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Distribution and abundance of euphausiid larvae and salps during austral summers in Prydz Bay, Antarctica

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Abstract The distribution and abundance of euphausiid larvae and salps was studied from samples collected in 2002 and 2006 from Prydz Bay, Antarctica. Larvae of *Thysanoessa macrura* and *Euphausia superba* were mainly distributed in the north of the continental shelf. *T. macrura* was more abundant and had a relatively wider distribution. In 2006, with ice having retreated and higher seawater temperatures and chlorophyll *a* levels, *E. superba* and *T. macrura* occurred in higher abundances and at more mature developmental stages. *Euphausia crystallorophias* was mainly distributed in the neritic region. In 2002, with severe ice conditions in the neritic region, abundance of *E. crystallorophias* was only 95.6 ind · (1000 m)$^{-3}$. In 2006 when a polynya existed, the abundance of *E. crystallorophias* reached 43966.6 ind · (1000 m)$^{-3}$. The population mainly consisted of metanauplius (MN) and calyptopis I (CI). Salps, mostly *Salpa thompsoni*, had a low abundance in Prydz Bay. In 2002, *S. thompsoni* was only found at one station in the north of the bay with an abundance of 10 ind · (1000 m)$^{-3}$. In 2006, *S. thompsoni* was found at three stations located near the continental slope and average abundance reached 146.7 ind · (1000 m)$^{-3}$. Environmental factors, such as the timing of ice melt, polynya formation and food concentration appear to have a marked effect on the distribution and abundance of euphausiid larvae and salps.

Key words Prydz Bay, euphausiid larvae, salp, distribution.

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1 Introduction

Euphausia superba and *Salpa thompsoni* are considered as two of the most important filter-feeding species in the Southern Ocean[1]. Their impact on the Antarctic ecosystem has received a great deal of attention[2,3]. It has been postulated that krill and salps may dominate the zooplankton community in some areas of the Southern Ocean alternately through competing with one another or spatial segregation[1,4]. Krill recruitment benefits from areas with large sea ice extent in the previous winter and high primary production during the summer ice retreat. Salps tend to occupy oceanic regions with higher temperature and lower primary production[1]. With the decrease of sea ice extent in the Antarctic Peninsula region during the last half century, krill stocks have declined while salps have appeared to increase [4]. These changes could have profound impacts on the food web of the whole Southern Ocean.

Much research has shown that krill, mainly *Euphausia superba*, is mostly distributed in the productive Atlantic sector of Southern Ocean[5,6]. Krill research in the Southern Ocean has focused on the west Antarctic region. Since the beginning of 1980s, work has been carried out on the krill ecology of Prydz Bay located in the Indian sector of Southern Ocean. Many results regarding reproductive ecology and age determination of *E. superba* have been obtained. However the distribution of krill larvae has been poorly documented[7-10]. For *Salpa thompsoni*, only a little research on feeling ecology exists for Prydz Bay, from 1999[11].

This study primarily aimed to describe the abundance and distribution of krill larvae and salps in Prydz Bay during the austral summer and to examine their relationships with environmental factors. Zooplankton samples collected in Prydz Bay during two separate cruises in 2001/2002 and 2005/2006 were used in the analyses.

2 Materials and methods

Zooplankton samples from 30 stations along 70.5°E and 73°E transects of the Prydz Bay region were collected using a NORPAC net (0.5 m^2 net mouth, mesh 330 μm) from a depth of 200 m to the surface during the period 9 to 13 January, 22 to 24 February 2002 and 17 to 24 January 2006 (Fig. 1). The volume filtered by the net was calculated using an electronic flowmeter positioned in the mouth of the net. Samples were preserved in 5% buffered formalin and examined in the laboratory. *E. superba*, *T. macrura* and *Euphausia crystallorophias* were sorted into different developmental stages and counted.

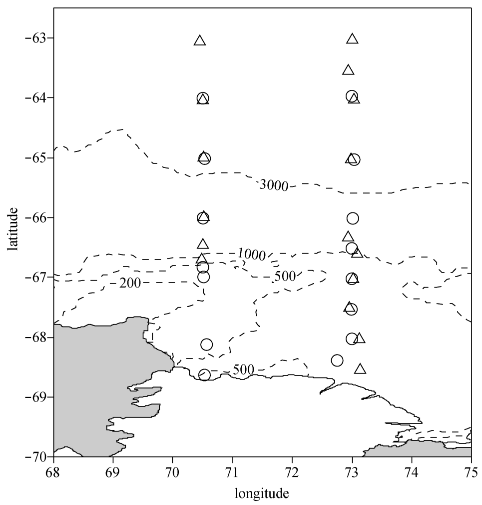


Fig. 1 Survey stations (△ and ○) used in 2002 and 2006, respectively.

Temperature, salinity and chlorophyll *a* were measured simultaneously at each station. CTD data was provided by the Ocean University of China, chlorophyll *a* data was provided by the Second Institute of Oceanography, State Oceanic Administration of China. At the surface and at depths of 25 m, 50 m, 100 m, 150 m and 200 m, water samples (500 ml) were collected. These samples were filtered through GF/F membranes, and chlorophyll extracted using 90% acetone for 24 h. Extracts were then measured using a Turner Designs Fluorometer, Model 10. Sea ice photos for each half month were provided by National Oceanic and Atmospheric Administration, USA (NOAA).

3 Results

3.1 Environmental factors

According to sea ice photos provided by NOAA, the ice edge of the first, middle and last 10 day periods of January in 2002 was approximately located in 66°S, 66.5°S and 67°S respectively and a polynya did not appear in the neritic zone. In 2006, the ice retreated earlier and a polynya appeared in the neritic region (Table 1). In 2002, average temperature in the upper 200 m of the oceanic region was −0.80°C (−1.82～0.98°C). In 2002, temperature was highest at 64°S and was higher in oceanic regions than that in neritic regions. In 2006, average temperature was 0.61°C (−1.59～0.17°C) and the lowest temperature appeared at 67°S where the shelf break is located. Temperature increased from the shelf break to the oceanic and neritic region. Average salinities in 2002 and 2006 were 34.31 (34.23—34.39) and 34.04 (33.53—34.34), respectively. The chlorophyll *a* concentration of the upper 200 m was low in the oceanic region and high in the neritic region. The average chlorophyll *a* concentration was 0.31 mg·m^{-3} (0.14～1.43 mg·m^{-3}) in 2002, while in 2006 it reached 0.76 mg·m^{-3} (0.18～2.64 mg·m^{-3}) (Fig. 2).

Table. 1 Sea ice conditions in 2002 and 2006

	first ten-day of January		second ten-day of January		last ten-day of January	
	ice edge	polynya	ice edge	polynya	ice edge	polynya
2002	～66°S	inexistent	～66.5°S	inexistent	～67°S	inexistent
2006	～66.5°S	existent	～67°S	existent	～67.5°S	existent

3.2 Distribution and abundance of krill larva and Salpa thompsoni

Larvae of *E. superba* only appeared at two oceanic stations (> 3000m) and the average density was 125 ind·(1000 m)$^{-3}$ (Fig. 1, Table 2), population composition was mainly calyptopis I (CI) in 2002. In 2006, larvae of *E. superba*, with an abundance of 891.4 ind·(1000 m)$^{-3}$, were collected from seven stations. The population was mainly composed of calyptopis II (CII), calyptopis III (CIII) and a small section of furcilia III (FIII) (Fig. 3 and Fig. 4).

T. macrura was a widespread species in Prydz Bay. In 2002, this species was collected from 11 stations located north of the shelf slope (1000 m isobath). The average abundance was 666.9 ind/1000 m^3 and the developmental stages were mainly CII-III and FI (Table 2, Fig. 3). In 2006, *T. macrura* was found in 10 stations and

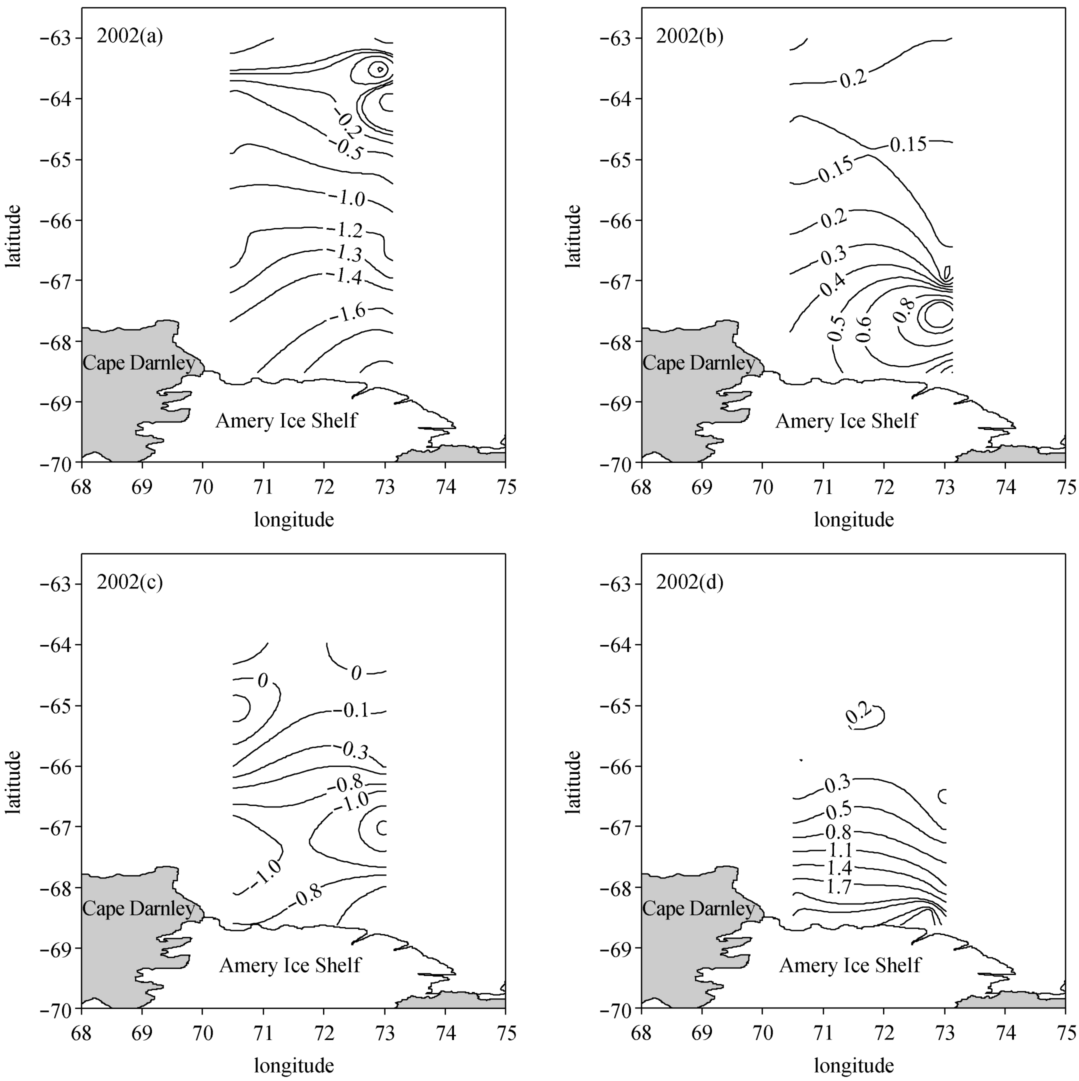
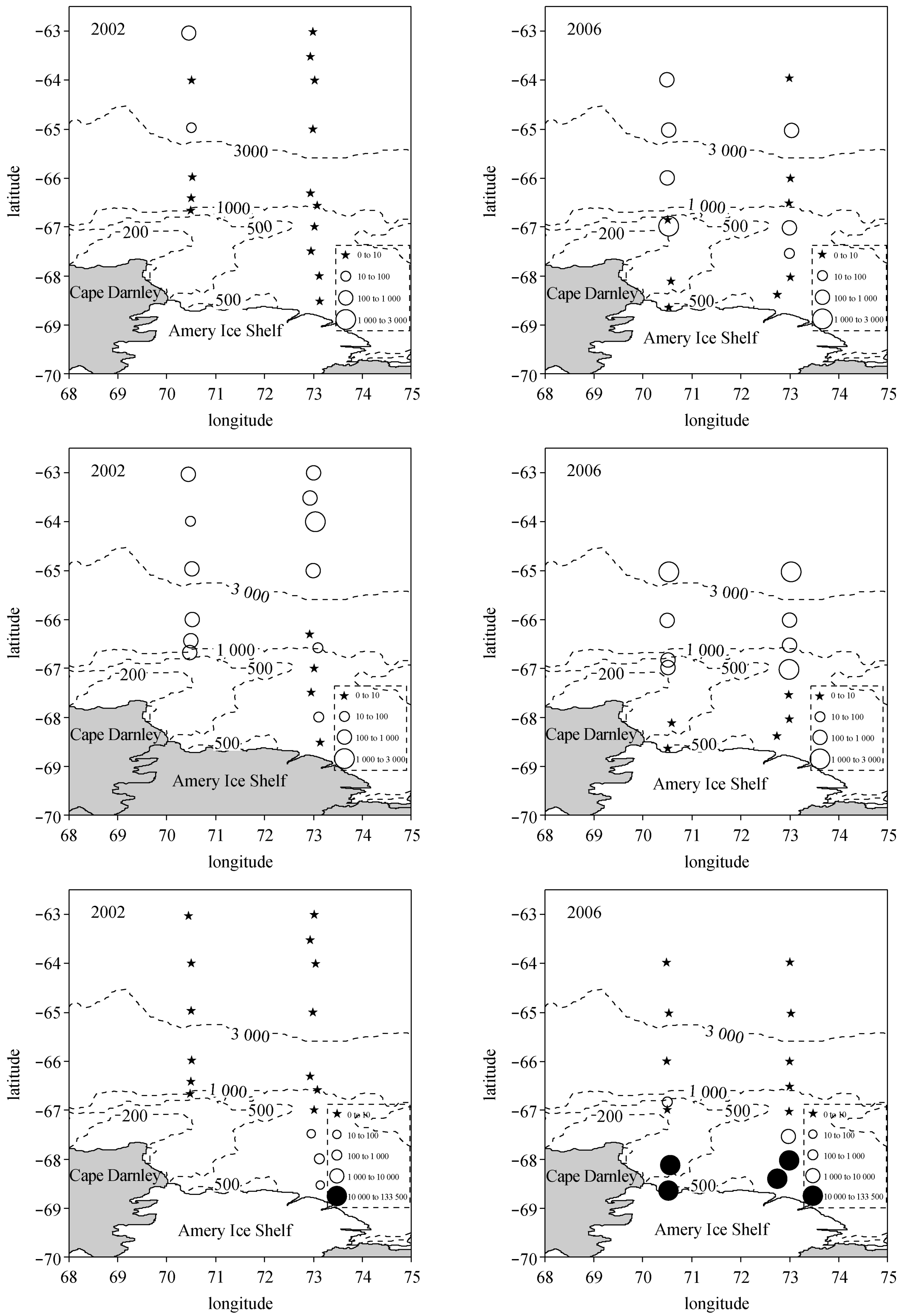


Fig. 2 Average (a) temperature and chlorophyll a concentration(b), integrated over the upper 200 m of the water column. Temperature: °C, chlorophyll a: mg • m^{-3}.

Table. 2 Mean densities for euphausiid larvae and salps, but only at sites where a particular species was collected and used for estimating the mean

species	year	n	mean(ind/1000m^3)	sd	min	max
Euphausia superba	2002	2	125.0	106.1	50.0	200.0
	2006	6	1038.3	1189.4	130.0	3400.0
Thysanoessa macrura	2002	11	666.9	889.1	30.0	3000.0
	2006	10	1195.0	595.1	200.0	1950.0
Euphausia crystallorophias	2002	3	95.6	74.3	40.0	180.0
	2006	6	43966.7	49305.4	300.0	133200.0
Salpa thompsoni	2002	1	10.0			
	2006	3	146.7	203.1	10.0	380.0


2002
2006
latitude
longitude
Cape Darnley
Amery Ice Shelf
3000
3 000
1000
1 000
500
200
0 to 10
10 to 100
100 to 1 000
1 000 to 3 000
1 000 to 10 000
10 000 to 133 500

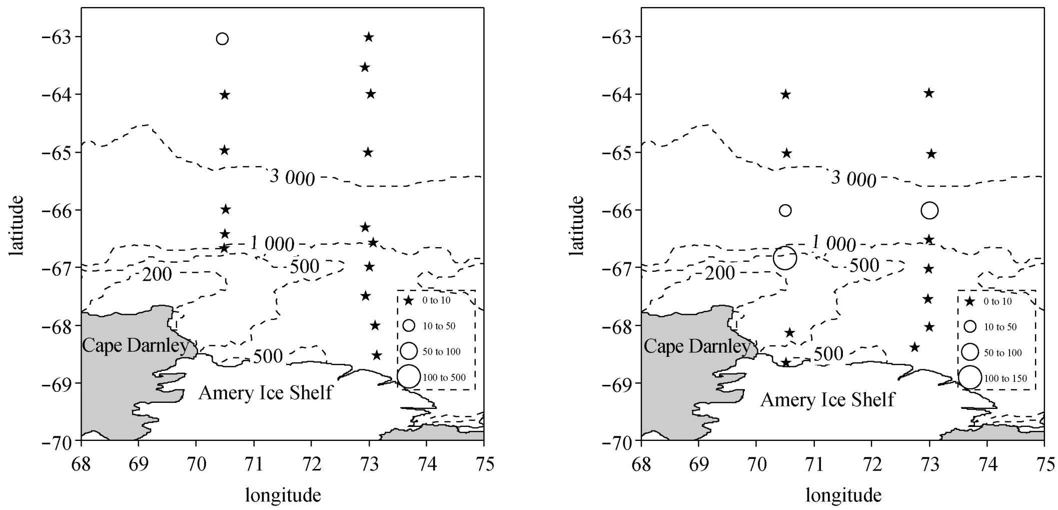
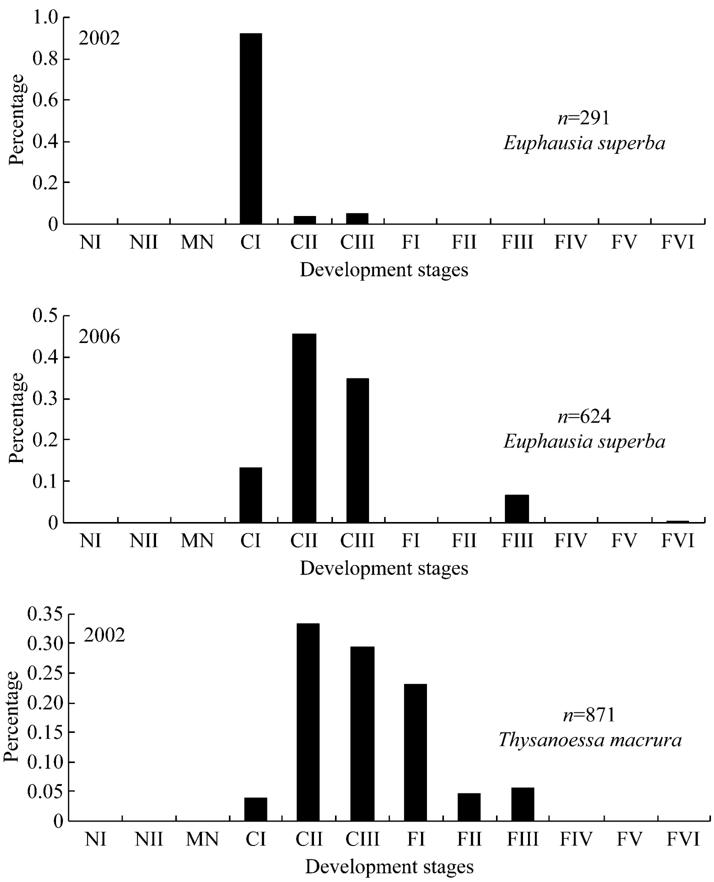


Fig. 3 Spatial density distribution of euphausiid larvae and salps(ind · (1000 m)$^{-3}$).



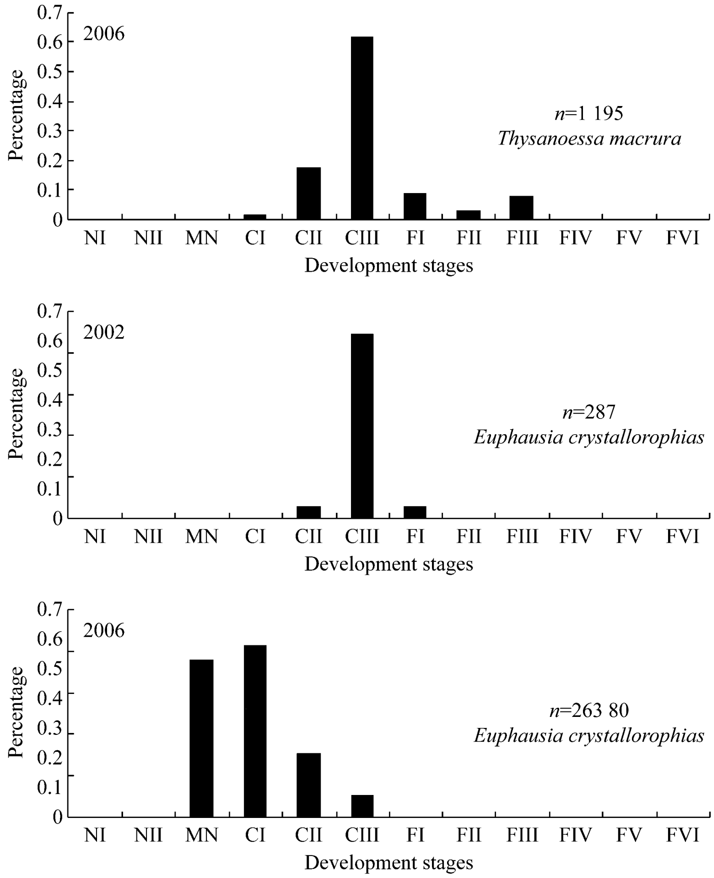


Fig. 4 Percentage frequency distribution of developmental stages within each species.

appeared south of the shelf slope compared with 2002. The average density was 1195 ind・(1000 m)$^{-3}$ and the main components were CIII with lower abundances of FI-III (Fig. 4).

E. crystallorophias was a distinct neritic species. In 2002, the average density was 95.6 ind・(1000 m)$^{-3}$ and 90% of the population was composed of CIII. In 2006, average abundance was as high as 43966 ind・(1000 m)$^{-3}$ and the population was mostly composed of metanauplius (MN) and CI-III (Table 2, Fig. 4).

S. thompsoni was very rare in Prydz Bay. It occurred at only one oceanic station in 2002 and the density was 10 ind・(1000 m)$^{-3}$. In 2006, it was found at three stations located at the shelf break and shelf slope region and the average abundance was 146.7 ind・(1000 m)$^{-3}$ (Table 2, Fig. 3).

4 Discussion

Most research has suggested that the abundance of adult *E. superba* is much lower in the Indian sector compared with the Atlantic sector[6]. The distribution of krill larvae in Prydz Bay recorded in this study confirmed these findings. Various mechanisms have been proposed to explain differences in the territorial distribution of Antarctic krill. The extent of the seasonal ice belt and the southern boundary of the Antarctic circumpolar current and other environmental features have been suggested as important factors[12, 13]. These have generally been ascribed to bottom-up control in which food availability affects the abundance of krill. Sea ice benefits population recruitment in *E. superba*. During winter, sea ice provides *E. superba* with a shield from predators and plentiful food from ice algae. The seasonal phytoplankton bloom accompanied by the ice retreating in summer provides a further food resource. From the ice photographs provided by NOAA, ice conditions were severe in 2002 as the ice did not retreat completely to the south of 65°S during sampling. The northerly distribution of *E. superba* corresponded well with this. Ice retreated earlier in 2006 and *E. superba* likewise exhibited a wider area distribution area; the abundance of *E. superba*larva was also higher.

The results of this study and previous research have shown that *T. macrura* is consistently the most abundant euphausiid larva type in Prydz Bay[14]. Like *E. superba*, *T. macrura* undergoes developmental ascent. Germ cells sink to the deep water before incubation. The larvae ascend and develop to CI which is the first stage to appear in the photic zone to feed[15]. This process benefits population recruitment through enhancing the hatching and survival rate of larvae[16]. Many studies have shown that for *E. superba* and *T. macrura* the nauplius and metanauplius larvae occur mainly between 500 m to 1000 m depth[15]. So it is not surprising that few nauplius and metanauplius larvae appeared in samples from this study which were hauled from 0～200 m. The larval development of *E. superba* and *T. macrura* was later in 2006 than that in 2002. In 2006, the earlier ice retreat and higher temperature and chlorophyll *a* may have caused earlier phytoplankton blooms and earlier krill ontogenesis. In most of the Southern Ocean, *E. superba* is regarded as the key species of zooplankton [16]. However, *T. macrura* may be the major food source for the higher trophic levels in Prydz Bay ecosystems, although this requires further study for clarification.

As the dominant euphausiid of the neritic region, *E. crystallorophias* may play a major role in the turnover of energy and matter in the Antarctic coastal ecosystem[17]. From the ice maps of 2006, a large polynya existed in the southern part of Prydz Bay. The neritic region had been in a state of open water when the northern ice edge was still moving to the south. Steady environments provide good conditions for phytoplankton blooms and thus polynyas are hotspots for all trophic levels[18]. The high chlorophyll *a* concentrations recorded for the neritic region in 2006 were proof of the increased phytoplankton production. *E. crystallorophias* recruitment benefited from this and correspondingly abundant metanauplius and CI developmental stages were captured.

S. thompsoni prefers regions with higher temperature and lower food concentrations compared with *E. superba*[19]. There may be direct competition and spatial separation between *S. thompsoni* and *E. superba* throughout the majority of the Southern Ocean[20,21]. Salps may prey on eggs and early larval stages of krill as krill debris has been found in gut contents of salps[22]. Advection of different water masses may also cause spatial segregation of these two species[1]. Low ice extent in the previous winter affects krill recruitment and increases the frequency of 'salp years'[20]. The shelf slope distribution of *S. thompsoni* in 2006 may be associated with large scale ice retreat. In the Antarctic Peninsula region with an obvious warming trend, ice extent has declined and biomass of *S. thompsoni* has increased. This could have important implications for the Southern Ocean ecosystem[1].

For the relatively small sampling region and narrow time span of this study, we cannot confirm either complimentary or alternate relationships between different krill larvae and salps in Prydz Bay. Studies over longer timescales and larger spatial coverage are required.

5 Conclusion

(1) The euphausiid larvae of Prydz Bay were mainly composed of *Euphausia superba*, *Thysanoessa macrura* and *Euphausia crystallorophias*. *T. macrura* was abundant and widely distributed. *E. crystallorophias* was restricted in the neritc region. *Salpa thompsoni* appeared in only a few stations with low abundance.

(2) In years with early and large-scale ice retreat, *T. macrura* and *E. superba* had earlier population recruitment and the abundance was higher.

(3) Polynya provided a good environment for the recruitment of *E. crystallorophias*.

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