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TARGET STRENGTH OF KRILL *IN SITU* AT THE FREQUENCY OF 200 KHZ

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Abstract: The acoustic survey for krill (*Euphausia superba*) was carried out in the Indian Sector of the Southern Ocean by the R. V. KAIYO MARU participating in SIBEX I 1983–84. In order to estimate the biomass from the mean volume back-scattering strength ($\bar{S}_v$) measured by the 200kHz echo sounder Furuno FQ-50, the mean target strength ($\overline{TS}$) of krill *in situ* at the same frequency was estimated in the area surveyed.

The $\overline{TS}$ was obtained from both density and $\bar{S}_v$ for the krill aggregation in the natural conditions. The density was estimated by means of the echo sounder Furuno FE-101 which possesses a resolution at 455 kHz high enough to detect the individual krills; the volume of water insonified by the beam was estimated from the recorded duration of the echo traces, and the number of krill in the volume was obtained by counting the echo traces.

Two experiments to estimate the $\overline{TS}$ were made about 1 hour before sunset, on board the vessel drifting over the aggregation spreading near the surface. The mean densities estimated from the experiments were 50.0 and 61.6 individ./m^3. The corresponding $\bar{S}_v$ were -51.0 and -50.4 dB, respectively. The mean wet weight of the krill samples from the aggregation was 0.62 g. An estimate of the $\overline{TS}$ of 0.62 g krill was -68.1 dB. The $\overline{TS}$ per kg was calculated as -36.0 dB.

1. Introduction

The acoustic survey aiming at clarifying the distribution of krill (*Euphausia superba*) and estimating the biomass of the species was carried out by the R. V. KAIYO MARU, Japan Fisheries Agency, participating in SIBEX I (Phase I of the Second International BIOMASS Experiment 1983–84). The outline of the acoustic survey was described by SHIRAKIHARA *et al.* (1986). In order to estimate the absolute biomass from the acoustic data measured by the 200 kHz echo sounder, it was essential to have the mean target strength ($\overline{TS}$) at this frequency. This paper, as one of the KAIYO MARU SIBEX I acoustic studies, refers to the $\overline{TS}$ estimation in the area surveyed.

2. Methods

The $\overline{TS}$ was obtained from both density and mean volume back-scattering strength ($\bar{S}_v$) for the krill aggregation in the natural conditions.

2.1. *Acoustic equipments*

Two echo sounders were used. The first used for estimating the density was Furuno FE-101 which possesses a resolution as high as 1.5 cm at 455 kHz and can record an echo trace of a single krill on the echogram. The second used for measuring the $\bar{S}_v$ was Furuno FQ-50. The operation condition of these echo sounders and the directivity pattern of FE-101 are shown in Table 1 and Fig. 1, respectively.

Table 1. Operation condition of two echo sounders, Furuno FE-101 and Furuno FQ-50.

FE-101	
Frequency	455 kHz
Range	0–10 m (from the transducer)
Pulse duration	20 μs
Pulse repetition rate	470 ppm
Pulse repetition period	0.128 s
Chart speed	60 mm/min
Gain adjustment	max (10)
FQ-50	
Frequency	200 kHz
Equivalent beam width	0.007 sr
Pulse duration	0.6 ms
Depth range	8–18 m
Depth channel	8–18 m (10 channels, 1 m interval)
Attenuator	20 dB
Threshold	10 dB
TVG	20 log R
Gain constant	93.8 dB
$\bar{S}_v$ mode	arithmetic mean of 100 transmissions
Draft correction	5 m

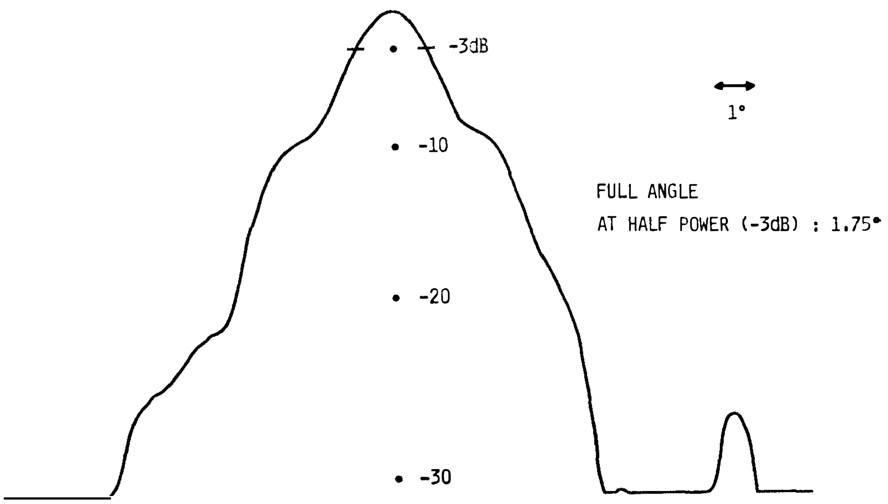

Fig. 1. Directivity pattern of the transducer of the echo sounder FE-101.

2.2. *Principle of $\overline{TS}$ experiments*

The $\overline{TS}$ can be obtained under the following conditions schematically shown in Fig. 2;

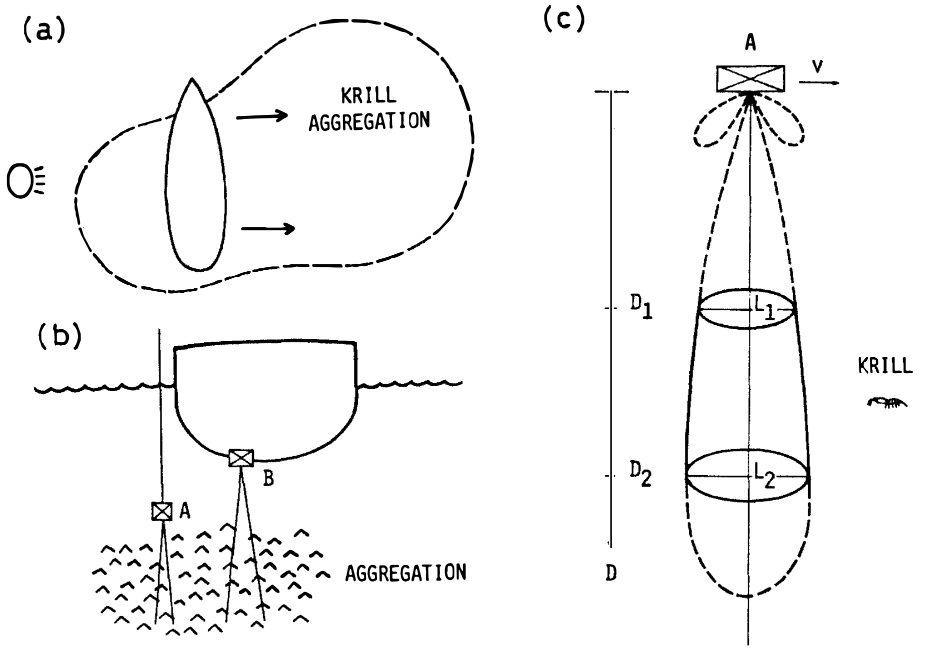

Fig. 2. Scheme of the experiments to estimate the target strength of krill in situ. (a) Vessel drifting over the aggregation. (b) Transducers of two echo sounders; A: FE-101, B: FQ-50. (c) Threshold beam and sampling volume of FE-101.

(a) The vessel is drifting at a constant speed over an aggregation of krill at a standstill when the sea is calm.

(b) A single krill to be measured is located at the depth where the effect of the side lobe of FE-101 is negligible.

(c) Individual krills are distributed uniformly with a low density.

To obtain the density from the echogram of FE-101, it is required to estimate the sampling volume of water where a single krill can be detected by the sounder. The volume is estimated by the threshold beam for krill; a single krill is detectable within it and not detectable outside it. From measurement of the echo traces of krill appearing in the center of the beam, the diameter of the beam is estimated from;

$$L(D)=(t_{\max}(D)+t_{\mathrm{p}})v\ , \qquad (1)$$

where L is diameter, D is distance from the transducer, $t_{\max}$ is maximum recorded duration of a single echo trace, t_{p} is pulse repetition period, and v is drifting speed of the vessel. The echo traces of krill appearing in the center are to be clearly recorded with the maximum duration. Then the beam diameter will be certainly given by the product of the maximum duration and drifting speed if the pulses are transmitted without interruption. But the transmission is actually made with a definite repetition period and the echo traces are recorded synchronously. The value of t_{p} is added for this correction. If the maximum recorded duration is longer enough than the pulse repetition period, the beam diameter can be approximately given by eq. (1). Then the beam volume (V) in the distance range of D_1–D_2 is calculated from;

$$V=\frac{\pi}{4}\int_{D_1}^{D_2} L^2(D)\,\mathrm{d}D\,. \qquad (2)$$

The number of krill in the beam is given by counting the echo traces. The mean number is obtained by averaging some counts at the instantaneous time. Then the mean density ($\bar{n}$) is estimated from;

$$\bar{n}=\bar{N}/V\,, \qquad (3)$$

where $\bar{N}$ is mean number of krill in the volume V.

Under the condition (c), the total echo intensity from the aggregation is equal to the arithmetic sum of echo contributions from individual krills (JOHANNESON and MITSON, 1983). Then the mean target strength in dB is estimated by combining $\bar{S}_v$ and $\bar{n}$ from the aggregation, as follows;

$$\overline{TS}=\bar{S}_v-10\log\bar{n}\,. \qquad (4)$$

If the mean weight of a single krill in the measured aggregation is known, the mean target strength per kg in dB ($\overline{TS}_{\mathrm{kg}}$) is calculated from;

$$\overline{TS}_{\mathrm{kg}}=\overline{TS}_{\bar{w}}-10\log\bar{w}+30\,, \qquad (5)$$

where $\bar{w}$ is mean weight in gram and $\overline{TS}_{\bar{w}}$ is mean target strength of krill with the weight of $\bar{w}$, equivalent to $\overline{TS}$ in eq. (4).

2.3. *Actual experiments*

The krill aggregation spreading near the surface was seized near a point of 58°13′S and 72°29′E, for the period of 20–22 hours on 29 January 1984 (sunset: 2226). Two experiments to estimate the $\overline{TS}$ were made when krill was distributed fairly uniformly. The periods and depth ranges were 2117–2120 and 13.5–14.5 m for the first experiment, and 2127–2129 and 12–13 m for the second. Just after the experiments, the aggregation was sampled using the KAIYO MARU Midwater Trawl with mesh size of 3.4 mm to determine the mean weight and length of the individuals. The temperature at the depth of the transducer of FQ-50 was 1.1°C, wind was ESE and 3 in Beaufort scale, sea condition was 2, and current was 270° and 0.03 kn.

The drifting speed was estimated from the shift of vessel position, which was observed using the Navy Navigation Satellite System with the error of less than ± 0.05 nautical mile. Measurement on the echogram of FE-101 was carried out carefully with the low magnification ($\times 10$) microscope. The reading error of $t_{\max}$ was less than ± 0.05 s.

It was clarified that the measured $\bar{S}_v$ was sensitive to the water temperature at the depth of the transducer of FQ-50 (FURUNO ELECTRIC CO., LTD., 1984). Following SHIRAKIHARA *et al.* (1986), the $\bar{S}_v$ was corrected by;

$$\bar{S}_v(\text{corrected})=\bar{S}_v(\text{measured})+5.4\,. \qquad (6)$$

3. Results

3.1. Drifting speed of the vessel

The vessel positions observed were 68°13.0′S, 72°30.6′E at 2043 and 68°13.4′S, 72°29.3′E at 2134. The drifting speed was estimated to be 0.365 m/s with the error less than ±0.061 m/s in the direction of 230°.

3.2. Density and spatial distribution of the krill aggregation

The echogarms of FE-101 in two experiments are shown in Fig. 3. The estimated beam diameters are shown in Fig. 4. Assuming the diameters (L in meter) is a linear function of the distance (D in meter) in the range of 2.7–5.2 m, the regression analysis gave the following equation;

$$L(D)=0.0493D+0.0928\,, \tag{7}$$

where sample size was 27 and correlation coefficient was 0.902. Then the beam in the range of the measured distances was approximated to a truncated cone. The beam volume (V) and mean number of krill in the V were obtained as shown in Table 2. The mean densities were estimated to be 50.0 individ./m^3 for the first measurement and

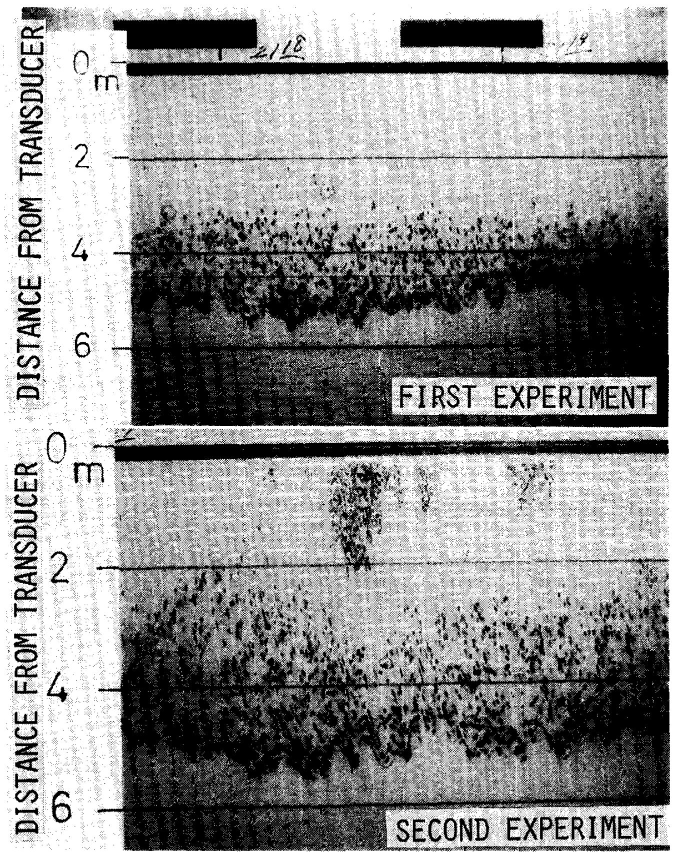

Fig. 3. Echograms of the echo sounder FE-101 in two experiments. The points on the echograms indicate the echo traces of individual krills.

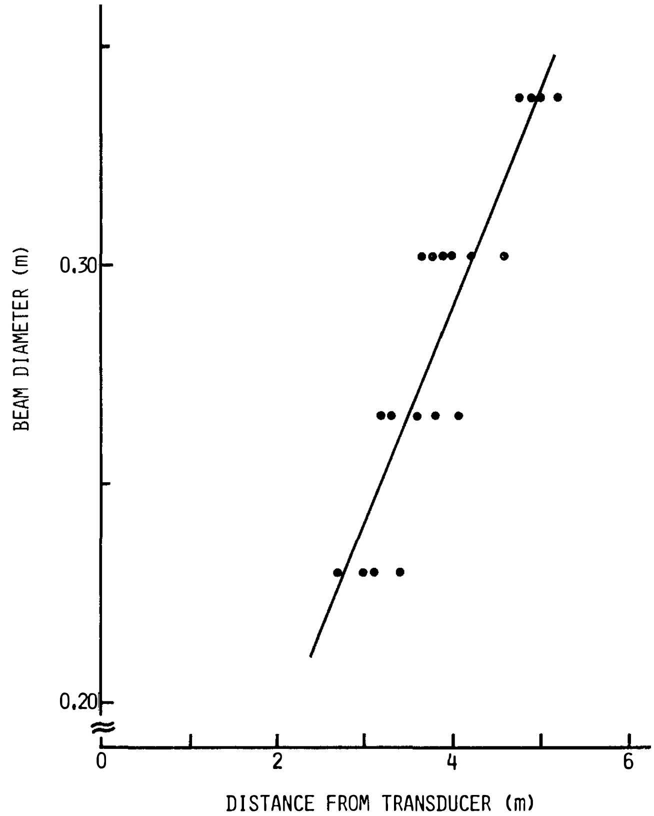

Fig. 4. Relation between the distance of the transducer and the beam diameter of the echo sounder FE-101.

Table 2. Krill densities estimated from the ecogram of FE-101. Numerals in parentheses are upper or lower distances from the transducer.

		First experiment	Second experiment
Depth of the transducer	(m)	10	9
Beam diameter	(m)	0.266 (3.5)	0.241 (3.0)
Beam diameter	(m)	0.315 (4.5)	0.291 (4.0)
Beam volume	(m^3)	0.0664	0.0557
Krill number in the volume (individ.)			
Mean		3.32	3.43
Standard deviation		1.19	1.20
Sample size		56	53
Density	(individ./m^3)	50.0	61.6

61.6 individ./m^3 for the second. These estimates were likely to belong to the category of low densities in the possible range of the aggregation density of 10–60000 individ./m^3 (MAUCHLINE, 1980).

The type of the spatial distribution was investigated to obtain information on the condition (c). The uniformity was checked by χ^2 test (ELLIOTT, 1977) using the statistics of krill number (Table 2). Since the variance to mean ratio was less than unity at the 5% level of significance, the distribution of the measured krill was rather uniform than random.

3.3. *Mean volume back-scattering strength*

The echograms of FQ-50 in two experiments are shown in Fig. 5. The $\bar{S}_v$ corrected by eq. (6) is shown in Table 3. The means of $\bar{S}_v$ were -51.0 dB for the first experiment and -50.4 dB for the second.

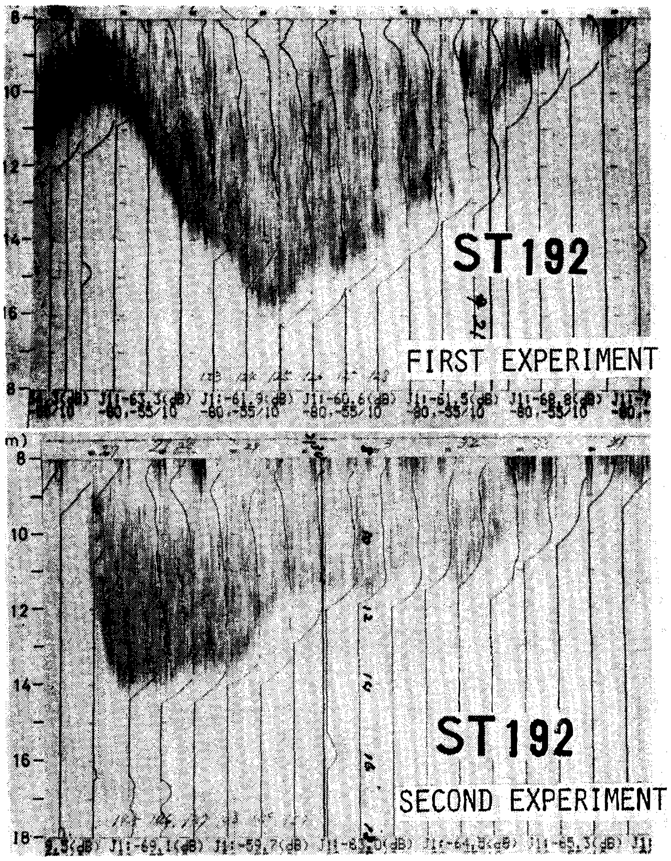

Fig. 5. Echograms of the echo sounder FQ-50 in two experiments.

Table 3. The mean volume back-scattering strength in dB. Symbol CV is coefficient of variation.

First measurement			Second measurement	
Time	Depth (m)		Time	Depth (m)
	13-14	14-15		12-13
2117	−50.1	—	2127	−50.5
2118	−52.3	−50.1	2128	−50.6
2118	−52.9	−50.3	2128	−50.2
2118	−51.1	—		
Mean	−51.0		Mean	−50.4
CV (%)	25.8		CV (%)	4.8

3.4. *Mean target strength*

The mean wet weight and mean total length of the individual krills were estimated as 0.62 ± 0.014 (standard error) g and 42.0 ± 0.28 mm, using 182 samples. The mean target strength of 0.62 g krill ($\overline{TS}_{0.62g}$) was estimated to be -68.1 dB from the first experiment and -68.3 dB from the second. Averaging two estimates, a single estimate of $\overline{TS}_{0.62g}$ was given as -68.1 dB. Then the mean target strength per kg ($\overline{TS}_{kg}$) was calculated as -36.0 dB.

4. Discussion

Some considerations on the errors or biases in the estimated mean target strength are given. Combining eqs. (3), (4) and (5), the $\overline{TS}_{kg}$ is expressed as follows;

$$\overline{TS}_{kg} = \bar{S}_v - 10 \log \bar{N} + 10 \log V - 10 \log \bar{w} + 30 . \qquad (7)$$

The value of $\overline{TS}_{kg}$ will be affected by the following factors;

a) Instability of the threshold beam angle; affecting V.
b) Variation of reflection properties of individual krills; $\bar{S}_v$.
c) Departure of the krill distribution from the complete uniformity; $\bar{S}_v$ and $\bar{N}$.
d) Error in the calibration including the temperature correction; $\bar{S}_v$.
e) Variation of the weight of individual krills; $\bar{S}_v$ and $\bar{w}$.

The sensitivities of $\overline{TS}_{kg}$ were examined to limited factors whose errors or variations were known quantatively. The temperature correction error in $\bar{S}_v$, about ± 1 dB (T. SASAKURA, personal communication) affected $\overline{TS}_{kg}$ with the same quantities. For $\bar{N}$ and $\bar{w}$, the sensitivities to the variations of the 95% confidence limits were about ± 0.4 and ± 0.2 dB, respectively. The estimation error in drifting speed (v) seemed serious ($V \propto v^2$). The sensitivity to this error was about ± 1.5 dB. It might not be expected that the maximum limit of all over $\overline{TS}_{kg}$ error was less than ± 3 dB (half to double).

Using FRANCOIS and GARRISON's equation, FURUSAWA (1985) has pointed out that the absorption attenuation coefficient (α) is sensitive to the water temperature and salinity at the frequency of 200 kHz. The coefficient α adopted in the present acoustic survey is about 10 dB/km higher than that recommended by him. This suggests that the $\bar{S}_v$ might have an upper bias and that the $\overline{TS}$ (general term for $\overline{TS}_{0.62g}$ and $\overline{TS}_{kg}$) might be overestimated. The correction for α, however, is likely to have little effect on the $\overline{TS}$, considering that measurement was carried out at the depth of about 10 m. A rough estimate of the upper bias of the $\overline{TS}$ is 0.2 dB (5%). The estimates of the $\overline{TS}$ presented in this paper should be regarded as those using α of 50.4 dB/km.

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