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The distribution and demography of *Euphausia superba* in Prydz Bay during the austral summer 2002

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Abstract This study documents the horizontal distribution and demography of Antarctic krill (*Euphausia superba* Dana), collected using trawls, from the Prydz Bay region during January 2002. *Euphausia superba* (*E. superba*) was distributed primarily south of 64°S. The average density and biomass were estimated as 68.85 ind·(1 000 m^{-3}) and 24.16 g wet weight·(1 000 m^{-3}), respectively. Highest values were located in the open sea (depth > 3 000 m). Body length of *E. superba* ranged from 30 to 55 mm (N=1 758), with a mean length of 38.45±3.68 mm (SD). The overall sex ratio was approximately 1∶1, 47.6% females (41.9% sub-adults and 5.7% adults), 46.6% males (42.7% sub-adults and 3.9% adults), while 5.8% were juveniles. The population structure of *E. superba* exhibited geographical variation. At stations in the western part of the survey area populations had a high proportion of juveniles, a lower sexual maturity stage for males and small body size, while the opposite was found at stations in the eastern part. A latitudinal difference was found at stations along 70.5°E and 73°E transects: body length was small and the sex ratio was high in regions of high latitude, while the opposite occurred in areas of low latitude.

Keywords ***Euphausia superba*, distribution, density, population structure, Prydz Bay**

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0 Introduction

Euphausia superba (*E. superba*) prey mainly on phytoplankton in the Southern Ocean[1-2]. They are also a primary food source for many vertebrates and invertebrates[3-4], making them a critical species for the Southern Ocean. Since they are rich in omega-3 fatty acids, antioxidants and high-quality protein and, unlike other sources of animal proteins, low in fat, *E. superba* have also become a major fishery resource for human consumption[5].

Although *E. superba* have a circumpolar distribution, this distribution is asymmetrical on a circumpolar scale and 58%—71% of krills are located the southwest Atlantic sector[6]. Many documents focus on this region[7-9], while there are fewer studies from the South Indian area, as the krill density there is low[10-11]. Several studies have examined the ecology of *E. superba* in the Prydz Bay region of the South Indian area since the 1980’s, referring to the distribution, age structure, fecundity and growth conditions of krills[12-15]. However, few have investigated geographical variations in the population structure.

In this study the distribution, density, population structure and regional variation of *E. superba* populations in the Prydz Bay region were analyzed, from samples collected in January 2002.

1 Materials and methods

Euphausia superba Dana were collected from 15 stations along three transects (68.5°E, 70.5°E and 73°E) in the Prydz Bay region from 5th to 13th January, 2002 (Figure 1). At each station, an Isaacs-Kidd Midwater Trawl (IKMT, mouth area 2 m^2, mesh size 6 mm) was hauled from 100 m depth to the surface at a ship speed of approximately 3.5 knots. Trawls were maintained at 100 m depth for at least 5 min prior to sampling and nets were hauled up at a

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rate of 0.2 m·s^{-1}. All samples were immediately preserved in 5% buffered formalin-seawater solution.

The number and wet weight of *E. superba* from each station were subsequently measured in the laboratory. Wet weight was accurate to 0.001 g. The mouth area of the IKMT net was considered as 2 m^2 for calculations. The volume of water filtered by the nets was determined by multiplying the ship's speed by the time for each trawl and the net mouth area. The density and biomass at each station were estimated from the krill number and wet weight of each catch, respectively, against the amount of water filtered. Values were expressed as number or as grams wet weight per 1 000 m^3.

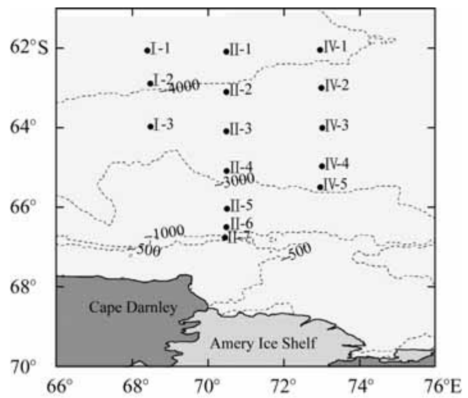

Figure 1 Survey stations in the Prydz Bay.

At stations with a large number of krill, 500 intact individuals selected randomly were used to measure body length and analyze maturity stages. At stations with less than 500 individuals, all intact krills were measured and analyzed. Body length was defined as the distance between the anterior tip of the rostrum and the tip of the uropod (standard 1 measurement)[16] and was measured using vernier calipers to an accuracy of 0.02 mm. Eye diameter was measured to an accuracy of 0.1 mm using a microscope. Male and female krills were classified into different maturation stages according to the system of Makarov and Denys[17]. Classification was as follows: J=Juvenile, these were identified as individuals with no external features or sexual differentiation; 2F = sub-adult female; 3AF = mature female not mated; 3BF=mated mature female, ovaries small; 3CF=mated mature female, ovaries filling thoracic space; 3DF=spawning female; 3EF=spent female; 2AM-2CM= sub-adult male with developing petasma; 3AM=mature male, no spermatophore in ampullae; 3BM=mature male with spermatophore, ready to mate. The frequency distributions of *E. superba* based on the maturity stages were recorded for each station. Sea-surface temperatures were recorded using a ship-board MAKE IIIC-CTD system (Probe model 0531, demarcate documents IM960531.C00). Water was sampled using a Houskin sampler (volume: 10 L) from the National Ocean Technology Center of China. Chl-*a* concentration profiles for each station were determined by filtering water samples from 0 m, 10 m, 25 m, 50 m, 100 m and 150 m depth through Whatman GF filters, Chl-*a* on the filters were extracted using 90% acetone. Chl-*a* concentrations were measured using a Turner Designs Fluorometer, model 10.

2 Results

2.1 Environmental factors

The average surface temperature across the research area was -0.17℃, ranging from -0.51℃ to 0.04℃. The surface temperature in the western part of the survey area (-0.5℃—0.2℃) was lower than that in the eastern and northern parts (-0.2℃—0℃). In the that southern part of the research area, temperature was less than -1℃ (Figure 2a). The surface salinity ranged from 33.24 to 34.00, with a mean value of 33.79. Salinity was higher in the central and western areas compared to the southern area (Figure 2b).

Profile distributions of temperature and Chl-*a* concentration were analyzed along 62°S, 63°S, 64°S and 65°S. Temperature decreased with depth along 62°S and 63°S, and dropped rapidly between 100 and 120 m (Figure 3a, 3b). Along the 64°S profile, the temperature distribution was different between east and west of 70.5°E. In the western area, the temperature decreased from 0.6℃ at the surface to -1.4℃ in the 100 m layer. It remained at about -1.4℃ from 100—150 m, and increased slightly below 150 m. In the eastern area, the similar trend was found, but the surface

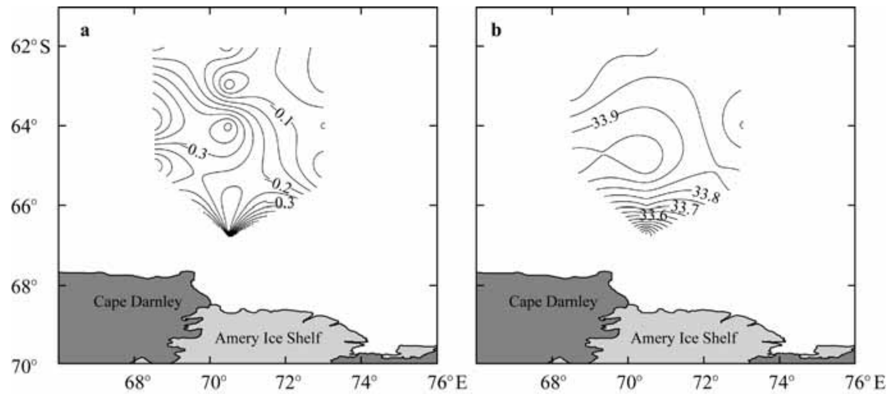

Figure 2 **a,** The horizontal distribution of surface temperature (℃) and **b,** salinity, in Prydz Bay.

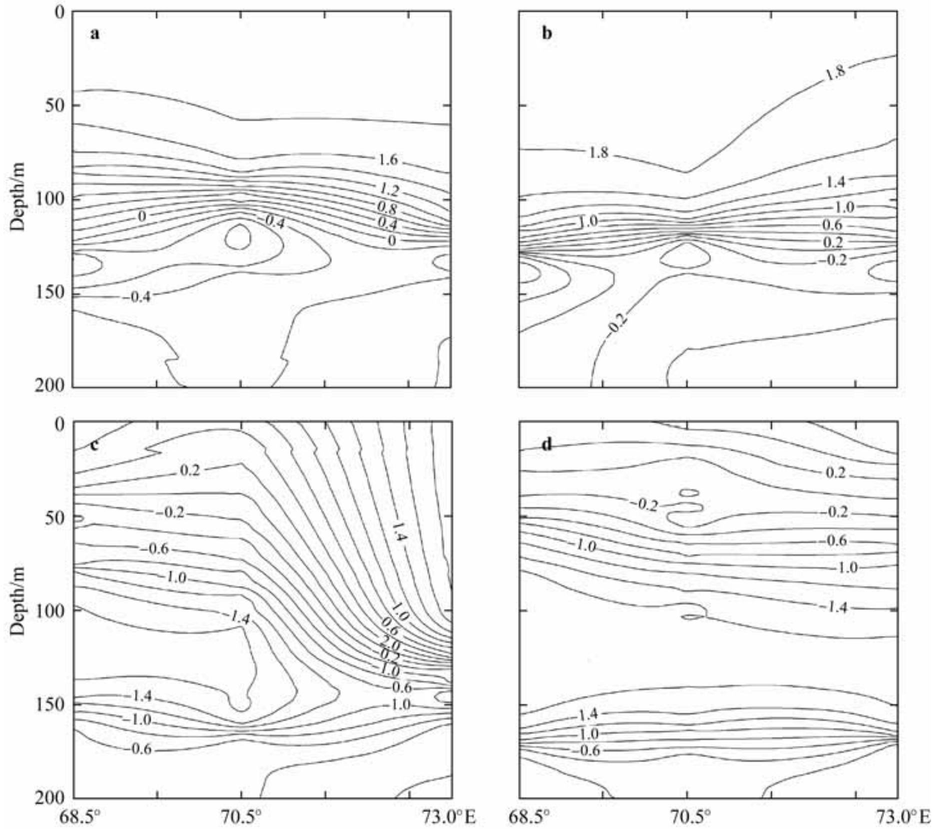

Figure 3 The vertical distribution of temperature (℃). **a,** 62°S. **b,** 63°S. **c,** 64°S. **d,** 65°S.

temperature was higher, and the temperarue dropped from 1.4℃ to -1℃ between 0 m to 150 m (Figure 3c). Along the 65°S profile, the temperature varied slightly between 68.5°E and 73°E. Variations in temperature trends were similar to those exhibited west of 70.5°E along the 64°S profile (Figure 3d).

Figure 4 shows the vertical distribution of Chl-*a* concentrations along 63°S, 64°S and 65°S. The Chl-*a* concentration across the entire survey area was relatively low, ranging from 0.02 to 0.85 mg·m^{-3}. In general, higher values were recorded along 63°S, with a maximum value found in the 75 m layer of 70.5°E (Figure 4a). An even higher value was found at the same depth at 73°E along 64°S, while the concentration was less than 0.2 mg·m^{-3} along the rest of that transect (Figure 4b). The Chl-*a* concentration was relatively low along 65°S, ranging from 0.02 to 0.34 mg·m^{-3}, with values in eastern part higher than the western part (Figure 4c).

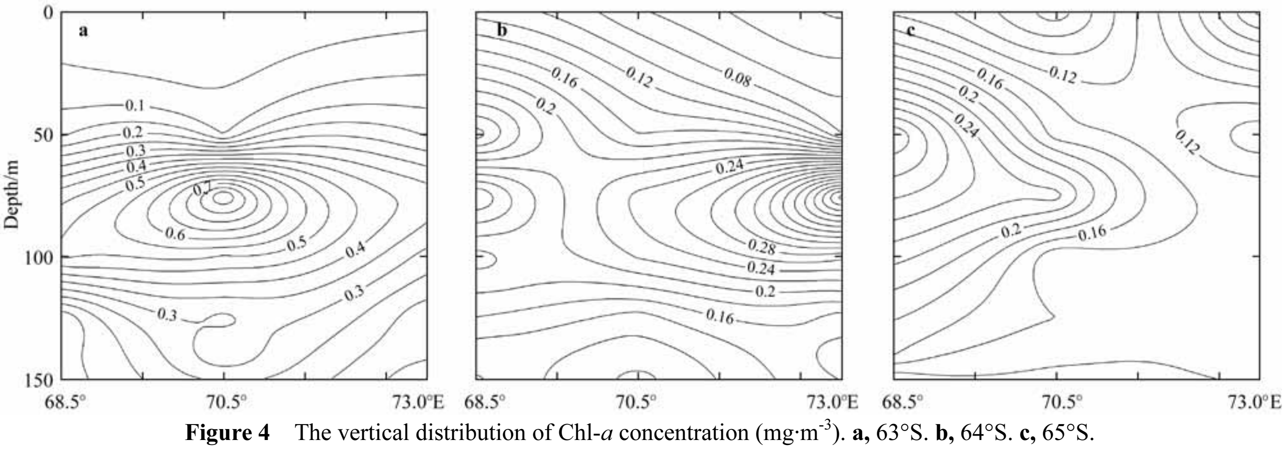

Figure 4 The vertical distribution of Chl-*a* concentration (mg·m^{-3}). **a,** 63°S. **b,** 64°S. **c,** 65°S.

2.2 Distribution and abundance

Post-larval krill were found at 12 of 15 stations, located between 62°S and 67°S; they were absent from I-1, I-2 and II-5. The average density and biomass of *E. superba* was 68.85 ind·(1 000 m^{-3}) and 24.16 g·(1 000 m^{-3}), respectively, and ranged from 0 to 519.75 ind·(1 000 m^{-3}) and from 0 to 175.25 g·(1 000 m^{-3}). The four stations with the greatest abundance of krills (values over 50 ind·(1 000 m^{-3}) or 20 g·(1 000 m^{-3})) were in the open sea (depth>3 000 m). Density and biomass were greater than 200 ind·(1 000 m^{-3}) and 80 g·(1 000 m^{-3}) at two of these stations: II-4 and IV-5. Higher values of density and biomass (17.98 ind·(1 000 m^{-3}) and 5.99 g·(1 000 m^{-3})) were also found at station II-7, on the shelf area (depth between 1 000 and 3 000 m). At the remaining seven stations, the density and biomass of *E. superba* were relatively low, ranging between 0.13—1.16 ind ·(1 000 m^{-3}) and 0.04—0.33 g·(1 000 m^{-3}), respectively (Figure 5).

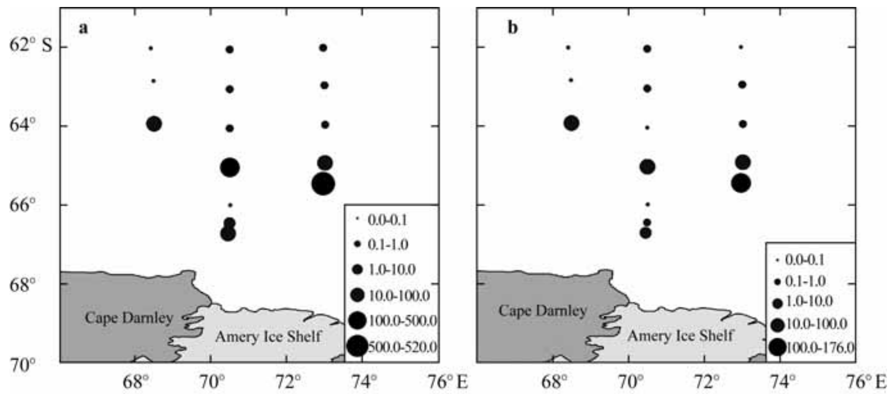

Figure 5 The horizontal distribution and density of *Euphausia superba*. **a,** Density: ind·(1 000 m^{-3}) and **b,** biomass: g·(1 000 m^{-3}).

2.3 Population structure

E. superba were analyzed at five stations, with krills over 10 individuals. The average body length of *E. superba* was 38.48±3.68 (SD) mm, ranging from 30 to 53 mm. The average body length was smallest at station I-3, and highest at IV-4 (Table 1). From the krill collected at 5 stations, 5.8% were juveniles, 84.6% were sub-adults and 9.6% were adults. Females made up 47.6% (41.9% sub-adults and 5.7% adults), and males 46.6% (42.7% sub-adults and 3.9% adults). The overall sex ratio was 1.02, and varied between 0.66 and 1.54 among the stations. Sex ratio exhibited geographical variation in the Prydz Bay region. Along the 70.5°E and 73°E transects, the sex ratio was highest at station II-7 which was located at the high latitude region, while it was lower in low latitude regions. The proportions of sub-adults varied with longitude and decreased from over 10% in the western area (station I-3) to less than 3.5% in the eastern area (stations IV-4 and IV-5). Stages 2F and 3AF dominated in the populations at each station, and few individuals of stages 3BF, 3CF, 3DF and 3EF were found. For males, stages 2AM and 2BM were found in the highest proportions, and few adults occurred. Maturity stages of males also showed geographical variation. Maturity stages were relatively high at station I-3 in the western area, with up to 29% of stage 2AM while other stages combined, only contributed 6.1%. At two stations along the 70.5°E transect, the proportions of stage 2BM increased, with 10% at II-4 and 17.5% at II-7, but higher maturity stage individuals were few in these populations. Percentages of stages 2CM, 3AM and 3BM increased to different degrees at two stations along 73°E (Table 2, Figure 6).

Table 1 Body length of *Euphausia superba* at each station

Station	Range of body length/(mm)	Average body length/(mm)
I-3	30.10–45.36	36.86 ± 2.56
II-4	30.66–49.38	38.41 ± 3.84
II-7	32.24–45.54	37.18 ± 2.24
IV-4	31.66–52.68	40.27 ± 3.42
IV-5	30.42–50.58	38.82 ± 3.99
Total	30.10–52.68	38.48 ± 3.68

Table 2 Number and average body length of different sexual maturity stages of *Euphausia superba*

Maturity stage	Number	Body length/(mm) ± SD
J	103	34.13 ± 2.26
2F	560	36.62 ± 2.35
3AF	269	41.41 ± 2.71
3BF	6	45.99 ± 2.03
3DF	1	52.68
2AM	379	36.65 ± 2.24
2BM	237	39.97 ± 2.06
2CM	134	42.23 ± 2.64
3AM	48	45.41 ± 3.11
3BM	21	45.77 ± 1.58

3 Discussion

The low abundance of *E. superba* in the Prydz Bay region-had been reported in several studies[18-20]. However, Antarctic krill have occurred in high densities in some years in this region[21-22]. In this study, the estimated density and biomass of Antarctic krill were relatively low. It is possible that sampling and estimation methods may have influenced this

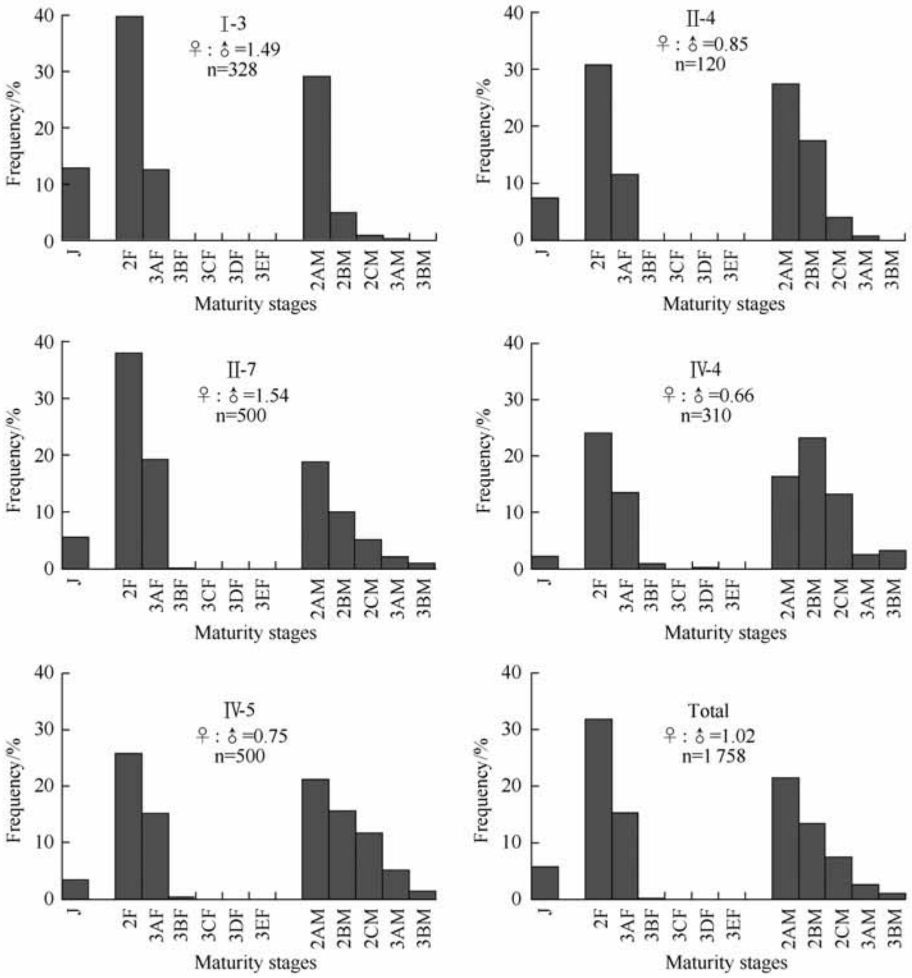

Figure 6 Percentage-frequency distribution of *Euphausia superba* post-larval sexual maturity stages (n=the number of krills measured).

result. The mouth area of the IKMT was assumed to be constant for density and biomass estimations; but the trawl was at a 60° angle during trawling, which could result in underestimates of around 13.5%. Nonetheless, the average and lowest values from 2001/2002 were higher than those recorded in 1999/2000[23], when the sampling and data processing methods were similar. The abundance of *E. superba* was lower than 1.5 ind·(1 000 m^{-3}) or 0.5 g·(1 000 m^{-3}) at half of the stations in this study. However, krill abundance was relatively high at some stations, e.g., IV-5, resulting in a higher average value than for 1999/2000[23]. It had been recorded that 19 of the 51 stations returned no krill and a further 20 stations had very low densities in this region, i.e., <1 ind· (1 000 m^{-3})[18]. The krill density and biomass in our results are consistent with those reported in previous studies[18-19,24]. However, direct comparison is not possible due to the differences in the methods used. Stations with higher abundances of *E. superba* were distributed mainly between 64°S and 67°S, which was supported by several previous studies[20,23-24].

Antarctic krill have been suggested to prefer cold waters. At regions with krills, the average water column temperature at the 200 m layer ranged from -1.19℃—0.99℃, however, the temperature was less than -0.6℃ at stations with high krill abundance. Siegel[25] documented that *E. superba* was distributed mainly in waters with high primary production. However, *E. superba* collected in the Prydz Bay region in the present study occurred in waters with low Chl-*a* concentrations. Witek et al.[26] suggested that such findings may reflect the feeding of krill on phytoplankton, resulting in low Chl-*a* concentrations occurring particularly in regions with dense krill swarms. The present study seems to support the suggestion of Witek et al.[26].

Sub-adult females (2F) and unmated females (3AF) dominated the krill populations at each station, while the proportion of mated females was very low, which indicated that the krill populations were under development during the sampling period. Few individuals of 3DF and 3EF were found in the population, suggesting that the population had not yet spawned. Sampling took place between 5—13

January, which suggested that the spawning time of *E. superba* was later than this date. In addition, it had been reported that no larvae were collected at most stations during the same cruise[27], supporting the idea of late spawning during this year. Wang et al.[12] suggested that the spawning time started from early-January in the Prydz Bay region during the austral summer 1990/1991, earlier than suggested here for 2001/2002. Hosie and Kirkwood[28] considered that low temperatures could postpone and prolong the process of reproduction. However, the average temperature in the upper 25 m of the water column was -0.75℃ in January 1990, and had no significant difference from the temperature in January 2002 (-0.22℃). Thus, it seems unlikely that the late spawning suggested by this study was due to temperature. On the other hand, the spawning time of *E. superba* may be related to sea ice. Melting of sea ice is accompanied by the spring phytoplankton bloom, providing a food supply for *E. superba*[29]. The biweekly sea ice image from NOAA showed that the sea ice melted to the South of 65°S between 17—31 December 2001. This was only two weeks prior to krill sampling, which may explain the late spawning of *E. superba* in 2002 and the low maturity levels of krill sampled.

The population structure of *E. superba* in the deep-sea area also showed geographical variation in body length, proportion of sub-adults, maturity stages of male and sex ratio. In the western part of the survey area, the population had a high percentage of sub-adults, low maturity stages of males and small body lengths, the opposite was found in the eastern part. Huntley and Niiler[30] suggested that horizontal advection was the single most important physical mechanism of the Southern Ocean exerted controlling the population dynamics of its resident zooplankton. Cold and high salinity water may intrude into the Prydz Bay region between 63°S—65°S, 68.5°E—71°E (Figure 2). The temperature profiles along the transect 64°S suggested an intrusion of a cold water mass in the 100—150 m layer between 68.5°E and 70.5°E (Figure 3). The station I-3 was located in the intrusion area, and II-4 was at the edge of the intrusion area. Variations in the population structure at these two stations suggested an overlap of two different populations, i.e. the intrusion population and the resident population; the intrusion population was characterized by a high percentage of sub-adults, low maturity state males and small body sizes, while the resident population exhibited the opposite trends. Station II-4 seemed to consist of these two overlapped *E. superba* populations, whilst only the local resident population occurred at IV-4 and IV-5.

The overall sex ratio of the krill population was generally 1∶1, as has been found in the previous studies[8,30]. However, geographical variation in the sex ratio was apparent. Along the transects 70.5°E and 73°E, the sex ratio was up to 1.45 at station II-7 located on the slope area, suggesting that females may dominate the slope area. The sex ratio decreased towards the deep sea area to values less than one (IV-5: 0.85; II-4: 0.75; IV-4: 0.66), suggesting a higher proportion of males in the deep sea area. A similar distribution of males and females had also been recorded in the southeast of the South Atlantic Ocean[9].

4 Conclusions

In Prydz Bay during the austral summer of 2002, post-larval *E. superba* were distributed primarily between 64°S—67°S and few individuals were found North of 64°S. The density and biomass of *E. superba* were relatively low in this region, with the average value 68.85 ind·(1 000 m^{-3}) and 24.16 g·(1 000 m^{-3}). The overall sex ratio of the krill population was generall 1∶1. And few individuals of stages 3DF and 3EF were found in the population, indicating late spawning in this year. In addition, the population structure and maturity stages of males exhibited geographical variation in the Prydz Bay.

(1) Post-larval *E. superba* were distributed primarily South of 64°S and few individuals were found North of 64°S. The average density and biomass of *E. superba* were 68.85 ind·(1 000 m^{-3}) and 24.16 g·(1 000 m^{-3}). The highest abundance was found in the open sea (depth > 3 000 m).

(2) The overall sex ratio of the krill population was generally 1∶1. Females contributed 47.6% (41.9% sub-adults and 5.7% adults), and males contributed 46.6% (42.7% sub-adults and 3.9% adults). Few individuals of stages 3DF and 3EF were found in the population, indicating late spawning in this year.

(3) The population structure and maturity stages of males exhibited geographical variation. A high percentage of sub-adults and low maturity stages in males were recorded from the western part of the survey area, while the opposite was occurred in the eastern area. The population structure of *E. superba* collected along transects 70.5°E and 73°E showed latitudinal differences. In the high latitude region, krill size was smaller and the sex ratio was larger than that in the low latitude region.

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