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Distribution and stock of krill in the Bransfield Strait and the Drake Passage during December 1983 — January 1984, BIOMASS-SIBEX*)

ABSTRACT: During SIBEX the acoustically evaluated amount of krill in the Bransfield Strait and Drake Passage was very low with the mean density 3.24 individuals/m^2 and 4.29 individuals/m^2 accordingly. Any substanlial quantities of krill were found North-West from the Elephant Island and North from the King George Island, where the density of krill exceeded 1000 individuals/m^2 (about 100 t/nM^2]). The total biomass was estimated at 70590 ton in the Bransfield Strait and at 122470 ton in the Drake Passage, which was many times less than during FIBEX 81, especially in the Bransfield Strait.

Key words: Antarctic, krill, distribution and stock

1. Introduction

The question "how much krill is in the Antarctic and if there is any surplus avalable for fishings", although stated more than twenty years ago has not been answered up to now. The evaluations of the total biomass of krill based on indirect estimations differ by four orders of magnitude. Marr (1962) on the basis of visual observations and net sampling estimated the total biomass of krill in the Antarctic at 521 mln t. Gulland (1970) assumed that krill constitutes 50% of herbivorous zooplankton and that the rate production: biomass is 1:1 and received the figure of 750 mln ton for the total krill biomass. Makarov and Ševcov (1972) on the basis of primary production evaluated total biomass

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of krill to be 953 to 1350 mln t, and Klumov (Lillo and Guzman 1982) also on the basis of primary production gives for the total amount of krill the value 5×10^6 mln t. Evaluations of krill biomass by acoustic methods also differ noticebly. According to Polish measurements made during 5 expeditions in a wide area of the Western Antarctic krill stocks may be estimated at the level 100—400 mln t (Kalinowski and Witek 1981). Doi and Kowakami (1978) on the basis of acoustic survey combined with commercial catches evaluated the total biomass at 1800 mln t. Finally according to preliminary FIBEX data analysis (Hampton 1982) the total biomass of krill is 200—600 mln t.

Lubimova and Šust (1980) on the basis of literature review and the author's own expeditional data have estimated the quantity of krill consumed by baleen whales, seals, birds, cephalopods and fish at 166 mln t and the possible catch (surplus of krill) at 60 mln t. If we assume the rate production: biomass to be between 1:1 and 1:2.5 we will get that Lubimova's estimation of the total krill biomass is close to those obtained by Kalinowski and integrated FIBEX results. The last two should be considered as the most reliable as they were based on the data collected from a great area of the Southern Ocean. From the figures cited above it is clear that at present we are not able to give any exact value for the total biomass of krill. It can be estimated with the tollerance of some hundreds mln t and in light of this the surplus of 60 mln t of krill is rather a matter for further discussions. In account of these difficulties SIBEX has been planned in a different way. It has been limited in area (Bransfield Strait and Drake Passage) but extended in time (two years) to answer the questions about the dynamics of changes in biological and hydrobiological processes. For acoustics it means to find out how great and how guick are the changes in the biomass and its distribution.

In the present paper we show preliminary results of the hydroacoustic investigations concerning the krill distribution and biomass in the Bransfield Strait and Drake Passage during the end of December 1983 and beginning of January 1984.

Papers on vertical krill migrations and swarm structure are in preparation.

2. Methods

2.1. Research equipment

In studies applying 24-hours hydroacoustic watch system, the following equipment was used:

— vertical echo sounder Simrad EK-120
— analog echo integrator Simrad QMMK II

— vertical echo sounder Simrad EK-38
— digital depth indicator DDI

Prior to the measurements, the hydracoustic instruments were calibrated in acoustic and electric units. For the EK-120 echo sounder the following parameters were obtained:

— source level SL — 219 dB/1μPa ref. 1 m
— voltage response VR — −97.4 dB/1 volt per 1 μPa
— working frequency f — 120000 Hz
— pulse duration — 0.0006 s

Echo recording was carried out continously usually in a layer 6—130 m, but the upper limit has been changed up to 12 m depending on the weather conditions. The result of the integratiom was recorded every 1 nM. The auxiliary echo sounder EK-38 was working with the depth scale 0—250 m to see if there were any krill aggregations below the integrated layer 5—130 m. The geographic position of the vessel was determined by the Redifon satellite navigation system.

2.2. Calculations

Estimation of the krill biomass was based on the mean volume backscaterring strenth for 1 nM intervals, which was calculated according to the instruction of the equipment producer (Simrad 1972). The mean surface density of krill i.e. the mean amount of krill individuals per square meter was calculated according to the formula:

$$\varrho = 10^{(0.1(SV + 10\log \Delta R - TS)} \quad (1)$$

where ϱ — mean surface density of krill (individuals/m^2)
SV — mean volume backscattering stregth (dB)
ΔR — thickness of the integration layer (m)
TS — mean target strength of individual krill (dB)

It can be seen from (1) that for calculation of ϱ we need to know krill target strenth TS. In our work TS was calculated using three different relationships:

1) According to the recommendations of the Post-FIBEX Data Interpretation Workshop the relationship between TS and length of krill for frequency 120 kHz is following:

$$TS = -97.2 + 20\log L \quad (2)$$

where L — length of krill in mm.

2) According to laboratory measurements by Kalinowski, Dyka and Kilian (1980), this relation is:

$$TS = 2.3\,L - 72 \quad (3)$$

where L — length of krill in cm.

3) According to the theoretical formula of Johnson (1977) modified by Godlewska (1982):

$$TS = 10\log\left[a^2\left(\frac{1-gh^2}{3gh^2}+\frac{1-g}{1+2g}\right)^2\cdot\frac{2\,(ka)^4}{2+3\,(ka)^4}\right] \tag{4}$$

where: $g = \frac{\varrho_k}{\varrho_w}$ is the ratio of krill density to sea water density

$h = \frac{c_k}{C_w}$ is the ratio of krill sound velocity to sound velocity of sea water

$k = 2\pi f/c$ is the wave number in the medium, f — frequency of the sound

$a = 4\sqrt[3]{3.075\times10^{-3}\,L^{3.3831}}$ is the radius of an equivalent sphere, L-length of krill in mm

Relationship (2) given by Russian investigators in Hamburg in 1981 has been changed afterwords (Protašuk and Lukašova, unpublished) to the following:

$$TS=2.1L-72.3 \tag{5}$$

L-length of krill in cm, which is very close to (3). Nevertheless to make our results comparable with FIBEX data, biomass was calculated from equation (2). For TS calculations, krill length was obtained from the nearest control haul by bongo or RMT.

On the basis of the received values of surface krill density per 1 Nm intervals, the mean values for the area of the Bransfield Strait and the Drake Passage were calculated. To find the mean density of krill biomass in t/nM^2 these values were multiplyed by the mean weight of krill

$$\sigma=\varrho\cdot W \tag{6}$$

where W was calculated according to Jażdżewski et al. (1978):

$$W=0.0018L^{3.3831}$$

and L was taken as a mean length of krill for the whole area i.e. 34 mm.

For graphical presentation of krill density distribution the density values calculated with the formula (3) were devided into four classes (in t/nM^2): 0 — 0.1, 0.1 — 10, 10 — 100 and 100 — 500. The upper limits for the 34 mm long animal correspond to the following values of SV: −94.18 dB, −74.18 dB, −64.18 dB and −57.19 dB. In Fig. 1 the ship track is presented as a 4 nM wide layer with the different designs corresponding to different classes. The value of 4 nM was chosen arbitrary. From Fig. 1 the area of the Bransfield Strait and the Drake Passage was determined by connecting the outer points of the track and measuring the area without islands. The total biomass in the Bransfield Strait and Drake Passage was estimated by multiplying the planimetered areas by the corresponding values of o, i.e.

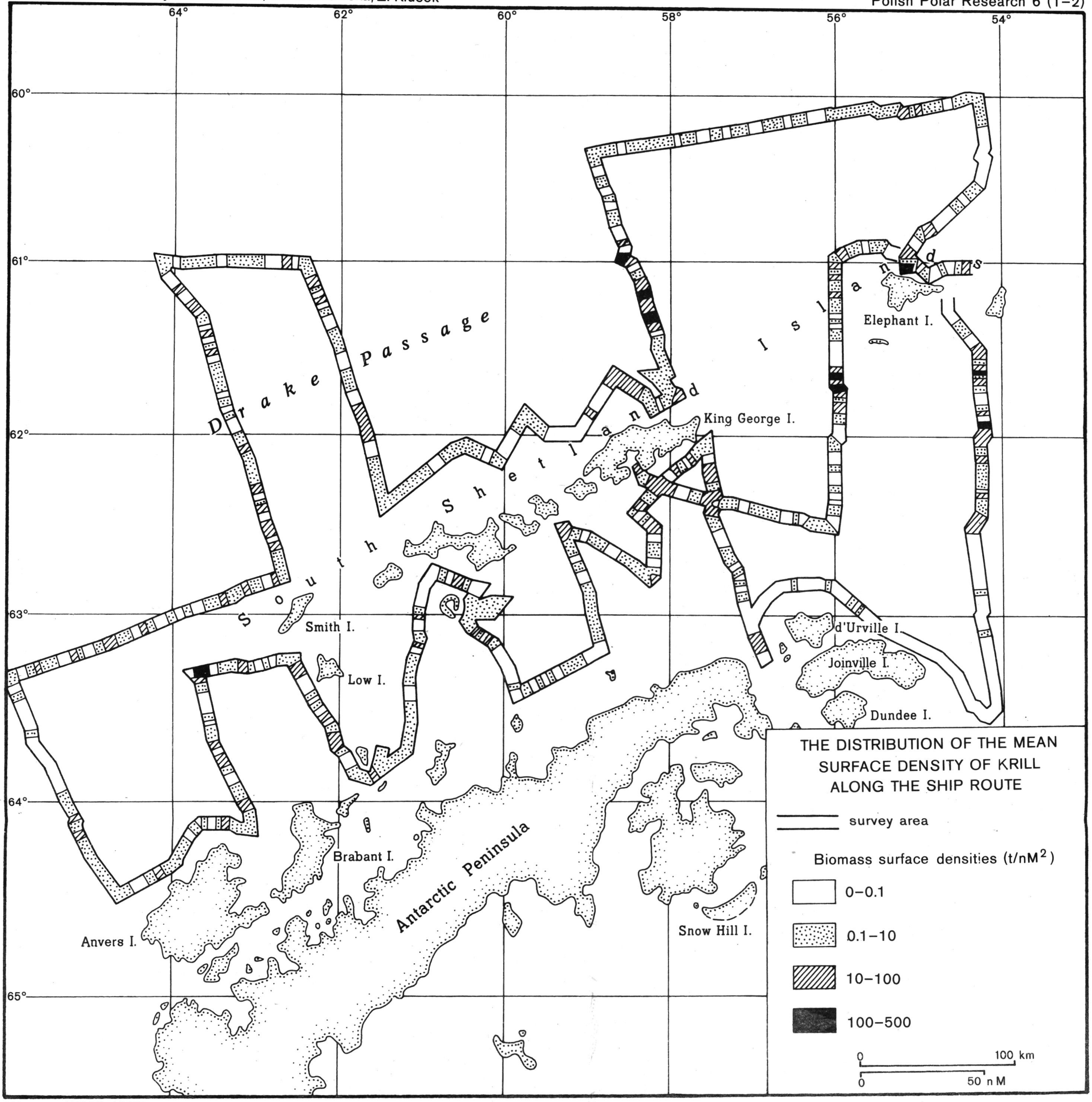

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Fig. 1. The distribution of the mean surface density of krill along the ship route

$$B = \sigma A \quad (7)$$

where σ — mean biomass density in t/nM^2

A — area in nM^2

B — total biomass in t.

3. Results

Echo survey was performed by the r/v "Profesor Siedlecki" from 21 December 1983 to 8 January 1984, along the total ship route of 2100 nM. The distribution of the mean surface density of krill along the ship route is presented in Fig. 1. It can be seen that the largest concentrations

Table I.

The total biomass nd the mean surface density in the Bransfield Strait and Drake Passage for different target strength formulas.

		Bransfield Strait 23269 nM^2	Drake Passage 30488 nM^2
TS = 2.3 L-72 Kalinowski (1980)	Biomass (t)	39654.57	70798.60
	Standard deviation	214029.50	356607.96
	Mean density (ind/m^2)	1.82	2.48
	Standard deviation	110	156
TS = −97.2 +20logL Anon (1981)	Biomass (t)	70593.84	122470.20
	Standard deviation	370709.98	570340.52
	Mean density (ind/m^2)	3.24	4.29
	Standard deviation	330	455
TS theoretical Godlewska (1982)	Biomass (t)	79744.90	136744.09
	Standard deviation	417220.32	635554.43
	Mean density (ind/m^2)	3.66	4.79
	Standard deviation	418	565

of krill were found in the vicinity of the Elephant Island and on the transect to the North from the King George Island. The density of krill in these regions exceeded sometimes 100 t/nM^2. In other parts of the area investigated very low amount of krill was noted and the most frequent krill density would fall in the class 0.1 — 10 t/nM^2. The mean surface density in the Bransfield Strait was 0.26 t/nM^2 and in the Drake Passage 0.34 t/nM^2. The total biomass in these areas was estimated at about 70 thousand t and 122 thousand t, respectively. The values of the total biomass and mean surface density for different TS are presented in Table. I.

Krill aggregations were found mainly in the layer down to 120 m. Below this level krill was observed only ocasionally.

4. Discussion

Let us compare results of two experiments, FIBEX 1981 and SIBEX 1983/84. The area investigated during SIBEX includes Drake Passage and Bransfield Strait up to Elephant Island i.e. corresponds to the FIBEX blocks A1, A2, A3 and A4. During FIBEX very high concentrations of krill (with the mean surface krill density of the order of 1000 t/nM^2) were observed in the vicinity of the Elephant Island (Mathisen and Macaulay 1983), in the Bransfield Strait and on the shelf of South Shetlands in the Drake Passage (Kalinowski 1982). During SIBEX such high concentrations of krill were never met. The largest amount of krill was also found near the Elephant Island, but with the mean surface density seldom higher than 100 t/nM^2. Contrary to what was found in FIBEX the amount of krill during SIBEX in the Bransfield Strait was very low, with the mean surface density two orders of magnitude lower than during FIBEX. The preliminary analysis of FIBEX data at an international data workshop gave the values for the total biomass and surface density of krill presented in the Table II (Hampton 1982). On the basis of the national Polish data the total biomass in the Bransfield Strait (A=6552 nM^2) which correspomds to the block A2 was estimated at 2.3 mln t and in the Drake Passage (A=41354 nM^2) which corresponds to the block A3 at 1.2 mln t. The mean surface density of krill was

Tabela II.

The total biomass and surface density of krill during FIBEX 80/81 (from Hampton 1982)

Block	Biomass (mln t)	Density (t/nm^2)	Area (nm^2)
A1	0.19	10.56	17600
A2	1.32	50.16	26100
A3	0.06	1.65	34900
A4	3.26	304.59	10600

Table III.

The total biomass in the Bransfield Strait and Drake Passage calculated for the areas A2 and A3 using the values of the surface density given by different authors.

Region	Total biomass in mln t		
	Hampton (1982)	Guzman (1982)	Kalinowski (1982)
Bransfield Strait (A2)	1.32	3.99	9.03
Drake Passage (A3)	0.06	2.98	1.01

equal 346 t/nM^2 and 28.9 t/nM^2 accordingly (Kalinowski 1982). From the national Chilean data Lillo and Guzman (1982) estimated the total biomass in the Bransfield Strait (A=5890 nM^2) at 0.9 mln t and in the

Drake Passage ($A = 2082\ nM^2$) at 0.18 mln t, with the mean surface density of krill equal $153\ t/nM^2$ and $85.4\ t/nM^2$ accordingly. We can see that the values indicated by different authors differ noticebly. To make these differencies more clear let us compare the total biomass calculated for exactly the same areas as blocks A2 and A3. The results are presented in Table III. While comapring it must be remembered that these results were obtained with different methods of calculations, for a bit different areas and in a different time. The Chilean meaurements were performed from 28 January to 28 February while the Polish ones were performed from 14 of February to 13 March. Although the FIBEX results given by different authors differ noticebly, they are of the same order of magnitude. The comparison between FIBEX and SIBEX results, especially in the Bransfiel Strait gives differencies in the mean surface density of krill of two orders of magnitude (hundreds times). This show, that the total biomass in the certain region may change from year to year dramatically. It is also worth noting, that the mean length of krill (the biomass is proportional to it in power of 3) during SIBEX was about 10 mm less than during FIBEX.

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5. Резюме

Гидроакустические измерения распределения и биомассы криля в проливе Брансфилда и Проливе Дрейка проводились с н/и судна „Профессор Седлецки" на протяжении 2100 Нм с 21 декабря 1983 по 8 января 1984. Распределение средней поверхностной плотности криля вдоль маршрута судна представлено на рис. 1. Наибольшие концентрации криля превышающие 1000 рачков/м^2 находились вблизи острова Элефант и на север от острова Кинг Джордж. В общем криля было очень мало, средняя плотность в Проливе Брансфилда была 3,24 рачков/м^2 и в Проливе Дрейка 4.29 рачков/м^2. Полная биомасса в обоих районах равнялась соответственно 70590 тон и 122470 т, вместе 193060 тон. Это было на много меньше чем во время ФИБЭКС, особенно в проливе Брансфилда.

6. Streszczenie

Hydroakustyczne badania rozmieszczenia i biomasy kryly w Cieśninie Bransfielda i Cieśninie Drake'a prowadzone były ze statku r/v "Profesor Siedlecki" od 21 grudnia 1983 do 8 stycznia 1984 na trasie 2100 nM. Rozkład średniej powierzchniowej gęstości kryla wzdłuż drogi statku przedstawia rys. 1. Największe koncentracje kryla, przekraczające 1000 osobników/m^2 występowały w okolicach wyspy Elephant i na północ od Wyspy Króla Jerzego. Generalnie kryla było bardzo mało, średnia gęstość w Cieśninie Bransfielda wynosiła 3.24 osobników/m^2 i w Cieśninie Drake'a — 4.29 osobników/m^2. Całkowita biomasa w obu tych rejonach wynosiła odpowiednio 70590 ton i 122470 ton, razem 193060 ton. Było to znacznie mniej aniżeli podczas FIBEX, zwłaszcza w Cieśninie Bransfielda.

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