TARGET STRENGTHS OF KRILL AT 136 AND 20 KHZ

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Abstract

Estimation of krill target strength was made by ensonifying encaged live krill and using trawl hydroacoustic method. Ensonification of encaged live krill. For aggregations with mean lengths from 45 to 50 mm the mean single-krill target strengths range from -68 to -69 dB at 136 kHz. For aggregations with mean lengths from 43 to 47 mm the mean single-krill target strengths range from -71 to -77 dB at 20 kHz. Trawl hydroacoustic method. For aggregations with mean lengths from 47 to 50 mm the mean target strengths ranged from -71 to -75 dB. At the same frequency for aggregations with mean lengths in the range 41 to 47 mm the mean single-krill target strength is in the range -76 to -81 dB.

Résumé

L'estimation de l'intensité de réponse acoustique du krill a été effectuée en ensonifiant le krill vivant en enceinte, par la méthode de chalutage acoustique. Ensonification de krill vivant en enceinte. Pour les concentrations dont les longueurs moyennes varient de 45 à 50 mm, l'intensité de réponse acoustique moyenne d'un individu de krill se situe entre -68 et -69 dB à 136 kHz. Pour celles dont les longueurs moyennes varient de 43 à 47 mm, l'intensité de réponse acoustique moyenne d'un individu de krill s'étale entre -71 et -77 dB à 20 kHz. Méthode de chalutage acoustique. Aux concentrations dont les longueurs moyennes varient de 47 à 50 mm correspond l'intensité de réponse acoustique moyenne située entre -71 et -75 dB. A la même fréquence, les concentrations dont les longueurs moyennes s'étalent de 41 à 47 mm ont pour intensité de réponse acoustique moyenne d'un individu de krill entre -76 et -81 dB.

Резюме

Оценка силы цели криля выполнялась путем облучения живых особей в садке и тралово-акустическим методом. Измерения с помощью садка. Для агрегаций криля со средней длиной рачков в диапазоне 45-50 мм получены средние значения силы цели в диапазоне -68-,-69 дБ на частоте 136 кГц, а для средних длин рачков 43-47 мм - значения силы цели -71,-77 дБ на частоте 20 кГц. Тралово-акустический метод. Для агрегаций криля со средней длиной особей в диапазоне 47,54 мм получены средние значения силы цели в диапазоне -71,-75 дБ, а для средних длин рачков 41- 47 мм - значения силы цели -76,-81 дБ на частоте 20 кГц.

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Resumen

Se calculó la potencia de blanco mediante la insonificación de krill cautivo, con el método de arrastre acústico: Insonificación del krill. Para los grupos de talla media de 45 a 50 mm, la potencia media del blanco de un ejemplar osciló entre -68 y -69 dB a 136 kHz; para las tallas medias de 43 a 47 mm, la potencia del blanco de un ejemplar fue -71 a -77 dB a 20 kHz. Método de arrastre acústico. Para los grupos de talla media de 47 a 50 mm, la potencia del blanco osciló entre -71 a -75 dB. A la misma frecuencia, la potencia media de blanco de un ejemplar de krill de talla media entre 41 y 47 mm fue de -76 a -81dB.

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1. INTRODUCTION

Despite the fact that research into the ability of krill to reflect sound ("reflectability") has been going on for more than ten years, this question is still far from fully understood.

The most recent works of Foote *et al.*, 1990 have identified lower target strengths (by almost 10 dB) compared to those values used until now in biomass estimates as recommended by the Post-FIBEX Workshop (Anon., 1986). With this in mind the CCAMLR Working Group on Krill called for a review of all current works on determination of krill target strength (**TS**) (SC-CAMLR, 1990).

Presented below are previously unpublished results of experimental evaluations of krill **TS** carried out by AtlantNIRO from 1980 to 1985. We feel that these may be useful in general discussion on the question of krill acoustic reflectability.

2. METHODS

Evaluation of krill **TS** was carried out using indirect methods, whereby **TS** calculation is based on recorded values of volume back-scattering strength obtained from ensonified aggregations of krill having a known density either by:

- ensonifying a known number of live caged krill, or
- using trawl hydroacoustic methods.

In this case krill **TS** was evaluated on the basis of the algorithm:

$$\mathbf{TS} = \mathbf{SV} - 10\ \ell g \rho \qquad (1)$$

where
SV - volume back-scattering strength, dB
TS - target strength, dB
ρ - krill mean weight density ($g{\cdot}m^{-3}$)

2.1 Target Strength Estimation of Encaged Krill

Measurements were taken from a vessel standing at anchor where wave strength did not exceed 2 points on the Beaufort scale. Hydroacoustic equipment included a Soviet echosounder "Sargan-E" (operating frequencies 19.7 kHz and 136 kHz), an echointegrator

QM-MK-II (Simrad, Norway), an interface device between the echosounder and the echointegrator and a calibration device with a hydroacoustic transducer.

Calibration was carried out using a device composed of a metal frame in the shape of a truncated pyramid. The hydroacoustic transducer connected to the impulse generator of the "Sargan-E" echosounder was affixed to the top part of the frame and the cage was affixed to the base. The geometrical dimensions of the structure were determined by calculating the directional diagram of the monostatical transducer being used taking into account the shape of the distant difraction zone in the area being measured and the optimal ratio of target sizes to the transducer size:

Operating frequency 20 kHz
- dimensions of the calibration device: height - 1.9 m, length of the base - 2 m
- hydroacoustic transducer (magnetostrictive)
- width of directional diagram at 3 dB - 11° x 28°.

Operating frequency 136 kHz
- dimensions of the calibration device: height - 3.5 m, length of the base - 2 m
- hydroacoustic transducer (piezoceramic)
- width of directional diagram at 3 dB - 10°.

The cage was cubic in shape and was made of netting with a 5 mm mesh size. It was attached by monofilament kapron line in the base of the calibration device.

Individual krill taken straight from catches were used in the experiments. Hauls were carried out by a commercial trawl and were brief, not exceeding from 5 to 10 minutes. Krill specimens were removed from the catch and placed in a container of sea-water. After sorting, groups of various numbers of live, undamaged krill were transferred into other containers of sea-water. The number of these containers corresponded to the number of experiments to be carried out for each set of measurements. Krill were placed in the cage using a funnel. The length of krill in the cage were then measured at the end of each test.

Hydroacoustic calibration was carried out using a standard sphere attached with a monofilament line to the base of the calibration device along the acoustic axis of the transducer. The calibration device was submerged to a depth of about 10 to 15 m over the side of the vessel using a winch. The following standard spheres were used:

- frequency 20 kHz: aluminium, diameter 120 mm, **TS** = -30.92 dB
- frequency 30 kHz: brass, diameter 100 mm, **TS** = -31.04 dB
- frequency 136 kHz: steel, diameter 76 mm, **TS** = -39.6 dB

Target strength of an empty cage was measured prior to assessing krill target strength. The calibration device was lowered to a depth of 10 to 15 m.

TS values for the empty cage and the cage containing krill were recorded 40 minutes after submersion in order to guarantee that the cage had become completely saturated and that there was no air trapped beneath krill carapaces. Each impulse was 1 ms in duration and the length of the integration period was 60 minutes. Integrated readings were recorded every six minutes, which corresponded to the vessel covering one mile at a speed of 10 knots.

2.2 Trawl Hydroacoustic Method

Assessing krill target strength using the trawl hydroacoustic method is based on the comparison of the catch obtained and volume back-scattering strength (**SV**), determined by integrating acoustic signals from krill within the trawl operating area (beneath the vessel).

If the catchability (**P**) of the trawl is known, and assuming that information on the operating area of the trawl (**B**) is completely accurate, the density of krill biomass can be calculated for the trawl swept volume. The trawl operating area (swept volume) **B** is defined as

$$B = L \cdot h_1 \cdot v \cdot \tau \qquad (2)$$

where
- L - horizontal opening between trawl doors (in metres)
- v - trawling speed (metres/second)
- τ - trawling duration (seconds)
- h_1 - vertical operating area of the trawl
- $h_1 = h_t$ at $h_t \leq H$
- $h_1 = H$ at $h_t > H$
- h_t - vertical opening of the trawl (metres)
- H - depth of water column containing relevant species

Density of krill in the swept volume area is defined as (Kasatkina, 1990)

$$Q = B \cdot \rho \cdot m \cdot P \qquad (3)$$

where
- Q - catch per haul (kg)
- B - trawl operating area (m^3)
- m - mean krill weight in the catch (kg)
- P - total trawl catchability
- ρ - mean density in the swept volume ($1/m^3$)

Equation (1) is the working algorithm for determining krill **TS**.

3. RESULTS

3.1 Target Strength Assessment of Encaged Krill

3.1.1 Krill Target Strength at Frequency 20 kHz

Experiments were conducted in the South Orkney area in May, 1983. Krill swarms were taken by a commercial trawl type 67.5/36 m. Trawling speed was 3.5 knots. Krill used in the experiments were selected from catches not exceeding 2 to 3 tonnes.

Krill ranging in size from 30 to 58 mm in length were caught. The modal group was between 41 and 44 mm. The mean length was $\bar{L}$ = 44.7 mm and the mean weight was $\bar{p}$ = 0.55 g. The sex ratio of females to males was 1.56:1. All females had sex organs in the second stage of maturity; the majority of these had been spawn before. Males had also spawn before. Krill intestines contained a very small amount of food.

Seven sets of measurements were made, comprising 19 experiments in which the number of encaged krill varied from 125 to 400 specimens. One trawl sample was taken for each set.

Target strength was only assessed in cases when krill removed from the cage after the test in another container were actively swimming.

3.1.2 Target strength (TS) of the empty cage was -53.06 dB.

Results of krill target strength assessment at a frequency of 20 kHz are presented in Table 1. Cage target strength and the number of specimens in it are abbreviated as **TS** (cage +

number of krill specimens). Table 1 shows the numerical characteristics (assessment of mathematical expectation $\bar{L}$ and standard deviation (**sd**) of length distribution in each experiment. Summary length composition of krill specimens used in the experiment is shown in Figure 1.

3.1.3 Krill Target Strength at Frequency 136 kHz

Experiments were conducted in the Elephant Island area in January, 1985. Krill swarms were taken by a commercial trawl type 72/308m.

Krill length varied from 32 to 59 mm and on average was 47.6 mm. The ratio of females to males was 1.43:1. All males were at the fourth stage of maturity, while females were at Stages III-IV. Krill had been feeding well.

Five sets of measurements were made (15 experiments). Krill target strength was assessed on the results of 11 experiments. The number of encaged krill varied from 76 to 165 specimens.

Target strength (TS) of the empty cage was -51.1 dB.

Results of krill target strength assessment at frequency 136 kHz and parameters $\bar{L}$ and $\bar{\rho}$ for encaged krill are shown in Table 2. Mean lengths of specimens used in the experiment are presented in Figure 2.

3.2 Krill Target Strength Assessment Using the Trawl Hydroacoustic Method

3.2.1 Krill target strength at frequency 30 kHz

Experiments were conducted in the Bouvet Island (December, 1979) and Maude Rise (February, 1980) areas.

In the Bouvet Island area large, mature krill were taken with females predominating over males. The sex ratio was 1:3. Length of specimens varied from 44 to 62 mm, most belonging to size group 50-56 mm (76%). Mean length was 54.6 mm and mean weight was 1.29 g.

Females were at Stage IV of maturity (97.4%). The majority of males (98.7%) were at Stage V.

In the Maude Rise area krill ranging from 30 to 51 mm in length were found in catches. Mean length was 39.55 mm and mean weight was 0.42 g. Sex ratio of females to males was 1:1. Males in catches were mainly immature with 97% being at Stage I. The overwhelming majority of females were immature; 80.4% were at Stage I.

Krill specimens had virtually not been feeding and the intestines were empty.

Krill swarms were fished with a trawl type 67.5/360m. Twenty two hauls were made. Mean values (SV) in the trawl operational area were made using an integrating system composed of an SRM-873 echosounder (Furuno, Japan) and the QM-MK-II echointegrator.

Table 3 shows the results of krill **TS** measurements.

Krill density ρ in the swept volume area is given taking into account trawl catchability. Moreover, results obtained by the author over the period 1983 to 1985 following research into the catchability of the 67.5/360m trawl over a wide range of patterns of targeted krill swarm distribution were used as a basis for **TS** assessments (Kasatkina, 1990).

Table 3 only gives the results of representative hauls for which:

- trawl catchability (P) was able to be determined (from specific data on krill distribution characteristics and trawling regime);

- trawl catchability (P) did not vary over the trawling period as a result of irregularities in the trawling regime, e.g. change in trawling speed, changes in length of trawl ropes as the vessel changes course or changes in trawling depth;

- size composition analysis of krill from the catch was carried out (Table 3, Figure 3).

3.2.2 Krill target strength assessment at frequency 20 kHz

Experiments were conducted in the South Orkney Islands area in May, 1983 and in the South Georgia area in July, 1983.

A biological description of krill samples from the South Orkney Islands area is given above. Krill varying from 35 to 58 mm in length (modal group 47 to 54 mm) were taken in June in the South Georgia area. Mean length of specimens was 49.9 mm and mean weight was 0.814 g.

Males were dominant in the catches and comprised 60%. All males were at Stage II of maturity. Females comprised 40% and were also at Stage II. Krill had been feeding poorly.

Krill swarms were fished with a trawl type 67.5/360m. Mean values (SV) in the trawl operational area were made using a system comprised of a "Sargan-E" echosounder and the QM-MK-II echointegrator.

Results of krill **TS** assessments are given in Table 4 which gives the numerical distributional characteristics of back-scattering cross section (estimate of mathematical expectation $\overline{L}$, standard deviation - sd) and their corresponding boundary target strength values TS_1 and TS_2 (where $TS_1 = 10 \ell g\,(\overline{\sigma}\text{ -sd})/\,4\pi$; $TS_2 = 10\ \ell g\,(\overline{\sigma}\text{ -sd})/\,4\pi$.

Krill size composition is given in Figures 1 to 5.

4. DISCUSSION

As one can see from Tables 1 to 4, the experiments which were conducted have made it possible to assess values of **TS** over a fairly wide range of sizes.

Measurements in a cage. At a frequency of 136 kHz mean **TS** values between -68 and -69 dB were obtained for swarms of krill with an average length of 45 to 50 mm, while at a frequency of 20 kHz target strength values of -71 to -77 dB were obtained for krill with an average length of 43 to 47 mm.

Trawl Hydroacoustic Method. At a frequency of 20 kHz mean **TS** values between -71 and -75 dB were obtained for krill swarms with an average length of 47 to 54 mm, while target strength values of -76 to -81 dB were obtained for krill with an average length of 41 to 47 mm. At a frequency of 30 kHz mean **TS** values between -71 and -82 dB were obtained for krill with an average length of 36 to 50 mm, while target strength values of -69 to -76 dB were obtained for krill with an average length of 53 to 54 mm.

Regression equations for **TS** and **L**, calculated using data in Tables 1 to 4, are shown in Table 5 and their corresponding regression plots in Figures 5 to 7.

It is well known that until now the majority of **TS** assessments have been carried out at 120 kHz (Anon, 1986; Kalinowski *et al.*, 1980; Yudanov, 1986; Foote *et al.*, 1990). Since **TS** of shrimps (and krill) do not greatly depend on frequency in the 100 to 170 kHz range we can compare the values of krill **TS** at 136 kHz with known **TS** values at 120 kHz.

Values for **TS** obtained at f=136 kHz are much lower (by as much as 4 to 5 dB) than **TS** values recommended by BIOMASS (Anon., 1986). One should expect to obtain **TS** values 3 to 5 dB higher than those obtained by Foote (Foote *et al.*, 1990) for krill 30 to 39 mm in length.

TS values assessed at 20 kHz with the use of a cage were higher than **TS** values obtained using the trawl-acoustic method both at 30 kHz, which is clearly contrary to the character of frequency dependence of krill **TS** (Samovolkin, 1980; Dalen, Kristansen, 1981), and at 20 kHz (Figure 7).

These highlighted differences in krill **TS** assessment may be attributable not only to biases in measurements but also to differences in biological condition and length composition of the ensonified krill swarms.

In our view, the large increase in krill **TS** at 30 kHz where specimens were 53 to 54 mm in length (Bouvet Island area: large mature krill; more females than males; Stages IV and V of maturity) in comparison to **TS** where krill length was from 40 to 50 mm (Maude Rise area: immature krill, sex ratio 1:1, Stage I of maturity) can to a large extent be attributed to the influence of such biological parameters as stage of sexual maturity, sex ratio and degree of stomach/intestinal fullness (Figure 8, Table 3).

It should be recalled that the nature of dependence between **TS** and the parameter L/λ (λ = wave length) excludes the possibility of such a divergence in **TS** values, while at the same time allowing a gradual increase in **TS** in the range $L/\lambda = 7 \div 12$ (Samovolkin, 1980; Andreeva and Samovolkin, 1986).

5. CONCLUSION

Experiments carried out demonstrated the dependence of krill **TS** on frequency of ensonification, length and biological condition of the specimens involved.

In general the assessments obtained for **TS** were lower than those recommended by BIOMASS but higher than those presented by Foote *et al.* (1990).

The low technical level of equipment used in experiments carried out in the period 1979 to 1985 somewhat reduces the reliability of **TS** assessments presented.

Given the current state of knowledge, we believe that the most representative experimental assessments of krill **TS** for small-sided krill are those carried out by Foote (Foote *et al.*, 1990). However, the necessity to apply **TS** data on krill to the calculation of its biomass means that research is still required into target strength in relation to biological condition and length composition of krill aggregations as well as the time of day, in order to take into account possible daily changes in **TS** (e.g. changes in krill's spatial orientation).

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Table 1: Results of krill target strength assessment at 20 kHz. South Orkney Islands area, May 1983.

Experiment No.	No. of Krill in the Cage	TS (cage + krill), dB	Krill TS, dB	Krill Length	
				$\bar{L}$ (mm)	sd
1	288	-52.0	-76.6	43.0	4.1
2	350	-45.1	-71.25	47.1	4.2
3	190	-48.3	-72.86	46.5	4.0
4	285	-48.6	-75.0		
5	400	-49.1	-77.37		
6	220	-48.7	-74.09		
7	400	-49.1	-77.37		
8	115	-49.5	-72.58	47.1	4.2
9	380	-46.6	-73.43		
10	230	-49.3	-75.24	44.7	4.8
11	350	-48.9	-76.36	44.0	4.3
12	300	-49.2	-76.16	43.9	4.1
13	200	-47.8	-72.36	45.3	4.0
14	125	-50.34	-71.3	45.3	4.1

Table 2: Results of krill target strength assessment at 136 kHz. Elephant Island area, January 1985.

Experiment No.	No. of Krill in the Cage	TS (cage + krill), dB	Krill TS, dB	Krill Parameters		
				$\bar{L}$ (mm)	sd	$\bar{\rho}$
1	100	-45.99	-68.10	47.1	4.78	0.762
2	85	-46.63	-68.50	46.5	3.39	0.742
3	80	-48.18	-68.07	47.1	4.77	0.778
4	165	-44.81	-68.50	46.4	4.15	0.726
5	140	-45.57	-68.90	46.3	3.85	0.655
6	76	-46.88	-68.48	47.1	4.78	0.764
7	107	-45.68	-67.91	48.9	3.62	0.846
8	99	-46.84	-68.84	45.9	3.99	0.684
9	105	-45.80	-68.05	47.7	4.86	0.811
10	130	-45.71	-68.81	45.1	3.65	0.600
11	117	-45.80	-68.46	46.2	3.51	0.694

Table 3: Results of krill target strength assessment at 30 kHz. Trawl-acoustic method.

Ship Time at Setting of Trawl	Krill Density in Swept Volume ($\rho \cdot m^{-3}$)	Back-Scattering Strength SV, dB	TS, dB	Krill Parameters		
				$\bar{L}$ (mm)	sd	$\bar{\rho}$
Bouvet Islands area (December 1979)						
8:50	1.43	-69.7	-71.8	53.6	4.8	1.22
11:10	5.6	-67.7	-75.7	53.7	4.9	1.1
16:20	1.3	-74.3	-75.4	53.9	3.9	1.19
20:30	0.14	-77.5	-69.0	54.2	5.7	1.23
Maude Rise area (February 1980)						
7:30	3.6	-72.5	-78.3	47.3	3.9	0.97
8:45	1.24	-70.0	-70.9	50.0	5.1	0.97
10:15	16.2	-70.3	-82.2	46.4	4.1	0.77
17.35	2.4	-71.7	-75.5	47.7	3.9	0.69
5:10	3.49	-74.7	-80.1	38.1	3.1	0.42
10:00	164.6	-60.3	-82.4	36.0	3.1	0.25

Table 4: Results of krill target strength assessment at 20 kHz. Trawl-Acoustic Method.

Area	σ (m^2)	sd (m^2)	TS, dB	TS_1	TS_2	Krill Parameters		
						$\bar{L}$ (mm)	sd	$\bar{\rho}$
May 1983 S. Orkneys	2.08×10^{-7}	1.0×10^{-7}	-77.8	-80.7	-76.1	44.7	3.0	0.56
June 1983 S. Georgia	7.39×10^{-7}	3.25×10^{-7}	-72.3	-74.8	-70.7	49.9	5.0	0.815

Table 5: Regression equations between krill target strength (TS, dB) and krill length (mm), Maude Rise area.

Method	Frequency (kHz)	Regression equation	Correlation coefficient
Encaged krill	136	TS = 0.39L - 86.50 (4)	0.87
Encaged krill	20	TS = 1.27L - 131.30 (5)	0.84
Trawl-Acoustic Method		TS = 1.1L - 127.3 (6)	0.79
Trawl-Acoustic Method		TS = 0.5L - 99.30 (7)	0.72

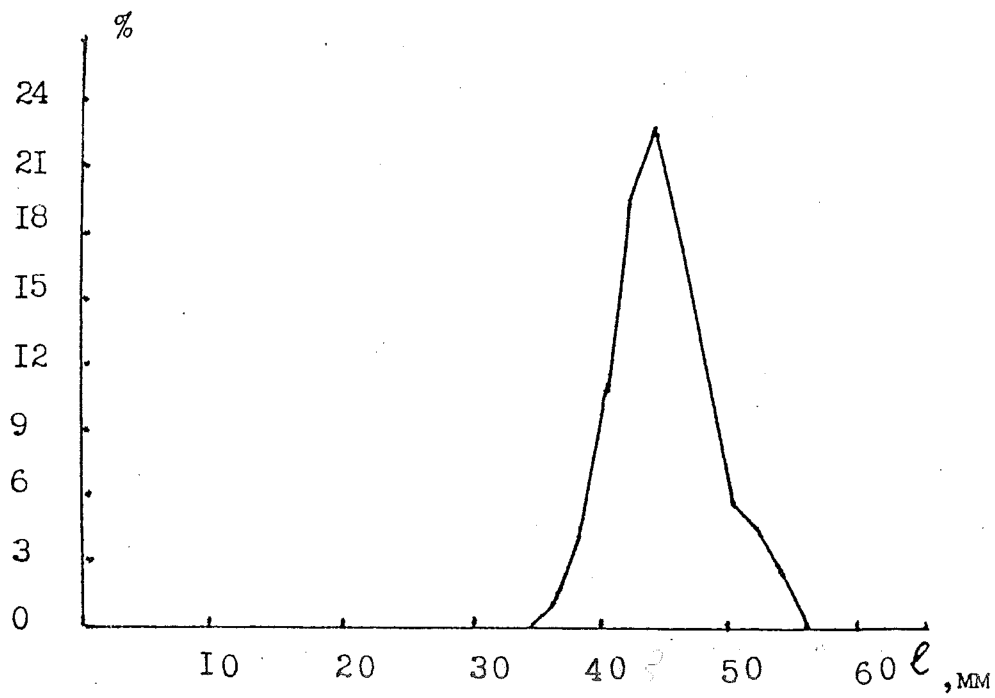

Figure 1. Krill length composition. South Orkney Islands area. May, 1983.

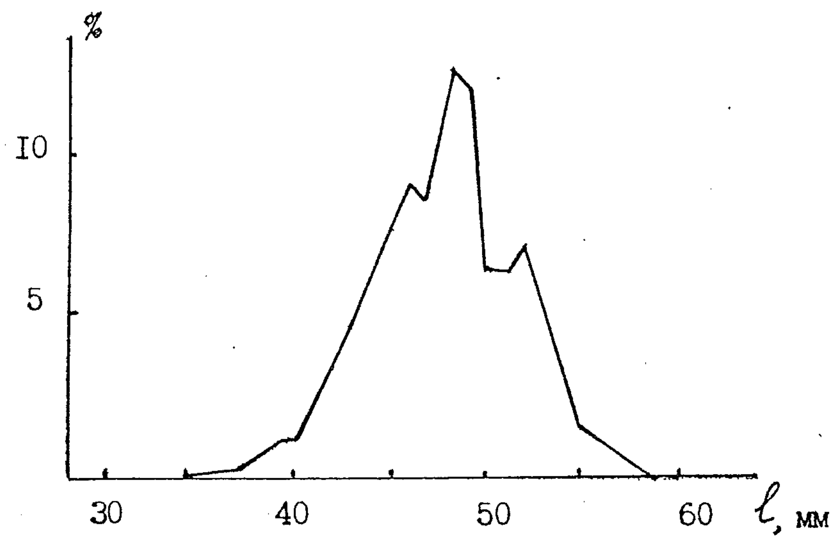

Figure 2. Krill length composition. Elephant Island area. January, 1985.

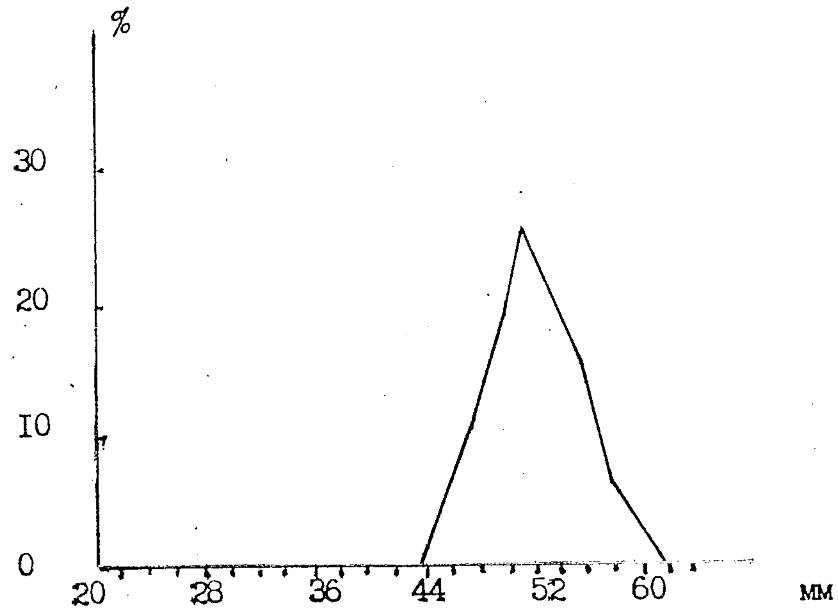

Figure 3. Krill length composition. Bouvet Island area. December, 1979.

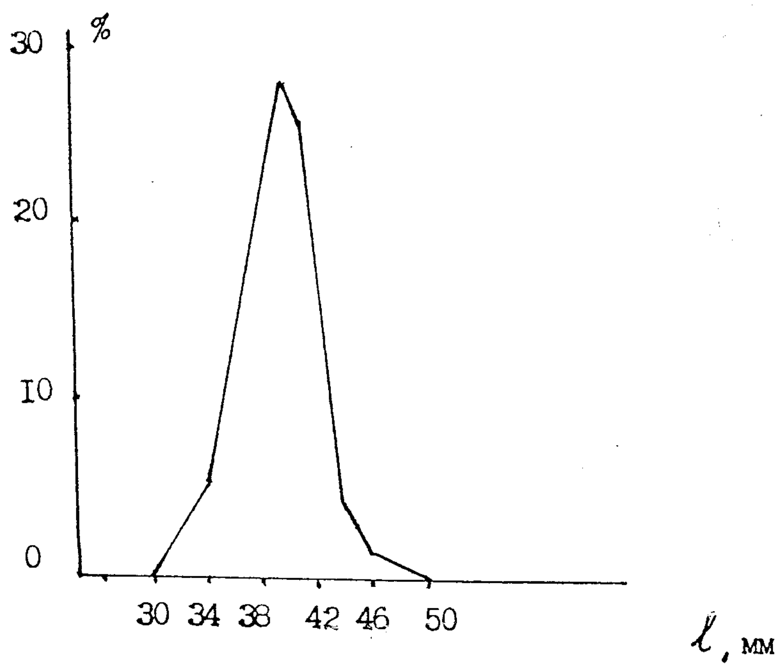

Figure 4. Krill length composition. Maude Rise area. February, 1980.

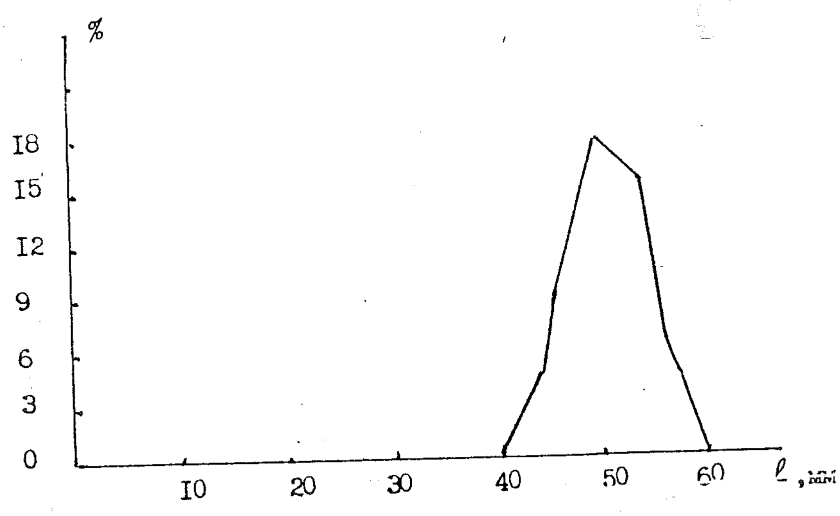

Figure 5. Krill length composition. South Georgia area. June, 1983.

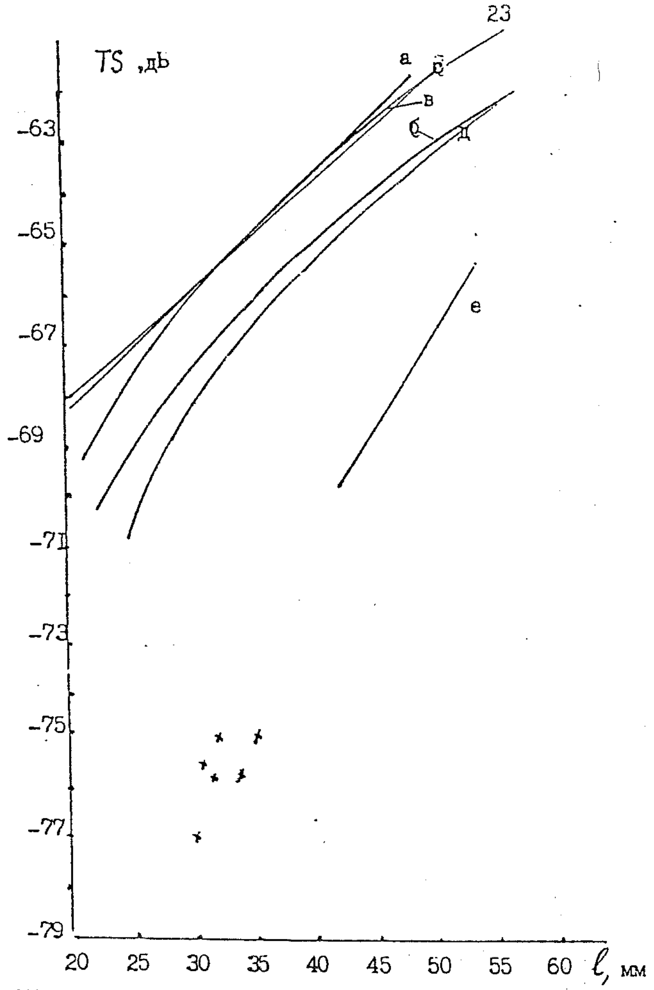

Figure 6. Krill target strength at 120 and 136 kHz.

a	-	Kalinowski *et al.* (1980)
b	-	Yudanov (1986)
c	-	Protaschuk, Lukashova (1986)
d	-	Anon. (1986)
e	-	Godlewska (1982)
f	-	Kasatkina, 136 kHz
×	-	Foote *et al.* (1990)

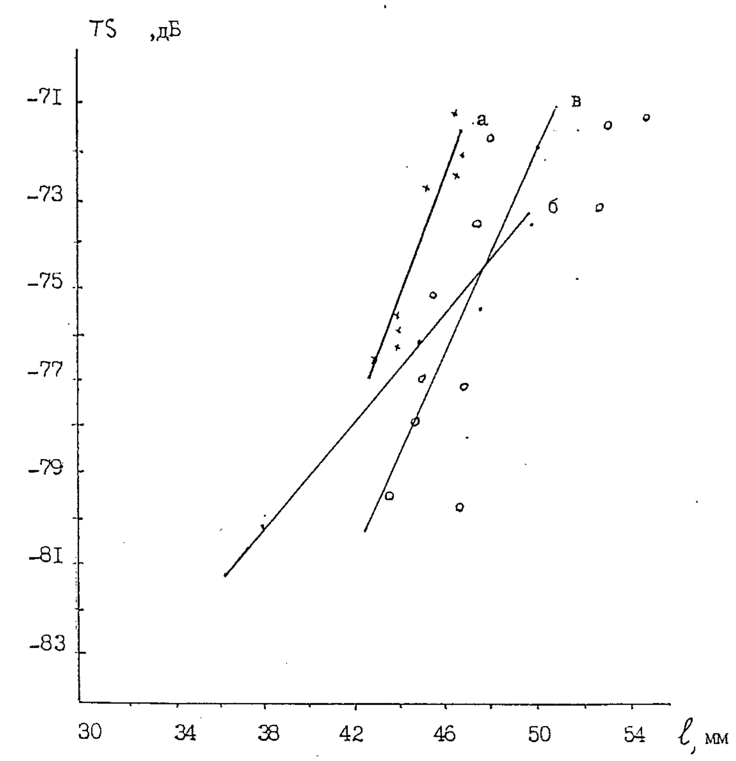

Figure 7. Results of krill target strength assessments at 20 and 30 kHz.
a - frequency 20 kHz (encaged krill)
b - frequency 30 kHz (trawl-acoustic method)
c - frequency 20 kHz (trawl-acoustic method)
× - experimental measurements at 20 kHz (encaged krill)
• - experimental measurements at 30 kHz (trawl-acoustic method)
o - experimental measurements at 20 kHz (trawl-acoustic method)

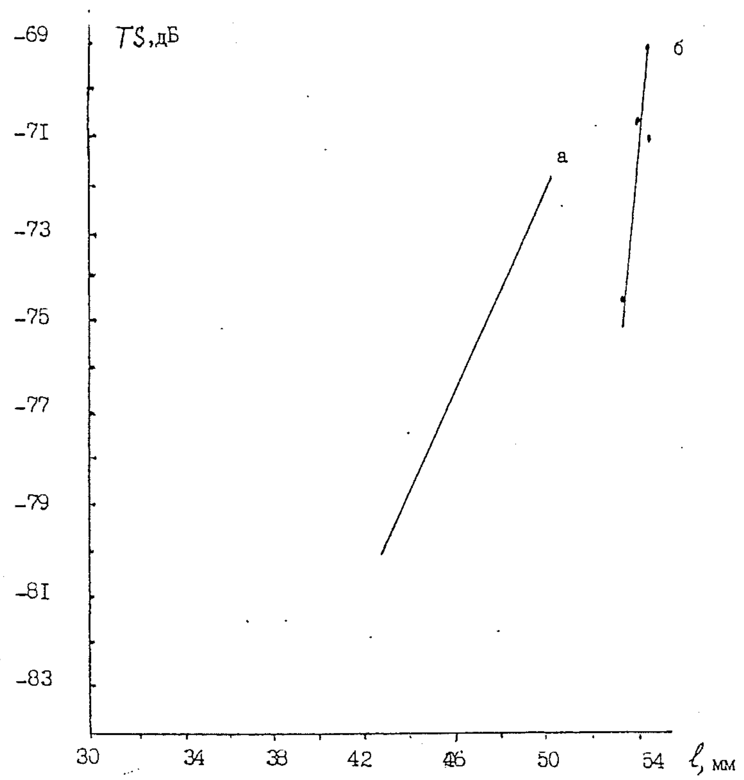

Figure 8. Results of krill target strength assessments at 30 kHz.
a - Maude Rise area, February, 1980 (trawl-acoustic method)
b - Bouvet Island area, December, 1979 (trawl-acoustic method)

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras