Estimation of krill biomass based on JARPAII acoustic surveys

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ABSTRACT

Krill biomass estimation surveys using quantitative echo sounder have been conducted during the JARPAII surveys to achieve one of the objectives of JARPAII which is 'Monitoring of the Antarctic Ecosystem' through the monitoring of krill abundance and the feeding ecology of whales. The echo sounder surveys were conducted during the course of sighting surveys. Complete data sets were obtained for only two JARPAII surveys, one carried out in the 2007/08 season in Areas III-East (35°E–70°E) and IV (70°E–130°E), and the other in the 2008/09 season in Areas V (130°E–170°W including the Ross Sea) and VI-West (170°W–145°W). The total biomass estimation of krill in Areas III-E and IV were 6.6 and 12.5million tons, respectively. In Areas V and VI-W the estimations were 24.0 and 3.4million tons, respectively. It was not possible to evaluate any trend in krill abundance with just two surveys conducted in different areas. However krill estimates were used to compare krill consumption by Antarctic minke whales and as input data for the development of ecosystem models for Area IV.

KEYWORDS: FOOD/PREY, ACOUSTICS; MODELLING; SCIENTIFIC PERMITS; ANTARCTIC

INTRODUCTION

The Antarctic krill (*Euphausia superba*) is a key prey species in the Antarctic ecosystem supporting different species of baleen whales, pinnipeds, birds and fish. Changes in its abundance could affect the biology and abundance on its predators as well the whole ecosystem. For this reason JARPAII considered it important to conduct yearly monitoring of krill biomass in the research area, which is incorporated into the Objective 1 of the JARPAII (Government of Japan, 2005; Pastene *et al*., 2014).

Due to the external interferences explained in Appendix 6 of Pastene *et al*. (2014) the planed survey of prey species (krill) using an echo sounder equipped vessel and sampling by Isaacs-Kidd Midwater Trawl (IKMT) could not be carried out as originally planed. Surveys were conducted between the 2005/06 and 2008/09 JARPAII seasons, and no survey was conducted from the 2009/10 season. Complete data sets were obtained for only two surveys, 2007/08 in Areas III-E and IV and 2008/09 in Areas V and VI-W (see details in Nishiwaki *et al*, 2014).

This paper presents the results of the krill biomass estimation based on the echo sounder data collected in 2007/08 and 2008/09 seasons. It was not possible to evaluate any trend in krill abundance with just two surveys conducted in different areas. However the krill biomass estimates obtained in the present study are useful to compare krill consumption by Antarctic minke whales in the research area (Tamura and Konishi, 2014), and as input data for the development of the ecosystem models, which is another of the JARPAII's research objectives (Kitakado *et al*., 2014).

MATERIALS AND METHODS

Survey area

The surveys covered the IWC management Areas III-E (35°E-70°E), IV (70°E-130°E), V (130°E-170°W) and VI-W (170°W-145°W), between south of 60°S and the ice edge line. Each Area was further divided into east and west, at 100°E in the case of Area IV and at 165°E in the case of Area V. Each longitudinal sector was further divided into north (between the 60°S and the line of 45n.miles from the ice edge) and south (between the line of 45n.miles from ice edge and the 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 "Prydz Bay'. The Prydz bay was covered with ice, such that the full survey could not be conducted in 2007/08 JARPAII (Figs. 1-a, b).

The following acronyms were used to describe strata name:

III-SE	South-East stratum in Area III	III-NE	North-East stratum in Area III
IV-SE	South-East stratum in Area IV	IV-NE	North-East stratum in Area IV
IV-SW	South-West stratum in Area IV	IV-NW	North-West stratum in Area IV

IV-PB	Prydz Bay region in Area IV		
V-SW	South-West stratum in Area V	V-NW	North-West stratum in Area V
V-SE	South-East stratum in Area V	V-NE	North-East stratum in Area V
V-NE-S	South stratum in Area V-NE		
VI-SW	South-West stratum in Area VI	VI-NW	North-West stratum in Area VI

Track-line design and timing

Saw tooth type zigzag lines were used in each survey. Details of the trackline designs were reviewed in Nishiwaki *et al*. (2014). The surveys were conducted in the austral summer seasons (December-March) of 2007/08 and 2008/09. Details of the surveys were summarized in Tables 1-a, b.

Survey vessels

The cetacean sighting and prey survey vessels *Kyoshin maru* No.2 (*KS2*: 372.00 GT) and *Kaiko maru* (*KK1*: 860.25 GT) were engaged in the sighting survey of cetaceans as well as in the echo sounder and oceanographic surveys. The nominal steaming speed of SVs on the track line was 10.5knots.

Echo sounder data

Quantitative echo sounder (EK500; Simrad, Norway) with software version 5.30 operating frequency at 38 and 120 kHz on board *KS2* and *KK1* were used to collect data for the acoustic survey. The transducers were hull-mounted at the depth of 4.3m from the surface. Echoview version 3.00 (*KS2*) or 3.50 (*KK1*) (Sonar Data Pty Ltd, Australia) was used. The copper sphere technique described in EK 500 operation manual (Simrad, 1997) was applied for the calibrations. Calibrations were conducted in Antarctic water every year.

Krill data

Biological samples of krill were obtained at 68 stations using 12 feet net-mouth IKMT by *KK1*. IKMT was mainly used to sample krill. IKMT was mainly used to investigate species identification and size compositions of backscattering from krill detected by the quantitative echo sounder. The samples were preserved in 10% formalin for species identification at the laboratory. Length frequency data of krill sampled by IKMT were measured. The body length of krill was measured to the nearest 1mm, from the anterior tip of the rostrum to the posterior end of the telson as described by Makarov and Denys (1981) and Mauchline (1981). The weight of whole or separate by species krill was measured to the nearest 1g. Depth of trawling was recorded by Catch monitoring system PI32 (Simrad), and Conductivity Temperature Depth profiler (CTD) was recorded at positions of IKMT sampling. Positions and main species of IKMT sampling stations are shown in Figs. 2-a, b. Proportion of main species in each stratum are shown in Figs. 3-a, b.

Data recording methodology

The survey was conduced during diurnal hours from one hour after sunrise to one hour before sunset. Maximum survey time per day was within 12 hours. Echo sounder data were recorded continuously while the vessel steamed on predetermined track line. The data were not used in the analysis when the vessels deviated from the track line such as during cetacean species confirmation. The positions conducted IKMT were recorded.

Data analysis methodology

We applied the acoustic data analysis described by method agreed at CCAMLR (2010). The following procedures came from this paper.

Krill wet weight (w) was calculated with the following formula: Jarvis *et al.* (2010). Where, L was average length of krill in each stratum that 5% of the upper and lower values were not included in the analysis.

$$w = 2.236 \times 10^{-6} L^{3.314} \quad (1)$$

Krill backscattering cross section area (σ) was calculated with the following formula based on krill target strength:

$$\sigma = 4\pi 10^{TS(L)/10} \quad (2)$$

where, *TS(L)* was Target Strength (TS) of krill that correspond to average length per 1mm (Calise and Skaret, 2011). TS was calculated by Simplified TS SDWBA.m of SDWBA package2010, version 1.1 June 2012. This package is run by Matlab (The MathWorks, USA). We used Matlab 2012a in this study.

Mean backscattering area per square n.mile of survey transect (S_A) attributed to krill for every 1n.mile of survey transect over 15 to 150m depth was calculated by following formula;

$$s_A = 4\pi r_0^2 1852^2 \int_{r_1=15}^{r_2=150} s_V dr (\frac{m^2}{n.mi^2}) \quad (3)$$

where, r is depth from the surface, $r0$ = 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. *ΔMVBS* was calculated quantitatively using Echoview.

Average area krill biomass density (ρ_i) was calculated as follows;

$$\rho_i = S_A \frac{w}{\sigma} \quad (4)$$

With this formula mean krill biomass of each transect in each stratum was calculated. Weighted mean of (ρ_k) of each block was;

$$\rho_k = \frac{\sum(\rho_i \times n_i)}{\sum n_i} \quad (5)$$

where, ρ_k = mean S_A in kth block, n_i = number of transects in kth block, Then variance of ρ_k was calculated with the formula;

$$Var(\rho_k) = \frac{N}{N-1} \frac{\sum(\rho_i - \rho_k)^2 n_i^2}{\left(\sum n_i\right)^2} \quad (6)$$

Biomass was estimated as;

$$B_k = A \times \rho_k \quad (7)$$

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

$$Var(B_k) = A^2 \times Var(\rho_k) \quad (8)$$

Coefficient of variation of B_k was calculated as;

$$CV(B_k) = \frac{\sqrt{Var(B_k)}}{B_k} \quad (9)$$

RESULTS AND DISCUSSION

Sizes of the krill sampled

The sample size, average length and target strength of krill by IKMT are shown in Tables 2-a, b. Results of the body length distribution of krill are shown in Tables 3-a, b and Figs. 4-a, b. The results suggest that the proportion of small sized krill was higher than that in the stomach contents of whales. Length of *Euphausia superba* ranged from 14 to 59 mm, on the other hand, length of Ice krill (*Euphausia crystallorophias*) ranged from 20 to 35 mm, and that of *Thysanoessa macrura* ranged from 6 to 39 mm (Tables 3-a, b). The body length of krill ingested by the fin (*Balaenoptera physalus*) and Antarctic minke (*Balaenoptera bonaerensis*) whales ranged from 22 to 58 mm (Tamura, 2014). In all areas, but IV-SW and V-SE, small sized krill seemed to be the dominant krill species in the environment (Figs. 4-a, b).

Biomass estimation of krill by each Area

The distribution and mean densities of krill in each area are shown in Figs. 5-a, b. Results of the density and biomass estimation by each area are shown in Tables 4-a, b, 5-a, b. In Area III-E and IV, total biomass estimation of krill in the 2007/08 season were 6.6 and 12.5million tons, respectively. In Area V (including the Ross Sea) and VI-W, these estimates in the 2008/09 season were 24.0 and 3.4million tons, respectively. The mean density by each area are from 24.9 to 37.8g/m^2, from 9.9 to 28.1g/m^2, from 13.3 to 23.1g/m^2 and from 27.1 to 28.7g/m^2 in Areas III-E, IV, V and VI-W.

The similar acoustic surveys were conducted in JARPA from 1998/99 to 2004/05 (Murase *et al.* 2006). Mean densities of krill were reported from 13.2 to 56.8g/m^2, from 13.7 to 41.0g/m^2, from 1.3 to 25.3g/m^2 and from 0.2 to 3.4g/m^2, in Areas III-E, IV, V and VI-W. The values in this study were similar to the estimates by Murase *et al*. (2006). Otherwise, surveys to estimate the distribution and abundance of krill between 80°E and 150°E, south of 63°S were conducted by Australian research vessel in the 1995/96 austral summer (Pauly *et al*. 2000). They reported krill densities of 5.5g/m^2, 6.7g/m^2, 4.2g/m^2 and 9.2g/m^2, in the whole survey area, west area (80°E-115°E), east area (115°E-150°E) and shelf break area, respectively. Acoustic survey in the Ross Sea was conducted in December to January in 1989/90 austral summer (Azzali and Kalinowski, 1997). They reported krill biomass densities as 9g/ m^2 at the end of December and at the beginning of January, and 11g/m^2 in January. Although those densities were similar to values reported in this paper, except for the case of their 2000/01 austral summer survey, difficulties experienced in the comparison of krill abundance derived from echo sounder surveys should be recognized. Factors that should be considered in the comparisons include differences in survey coverage, differences in design and timing of surveys and differences in the methods for estimating biomass of krill.

There are some general limitations to the interpretation of the result of abundance estimation of krill using echo sounder: 1) background krill 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).

These three general limitations would contribute to an underestimation of krill biomass. Over all, the results presented here provided general distribution and biomass patterns of krill in the survey area. The 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) prey survey should be conducted concurrently with cetacean samplings.

Notwithstanding limitations, the estimations in this paper were useful to evaluate the comparison of the krill consumption by Antarctic minke whales (Tamura and Konishi, 2014) and as input data for the development of ecosystem models in Area IV (Kitakado *et al*., 2014). Continuous monitoring of krill biomass is recommended.

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Table 1-a.

Detail of survey in 2007/08 JARPAII

Stratum	Date	Number of transects	Surveyed distance (1,000m)	Surveyed area (n.miles^2)
III-SE	17-25, 28-30 Dec. 2007 1-4 Jan. 2008	15	2,328	50,431
III-NE	16-31 Dec. 2007 1-7 Jan. 2008	8	3,132	228,382
IV-SW*	4-7, 10-11 Jan. 2008 28 Feb. - 5 Mar. 2008	15	2,211	37,758
IV-NW	7-9, 11-13 Jan. 2008 23-29 Feb. 2008 5-8 Mar. 2008	6	3,096	213,311
IV-SE	13-16 Feb. 2008 2-4, 8-17 Mar. 2008	13	1,791	36,277
IV-NE	16-22 Feb. 2008 4-9, 17-20 Mar. 2008	7	3,183	218,265

*Include IV-Prydz Bay

Table 1-b.

Detail of survey in 2008/09 JARPAII

Stratum	Date	Number of transects	Surveyed distance (1,000m)	Surveyed area (n.miles^2)
V-SW	10-12, 15-23 Dec. 2008 26 Dec. 2008-1 Jan. 2009 11,13 Mar. 2009	12	1,521	64,901
V-NW	10-26 Dec. 2008 11, 14, 15 Mar. 2009	9	3,047	224,275
V-SE	4-27 Feb. 2009	8	6,823	277,209
V-NE*	1-8 Feb. 2009 28 Feb. - 13 Mar. 2009	13	4,927	324,889
VI-SW	4, 10-27, 29-31 Jan. 2009	10	2,838	76,255
VI-NW	1-4, 10-14 Jan. 2009 22 Jan.-2 Feb. 2009	5	2,543	166,610

*Include V-NE-S

Table 2-a.

The number of individuals, average length and target strength of krill in 2007/08 JARPAII. Average length was 5% of the upper and lower values deleted.

Stratum	III-SE	III-NE	IV-SW*	IV-NW	IV-SE	IV-NE
Sample Size	373	662	142	98	540	251
Average Lenght(mm)	16.92	27.98	31.55	20.08	25.85	25.01
Target Strength (dB)	-83.5591	-76.8838	-75.5301	-81.0343	-77.6995	-78.1515

*Include IV-Prydz Bay

Table 2-b.

The number of individuals, average length and target strength of krill in 2008/09 JARPAII. Average length was 5% of the upper and lower values deleted.

Stratum	V-SW	V-NW	V-SE	V-NE*	VI-SW	VI-NW
Sample Size	189	138	848	693	286	764
Average Lenght(mm)	32.64	20.67	36.01	19.37	12.00	21.26
Target Strength (dB)	-75.2379	-80.3535	-74.4491	-81.7858	-90.6619	-80.3535

*Include V-NE-S

Table 3-a.

The average, median, minimum and maximum of body length of krill sampled by IKMT in 2007/08 JARPAII

Species	Krill Length (mm)			
	Min	Max	Average	Median
Euphausia superba	15.55	59.13	38.06	38.55
Thysanoessa macrura	7.61	29.99	17.69	17.53
Thysanoessa sp.	8.71	21.77	12.75	12.12
All	7.61	59.13	26.35	21.59

Table 3-b.

The body length distribution of krill sampled by IKMT in 2008/09 JARPAII

Species	Krill Length (mm)			
	Minimum	Maximum	Average	Median
Euphausia superba	14.00	58.00	40.36	43.00
Euphausia crystallorophias	20.00	35.00	28.65	29.00
Thysanoessa macrura	6.00	39.00	11.00	10.00
Thysanoessa macrura?	9.00	29.00	17.69	18.00
Thysanoessa sp.	5.00	13.00	8.52	8.00
All	5.00	58.00	25.26	21.00

Table 4-a.

Density of krill in areas III-E and IV in 2007/08 JARPAII

Transect	III-SE			III-NE			IV-SW*			IV-NW			IV-SE			IV-NE		
	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i
1	70	11.3	0.8	467	21.4	3.4	129	3.3	0.6	384	2.3	0.3	50	216.8	31.8	466	47.4	6.9
2	144	69.7	5.2	472	20.4	3.2	195	27.8	4.8	438	4.8	0.7	107	115.8	17.0	515	61.6	9.0
3	333	28.2	2.1	528	3.8	0.6	132	38.4	6.6	440	61.1	8.4	165	123.8	18.1	587	51.1	7.4
4	295	3.1	0.2	238	1.3	0.2	458	1.1	0.2	591	67.6	9.2	113	109.4	16.0	233	48.4	7.0
5	68	81.2	6.1	193	52.1	8.2	145	20.6	3.5	711	49.8	6.8	145	192.5	28.2	283	23.8	3.5
6	158	24.4	1.8	437	129.3	20.4	92	22.6	3.9	532	37.9	5.2	135	124.0	18.2	519	25.4	3.7
7	145	132.9	10.0	363	43.7	6.9	10	1,040.7	179.1				119	145.0	21.2	580	33.0	4.8
8	162	28.4	2.1	434	86.1	13.6	29	85.7	14.7				135	81.8	12.0			
9	140	136.3	10.2				122	84.5	14.5				219	224.0	32.8			
10	141	261.3	19.6				197	101.0	17.4				133	91.6	13.4			
11	116	146.6	11.0				207	44.4	7.6				145	221.7	32.5			
12	97	136.5	10.2				127	56.3	9.7				131	214.4	31.4			
13	189	137.9	10.3				219	64.2	11.1				194	136.1	19.9			
14	143	102.1	7.6				111	71.1	12.2									
15	127	40.4	3.0				38	72.8	12.5									
Σn_i	2,328			3,132			2,211			3,096			1,791			3,183		
Weighted mean ρ_k			6.0			7.1			7.8			5.5			22.7			6.1
Weighted variance $Var(\rho_k)$			2.2			7.3			4.8			2.0			5.0			0.7

*Include IV-Prydz Bay

[n_i: number of 1,000m averaging intervals on ith transect; S_A: backscattering area per 1,000 of sea surface; ρ_i: weight density of euphausiids per square meter (g/m^2)]

Table 4-b.

Density of krill in areas V and VI-W in 2008/09 JARPAII

Transect	V-SW			V-NW			V-SE			V-NE*			VI-SW			VI-NW		
	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i	n_i	S_A	ρ_i
1	94	99.9	18.0	385	50.1	6.4	989	58.9	12.2	780	70.3	10.1	267	40.8	9.3	497	39.3	5.5
2	143	51.4	9.3	416	68.2	8.8	993	105.8	22.0	888	69.7	10.0	296	35.6	8.1	633	35.4	5.0
3	147	109.4	19.7	466	53.3	6.9	687	39.3	8.2	516	14.0	2.0	223	35.7	8.1	356	47.5	6.7
4	145	44.6	8.0	87	44.2	5.7	1,196	74.8	15.5	54	12.5	1.8	609	27.0	6.2	458	9.6	1.4
5	26	122.6	22.1	363	26.0	3.3	1,058	42.9	8.9	777	31.2	4.5	252	37.8	8.6	599	8.3	1.2
6	174	16.2	2.9	388	19.1	2.5	566	54.3	11.3	992	31.3	4.5	112	24.9	5.7			
7	58	38.4	6.9	459	6.6	0.8	221	9.2	1.9	97	14.5	2.1	212	120.3	27.4			
8	45	27.4	4.9	457	21.5	2.8	1,113	66.5	13.8	202	105.7	15.2	304	8.7	2.0			
9	96	55.7	10.0	26	82.6	10.6				106	17.8	2.6	243	5.7	1.3			
10	136	70.2	12.6							17	18.6	2.7	320	5.8	1.3			
11	137	17.8	3.2							223	22.2	3.2						
12	320	79.3	14.3							143	20.2	2.9						
13										132	11.4	1.6						
Σn_i	1,521			3,047			6,823			4,927			2,838			2,543		
Weighted mean ρ_k			10.8			4.6			13.2			6.3			7.2			3.8
Weighted variance $Var(\rho_k)$			3.2			1.1			3.1			1.6			3.8			1.2

*Include V-NE-S

[n_i: number of 1,000m averaging intervals on ith transect; S_A: backscattering area per 1,000 of sea surface; ρ_i: weight density of euphausiids per square meter (g/m^2)]

Table 5-a.

Mean density and biomass of krill in areas III-E and IV in 2007/08 JARPAII

Stratum	Mean density (g/m^2)	Biomass (million t)	CV (%)
III-SE	6.0	1.0	24.9
III-NE	7.1	5.6	37.8
IV-SW*	7.8	1.0	28.1
IV-NW	5.5	4.1	25.4
IV-SE	22.7	2.8	9.9
IV-NE	6.1	4.6	13.2

*Include IV-Prydz Bay

Table 5-b.

Mean density and biomass of krill in areas V and VI-W in 2008/09 JARPAII

Stratum	Mean density (g/m^2)	Biomass (million t)	CV (%)
V-SW	11.8	2.6	16.6
V-NW	4.4	3.4	23.1
V-SE	11.4	10.8	13.3
V-NE*	6.5	7.2	19.9
VI-SW	4.7	1.2	27.1
VI-NW	3.9	2.2	28.7

*Include V-NE-S

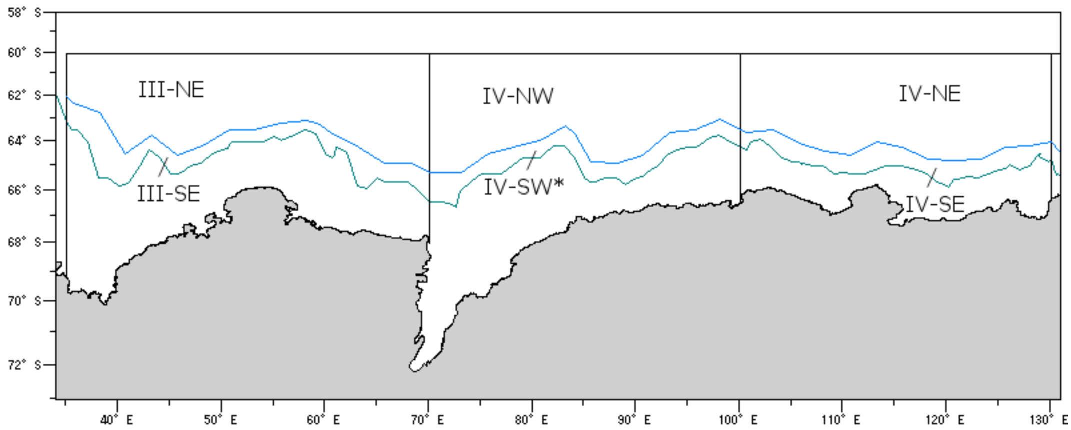


Fig.1-a.   Research strata in 2007/08 JARPAII.
The Prydz bay was covered ice, and then survey almost could not be conducted.

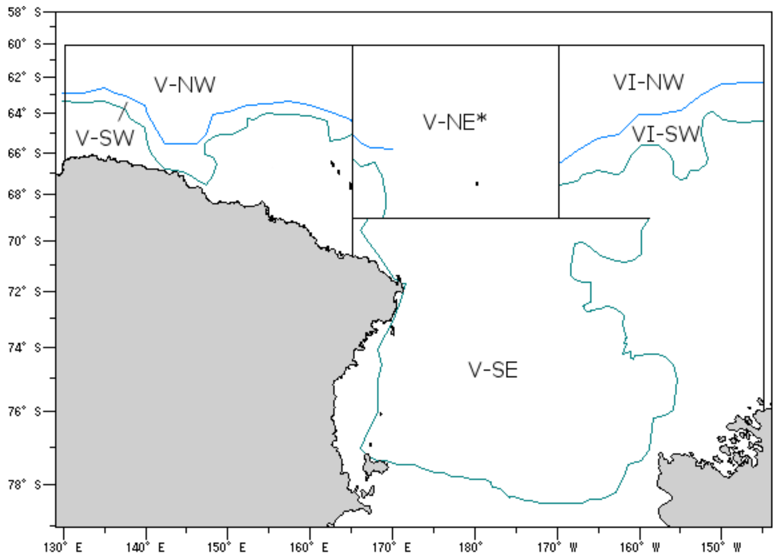
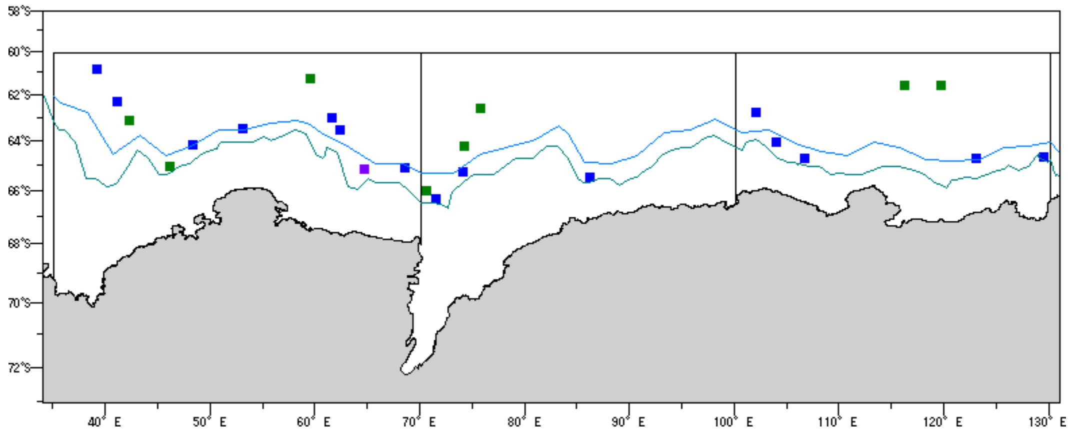
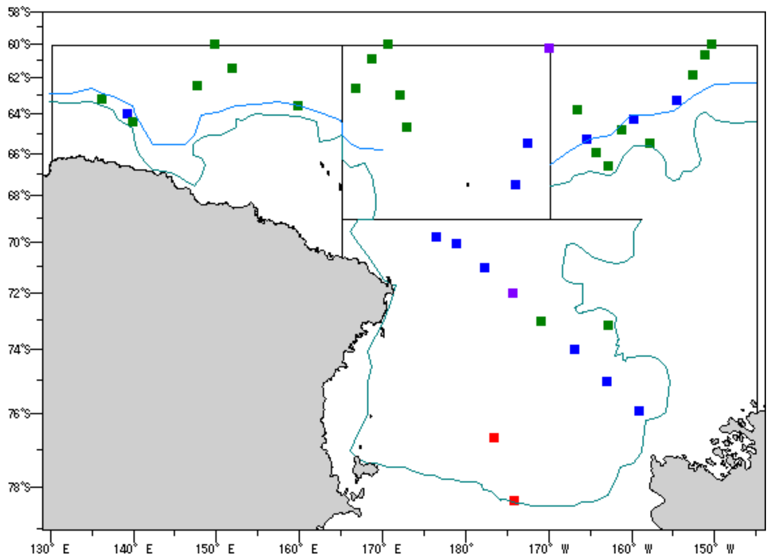


Fig.1-b.   Research strata in 2008/09 JARPAII.



■*Euphausia superba* ■*Thysanoessa macrura* ■*Thysanoessa* sp.

Fig. 2-a. The position of IKMT sampling and main species in area III-E and IV in 2007/08 JARPAII.



■*Euphausia superba* ■*Euphasia crystallorophias* ■*Thysanoessa macrura* ■*Thysanoessa* sp.

Fig. 2-b. The position of IKMT sampling and main species in area V and VI-W in 2008/09 JARPAII.

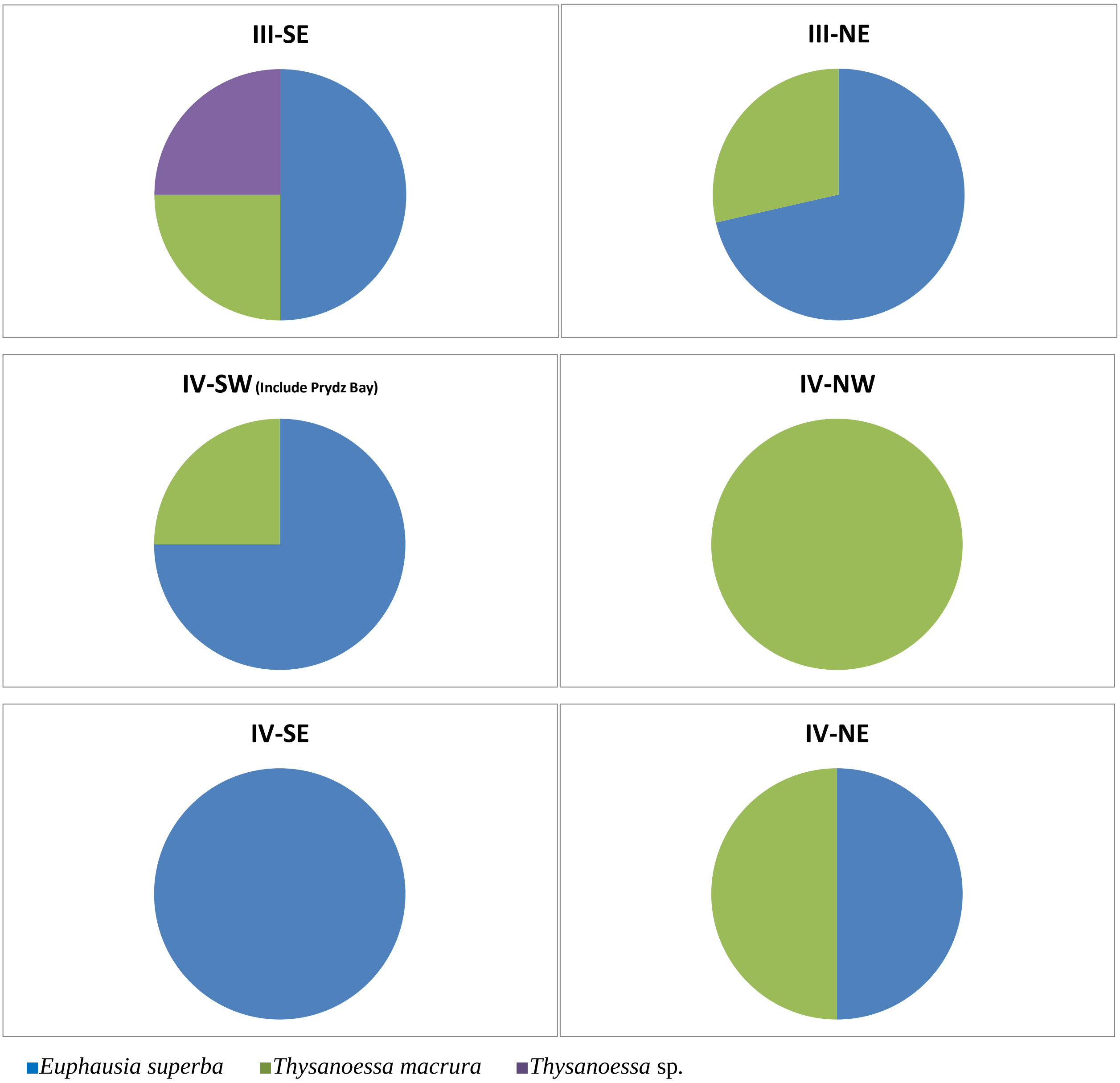


Fig.3-a. Main species of krill sampled by IKMT in each stratum in 2007/08 JARPAII

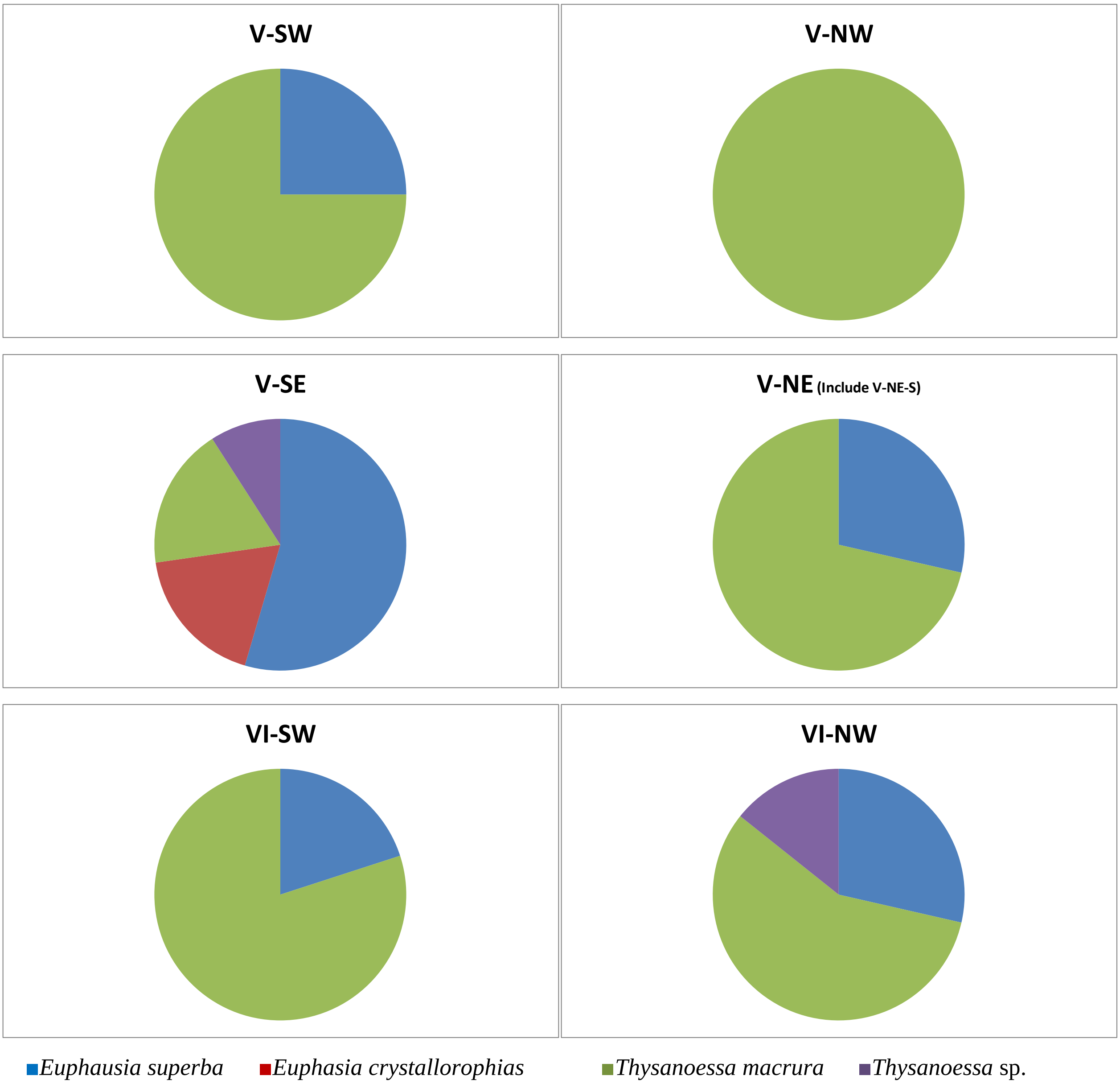


Fig.3-b. Main species of krill sampled by IKMT in each stratum in 2008/09 JARPAII

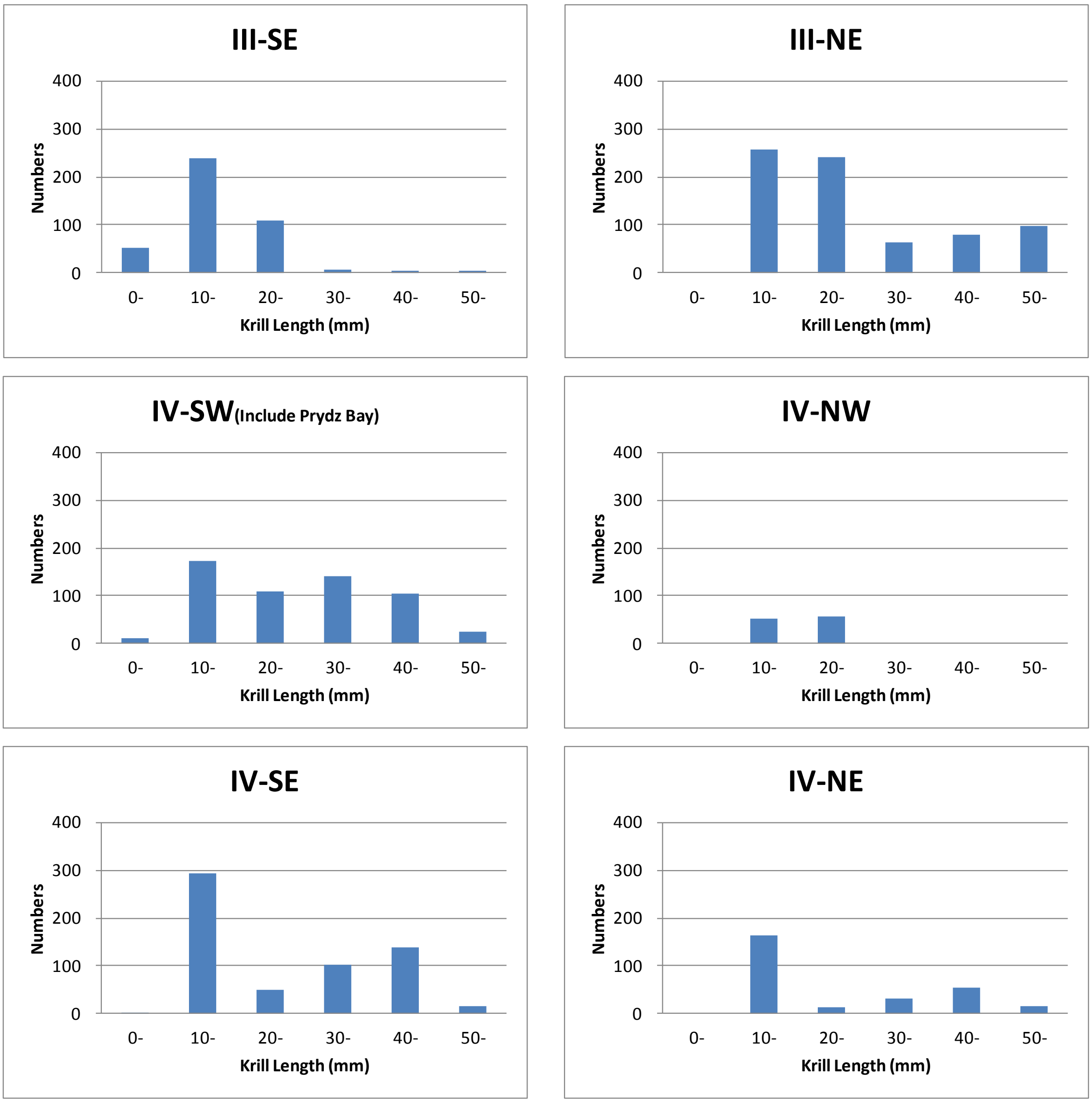


Fig.4-a. Body length distribution of krill sampled by IKMT in each stratum in 2007/08 JARPAII

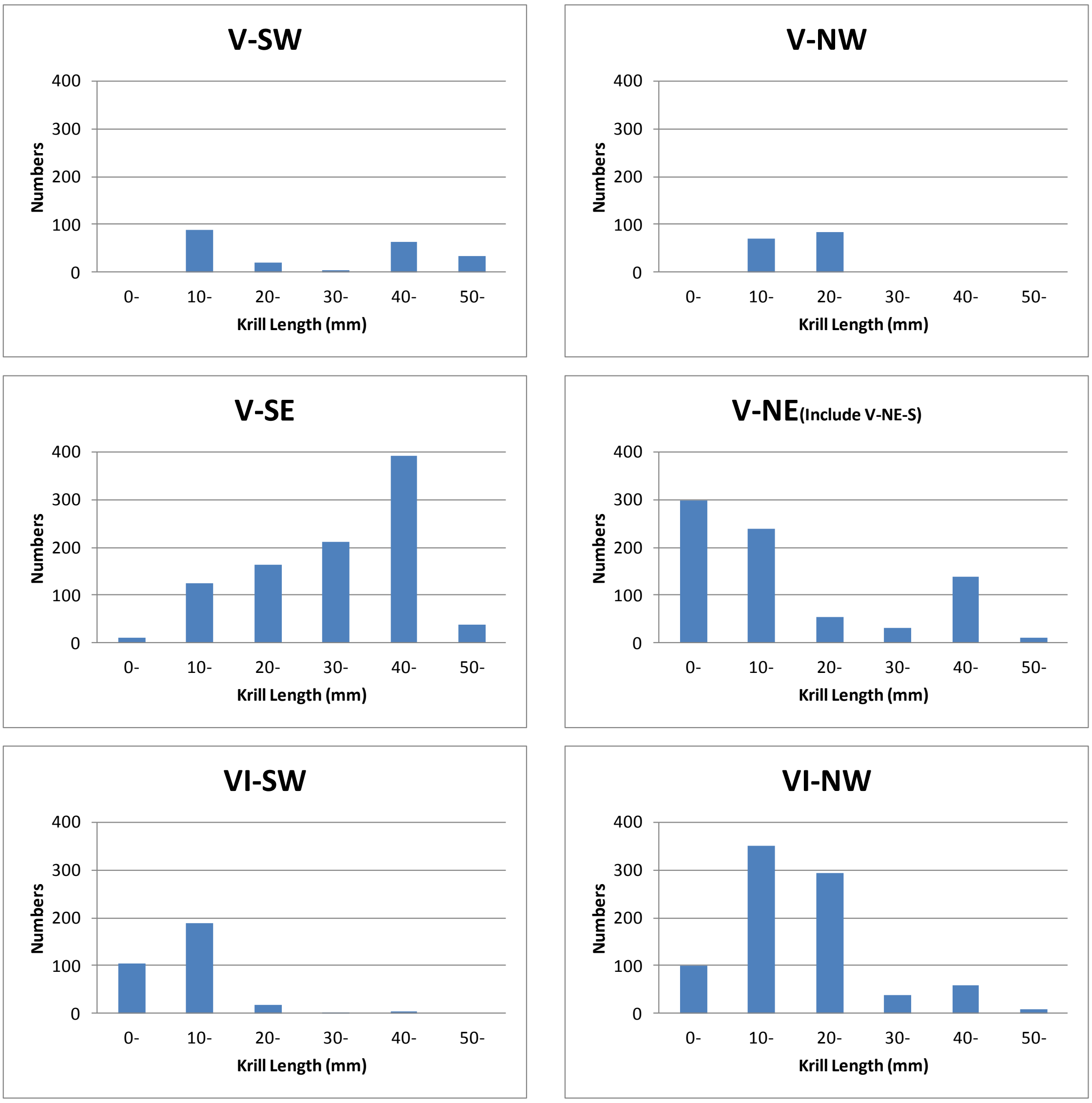


Fig.4-b. Body length distribution of krill sampled by IKMT in each stratum in 2008/09 JARPAII

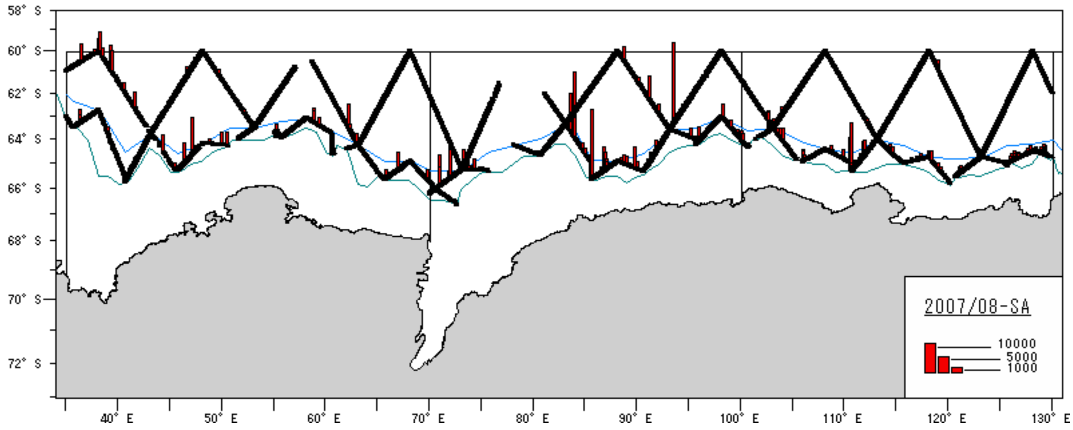


Fig. 5-a. Distributions and densities of krill in area III-E and IV in 2007/08 JARPAII.

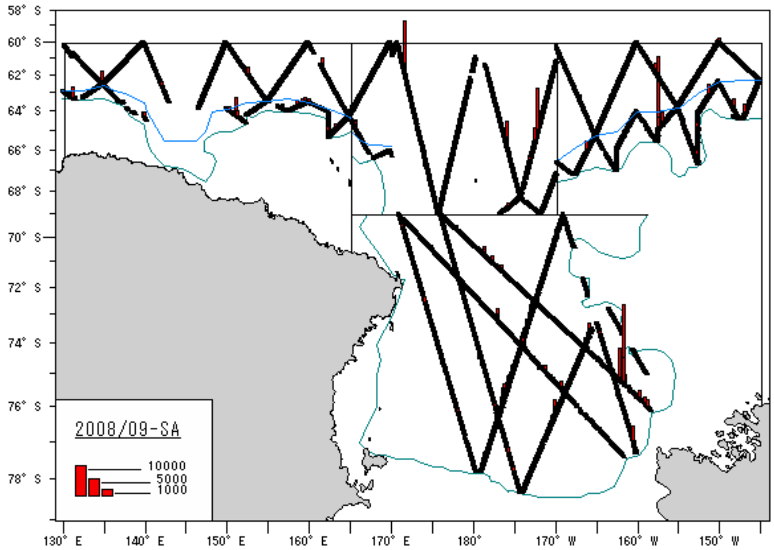


Fig. 5-b. Distributions and densities of krill in area V and VI-W in 2008/09 JARPAII.