Results of the cetacean prey survey using a quantitative echo sounder in JARPA from 1998/99 to 2004/2005

HIROTO MURASE, HIROSHI KIWADA, KOJI MATSUOKA, SHIGETOSHI NISHIWAKI

The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo, 104-0055, Japan

ABSTRACT

Krill biomass estimation surveys using a quantitative echo sounder have been conducted in JARPA since 1998/99 season to achieve one of the main objectives of JARPA which is elucidation of the role of whales in the Antarctic marine ecosystem. The survey was conducted concurrently with cetacean survey. Similar biomass estimates were obtained in Area IV in the 1999/2000 (34.2 million t) and 2001/2002 (34.1 million t) seasons. In Area V, biomass in the 2000/2001 (20.7 million t) and in the 2002/2003 (22.6 million t) seasons were similar but biomass in 1998/1999 (29.7 million t) was higher than the other two years. Higher biomass in 1998/99 could be explained by seasonal effect and area coverage differences. Biomass density in each stratum as well as overall biomass (7.0 million t) in Area V were low in 2004/2005 even if no krill biomass estimate in North-West stratum because of prevailing poor weather conditions for acoustic survey was taken account. Biomass in Area IV was higher than Area V. There was a unique opportunity to compare the biomass estimate from two independent vessels in the Ross Sea region in 2004/2005. One vessel, *Kaiyo Maru*, conducted standardized krill biomass estimation survey adopted by CCAMLR using both RMT net sampling and acoustic survey while the other vessel, *Kyoshin Maru #2*, only conducted acoustic survey as in previous JARPA cruises. The results of biomass estimates from two vessels were comparable. The result suggested that biomass estimations in previous JARPA cruises which thoroughly relied on acoustic were reliable. Because krill biomass surveys in the whole of Area IV and Area V were rarely conducted in the past, krill data collected by JARPA were quite important to understand krill-baleen whale relationships in the Antarctic.

INTRODUCTION

It is well known that krill is the key species in the Antarctic marine ecosystem because krill is a major link in the transfer of energy from primary producers to larger organisms such as baleen whales (Laws, 1985; Murphy et al., 1988). Krill have been known as the major food source of baleen whales in the Antarctic (Kawamura, 1994). "Krill surplus" caused by intensive commercial harvesting of large whales, blue (*B. musculus*), fin (*B. physalus*) and humpback whales (*Megaptera novaeangliae*), has been central theorem of the Antarctic ecosystem study. "Krill surplus" resulted in increasing in amount of available food to other krill feeders such as Antarctic minke whales (*B. bonaerensis*) (Laws, 1977). But it appears that the situation is changed in recent years. After the ban of commercial whaling of large whales in 1987, it was reported that abundance of those species increased in recent years. For example, abundance of blue whales increase 8% per year at the circumpolar level (Branch et al., 2004) though the abundance was still low comparing with pre exploitation population size. Some stocks of humpback whales in southern hemisphere have been showed remarkable recovery even to near pre-exploitation level (Johnston and Butterworth, 2004). To test the magnitude of interaction, preliminarily baleen whales-krill interaction model was developed but the interpretation was limited at this moment because of paucity of information including biomass estimation of krill (Mori and Butterworth, 2006). Krill density showed both short and long term changes. In short term, krill density showed large year to year fluctuation at decadal scale in response to environmental variability such as sea ice extent and oceanographic conditions (e.g. Pakhomov, 2000; Hewitt and Demer, 2003). It was reported that krill density have showed statistically significant decreasing trend in the southwest Atlantic since 1976 (Atkinson et al. 2004) though the magnitude of decrease should be studied further to draw the conclusion because wide varieties of net types were used in the analysis. Given the krill density change information, krill biomass survey should be conducted regularly in the same region. To assess the magnitude of interspecific competition among baleen whales for krill and the consequences of the competition quantitatively, conducting concurrent cetacean and krill survey is critical.

The Japanese Whale Research Program under Special Permit in the Antarctic (JARPA) provided unique opportunity to conduct the concurrent cetacean and krill survey. JARPA has been conducted during the austral summer every year since the 1987/1988 season. One of the primary objectives of the JARPA is “Elucidation of the role of whales in the Antarctic marine ecosystem through the study of whale feeding ecology”. The JARPA interim review meeting took place in May, 1997. In the meeting, it was pointed out that concurrent studies on the distribution and abundance of prey species was required to achieve the objective. In response to the comments, echo sounder survey to examine distribution and abundance of krill has been conducted concurrently with cetacean survey since 1998/99 season. Krill distribution data will be linked with distribution patterns of baleen whales whereas krill abundance data will allow us to examine the magnitude of the interspecific relationship among baleen whales for krill. The preliminary report of the echo sounder surveys of krill that were conducted in 1998/1999 and in 1999/2000 were reported to the International Whaling Commission (IWC)/Scientific Committee (SC) as SC/52/E5 (Murase et al., 2000) and published in scientific journal (Murase et al., 2002). This paper presents the echo sounder survey methodology and the results of biomass estimation of krill in JARPA from 1998/99 to 2004/2005. In addition, the results of the comparison of two krill biomass estimates in the Ross Sea region in 2004/2005 using two independent echo sounder data from two vessels were briefly discussed.

MATERIALS AND METHODS

Survey area

Two baleen whale management area defined by the International Whaling Commission (IWC), Area IV (70°E-130°E) and Area V (130°E-170°W), were surveyed alternative years. The areas between south of 60°S and the ice edge line were surveyed. Each area was further divided into two, east and west, at 100°E in Area IV and at 165°E in Area V. Each sector further divided into two strata, north (between the 60°S latitude line to the line of 45 n.miles from ice edge) and south (between the line of 45 n.miles from ice edge and ice edge). Exceptions were the Prydz Bay region (south of 66°S between 70°E and 80°E) and the Ross Sea region (South of 69°S between 165°E and 170°W). The Ross Sea region was defined as south-east stratum of Area V whereas the Prydz Bay region was called as it was. In addition to two Areas, eastern part of Area III and western part of Area VI were also surveyed alternative years. No specific stratification was set in those Areas. Following acronyms were used to describe strata name;

III-E-F	Eastern half of Area III, first period
III-E-S	Eastern half of Area III, second period
IV(or V)-NE	North-East stratum in Area IV (or V)
IV(or V)-NW	North-West stratum in Area IV (or V)
IV(or V)-SW	South-West stratum in Area IV (or V)
IV(or V)-SE	North-East stratum in Area IV (or V)
IV-PB	Prydz Bay region in Area IV
VI-W-F	Western half of Area VI, first period
VI-W-S	Western half of Area VI, second period

Timing of surveys

Surveys were conducted during austral summer (December-March). Detailed survey dates were summarized in Table 1 and 2.

Trackline designs

Sawtooth type zigzag lines were used in each survey. Details of the trackline designs were reviewed in Nishiwaki et al. (2006).

Survey vessel

The cetacean sighting vessel, *Kyoshinmaru No.2* (KS2, 368 GT) was engaged in the sighting survey of cetaceans as well as echo sounder and oceanographic surveys. The nominal steaming speed of SV on the track line was 10.5 knots.

Data acquisition and storage system

An EK500 scientific echo sounder (Simrad, Norway) with software version 5.30 operating frequency at 38 and 120 kHz on board Kyoshin-maru No.2 was used to collect data for the acoustic survey from 1998/99 to 2003/04. The transducers were hull-mounted at the depth of 4.3 m from the surface. Each transducer was covered with a 40 mm polycarbonate acoustic window to minimize the damage on the transducer surface from contacting sea ice. The hydraulic oil filled the space between the transducer surfaces and the acoustic windows. Data were recorded with the aid of a BI500 post processing system (Simrad, Norway) from 1998/99 to 2004/05.

Data analysis system

BI500 was used for the data analysis in 1998/99 and in 1999/2000. Echoview version 3.00.74.01 (SonarData Pty Ltd, Australia) was used from 2000/01 to 2004/05. Major function of Echoview was same as BI500 but it allowed more detailed analysis than BI500. Echoview was software operated under the Microsoft Windows. Echoview was capable to analyze BI500 data file.

Calibrations

The copper sphere technique that described in EK 500 operation manual (Simrad, 1997) was applied for the calibrations. Calibrations were conducted in Antarctic water every year. In 2002/03 and 2003/04, calibrations were attempted but the results weren't applied to the analysis because those were conducted in unsuitable conditions for calibration. For those years, the result of the calibration in 2001/02 was applied for analysis.

Data recording methodology

The survey was conduced during diurnal hours from an hour after sunrise to an hour before sunset. Maximum survey time per day was 12 hours. Data were recorded continuously while the vessel steamed on predetermined trackline. The data were not used in the analysis when the vessels deviated from the trackline such as during cetacean species confirmation.

Data analysis methodology

We applied the acoustic data analysis described by Hewitt and Demer (1993) and Demer and Hewitt (1995). The following procedures came from those papers. Mean backscattering area per square n. mile of survey transect (s_A) attributed to krill for every 1 n. mile of survey transect over 10 to 250 m depth was calculated by following formula;

$$s_A = 4\pi r_0^2 1852^2 \int_{r_1=10}^{r_2=250} s_V dr \left(\frac{m^2}{n.mi^2}\right)$$

where, r is depth from the surface, r_0 = 1m representing the reference range for backscattering strength and $s_V = 0$ if 10 log (s_V) ≦ -80dB, because threshold backscattering was set at –80dB. Because direct sampling method (e.g. net sampling) to identify species was not available, the difference between the mean volume backscattering strength (ΔMVBS) of 120 and 38 kHz fell between 2 and 16 dB is classified as krill (Hewitt et al., 2004). Because BI500 didn't have capability to calculate ΔMVBS, the differences were visually identified using the echogram in 1998/99 and 1999/2000. For the lest of year, ΔMVBS was calculated quantitatively using Echoview. Krill backscattering cross section area (σ) was calculated with the following formula based on krill target strength described by Greene et al. (1991):

$$\sigma = 4\pi r_o^2 10^{-12.745} l^{3.485}$$

where, l was standard length of krill. Krill wet weight (w) was calculated with the following formula based on Siegel (1986):

$$w = 0.00193 l^{3.325} .$$

Average area krill biomass density ($\overline{\rho}$) was calculated as follows;

$$\overline{\rho} = S_A \frac{w}{\sigma} = 0.249 l^{-0.16} S_A .$$

Then, frequency distribution of euphausiids standard length (f_i) was applied to the following formula;

$$\overline{\rho} = 0.249 \sum_{i=1}^{n} f_i (l_i)^{-0.16} S_A .$$

Because minor variation in the frequency distribution of krill length did not affect the krill biomass estimate, a combined distribution data based on Loeb and Siegel (1992) was used (Demer and Hewitt, 1995) as follows;

$$\sum_{i=1}^{n} f_i (l_i)^{-0.16} \cong 0.562 .$$

With this formula mean krill biomass of each transect in each stratum was calculated. Following procedures were adopted from Jolly and Hampton (1990). Weighted mean of S_A of each block was;

$$\overline{S_{Ak}} = \frac{\sum_{i=1}^{N_k} \overline{S_{Aki}} (n_{k_i})}{\sum_{i=1}^{N_k} n_{k_i}}$$

where, $\overline{S_{Ak}}$ = mean S_A in kth block, N_k = number of transects in kth block, $\overline{S_{Aki}}$ = mean S_A on the ith transect in kth block and n_{k_i} = number of 1 n. mile averaging intervals on the ith transect in kth block. In this formula, each transect was regarded as a single biomass density sample. Then variance of $\overline{S_{Ak}}$ was calculated with the formula (Jolly and Hampton, 1990);

$$Var(\overline{S_{Ak}}) = \frac{N_k}{N_k - 1} \frac{\sum_{i=1}^{N_k} (\overline{S_{Ak\,i}} - \overline{S_{Ak}})^2 {n_{k_i}}^2}{\left(\sum_{i=1}^{N_k} n_{k_i} \right)^2}$$

$\overline{S_A}$ was converted to $\overline{\rho}$ using above motioned formula. Biomass was estimated as;

$$B_k = A_k \rho_k$$

where, B_k is density biomass in kth block and A_k is area of kth block. Variance of B_k was calculated with following formula;

$$\mathrm{var}(B_k) = {A_k}^2 \, \mathrm{var}(\overline{\rho_k}) .$$

Coefficient of variation of B_k was calculated as;

$$CV(B_k) = \frac{\sqrt{\mathrm{var}(B_k)}}{B_k} .$$

Biomass (B_0) in each Area was calculated as;

$$B_0 = \sum_{k=1}^{N} B_k .$$

Overall survey variance of B_0 was;

$$Var(B_0) = \sum_{k=1}^{N} \mathrm{var}(B_k)\ .$$

Coefficient of variation of B_0 was calculated as;

$$CV(B_0) = \frac{\sqrt{Var(B_0)}}{B_0}\ .$$

Krill biomass estimation in *Kaiyo Maru* – JARPA joint survey

Kaiyo Maru–JARPA joint survey in the Ross Sea (south of 69°S) in 2004/05 was designed as multi-disciplinary study combining the cetacean, krill and oceanographic studies. In the joint survey, two vessels, Kaiyo Maru (2,630 GT) and KS2, conducted krill biomass surveys using the EK500. In addition to echo sounder survey, *Kaiyo Maru* also conducted net sampling using a Rectangular Midwater Trawl with 1m^2 and 8m^2 mouth opening (RMT8+1) for sampling of krill. Details of the krill biomass estimation methods in *Kaiyo Maru*-JARPA joint survey were described in Murase et al. (2006).

RESULTS

Krill biomass in each stratum in Area IV and eastern part of Area III

Surveys were conducted in Area IV and eastern part of Area III in 1999/2000 and 2001/2002. No data was available for analysis in 2003/2004. Density and biomass in each stratum in each year were summarized in Table 1. Distribution patterns were shown in Fig. 1. Timings of surveys were almost same for two years. Density and biomass in IV-SW in 2001/2002 were remarkably higher than 1999/2000. It should be noted that survey effort in Northern strata in Area IV in 2001/2002 was lower than that of in 1999/2000 because of poor weather conditions for the echo sounder survey.

Krill biomass in each stratum in Area V and western part of Area VI

Surveys were conducted in Area V and western part of Area VI in 1998/1999, 2000/2001, 2002/2003 and 2004/2005. Density and biomass in each stratum in each year were summarized in Table 2. Distribution patterns were shown in Fig. 2. Timing of survey in 1998/1999 was different from other years. Because the mouth of the Ross Sea was closed in 1998/1999, the Ross Sea region was not surveyed. In addition, V-NE was not surveyed as well.

Krill biomass estimation by Area

Results of biomass estimation of krill by area by year were summarized in Table 3. Overall, year to year differences of biomass estimations and CVs were small except 1998/1999 and 2004/05, though each stratum in each area showed year to year biomass and CV variations. It should be noted that the survey timing and coverage in Area V in 1998/1999 were different from other years. Estimated biomass in Area V were low in 2004/2005 even if no krill biomass estimate in North-West because of prevailing poor weather conditions for acoustic survey was taken account.

Krill biomass estimation in *Kaiyo Maru* – JARPA joint survey

Following results were described in Murase et al. (2006). Biomass densities of *Eupahsia. superba* with 95% CI estimated using *Kaiyo Maru* and KS2 data were 5.36±7.45 and 2.64±2.35 g/m^2, respectively. Biomass densities of *E. crystallorophias* with 95% CI estimated using Kaiyo Maru and KS2 data were 3.44±1.96 and 1.56±0.89 g/m^2, respectively. Because there was no significant difference between the biomass density estimates from both vessels, two data sets were combined to estimate the biomass. The biomasses of *E. superba* and *E. crystallorophias* in this study were estimated as 1.46 (CV=0.32) and 0.82 (CV=0.18) million t, respectively (Table 1). Total krill (*E. superba* + *E. crystallorophias*) biomass was 3.1 million t (CV=0.22).

DISCUSSION

The position of the Southern Boundary of the Antarctic Circumpolar Current (SB-ACC) in 2001/2002 shifted to south in comparison with that in 1999/2000 (Watanabe et al., 2006). The SB-ACC was corresponded to high primary production and hence to distribution of whales (Tynan, 1998). It was postulated that krill would be coastally constrained when the position of the SB-ACC shows southerly shift (Nicol et al., 2000(a)). Higher density and biomass in VI-SW in 2001/02 than in 1999/2000 could be related to the southerly shift in position of the SB-ACC. This is the first time to confirm the hypothesis proposed by Nicol et al. (2000(a)) in this region. Few echo sounder surveys were conducted between 35°E to 170°W in the past except the Prydz Bay region. Survey of distribution and abundance between 80°E and 150°E from south of 63°S to ice edge was conducted by Australian research vessel in 1995/96 austral summer (Pauly et al. 1997). They reported krill densities of 5.5 g/m^2, 6.7 g/m^2, 4.2 g/m^2 and 9.2 g/m^2, in whole survey area, west area (80°E-115°E), east area (115°E-150°E) and shelf break area, respectively. Those densities were significantly lower than those reported in this paper, though it was difficult to compare the two results directly because survey coverage, design and timing were totally different from each other. Quite significant inter annual variability of biomass densities caused by environmental factors were reported in the Cooperation Sea (50°E-85°E) (Pakhomov, 2000) and in the South Shetland Islands region (Hewitt and Demer, 2003). Such inter-annual variability could explain the differences but frequent surveys in this area should be conducted in future to clarify the existence of the inter-annual variability and the causes of variability. Azzali *et al.* (2006) postulated that the distribution pattern of *E. superba* and *E. crystallorophias* shifted to north as the ice edge moved to northward in austral summer but the magnitude of movement was more significant for *E. superba*. As the results, density of *E. superba* in January 2000 was low by comparison with November in 1994 and December in 1994 and 1997 though one need caution of the interpretation because of methodological differences among those surveys (Azzali et al., 2006). Our surveys in the Ross Sea were mainly conducted in January. It seemed that there was general agreement between our results and the hypothesis proposed by Azzali *et al.* (2006). Though this survey could not have biomass estimates for each krill species, densities of krill were similar to the value in January in Azzali *et al.* (2006) while biomass estimates were in the comparative range regardless of month. Even if densities were low in January, surveyed area in January was generally large as the result of sea ice retreat. Dispersal response of krill distribution to seasonal sea ice retreat in the Ross Sea should be studied further in the future cruises.

It should be noted that highest biomass recorded in Area V in 1998/1999 especially in V-NW and V-SW. In 1998/99, those two strata were surveyed earlier about a month than latter two years (2000/2001 and 2002/2003). V-NW and V-SW were surveyed in mid January to mid February in 1998/1999 while they were surveyed in mid February to at beginning of March in latter two years. Intra-annual variability in krill abundance was reported around South Georgia (Brierley, et al., 2002). They reported that krill abundance late (March) austral summer was significantly lower than that in January. Such intra-annual variability of krill abundance could explain the abundance difference among three survey years in V-NW and in V-SW. Effect of intra-annual variability of krill abundance should be considered in data from III-E and VI-W where surveys were conducted in either December or March. The reasons of the seasonal differences of krill biomass could be either or combination of 1) onshore migration of krill in autumn to winter (Siegel et al., 1997) and 2) depletion of krill by predators (Brierley et al. 2002).

There were two main categories of limitations to interpret the result of this analysis. First category of limitation was applied to acoustic survey of krill in general. Those general limitations were 1) background krill which could not be detected by echo sounder because of low density, 2) krill refuge which meant that krill could distribute where the survey vessel could not enter such as under sea ice and 3) surface krill which meant that krill could distribute shallower than the transducers (Nicol et al., 2000(b)). Those three general limitations of abundance estimation of krill using echo sounder would contribute to underestimation of krill biomass. The other category of limitation was applied specifically to this analysis. Though krill identification using ΔMVBS between 120 kHz and 38 kHz have been well established, there was some uncertainty associated species identification of mark on echogram because no net sampling was conducted in the surveys presented here. Along with this, there was no in-situ length frequency and weight data of krill to convert acoustic backscattering to biomass except the Ross Sea in 2004/2005. The results of comparison of biomass between *Kaiyo Maru* and KS2 suggested that data from two vessels were comparable. Murase et al. (2006) suggested that krill distributions and the length frequency data for the purpose of acoustical biomass estimation could be obtained from stomach contents of Antarctic minke whales. The results of this paper could be updated using krill distributions and the length frequency data from stomach contents of Antarctic minke whales. Calibration of echo sounder is very important because subtle parameter setting change will results in large effect on biomass estimation of krill. Because there was no calibration result in 2002/03, interpretation of the result in that year may need caution. Demer and Conti (2005) proposed the new TS for *E. supreba* using Stochastic Distorted-Wave Born-Approximation (DSDWBA) model. If the new TS applied to our results, krill biomass would be 2.5 times higher than the current estimates. Methods of TS estimation would also introduce bias to the biomass estimates.

Over all, the results presented here provided general distribution and biomass patterns of krill in the survey area. Following points should be considered to improve the echo sounder survey in future: 1) survey should be conducted in peak abundance season of krill (January and February) to minimize seasonal effect on abundance estimation, 2) survey should be conducted in same area in same survey timing to interpret yearly changes, 3) target net sampling should be conducted to identify species compositions of marks detected by the echo sounder so that appropriate amount of backscattering can allocate to krill and 4) calibration must be conducted every year to set appropriate parameters in the echo sounder.

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REFERENCES

Azzali, M., Leonori, I., De Felice, A. and Russo, A. 2006. Spatial-temporal relationships between two euphausiid species in the Ross Sea. Chem. Ecol. (Suppl.) 22:219-233.

Atkinson, A, Siegel, V., Pakhomov, E. and Rothery, P. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. Science 432:100-103.

Brierley, A. S., Goss, C., Grant, S. A., Watkins, J. L., Reid, K., Belchier, M., Everson, I., Jessop, M. J., Afanasyev, V. and Robst, J. 2002. Significant intra-annual variability in krill distribution and abundance at south Georgia revealed by multiple acoustic surveys during 2000/01. CCAMLR Sci. 9:71-82.

Branch, T. A., Matsuoka, K. and Miyashita, T. 2004.Evidence for increases in Antarctic blue whales based on Bayesian modeling. Mar. Mamm. Sci. 20:726-754.

Demer, D. A. and Hewitt, R. P. 1995. Bias in acoustic biomass estimates of *Euphausia superba* due to diurnal vertical migration. Deep-sea Res. 42:455-475.

Demer, D. A. and Conti, S. G. 2005. New target-strength model indicates more krill in the Southern Ocean. ICES J. Mar. Sci. 62:25-32.

Greene, C. H., Stanton, T. K., Wiebe, P. H. and McClatchie, S. 1991. Acoustic estimates of Antarctic krill. Nature 349: 110.

Hewitt, R. P. and Demer, D. A. 1993. Dispersion and abundance of Antarctic krill in the vicinity of Elephant Island in the 1992 austral summer. Mar. Ecol. Prog. Ser. 99: 29-39.

Hewitt, R. P. and Demer, D. A. 2003. An 8-year cycle in krill biomass density inferred from acoustic surveys conducted in the vicinity of the South Shetland Islands during the austral summers of 1991-1992 through 2001-2002. Aquat. Living . Res. 16:205-213.

Hewitt, R. P., Watkins, J., Naganobu, M., Sushin, V., Brierley, A. S., Demer, D., Kasatkina, S., Takao, Y., Goss, C., Malyshko, A., Brandon, M., Kawaguchi, S., Siegel, V., Trathan, P., Emery, J., Everson, I., Miller, D. 2004. Biomass of Antarctic krill in the Scotia Sea in January/February 2000 and its use in revising an estimate of precautionary yield. Deep Sea Res. II 51:1215-1236.

Johnston, S. J. and Butterworth, D. S. 2004. Updated age-aggregated production modelling assessments of the Southern Hemisphere humpback whale breeding stocks A and C. Paper SC/56/SH20 presented to 56th Scientific Committee, June 2004 (unpublished). 21pp. [available from IWC]

Jolly, G. M. and Hampton, I. 1990. A stratified random transect design for acoustic surveys of fish stock. Can. J. Fish. Aquat. Sci. 47: 1282-1291.

Kawamura, A. 1994. A review of baleen whale feeding in the Southern Ocean. Rep. Int. Whal. Commn. 44: 261-271.

Laws, R. M. 1985. The ecology of the Southern Ocean. Am. Sci. 73: 26-40.

Laws, R. M. 1977. Seals and whales of the southern ocean. Philos. Trans. R. Soc. Lond. (B Biol. Sci.) 279: 81-96.

Loeb, V. and Siegel, V. 1992. AMLR Program; krill stock structure in the Elephant Island area, January –March, 1992. U. S. Antarct. J. 214-216.

Mori, M. and Butterworth, D. S. 2006. A first step towards modelling the krill-predator dynamics of the Antarctic ecosystem. CCAMLR Sci. 13:217-277.

Murase, H., Matsuoka, K., Ichii, T. and Nishiwaki, S. 2000. Relationship between the distribution of euphausiids and baleen whales in the Antarctic examined using JARPA data. Paper SC/52/E5 presented to the 52th IWC Scientific Committee, June 2000 (unpublished). 18pp. [available from IWC]

Murase, H., Matsuoka, K., Ichii, T. and Nishiwaki, S.2002. Relationship between the distribution of euphausiids and baleen whales in the Antarctic (35°E-145°W). Polar Biol. 25:135-145.

Murase, H., Tamura, T., Matsuoka, K., Nishiwaki, S., Yasuma, H., Matsukura, R., Yabuki, T, Takao, Y., Taki, K., Hayashi, T. and Naganobu, M. 2006. Distribution patterns and biomasses of Antarctic krill (*Euphausia superba*) and ice krill (*E. crystallorophias*) with referece to Antarctic minke whales in the Ross Sea in 2004/05 using Kaiyo Maru-JARPA joint survey data. Paper SC/D06/J24 presented to the JARPA Review Meeting, December 2006 (unpublished).

Murphy, E. J., Morris, D. J., Watkins, J. L. and Priddle, J. 1988. Scales of interaction between Antarctic krill and the environment. In Sahrhage, D. ed.: Springer-Verlag, Berlin. 120-130.

Nicol, S. Constable, A. J. and Pauly, T. 2000 (a). Estimates of circumpolar abundance of Antarctic krill based on recent acoustic density measurement. CCAMLR Sci. 7:87-99.

Nicol, S., Pauly, T., Bindoff, N. L., Weight, S., Thiele, D., Hosie, G. W., Strutton, P. G. and Woehler, E. 2000(b). Ocean circulation off east Antarctica affects ecosystem structure and sea-ice extent. Nature 406: 504-507.

Nishiwaki, S., Ishikawa, H. and Fujise, Y. 2006. Review of general methodology and survey procedure under the JARPA. Paper SC/D01/J2 presented to the JARPA Review Meeting, December 2006 (unpublished).

Pakhomov, E. A. 2000. Demography and life cycle of Antarctic krill, *Euphausia superba*, in the Indian sector of the Southern Ocean: long-term comparison between coastal and open-ocean regions. Can. J. Fish. Aquat. Sci. 57(Suppl. 3):68-90.

Pauly, T., Nicol, S, Higginbottom, I, Hosie, G and Kitchener, J. 2000. Distribtuion and abundance of Antarctic krill (*Euphusia superba*) off east Antarctica (80-150°E) during the Austral summer of 1995/96. Deep-Sea Res. Part II 47:2465-2488.

Siegel, V. 1986. Structure and composition of the Antarctic krill stock in the Bransfield Strait (Antarctic Peninsula) during Second International BIOMASS Experiment (SIBEX). Arch. Fishc. Wiss. 37: 51-72.

Siegel, V., de la Mare, W. and Loeb, V. 1997. Long term monitoring of krill recruitment and abundance of indices in the Elephant Island area (Antarctic Peninsula). CCAMLR Sci. 4:19-35.

Simrad. 1997. Simrad EK500 Scientific Echo Sounder Operation Manual P2170G. Simrad AS Horten, Norway.

Tynan, T. C. Ecological imporatance of the Southern Boundary of the Antarctic Circumpolar Current. Nature 392:708-710.

Watanabe, T., Yabuki, T., Suga, T., Hanawa, K., Matsuoka, K. and Kiwada, H. 2006. Results of oceanographic analyses conducted under JARPA and possible evidence of environmental changes. Paper SC/D01/J30 presented to the JARPA Review Meeting, December 2006 (unpublished).

Table 1. Density and biomass of krill in each stratum in Area IV and eastern part of Area III in 1999/2000 and 2001/2002

Year	Stratum	Date	Number of transects	Surveyed distance (n.miles)	Surveyed area (n.mile^2)	Mean desnsity (g/m^2)	Biomass (million t)	CV (%)
1999/2000	III-E-F	12/5/99-12/26/99	13	1,749	352,919	13.2	16.0	29.9
2001/2002		11/29/01-12/24/01	8	1,116	355,477	34.5	42.1	30.2
1999/2000	IV-NE	12/27/99-1/11/00	5	1,117	226,222	20.3	15.7	33.7
2001/2002		12/25/01-1/8/02	2	165	247,657	14.2	12.1	50.9
1999/2000	IV-NW	1/11/00-1/26/00	5	1,257	203,752	19.0	13.3	54.1
2001/2002		1/9/02-1/25/02	5	582	223,617	18.3	14.0	49.3
1999/2000	IV-PB	1/28/00-2/18/00	15	1,061	22,047	16.7	1.3	22.6
2001/2002		1/26/02-2/8/02	17	1,092	28,570	13.7	1.3	44.0
1999/2000	IV-SE	2/18/00-2/29/00 3/6/00-3/9/00	17	926	33,332	16.3	1.9	28.9
2001/2002		2/10/02-2/21-02	14	975	33,781	20.3	2.3	27.7
1999/2000	IV-SW	3/1/00-3/6/00	4	428	43,125	13.7	2.0	21.8
2001/2002		2/22/02-2/27-02	3	432	30,837	41.0	4.3	15.9
1999/2000	III-E-S	-	-	-	-	-	-	-
2001/2002		2/28/02-3/8-02	3	300	389,700	56.8	75.9	57.8

Table 2. Density and biomass of krill in each stratum in Area V and western part of Area VI from 1998/1999 to 2002/2003.

Year	Stratum	Date	Number of transects	Surveyed distance (n.miles)	Surveyed area (n.mile^2)	mean desnsity (g/m^2)	Biomass (million t)	CV (%)
1998/1999	VI-W-F	-	-	-	-	-	-	-
2000/2001		12/11/00-12/31/00	5	658	289,954	3.4	3.4	60.6
2002/2003		12/3/02-12/30/02	14	1,810	308,374	1.5	1.6	34.2
2004/2005		12/7/04-12/23/04	10	736	278,538	0.5	0.4	38.6
1998/1999	V-NE	-	-	-	-	-	-	-
2000/2001		1/1/01-1/23/01	5	896	348,548	11.6	13.9	27.4
2002/2003		1/5/03-1/25/03	9	1,329	345,010	5.7	6.8	27.3
2004/2005		12/26/04-1/5/05	6	471	336,138	3.2	3.6	37.0
1998/1999	V-NW	1/14/99-2/2/99	5	1,405	314,710	21.7	23.4	20.0
2000/2001		2/10/01-2/23/01	4	565	270,666	1.3	1.2	19.4
2002/2003		2/11/03-2/20/03 3/5/03-3/7/03	5	805	266,896	10.1	9.3	25.4
2004/2005		-	-	-	-	-	-	-
1998/1999	V-SW	2/3/99-2/21/99	17	1,152	48,361	25.3	4.2	33.5
2000/2001		2/25/01-3/19/01	13	857	80,503	8.6	2.4	49.4
2002/2003		2/21/03-3/5/03	5	377	79,072	16.8	4.6	20.0
2004/2005		2/27/05-3/7/05	5	272	51,449	5.9	1.0	49.0
1998/1999	V-SE	2/22/99-3/13/99	13	541	24,795	24.7	2.1	36.0
2000/2001		1/24/01-2/9/01	15	1,401	148,831	6.5	3.3	30.5
2002/2003		1/27/03-2/9/03	10	775	68,928	8.3	2.0	27.8
2004/2005		1/16/05-2/13/05	12	1,448	212,214	3.2	2.4	28.2
1998/1999	VI-W-S	3/14/99-3/28/99	12	590	287,627	0.2	0.2	67.0
2000/2001		-	-	-	-	-	-	-
2002/2003		-	-	-	-	-	-	-
2004/2005		-	-	-	-	-	-	-

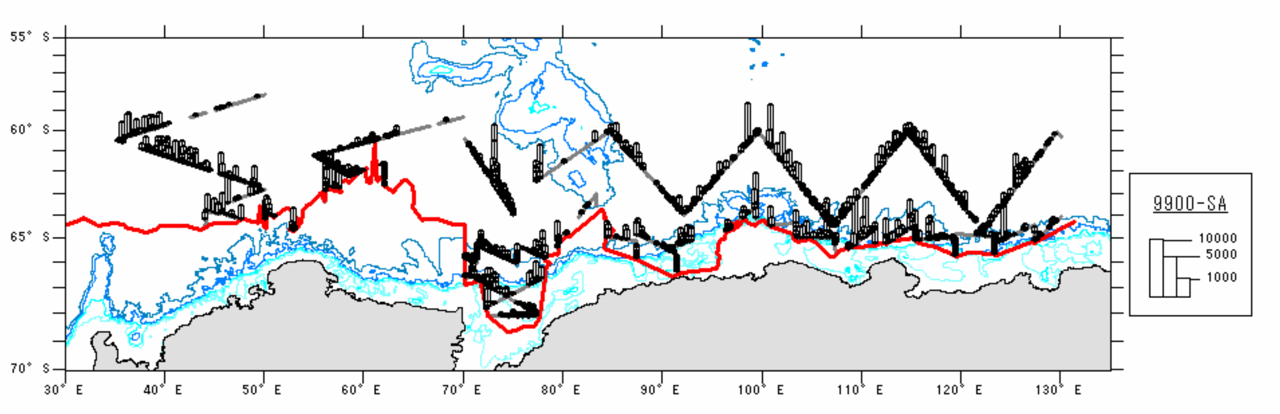
Table 3. Estimated biomass of krill in Area IV and V from 1998/1999 to 2004/2005.

Area	Year	Surveyed area (n.mile^2)	Number of transcts	Surveyed distance (n.mile)	Biomass (Million t)	CV (%)	Note
IV	1999/2000	528,477	59	4,789	34.2	26.2	
	2001/2002	564,463	52	3,246	34.1	27.3	
V	1998/1999	387,867	35	3,098	29.7	16.6	No survey in NE
	2000/2001	848,548	37	3,719	20.7	19.8	
	2002/2003	759,906	29	3,286	22.6	14.1	
	2004/2005	599,801	23	2,191	7.0	22.6	No survey in NW

Table 4. Density and biomass of *E. superba* and *E. crystallorophias* in the Ross Sea in 2005 (from Mureae et al. 2006).

	E. superba			*E. crystallorophias*			
	Kaiyo Maru	*Kyoshin Maru #2*	Total	*Kaiyo Maru*	*Kyoshin Maru #2*	Total	Gross Total
Weighted mean ρ (g/m^2)	5.4	2.6	3.9	3.4	1.6	2.2	3.1
Surveyed area (n.mile^2)		110792			106800		217592
Biomass (million t)	2.04	1.00	1.46	1.26	0.57	0.82	2.28
CV (million t)	0.44	0.36	0.32	0.21	0.26	0.18	0.22

1999/2000



2001/2002

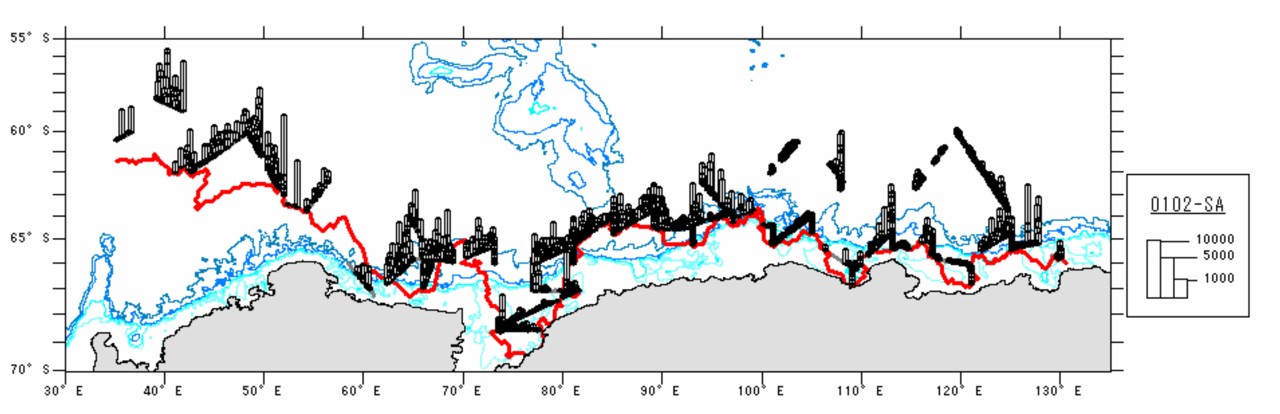


Fig. 1. Distributions and densities of krill in Area IV and eastern part of Area III in 1999/2000 and 2001/2002. Densities were shown as mean backscattering area per square n. mile of survey transect (S_A) in square root scale. Bottom depth contour lines: (500m), (1000m), (1500m) and (2000m). Ice edge line: .

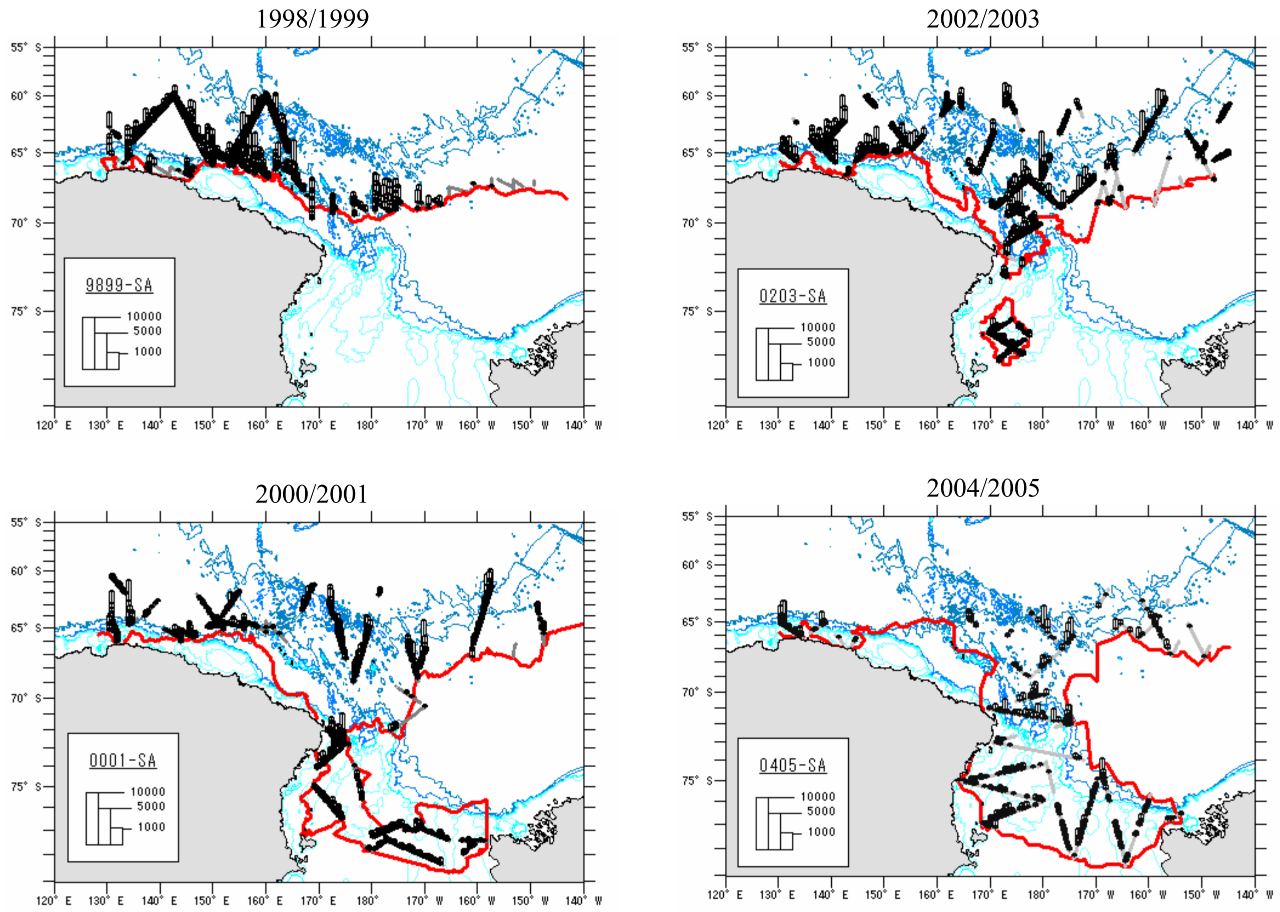


Fig. 2. Distributions and densities of krill in Area V and western part of Area VI from 1998/1999 to 2004/2005. Densities were shown as mean backscattering area per square n. mile of survey transect (S_A) in square root scale. Bottom depth contour lines: (500m), (1000m), (1500m) and (2000m). Ice edge line: .