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SOME CHARACTERISTICS OF THE ZOOPLANKTON DISTRIBUTION IN THE PRYDZ BAY REGION OF THE INDIAN SECTOR OF THE ANTARCTIC OCEAN IN THE SUMMER OF 1983/84

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Abstract: During the SIBEX I cruise of the R. V. KAIYO MARU of the Fisheries Agency in the 1983/84 season, zooplankton samplings were conducted in the Prydz Bay region in the Indian Ocean sector of the Antarctic Ocean. The sampling scheme consisted of two legs, *i.e.* December 4–24, 1983 (Leg I) and January 19–February 2, 1984 (Leg II), and a total of 63 stations were occupied. At the six stations between 62° and 64°S, zooplankton samplings were repeated in both December and January. The vertical hauls with a WP-2 net were made at all stations usually from 100 m to the surface and from 500 m to the surface. In the catches of 100–0 m layer in December, it was shown that the abundance of the total zooplankton in terms of both individual number and wet weight per m^2 was larger in the Subantarctic and the Antarctic Convergence regions where chl. *a* was remarkably high. This high abundance is mainly due to the ontogenetic migration of the major copepod species from deeper layers. In January, both zooplankton abundance and chl. *a* were more abundant at the southernmost station (Stn. 194, 69°S), which was probably due to the anomalous hydrographic situation of Prydz Bay by earlier ice melt. The zooplankton at this station was represented by the major large-sized copepods (*Calanoides acutus, Calanus propinquus* and *Metridia gerlachei*) of the more advanced developmental stages. The individual number and wet weight of total zooplankton in Januray at the repeated sampling stations became 64.5 and 38.8% of those in December, respectively, and this accompanied a decrease in all taxonomic groups. In Copepoda occupying more than 60% of the total zooplankton abundance throughout this investigation, there was observed a distinct decrease in their wet weight in January showing 35.1% of the weight in December while the individual number showed a little decrease during the same period. This was due to a large decrease in the abundance of the copepodite IV–VI stages of the major large-sized copepods, especially, *C. acutus* and *Rhincalanus gigas*. On the contrary, there were very little changes in total zooplankton abundance for the 500–100 m layer. In this study, it was shown that the geographical and seasonal changes in the abundance of *C. acutus, R. gigas, C. propinquus* and *M. gerlachei* were related to their growth and ontogenetic migration, which largely influenced the abundance of total zooplankton in the 100–0 m layer during the austral summer.

1. Introduction

The krill, *Euphausia superba*, is considered to be a key species in the Antarctic marine food webs by its year round enormous biomass along with a variety of body size that enable the krill to be utilized by many animals of different trophic levels. Because of this, many planktological works in the Antarctic waters have been focussed on studying this organism. But it has been also indicated that the net-zooplankton other than *E. superba* are also important in the marine ecological point of view in the Antarctic Ocean. EVERSON (1984) suggests that other zooplankton species or some of their groups, especially Copepoda, are undoubtedly another important member for the animals of somewhat lower trophic levels in terms of their biomass and production. Thus, it is one of two major study areas to increase the knowledge about distribution characteristics of the net-zooplankters especially in the field of abundance, distribution pattern and seasonal changes in community assemblages for the better understanding of the Antarctic marine ecosystems. But generally less attention has been paid to the net-zooplankton other than *E. superba* because of their possible utilization to predators with lesser extent and also a lack of potential in commercial importance.

The aim of this study is to give a general characteristics of the horizontal distribution of net-zooplankton and its monthly variation in the Prydz Bay region, one of the least studied areas of the Indian Ocean sector of the Antarctic Ocean.

2. Materials and Methods

During the SIBEX I cruise of the R. V. KAIYO MARU of the Fisheries Agency in the 1983/84 season, zooplankton samplings were conducted in the Prydz Bay region in the Indian Ocean sector of the Antarctic Ocean. The sampling scheme consisted of two legs, December 4–24, 1983 (Leg I) and January 19–February 2, 1984 (Leg II) (Fig. 1). In Leg I, a total of 30 stations were occupied to form a grid in the area surrounded by 46° and 64°S parallels and by 65° and 75°E meridians. The southernmost stations were located close to the retreating pack ice edge. In Leg II, a total of 33 stations were occupied to form a grid in the area surrounded by 62° and 69°S parallels and by 65° and 75°E meridians. The slope and shelf edge as shown in Fig. 1C indicate the locations of the continental slope (*ca.* 1182 m) and the continental shelf edge (*ca.* 410 m). At the six stations occupied between 62° and 64°S, zooplankton samplings were repeated; the first sampling on December 11–22 and the second on January 20–February 2. The position and sampling depth for each six paired station (Stns. 42–214, 53–178, 66–177, 75–153, 91–148, 94–146) were completely the same. This replicate sampling was conducted in order to know possible seasonal changes in distribution of zooplankton. The observed hydrographical conditions suggested that the Antarctic Convergence or the Polar Front zone existed between 48° and 52°S. In Leg I, there were observed no hydrological structures that indicate the Antarctic Divergence.

The vertical hauls were usually made at all stations from 100 m to the surface and from 500 m or bottom to the surface with a WP-2 net of 56-cm mouth diameter, 250 cm long and 0.33 mm mesh apertures (UNESCO, 1968). A flow-meter was mounted on the mouth ring of the net to calculate the volume of water filtered by the net. In sampling at Stn. 175, no volume of water filtered was calculated because the flow-meter showed unreliable rotations and the data at this station were excluded from the present results. The zooplankton samples were preserved in 10% buffered formalin immediately after the collection.

All 58 samples collected in the 100–0 m layer and 28 samples collected in the 500–0 m layer were sorted out into ten taxonomical groups. Some samples with large amount

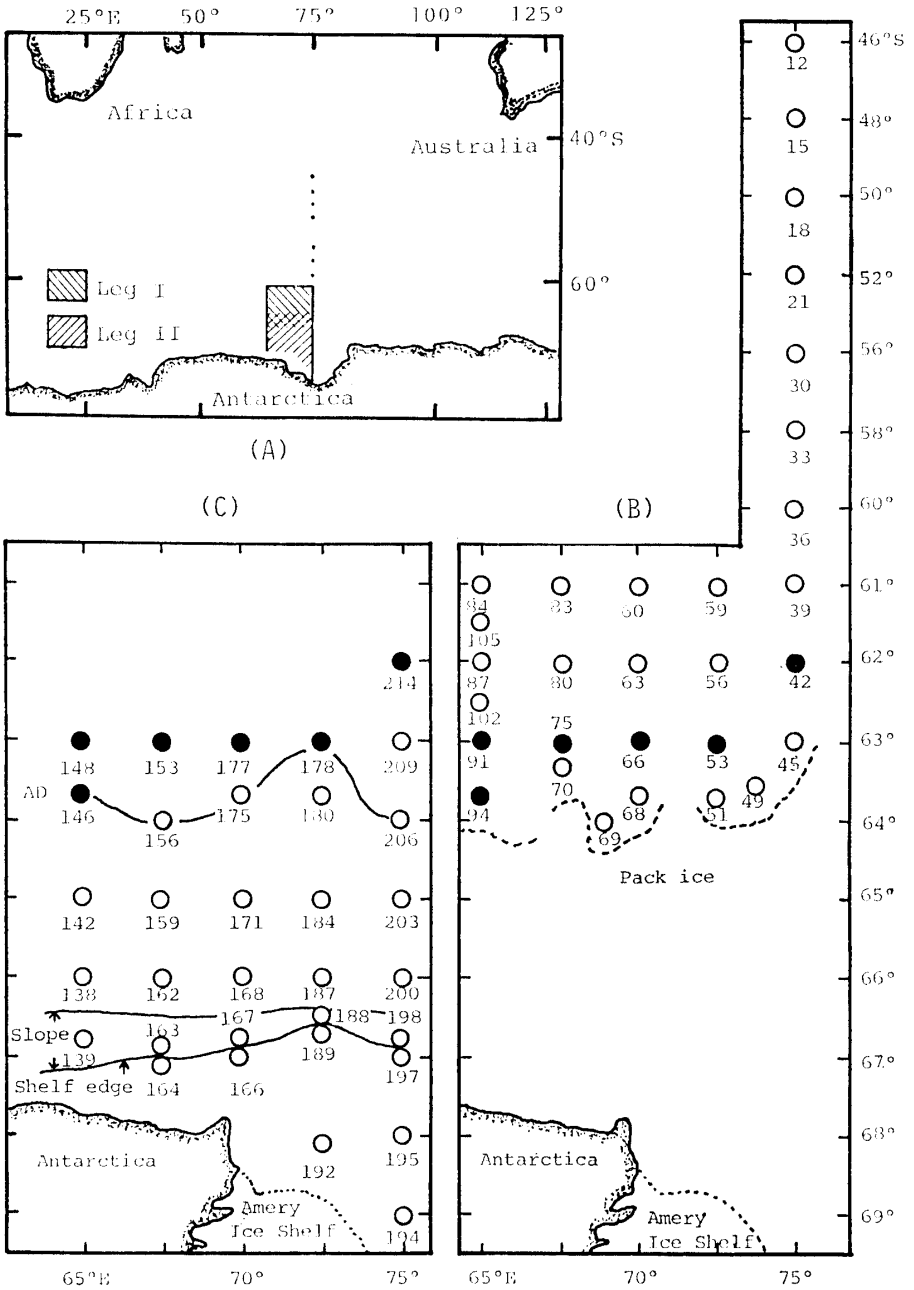

Fig. 1. Location of study area (A) and sampling stations occupied during the R.V. KAIYO MARU cruise (BIOMASS SIBEX I) to the Antarctic Ocean in (B) December 4–24, 1983, (Leg I) and (C) January 19–February 2, 1984, (Leg II). Filled circle denotes repeated sampling stations (see text). AD indicates the Antarctic Divergence. The Polar Front (Antarctic Convergence zone) was observed between 48° and 52°S.

of catches were subsampled to get reasonable aliquots ranging from 1/2 to 1/32 using a box splitter (MOTODA, 1959). All organisms found in the samples were enumerated and the wet weight was measured by each taxonomical group. Total individual number and wet weight of each sample were obtained by summing up the individual number

Table 1. Surface temperature, chl. a in 100–0 m column and total zooplankton abundance in both 100–0 m and 500–100 m columns at all stations occupied.

Subareas	Dec. 4–24, 1983			Jan. 19–Feb. 2, 1984		
	SA*	AC*	South of AC	North of AD*	AD-Slope	Slope-Shelf
No. of station included						
100–0 m	1	3	22	9	11	12
500–0 m	—	2	8	6	5	7
Surface temperature (°C)	6. 8	2. 0-5. 6	−1. 1-0. 4	0. 4-1. 3	−0. 6-0. 7	−1. 0-2. 2
Chl. *a* for 100–0 m (mg/m²)	70 8	218. 6 (99. 7-432. 8)	24. 3 (7. 9-54. 6)	14. 0 (5. 8-26. 7)	19. 9 (12. 1-29. 6)	53. 2 (12. 0-176. 1)
Wet weight (g/m²)						
100–0 m	33. 72	19. 73 (14. 62-31. 72)	5. 40 (0. 76-12. 26)	2. 93 (0. 79-9. 84)	2. 79 (0. 42-5. 48)	1. 42 (0. 25-3. 81)
500–100 m	—	11. 60 (7. 60-15. 60)	6. 48 (0. 00-17. 76)	7. 68 (2. 48-13. 60)	6. 44 (3. 56-10. 60)	10. 20 (1. 60-39. 68)
Individuals (No./m²)						
100–0 m	199385	72541 (26763-142509)	21411 (1587-104091)	11595 (2328-31632)	2646 (805-8190)	8886 (98-45892)
500–100 m	—	39508 (25988-53028)	30956 (4388-94900)	20944 (0-46528)	21416 (9748-39996)	23852 (1876-93992)

* SA: Subantarctic, AC: Antarctic Convergence, AD: Antarctic Divergence ( ): range

and wet weight by each taxonomical group. The zooplankton abundance for the 500–100 m column was obtained by reducing the catches of the 100–0 m layer from those of the 500–0 m layer.

The hydrographic data were quoted from the cruise reports (FISHERIES AGENCY, 1985). The whole study area was divided into three sub-areas by each leg being based on the hydrographic conditions as indicated in Table 1. In December, Stn. 12 (46°S) was in the Subantarctic area with high surface temperature (6.8°C) while the Stns. 15–21 (48°–52°S) were in the Antarctic Convergence (AC) zone as defined with intensive temperature gradient. In the south of the AC, there was a cold Antarctic surface water. In January, the Antarctic Divergence (AD) was found at about 64°S. The south of the AD was the East Wind Drift zone. In the slope-shelf region, the surface temperature was somewhat high (−1.0°–2.2°C), but there existed very cold shelf water (−1.8°C) below 50 m.

3. Results

The abundance of the total zooplankton for the 100–0 m and 500–100 m layers and chl. *a* for the 100–0 m layer are given in Table 1. In the 100–0 m layer, both number of individuals and wet weight of zooplankton in December were larger in the Subantarctic and the Antarctic Convergence regions. The wet weight in January was low and relatively constant throughout all sub-areas but the number of individuals was remarkably small in the AD-slope area. The average weight per individual in this area was about four to six times greater than other areas. It seems that this is due to the different species composition from other areas, *i.e.* large size species were dominant. Chlorophyll *a* was remarkably high in the Subantarctic and the Antarctic Convergence regions in

December and also in the slope-shelf region in January. In the 500–100 m layer, on the other hand, zooplankton showed slightly larger abundance in the AC stations occupied in December but the zooplankton abundance throughout the regions was nearly equal. It was shown that in this study, the abundance of the total zooplankton for the 100–0 m layer was more abundant in the northern region in December than the southern region in January. FOXTON (1956) reported that the biomass of the total zooplankton for the whole Southern Ocean was more abundant in the Antarctic Convergence region and it decreases toward high latitudes, but he (FOXTON, 1956) reported also that the zooplankton biomass for the surface layer (100–0 m) remarkably changed at times.

At six stations, zooplankton was collected in both December and January, some environmental factors and zooplankton abundances in both 100–0 m and 500–100 m layers are given in Table 2. The integrated temperature for the 100–0 m layer showed from −99.66° to −20.75°C, a 78.91°C elevation from December to January. The average depth of maximum temperature became shallower while it became slightly deeper for average minimum temperature. The integrated chl. *a* value for 100–0 m was 25.07 mg/m² in December, but it decreased to 10.05 mg/m² in January. The maximum value of chl. *a* also decreased from 1.06 to 0.32 mg/m³ and the average depth of maximum value became deeper (48–100 m). This may indicate that phytoplankton crops in the 100–0 m column decreased remarkably during this period. In the 500–100 m layer, on the other hand, there were observed very little changes in the environmental factors between December and January. These evidences indicate that remarkable changes in the environmental factors in high latitudes of Antarctic waters may take place in the 100–0 m layer.

Table 2. Abundance of total zooplankton and environmental factors as observed on December 4–24, 1983 and January 19–February 2, 1984.

Items	(a) 100–0(m)		(b) 500–100(m)	
	December	January	December	January
Temperature (°C)				
Integrated*	−99.66	−20.75	851.15	773.03
Range	−1.77-0.7	−1.68-1.3	−0.67-1.9	−0.06-1.98
Max. value	0.37	0.9	1.85	1.77
layer, m ($\bar{X}$)	0-100(67)	0(0)	300-400(340)	300-400(380)
Min. value	−1.57	−1.31	0.06	−0.13
layer, m ($\bar{X}$)	30-75(50)	50-100(75)	100(100)	100(100)
Salinity range (‰)	33.602-34.447	33.715-34.382	34.240-34.736	34.288-34.743
Chlorophyll *a*				
Integrated* (mg/m²)	25.07	10.05	ND	
Max. value	1.06	0.32	ND	
layer, m ($\bar{X}$)	0-75(48)	100(100)	ND	
Average no. of taxon occurred	8.2	6.0	7.4	7.4
Total zooplankton				
No. of animals (inds/m²)	14953	9652	21345	18757
Wet weight (g/m²)	5.16	2.00	3.58	5.09

* Integrated 5 layers of same depth from surface to 100 m column (a), and layers from 100 to 600 m column for (b).

$\bar{X}$: Average depth.

The average number of taxon occurred and the total zooplankton abundances in the 100–0 m layer showed a considerable decrease toward January. For the 500–100 m layer, on the other hand, the number of zooplankton was almost unchanged during this period.

Monthly changes in the zooplankton abundance in the 100–0 m layer are shown in Table 3a. Both individual number and wet weight of zooplankton throughout all taxonomic groups showed a trend to decrease toward January. In Copepoda, the most dominant group, there was observed a distinct decrease in the wet weight, showing 35.1% of the biomass in December, while the individual number was unchanged (81.5%). In Appendicularia, both individual number and wet weight remarkably decreased. In Chaetognatha, the decrease in the individual number was more remarkable than that in the wet weight. The total individual number and wet weight decreased 35.5 and 61.2% respectively during the period. It seemed that the decreasing trend in the total

Tables 3a, b. Abundance of zooplankton of each taxonomical group in December and January at 6 stations where the sampling was duplicated. Percentages to total zooplankton are indicated in parentheses.

(a) Water column	100–0 m			
Zooplankton taxa	Number of individuals/m²		Wet weight g/m²	
	December	January	December	January
Copepoda	9820 (65.7)	8005 (82.9)	3.50 (67.8)	0.23 (61.5)
Appendicularia	3281 (21.9)	1260 (13.1)	0.30 (5.8)	+ (—)
Euphausiacea larvae	863 (5.8)	218 (2.3)	0.10 (1.9)	0.12 (6.0)
Euphausiacea	0 (—)	1 (0.0)	0.00 (—)	+ (—)
Gastropoda	52 (0.3)	16 (0.2)	0.47 (9.1)	0.38 (19.1)
Thaliacea	0 (—)	0 (—)	0.00 (—)	0.00 (—)
Chaetognatha	844 (5.6)	135 (1.4)	0.60 (11.6)	0.25 (12.5)
Polychaeta	62 (0.4)	17 (0.2)	0.05 (1.0)	0.02 (1.0)
Amphipoda	25 (0.2)	0 (—)	+ (—)	0.00 (—)
Hydrozoa	10 (0.1)	0 (—)	0.14 (2.7)	0.00 (—)
Ostracoda	6 (0.0)	0 (—)	+ (—)	0.00 (—)
Total	14953 (100.0)	9652 (100.0)	5.16 (100.0)	2.00 (100.0)
(b) Water colume	500–100 m			
Copepoda	18828 (88.2)	14488 (77.2)	1.76 (48.9)	3.08 (60.5)
Appendicularia	76 (0.4)	232 (1.2)	+ (—)	0.04 (0.8)
Euphausiacea larvae	168 (0.8)	1716 (9.1)	+ (—)	0.08 (1.6)
Euphausiacea	1 (0.0)	1 (0.0)	0.08 (2.2)	0.12 (2.4)
Gastropoda	40 (0.2)	76 (0.4)	0.16 (4.4)	0.12 (2.4)
Thaliacea	0 (—)	16 (0.1)	0.00 (—)	0.01 (0.2)
Chaetognatha	1728 (8.1)	1716 (9.1)	1.24 (34.4)	1.12 (22.0)
Polychaeta	120 (0.6)	124 (0.7)	0.08 (2.2)	0.16 (3.1)
Amphipoda	36 (0.2)	32 (0.2)	0.04 (1.1)	0.08 (1.6)
Hydrozoa	28 (0.1)	36 (0.2)	0.16 (4.4)	0.24 (4.7)
Ostracoda	320 (1.5)	320 (1.7)	0.04 (1.1)	0.04 (0.8)
Total	21345 (100.0)	18757 (100.0)	3.58 (100.0)	5.09 (100.0)

+: <0.01

zooplankton was largely influenced by the change in the abundance of Copepoda that occupied more than 60% in the total zooplankton abundance. For the 500–100 m layer, Copepoda was again the most important taxon among all, especially in terms of individual number (Table 3b). In Copepoda, the individual number slightly decreased and the wet weight slightly increased during December–January. The Appendicularia and euphausiid larvae showed a trend of increase in both individual number and wet weight. But all other taxa showed little difference between December and January.

The averaged individual number and the percentage of dominant copepod species in the 100–0 m layer are given in Table 4. Since the individual number varied widely with species and with sampling station as suggested by somewhat wide ranges in the individual numbers, the averaged number was given to observe the general trend. The total number of dominant species showed a slight decrease toward January. On the other hand, the number of *Calanoides acutus* CIV–VI (copepodites IV–VI stages), *Rhincalanus gigas* CIV–VI, I–III and *Oncaea* spp. decreased extremely from December to January, while the number of *Metridia gerlachei* and *Oithona* spp. increased during the period. The other species showed little difference between December and January. The monthly percentage occupation for the copepodites IV–VI stages of the major large-sized species (*C. acutus*, *C. propinquus*, *R. gigas* and *M. gerlachei*) was 10.7% in December and 2.4% in January when combined all together. The intense decrease in wet weight of net-zooplankton during December to January seems to be largely related to the monthly changes in the abundance of large-sized copepod species.

Table 4. Number of individuals for dominant copepod species in 100–0 m collections in December and January at 6 stations.

Species and copepodite stages	December		January	
	Individual number/m²	%	Individual number/m²	%
Calanoides acutus IV–VI	429.2 (16.5– 903.2)	5.0	14.9 (0.0– 38.5)	0.2
Calanus propinquus IV–VI	99.8 (0.0– 248.7)	1.2	78.3 (28.8– 172.2)	1.1
C. acutus+*C. propinquus* I–III	637.8 (215.4– 1333.4)	7.4	282.5 (44.5– 788.5)	4.1
Rhincalanus gigas IV–VI	350.6 (11.0– 586.9)	4.1	0.0	0.0
Rhincalanus gigas I–III	34.0 (0.0– 120.6)	0.4	0.0	0.0
Metridia gerlachei IV–VI	31.2 (0.0– 92.7)	0.4	77.1 (0.0– 173.1)	1.1
Metridia gerlachei I–III	24.0 (0.0– 103.6)	0.3	41.0 (0.0– 173.1)	0.6
Ctenocalanus vanus	4090.4 (1591.2– 6633.2)	47.6	3621.5 (816.7– 6442.3)	52.6
Oithona spp.	1521.3 (248.6– 3859.3)	17.7	2553.0 (438.9–10153.8)	37.1
Oncaea spp.	805.3 (11.0– 2251.3)	9.4	12.0 (0.0– 43.3)	0.2
Others	563.1 (33.4– 1085.4)	6.6	207.8 (22.7– 769.2)	3.0
Total	8586.7 (2165.7–15718.6)	100.0	6888.1 (1566.7–15990.4)	100.0

4. Discussion

In the Antarctic waters, it has been known generally that the standing crop of macrozooplankton increases in the surface layer (upper 250 m) during the summer. This is mainly due to the ontogenetic migration of major copepod species from deeper layers (*e.g.* OMMANNEY, 1936; MACKINTOSH, 1937; ANDREWS, 1966; HOPKINS, 1971) and this phenomenon is considered to be more distinct in the Antarctic Convergence region (*e.g.* FOXTON, 1956). In the present study, extremely large abundance of zooplankton was found in the 100–0 m layer in the Subantarctic and the Antarctic Convergence regions where a remarkably high concentration of chl. *a* (70.8–218.6 mg/m^2) was observed (Table 1). In January, the zooplankton abundance was poor at the southern stations in the shelf region while chl. *a* was relatively rich. However, there were observed remarkable high chl. *a* values (137.3–178.1 mg/m^2) at Stns. 194 and 195 both of which are located in the southernmost region in the present study (Fig. 1), and zooplankton crops were also larger at these two stations (1.65–3.81 g/m^2, 21249–45892 individ./m^2). In this study, Copepoda occupied 65.9% of net-zooplankton biomass throughout the whole study area. The figure roughly corresponds to 72.8% in the Indian Ocean sector (VORONINA, 1967) and 67.3% in the Pacific sector (HOPKINS, 1971). At Stn. 194, Copepoda occupied 85% of total zooplankton biomass. The major composition for *C. acutus*, *C. propinquus* and *M. gerlachei* populations was the CI–III stages, and the CIV–VI stages for these species were largely composed on the CIV. This roughly corresponds to the results by ŻMIJEWSKA (1983), where it was reported that the highest number of copepods was composed mainly of more advanced copepodites (III and IV stages) of *C. acutus*, *C. propinquus* and *M. gerlachei* in the southern part of Prydz Bay in February 1969 and this was due to the anomalous hydrographic situation, *i.e.* the melting of ice began from the southern region of the bay where the water warmed up faster. SMITH *et al.* (1984) also stated that such an environment is known as a characteristic feature of this bay. This means that the "biological spring" begins from the southern region in Prydz Bay. In this study, the highest surface temperature (2.2°C) throughout all stations occupied in January was observed at Stn. 194, the southernmost station.

At the stations where the collection of zooplankton was made in December and again in January, the abundance of zooplankton in the 100–0 m layer showed a considerable decrease in January and this was especially distinct in total wet weight, *i.e.* from 5.16 g/m^2 in December to 2.00 g/m^2 in January. Each zooplankton taxon showed a decreasing trend during this period. According to FOXTON (1956), two seasonal maxima of zooplankton abundance exist in the 100–0 m layer: in November–December and in February–April. FOXTON's data were represented by the displacement volume per haul. Since the wet weight data for the Antarctic zooplankton of upper 150 m can be compared directly with displacement volume data without correction (KAWAMURA, 1986), FOXTON's data by displacement volume per haul can be expressed by g/m^2, assuming 100% filtering efficiency, his data would be converted as 6.78 g/m^2 (December) and 4.31 g/m^2 (January) for the whole Antarctic zooplankton. The figure for December is approximately equal to that of the present study but the figure for January is larger than the present study. VINOGRADOV and NAUMOV (1958) believe that the first maximum of zooplankton abundance reported by FOXTON (1956) is associated with the upward migration of wintering organisms into the surface layer, but the second one is due to the development of new generations. In this connection, the quite high percentage of the CIV–VI stages of the major component species, *C. acutus*, *C. propinquus*, *R. gigas* and *M. gerlachei* in December (10.7%) than that in January (2.4%) may support the opinion of VINOGRADOV and NAUMOV (1958). The decrease in the percentage for CIV–VI stages of these four species toward January was largely due to the decrease in *C. acutus* and *R. gigas* populations. In the region of the Antarctic Convergence, VORONINA *et al.* (1978) reported that population of *C. acutus* in late November was composed of only the CV and CVI stages, but a month later, it changed to a population dominated by the CII and III stages. In the present study, the populations of *C. acutus* and *C. propinquus* were composed of the CI, II and V stages that were dominant in December. In January, however, the CII and III stages were dominant, so it seems that the change in the composition is quite similar to the results by VORONINA *et al.* (1978).

It was shown in this study that the ontogenetic migration, and growth of the major copepod species largely influenced the abundance of total zooplankton in the Antarctic surface waters during the summer. It was shown that the abundance of zooplankton coincided well with the abundance of chl. *a* concentration, especially in the Subantarctic and the Antarctic Convergence regions. A similar trend was also found at Stn. 194. SCHNACK (1985) proved that *Euphausia superba* and dominant copepod species (*C. acutus*, *C. propinquus*, *R. gigas*, *M. gerlachei* and *M. curticauda*) feed on similar food items by feeding experiment. KAWAMURA (1986) suggested that with a marked decrease in the biomass of southern baleen whales, an enormous surplus of *E. superba* in recent years may influence the other macrozooplankton community, especially the population size of dominant herbivorous copepods such as *C. acutus*, *C. propinquus* and *R. gigas*. Among differently oriented zooplankton studies, it may be one of such directions as study of the spatial and temporal distributions of the herbivorous zooplankton populations along with their life cycles, for the understanding and monitoring a possible changing ecosystem of the Antarctic Ocean.

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