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Distribution and stocks of krill in the Drake Passage and the Bransfield Strait, during the BIOMASS-FIBEX expedition 1981*)

ABSTRACT: Stocks of krill in the southern part of the Drake Passage and in the Bransfield Strait were estimated by the hydroacoustic method, during the BIOMASS-FIBEX expedition (Febr.-March 1981). Krill stocks in the Drake Passage and Bransfield Strait were assessed at about 1.2 and 2.3 mln tons, respectively. A map of krill distribution in these regions was prepared. The main krill biomass (66%) was found to occur within the Bransfield Strait which accounts for only 13.7% of the total area under survey.

Key words: Antarctic, krill stocks

1. Introduction

Studies of krill stocks in the Antarctic have been performed since many years. Within some relatively small, selected water regions, various investigators have used different methods for assessment of the mean krill biomass per area unit (m^2), whereupon by simple recalculation of this value they obtained the estimated krill biomass per the total area of Antarctic waters. Evidently, there have often been very big differences — between the regions studied — in the mean krill biomass per area unit, and consequently the estimated krill biomass per total area of the Antarctic also assumed very dissimilar values. Everson (1977) has utilized the results of Marr (1962) and estimated the krill biomass at 44.5 mln tons; using the findings of Gulland (1970), Everson (1977) has evaluated the krill stocks at 750 mln tons. Makarov and Ševcov (1972) have assessed them at 953—1350 mln tons, Doi and Kawakami (1979) — at 1200 mln tons, and Kalinowski and Witek (unpublished data) — at 100—400 mln tons. An estimation obtained simultaneously for the total Antarctic would be most reliable; obviously,

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this task could not be accomplished by one or even by several vessels. To attain this purpose, within the research project BIOMASS, the expedition FIBEX was organized, with participation of — among others — the Polish vessel r/v "Profesor Siedlecki". The Polish Survey Zone comprised the Drake Passage and Bransfield Strait (region "A").

The present paper reports the results of an estimation of krill stocks and a map of their distribution within the region under survey, obtained by hydroacoustic studies.

2. Methods

2.1. Research equipment

In studies applying a 24-h hydroacoustic watch system, the following equipment was used:
— EK-120 vertical echo sounder (basic instrument);
— QMMKII analog echo integrator connected with the EK-120 echo sounder;
— EK-38 vertical echo sounder (auxiliary instrument);
— EK-50 net echo sounder;
— DDI digital depth indicator;
— SU2 sonar.

All this equipment is manufactured by the Simrad Co. The hydrolocation system installed on r/v "Profesor Siedlecki" has been described by Burczyński (1973).

The area of the vertical cross-section of the krill aggregation was measured in the echogram with a planimeter, and the length of this aggregation — with a ruler.

Prior to the measurements, the hydroacoustic instruments were calibrated in acoustic and electric units.

For the EK-120 echo sounder, the following settings were applied:
— source level SL — 224 dB//μPa
— voltage response VR — – 101.8 dB//1v/μPa
— working frequency — 120015 Hz;
— bandwidth — 3110 Hz;
— pulse power output — 441 W;
— pulse duration — 0.6 ms;
— range — 0—125 m;
— ceramic transducer (beam width 4.5 deg);
— time-varied gain TVG — 20 log R.

Echo integration was carried out continuously in a 6—130 m water layer.

The geographic position of the vessel was determined by the REDIFON satellite navigation system installed on r/v "Profesor Siedlecki".

2.2. Measurements

Krill stocks were estimated from the measurements of the physical parameters of krill aggregations. For close insight into the estimation method applied, the procedures for measurement of the physical parameters are briefly described.

The term "physical parameters" comprises the length, vertical cross-section area, density and weight of the krill aggregation. These parameters were calculated by the method reported by Olsen (1969), and by Johannenson and Losse (1973). It was assumed that the shape of the aggregation is cylindrical. A vessel flowing over the aggregation moves along some of its vertical cross-section area. According to Olsen (1969), the mean aggregation length d_T (calculated from the echo sounder record) amounts for aggregations of different spherical shapes to $\pi/4$ of the total real aggregation length d_c. Thus:

$$d_c = \frac{4}{\pi} d_T \tag{1}$$

where:

d_c — total real aggregation length (m);

d_T — mean aggregation length recorded by the echo sounder (m).

When calculating the vertical cross-section area of the aggregation, it was assumed that the apparent area of the surface Po, measured from the echogram, equals the area of an ellipse with equivalent surface Po.

On the assumption that one axis of the ellipse equals the length d_c from the formula for the area of ellipse, the height H was calculated.

The aggregation volume was calculated from the formula for the volume of a rotational ellipsoid:

$$V = \frac{4}{3} \pi \left(\frac{d_c}{2} \right)^2 \cdot H \tag{2}$$

where:

V — aggregation volume (m^3);

H — real aggregation height (m).

The aggregation density was calculated from the equation reported by Forbes and Nakken (1972), and by other authors:

$$\bar{\varrho} = 10^{0.1(\bar{S}_v - \overline{TS})} \tag{3}$$

where:

$\bar{\varrho}$ — mean aggregation density (krill individuals/m^3);

$\bar{S}_v$ — mean volume-back-scattering strength (dB);

$\overline{TS}$ — mean target strength of krill (dB).

Krill target strength TS was determined from the formula reported by Kalinowski, Dyka and Kilian (1981).

The volume-back-scattering strength S_v was determined by means of an echo integrator, according to the method given by the manufacturer (Simrad 1972).

When the aggregation volume V, density ϱ and individual krill weight p are known, the aggregation weight W can be calculated:

$$W = \varrho \cdot V \cdot p \cdot 10^{-3} \tag{4}$$

where:

W — aggregation weight (kg);

p — weight of individual krill (g).

From the calculated length d_c and weight W of each aggregation recorded, the krill biomass was calculated at 1-h measurement intervals.

Let's assume that on rout l, n krill swarms, with weights W_1, $W_2, \ldots,$ W_n and lengths $d_{c1}, d_{c2}, \ldots d_{cn}$, were met. In accordance with the assumed model of the aggreagation (rotational ellipsoid), the swarm length d_c equals its breadth. Krill biomass per an area of length l and breadth d_{ci} corresponding to the different aggregations amounts to:

$$\varrho_p = \frac{W_1}{l \cdot d_{c1}} + \frac{W_2}{l \cdot d_{c2}} + \ldots + \frac{W_n}{l \cdot d_{cn}} \tag{5}$$

for $l = 1$ nM

$$\varrho_p = 1.852 \sum_{i=1}^{n} \frac{W_i}{d_{ci}} \tag{6}$$

where:

ϱ_p — biomass (t/nM^2);

W_i — weight of i$^{\text{th}}$ aggregation (kg);

d_{ci} — length of i$^{\text{th}}$ aggregation (m);

n — number of aggregations.

So obtained the biomass values were grouped into the following class intervals (t/nM^2): 0, 0.1—10, 10—100, 100—1000, 1000—10000.

The mean yields of krill cathes in hauls, carried out on r/v "Profesor Siedlecki" in seasons 1975/1976 and 1976/1977, indicate that:

— concentrations involving a biomass up to 100 t/nM^2 are low,

— concentrations with biomass between 100—1000 t/nM^2 are medium, with catch yields of 5—10 tons per hauling hour,

— concentrations higher than 1000 t/nM^2 are high, with catch yields exceeding 10 tons per hauling hour.

3. Results

During the studies performed in the Drake Passage and Bransfield Strait between 14 Febr. — 12 March 1981, a total of 2775 krill aggregations (including 1428 and 1347 aggregations in the Drake Passage and Bransfield Strait, respectively) were measured for estimation of the krill stocks. The total krill biomass in the Polish Survey Zone was assessed at about 3.5 mln tons, with comprising about 1.2 and about 2.3 mln tons in the Drake Passage and Bransfield Strait, respectively (Table I). It is noteworthy that the region with a biomass greater than 100 t/nM^2, i.e. the region promising high catching yields, accounts for only 13.5% of the whole area studied, whereas the region with a biomass above 1000 t/nM^2, i.e. the region with the highest yields, represents only 1.4% of the whole area. This indicates that the main mass of krill accumulates within a relatively small water

Table I.

Assessment of krill stocks in the Polish Survey Region performed during the FIBEX experiment

Region	Biomass interval t/nM^2	Mean biomass t/nM^2 (g/m^2)	Standard deviation	Area nM^2 (% of total survey area)	Total biomass (mln tons)	Standard deviation
Drake Passage	0	0	—	19728 (47.7)	0	—
	0—10	2.08 (0.84)	2.5	15552 (37.6)	0.044790	0.038880
	10—100	38.20 (11.00)	27.8	3456 (8.3)	0.132019	0.096077
	100—1000	277.60 (81.00)	180.7	2448 (5.9)	0.679565	0.442353
	1000—10000	1963.00 (572.00)	1146.0	173 (0.4)	0.339599	0.198258
	total	28.9 (8.4)	—	41357 (86.3)	1.195572	—
Bransfield Strait	0	0	—	144 (1.00)	0	—
	0—10	4.38 (1.3)	2.36	504 (1.20)	0.022080	0.001189
	10—100	37.00 (11.0)	21.00	2880 (6.96)	0.106560	0.060480
	100—1000	321.00 (93.5)	213.00	2592 (6.26)	0.832032	0.552096
	1000—10000	3080.00 (898.0)	2286.00	432 (1.00)	1.330560	0.987552
	total	346.00 (100.0)	—	6552 (13.70)	2.271360	—
Total		72.00 (21.0)	—	47909	3.467332	2.376885

zone. In the course of the FIBEX expedition, the Bransfield Strait was such a zone. It is of interest that during the earlier Antarctic expeditions of r/v "Profesor Siedlecki", krill accumulation was never so big in this zone. An analysis of the krill stock distribution map (Fig. 1) indicates that big krill concentrations in the first place occur over the shelf regions.

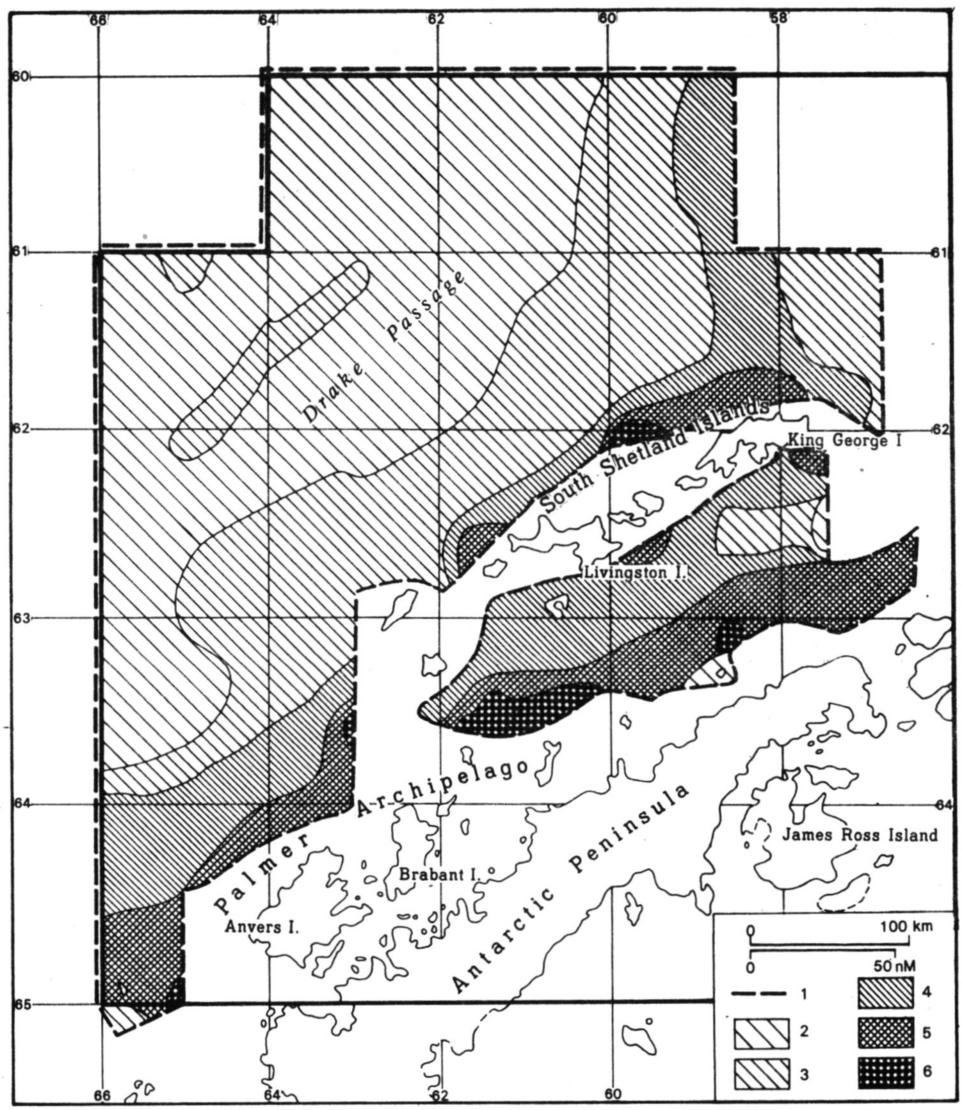

Fig. 1. Distribution of krill biomass (t per nM^2) 1 — survey area, 2 — region without krill, 3 — 0.1 ÷ 10 t per nautical square mile, 4 — 10 ÷ 100, 5 — 100 ÷ 1000, 6 — 1000 ÷ 10000.

4. Discussion

Krill stocks have been studied since a long time by different methods, beginning from the simplest ones (visual observations), through plankton net catches, and ending with hydroacoustic methods applied during the FIBEX expedition. The dissimilarities in the methods result in differences in the accuracy of the results. The hydroacoustic method permitting continuous 24-h observations of waters and applying equipment based on the most up-to-date measurement techniques (echo sounder, echo integrator, computer) provides the most reliable results. Findings of various authors using different measurement methods are presented in Table II. Marr (1962) has estimated

Table II.

Krill biomass estimation by various authors

Author	Biomass density (g/m^2)	Region	Method
Marr (1962)	2.5	Weddell Sea	visual observations, net sampling
Marr (1962)	28.29	South Georgia	visual observations, length measurements, krill from whale stomachs
Pommerantz (1978)	0.0015—123.8 (median 0.83)	Scotia Sea	net sampling
Doi and Kawakami (1979)	129	54°—58° E 65°—66° S	acoustic surveying combined with commercial catches
Kalinowski and Witek (unpublished data)	7.1—25	Western Antarctic	acoustic surveying by means of echosounder echointegrator and krill target strenght measurements
Kalinowski	8.4	Drake Passage	as above
Kalinowski	100	Bransfield Strait	as above

the density of krill and the size of its aggregations by visual observations from a vessel in the Weddell Sea; on the basis of hauls performed at oceanographic stations using plankton nets, he has assumed the mean weight of a single individual to be 0.06 g and then estimated the mean krill biomass at 2.5 g/m^2. However, in the light of Heyerdahl's data of 1932, Marr (1962) has concluded that the above-mentioned weight of a single individual (0.06 g) is very small and cannot be representative of the total Antarctic. Thus, Marr (1962) has assumed after Heyerdahl (1932) that the mean weight of a single individual is 0.72 g; on this basis he has calculated the mean biomass to be 28.29 g/m^2, and suggested that this level may apply to the total Antarctic. Doi and Kawakami (1979) have performed hydroacoustic observations and used the results of industrial catches carried out within an area with coordinates 54°—58° E and 65°—66° S; from these data they have evaluated the mean krill biomass at

129 g/m². Pommerantz (1978)[1]) has estimated the krill biomass from the results of plankton net catches at stations in the Scotia Sea; his results remain within the range of 0.0015—123.8 g/m² and the calculated median is 0.83 g/m³. Kalinowski and Witek (unpubl. data) on the basis of echo sounding and echo integration, performed in the Western Antarctic, have specified the biomass density distribution to be asymetric right — slanting and then calculated the modal biomass amount to 7.1 g/m² and arithmetic mean 25 g/m². It is evident that the dissimilarities between the results of various authors are very great; this is — among others — due to differences in the areas surveyed. The Bransfield Strait or the Japanese Survey Zone (Doi and Kawakami 1979) exhibit very great krill concentrations, whereas the Scotia Sea and Drake Passage are characterized by low ones. The above discussed biomass value in g/m² has been used for estimation of the krill stock in the Antarctic; since this value greatly depends on the area under study, the total krill biomass expressed as the product of the Antarctic waters surface area and mean biomass also differs. Doubtless, the value given by Kalinowski and Witek (unpubl. data) seems to be most reliable for estimation of the total krill biomass in the Antarctic, on account of the very wide area surveyed (Western Antarctic — assumed to be the area from Peter I Island in the Bellingshausen Sea to South Shetland Islands in the Scotia Sea) as well as owing to the up-to-date measurement methods used. According to these authors, krill stocks in the Antarctic may be estimated at the level of 100—400 mln tons.

5. Резюме

В рамках эксперимента ФИБЭКС с 14 февраля по 12 марта 1981 г. в районах пролива Дрейка и пролива Брансфилд была проведена акустическая оценка ресурсов криля с использованием гидроакустической аппаратуры на НИС "Професор Седлецки". Полученные результаты представлены в таблице I, а карта распределения криля изображена на рис. 1. Общие количество криля в исследуемом районе оценено на 3.5 млн. тон, в этом 1.2 млн. тон в проливе Дрейка и 2.3 млн. тон в проливе Брансфилд.

Обнаружено, что основная биомасса криля находится в относительно небольшом по отношению к прослеженному району акватории. Таким районом является пролив Брансфилд, который занимает 13.7% всей поверхности исследований и содержит 66% оцененой биомассы криля.

6. Streszczenie

W czasie trwania eksperymentu FIBEX, w dniach 14 luty—12 marzec 1981, w rejonie Cieśniny Drake'a i Cieśniny Bransfielda, na statku r/v "Profesor Siedlecki", przy użyciu sprzętu hydroakustycznego, przeprowadzono szacowanie zasobów kryla. Wyniki tego szacowania przedstawiono w tabeli I, a mapę rozmieszczenia zasobów na rys. 1. Łączne zasoby kryla w tym rejonie oszacowano na 3,5 mln ton. W tym 1,2 mln ton przypada na Cieśninę Drake'a, a 2,3 mln ton na Cieśninę Bransfielda.

[1]) Pommerantz T. 1978 — Attempts for quantitative studies on the distribution of adult krill *Euphausia superba* Dana in the Scotia Sea — Pap. ICES C. M. 1978/L:5.

Stwierdzono, że podstawowa biomasa kryla występuje na niewielkim w stosunku do przebadanego obszarze wodnym. Takim rejonem w czasie FIBEX była Cieśnina Bransfielda, gdzie na obszarze stanowiącym 13,7% całości było nagromadzone 66% oszacowanej biomasy kryla.

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