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Population distribution, structure and growth condition of Antarctic krill (*Euphausia superba* Dana) during the austral summer in the Southern Ocean

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Abstract Antarctic krill (*Euphausia superba* Dana) was collected using a High Speed Collector and an Isaac–Kidd midwater trawl (IKMT) net during the austral summer of 2007/2008 and 2008/2009 in the circumpolar and Prydz Bay regions of the Southern Ocean, respectively. Combined with the simultaneous recording of environmental factors, spatial distribution, population structure and growth condition of *E. superba* were studied. The abundance of *E. superba* in the Weddell Sea was higher than in Prydz Bay. However, the abundance of E. superba in both the Weddell Sea and Prydz Bay was lower than figures reported in previous krill surveys for the same time period. With respect to the total study area, *E. superba* displayed a normal growing state during the two expeditions. *E. superba* grew relatively poorly in some stations, which may be due to the late retreat of sea ice or lower chlorophyll *a* concentrations. The number of juvenile *E. superba* collected using the High Speed Collector was proportionally greater in stations located at the edge of the sea ice, while adults dominated in long-term non-ice regions. This phenomenon reflects the different distribution pattern between juvenile and adult krill. The population structure of *E. superba* differed between sea regions, which may affect recruitment.

Keywords ***Euphausia superba*, population distribution, growing state, sea ice, Weddell Sea, Prydz Bay**

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1 Introduction

Krill is a crucial link in the Antarctic marine food-web. As an important predator of autotrophic and heterotrophic plankton and major prey item for many higher trophic-level organisms, it plays a significant role in the marine ecosystem[1]. Krill living in the Southern Ocean are known as Antarctic krill, which usually refer to *Euphausia superba* Dana. *E. superba* has a circumpolar but uneven distribution in the Southern Ocean, and over 50% of krill are located in the southwest Atlantic[2-4]. As a major prey resource, variations in krill abundance have had a profound effect on its predators[5]. Recent studies have demonstrated a decrease in sea-ice with climate warming and a corresponding decline in krill stocks, while salp populations (mainly *Salpa thompsoni*) have increased, changes that could significantly affect the marine food-web and even the whole Southern Ocean ecosystem[3,5].

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E. superba is the largest single-species biological resource on the planet, and with a standing stock estimated at 0.65–1 billion tons[6,7], one of the most successful species on Earth and a major attraction for human exploitation[6,8]. For China, with a large and growing population and relatively poor marine biological resources, it has important strategic significance that warrants investigation, development and utilization of resources within the Antarctic region. China has been carrying out scientific research in the Southern Ocean since the 1980s, and has undertaken ecological and biological studies on Antarctic krill near the Antarctic Peninsula and Prydz Bay, including studies on reproduction, population structure, age composition, abundance and growth condition[9-14]. However, few studies have examined the growth condition or population structure of *E. superba* in other polar regions.

In this study, *E. superba* samples collected during the Chinese Antarctic expeditions of 2007/2008 and 2008/2009 were analyzed. Combined with the simultaneous recording of environmental factors, spatial distribution, abundance, population structure and growth condition of *E. superba* in the Southern Ocean were studied. It will provide practical data for marine ecosystem research in the Antarctic region and for the development and utilization of Antarctic krill resources.

2 Materials and methods

2.1 Stations and sampling

Between 2 January and 15 March 2008, krill samples were collected during a circumpolar voyage in the Southern Ocean south of latitude 50°S and at a longitude ranging from 64.95°W to 80.61°E. Between 11 January and 13 March 2009, samples were collected in Prydz Bay and adjacent areas at a longitude ranging from 70.47°E to 141.84°E. The sampling stations are shown in Figure 1.

E. superba was sampled using a High Speed Collector and an Isaac–Kidd midwater trawl (IKMT) net during both cruises. The High Speed Collector (a 70-mm mouth diameter net with 350-μm mesh size) was used to collect samples every 6 h during normal navigation. During operation, the net and rope was released for 400 m, then dragged steadily for about 20 min and hauled in at low speed (about 0.3 $m·s^{-1}$). Based on fishery detector images, the IKMT net (with a 2-m^2 mouth area and 6-mm mesh size) was used to collect samples at a speed of 3–4 knots. The net with rope was released for 300 m, then dragged steadily for about 20 min and hauled in at a speed of <0.3 $m·s^{-1}$. The two types of net were towed obliquely to sieve water of <50 m depth, collecting *E. superba* within the surface and subsurface layers.

2.2 Analysis of samples

Krill samples were preserved in 5% neutral seawater formalin, and later identified, measured and analyzed in the laboratory. For each station, *E. superba* (including both damaged and complete individuals) was sorted and counted, then the total weight (wet weight, accurate to 0.001 g) was recorded. The volume of water filtered by both types of net was obtained by multiplying the trawl speed by trawl time and net mouth area. The abundance or biomass of *E. superba* at each station was obtained by dividing the total number or total weight of *E. superba* by the filtered volume, with units of ind·$(1\ 000\ m)^{-3}$ or g·$(1\ 000\ m)^{-3}$, respectively.

For stations with more samples of *E. superba*, 30 complete individuals were randomly selected for the measurement of body length and eye diameter, and analysis of maturity stage. For the stations with fewer krill samples, all complete *E. superba* individuals were measured and analyzed. Body length measurements of *E. superba* were based on standard 1 in Mauchline[15]: measured with vernier caliper to 0.02 mm from the tip of the rostrum to the tip of the uropod. The left compound eye was severed and the diameter was measured using a dissecting microscope with a micrometer accurate to 0.05 mm. According to the standard in Makarov and Denys[16], the maturity stage of *E. superba* was identified using a dissecting microscope. Individuals with no obvious male or female features were expressed as "Juvenile". Separation of female maturity stages was as follows: sub-adult females were not categorized and expressed as 2F; adults were subdivided into five stages: 3AF represented mature unmated females, 3BF represented mated mature females with small ovaries, 3CF represented mated mature females with ovaries filling the thoracic space, 3DF represented spawning females, and 3EF represented spent females. Male maturity stages were classified as follows: sub-adult males with developing petasma were divided into three stages: 2AM, 2BM and 2CM; adults were divided into two stages: 3AM were mature males without spermatophore in

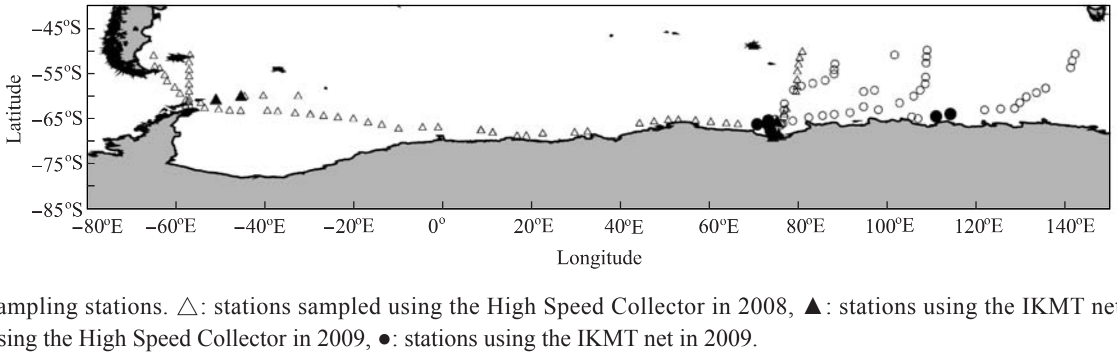

Figure 1 Sampling stations. △: stations sampled using the High Speed Collector in 2008, ▲: stations using the IKMT net in 2008; ○: stations using the High Speed Collector in 2009, ●: stations using the IKMT net in 2009.

ampullae, and 3BM were ready to mate mature males with spermatophores.

2.3 Measurement of environmental factors

Surface seawater temperatures and chlorophyll *a* concentrations were recorded synchronously at each station during the voyage. The sampling depth and temperature were measured simultaneously using a small self-contained temperature-depth profile measuring instrument (COMPACT-TD, model ATD-HR; JFE Alec Co. Ltd.). Seawater was collected from the surface at each station for the measurement of chlorophyll *a* concentrations. After collection, 500 mL of seawater was filtered through a Whatman GF/F glass-fiber membrane (0.70 μm) and the membrane immediately preserved at −20℃. Chlorophyll *a* was extracted with 90% acetone at 4℃ for 24 h and measured using a Turner Designs fluorometer. Sea-ice photographs for each 10-day period were provided by the US National Oceanic and Atmospheric Administration (NOAA).

3 Results

3.1 Environmental factors

Sampling time, surface seawater temperature and chlorophyll *a* concentrations for stations in which *E. superba* was collected are shown in Table 1 (“G” indicates samples collected using the High Speed Collector, and “K” indicates samples collected using the IKMT net). With the exception of stations K24-01 (0.56℃) on 3 January, K24-02 (2.28℃) on 4 January and G24-01 (1.86℃) on 9 February, surface seawater temperatures recorded at all other stations during the voyage were <0℃ during 10–20 February 2008. In the survey of Prydz Bay and adjacent areas in 2009, surface seawater temperatures at most stations were >0℃. Surface chlorophyll *a* concentrations at stations where *E. superba* was recorded were in the range of 0.09–0.65 $\mu g \cdot L^{-1}$ in 2008, with maxima recorded at stations K24-01 and G24-02 in the Weddell Sea. Chlorophyll *a* concentrations at stations where *E. superba* was collected in 2009 were in the range of 0.13–3.09 $\mu g \cdot L^{-1}$, with chlorophyll *a* concentrations higher than 1.5 $\mu g \cdot L^{-1}$ at stations G25-03 and G25-04, both in a region east of Prydz Bay. In Prydz Bay, chlorophyll *a* concentrations were in the range of 0.13–0.80 $\mu g \cdot L^{-1}$.

From sea-ice photographs for each 10-day period provided by NOAA, the development of sea ice in Prydz Bay between 2008 and 2009 was compared. The results showed that ice retreated earlier and the ice edge was closer to the shore in 2009. Based on the earliest sampling date for stations where more *E. superba* were recorded (Sections 3.2 and 3.3), the relative position between sampling stations and location of sea ice at least 1 month prior to sampling time were compared (Tables 2 and 3). In the summer of 2007/2008, stations K24-01, K24-02 and G24-09 had been at the ice edge or free of sea ice for almost 1 month when sampled, while stations G24-03, G24-07 and G24-10 experienced a short period without ice cover before the sampling time. In the summer of 2008/2009, with the exception of K25-01 and K25-02 that experienced a short period without ice cover before sampling, all other stations were free of sea ice for more than 1 month when sampled.

3.2 Distribution and abundance of *E. superba*

During the summer voyage of 2007/2008, 66 samples were collected using the High Speed Collector south of latitude 50°S in the Southern Sea, but only 10 samples returned post-

Table 1 Sampling time, surface seawater temperature (SST) and chlorophyll *a* concentration (Chl *a*) at stations where *E. superba* was found in summer 2008 and 2009

2008 Station	Sampling time	SST /℃	Chl *a* /($\mu g \cdot L^{-1}$)	2009 Station	Sampling time	SST /℃	Chl *a* /($\mu g \cdot L^{-1}$)
G24-01	9 Feb	1.86	0.41	G25-01	20 Jan	−0.30	0.63
G24-02	10 Feb	−0.41	0.54	G25-02	21 Jan	0.50	0.20
G24-03	12 Feb	−0.08	0.21	G25-03	22 Jan	0.40	1.54
G24-04	12 Feb	−0.75	0.09	G25-04	22 Jan	−1.10	3.09
G24-05	12 Feb	−0.73	0.09	G25-05	23 Jan	1.00	0.80
G24-06	13 Feb	−0.81	0.10	G25-06	14 Feb	2.07	0.43
G24-07	13 Feb	−0.95	0.22	G25-07	10 Mar	−0.60	0.48
G24-08	15 Feb	−0.14	0.41	G25-08	10 Mar	0.70	0.13
G24-09	17 Feb	−0.10	0.29	G25-09	10 Mar	1.20	0.17
G24-10	20 Feb	−0.53	0.16	G25-10	11 Mar	1.70	0.26
K24-01	3 Jan	0.56	0.65	K25-01	14 Jan	0.50	0.39
K24-02	4 Jan	2.28	0.18	K25-02	14 Jan	0.30	0.23
				K25-03	14 Feb	2.00	0.17
				K25-04	15 Feb	1.49	0.13

Table 2 Relative positional relationship between sea ice and stations recording *E. superba* in summer 2007/2008

Station	07.12.01	07.12.11	07.12.21	08.01.01	08.01.11	08.01.21	08.02.01	08.02.11	08.02.21
K24-01	**edge**	**out**	**edge**	**out**	out	out	out	edge/out	out
K24-02	**edge**	**out**	**edge**	**out**	out	out	out	out	out
G24-02	**in**	**in**	**in**	**out**	**edge**	**in**	**out**	out	out
G24-03	**in**	**in**	**in**	**in**	**in**	**in**	**out**	**out**	out
G24-07	**in**	**in**	**in**	**in**	**in**	**in**	**edge/in**	**in**	out
G24-09	**in**	**in**	**in**	**in**	**out**	**out**	**out**	**out**	out
G24-10	**in**	**in**	**in**	**in**	**edge**	**edge**	**edge/out**	**edge**	out

Notes: Labeled rows indicate the time of sea-ice photographs expressed as 'year.month.day'; 'in' indicates sea ice covering the station; 'out' indicates station being free of sea ice; 'edge' indicates station located at the ice edge; bold indicates that the time was earlier than the sampling time.

Table 3 Relative positional relationship between sea ice and stations recording *E. superba* in summer 2008/2009

Station	08.12.11	08.12.21	09.01.01	09.01.11	09.01.21	09.02.01	09.02.11	09.02.21	09.03.01	09.03.11
K25-01	**edge**	**in**	**edge**	**edge/out**	out	out	out	out	out	out
K25-02	**in**	**in**	**in**	**edge/out**	out	edge/in	edge	out	out	out
K25-04	**in**	**in**	**in**	**out**	**out**	**out**	**out**	out	out	out
G25-06	**in**	**in**	**out**	**out**	**out**	**out**	**out**	out	out	out
G25-07	**in**	**in**	**edge/in**	**edge/in**	**out**	**edge**	**out**	**out**	**out**	out
G25-09	**in**	**in**	**out**	**out**	**out**	**out**	**out**	**out**	**out**	out

Notes: Labeled rows indicate the time of sea-ice photographs expressed as 'year.month.day'; 'in' indicates sea ice covering the station; 'out' indicates station being free of sea ice; 'edge' indicates station located at the ice edge; bold indicates that the time was earlier than the sampling time.

larval stages (from juvenile to adult) *E. superba*. In the five samples collected with the IKMT net, only two samples collected in the Weddell Sea returned *E. superba* (Figure 2). Owing to the different types of nets employed, analysis of *E. superba* population abundance and distribution needed to be treated differently. In the survey area, krill distribution was patchy. In samples collected using the High Speed Collector, the abundance of *E. superba* ranged from 25.7–2 428.4 ind·(1 000 m)$^{-3}$, and biomass ranged from 4.3–921.3 g·(1 000 m)$^{-3}$. The highest density of *E. superba* was recorded at stations G24-09 and G24-02, both of which had levels above 2 200 ind·(1 000 m)$^{-3}$ in number and 700 g·(1 000 m)$^{-3}$ in weight. There were five stations where the abundance of *E. superba* was lower than 500 ind·(1 000 m)$^{-3}$. *E. superba* was collected at stations K24-01 and K24-02 using the IKMT net, with an abundance of 28.9 and 7.8 ind·(1 000 m)$^{-3}$, respectively. With respect to the study area, no *E. superba* was collected in Prydz Bay; however, *E. superba* was abundant in the Weddell Sea and the krill catch was also high along the shelf edge from 30°E to 50°E.

In the summer of 2008/2009, the survey area focused on Prydz Bay and adjacent regions to the east. Of the 44 samples collected south of latitude 50°S in the Southern Sea using the High Speed Collector, 10 samples returned E. superba, while four of the six samples collected using the IKMT net recorded *E. superba* (Figure 3). Of the samples collected using the High Speed Collector, the abundance of *E. superba* ranged from 17.4–949.4 ind·(1 000 m)$^{-3}$ and biomass ranged from 15.3–693.0 g·(1 000 m)$^{-3}$. Catches of *E. superba* were higher in the Prydz Bay stations; the two stations (G25-06 and G25-09) with maximum numbers were both in Prydz Bay with an abundance higher than 750 ind·(1 000 m)$^{-3}$. The abundance of *E. superba* in samples collected using the IKMT ranged from 0.1 to 8.0 ind·(1 000 m)$^{-3}$, and the station with maximum abundance (K25-04) was also in Prydz Bay.

Comparing survey results between the summer of 2007/2008 and 2008/2009, maximum abundance of *E. superba* was higher in the Weddell Sea than that in Prydz Bay, whether collected using the High Speed Collector or IKMT net.

3.3 Growth condition and population structure of *E. superba*

The number of *E. superba* in samples collected using the High Speed Collector was much less than that collected using the IKMT net because of the relatively small mouth area of the High Speed Collector. Both nets damaged krill samples; therefore, relatively complete *E. superba* individuals from each station were selected and measured for stage of maturity, body length and eye diameter. Samples would only be analyzed when the number of individual *E. superba* was greater than eight. The results for growth condition and percentage distribution of sexual maturity stages of *E. superba* are shown in Figures 4 and 5, respectively. The "negative growth" of *E. superba* refers to the unique growing mode of adult krill. Adult *E. superba*

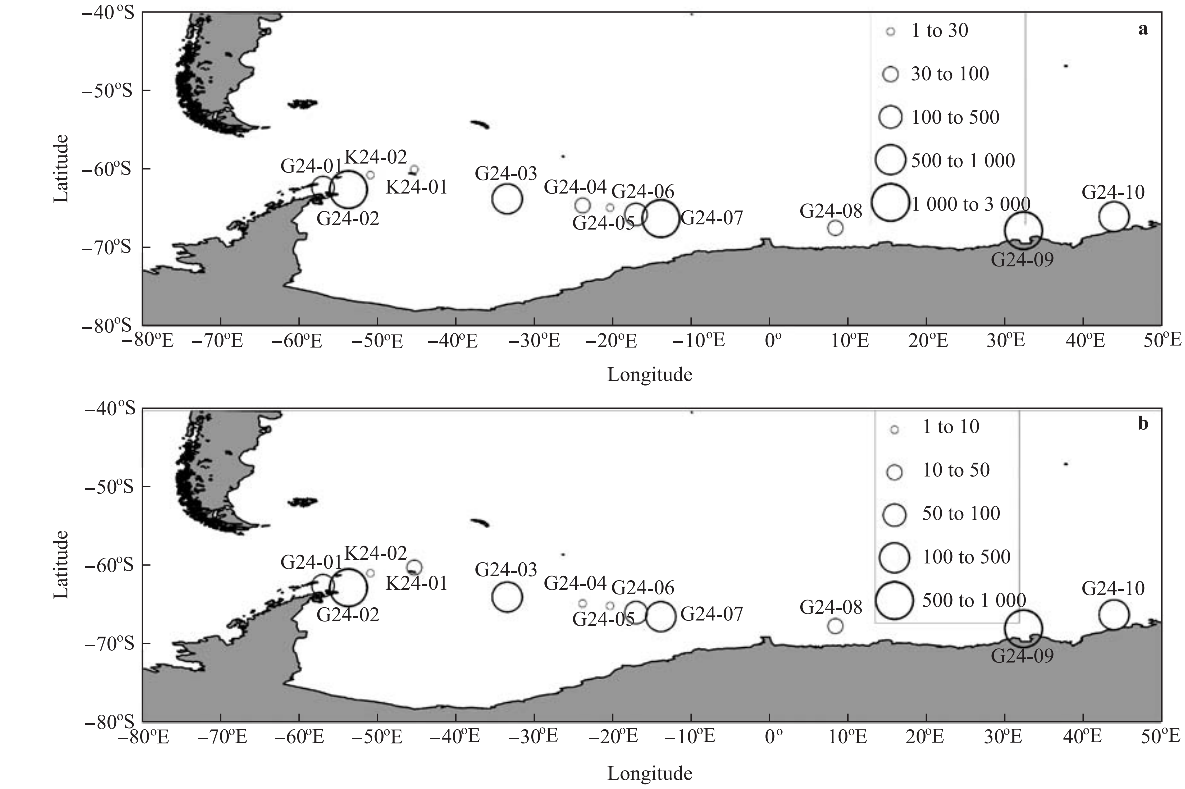

Figure 2 Spatial distribution, abundance and biomass of *Euphausia superba* in summer 2008. **a**, abundance (ind·(1 000 m)$^{-3}$); **b**, biomass (g·(1 000 m)$^{-3}$).

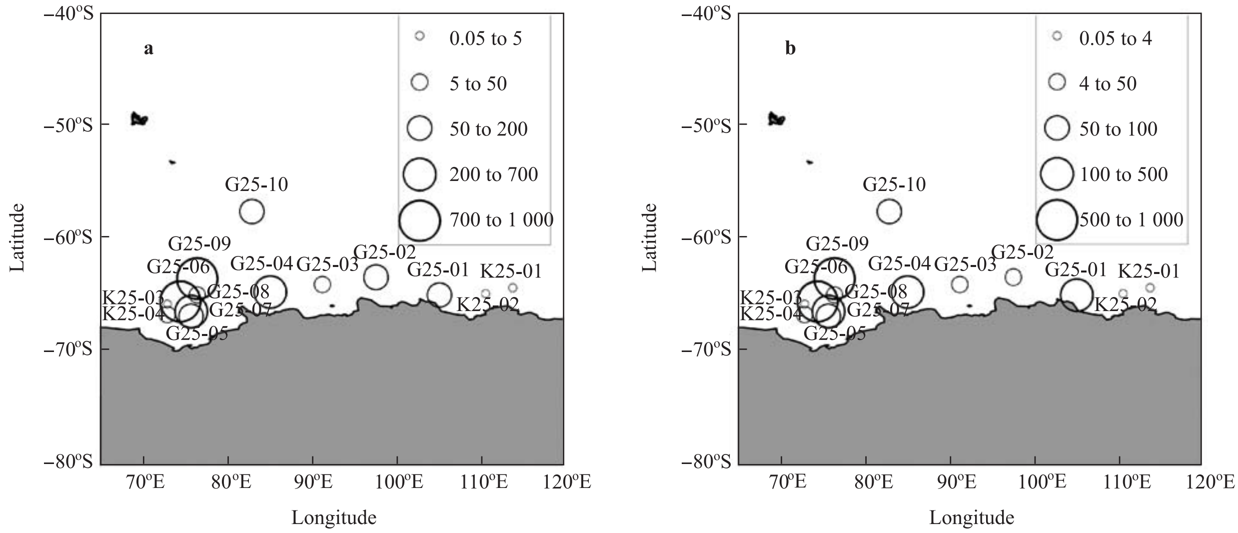

Figure 3 Spatial distribution, abundance and biomass of *Euphausia superba* in summer 2009. **a**, abundance (ind·(1 000 m)$^{-3}$); **b**, biomass (g·(1 000 m)$^{-3}$).

molts normally under conditions of food shortage, but shrinks (negative growth) after every molt to survive when food is scarce or under adverse environmental conditions[17]. Sun et al.[18-19] first proposed the method of using crystalline cone number and diameter of the compound eye to evaluate the growth condition of *E. superba*, and thereby determined the influence of environmental factors on the krill population and employed *E. superba* as an indicator of interannual environmental variations[20-21]. Sun and Wang[19] revealed that there was an apparent exponential relationship between eye diameter (*ED*) and body length (*BL*) of *E. superba* under normal growth condition, which could be expressed as:

$$ED = 0.574\mathrm{e}^{0.0292BL}, r = 0.949\,5 \tag{1}$$

where the *ED* and *BL* units are both in mm, and the function was obtained by measuring juvenile, male and female *E. superba*. Taking the function as the standard curve (*r*=1), the points representing *ED* values will be located above the standard curve when shrinkage occurs in *E. superba*, and will be close to or below the standard curve when *E. superba* is in the normal growing state. Figure 4 shows the relationship between the standard curve with eye diameter and body length of *E. superba* for each station. From the results, it is clear that *E. superba* was in a normal growing state during 2007/2008, but the growing state of E. superba was relatively slower at stations K24-02 and G24-02, where shrinkage may occur. Similar to the results in 2007/2008, in the summer of 2008/2009, *E. superba* was generally in a normal growing state, but grew relatively slower at stations K25-02 and G25-09 and grew better at other stations.

The percentage distribution of the post-larval sexual maturity stages of *E. superba* is shown in Figure 5. In 2007/2008, the proportion of juveniles was higher than 85% at G24-03, G24-07 and G24-10, and the catch at G24-07 comprised all juvenile *E. superba*. Only juveniles and sub-adults were collected at G24-02. The 3DF stage (spawning female) was only recorded at G24-09 and K24-02, with the proportion of 3DF being >45% at G24-09. The proportion of adult males was higher than 50% at K24-01, but they were also recorded at G24-09. In 2008/2009, the 3AM stage of *E. superba* was recorded from all stations, with relatively higher proportions at G25-09, K25-01 and K25-03. Stage 3BM was also collected at all stations, except G25-07, and the proportion was relatively high at K25-02. With the exception of G25-09, stage 3DF was recorded from all other stations, with a high proportion at G25-06, K25-01 and K25-02. In general, the sexual maturity of *E. superba* was higher in the summer of 2008/2009 than in 2007/2008.

4 Discussion

Research has suggested that the abundance of *E. superba* is much higher in the south Atlantic sector than in the south Indian sector of the Antarctic[2-4,22]. In the 2007/2008 survey, *E.*

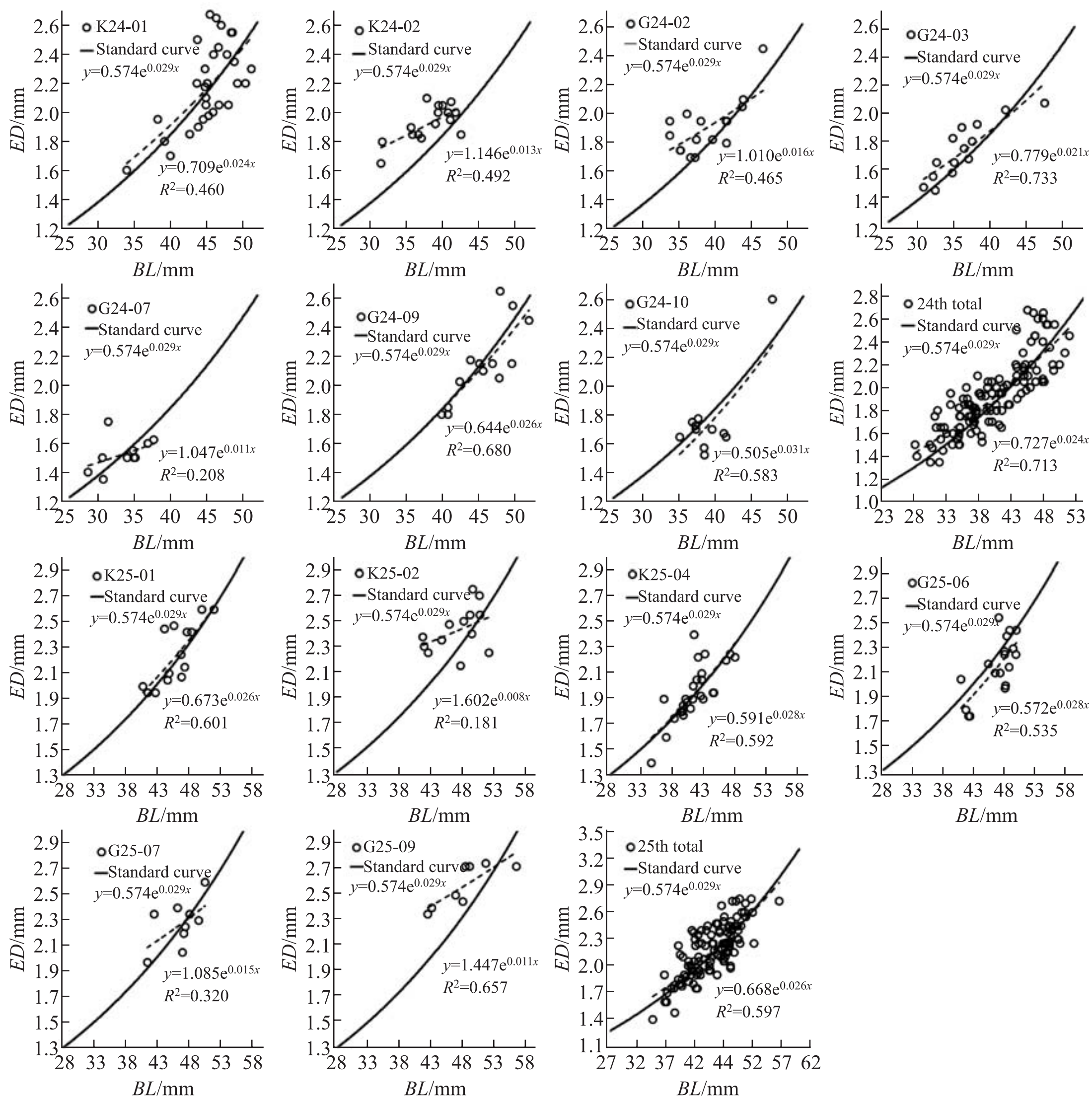

Figure 4 Growth condition of *Euphausia superba* in summer 2007/2008 and 2008/2009.

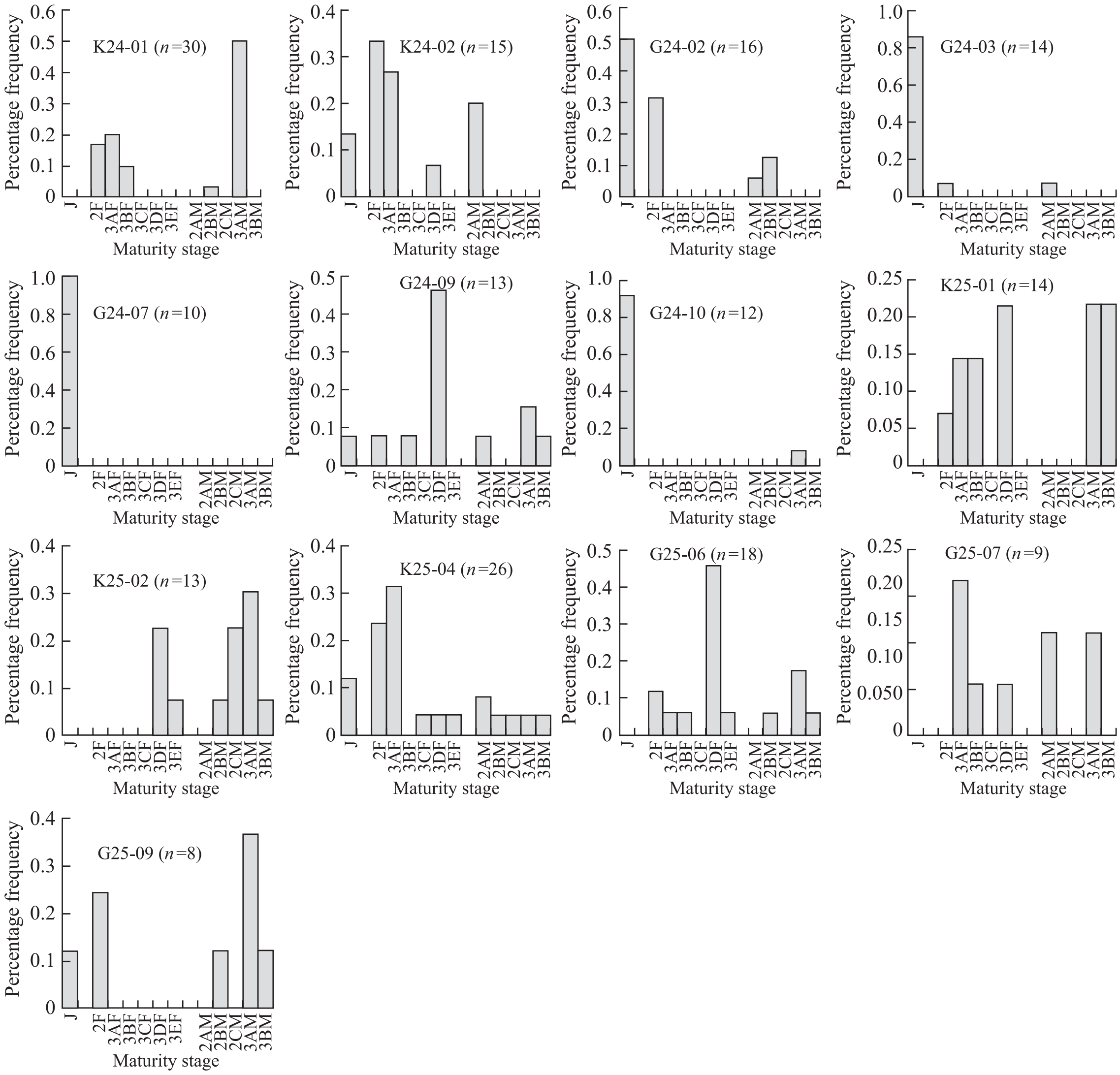

Figure 5 Percentage distribution of *Euphausia superba* in post-larval sexual maturity stage in summer 2007/2008 and 2008/2009. *n*–the number of krill measured.

superba was not recorded at any stations in Prydz Bay using either the High Speed Collector or the IKMT net, while the abundance of *E. superba* was relatively high in the Weddell Sea. In 2008/2009, the survey area focused on Prydz Bay and adjacent regions to the east. Average abundance of *E. superba* collected in Prydz Bay using the IKMT net was 2.02 ind·(1 000 m)$^{-3}$ in 2008/2009, while average abundance in the Weddell Sea using the same net was estimated at 18.33 ind·(1 000 m)$^{-3}$ in 2007/2008–approximately a nine-fold difference. The results of the two surveys not only confirmed that the abundance and capture rates of *E. superba* were higher in the Weddell Sea than Prydz Bay, but also that the abundance of *E. superba* showed interannual variations[5,23-24]. Atkinson et al.[3] have shown that the density of *E. superba* has clearly declined since the 1970s in the southwest Atlantic sector. By comparing historical data[25], it is obvious that the capture rate and abundance of *E. superba* collected during the circumpolar voyages with a High Speed Collector were higher in the summers of 1992/1993 and 1997/1998 than in 1999/2000 or 2007/2008 (this study). Average abundances of *E. superba* recorded from Prydz Bay using the IKMT net were 16.17 ind·(1 000 m)$^{-3}$[9] and 68.85 ind·(1 000 m)$^{-3}$[11] in January 2000 and 2002, respectively; both values were significantly higher than the 2.02 ind·(1 000 m)$^{-3}$ reported in 2008/2009. The abundance of *E. superba* may be affected by sampling time and the patchy distribution of krill in the field. However, in general, the abundance of *E. superba* in the summers of 2007/2008 and 2008/2009 was lower than the values reported in previous krill surveys for the same period.

Considering the effects of factors such as environmental conditions and food availability, the growth condition of *E. superba* should be different for different geographical areas. The strategy of "negative growth" can help *E. superba* survive when food is scarce or under adverse environmental conditions[17]. From the results of the two surveys considered in this study, *E. superba* was in a normal growing state at most stations, but growth was slower at stations K24-02, G24-02, K25-02 and G25-09. The relative position between sea ice and the sampling station was similar at K24-01 and K24-02, but the chlorophyll *a* concentration at K24-02 was lower. Therefore, it could be speculated that food scarcity may be the main reason for the relatively poor growth of *E. superba* at K24-02. *E. superba* experienced poor growth condition at station G25-09, which was in a deep-sea zone, and in agreement with results reported from Prydz Bay by Liu et al.[9]. In addition, retreating sea ice may also affect the growing state of *E. superba*, as sea ice plays an important role in krill recruitment[3,26]. In winter, sea ice provides shelter for *E. superba*, and sea-ice communities, dominated by ice algae, provide food for krill. In spring, phytoplankton blooms associated with retreating sea ice supply a plentiful food resource for krill[27-29]. When sampled, the duration without sea ice covered was short at G24-02 and K25-02. It is assumed that *E. superba* shrank because of food scarcity in periods of sea-ice cover, and because of the short period without ice cover, krill had not recovered from negative growth, resulting in the poor growing state at stations G24-02 and K25-02.

The retreat of sea ice influences the composition and distribution of the stages of sexual maturity of *E. superba* in the Southern Sea. Siegel[30] suggested that there is spatial distribution of larvae, juveniles and adult *E. superba* during the seasons. In winter, juvenile and adult krill move to deeper water layers with sea-ice cover on the surface. In spring, phytoplankton blooms occur in the thawing sea-ice zone, and krill juveniles are mainly found at the ice edge, while the distribution of adult krill is principally offshore[31]. In this study, the proportion of juveniles was greater than 85% at G24-03, G24-07 and G24-10. The retreat of sea ice was late at all three stations, and G24-07 and G24-10 were located at the ice edge when sampled, coinciding with the distribution pattern for juvenile krill. There was a high proportion of adult krill at G24-09, G25-06, G25-07 and G25-09, and sea ice had been retreating for more than 1 month when sampled. The distance between the four stations and the ice edge was great; thus, the distribution pattern of adult *E. superba* indicates that they are found far from the ice edge. In addition, under abundant food and specific time conditions, some juveniles may have developed into adults at this stage.

Under natural conditions, the 1-year age group of krill was mainly made up of juveniles; sub-adults comprised most of the 2-year age group, while adults accounted for the highest proportion in the 3-year and older age groups[32]. From September to April of the next year, the reproductive organs of female juveniles and 3AFs in the 3-year and older age groups gradually matured, and after the reproductive cycle and several egg releases, reorganization of the ovaries commenced for winter[33]. In Prydz Bay, male krill usually matured more quickly than females[9]; the spawning season began in January with maximum spawning occurring in mid- or late-February[13]. Early spawning is extremely important for the survival of larval krill[34-35]. In this study, adult male krill were found at K24-01 using the IKMT net, but no female adults were reported, suggesting that in this region *E. superba* may be in the early period of the spawning season. Spawning females (3DF) were collected at K24-02, where sampling times were in early January 2008 both at station K24-01 and K24-02; thus, it can be speculated that the spawning time of *E. superba* was early in the Weddell Sea. A high proportion of adult male krill (3AM+3BM) was collected at K25-01 and K25-02 to the east of Prydz Bay (110°E–114°E), and spent females (3EF) were also recorded at K25-02, indicating that krill had spawned in this region in mid-January 2009. Adult male krill, 3DF and 3EF were also collected at K25-04 in Prydz Bay. In 2007/2008, 3DF together with 3AM and 3BM were caught at G24-09 using the High Speed Collector. However, in 2008/2009, the maturity of male krill was relatively high at G25-06, G25-07 and G25-09, and 3DF was collected at G25-06 and G25-07, indicating that *E. superba* had spawned during mid-February to mid-March 2009 in Prydz Bay. Thus, the population structure of *E. superba* differed between sea regions, which may affect recruitment.

5 Conclusions

E. superba was sampled from specific areas during January–March 2008 and January–March 2009, and environmental factors, spatial distribution, population structure and growth condition of *E. superba* were studied in this study. From the results, we can conclude that:

(1) The abundance and capture rates of *E. superba* in the Weddell Sea were higher than in Prydz Bay. However, the abundance of *E. superba* in the Weddell Sea in 2007/2008 and in Prydz Bay in 2008/2009 was lower than the figures reported in previous years.

(2) With respect to the total study area, *E. superba* displayed a normal growing state during the two Antarctic expeditions. The poor growth of *E. superba* at some stations may be related to a late retreat of sea ice or lower chlorophyll *a* concentrations.

(3) In samples collected using the High Speed Collector, there was a greater proportion of juvenile krill in stations at the sea-ice edge, while adult krill were more common in the stations with no long-term ice cover. This suggests a different distribution pattern between juveniles and adults, and the possibility that some juveniles may have developed into adults under abundant food and time conditions because of the early retreat of sea ice.

(4) The population structure of *E. superba* differed between sea regions, which may affect recruitment.

Futurer, long-term observations within the study area are required to ascertain the interannual variations in growth condition and population structure of *E. superba*, and to devise indicators of interannual environmental changes in the Antarctic.

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