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# SEASONAL VARIATION OF DOWNWARD FLUX OF PARTICULATE ORGANIC MATTER UNDER THE ANTARCTIC FAST ICE*

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***Abstract:*** During the BIOMASS study of the SIBEX (1984/85), seasonal variation of downward flux of particulate organic matter under the Antarctic fast ice was studied throughout the year in the Kita-no-ura Cove (69°00′S, 39°35′E) off East Ongul Island in Lützow-Holm Bay. Marked seasonal variation of particulate organic carbon (POC) flux was observed; larger fluxes in summer (max: 136 mgC/$m^2$ day) but smaller fluxes in winter (min: 1.5 mgC/$m^2$ day). Although both particulate organic nitrogen (PON) and particulate phosphorus (PP) flux showed similar trends to POC variation, C: N: P ratio also varied seasonally. Chlorophyll *a* flux varied more drastically than POC did (max: 4500 in summer, min: 3 $\mu$g/$m^2$ day in winter), suggesting the direct input of ice algae and/or phytoplankton to the benthic community in summer. Judging from the variation of POC/chl. *a* ratio, fresh algae dominated from November through February among trapped sediments. While, a small amount of sinking particles mainly composed of deteriorated material was observed in winter. Relative abundance of chl. *a* and pheopigments differed between sampling depths, which indicated the decomposition of particles during sinking. The seasonal variation of total mass flux generally well reflected those of chlorophyll and POC concentration, hence the seasonal variation of primary production under the fast ice.

## 1. Introduction

Under the fast ice in the Antarctic region primary production is brought mainly by phytoplankton and ice algae only in a relatively short period of summertime in a year (*e.g.* BUNT and LEE, 1970; HOSHIAI, 1977; FUKUCHI *et al.*, 1984), since underwater irradiance is insufficient in other seasons (SULLIVAN *et al.*, 1985). Therefore, the issue that how animals survive under the long and dark winter condition without any actual primary production is one of the important foci in the Antarctic marine ecosystem. While, as benthic biomass in the allied region proved to be pretty high (HAMADA *et al.*, 1986), the transportation of the organic matter produced in the upper part of the water column to the benthic community is another unknown process. From these points of view, seasonal variation of downward flux of particulate organic

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matter and also the quality of sinking particles should be estimated as important factors in the organic food cycles under ice.

The sediment trap experiment to evaluate the downward flux of materials has been actively performed in both the ice-free and coastal fast ice regions of the Antarctic sea (FUKUCHI and SASAKI, 1981; SASAKI and HOSHIAI, 1986), but only during the austral summer. The downward flux measurement throughout the year including winter has rarely been made under the fast ice. Hence we tried to determine continuously the vertical flux of particulate organic matter and also the chemical characteristics of sinking particles all year round by the use of sediment traps during the 25th Japanese Antarctic Research Expedition (JARE-25).

In the present study, we investigated not only the seasonal variation of downward flux as expressed by carbon, nitrogen, phosphorus and chlorophylls but also the seasonal variation of the characteristics of sinking particles, with special reference to the fate of algal products in the organic food cycles under the Antarctic fast ice. These experiments were conducted as part of the JARE-BIOMASS project operated from 1981 through 1985.

## 2. Method

Sediment trap experiments were conducted during almost one year from January 1984 through January 1985 in the Kita-no-ura Cove off East Ongul Island in Lützow-Holm Bay (Fig. 1) during the wintering of JARE-25 at Syowa Station. Twelve sets of field observation were made in total, among which eleven were done at Stn. 3.

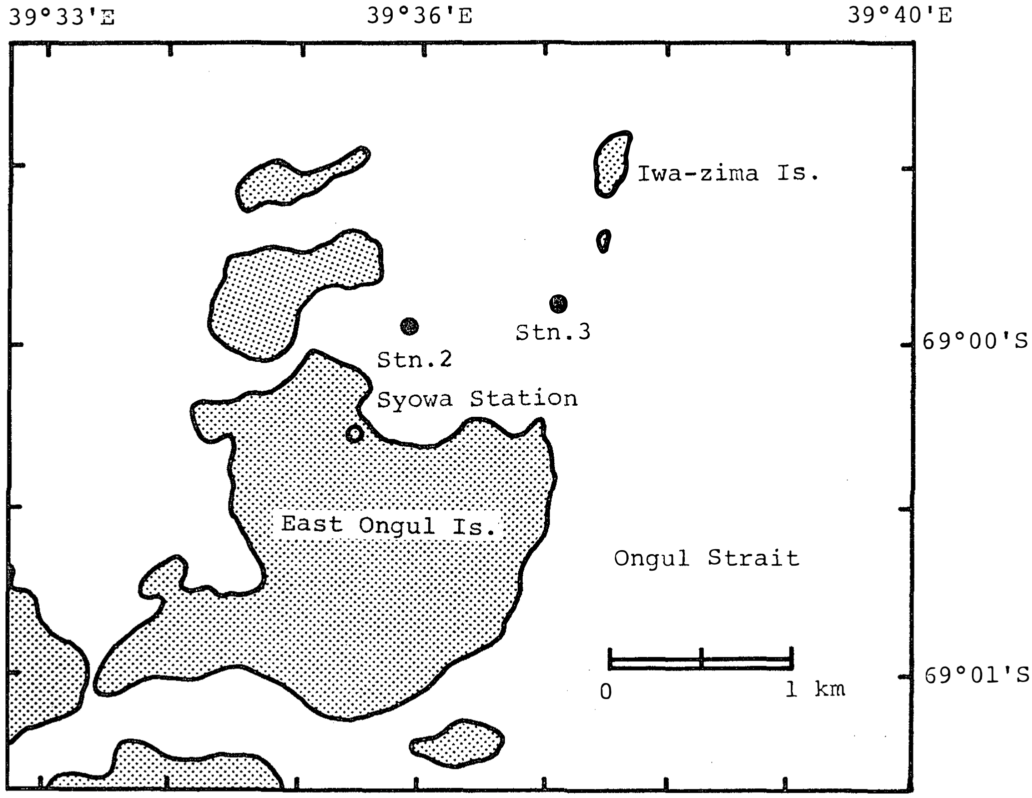


*Fig. 1. Location of sampling stations.*

Only one exception was carried out at Stn. 2 instead of Stn. 3 from April 30 through May 16 because of the breakdown of the fast ice around Stn. 3. All the data obtained at two stations were presented and discussed together as a same series of data in the present study primarily because stations were in the close vicinity and were similar in environmental conditions (MATSUDA *et al.*, 1987).

Sediment traps employed were of a cylindrical type with 150 mm opening and 500 mm height made of polyvinylchloride (MATSUDA *et al.*, 1986). Two sets of the trap were suspended at 5 and 25 m depths beneath the ice, respectively. The period of the collection of sinking particles ranged from two weeks to thirty days (Table 1). Some irregularity of the period was primarily due to climatic conditions, especially to blizzards.

Each trap cylinder was provided with six subsampling chambers at the bottom. Consequently, twelve subsamples in total were obtained at a time at the same depth of the station. Every subsample was treated as the same aliquot.

*Table 1. Data on sampling of sinking particles by sediment traps.*

| Sampling No. | Station | Date of trap development | Time for collection (days) |
|---|---|---|---|
| 1 | 3 | Jan. 27–Feb. 17, 1984 | 21 |
| 2 | 3 | Feb. 17–Mar. 6 | 18 |
| 3 | 2 | Apr. 30–May 16 | 16 |
| 4 | 3 | May 18–June 12 | 25 |
| 5 | 3 | June 14–July 16 | 32 |
| 6 | 3 | Aug. 6–Sep. 1 | 26 |
| 7 | 3 | Sep. 6–Sep. 27 | 21 |
| 8 | 3 | Oct. 12–Oct. 26 | 14 |
| 9 | 3 | Oct. 31–Nov. 15 | 15 |
| 10 | 3 | Nov. 19–Dec. 4 | 15 |
| 11 | 3 | Dec. 6–Dec. 21 | 15 |
| 12 | 3 | Dec. 21–Jan. 4, 1985 | 14 |

Measurements were made on dry weight, particulate organic carbon (POC), particulate organic nitrogen (PON), particulate phosphorus (PP), chlorophyll *a* and pheopigments of the collected particulate matter after filtration. Dry weight and chlorophyll pigments were determined as indicators of the total mass of particulate material trapped and the algal condition, respectively. Determination of POC, PON and PP was made as representative parameters of particulate organic substances, in which the C: N and C: N: P ratios were calculated to characterize the general feature of the material collected.

Determination of POC and PON collected on precombusted (450°C for 1 h) Whatman GF/C glassfiber filters was made by the CHN analyzer (Yanagimoto MT-3). Chlorophyll and pheopigments were spectrophotometrically analyzed based on the method of LORENZEN (1967) using the same glassfiber filter. Determination of PP was done with a preweighed Millipore filter (HA; pore diameter 0.45 $\mu$m). After dry weight determination the samples were successively used for PP analysis in which particulate material was digested in a Teflon container with perchloric acid and nitric acid at 150°C for 5 h, resulting phosphate being determined by the method of MURPHY and RILEY (1962) as modified by STRICKLAND and PARSONS (1972).

Pigment ratio was defined as the value of chlorophyll *a* divided by the sum of chlorophyll *a* and pheopigments. As pheopigments are intermediary substances produced during the degradation process of chlorophyll, the ratio indicates the relative abundance of fresh and living algae among algal substances.

Downward flux of total particulate matter as expressed by dry weight and of each component of the particulate matter such as POC, PON, etc., were calculated as the value per square meter per day.

## 3. Result and Discussion

### *3.1. Seasonal variation of total mass flux*

Seasonal variation of total mass flux of sedimenting particles expressed by dry weight showed a marked increase from January through March, the flux exceeding 670 mg/m$^2$ day, but it decreased rapidly in May. In consequence, the flux was extremely depleted in winter, and it was November when the flux was restored again (Fig. 2). Seasonal variation of total mass flux well reflected those of chlorophyll (Fig. 3) and POC (Fig. 4), and hence may be strongly due to the seasonal variation of primary production under fast ice.

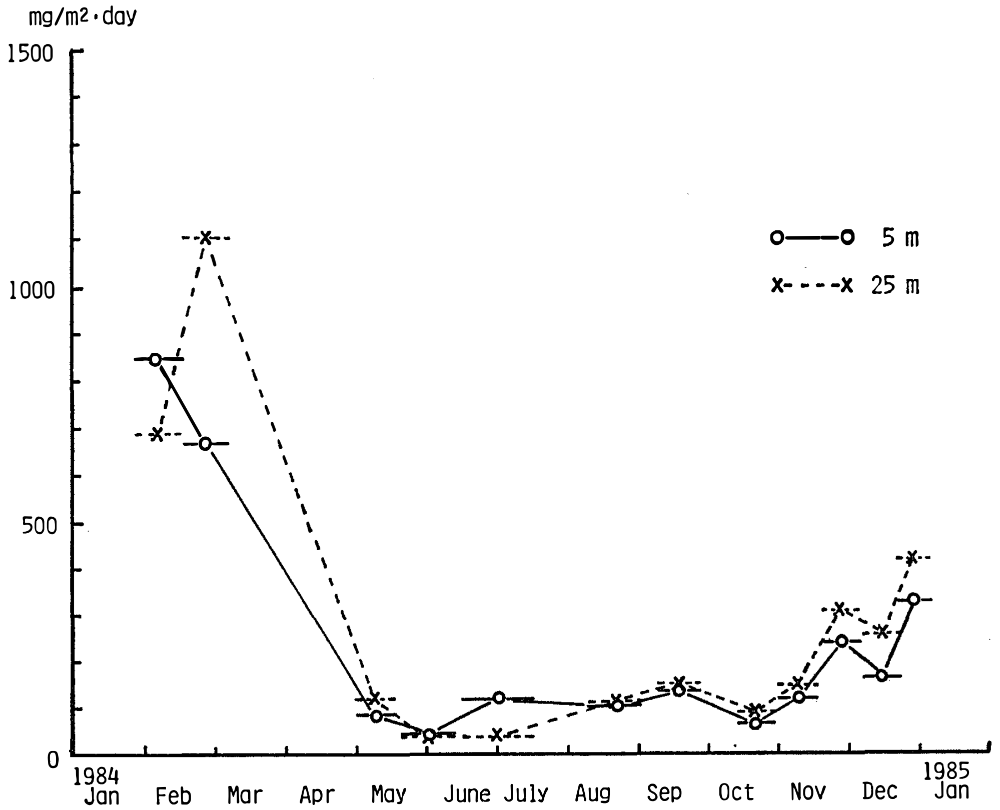


*Fig. 2. Seasonal variation of total mass flux (flux expressed by dry weight) observed under the Antarctic fast ice. Horizontal bar indicates the period of individual observation, the center of which is connected as representative.*

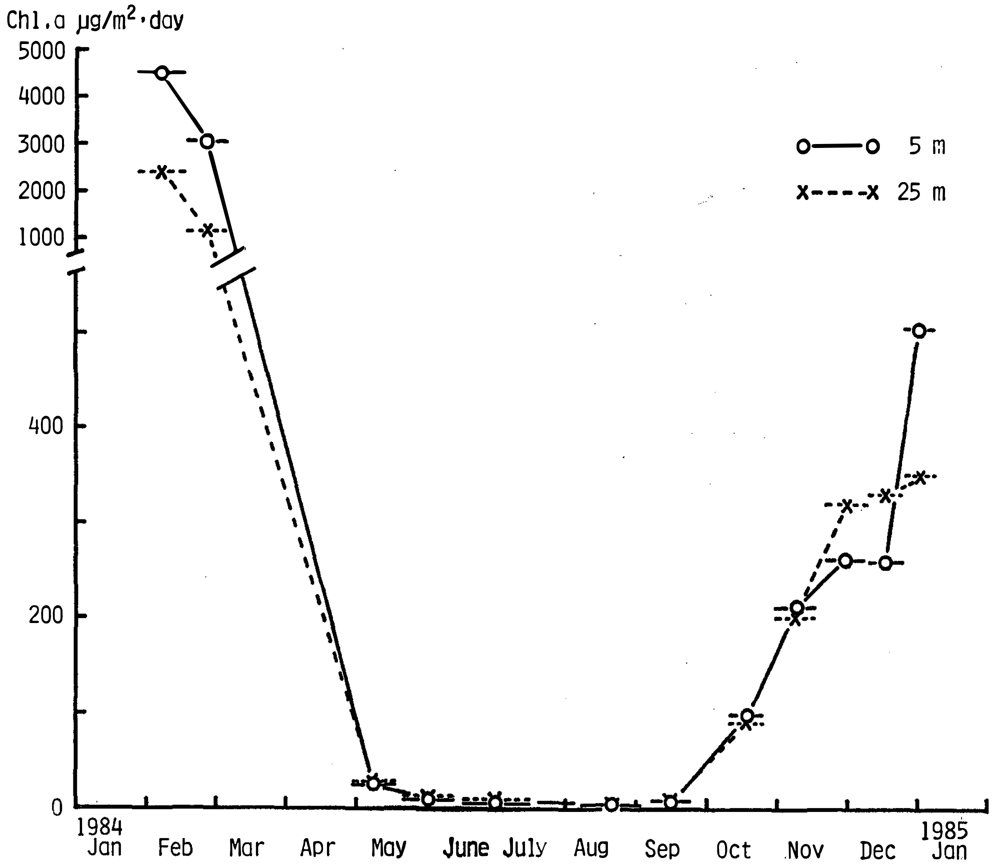


*Fig. 3. Seasonal variation of chlorophyll a flux observed under the Antarctic fast ice.*

The POC/dry weight ratio also presented a characteristic seasonal variation, namely the ratio increased in summer when the organic flux was intensified, but decreased in winter. These results indicate that relative contribution of organic material to total mass flux was very small in winter (Fig. 5). Assuming that twice of POC is equivalent to an approximate weight of organic matter, the contribution of organic matter to total mass flux ranged from about 2 to 36%.

### *3.2. Seasonal variation of C, N, P flux*

Seasonal variation of POC flux showed a marked increase (max: 136 mgC/m$^2$ day) from January through March 1984. While, an amazing flux depletion occurred from June through September (min: 1.5 mgC/m$^2$ day), then the flux began to increase gradually in October and reached the maxima again in midsummer (Fig. 4). As POC is one of the most appropriate indicators of total particulate organic matter, the result indicates the definite seasonal variation of downward flux of organic particles under the Antarctic fast ice. The differences of POC fluxes between 5 and 25 m depths was not so obvious but generally the flux was a little larger at the upper layer.

PON flux showed an almost identical seasonal variation with that of POC. Seasonal variation of PP flux generally presented the similar trend to that of POC or PON flux, indicating a maximum flux of 2.2 mgP/m$^2$ day in February and a minimum flux of 0.06 mgP/m$^2$ day in June (Fig. 6).

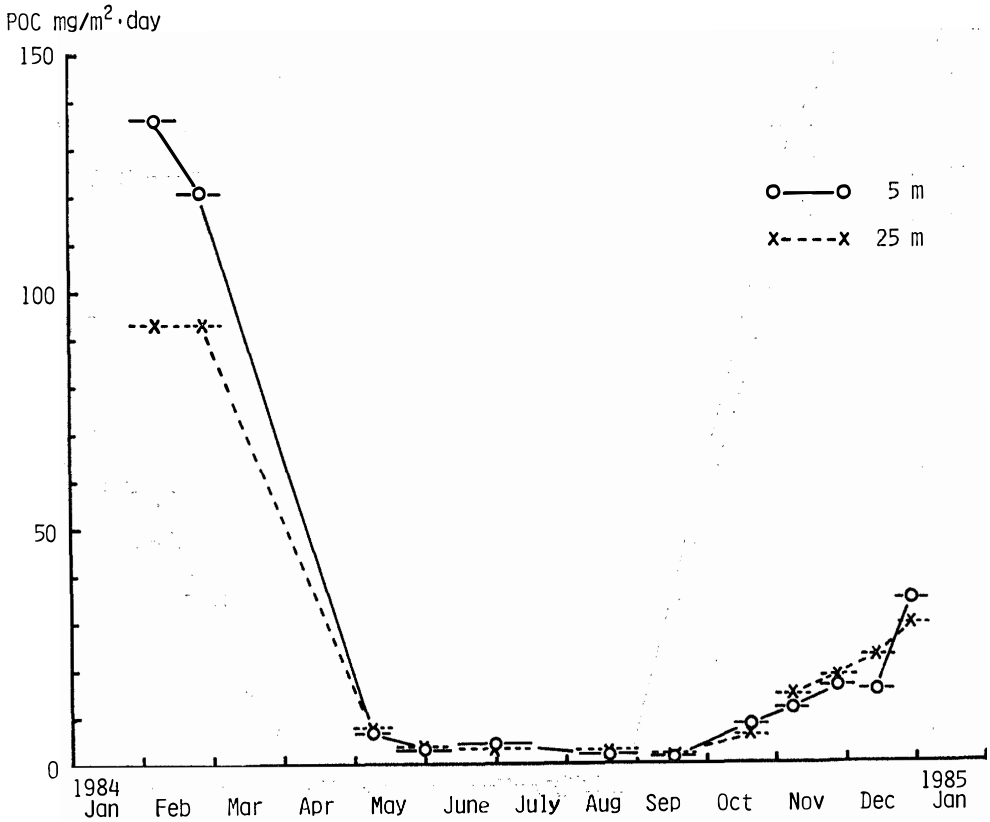


*Fig. 4. Seasonal variation of POC (particulate organic carbon) flux observed under the Antarctic fast ice.*

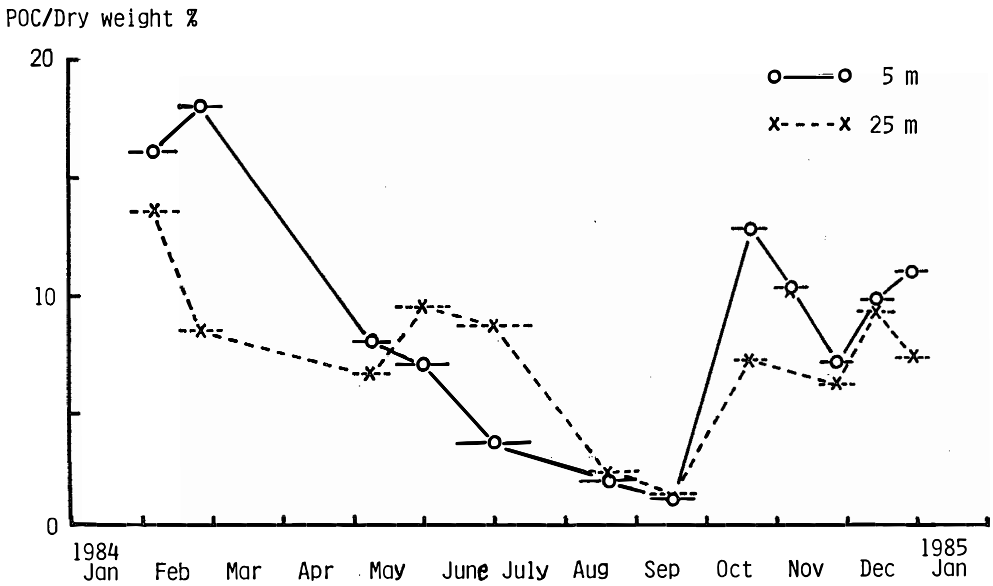


*Fig. 5. Seasonal variation of POC/dry weight ratio observed in the trapped sediment.*

### 3.3. *Seasonal variation of C: N: P ratio of collected particles*

As was already described, PON flux showed an almost identical seasonal variation with that of POC. However, detailed analysis made it clear that the POC/PON

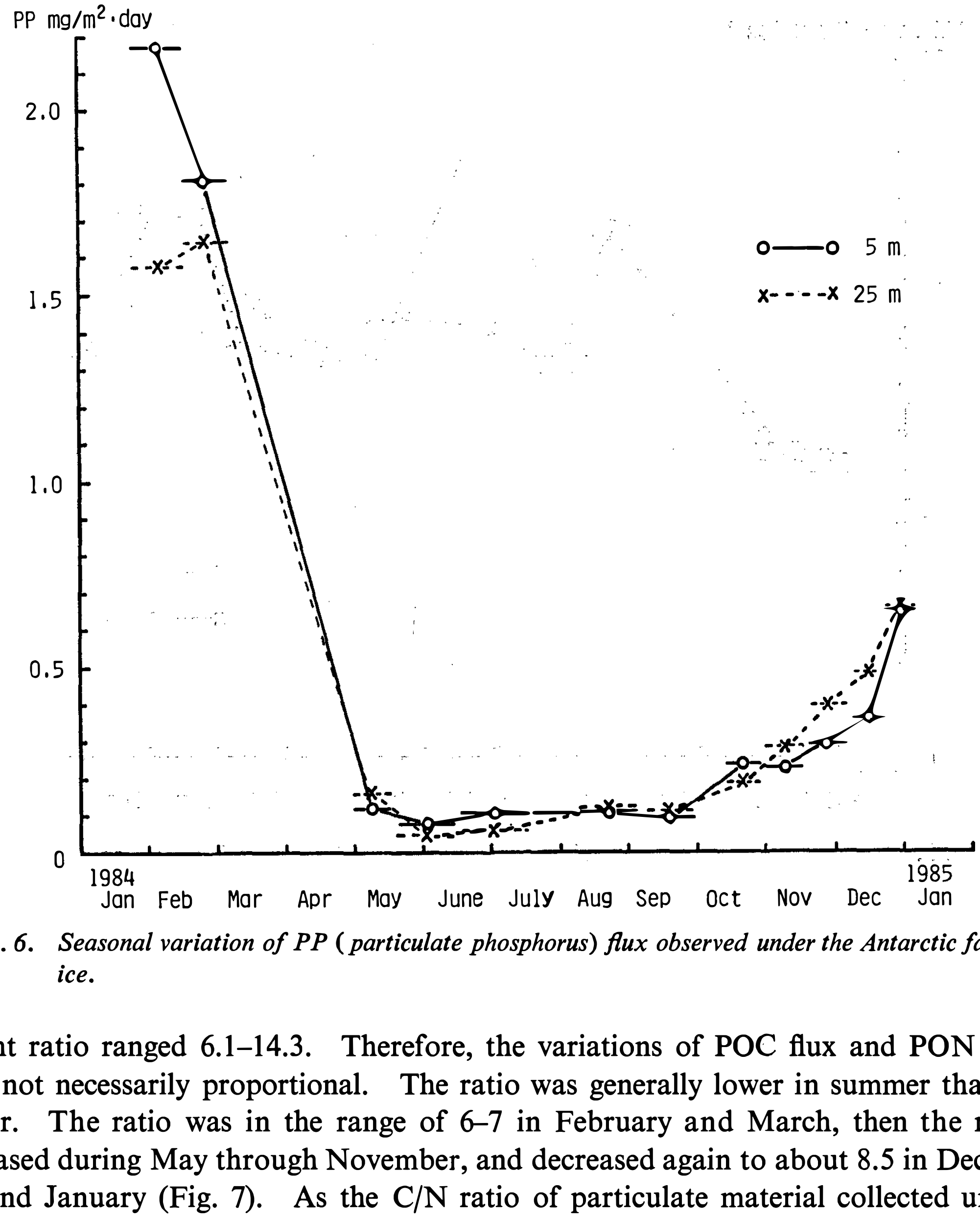


*Fig. 6. Seasonal variation of PP (particulate phosphorus) flux observed under the Antarctic fast ice.*

weight ratio ranged 6.1–14.3. Therefore, the variations of POC flux and PON flux were not necessarily proportional. The ratio was generally lower in summer than in winter. The ratio was in the range of 6–7 in February and March, then the ratio increased during May through November, and decreased again to about 8.5 in December and January (Fig. 7). As the C/N ratio of particulate material collected under ice generally increases with progressing decomposition (MATSUDA *et al.*, 1986), the organic particles with low C/N ratios in summer (December–March) should be relatively fresh, while those with high C/N ratios in winter should be affected by the long exposure to decomposition processes and/or transformation.

Compared with the range of the C/N ratio, the POC/PP ratio by weight widely varied from 17.4 to 66.5. This result indicates the wider variation of the phosphorus content in the sinking particles.

To estimate the material balance of particles, the C: N: P atomic ratio of the trapped sediment was then examined. The results were separately expressed as the variation of C/P and N/P atomic ratios (Fig. 8), in which C and N were relatively abundant compared with P in February through March but decreased rapidly and reached to the winter minima in September and then recovered again in November.

The proportion of C and N became smaller than the value of the Redfield ratio

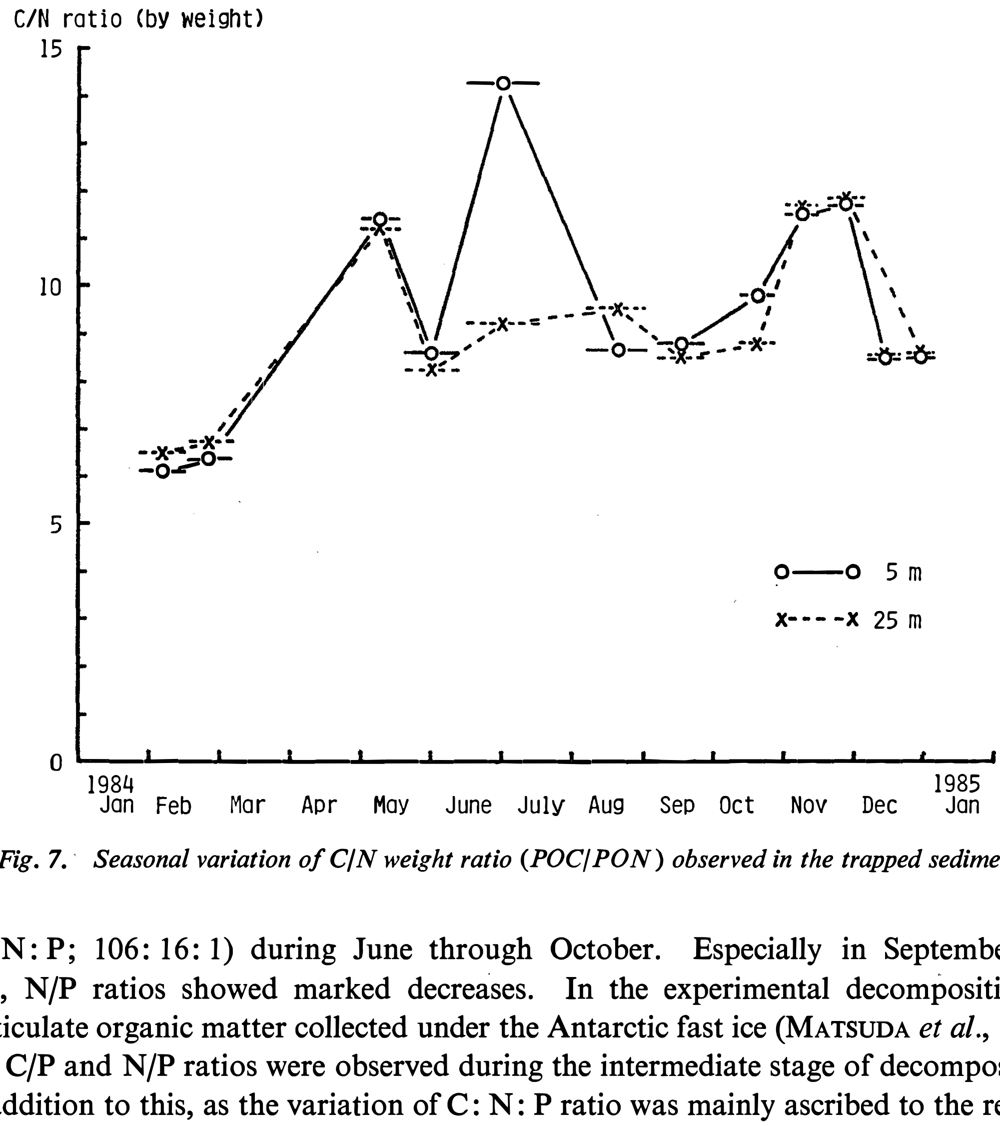


*Fig. 7. Seasonal variation of C/N weight ratio (POC/PON) observed in the trapped sediment.*

(C: N: P; 106: 16: 1) during June through October. Especially in September the C/P, N/P ratios showed marked decreases. In the experimental decomposition of particulate organic matter collected under the Antarctic fast ice (MATSUDA *et al.*, 1986), low C/P and N/P ratios were observed during the intermediate stage of decomposition. In addition to this, as the variation of C: N: P ratio was mainly ascribed to the relative contribution of the uptake rate of individual nutrient by algae and its decomposition, these seasonal variations of the ratio not only account for the relative domination of organic production in summer but also suggested the prevalence of the deteriorated material in winter.

### *3.4. Seasonal variation of chlorophyll flux*

The chlorophyll flux showed a very drastic variation (Fig. 3) compared with those of POC, PON and PP shown before. The flux amounted to more than 1000 $\mu$g/m$^2$ day from January through March showing the maximum value of 4500 $\mu$g/m$^2$ day. The flux extremely decreased toward winter (minimum; 3 $\mu$g/m$^2$ day) but recovered again since October. This variation of chlorophyll *a* flux was far more drastic than that of chlorophyll *a* standing stock (KAWAGUCHI *et al.*, 1986) in the water column. For example, the marked flux increase at both depths and the concomitant relatively low chlorophyll *a* concentrations in the water column were observed in February, strongly suggesting that numerous flocs of ice algae were detached from the under-surface of fast ice and probably sank down directly to the sea floor.

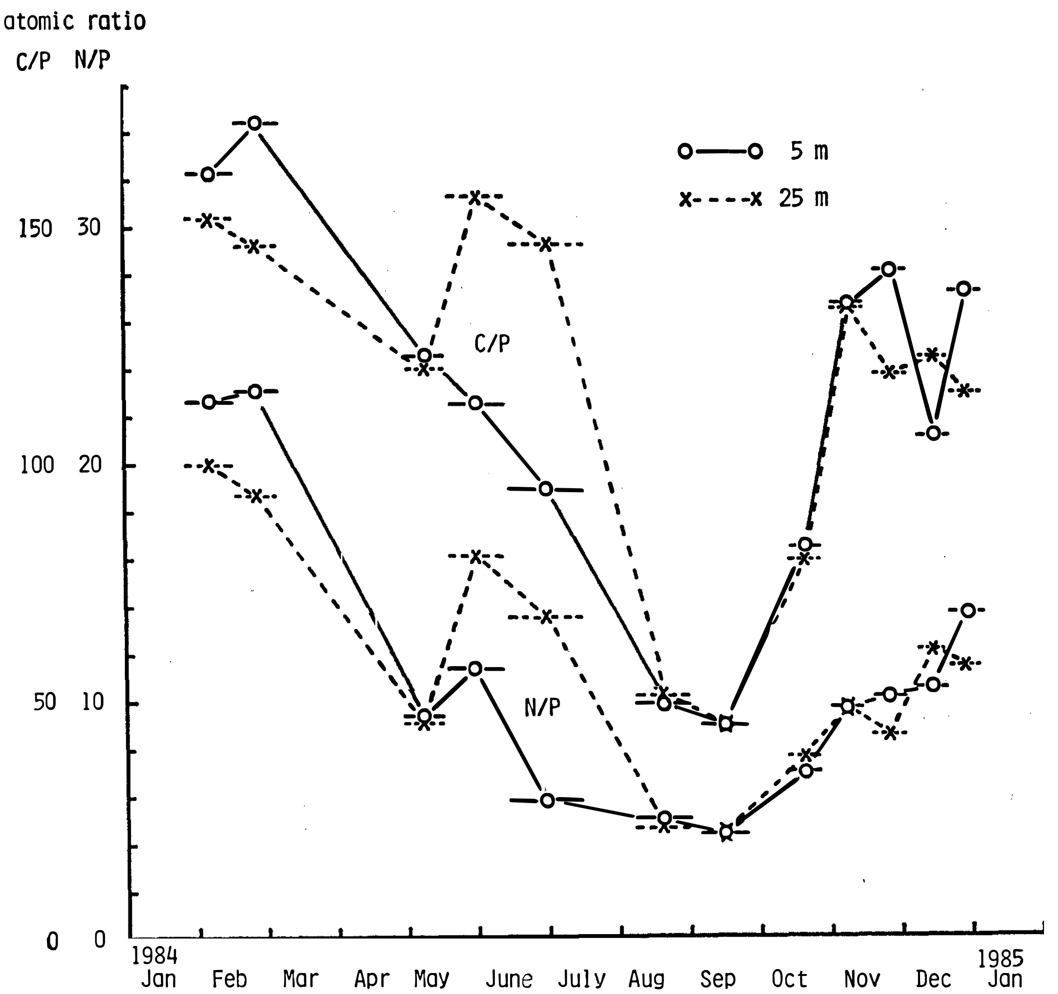


*Fig. 8.* *Seasonal variation of C/P and N/P atomic ratios (POC/PP, PON/PP) observed in the trapped sediment.*

The POC/chl. *a* ratio of sinking particles indicated a marked seasonal variation (Fig. 9), in which the ratio ranged from 30 to 790. Generally detrital material has a higher POC/chl. *a* ratio than fresh algae. Therefore, the seasonal change of the POC/chl. *a* ratio suggested that pretty fresh algae dominated any trapped particulate materials from November through February but chlorophyll-less organic matter prevailed in winter.

Pigment ratio (chl. *a*/total pigments) stands for relative freshness of algal component itself. Seasonal variation of this ratio showed that the ratio of the trapped sample at 5 m depth was pretty high even in winter, while at 25 m depth the ratio was generally low especially in winter (Fig. 10). It is noticeable that fluxes were not much different between two depths but pigment ratio was quite different. This suggests some processes of chemical or biological transformations and decomposition of particles occurring in this depth range.

As fecal pellets of zooplankton dominated among trapped particles, especially at the deeper layer in winter, low pigment ratios of particles might explain that chlorophyll *a*-containing particles were substantially digested in the present case. Whereas,

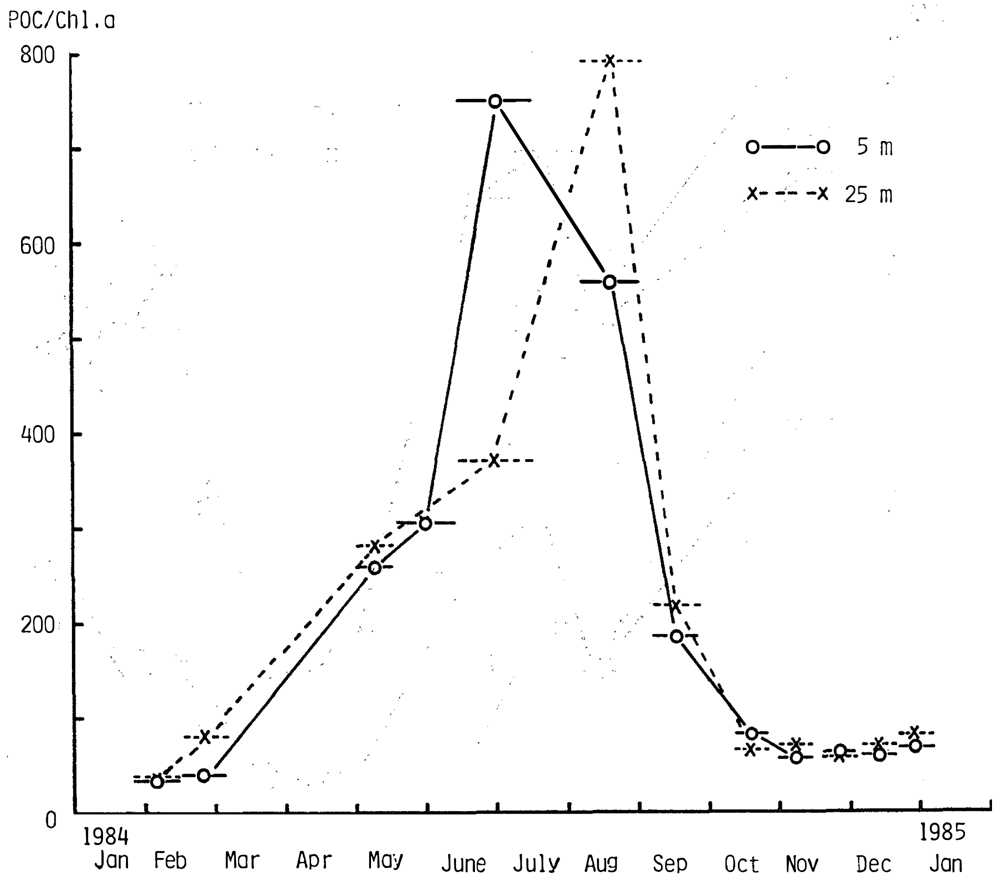


*Fig. 9. Seasonal variation of POC/chl. a ratio observed in the trapped sediment.*

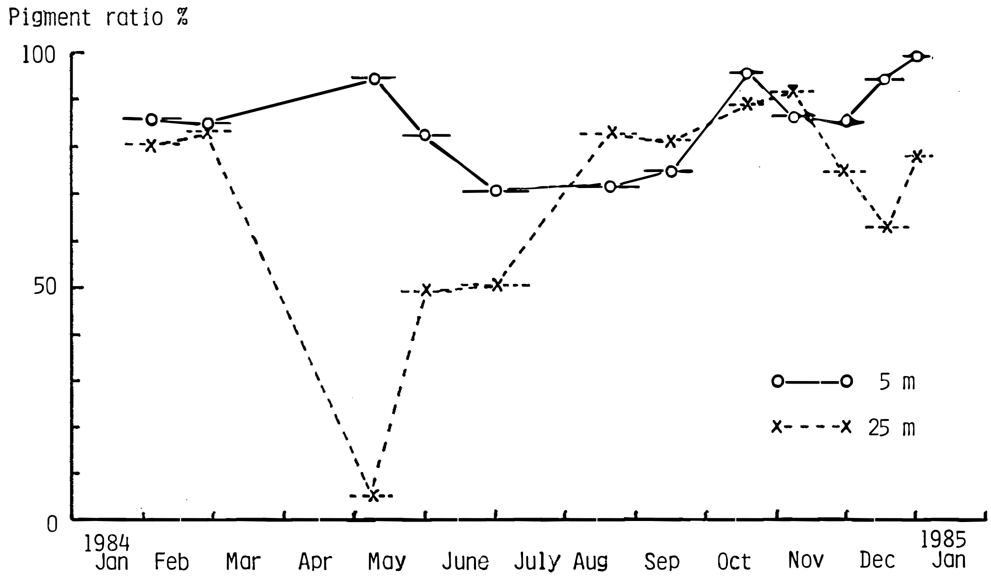


*Fig. 10. Seasonal variation of pigment ratio (chl. a/total pigments) observed in the trapped sediment.*

relatively high pigment ratios at the upper layer suggest the existence of active algal cells free from strong grazing pressure of animals. Judging from both pretty high POC/chl. *a* and pigment ratios observed at 5 m in winter, almost all trapped organic particles were generally supposed to be deteriorated but a very small amount of algal cells should certainly be still active, even in the midst of winter.

In the present work, we described the seasonality of vertical fluxes and the characteristics of sinking particles. In order to understand the material budgets for under-ice ecosystem, it is very important to evaluate the standing stock and features of suspended particles. However, further study of the vertical fluxes with special reference to the contribution of suspended particles is to be published in the separate paper.

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