SEASONAL CHANGE OF CHLOROPHYLL *a* UNDER FAST ICE IN LÜTZOW-HOLM BAY, ANTARCTICA

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Abstract: Chlorophyll *a* concentration in water column under the Antarctic fast ice was measured at five stations (10–675 m depths) near Syowa Station (69°00′S, 39°35′E) for the period of 13 months from January 1982 to January 1983. High chlorophyll *a* concentrations were seen between December and March, while peaks were observed in late January. Maximum concentration was 11.30 mg chl. *a*/m³. During four months of the austral summer, a rapid increase of chlorophyll *a* was observed in late January. This phenomenon seemed to be caused by a slight increase of temperature (>−1.73°C) and a slight decrease of salinity (<34.15). Average chlorophyll *a* stock in water columns was 1.05–6.72 mg/m³, at least one order of magnitude higher than that reported from the Antarctic open water.

1. Introduction

Many studies on phytoplankton abundance and production in the Antarctic open water have been carried out mainly during the austral summer. These works revealed that the Antarctic Ocean may not be so productive as previously believed (EL-SAYED and TURNER, 1977; HOLM-HANSEN *et al.*, 1977; FUKUCHI, 1980). On the other hand, seasonal studies on phytoplankton under the Antarctic fast ice are very limited. Only two seasonal observations by BUNT (1960) and HOSHIAI (1969) were reported from the ice-covered coastal areas.

In order to deepen our knowledge of seasonal changes of phytoplankton chlorophyll *a* under the fast ice, the present work was carried out at five stations covering the depth range of 10–675 m for a period of 13 months from January 1982 to January 1983. Although a framework and a preliminary report of the present study are published by FUKUCHI *et al.* (1984), the magnitude of chlorophyll *a* stock and possible factors to induce a rapid increase of chlorophyll *a* are discussed.

2. Methods and Materials

Five stations were occupied along the transverse line of 69°S latitude between East Ongul Island and the Antarctic Continent in the eastern part of Lützow-Holm Bay, Antarctica. Sea depths at Stns. 1, 2, 3, 4 and 5 were 10, 25, 50, 160 and 675 m, respectively. Horizontal distance between Stns. 1 and 5 was 3620 m (Fig. 1). Station 5 was located on the deep glacial trough in the Ongul Strait. Bottom topography of Lützow-Holm Bay is also shown in Fig. 1 after MORIWAKI and YOSHIDA (1983).

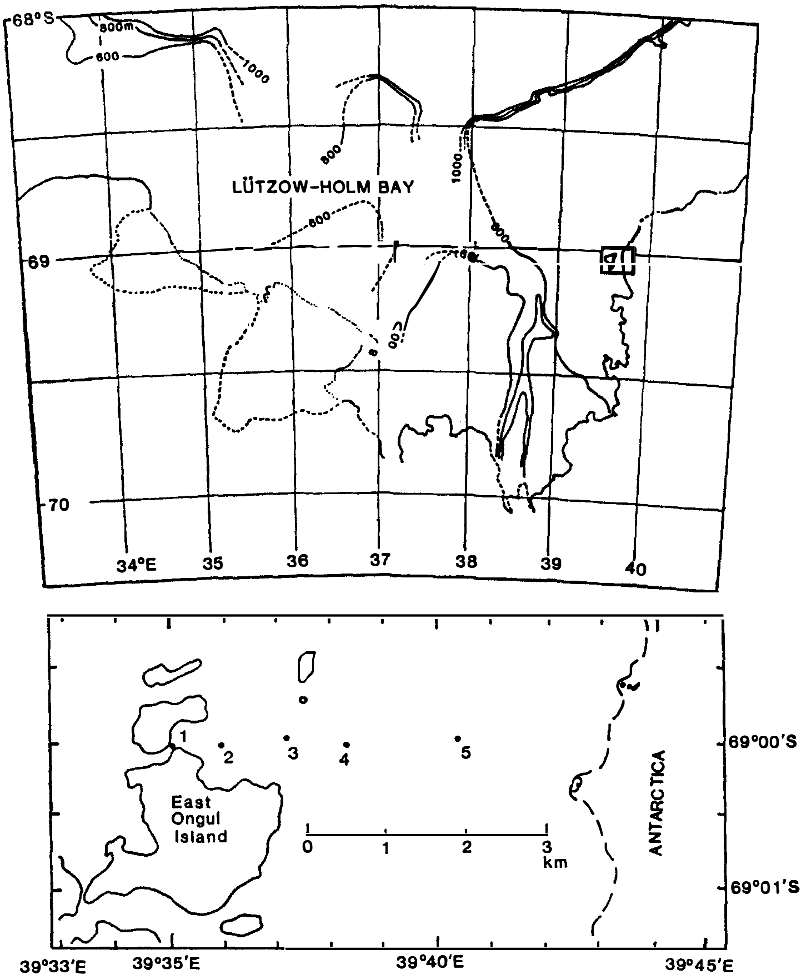

Fig. 1. Bottom topography of Lützow-Holm Bay, Antarctica (upper; after MORIWAKI *and* YOSHIDA*, 1983). Encircled area around five stations in the upper figure was enlarged in the bottom figure (Stn. 1: 69°00'00"S, 39°35'00"E; Stn. 2: 69°00'00"S, 39°36'00"E; Stn. 3: 68°59'57"S, 39°37'16"E; Stn. 4: 69°00'00"S, 39°38'20"E and Stn. 5: 68°59'57"S, 39°40'25"E).*

Generally, the fast ice remains in the area south of the 1000 m isobath throughout the summer season.

Van Dorn bottles were lowered through a hole to collect water from 0 m depth just beneath the undersurface of fast ice to near bottom. Sampling depths were usually as follows: 0, 2, 4 and 6 m at Stn. 1; 0, 5, 10, 15 and 23 m at Stn. 2; 0, 5, 10, 20, 30 and 45 m at Stn. 3; 0, 10, 25, 50, 75, 100 and 150 m at Stn. 4 and 0, 10, 25, 50, 75, 100, 200, 300, 400 and 600 m at Stn. 5.

Chlorophyll *a* concentration was determined by fluorometry (after SAIJO and NISHIZAWA, 1969) and by colorimetry (UNESCO, 1966) using a Shimadzu model RF-510 spectrofluorometer and a HITACHI model 101 spectrophotometer, respectively, in order to obtain values of R and f_{ph} for fluorometric determination and to intercalibrate the two methods. Values of R and f_{ph} were 3.8989 and 0.1038, respectively. A regression of chlorophyll *a* observed by the fluorometric method on chlorophyll *a* determinded by the colorimetric method for 50 sets of data in January 1982 was as follows;

$$\text{Chl. } a\ (\text{mg/m}^3,\ \text{fluor.}) = 0.9858 \times \text{Chl. } a\ (\text{mg/m}^3,\ \text{color.}) - 0.0768$$
$$(N=50,\ r=0.9910).$$

Between March 1982 and January 1983, one liter of sample water was filtered through a Whatman GF/C glass fiber filter and chlorophyll *a* concentration was determined by the fluorometric method. An aliquot of 100 m*l* of water was preserved in 2–3 % neutralized formalin solution for the later microscopic examination. All data obtained in this study will be published in JARE Data Reports (Marine Biology).

Concurrently, routine physical and chemical observations were carried out (see FUKUCHI *et al.*, 1984). Global solar radiation at Syowa Station (69°00′S, 39°35′E) was measured as a routine meteorological observation (JAPAN METEOROLOGICAL AGENCY, 1984).

3. Results

In January 1982, the fast ice around Stns. 1–5 was firm and the thickness of ice was 90–137 cm. Formation of puddles was not conspicuous. No breakout of ice occurred throughout the rest period of 1982. In January 1983, the fast ice became less firm compared with that observed in 1982 and the formation of puddles progressed especially around Stns. 1, 2, 4 and 5, while no breakout of ice was seen.

Seasonal change of the ten-day mean of global solar radiation observed at Syowa Station is shown in Fig. 2. The ten-day mean of global radiation was 25.7, 25.4 and 24.5 MJ/m²/day in January 1982 and it decreased rapidly toward May. It increased from July toward December. The ten-day mean was 30.0, 31.3 and 29.9 in December 1982 and 29.3, 31.0 and 25.5 MJ/m²/day in January 1983. Radiation in January 1983 was higher than that in January 1982.

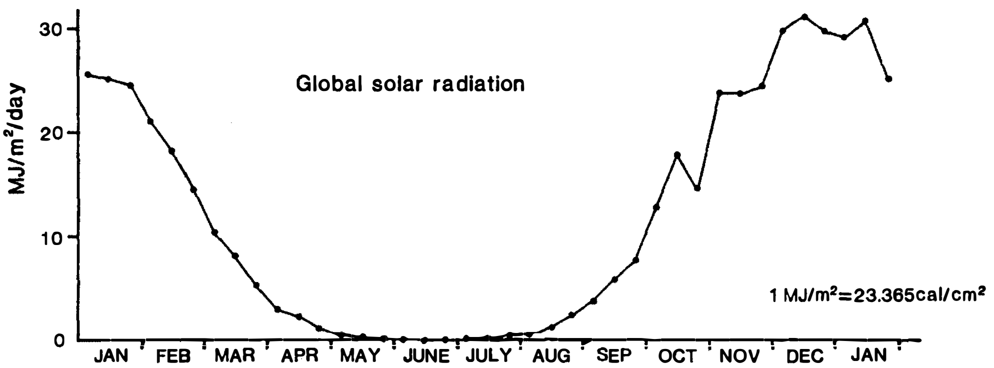

Fig. 2. Seasonal change of the ten-day mean of global solar radiation (MJ/m²/day) at Syowa Station (69°00′S, 39°35′E) from January 1982 to January 1983.

In Fig. 3, the maximum chlorophyll *a* concentrations in the water column at each station are plotted against months while the concentrations exceeded 0.1 mg/m³. The first observation of chlorophyll *a* concentration was carried out at Stns. 1 and 2 in late January 1982 when the maximum concentration was 2.22 mg/m³ at Stn. 1 (0 m depth; January 23) and 0.72 mg/m³ at Stn. 2 (2 m; January 27). In February, no observation was done. In early March, a high value of 4.61 mg/m^3 was measured at Stn. 3 (0 m; March 2). In late March–early April, a complete set of observations covering five stations was started. Maximum values (mg chl. *a*/m^3) at each station observed in this period were as follows; 4.70 at Stn. 1 (0 m; March 30), 0.38 at Stn. 2 (0 m; March 30), 0.26 at Stn. 3 (0 m; March 31), 0.11 at Stn. 4 (150 m; March 30) and 0.07 at Stn. 5 (74 m; April 9). Since then, the chlorophyll *a* observations at five stations were continued at 2–3 week intervals until the end of 1982. However, the concentrations were less than 0.1 mg/m^3 from April to October. In early-middle November, the concentration exceeded 0.1 mg/m^3 throughout the five stations. At Stn. 5, the concentration increased to 0.49 mg/m^3 from early to late November. Increase of chlorophyll *a* started from 25 m depth at Stn. 5 and reached a peak of 1.97 mg/m^3 at the same depth on December 3, while the concentrations below 50 m depth were less than 0.1 mg/m^3. During these periods, the concentrations at the other four stations decreased to less than 0.1 mg/m^3 again. From middle to late December, the decrease of chlorophyll *a* concentrations was seen at Stn. 5, while chlorophyll *a* increased at 0 m depth throughout the other four stations. In January 1983, two series of observations were done at only Stns. 1–4, because Stn. 5 was not accessible due to heavy melting of ice. The concentrations continued to increase at the four stations in January and peaks were observed

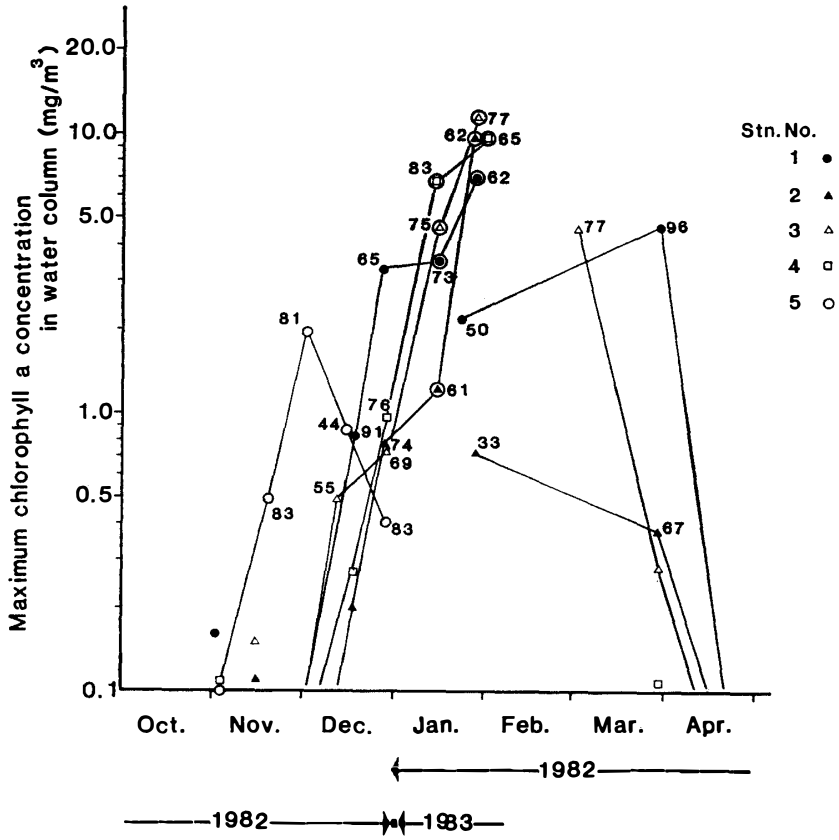

Fig. 3. Seasonal changes of the maximum chlorophyll a concentrations in water columns at five stations. Encircled data were obtained in 1983. Numerals indicate the pigment ratio (percent of chlorophyll a to the sum of chlorophyll a and phaeopigments).

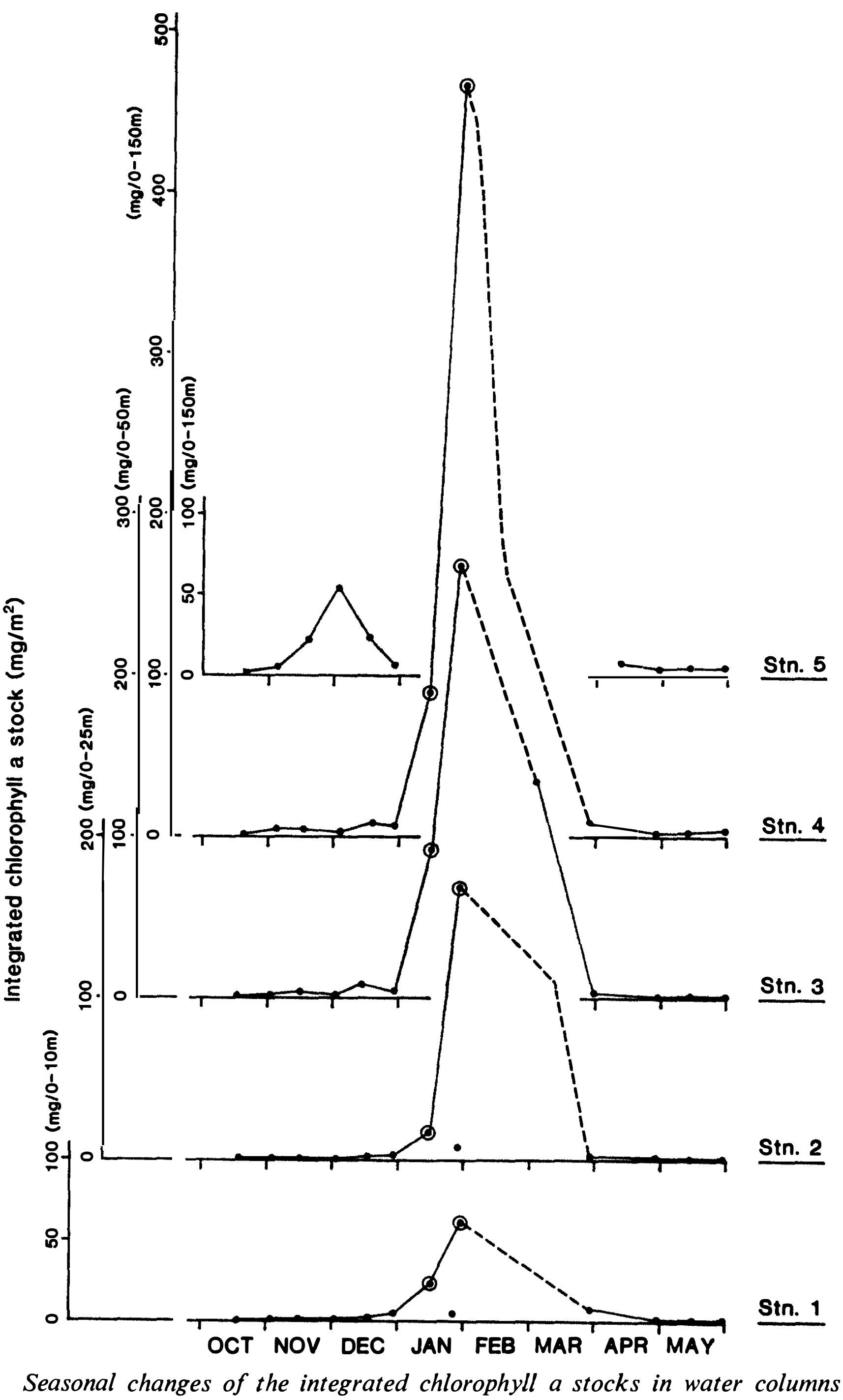

Fig. 4. Seasonal changes of the integrated chlorophyll a stocks in water columns at five stations. Encircled data were obtained in 1983.

in late January. Peak values at each station were 7.01 at Stn. 1 (6 m; January 28), 9.74 at Stn. 2 (5 m; January 28), 11.30 at Stn. 3 (5 m; January 27) and 9.91 mg/m^3 at Stn. 4 (0 m; January 27). High values more than 1 mg/m^3 were seen throughout water column at Stns. 1–3 but these were restricted to the upper 100 m depth at Stn. 4. High pigment ratios (percent of chlorophyll *a* to the sum of chlorophyll *a* and phaeopigments) were generally observed when chlorophyll *a* concentrations exceeded 0.5 mg/m^3. There was a time lag of about two months between the time of peak observed at Stn. 5 and those at Stns. 1–4.

Seasonal changes of integrated chlorophyll *a* stocks at each station are shown in Fig. 4 and were similar to those of the maximum chlorophyll *a* concentration (Fig. 3). A peak of the integrated stock at Stn. 5 was observed in early December as much as 55.1 mg/m^2, 0–150 m. On the other hand, peaks at Stns. 1–4 were seen in late January when the maximum concentrations were observed (62.2 mg/m^2, 0–10 m, at Stn. 1; 168.0 mg/m^2, 0–25 m, at Stn. 2; 269.5 mg/m^2, 0–50 m, at Stn. 3; 466.5 mg/m^2, 0–150 m at Stn. 4).

Throughout the present observations, concentrations of nutrient salts under ice such as silicate-Si, phosphate-P and nitrate-N were very high and showed neither any distinct seasonal fluctuations nor any differences among the five stations.

4. Discussion

BUNT (1960) occupied two stations (24 and 100 m depths) near Mawson Station and observed chlorophyll *a* concentrations for a period of eight months from June 19, 1956 to February 10, 1957. However, the latter part of his observations was not done on the fast ice but was carried out under the circumstances of pack ice or open water due to breakout of ice. HOSHIAI's (1969) observations near Syowa Station covered periods of 11 months at one station (9 m depth) and nine months at another station (92.5 m depth) in the fast ice area. The present observations, which occupied five stations in the fast ice area covering the depth range of 10–675 m as well as the temporal expansion for 13 months, are thought to be notable ones.

As seen from Figs. 3 and 4, chlorophyll *a* increases from November to January and the maximum integrated stock of chlorophyll *a* in water columns is attained when the maximum chlorophyll *a* concentration in water column is observed. However, there is a time lag of about two months between the peak observed at Stn. 5 in early December and the peaks at Stns. 1–4 in late January. Levels of nutrient salts are quite high and are similar among the five stations from November to January. Average concentrations of nutrients are as follows: phosphate, 1.19–2.45 μg-at P/*l*; silicate, 52.2–77.9 μg-at Si/*l* and nitrate, 16.1–33.4 μg-at N/*l*. There is no clear correlation between chlorophyll *a* concentrations and nutrient concentrations in water column. It seems that nutrients do no limit the growth of phytoplankton.

To explain why the chlorophyll *a* concentration at Stn. 5 increased earlier than those at the other four stations, the temporal and spatial changes of temperature and salinity were compared with those of chlorophyll *a* concentrations as shown in Fig. 5. Water temperature gradually increases and salinity decreases from October to November. Occurrence of water showing temperature higher than -1.73°C and salinity less than 34.15 is indicated with hatched areas in Fig. 5. It is clearly seen that the warmer and less saline water occurs in late November at Stn. 5 but such water occurs from late December at the other four stations. Occurrences of chlorophyll *a* concentration of more than 0.5 mg/m^3 generally coincide with those of warmer and less saline water. Slight changes of water temperature and salinity during an austral summer season might induce a rapid increase of phytoplankton.

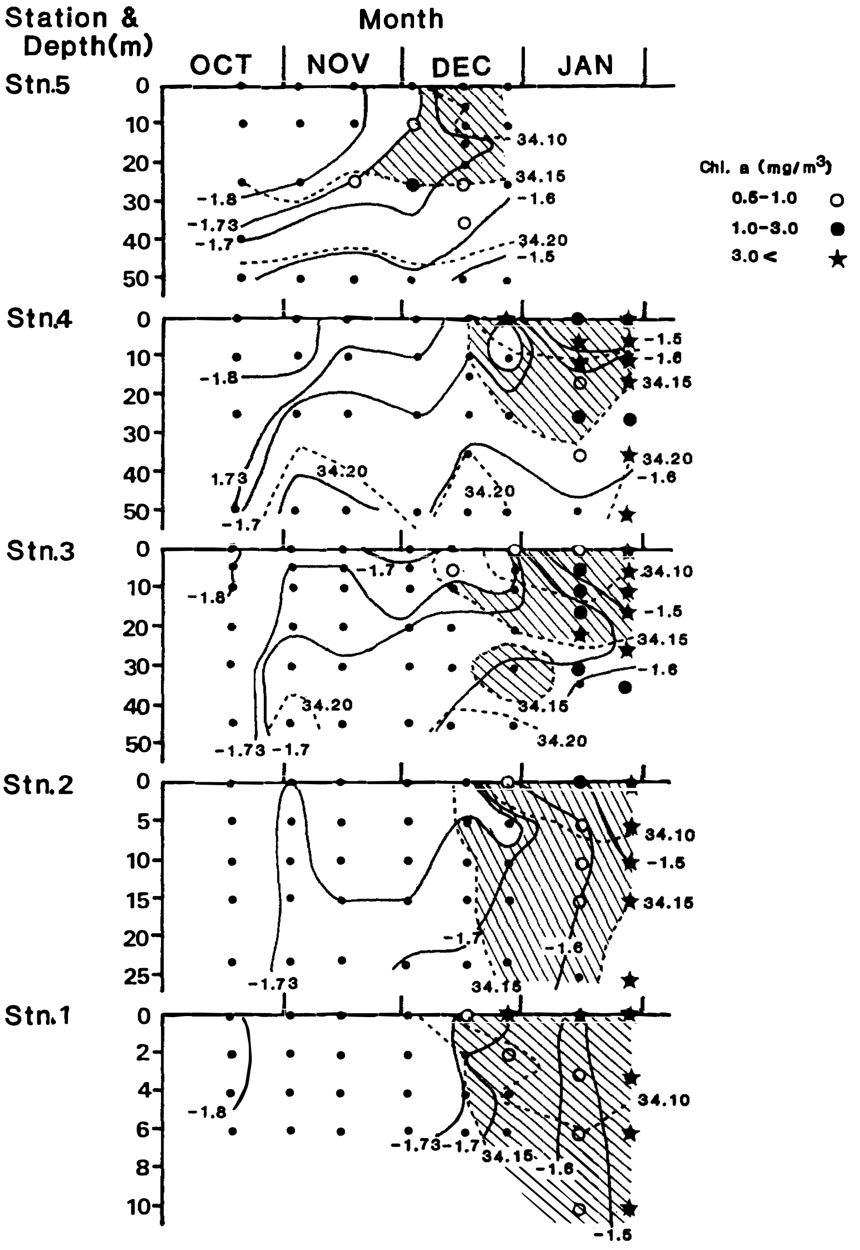

Fig. 5. Temporal and spatial changes of temperature (°C, solid line) and salinity (practical salinity scale, dashed line) together with chlorophyll a concentration (symbols) from October 1982 to January 1983. Hatched area indicates water of temperature higher than −1.73°C and salinity less than 34.15.

Although there is no data in February, high chlorophyll *a* concentrations are still observed at Stn. 3 (4.61 mg/m^3) and Stn. 1 (4.70 mg/m^3) in March. Warmer and less saline water (temperature, >-1.73°C; salinity, <34.15) also exists until March. Therefore, it is considered that the active growth of phytoplankton persists for four months period from December to March under a wide range of solar radiation (see Fig. 2).

Maximum chlorophyll *a* concentrations and integrated stocks obtained in the present study are summarized in Table 1, together with the results reported by the pre-

Table 1. *Summary of chlorophyll a observations under sea ice in the Antarctic coastal areas.*

Area	Stn. No.	Sea depth (m)	Period of observation	Range of depth observed (m)	Maximum chlorophyll *a* observed					Author
					Date	Depth (m)	Concentration (mg/m^3)	Integrated stock (mg/m^2)	Average stock* in water column (mg/m^3)	
Mawson Station	Stn. 1	24	June 19, 1956 -Jan. 12, 1957	0–24	Dec. 23	5	3.92	70.3/0–24 m	2.93	BUNT (1960)**
〃	Stn. 2	100	June 19, 1956 -Jan. 28, 1957	0–100	Jan. 28	75	2.15	152.0/0–100 m	1.52	〃
McMurdo Sound	Stn. 61B	300	Nov. 20, 1961 -Jan. 2, 1962	0–100	Dec. 24	0	37.5	*ca.* 2500/0–100 m	*ca.* 25	BUNT (1964)
〃	Stn. 62B	300	Dec. 10, 1962 -Jan. 16, 1963	0–20	Jan. 2–14	15	16.0	*ca.* 200/0–20 m	*ca.* 10	〃
Syowa Station	Stn. 1	9	Mar. 12, 1967 -Jan. 29, 1968	0–8	Jan. 29	6	11.93	59.3/0–9 m	6.59	HOSHIAI (1969)
〃	Stn. 2	92.5	Apr. 4–Dec. 16, 1967	0–90	Dec. 7	0	0.46	8.6/0–50 m	0.17	〃
Syowa Station	Stn. 1	10	Jan. 22, 1982 -Jan. 28, 1983	0–10	Jan. 28, 1983	6	7.01	62.2/0–10 m	6.22	Present work
〃	Stn. 2	25	Jan. 27, 1982 -Jan. 28, 1983	0–25	Jan. 28, 1983	5	9.74	168.0/0–25 m	6.72	〃
〃	Stn. 3	50	Mar. 2, 1982 -Jan. 27, 1983	0–45	Jan. 27	5	11.30	269.5/0–50 m	5.39	〃
〃	Stn. 4	160	Mar. 30, 1982 -Jan. 27, 1983	0–150	Jan. 27	0	9.91	244.1/0–50 m	4.88	〃
〃	Stn. 5	675	Apr. 9–Dec. 27, 1982	0–600	Dec. 3	25	1.97	52.6/0–50 m	1.05	〃

* Integrated stock was divided by integrated depth.
** Maximum chlorophyll *a* was observed in pack ice or open water.

vious workers. Maximum chlorophyll *a* concentration ranged from 0.46 to 37.5 mg/m^3. As the integrated stocks are estimated for different sea depths, average stocks in water column are calculated in order to compare one with another. Average stocks are 1.05–25 mg/m^3 except for one extreme low value. These values under the fast ice are at least one order of magnitude higher than those reported from the Antarctic open waters, such as 0.39 mg/m^3 by EL-SAYED and JITTS (1973), 0.22 mg/m^3 by HOLM-HANSEN *et al.* (1977) and 0.52 mg/m^3 by KURODA and FUKUCHI (1982).

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