Mem. Natl Inst. Polar Res., Spec. Issue, **40**, 140–152, 1986

ACOUSTIC ESTIMATION OF KRILL BIOMASS IN R. V. KAIYO MARU SIBEX I SURVEY AREA (INDIAN SECTOR OF THE SOUTHERN OCEAN)

Kunio SHIRAKIHARA[1], Kakusuke NAKAYAMA[2] and Yuzo KOMAKI[3]

[1]*Shimonoseki University of Fisheries, Yoshimi 1944, Shimonoseki 759–65*
[2]*Hokko Maru, Hokkaido Regional Fisheries Research Laboratory, Katsurakoi 116, Kushiro 085*
[3]*Far Seas Fisheries Research Laboratory, 7–1, Orido 5-chome, Shimizu 424*

Abstract: During the austral summer of 1983–84, the acoustic survey to estimate the biomass of krill (*Euphausia superba*) was carried out twice in the area between 65° and 75°E and south of 61°S in the Indian Sector of the Southern Ocean by the R. V. KAIYO MARU participating in SIBEX I. The southern limits of the study areas were 64°S for the first survey and 69°S for the second.

The mean volume back-scattering strength was measured by horizontal interval of 1 nautical mile and 7 vertical channels in the depth range between the top depth (10–25 m) and 200 m, using the 200 kHz echo sounder with a digital integrator. The scattering strength was converted into the weight density using the constant mean target strength per kg.

The estimated mean weight density per unit surface area in the nighttime was significantly lower than the density in the daytime. The tendency for krill to rise near the surface at night might give a lower bias to the nighttime estimate. The analysis using only the daytime data (3346 intervals throughout the whole survey) resulted in the mean surface density of 15.9 g/m^2 in the area (3.45×10^5 km^2). The total biomass estimated from the survey was 5.49 million t. Discussion was made on possible errors or biases of the estimate, derived from adequacy of the absorption attenuation coefficient adopted in the survey, statistical sampling error, occurrence of krill beyond the depth range of the acoustic detection, and target strength error.

1. Introduction

The acoustic survey aiming at clarifying the distribution of krill (*Euphausia superba*) and estimating the biomass of the species was carried out in the Indian Sector of the Southern Ocean by the R. V. KAIYO MARU, Japan Fisheries Agency, participating in SIBEX I (Phase I of the Second International BIOMASS Experiment 1983–84). Beyond the area scheduled to be investigated, the survey was continued on her way to and from the ports located between 32° and 34°S until krill came to be undetected in the lower latitudinal area.

This paper, as one of a series of the KAIYO MARU SIBEX I acoustic studies, refers to the estimation of the krill biomass in the area scheduled to be investigated and some information on the distribution associated with the estimation.

2. Outline of Acoustic Survey

KAIYO MARU attempted to operate twice in the same area between 65° and 75°E and south of 61°S (Fig. 1). But the southern limits of the area surveyed were different between the two expeditions mainly due to the change in the occurrence of pack ice. The first survey covered the sector north of about 64°S during the period from December 11 to 24 in 1983, whereas the second one covered a wider area extending to 69°S at 75° E during the period from January 19 to February 3 in 1984. The cruise transects were set along the latitudinal lines with the longitudinal interval of 2.5°.

The echo sounder used was Furuno FQ-50 with a digital integrator. The downward-sounding transducer Furuno 200B-8B was operated at 200 kHz. The operating condition of the acoustic system is summarized in Table 1. The gain costant was sub-

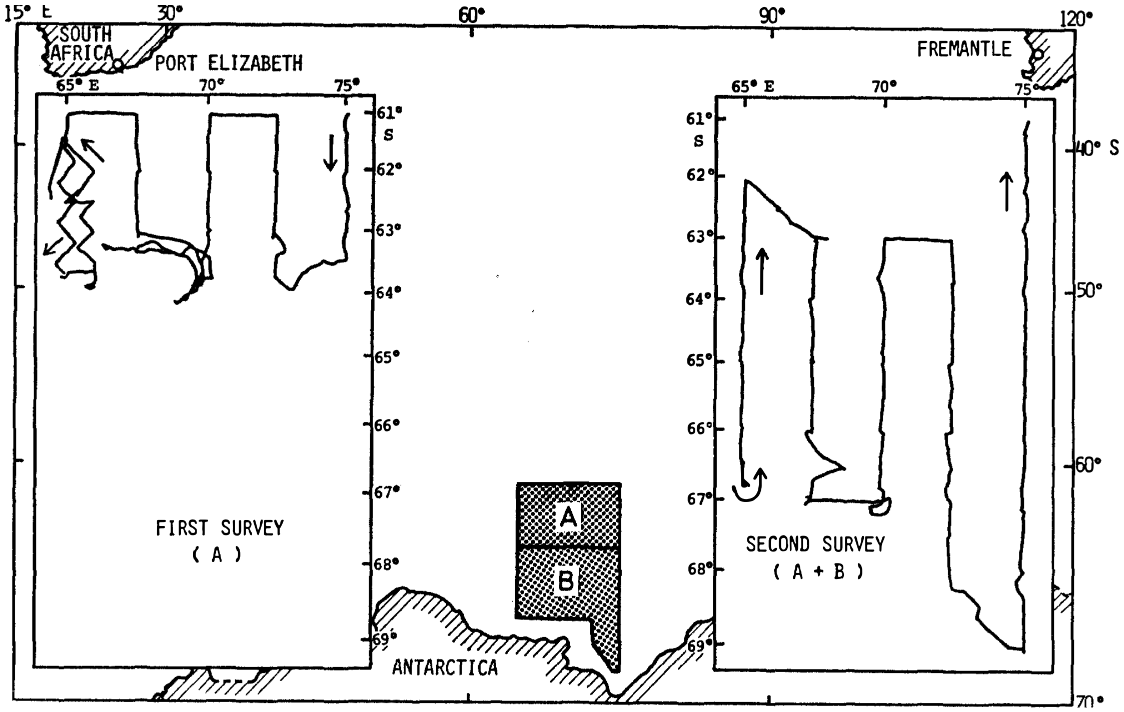

Fig. 1. Cruise tracks and survey areas of R. V. KAIYO MARU.

Table 1. The operation condition of the echo sounder Furuno FQ-50.

Frequency	200 kHz
Equivalent beam width	0.007 sr
Pulse duration	1.8 ms
Depth range	0–200 m
Depth channel	10*–200 m (7 channels)
Integration interval	1 nautical mile
Attenuator	10–20 dB
Threshold	10–30 dB
TVG	20 log R
Gain constant	92.8 dB

* The top depth of integration was changed to 25 m at the maximum when the sea was rough.

Table 2. Results of the calibration.

Date	Place	T (°C)	SL (dB)	ME (dB)	R_1 (dB)
28 October, 1983	Tokyo	18.0	121.76	−78.52	93.8
13 February, 1984	Fremantle	25.0	121.71	−78.65	93.5

T: Water temperature at the depth of the transducer.
SL: Source level.
ME: Receiving sensitivity.
EG: Amplifier gain (=50.4 dB).
R_1: Gain constant at 200 kHz ($R_1=SL+ME+EG$).

tracted 1 dB as the correction on the cruising loss (compare Tables 1 and 2).

Throughout the whole survey period, the mean volume back-scattering strength was continuously measured by the constant horizontal integration interval of 1 nautical mile and 7 depth channels (10–20, 20–30, 30–40, 40–80, 80–120, 120–200 and 10–120 m). But the top depth of integration, 10 m, was changed sometimes to 15, 20 or 25 m to prevent the surface noise. The allocation of depth channels was determined in advance of the survey, predicting that krill would occur in the depth range shallower than 120 m. The channel 120–200 m was the preliminary one to check krill below 120 m. The target strength of krill, essential parameter to convert the scattering strength into the absolute density, was also estimated in the area surveyed (NAKAYAMA *et al.*, 1986).

The calibration using the hydrophone was carried out in the ports at Tokyo (before the first survey period) and at Fremantle (after the second survey period). The surface of the transducer was cleaned by SCUBA divers at Fremantle (before the first survey period) and at Port Elizabeth (before the second survey period) to prevent the sensitivity reduction of the transducer. Two experiments of the calibration resulted in little change in the parameters (Table 2). As clarified later in Table 3, however, these observations do not mean that the source level and the receiving sensitivity remained constant throughout the whole survey period.

3. Materials

The underlying materials to estimate the biomass were the mean volume back-scattering strength data. It was clarified that the measured strength was sensitive to the water temperature at the depth of the transducer. The correction table (Table 3) was presented by FURUNO ELECTRIC CO., LTD. (1984). The actual correction was made as follows, taking account of the error of about ±1 dB (T. SASAKURA, personal communication). The correction values were obtained from the difference between the total sensitivity ($SE+ME$) at the temperature in the calibration at Tokyo (18°C) and that at the mean temperature over each area surveyed (−0.5°C for the first survey and 0.6°C for the second). From the interpolation of the discrete data in Table 3, the total sensitivity at −0.5, 0.6 and 18°C was estimated to be −6.2, −5.9 and −0.3 dB, respectively. Then the measured strength was corrected by;

$$\bar{S}_{v_{ij}}\,(\text{corrected})=\bar{S}_{v_{ij}}\,(\text{measured})+\begin{cases}5.9 \text{ for the first survey}\\ 5.6 \text{ for the second survey,}\end{cases} \qquad (1)$$

Table 3. Temperature-dependent source sensitivity (SE) and receiving sensitivity (ME) of the transducer Furuno 200B-8B (after FURUNO ELECTRIC CO., LTD., 1984).

Sensitivity (dB)	Temparature (°C)				
	−2	4	10	20	30
SE	72.1	72.8	74.1	75.8	76.7
ME	−85.4	−84.2	−83.1	−82.6	−82.9
SE+*ME*	−13.3	−11.4	− 9.0	− 6.8	− 6.2
SE+*ME* at 20°C=0	− 6.5	− 4.6	− 2.2	0.0	0.6

where $\bar{S}_v$ is mean volume back-scattering strength in dB, i is integration interval, and j is depth channel.

The $\bar{S}_v$ including the noise was refined when the echo traces of krill were distinguishable from others in the echogram. But due to practical difficulty in refinement for the $\bar{S}_v$ with a trivial value, the threshold of $\bar{S}_v$ was set at −82.0 dB. The $\bar{S}_v$ less than the threshold was modified as $-\infty$ dB (zero density).

4. Methods of Estimating Mean Density and Biomass

The mean weight density per unit volume (g/m^3) for integration interval (i) and depth channel (j) was estimated from;

$$\rho_{ij}=10^{0.1(\bar{S}v_{ij}-\overline{TS}_{kg}+30)}, \quad (2)$$

where ρ is density per unit volume and $\overline{TS}_{kg}$ is mean target strength per kg; −36.0 dB (NAKAYAMA *et al.*, 1986).

The mean density per unit surface area (g/m^2) for integration interval was estimate from;

$$x_i=120\rho_{ij_0}, \quad (3)$$

where x is surface density and j_0 is depth channel from the top depth of integration to 120 m. This equation stands on two assumptions;

(a) The unknown density from 0 m to the top depth is equal to the measurable density from the top depth to 120 m.

(b) Krill occurs only in the depth range shallower than 120 m.

The distribution of the density x_i was originally continuous, but this was truncated due to the threshold of $\bar{S}_v$; density which was originaly less than the truncated density (x_{TR}=3.0 g/m^2) was modified to be 0 g/m^2.

The density for integration interval x_i was assumed to be a random and independent sample from the area surveyed. The estimated mean density in the area surveyed was given by the sample mean ($\bar{x}$). Then the biomass (B) in this area was estimated from;

$$B=A\bar{x}, \quad (4)$$

where A is area. The statistical methods applied to estimate variances and confidence limits of both $\bar{x}$ and B were decided after the analysis of the sample distributions. Here two alternative methods actually used are described briefly.

1) Simple method

Variances and confidence limits were estimated by the standardized method commonly applied to large sized samples, assuming that the sample means followed the normal distribution.

2) Stratified method

A post-sampling strafication was applied, using the frequency distributions of samples. The expected frequencies of samples were estimated by fitting some theoretical model. Then the area surveyed was divided into two strata; stratum 1 was the area where the krill was not detectable for integration interval ($x_i=0$), and stratum 2 was the krill-detectable area ($x_i>0$). The areas by stratum were estimated with the assumption of the random sampling as follows;

$$A_s=An_s/n\,, \tag{5}$$

where n is sample size and s is stratum. The sample mean and sample variance were calculated from the moments about the origin. For stratum 1, the moments were obviously all zero. For stratum 2, the moments were obtained using the expected frequencies for the range of $0\,\mathrm{g/m^2}-x_{\mathrm{TR}}$ and the observed samples for the range equal to or greater than x_{TR}. Then stratified estimates from large sized samples were obtained as follows:

For the mean density in the area surveyed;

mean $$E(\bar{x})=(\sum_s E_s(\bar{x})A_s)/A\,, \tag{6}$$

variance $$V(\bar{x})=(\sum_s V_s(\bar{x})A_s^2)/A^2\,, \tag{7}$$

95% confidence limit $$E(\bar{x})\pm 1.96\ V(\bar{x})^{1/2}\,. \tag{8}$$

For the biomass in the area surveyed;

mean $$E(B)=\sum_s E_s(\bar{x})A_s\,, \tag{9}$$

variance $$V(B)=\sum_s V_s(\bar{x})A_s^2\,, \tag{10}$$

95% confidence limit $$E(B)\pm 1.96\ V(B)^{1/2}\,. \tag{11}$$

5. Day/Night Difference in Vertical Distributions and Estimated Densities

HAMPTON (1983) suggested that the nighttime surface density estimated from the downward-sounding acoustic system might have a negative bias. To check this and the depth range of krill occurrence, the mean densities by the depth channel throughout the whole survey were plotted by day and night (Fig. 2). In the daytime, krill concentrated in the depth range of 30–80 m, while the densities in the range less than 40 m were relatively high at night. This suggests that krill would rise near the surface

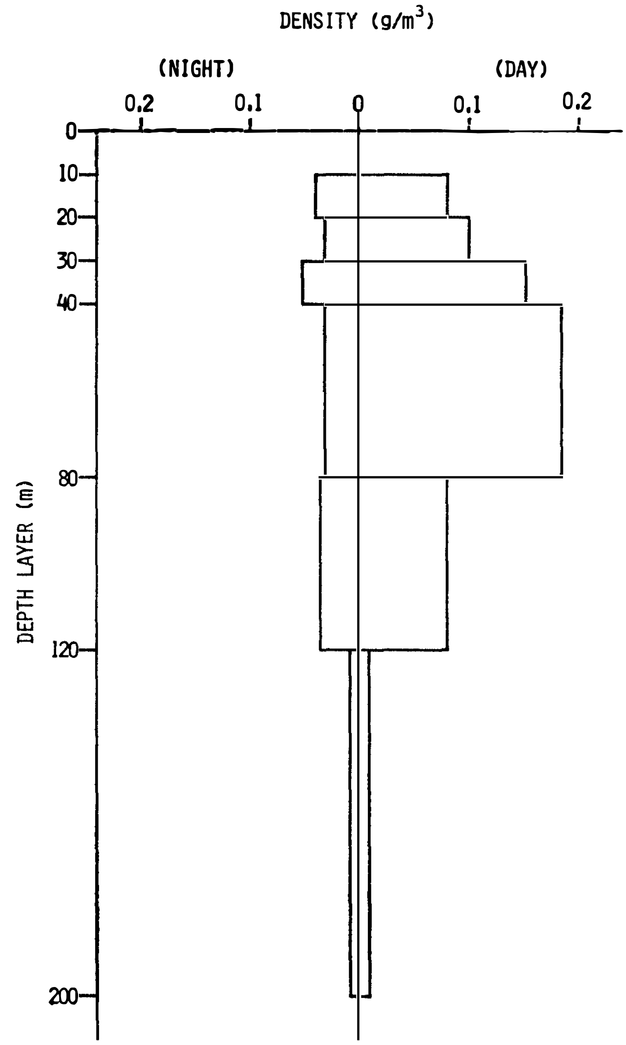

Fig. 2. Mean densities of krill by depth channel (layer) throughout the whole survey.

at night in the area surveyed. The extremely low densities from 120 to 200 m both in the daytime and at night suggest that the assumption (b) in Section 4 holds good.

The mean surface densities throughout the whole survey were 15.7 ± 1.10 g/m^2 for day (95% confidence limit by the simple method described before) and 3.89 ± 0.890 g/m^2 for night. The daytime estimate was significantly higher than the nighttime one ($P < 0.001$). The latter was considered to be underestimated, because some krill rising near the surface at night might not be detected acoustically. The nighttime $\bar{S}_v$ data were discarded in the analysis performed later.

6. Horizontal Distribution

6.1. Geographical distribution

Figure 3 shows the mean surface density maps based on the continuous 10 integration intervals. Krill was distributed over the area surveyed, though it was fairly

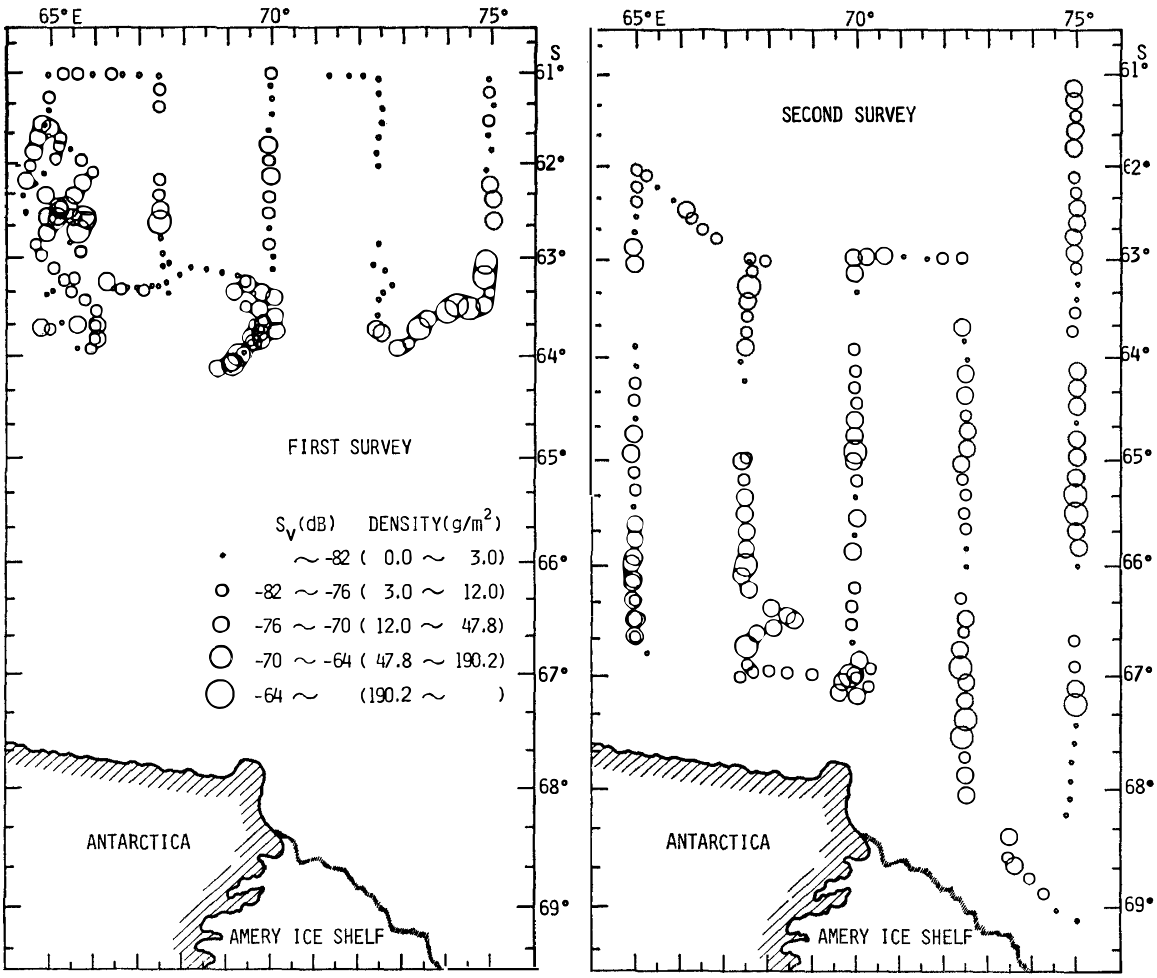

Fig. 3. Mean surface densities of krill. Symbol S_v is mean volume back-scattering strength in the depth range between the top depth (10–25 m) and 120 m.

abundant in the southern parts. Due to the wide variation of density, the approach by the density contour from these maps was not applied to the estimation of the biomass.

6.2. *Statistical distribution*

The frequency distribution of the pooled samples (surface densities for integration interval) from the whole survey (both first and second surveys) showed the positive skewness with the range of 0–512 g/m² (Fig. 4). The frequency of the densities less than x_{TR}, which was modified to be 0 g/m², was 46.4%. This modification might give some effect on the estimation of the mean surface density and the biomass in the area surveyed. Thus the frequency distribution of the densities less than x_{TR} was estimated by fitting some theoretical model to the observed distribution.

Since the sample variance was greater than the sample mean, the sample distribution was contagious. To normalize the distribution, two alternative transformations of samples were carried out;

$$x_i \longrightarrow \log(x_i+1)\,. \tag{12}$$

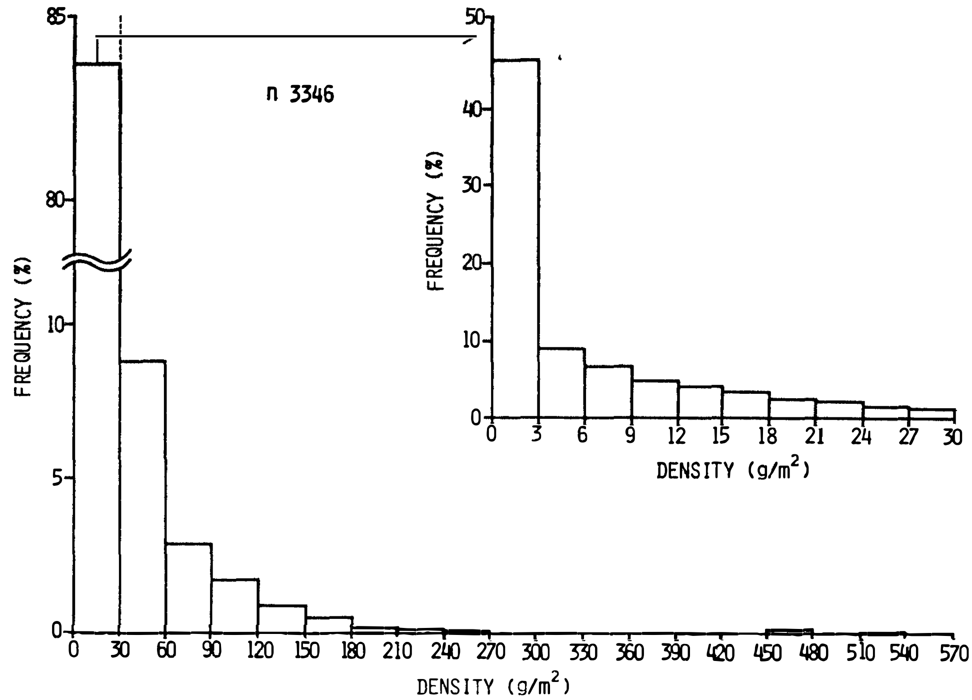

Fig. 4. Frequency distribution of samples (krill densities for integration interval of 1 nautical mile) from the whole survey.

$$x_i \longrightarrow x_i^p \ . \tag{13}$$

The log transformation was derived from the log-normal or negative binomial distribution (ELLIOTT, 1977). The alternative was obtained from the TAYLOR's power law; variance is proportional to a fractional power of the mean (TAYLOR, 1961). The parameter p was estimated to be 0.155 from the relation between means and variances in the 25 divided sample groups. The frequency distributions of the transformed samples are shown in Fig. 5. The parameters of the expected normal distribution were estimated as shown in Table 4 by the maximum likelihood method applied to the truncated distribution (MAKABE *et al.*, 1972). The frequencies of the transformed samples less than the truncated values were given by the expected frequencies (Fig. 5). The agreement of

Table 4. The statistics of the transformed samples.

Transformation	Survey	Expected normal distribution		Observed distribution		
		Mean	Standard deviation	Skewness	Kurtosis	n**
Log	1+2	1.09	0.532	−0.0198	2.70*	2178
Power	1+2	1.42	0.351	0.0306	2.88	2404
	1	1.48	0.357	0.0177	2.86	840
	2	1.39	0.338	0.0343	2.88	1544

* Different from the kurtosis of samples from the normal distribution at the 5% level of significance.

** Size of samples greater than (mean−3× standard deviation).

the observed distribution with the expected normal one was checked by the test based on the statistics of skewness and kurtosis (KISHINE, 1970). Table 4 shows that the power transformation was more appropriate than the alternative.

The sample distribution from each survey was also analyzed. Since the variance was greater than the mean for each survey, the power transformation with the param-

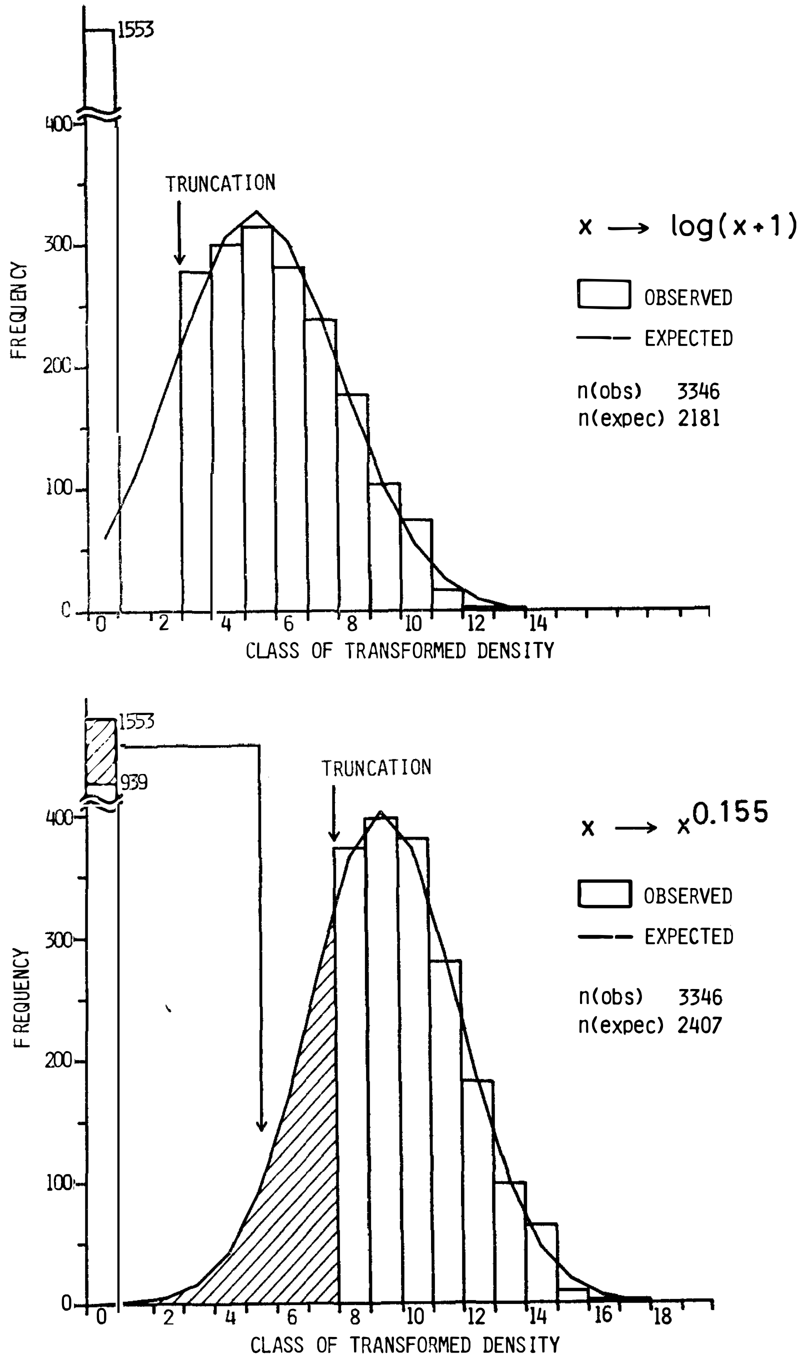

Fig. 5. Frequency distributions of the transformed samples from the whole survey. Symbol x is krill density (g/m^2) for integration interval. The class-intervals of distributions are 0.201202 for the log ($x+1$) transformation and 0.148314 for the $x^{0.155}$ transformation.

eter p of 0.155, same as used in the analysis of samples from both surveys, was carried out. The frequency distributions of the transformed samples could be approximated to the normal distributions (Table 4).

7. Estimated Mean Surface Density and Biomass

The frequency distributions of the original samples from the first, second and both surveys, departed from the normality (*e.g.* Fig. 4). It was examined whether variances and confident limits of the mean surface density could be obtained by the method associated with the normality. If the sample size is greater than the following minimum size for populations exhibiting the marked positive skewness, the distribution of the mean of random samples can be approximated to the normality regardless of the form of population distributions (JOHANNESON and MITSON, 1983);

$$n_{min}=25\,g_1^2\,, \tag{14}$$

$$n>n_{min}\,, \tag{15}$$

where n_{min} is minimum sample size and g_1 is skewness. Since the sample sizes satisfied the criteria as shown in Table 5, the stratified method was applied to the estimation of the mean surface density and biomass. The ratios of the sample size belonging to

Table 5. The statistics of the original samples.

Survey	Skewness	Sample size		
		n_{min}	n_2	% n_2/n
1+2	4.76	566	2407	71.9
1	4.91	603	842	51.2
2	3.57	319	1546	90.8

n_{min}: Minimum size shown in eq. (14).
n_2: Size of samples with positive density (belonging to stratum 2 in the stratified method).
n: Total size of samples with both zero and positive densities.

Table 6. Mean surface density and biomass.

Survey	Area (10^5 km^2)	n	Method	Mean density (g/m^2)			Biomass (10^6 t)		
				E	V*	CL	E	V**	CL
1+2	3.45	3346	T	15.9	0.284	14.9–17.0	5.49	0.0338	5.13–5.85
			I	15.7	0.316	14.6–16.8	5.41	0.0376	5.03–5.79
1	1.71	1643	T	14.3	0.635	12.7–15.8	2.44	0.0186	2.17–2.70
			I	14.1	0.754	12.4–15.8	2.41	0.0221	2.12–2.70
2	3.45	1703	T	17.5	0.489	16.1–18.9	6.04	0.0583	5.57–6.51
			I	17.2	0.514	15.8–18.6	5.93	0.0611	5.45–6.42

T: Stratified method, I: Simple method.
E: Mean, V: variance, CL: 95% confidence limit, n: sample size.
*: g^2/m^4, **: 10^{12} t^2.

stratum 2 to the total (Table 5) indicate the estimated ratios of the area of the krill detection to the area surveyed.

The estimates obtained by the stratified method are summarized in Table 6. The mean surface density throughout the whole survey, 15.9 g/m^2, was not very far from that in all sectors during FIBEX, 17.0 g/m^2 (HAMPTON, 1983). The total biomass throughout the whole survey was 5.49 million t.

8. Discussion

The reliability of the estimates is discussed from some points of view.

8.1. Absorption attenuation

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 the upper bias, whose magnitude is roughly estimated to be 0.2 dB (5%) at the depth of 10 m, 1 dB (26%) at 50 m and 2 dB (58%) at 100 m. On the other hand, the correction for α is likely to have little effect on the mean target strength obtained from the survey because measurement was carried out at the depth of 10 m. These situations might cause the biomass to be rather overestimated. The estimates of the density and biomass should be regarded as those using α of 50.4 dB/km.

8.2. Statistical sampling error

The alternative estimates by the simple method are shown in Table 6. The stratified estimates with narrower confidence intervals were better than the simple ones. But the difference in the estimates from two methods was not significant. This indicates that the truncation of the sample distributions due to the threshold of $\bar{S}_v$ had little effect on the estimation of the density and biomass and that the simple estimates which could be obtained without the laborious calculations were also useful.

In the statistical analysis, samples were tentatively assumed to be independent of each other. The variances might be underestimated, because the possible levels of the covariances associated with the serial nature of the sampling were not taken into account. It is a future work to correct the variances by such a method as MACAULAY *et al.* (1984) applied. It should be also noted that the estimates summarized in Table 6 were obtained without considering the errors discussed below, whose magnitudes could not be estimated definitely.

8.3. Non-detection of krill

The depth range of the acoustic detection between the top depth of integration (10–25 m) and 200 m could not always cover the full range of krill occurrence. For krill below 200 m, the search using another echo sounder, Sanken NTL 3000, was occasionally performed. No observations suggest that the abundance of krill below 200 m might be negligibly small in the area surveyed. For the undetectable krill near the surface, no quantitative information on the abundance was given by the KAIYO MARU

SIBEX I expedition. Thus it was unavoidable to estimate the mean surface density with the assumption that the unknown density per unit volume near the surface was equal to the measurable density from the top depth to 120 m, though the vertical distributions in Fig. 2 suggest that the former was likely to be lower than the latter in the daytime. A numerical examination on this assumption was made as follows: Assuming that krill was not distributed at all in the range shallower than the top depth, the minimum estimate of the mean surface density throughout the whole survey was given as 13.9 g/m^2 by the simple method. The corresponding estimate of the mean density in Table 6, 15.7 g/m^2, was only 13% higher than the minimum estimate. This suggests that the assumption of the equal densities might not be so unreasonable.

8.4. *Target strength error*

The mean target strength ($\overline{TS}$) error is likely to be the most serious of all sources of errors mentioned in this section. To exclude the $\overline{TS}$ error, the means of $\bar{S}_v$ (from the top depth to 120 m) estimated by the simple method were shown; -75.3 dB (95% confidence limit $-75.9 \sim -74.8$) for the first survey, -74.4 dB ($-74.8 \sim -74.1$) for the second, and -74.8 dB ($-75.2 \sim -74.5$) for the whole survey.

EVERSON (1982) suggested that the diurnal variations in aggregation and orientation might affect the $\overline{TS}$ of krill and presented a hypothesis that the nighttime $\overline{TS}$ is lower than the daytime one. For the future discussion on $\overline{TS}$ adopted in this study, the available information is noted; time of the experiments for the krill aggregation *in situ*: about 1 hour before the sunset, aggregation density: 50.0–61.6 individ./m^3, mean length and weight of krill: 42 mm and 0.62 g (NAKAYAMA *et al.*, 1986).

8.5. *Krill under pack ice*

Any intensive investigation of krill under pack ice could not be carried out by the KAIYO MARU which was not sufficiently ice-resistant. Krill, however, tended to be comparatively abundant near the edge of pack ice. The same phenomenon was observed in the Western Atlantic Sector during FIBEX (HEMPEL, 1983). The estimated biomass in this study should be regarded as that in the area north of the edge of pack ice.

Acknowledgments

The authors thank Messrs. Y. KIKUCHI, T. TSUKEKAWA, T. YANO and K. HATA for their co-operation in the acoustic surveys on board R. V. KAIYO MARU. They extend their thanks to Dr. T. DOI, Japan NUS Co., Ltd., and Mr. T. SASAKURA, FURUNO Electric Co., Ltd., for constructive comments on the research plan and data analysis. Thanks are also due to Dr. H. MAEDA, Messrs. Y. TAGUCHI and T. YAMADA, Shimonoseki University of Fisheries for their assistance in treating the data. The authors are indebted to Dr. T. NEMOTO, University of Tokyo, and Drs. T. HOSHIAI and Y. NAITO, National Institute of Polar Research, for their encouragement and help in preparating the manuscript.

References

ELLIOTT, J. M. (1977): Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biol. Assoc., Sci. Publ., **25**, 157 p.

EVERSON, I. (1982): Diurnal variations in mean volume backscattering strength of an Antarctic krill (*Euphausia superba*) patch. J. Plankton Res., **4**(1), 155–162.

FURUNO ELECTRIC Co., LTD. (1984): Kagaku gyotan FQ-50/FQ-60 ni shiyô shiteiru sôjuhaki no ondo tokusei ni tsuite (On the temperature properties of the transducers used in FQ-50/60). 6 p.

FURUSAWA, M. (1985): Gyogun tanchiki no TVG ni tsuite no kentô (Consideration on TVG of echo-sounder). Tech. Rep. Natl Res. Inst. Fish. Eng., Fish. Boat Instr., **6**, 33–49.

HAMPTON, I. (1983): Preliminary report on the FIBEX acoustic work to estimate the abundance of *Euphausia superba*. Mem. Natl Inst. Polar Res., Spec. Issue, **27**, 165–175.

HEMPEL, G. (1983): FIBEX–An international survey in the Southern Ocean; Review and outlook. Mem. Natl Inst. Polar Res., Spec. Issue, **27**, 1–15.

JOHANNESON, K. A. and MITSON, R. B. (1983): Fisheries acoustics. A practical manual for aquatic biomass estimation. FAO Fish. Tech. Pap., **240**, 249 p.

KISHINE, T. (1970): Riron Ôyô Tôkeigaku (Theoretical and Applied Statistics). 4th ed., Tokyo, Yokendo, 600 p.

MACAULAY, M. C., ENGLISH, T. S. and MATHIESEN, O. A. (1984): Acoustic characterization of swarms of antarctic krill (*Euphausia superba*) from Elephant Island and Bransfield Strait. J. Crust. Biol., **4** (Spec. No. 1), 16–44.

MAKABE, H., KAMINUMA, Y., SIBUYA, M. and TAKEUCHI, J. (1972): Kireta bunpu to uchikiri hyôhon (Truncated distributions and censored samples). Tôkei Sûchihyô (Statistical Tables and Formulas with Computer Applications), ed. by Z. YAMAUCHI. Tokyo, Nihon Kikaku Kyôkai, 241–266.

NAKAYAMA, K., SHIRAKIHARA, K. and KOMAKI, Y. (1986): Target strength of krill *in situ* at the frequency of 200 kHz. Mem. Natl Inst. Polar Res., Spec. Issue, **40**, 153–161.

TAYLOR, L. R. (1961): Aggregation, variance and the mean. Nature, **189**, 732–735.

(*Received March 26, 1985; Revised manuscript received August 31, 1985*)