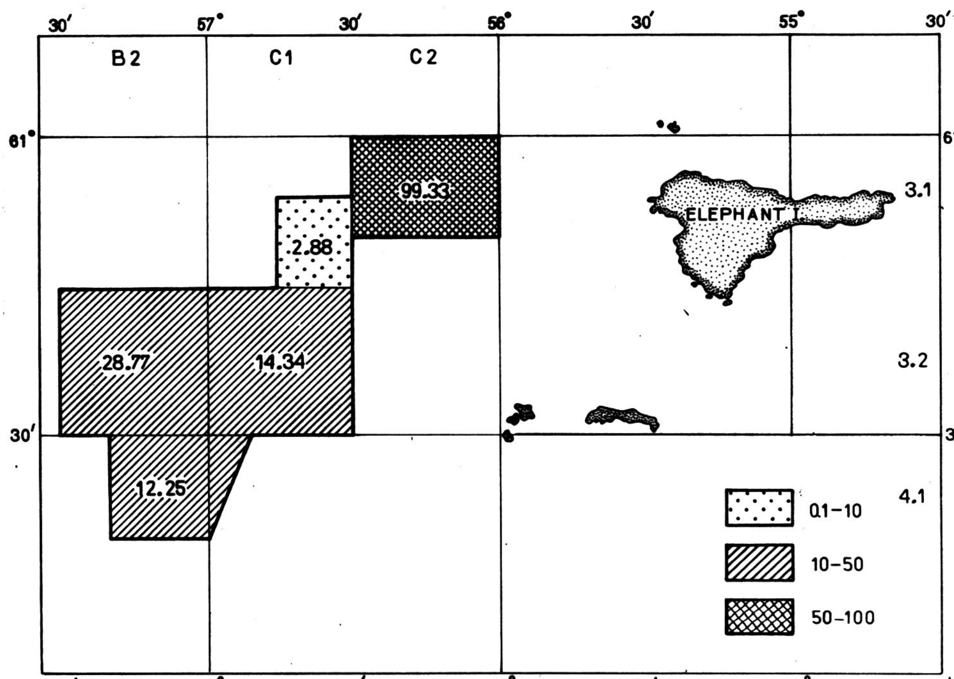

Fig. 2. Distribution of krill biomass (t nM^{-2}); 30—31 October 1986, Polygon I
Numbers in each field indicate mean values of biomass density in square

Table 1

Estimates of krill stocks in the region of Polygon I
(30—31 October 1986)

Square	Area nM^2	Mean biomass density $t\ nM^{-2}$	Biomass t
C2—3.1	150	99.33	14899
C1—3.1	63	2.88	181
C1—3.2	225	14.34	3226
B2—3.2	225	28.77	6473
B2—4.1	95	12.25	1164
C1—4.1	23	44.64	955
Total	781		26898

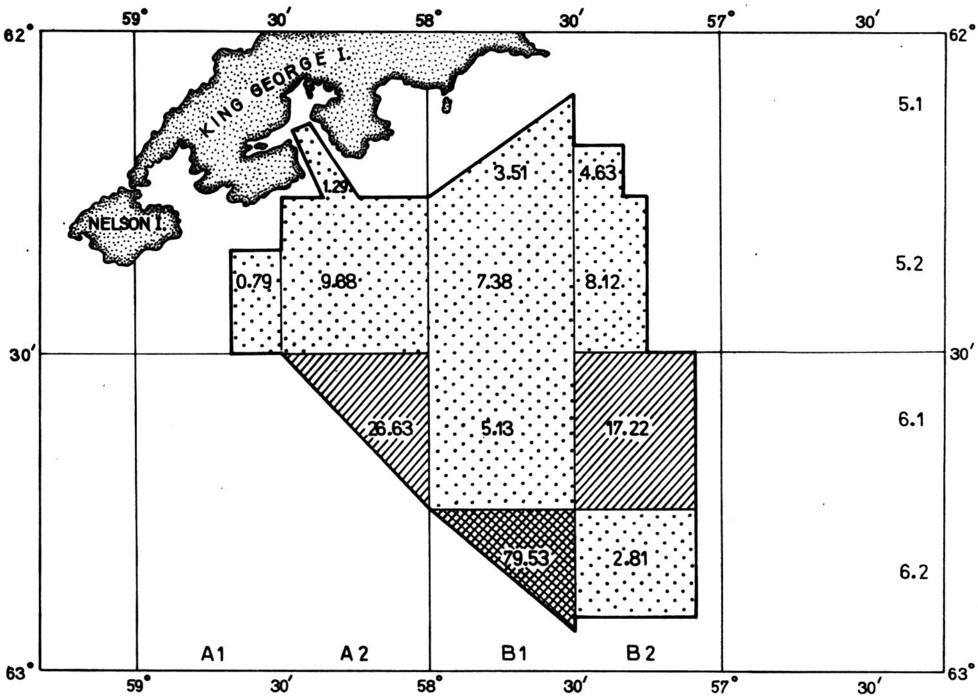

Fig. 3. Distribution of krill biomass ($t\ nM^{-2}$); 6—10 November 1986, Polygon II. Explanations as in Fig. 2

occasion no larger krill aggregations were observed, whereas a day later swarms of high density appeared which resulted in a high biomass density per unit of area in this square clearly different from the other squares. In Polygon I biomass density values were generally higher and in the square C2 — 3.1 a considerable value of about 100 $t\ nM^{-2}$ was moted.

Table 2
Estimates of krill stocks in the region of Polygon II
(6—10 November 1986)

Square	Area nM^2	Mean biomass density $t\ nM^{-2}$	Biomass t
A1—5.2	50	0.79	39
A2—5.2	225	9.68	2178
A2—5.1	17	1.29	22
A2—6.1	112	26.63	2982
B1—5.1	75	3.51	263
B1—5.2	225	7.38	1660
B1—6.1	225	5.13	1154
B1—6.2	165	79.53	13122
B2—5.1	25	4.63	116
B2—5.2	105	8.12	852
B2—6.1	180	17.22	3100
B2—6.2	120	2.81	337
Total	1524		25825

The present study differed from those carried out in previous years (Kalinowski 1982, 1984a; Kalinowski, Godlewska and Klusek 1985) being conducted just after related compact ice cover. In general aggregated krill occurred exclusively in swarms (nomenclature of krill aggregations see Kalinowski and Witek 1985a, b) and much less frequently than it was observed in previous years in later seasons. Presently no aggregation forms called concentrations were at all recorded, possibly due to the earlier study period; probably we have studied the area before hydrological conditions favouring the appearence of such concentrations have arisen. No *E. superba* aggregations were recorded below the depth of 120 m.

In contrast to the first stage of study already in January 1987 a higher number of *E. superba* aggregations were encountered; sometimes they were stretching along several nautical miles. They occurred, although not very frequently, down to the depth of 200 m. Some pelagic recordings were made below this depth, but due to the lack of deep sea fishings we were not sure that these echograms concerned krill only.

In January 1987 rather frequent echograms were so called irregular forms which might be explained by the multi-species character of these aggregations, and also by their occurrence close to water layers of different parameters (thermoclines, pycnoclines), these layers being recorded on the echosounder paper in the form of layers of various shapes.

Similarly as it was the case during earlier investigations on the so called polygons (October, November 1986), krill biomass was also estimated

(Fig. 4). The respective values amounted to 112372 t in the Bransfield Strait and to 390309 t in the region of Elephant Island, which gives a total of 502681 t. Biomass densities were much higher than those in November and amounted on the average to several dozens tons per nM^2. Results of the estimates are presented in Table 3.

In conclusion, it may be stated that in January, in contrast to November, krill occurred in the whole study area, in amounts exceeding sometimes 500 t nM^{-2} and thus marking commercial krill fishery possible.

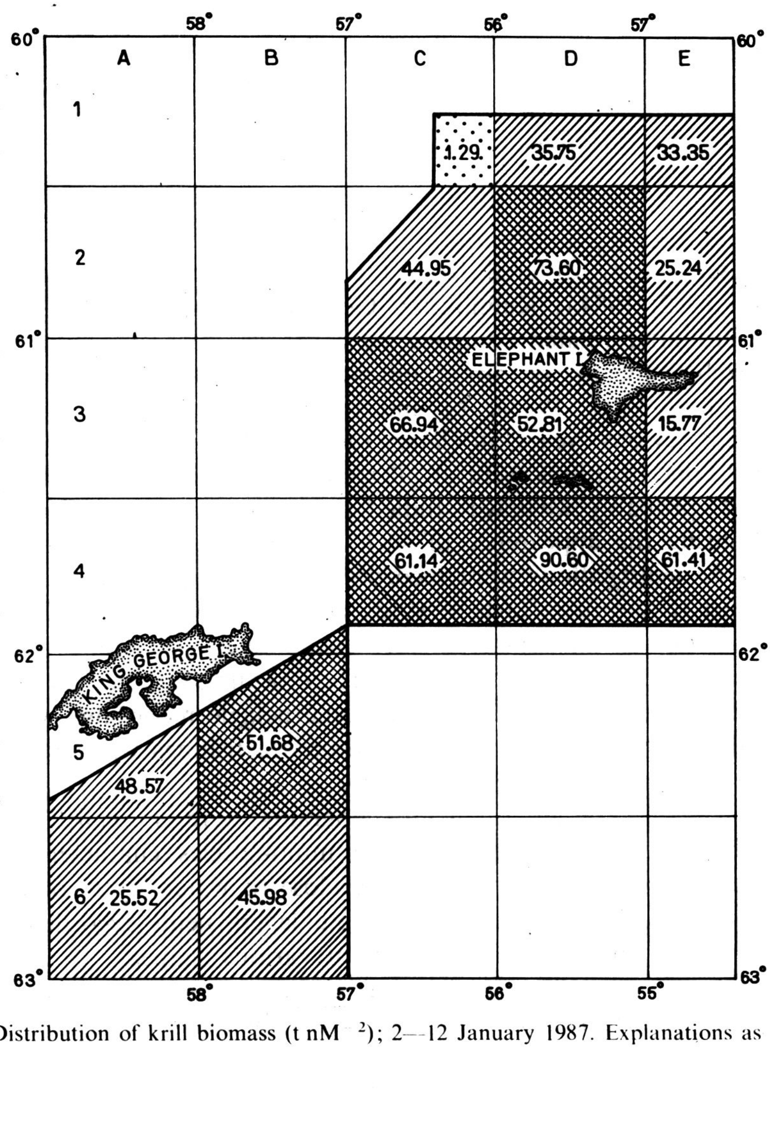

Fig. 4. Distribution of krill biomass (t nM^{-2}); 2—12 January 1987. Explanations as in Fig. 2

Table 3
Estimation of the krill resources in the Bransfield Strait and the Elephant Island region (2—12 January 1987)

Region	Square	Surface nM²	Mean biomass density t nM⁻²	Biomass t
Bransfield Strait	A6	822	25.52	20980
	A5	315	48.57	15300
	B6	822	45.98	37797
	B5	741	51.68	38295
	total	2700		112372
Elephant Island region	C4	685	61.15	41885
	D4	685	90.60	62062
	E4	393	61.41	24136
	C3	867	86.94	75380
	D3	780	52.81	41193
	E3	510	15.77	8045
	C2	733	44.96	32953
	D2	885	73.60	65137
	E2	532	25.24	13429
	C1	225	1.30	292
	D1	450	35.76	16090
	E1	291	33.36	9707
	total	7036		390309
Total		9736		502681

5. Discussion

Investigations carried out in Western Antarctica for many years indicate to a high dynamism in krill biomass depending upon the season and the employed recording technique. While methods, based on the results of catches obtained from planktonic net hauls, show the situation in particular stations, the hydroacoustic technique enables the continuous monitoring of the water area. Using nets krill reaction to the fishing 7 gear has to be taken into account, while only aggregated krill may be an object of hydroacoustic observations. Accordingly, while estimating the total *E. superba* biomass it is also necessary to assess how large part of krill is then dispersed. Siegel (1985) observed that the change in hydrological conditions may bring about a complete change in the local stock and composition of krill population over a short period of several hours. Siegel (1986) has studied krill stocks using the RMT net 1+8. This author estimated the biomass of krill in the Bransfield Strait as 392000 t in October 1983 and 372000 t in March 1985. Siegel (1986) suggested that after the spawning period krill migrates along the Antarctic Peninsula from oceanic and outer shelf areas to the neritic areas. Nast (1986) has carried out also similar estimations in the region of Elephant Island, using the RMT net 1+8. He has obtained 723000 t for November 1983, 252000 t for November 1984 and 164000 t for March 1985, and concluded that there were no statistically significant differences between austral summers 1983/1984 and 1984/1985 but such differences existed between the seasons 1982/83 and 1984/85. Klindt (1986) estimated krill stocks around Elephant Island using hydroacoustic equipment, obtaining 51680 t for 1983, 379000 t for 1984 and 16490 t for 1985. These results much differed from those of Nast (1986) which were obtained in the same region but using a different technique.

A comparison of the presently obtained results with the results of earlier Polish research during FIBEX 1981 (Kalinowski 1982, 1984) and SIBEX 1983/1984 (Kalinowski 1984; Kalinowski, Godlewska and Klusek 1985) reveals a certain repeatability of data from the area of Elephant Island, whereas a conspicuous variability of the results was noted for the Bransfield Strait. During FIBEX mean biomass density amounted to about 40 t nM^{-2}, while in the course of SIBEX I the biomass density amounted to only several tons per 1 nM^2 in a similar area. A similar results was obtained in the present voyage in November 1986, whereas already in January biomass density values much increased, sometimes even 10 times. This might evidence for a higher dynamics of the Bransfield Strait waters, not favouring the appearence of stationary concentrations and causing continuous movement of krill patches, in contract to the Elephant Island region. The fact that the sea currents strongly, if not decisively, influence the formation of krill concentrations is supported by results of investigations carried out on board of r/v "Profesor Siedlecki" (Kalinowski and Witek 1985b; Witek, Grelowski and Kalinowski 1984) and also in other countries (e.g. Makarov et al. 1987; Nast et al. 1987). However, it is worth mentioning that measurements carried out with planktonic nets at oceanographical stations during SIBEX I supplied slightly different results than the hydroacoustic ones. Witek et al. (1985) presented the results of macrozooplankton studies carried out down to 200 m with the Bongo net at 63 stations in the western part of the Bransfield Strait and at the Palmer Archipelago; their values were much higher and at one station (No 99) reached even 156.2 t nM^{-2}. This might evidence for krill dispersion in a way which makes their detection with hydroacoustic equipment impossible. Therefore the estimation of krill stocks using the hydroacoustic equipment should always be complemented with planktonic nets fishing, which enables to estimate the degree of krill dispersion.

In conclusion it seems that in early spring krill occurrs in aggregated form only in swarms but not in the form of stationary aggregations called concentrations. High differences in krill biomass values between early spring and summer were recorded in the same area; the differences even of an order of magnitude. The Bransfield Strait is not an area of stationary concentrations formation, despite the fact that moving swarms of high densities and sizes occurred there.

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7. Streszczenie

W czasie badań przeprowadzonych w rejonie Szetlandów Południowych w okresie od października 1986 do stycznia 1987 (BIOMASS III) dokonano próby określenia zmian biomasy kryla w czasie poprzez ocenę jej wielkości metodą hydroakustyczną. Wyniki szacowania zestawiono w tabelach 1, 2 i 3.

Wielkość biomasy kryla, oszacowana dla tego samego rejonu badań w okresie letnim była około 10-krotnie razy wyższa od biomasy kryla w okresie wczesno-wiosennym.

Stwierdzono, że w okresie tuż po ustąpieniu zwartej pokrywy lodowej jedyną formą skupień kryla były roje.