PHYTOPLANKTON AND ZOOPLANKTON STANDING STOCKS AND DOWNWARD FLUX OF PARTICULATE MATERIAL AROUND FAST ICE EDGE OF LÜTZOW-HOLM BAY, ANTARCTICA

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***Abstract*:** Phyto- and zooplankton standing stocks in the fast ice and in the water column under the ice and downward flux of particulate material through the water column were investigated in Lützow-Holm Bay, Antarctica, during the austral summers, *i.e.*, in January 1977 and February 1979. Chlorophyll *a* standing stock integrated through the ice was 0.38–0.80 mg/m^2 and that in the water column beneath the ice down to 150 m was 3.06 mg/m^2. Microdistribution of zooplankton beneath the ice was observed by the pumping collections and the dense populations were found just beneath the ice. Zooplankton density was in a range of 12–60 indiv/m^3 and the zooplankton stocks integrated through the 150 m water column ranged from 6000 to 7675 indiv/m^2. By the sediment trap operation, the fecal materials were found to comprise a large proportion of the collected particles. The maximum daily vertical flux of particulate organic carbon (POC) was found at the 100 m depth (103 mg C/m^2/day) and concentration of POC in the water column was in a range of 24–56 mg C/m^3. These data on standing stocks of phyto- and zooplankton and vertical flux of POC in the ice-covered Lützow-Holm Bay were compared with those in the other sea areas.

1. Introduction

The Antarctic Ocean is known as one of the productive seas in the world. The high productivity is ascribed to some characteristic oceanographic features of this Ocean. Among them, the ice-coverages around the Antarctic Continent are the most predominant character of the Ocean. Nevertheless, progression of marine biological investigation in the ice-covered sea is far behind that in the open water areas.

Most works done in the ice-covered sea have been focused on epontic phytoplankton associated with pack ice or fast ice (MEGURO, 1962; BUNT, 1968; HORNER, 1977; HOSHIAI, 1977a). These works indicate that the ice micro-algae are able to form very dense community and then primary production is restricted to the undersurface of the sea ice and/or extremely shallow layer of water column.

The studies on the pelagic communities beneath the ice were published for zooplankton distribution by RAKUSA-SUSZCZEWSKI (1972), ZVEREVA (1972) and FUKUCHI *et al.* (1979), and for fish by GRUZOV *et al.* (1967) and HOSHIAI and TANIMURA (1981). However, although the importance of more extensive investigations has been emphasized (ANDRIASHEV, 1970; EL-SAYED, 1971; BRADFORD, 1978), the most basic information and data to elucidate the structure of marine ecosystem in the ice-covered sea in the Antarctic Ocean are still insufficient.

Apart from those basic data, downward transport of the organic materials produced in the shallow layer is also one of the key problems in the Antarctic marine ecosystem. The vertical transport processes of the primary products have a vital importance to heterotrophic communities in the depths. Some direct estimations of the vertical transport by using sediment traps have been done in the open seas (*e.g.*, BISHOP *et al.*, 1977; ISEKI, 1977; SASAKI, 1979), but no such works have been reported in the ice-covered sea of the Antarctic Ocean.

The present work is undertaken to procure the fundamental knowledge on phytoplankton and zooplankton standing stocks and the direct evidence of downward transport of the surface products in the sea area covered with ice in Lützow-Holm Bay, Antarctica. The work was done during the two austral summers of 1976/1977 and 1978/1979, as a part of the scientific programs of the Japanese Antarctic Research Expedition (JARE) and the national BIOMASS project in which the senior author participated.

2. Methods and Materials

Sampling site on the fast ice in Lützow-Holm Bay, Antarctica, is shown in Fig. 1. Three stations (Stns. I, II and III) and one station (Stn. 1) were occupied in January 1977 (JARE-18) and February 1979 (JARE-20), respectively. All stations were located in the shelf water region (*cf.* MORIWAKI, 1979) and depth of the sea bottom ranged from 244 to 320 m. The boundaries between the fast ice and the pack ice regions were situated about 12 miles north of Stn. I in 1977 and about six miles north of Stn. 1 in 1979. Samplings and observations on several items were performed at a hole (about 60×60 cm) through the fast ice of 85–139 cm thick (Table 1). The holes were bored about 300–500 m apart from the icebreaker FUJI (see Fig. 3). The fast ice seemed to be one year old.

2.1. Samplings and observations in January 1977 (JARE-18)

Three stations were located within a narrow area, *i.e.*, at intervals of about one to four miles, and occupied within two weeks. Therefore, the data obtained from these stations were regarded as from one origin.

Zooplankton sampling: A double net of 35 cm in mouth diameter was hauled vertically at a speed of *ca.* 1 m/s from a 50 m depth to the surface. The double net was composed of two conical nets, an outer net of 135 cm long with XX13 netting (mesh size: 0.11 mm) and an inner net of 95 cm long with GG54 netting (mesh size: 0.33 mm). The double net was used to obtain medium-sized zooplankton (retained on the inner

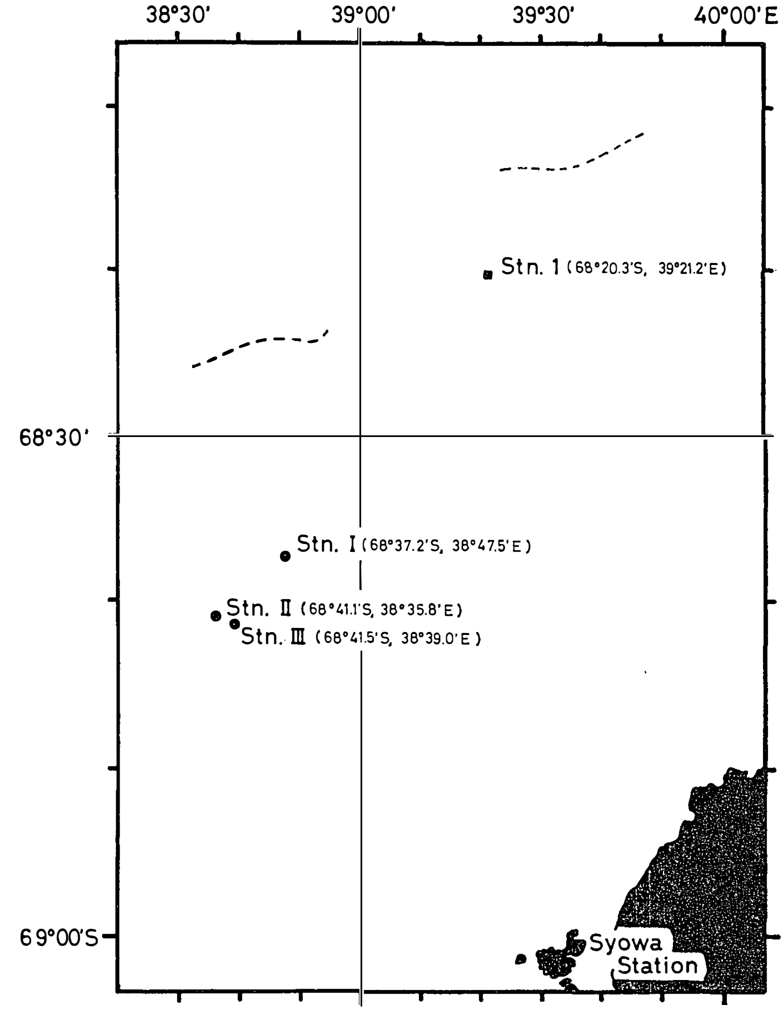


Fig. 1. Locations of sampling stations in JARE-18 (Stns. I, II and III) in January 1977 and in JARE-20 (Stn. 1) in Feburary 1979, in continental shelf area in Lützow-Holm Bay, Antarctica. Dotted lines indicate approximate boundaries between fast ice and pack ice regions observed in two years.

Table 1. Position of station, depth of sea bottom, thickness of sea ice and period of observation in the ice-covered Lützow-Holm Bay, Antarctica, in 1977 (JARE-18) and 1979 (JARE-20).

Station No.	Position		Depth of sea bottom (m)	Thickness of sea ice (m)	Period of observation	Expedition No.
	Latitude	Longitude				
Stn. I	68°37.2′S	38°47.5′E	250	1.39	11–19 Jan. 1977	JARE-18
Stn. II	68°41.1′S	38°35.8′E	244	1.33	22–23 Jan. 1977	JARE-18
Stn. III	68°41.5′S	38°39.0′E	267	1.35	24–27 Jan. 1977	JARE-18
Stn. 1	68°20.3′S	39°21.2′E	320	0.85	1–16 Feb. 1979	JARE-20

net) separately from phytoplankton and smaller zooplankton (retained on the outer net). All samples were preserved in *ca.* 10% buffered formalin sea water. Samplings were performed from 11 to 27 January and 32 samples in total were obtained. Among them, eight samples from the inner net were subjected to the primary sorting. Individual number of zooplankters was counted and the number was expressed for a 0–50 m haul. The volume of water filtered by a 0–50 m vertical haul can be calculated to be 4.8 m^3 when filtration efficiency of the net is 100%.

2.2. *Samplings and observations in February 1979 (JARE-20)*

Sea water sampling: Sea water was sampled at 1245–1500 hr on 1 February using a 6 *l* Van Dorn water bottle from 16 layers; surface water exposed in the hole, and 0.0, 0.5, 1.0, 2.5, 5.0, 7.5, 10, 15, 20, 30, 50, 75, 100, 125 and 150 m beneath the sea ice. Sea water was analyzed for the following general elements; temperature, salinity, pH, dissolved oxygen, phosphate-P, silicate-Si, nitrate-N, nitrite-N, ammonium-N and alkalinity. The analyses were carried out in a shipboard laboratory of the icebreaker FUJI within several hours after the samplings. The data obtained by those analyses will be published elsewhere (SUZUKI and KURANO, in preparation). An aliquot of 500 m*l* of the sea water from each layer was preserved in *ca.* 3% buffered formalin solution for later analysis of phytoplankton community. Chlorophyll *a* concentration was also determined by the fluorometric method (after SAIJO and NISHIZAWA, 1969) using Shimadzu model RF-500 spectrofluorometer.

XBT observation: Vertical profile of water temperature down to the sea bottom was recorded by expendable bathythermographs. The XBT was operated by an ordinary portable generator (HONDA model E330, 100V, 300W) at 0835 on 6 February, 1246 on 7 February and 1215 on 16 February.

Ice core sampling: Sea ice cores were taken in duplicate at 1250–1450 on 6 February with a SIPRE ice-coring auger at each of three sites selected within 15 m from Stn. 1. Snow accumulation on the ice was 10–15 cm. Each core was divided into four sections according to coloration and structure of the ice. Each section was examined for the chlorophyll *a* content by the fluorometric method after melting at room temperature. An aliquot of 500 m*l* from each section was preserved in *ca.* 3% buffered formalin solution for light and scanning electron microscopic observations.

Pumping collection of zooplankton: Pumping collection of zooplankton under the fast ice was done on 4 February. Sea water was pumped up from each of eight layers; 0.00, 0.15, 0.25, 0.50, 1.65, 4.15, 6.65 and 8.15 m beneath the ice. The pumping collection system is schematically represented in Fig. 2. A PVC (polyvinyl chloride) tube of 20 mm inner diameter was lowered to the desired depth to pump water up by an IWAKI magnetic pump model MD-80 (100 V, 231/290 W, 50/60 Hz, max flow 70/80 *l*/min, max head 7/10 m), which was driven by the generator as mentioned in the previous section. It took 15 to 28 minutes to pump up 500 *l* of the sea water. A suction speed of water at the inflow tube was tentatively calculated to be

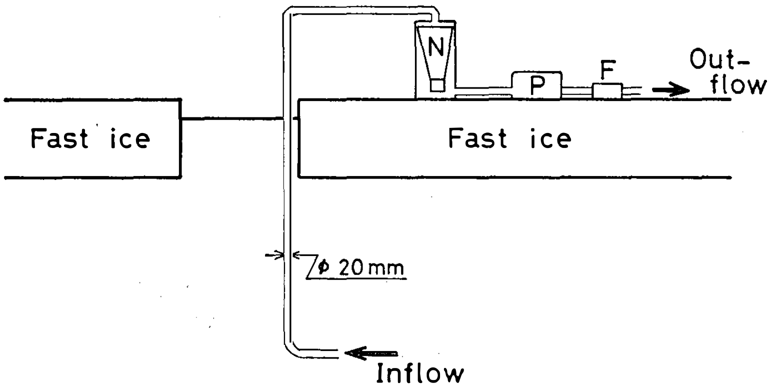


Fig. 2. Schematic representation of pumping collection of zooplankton on fast ice in Lützow-Holm Bay, Antarctica (see text for details). N: plankton net (ø 20×35 cm, 0.11 mm mesh); P: magnetic pump; F: flow-meter.

95–177 cm/s. Sea water was filtered through a conical net (ϕ 20×35 cm, 0.11 mm mesh size) installed in a PVC cylinder and zooplankton was collected at a cod end of the net. The volume of water filtered through the net was measured by a flow-meter. Eight samples were then treated and processed in the same manner of zooplankton samplings in 1977.

Norpac net sampling of zooplankton: The standard vertical samplings with a Norpac net (ϕ 45×180 cm; MOTODA, 1957) were performed. Mesh size of the net was 0.33

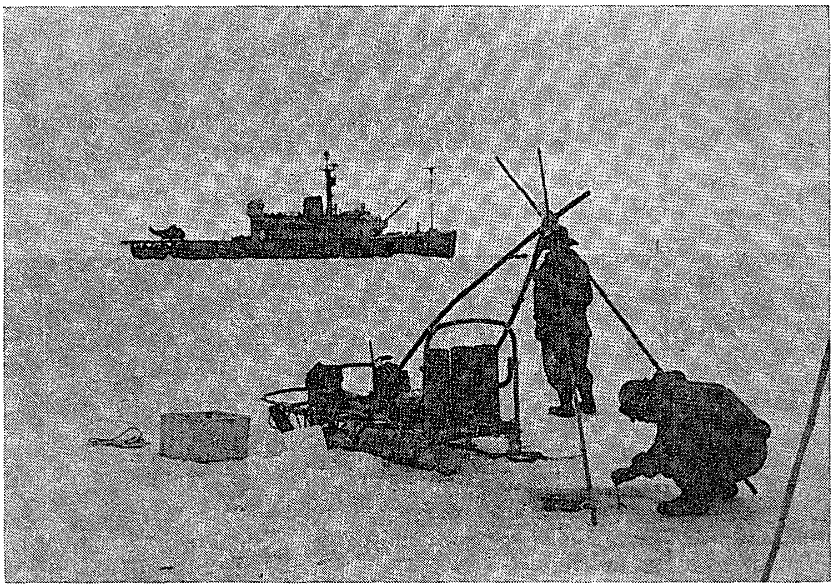


Fig. 3. Three sediment traps (ø 150×500 mm, on a sledge) before deployment through a hole 394 m apart from the icebreaker FUJI in the ice-covered Lützow-Holm Bay, Antarctica, in February 1979.

mm (GG54 netting). A flow-meter (Rigosha No. 51) was mounted at the center of the mouth ring of the net to register the volume of water filtered through the net. The Norpac net was hauled vertically from 50, 100 and 150 m to the surface at a speed of *ca.* 1 m/s. A wire length paid out was corrected when wire angle exceeded 10 degree. A total of 24 samples was collected from 1 to 16 February. While the samples were treated in the same manner as in 1977, six of 24 samples obtained on 4–5 February were used in the present work.

Transparency observation: Secchi disk readings were made on 1, 2, 5, 6, 7, 15 and 16 February before or after the Norpac net hauls.

Sediment trap sampling: Three cylindrical sediment traps (150 mm in mouth diameter and 500 mm high, Fig. 3) were suspended at 50, 100 and 150 m depths beneath the fast ice for about 16 hours, from 1618 on 4 February to 0811 on 5 February. A Millipore AA filter (ϕ 150 mm) was mounted at the bottom of the traps and three sheets of Whatman GF/C glassfiber filter (ϕ 47 mm) pre-ignited were placed randomly on the Millipore filter. The Millipore and Whatman GF/C filters were subjected to light and electron microscopic observations and to determination of particulate organic carbon (POC), respectively. Details of the configuration of the sediment trap, field operation and analyses of the collected particles were published by SASAKI (1979). Sea water at these three depths was also collected by a Van Dorn water bottle at 1545–1600 on 4 February and was analyzed to determine the POC concentration. The determination was made according to the method recommended by STRICKLAND and PARSONS (1968).

3. Results

3.1. *Zooplankton occurrence in January 1977*

Table 2. Individual numbers of zooplankters collected by the inner net of the double net in the ice-covered Lützow-Holm Bay, Antarctica in January 1977 (JARE-18). Numbers were expressed for a 0–50 m vertical haul.

Sample No.	770111-I	770112-I	770113-I	770116-I	770119-I	770122-I	770125-I	770127-3-I
Medusae	0	0	1	0	0	0	0	0
Chaetognatha	0	1	0	0	0	0	0	0
Polychaeta	5	2	1	0	0	2	1	0
Copepoda	50	74	39	47	24	37	9	14
Amphipoda	0	1	0	0	0	0	0	0
Pteropoda	0	1	0	1	0	0	0	0
Echinodermata, pelagic larvae	2	6	2	14	6	11	20	9
Appendicularia	6	0	5	34	29	18	72	16
Fish larvae	0	1	0	0	0	0	0	0
Unidentified	7	3	0	2	0	1	3	3
Total	70	89	48	98	59	69	105	42

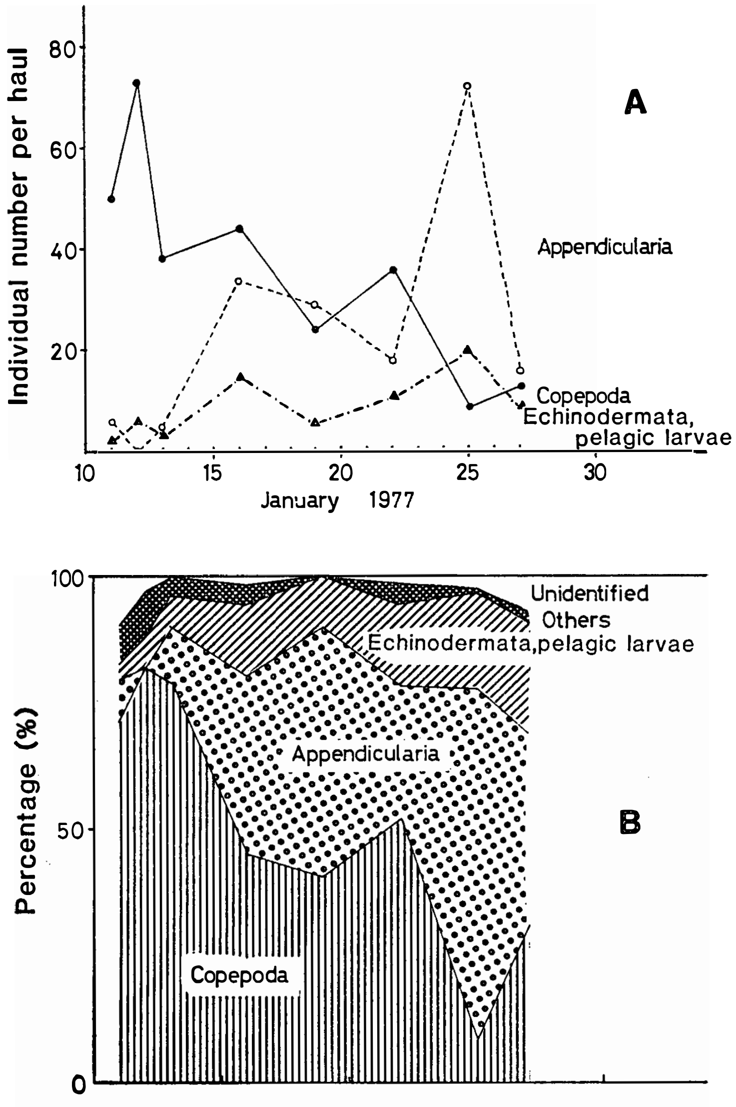


Fig. 4. Changes in individual numbers of Copepoda, Appendicularia and Echinodermata, pelagic larvae (A), and in percentage composition of zooplankton (B) observed with a double net in January 1977 (JARE-18).

The number of individual zooplankters retained in the inner net varied from 42 to 105 per 0–50 m vertical haul (Table 2). Copepoda and Echinodermata, pelagic larvae, were found in all samples and Appendicularia was also obtained in most samples. These three taxa occurred abundantly and occupied 83–100% of total zooplankton number. In addition, Chaetognatha, Polychaeta larvae, Amphipoda, Pteropoda and fish larvae were collected in small numbers.

Daily changes in the numbers of Copepoda, Appendicularia and Echinodermata are shown in Fig. 4A. Copepoda fluctuated between 9 and 74 individuals and tended to decrease from 11 to 25 January. On the other hand, Appendicularia seemed to increase during the period and the numbers were in a range of 0–72. Echinodermata were less abundant (2–20 individuals) than the former two taxa. Percent composition of these three taxa then changed as the sampling period proceeded (Fig. 4B); Copepoda decreased from 82 to 6%, while Appendicularia and Echinodermata increased from 0 to 69% and 3 to 21%, respectively.

3.2. Environmental condition beneath fast ice in February 1979

Vertical profile of water temperature beneath the fast ice was observed to be constant during the present observations. Water temperature just beneath the ice was −1.3°C and it decreased to −1.5°C at a 50 cm depth. At further depths, a constant temperature of −1.6°C was observed down to the bottom (Fig. 5A). Surface water in the hole, which was exposed to air, was warmed to +0.6°C. In Fig. 5A, vertical profiles of salinity, dissolved oxygen and pH are also illustrated. Salinity increased from 33.6‰ at 0 m (just beneath the ice) to 34.1‰ at 30 m and became

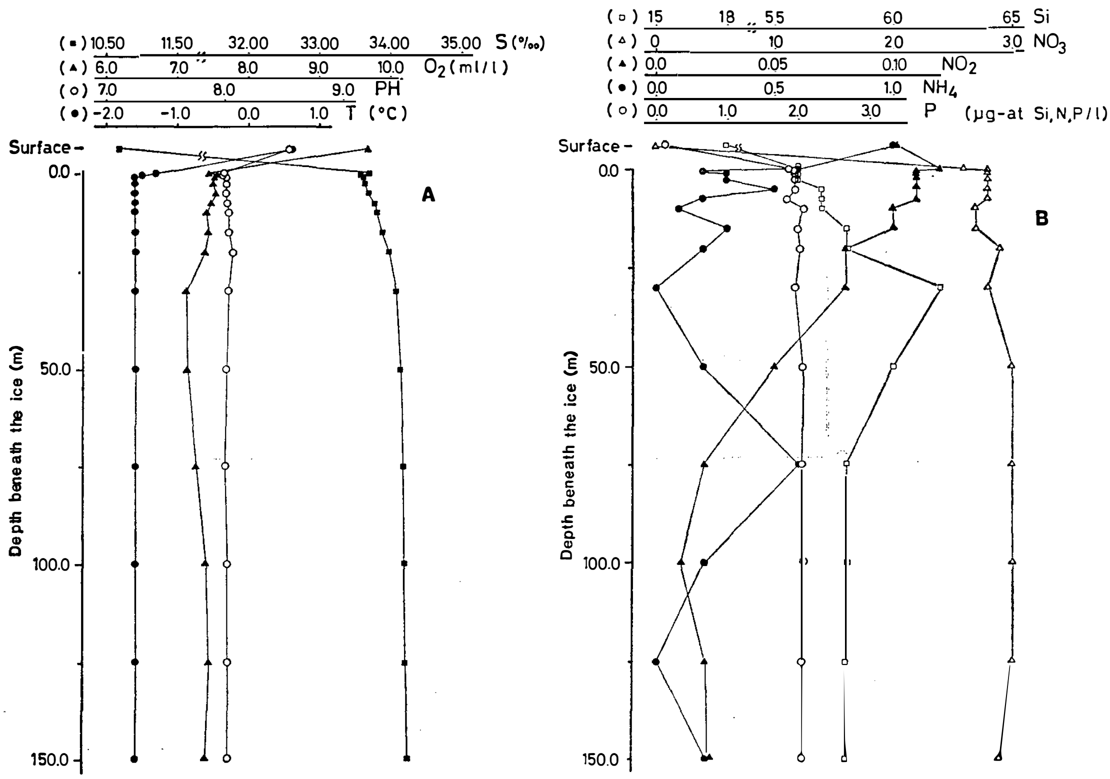


Fig. 5. Vertical profiles of water temperature, salinity, dissolved oxygen and pH (A), and those of phosphate-P, silicate-Si, nitrate-N, nitrite-N and ammonium-N (B) observed at Stn. 1 in the ice-covered Lützow-Holm Bay, Antarctica, on 1 February 1979 (JARE-20) (after SUZUKI and KURANO).

constant below 30 m (34.1–34.2‰). Dissolved oxygen was in a range of 7.4–7.5 m*l* O_2/l, although a low value of 7.1 m*l* O_2/l was observed at the 30–50 m layer. PH was constant at about 8.0 throughout the water column. In these elements, great differences between the surface in the hole and the 0 m level (just beneath the ice) were also observed. This might be caused by the direct exposure to the air and solar radiation. Fig. 5B shows the vertical profiles of nutrient salts such as phosphate-P, silicate-Si, nitrate-N, nitrite-N and ammonium-N. Phosphate was almost constant between 0 and 150 m (1.9–2.1 μg at-P/*l*). Silicate increased from 0 m (55–56 μg at-Si/*l*) to 30 m (62 μg at-Si/*l*) and then decreased gradually to 150 m (58 μg at-Si/*l*). Nitrate increased gradually from 0 m (26 μg at-N/*l*) to 150 m (29–30 μg at-N/*l*). On the other hand, nitrite decreased from 0 m (0.12 μg at-N/*l*) to 150 m (0.02 μg at-N/*l*). Ammonium fluctuated largely (0.0–0.6 μg at-N/*l*), although the analytical precision of ammonium-N could not be comparable to those of the above-mentioned elements. Transparency observed on 1, 2, 5, 6, 7, 15 and 16 February were 9.5, 18.0, 13.5, 13.5, 13.5, 17.5 and 19.5 m, respectively.

3.3. *Chlorophyll a standing stock within fast ice and water column beneath the ice*

Bottom section of 10 cm thick of the ice cores exhibited a little coloration of

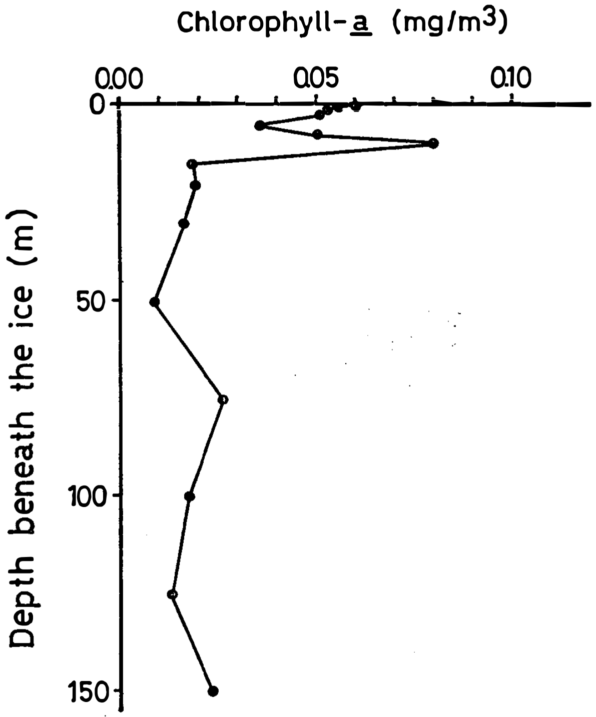


Fig. 6. Vertical profile of chlorophyll a concentration (mg/m³) beneath the ice obtained at Stn. 1 in the ice-covered Lützow-Holm Bay, Antarctica, on 1 February 1979 (JARE-20).

greenish brown. Chlorophyll *a* concentration of this section was as high as 2.09–4.53 mg/m^3. It decreased upwards and the lowest values of 0.07–0.12 mg Chl *a*/m^3 were detected in the surface section. Integrated chlorophyll stock through the fast ice under unit area (1 m^2) was calculated as 0.38–0.80 mg/m^2 (Table 3).

The vertical profile of chlorophyll *a* concentrations in the water column beneath the ice is shown in Fig. 6. The concentration in the water was much lower than those in the ice and was in a range of 0.01–0.08 mg Chl *a*/m^3. The maximum value of 0.08 mg/m^3 was seen at 10 m and below this the concentration was as small as 0.01–0.03 mg Chl *a*/m^3. Integrated chlorophyll *a* stock under unit surface area from 0 m down to 150 m was 3.06 mg/m^2.

3.4. *Microdistribution of zooplankton observed by pumping collection*

Numbers of zooplankters and the related materials collected by the pumping collection from eight layers beneath the ice are tabulated in Table 4. Their densities were expressed as the number per one cubic meter of water filtered through the net. Total numbers of zooplankters were 4–1132 and copepods were exclusively predominating. Among them, *Paralabidocera antarctica* was dominant. One calyptopis larva of a euphausiid was collected at 50 cm beneath the ice. This was the only zooplankter other than copepods in the present pumping collection. Large numbers of copepods were observed at top layers, but below 1.65 m the numbers were quite small. Molts, fecal pellets and eggs of copepods seemed to be accumulated around 25 cm.

3.5. *Zooplankton collected by Norpac net*

Individual numbers of zooplankters per a haul of Norpac net on 4 and 5 February are listed in Table 5. Copepods were most abundant and occupied 77–99% of the total number. Next to copepods, Foraminifera, Appendicularia and Chaetognatha were abundant. Other than these animals, Medusae, Siphonophora, Polychaeta, Amphipoda and Euphausiacea occurred in small numbers.

To know the vertical distribution of zooplankton in the 0–150 m water column, the individual numbers in each 50 m layer of the water column were calculated by subtracting the number in the shallower haul from that in the deeper haul (*cf.* Table 5). The densities for 50 m layers are shown in Fig. 7. Copepods predominated in every layer occupying 55–99%. However, its dominancy lowered in deeper layers, becoming minimum in the bottom layer. On the other hand, Foraminifera and Appendicularia became abundant in deeper layers. In detail, extremely high dominancy of copepods (98–99%) and total zooplankton numbers (51.1 and 46.6 indiv/m^3) were constant on both 4 and 5 February, but no constancy in total catches and composition was seen in 50–100 m and 100–150 m layers over 4 and 5 February. In the 50–100 m layer, the total catch was the smallest (11.8 indiv/m^3) on 4 February but was the largest (59.9 indiv/m^3) on 5 February. Furthermore, dominancies of Foraminifera and Chaetognatha were 14 and 6% on 5 February but negligible on 4 February. In the 100–150 m layer, while the total number was rather constant on both 4 and 5 February

Table 3. Chlorophyll a concentration (mg/m³) and integrated chlorophyll stock (mg/m²) in sea ice at Stn. 1 in the ice-covered Lützow-Holm Bay, Antarctica on 6 February 1979 (JARE-20).

Sample No.	Ice core-1			Ice core-2			Ice core-3		
Thickness of sea ice (cm)	85			103			78		
Chlorophyll *a* concentration (mg/m³)	Section of ice core (cm)	Length of section (cm)	Chl. *a* (mg/m³)	Section of ice core (cm)	Length of section (cm)	Chl. *a* (mg/m³)	Section of ice core (cm)	Length of section (cm)	Chl. *a* (mg/m³)
	surface-60	25	0.07	surface-83	20	0.12	surface-53	25	0.07
	60–44	16	0.19	83–50	33	0.21	53–33	20	0.31
	44–10	34	2.22	50–10	40	0.63	33–10	23	0.38
	10-bottom	10	2.86	10-bottom	10	4.53	10-bottom	10	2.09
Chlorophyll *a* standing stock in sea ice (mg/m²)			0.41			0.80			0.38

Table 4. Individual numbers of zooplankters and related materials per one cubic meter of sea water sampled by the pumping collections from eight depths beneath the ice-covered Lützow-Holm Bay, Antarctica, 4 February 1979 (JARE-20).

Time	1323–1346	1302–1322	1405–1422	1345–1405	1245–1300	1051–1108	1020–1048	0940–0955
Depth beneath the ice (m)	0.00	0.15	0.25	0.50	1.65	4.15	6.65	8.15
Zooplankters:								
Harpacticoids	0	2	16	36	0	4	2	0
Paralabidocera antarctica, ♀	820	594	94	22	0	0	0	0
Paralabidocera antarctica, ♂	298	390	84	30	0	0	0	0
Copepods, nauplius stages	0	2	22	38	0	6	2	0
Copepods, copepodite stages	14	72	170	126	4	8	20	22
Euphausiid, calyptopis stage	0	0	0	2	0	0	0	0
Total	1132	1060	386	254	4	18	24	22
Others:								
Molts of copepods	24	16	10	20	4	2	4	0
Fecal pellets of copepods	84	106	426	126	38	18	38	10
Eggs of copepods	16	6	30	0	12	8	6	10
Total	124	128	466	146	54	28	48	20

Table 5. Individual numbers of zooplankters collected by the Norpac net in the ice-covered Lützow-Holm Bay, Antarctica, 4 and 5 February 1979 (JARE-20). Numbers were expressed for each vertical haul.

Date	4 February			5 February		
Depth of haul (m)	0-50	0-100	0-150	0-50	0-100	0-150
Sample No.	790204-1	790204-2	790204-3	790205-1	790205-2	790205-3
Foraminifera	0	7	36	2	53	144
Medusae	0	0	0	0	1	2
Siphonophora	1	0	3	0	2	2
Chaetognatha	2	2	10	2	24	26
Polychaeta	0	0	2	0	0	0
Copepoda	322	388	730	280	571	736
Amphipoda	0	1	1	1	1	0
Euphausiacea	0	0	1	0	0	3
Appendicularia	0	1	5	1	8	46
Total	325	399	788	286	660	959

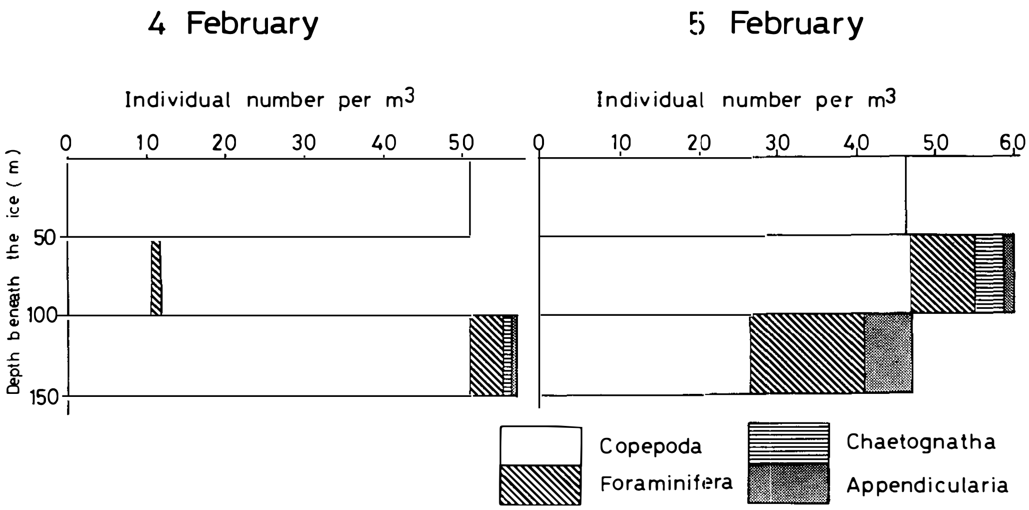
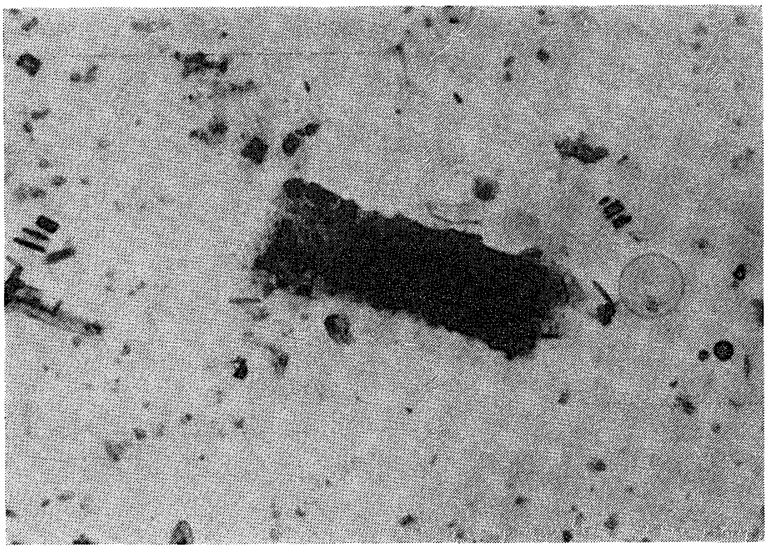


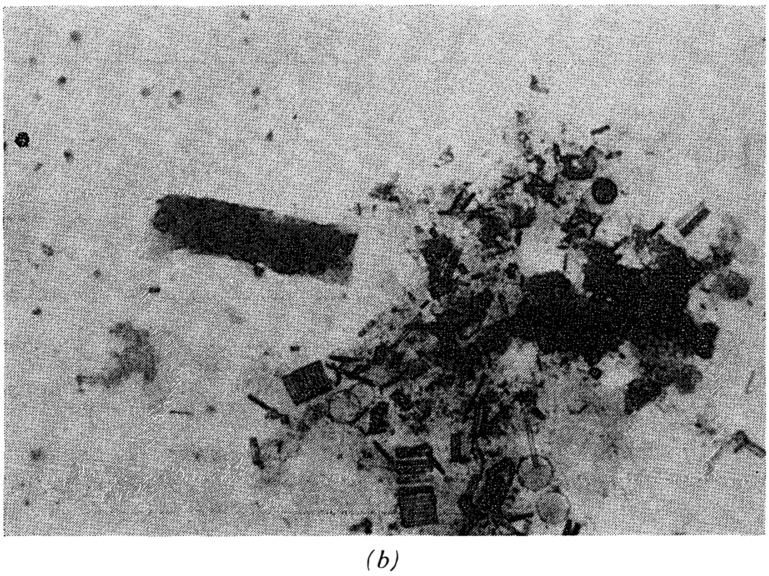
Fig. 7. Vertical distribution of zooplankton observed with Norpac net samplings at Stn. 1 in the ice-covered Lützow-Holm Bay, Antarctica, on 4 and 5 February 1979 (JARE-20).

(57.1 and 47.2 indiv/m^3), the dominancy of copepods was quite reduced or those of Foraminifera and Appendicularia increased during these days.

Standing stocks of zooplankters integrated through the surface down to 150 m on 4 and 5 February were as follows; 6000 and 7675 indiv/m^2 for total zooplankton, 5550 and 5895 for Copepod, 75 and 205 for Chaetognatha, 40 and 365 for Appendicularia, 270 and 1140 for Foraminifera and 65 and 70 for the others. The stocks of total zooplankton, Copepoda and the others did not greatly vary during two successive days, but those of Appendicularia, Foraminifera and Chaetognatha showed a great difference.



(a)



(b)

Fig. 8. Light microphotographs of collected particles in sediment traps at 100 m in Lützow-Holm Bay, Antarctica, in February 1979 (JARE-20). a. Fresh fecal pellets. b. Degraded fecal matter (right).

3.6. Observations by sediment trap

Collected particles in the traps were examined under a light microscope. Many particles larger than 100 μm in length were trapped. Among them, fresh fecal pellets of zooplankton were abundant, their size ranging from 200 to 1000 μm long, and observed as greenish brown (Fig. 8a). Degraded loose clumps of those fece origin were also found abundantly (Fig. 8b) and are called fecal matter below (after BISHOP

Table 6. Numbers of trapped particles larger than 100 μm in longest dimension found on Millipore AA filter in each of three sediment traps set at 50, 100 and 150 m depths in Lützow-Holm Bay, Antarctica, in 1979 (JARE-20). Numbers were expressed for 10 cm^2 of the filter. Numbers in parenthesis indicate the relative composition of particles in each filter.

Depth (m)	Fecal material		Detrital particles	Fragments	Foraminifera	Total
	Fecal pellet	Fecal matter				
50	41.4 (28.6)	75.9 (52.3)	0.0 (0.0)	3.5 (2.4)	24.2 (16.8)	145.0
100	38.0 (18.2)	124.2 (59.5)	24.2 (11.6)	3.5 (1.7)	18.7 (9.0)	208.6
150	6.9 (5.9)	31.1 (26.4)	27.7 (23.5)	41.5 (35.2)	10.7 (9.1)	117.9

Table 7. A list of dominant species of micro-algae found in the bottom section of sea ice, water just beneath the ice and fecal materials from 100 m sediment trap.

Sample	Species
Bottom section of sea ice	*Nitzschia* spp.* *Chuniella* sp. *Fragiraliopsis* spp. Unidentified Flagellata
Water just beneath sea ice	*Nitzschia* spp.* *Chuniella* sp.* *Navicula* spp. *Fragiraliopsis* spp. *Coscinodiscus* spp. Unidentified Flagellata
Fecal materials	*Nitzschia* spp.* *Navicula* spp. *Fragiraliopsis* spp.* *Chuniella* sp. *Coscinodiscus* spp.

* Most abundant species.

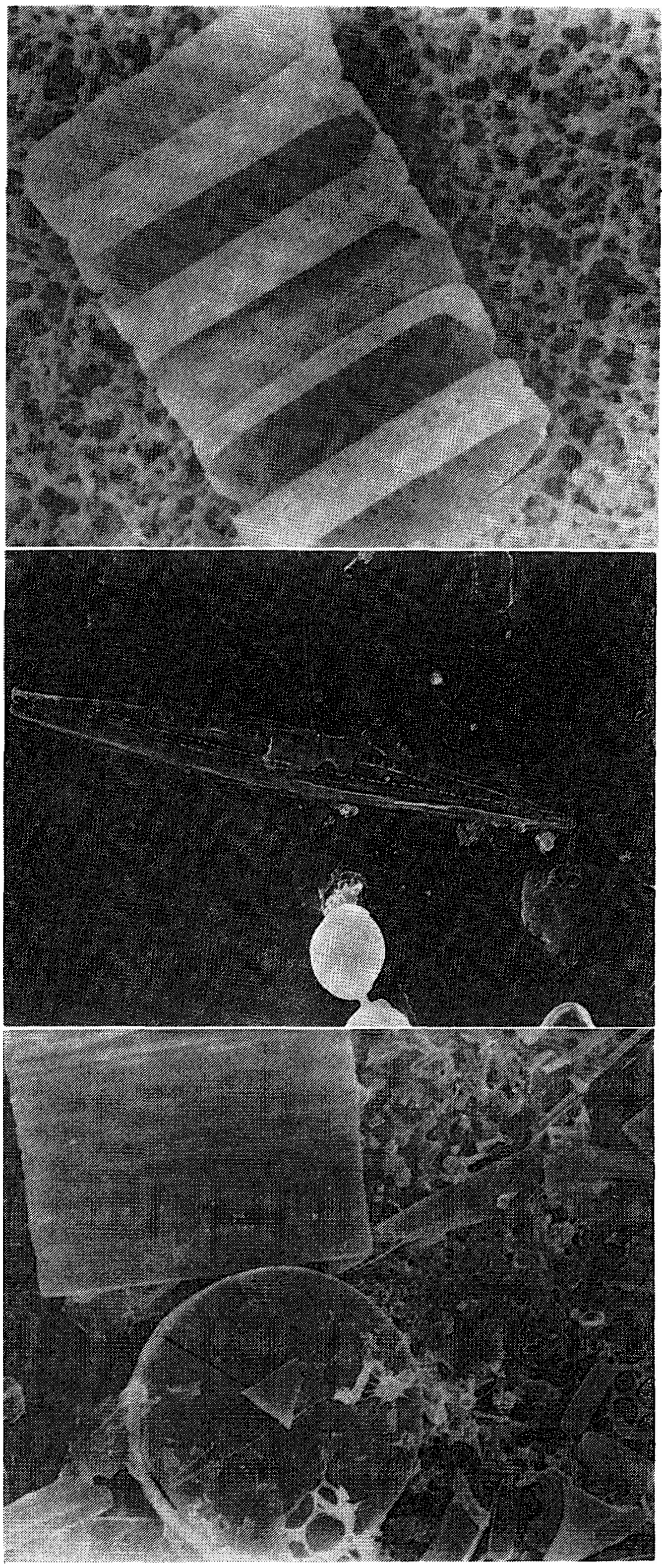


Fig. 9. Scanning electron microphotographs of algae found in bottom section of the sea ice (a), in water just beneath the ice (b) and in fecal materials collected by a sediment trap at 100 m (c).

a. *Fragiraliopsis* sp.

b. *Nitzschia* sp.

c. *Coscinodiscus* sp., *Fragiraliopsis* sp. and a silicoflagellate.

Table 8. Concentration of particulate organic carbon (POC) at 50, 100 and 150 m depths and the vertical flux of POC at each depth under the ice-covered Lützow-Holm Bay, Antarctica, 1979 (JARE-20).

Depth (m)	Concentration of POC ($mg\ C/m^3$)	Vertical flux of POC ($mg\ C/m^2/day$)
50	56	21
100	24	103
150	30	27

et al., 1977). Apart from non-living particles, Foraminifera, *Globigerina pachiderma*, was trapped as the only living particle. The rest included fragments of phytoplankton and zooplankton and unclassified detrital particles.

The numbers of particles longer than 100 μm were counted and were expressed as a density per 10 square centimeters of the Millipore filter mounted at the bottom of the traps (Table 6). The density itself can be the vertical flux in number through 10 cm^2 for 16 hours. The flux was larger at 100 m (208.6/10 cm^2) than at 50 m (145.0/10 cm^2) and 150 m (117.9/10 cm^2). Relative contribution to the flux of fecal material (sum to fecal pellets and fecal matter) decreased in deeper layers, while the contributions of detrital particles and fragments increased with depth, especially at 150 m. Number of Foraminifera was larger in shallower traps.

Dominant micro-algae in the bottom section of the ice and in the water just beneath the ice as well as in the fecal materials were identified under the scanning electron microscope (Table 7). In the ice, epontic diatoms such as *Nitzschia* spp. and *Chuniella* sp. (referred to HOSHIAI and KATO, 1961) and non-epontic diatoms, *Fragiraliopsis* spp. and unidentified flagellates were dominant. Although precise quantitative treatment could not be done, the above-mentioned *Nitzschia* spp. and *Fragiraliopsis* spp. were also found commonly in the water and the fecal material (Fig. 9).

The POC concentrations in the surrounding water and the vertical flux of the POC observed by the traps at 50, 100 and 150 m are listed in Table 8. The POC concentrations were highest at 50 m, as large as 56 mg C/m^3, and lowest at 100 m with only 24 mg C/m^3. On the other hand, the flux was largest at 100 m (103 mg C/m^2/day) and the value at 50 and 150 m depths was 21 and 27 mg C/m^2/day, respectively. The latter two figures were comparable to values of the concentrations of POC at corresponding depths.

4. Discussion

4.1. Environmental conditions

Environmental conditions other than light were uniform throughout the whole water column beneath the fast ice down to 150 m depth and no stratification could be detected (see Fig. 5). Level of nutrient concentrations is comparable to that in open water off Lützow-Holm Bay; ODA and IMANISHI (1979) reported that nutrient concentrations in the upper 150 m at 64°50′S, 39°59′E ranged 1.72–2.25 μg at-PO_4-P/*l*, 58–104 μg at-SiO_4-Si/*l*, 27.6–34.0 μg at-NO_3-N/*l*, 0.04–0.54 μg at-NO_2-N/*l* and 0.6–1.0 μg at-NH_3-N/*l*. Transparency increased from 9.5 m on 1 February to 19.5 m on 16 February. SENO (1958) reported transparency of 20 m on an average (range; 7–30 m) over 40 stations in open water east and west of the Cook Peninsula (named Riiser-Larsen Peninsula thereafter) near Lützow-Holm Bay. Although our data were lower than his mean value, to confirm those two values evaluation of the Secchi disk readings in the ice-covered sea must be checked.

4.2. Chlorophyll a stocks

HOSHIAI (1969a, 1977a, b) investigated seasonal changes of chlorophyll *a* concentrations in sea ice near Syowa Station. He reported high concentrations at the bottom section of the ice in April (829 mg/m^3) and in December (more than 1000 mg/m^3). He also reported that standing stock of chlorophyll *a* in the ice under one square meter attained to two peaks in April and December (*ca.* 30 mg Chl *a*/m^2) and less than 10 mg Chl *a*/m^2 in the rest of the year. While the stocks in January and February were not estimated in his works, it seems to be most likely that the stocks in the ice in the present area were much lower than those near Syowa Station.

Seasonal variation of chlorophyll *a* concentration and standing stock in water column beneath the ice at two stations near Syowa Station, depths of which were 9 m in the Kita-no-seto Strait and 92.5 m in the Ongul Strait, were studied by HOSHIAI (1969b). At shallower station the chlorophyll stock in January was *ca.* 60 mg/m^2 in 0–9 m water column and at deeper station that in December was 10.51 mg/m^2 in 0–90 m (the latter figure was recalculated by the present authors from his Table 3). HOLM-HANSEN *et al.* (1977) reported integrated chlorophyll *a* stock through the upper 200 m at three stations in open water in the Indian sector of the Antarctic Ocean in austral summer as 10.6–30.8 mg Chl *a*/m^2. The chlorophyll *a* stock obtained at Stn. 1 in the present work (3.06 mg Chl *a*/m^2, 0–150 m) seems to be comparable to that at deeper station near Syowa Station, but much lower than that from shallower station near Syowa Station.

4.3. Zooplankton abundance

The previously reported data on zooplankton abundance and composition from open water and ice-covered areas in the Antarctic Ocean are summarized with the present data in Table 9. According to HOPKINS (1971) and VORONINA and NAUMOV (1968), Copepoda, Chaetognatha and Euphausiacea constitute major components of zooplankton community in open water. In the ice-covered area Copepoda is again the most abundant taxon, but Chaetognatha and Euphausiacea are relatively few (referred to the present work). FUKUCHI and TANIMURA (1981) reported that the latter taxa could not be caught under the sea ice; since these animals are agile, their absence in the samples from the fast ice region might be due to the net avoidance.

Table 9. Individual numbers of zooplankton and contribution of each group to total zooplankton number reported from the open water as well as obtained in the fast ice region in the Antarctic Ocean.

Region*	Indiv. No. of total zoopl. (No./m³)	Contribution of each group to total zooplankton number (%)						Net used		Sampling depth (m)	Author
		Copepoda	Chaeto-gnatha	Euphau-siacea	Appen-dicularia	Echinoder-mata, pe-lagic larvae	Foramini-fera	Type	Mesh size (μm)		
Open water:											
Pacific-											
AC zone	906	—	—	—	—	—	—	Bé net, ø50cm	76	0-1000	HOPKINS (1971)**
〃	216	—	—	—	—	—	—	〃, 50×50cm	202	〃	〃
〃	86	—	—	—	—	—	—	〃, ø100cm	303	〃	〃
SA zone	—	68.8	12.3	8.2	—	—	—	〃, 70×70cm	202	0-1000	〃
AC zone	—	70.1	14.4	11.0	—	—	—	〃	〃	〃	〃
An zone	—	67.3	10.0	7.5	—	—	—	〃	〃	〃	〃
Atlantic	—	74.5	21.9	0.6	—	—	—	Discovery net, ø70cm	180	—	VORONINA and NAUMOV (1968)
Pacific & Indian	—	95.5	0.6	0.4	—	—	—	Juday net, ø38×130cm	180	0-500	〃
Indian-An zone	1-356	62.0-99.2	0.0-30.3	0.1-16.0	0.1-6.8	—	—	MTD net, ø58×200cm	350	30-150	FUKUCHI (1978)***
Fast ice:											
Syowa Stn.	8-6183	25.6-91.1	—	—	0.0-7.7	—	—	a conical net, ø30×120cm	110	0-15	FUKUCHI and TANIMURA (1981)
Lützow-Holm Bay	—	100.0	—	—	—	—	—	NIPR-I	110	0-10	FUKUCHI *et al.* (1979)
〃	9-22	8.6-82.0	0.0-1.1	—	0.0-68.6	2.9-21.4	—	a double net ø35×95cm	330	0-50	Present work
〃	4-1132	99.2-100.0	—	0.0-0.8	—	—	—	pumping coll.	110	0-8.15	〃
〃	12-60	54.9-99.0	0.0-5.8	0.0-1.1	0.0-12.7	—	0.0-30.3	Norpac net, ø45×180cm	330	0-150	〃

* SA: Subantarctic; AC: Antarctic Convergence; An: Antarctic (south of AC).
** Contribution figures were based on dry weight basis.
*** FUKUCHI, M. (1978): Preliminary report on zooplankton community off Enderby Land, Antarctica. Paper presented at the Annual Meeting of Oceanogr. Soc. Jap., Tokyo.

On the other hand, sluggish Appendicularia, Echinodermata, pelagic larvae, and Foraminifera were caught to some extent from the fast ice region. These might reflect on apparent differences in the composition of zooplankton taxa between open area and ice-covered area in the Antarctic Ocean.

High density of zooplankton exceeding 1000 indiv/m^3 are recorded from the ice-covered area near Syowa Station by FUKUCHI and TANIMURA (1981) and by the present pumping collection as tabulated in Table 9. These are thought to be a result of fine mesh net (0.11 mm) employed by them. Density of macro-zooplankton observed with 0.33 mm netting in the present work (12–60 indiv/m^3) seems to be comparable to that estimated in the open water (86 indiv/m^3) by HOPKINS (1971), who employed 0.303 mm mesh size. However, the zooplankton density off Enderby Land estimated with the MTD horizontal nets (*cf.* MOTODA, 1971), though the same 0.35 mm netting was used, reached 356 indiv/m^3 being one order of magnitude larger than HOPKIN's and the present values. Although the zooplankton stocks on a numerical basis obtained in the present work seem to be slightly lower than those in open water, measurements of size and weight of zooplankters are necessary to estimate the zooplankton biomass more quantitatively.

According to FUKUCHI and TANIMURA (1981) and ZVEREVA (1972), composition of the Antarctic zooplankton community under the ice would change markedly with seasons. The present work reveals that a sharp change of the composition in the upper 50 m can occur within a short period in midsummer. However, the difference in vertical changes of abundance and composition of zooplankton observed between the two successive days (Fig. 7) was too large, perhaps partially due to some errors in

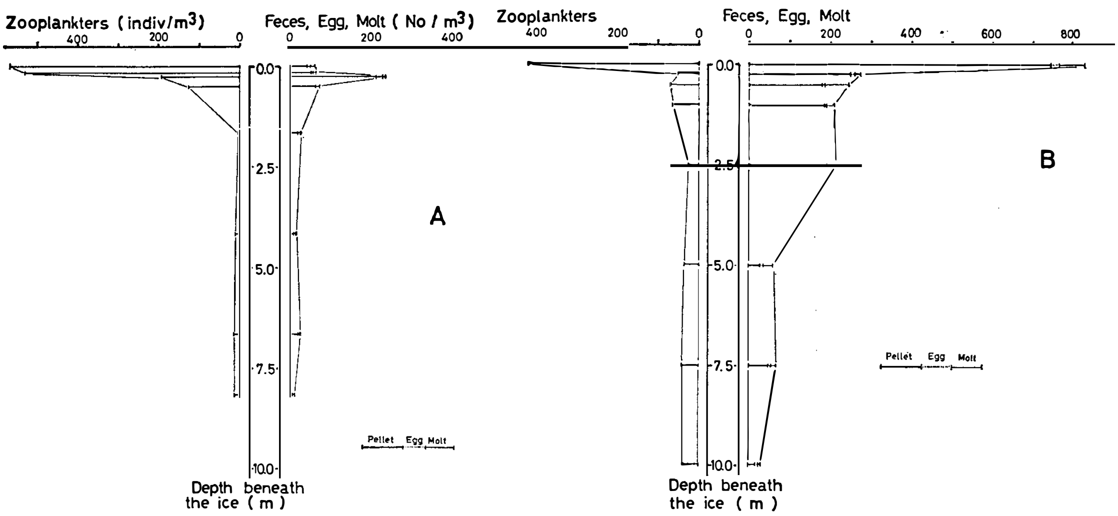


Fig. 10. Microdistribution of zooplankton and others under the fast ice observed with pumping collections (A) and "NIPR-I" samplings (B). The latter is cited from FUKUCHI et al. (1979).

sampling. One of the possible reasons is as follows; there was a dense community composed of Appendicularia, Chaetognatha and Foraminifera as well as Copepoda around the 100 m depth. The vertical haul from 100 m did not fish these dense populations on 4 February but did on the next day. Further investigations are necessary to ascertain this.

The present data on the microdistribution of zooplankton and their related materials under the fast ice obtained by the pumping collections are shown in Fig. 10A with those obtained by the "NIPR-I" sampler (Fig. 10B), which was concurrently performed (cited from FUKUCHI *et al.*, 1979). Despite the difference of sampling methods, the similar trend is seen in Fig. 10A and Fig. 10B; zooplankton are likely to form dense populations just beneath the fast ice.

4.4. *Vertical flux of POC*

This may be the first attempt to measure directly the vertical flux of particulate matter in the ice-covered area in the Antarctic Ocean. The depth of the maximum vertical flux occurred in the present sea (100 m depth) is comparable to those reported in the other seas, *e.g.*, 100–150 m in the cold Oyashio current region off Sanriku and 150 m in the tropical Philippine Sea (Table 10). These are reported to roughly coincide with the maximum layer of zooplankton biomass. Therefore, it has been emphasized that the large flux is attributable to fecal materials produced there (SASAKI, 1979). If the dense populations of zooplankters exist around 100 m as mentioned above the maximum flux observed at 100 m in the present work can be explained.

Table 10. Concentration of POC, vertical flux of POC and depth of maximum flux reported from open water according to the same trap operations as well as obtained in the present work.

Area	Date	Range of depth (m)	Range of vertical flux of POC (mg C/m^2/day)	Range of POC (mg C/m^3)	Author
Cold Oyashio current off Sanriku, Japan	June 1977	50-150	45-204(150)*	48-87	SASAKI (1979)
	May 1978	50-500	28-418(100)	9-73	SASAKI (1979)
Warm water mass off Sanriku, Japan	June 1977	50-150	73-311(50)	63-79	SASAKI (1979)
Philippine Sea	Feb. 1979	50-1450	6-43(150)	—	FUJITA *et al.* (1981)
Ice-covered sea in Lützow-Holm Bay, Antarctica	Feb. 1979	50-150	21-103(100)	24-56	Present work

* Depths in parenthesis indicate the depths of maximum vertical flux.

The maximum carbon flux in the present area is smaller than those in the Oyashio water during northern spring to summer, but larger than that in the Philippine Sea. This fact suggests that the primary and secondary productivities in the ice-covered sea in summer would not be so low.

The preponderance of the fecal materials among the trapped particles implies that significant fraction of vertical mass flux in the ice-covered sea might depend on the fecal materials as in the open water. A coincidence in the dominant species of phytoplankton in the fecal materials and in both the ice and the water just beneath the ice (see Table 7 and Fig. 9) indicates that a large part of zooplankton metabolic need could be met just below the undersurface of the ice. If so, it is again suggested that a significant amount of energy fixed in the surface could be transported downward by sinking fecal materials egested in the surface as well as by downward migrating zooplankton. Final conclusion must be deferred until the vertical distribution and migration of zooplankton are comprehended in detail.

In the present work only a fragmental knowledge about structure and function of pelagic ecosystem in the ice-covered sea can be acquired. Further investigations must be carried out in time and space expansion to elucidate such a characteristic marine ecosystem of the Antarctic Ocean.

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