POLISH POLAR RESEARCH	9	2-3	339—348	1988

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Characteristics of krill stocks west of Elephant Island (BIOMASS III, October—November 1986)

ABSTRACT: Results of hydroacoustic investigations of krill swarms occurring southwest of Elephant Island carried out between 30 October and 5 November 1986, are presented. Krill swarms of the geometric length of 32 m, mean vertical cross section area of 206 m^2, and mean density of 133 g m^{-3} were recorded and measured. Biomass distribution is presented in maps. The highest density values amounting to 500 t nM^{-2} were recorded in the eastern part of the survey area, above the slope of Elephant Island's shelf. On the basis of upper and lower limits of the occurrence of given krill swarms, a scheme of their vertical, diurnal distribution was constructed.

Key words: Antarctic, krill stocks, swarms, BIOMASS III.

1. Introduction

The BIOMASS Project is carried on in the Antarctic since 1980 and aims, among others, at estimating krill stocks and gaining knowledge on environmental conditions which make krill aggregate. The first experiment of the project, BIOMASS FIBEX 1981, attempted to evaluate *Euphausia superba* stocks in the whole Antarctic and thus was mega-scale one. The stocks were estimated using one common hydroacoustic method and the biomass obtained for the Atlantic Sector of the Antarctic of the area of 590000 km^2 amounted to 2.65 mln ton (Post FIBEX Acoustic Workshop 1984). The second experiment, SIBEX I and II, was restricted to the area around the South Shetlands and aimed, besides the estimation of the stocks resources, at the understanding of the environmental conditions influencing the appareance of krill aggregations. Thus it was a meso-scale investigation. The presently described results of hydroacoustic observations were limited to a small area above the slope of the shelf, west of Elephant Island, consequently they were of coarse scale character. Contrary to the BIOMASS SIBEX, in which a whole season investigation cycle was carried out (seasonal scale) the present investigations lasted 5 days only thus being of weather scale.

Basing on hydroacoustic observations, horizontal and vertical krill distribution is presented as well as the estimation of the size of krill swarms. The biomass distribution was related to the actual hydrological situation.

2. Methods

Investigations were carried out in the pattern of 24 hour cycles of hydroacoustic watches. The basic equipment was an echosounder Simrad EK-120 connected with the anolog echo integrator Simrad QMMKII. The water layer down to 500 m was investigated using the echosounder Simrad EK-38. The area of the swarm vertical cross-section was measured with a planimeter.

Physical parameters of swarms were measured according to the following procedure (Fig. 1):

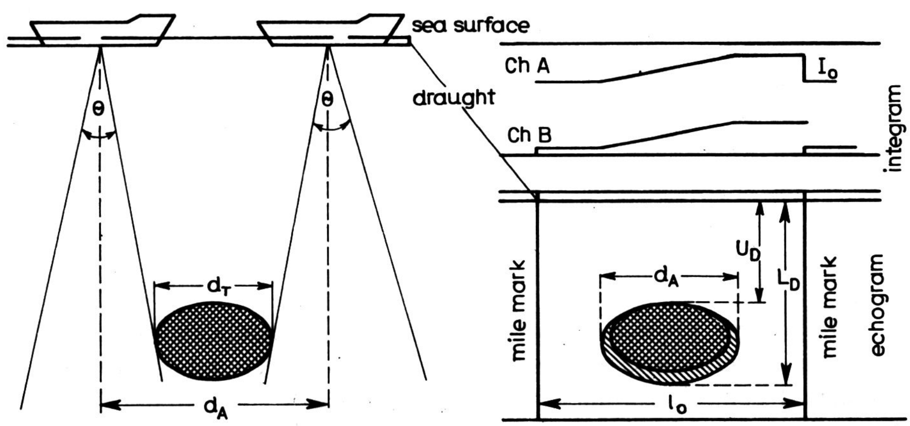

Fig. 1. Scheme of swarm physical parameters measurements: θ — beam angle; d_A — apparent length; d_T — true length; U_D — upper limit of depth; L_D — lower limit of depth; I_0 — echointegrator deflection; ChA — channel A; ChB — channel B

While sailing above a swarm the ship moved along the random cross section, the length of which on the echosounder paper was registered as the apparent length d_A. The actual length of the swarm d_T was calculated taking into account the width of acoustic wave emitted by the transformer:

$$d_T = d_A - 2\frac{U_D + L_D}{2}\,\mathrm{tg}\,\frac{\Theta}{2} \qquad (1)$$

where:

d_T — true length of swarm (m),
d_A — apparent length of swarm (m),
U_D — upper limit of swarm depth (m),
L_D — lower limit of swarm depth (m),
θ — beam angle (degree)

From statistical analysis it follows that while a circle is being cut at random the mean length of chaords obtained approaches the limit of $\frac{\Pi}{4}$ of the circle diameter. On this basis it may be assumed that:

$$d_C = \frac{\Pi}{4} \qquad (2)$$

where:

d_C corrected length of swarm (m).

The swarm's density was calculated from the equation:

$$\log \varrho_v = 0.1\,(\bar{S}_v - \bar{TS}) + \log \bar{w} \qquad (3)$$

where:

$\bar{\varrho}_v$ — the mean volume density of krill in swarm (kg m^{-3}),
$\bar{S}_v$ — the mean volume back scattering strength (dB),
$\bar{TS}$ — the mean target strength of krill (dB),
$\bar{w}$ — the mean weight of krill (kg).

$$TS - 10 \log w = TS_{kg} \qquad (4)$$

where:

TS_{kg} — target strength per 1 kilogram of krill (dB_{kg})

hence:

$$\bar{\varrho} = 10^{0.1(S_v - TS_{kg})} \cdot 10^3 \qquad (5)$$

where:

ϱ_v — the mean volume density of krill in swarm (g m^{-3})

S_v was calculated for each swarm using the echo integrator:

$$S_v = V_0 - A + C \qquad (6)$$

where:

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).

$$V_0 = V_{01} + 10 \log I_{01} - 10 \log \bar{\Delta R} \qquad (7)$$

where:

V_{01} — normalized values of an average V_0, corresponding to the echo integrator unit deflection. For QMMKII = −2 dB

I_{01} — echo integrator deflection over 1 naut. mile (mm),
$\overline{\Delta R}$ — the mean thickness of integration layer (m).

$\overline{\Delta R}$ values were determined according to the equation:

$$\overline{\Delta R} = \frac{P}{d_A} \quad (8)$$

where:

P — the vertical cross-section of a swarm (m^2),
d_A — apparent length of swarm [length measured from echogram (m)].

The mean krill biomass per unit of area was calculated according to the procedure given by Kalinowski (1988).

3. Material

Hydroacoustic observations carried out in the research area (Area 1 of the BIOMASS III operation, Rakusa-Suszczewski 1988a) may be divided into two parts:

a) 30—31 October 1986 (Fig. 2) — hydroacoustic cross-section along the previously established route. The collected materials were then used to determine physical parameter values of swarms, their vertical distribution and biomass distribution in relation to the sea bottom configuration;
b) 31 October to 5 November 1986 (Fig. 3) — oceanographic investigations. The collected hydroacoustic data were used to determine the biomass density distribution.

4. Results and discussion

In the first part of the investigations an area of ca 781 nM^2 was sounded along an etablished searching grid. Interesting conclusions can be drawn from the analysis of the krill horizontal distribution (Fig. 2 and 3) and general hydrological situation. Basing on the results of measuring physical parameters at oceanographic stations (Grelowski and Wojewódzki 1988, Rakusa-Suszczewski 1988a) it was proved that a frontal zone, being the northern limit of the Weddell-Scotia Confluence (WSC), occurred in the northern part of the investigated area. In this zone, 10 miles from edge of the shelf there occurred an anticyclonal meander, and above the edge of the shelf a water current was noticed which lost its energy at the western shallow of the Elephant Island shelf, where bottom depth was only 100—200 m. An anticyclonal whirl occurred close to station 31. Imposing the above situation on the maps of krill distribution (Fig. 2 and 3) we can see that larger swarms, exceeding 100 tons nM^{-2} occurred in the areas of these water disturbances, which supports the assumption of Witek, Grelowski and Ka-

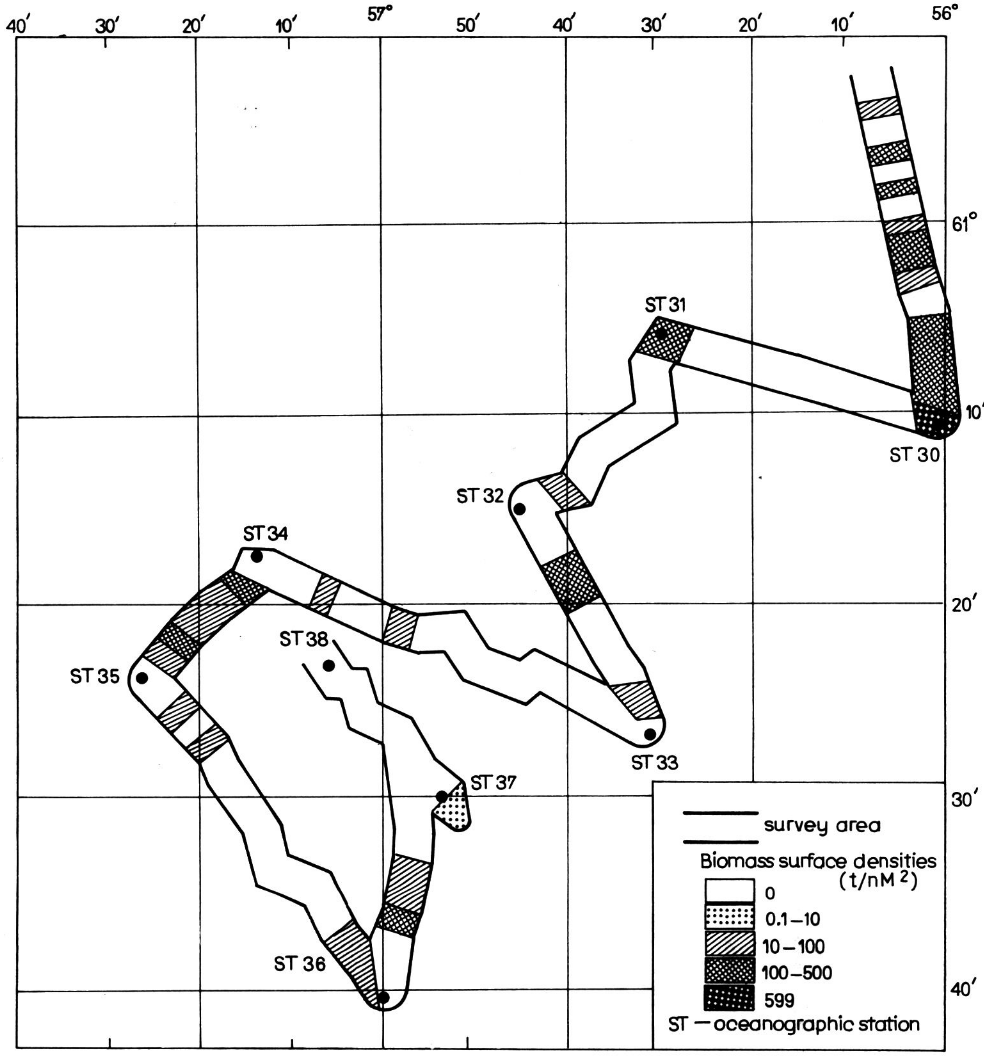

Fig. 2. Distribution of krill biomass density during 30—31 October 1986

linowski (1982) that larger krill swarms of *Euphausia superba* do occur within the limits of frontal zones, especially in areas of meanders and whirls, and especially in these parts where high velocity gradients took place. Similarly Stein and Rakusa-Suszczewski (1984) mentioned that the highest biomass densities occurred in areas of highest differences in the structure of water masses, above the slope of the continental shelf of Antarctic Peninsula. Krill biomass in the searched area was estimated as 26899 t (Kalinowski 1988). The highest densities were recorded in the north-eastern part of the

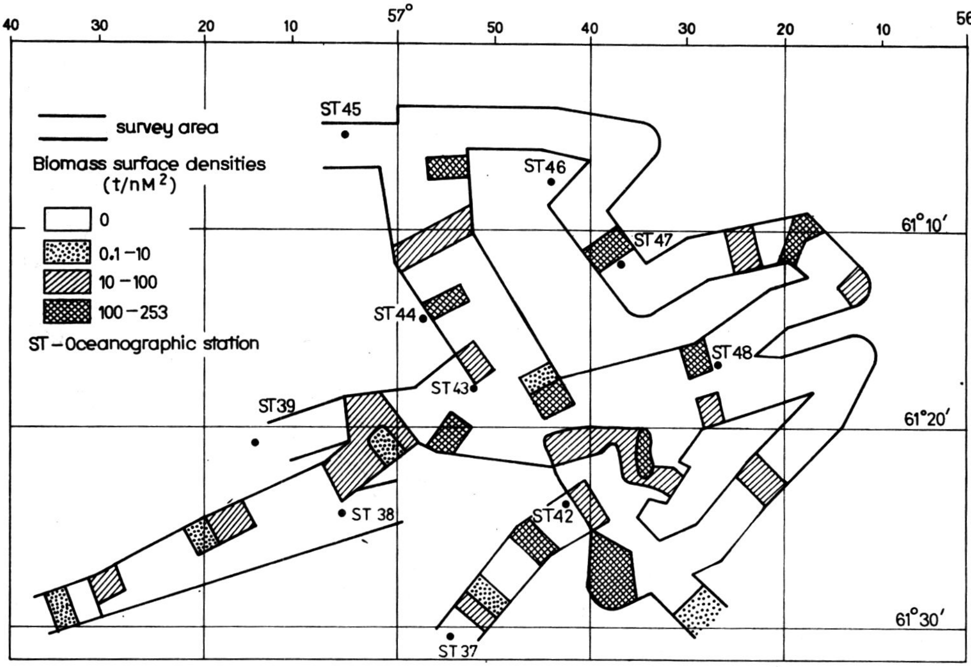

Fig. 3. Distribution of krill biomass density during 31 October — 5 November 1986

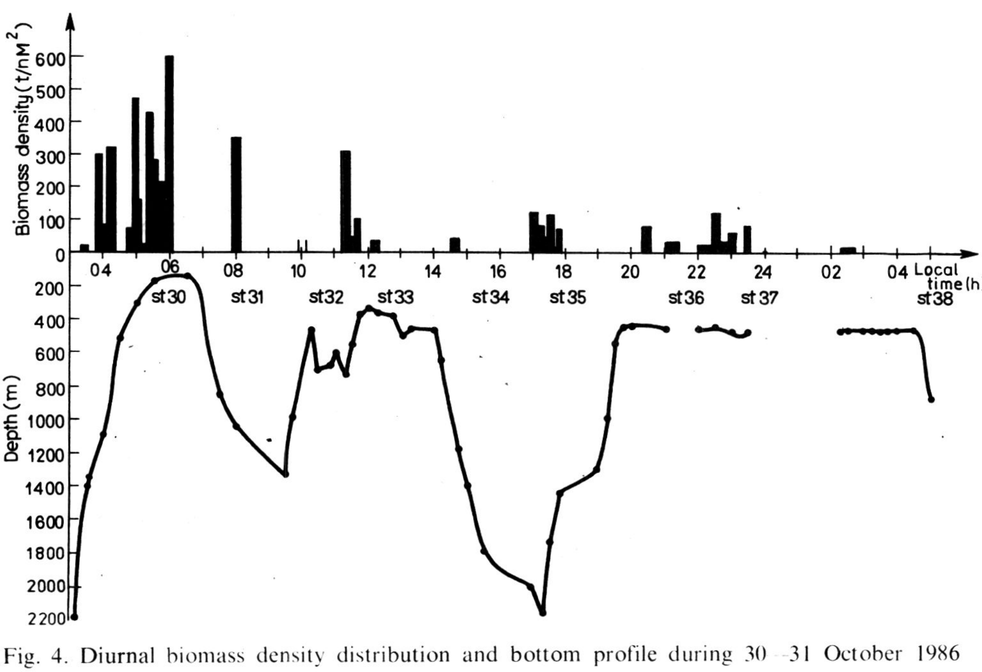

Fig. 4. Diurnal biomass density distribution and bottom profile during 30–31 October 1986

area, between oceanographic stations 29 and 30. The biomass density distribution in relation to the shape of the sea bottom is given in Fig. 4. A steep rise of the bottom between stations 29 and 30, from 2500 to 120 m, obviously affected the character of water flow possibly causing the formation of larger *E. superba* swarms. The results obtained in this part of study allowed to determine the values of physical parameters of swarms. Krill occurred only in swarms of which 62 were recorded. Distribution of their length (d_c) of the area of vertical cross-section (P) and of the density are presented in Fig. 5. They were log-normal distributions and the geometric means for these parameters were 32 m, 206 m^2 and 133 g m^{-3}, respectively. The krill swarms parameters were discussed by Kalinowski and Witek (1981, 1985a). From measurements of 25000 krill swarms they obtained the mean geometrical length of 40 m and density of 72 g m^{-3}, which are values close to those obtained in the presently discussed area.

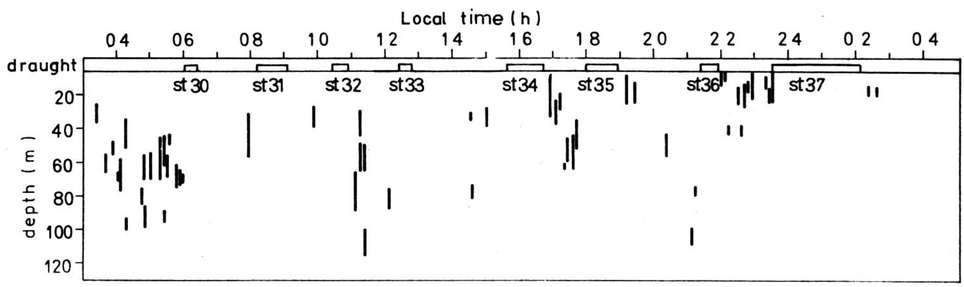

Fig. 5. Diurnal vertical distribution of krill during 30—31 October 1986. Rectangles denote the duration of oceanographic station

The assessment of size and character of krill swarms was a part of the BIOMASS FIBEX 1981 study. The mean arithmetic length of swarms was 73 m and their mean density — 59 g m^{-3} (Table XI of Post FIBEX Acoustic Workshop 1984). As the arithmetic mean is not a good measure of swarm parameters values (Kalinowski and Witek 1985b) it is worthy of note that the geometric mean length of krill swarms found on the basis of Polish investigations amounted to 33 m and mean density — to 90 g m^{-3} (Kalinowski, unpublished). Macaulay, English and Mathisen (1984) observed in 1981 a superaggregation of a density of 5000 g m^{-3} north of Elephant Island which is really extremely high value. Witek et al. (1981) gave 50—90 m as the mean swarm length for the Antarctic Peninsula area, while Kalinowski and Witek (1981) calculated geometric means for the whole Western Antarctic obtaining the values of 72 g m^{-3} in density and 40 m in length. Brinton et al. (1987) noted that during the investigations at the Elephant Island in March 1984 the swarms were dispersed (several hundred meters in width) and not dense (2 to 10 g m^{-3}). Vertical krill swarms distribution is presented in Fig. 6. It is difficult to draw general conclusions on the basis of 24 hour period observations, still it can be noticed a tendence of krill to migrate to the surface in the evening, in accordance to the generally accepted scheme of krill vertical distribution.

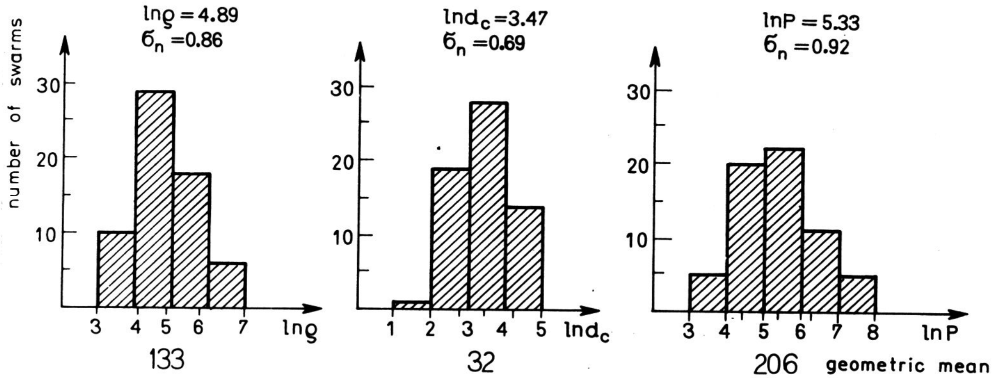

Fig. 6. Frequency distribution of physical parameters of krill swarms; ϱ — density of swarm; d_c — length of swarm; P — vertical cross-section of swarm

This vertical distribution was the subject of numerous papers whose authors stressed various aspects of this phenomenon: Pavlov (1974) pointed out to the significance of feeding and distinguished its 12 hour cycle; Kalinowski (1978) described differences in krill distribution between day and night; Witek et al. (1981) observed that at night krill occurred only in the uppermost 40 m layer and in general in the layer between 10 and 90 m. Kalinowski and Witek (1985b) noted that krill swarms occurred only in the surface water layer and that the thermocline defined the lower limit of their distribution; they stressed the importance of light factor and confirmed the relation between vertical migrations rhythm and feeding. Loeb and Shulenberger (1987) related the changes in krill distribution to environmental factors such as the intrusion of cold waters. Godlewska and Klusek (1987) described this phenomenon using a function whose coefficients were described by krill body length and light conditions; they stressed also the importance of feeding.

In conclusion:

— krill occurred in swarms characterized by the parameter values close to average ones;
— larger aggregations of krill swarms occurred in places of velocity gradients of currents that was related to the sea bottom configuration.

The study was sponsored by the Project C.P.B.P.03.03. of Polish Academy of Sciences.

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Received January 14, 1988
Revised and accepted March 10, 1988

6. Streszczenie

W pracy przedstawiono obraz rozmieszczenia i charakterystykę skupień kryla w pierwszym obszarze badawczym BIOMASS III (Area 1), na zachód od wyspy Elephant. Stwierdzono, że największe gęstości, dochodzące do 500 t/Mm^2, wystąpiły w miejscach nieciągłości przepływającej wody. Kryl występował wyłącznie w rojach o parametrach zbliżonych do przeciętnych; średnia geometryczna długość rojów wynosiła 32 m, a ich średnia gęstość 133 g/cm^3. Przedstawiono również obraz dobowego, pionowego rozmieszczenia rojów kryla.