DISTRIBUTION OF NANO- AND MICROPLANKTON IN THE INDIAN SECTOR OF THE SOUTHERN OCEAN

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Abstract: Standing stock and distribution of phytoplankton chlorophyll were studied in the Indian sector of the Southern Ocean, along the course of the FUJI during the period from December 1982 to March 1983. Surface observations showed that the mean chlorophyll concentrations in the Subantarctic and the Antarctic waters in December were higher (>0.5 mg/m^3) than those in February–March (<0.3 mg/m^3) and those in the subtropical waters in two periods (<0.2 mg/m^3). Surface standing stocks of nanoplankton (<10 μm) did not change greatly over different water masses, while the microplankton (>10 μm) showed a wide fluctuation and the relative contribution generally increased with increasing total phytoplankton concentration. Integrated chlorophyll stocks in February–March were in a range of 16–38 mg/m^2 (0–200 m) with microplankton contributions of 35–79%.

1. Introduction

Many studies on the phytoplankton distribution have been performed, and provided much usefull information on the geographical and seasonal variations in the Indian sector of the Southern Ocean. The surface chlorophyll concentrations in this sector were summarized by FUKUCHI (1980) using the data obtained by the Japanese Antarctic Research Expeditions (JARE). He presented the gross pattern of the regional and seasonal variations and demonstrated that the chlorophyll abundance increased in waters south of the Antarctic Convergence in summer, while the average standing stocks in the Indian sector of the Antarctic Ocean were almost comparable to those in the temperate waters of the world oceans.

A size fractionation of natural phytoplankton is known to provide a convenient way of getting primary information on the specific response of each size group to particular environmental conditions (MALONE, 1971; TUNDISI, 1971). MALONE (1971) showed that nanoplankton population (<22 μm) was most important quantitatively in all the seasons and areas, while microplankton (>22 μm, he called it netplankton) varied seasonally and regionally. In the Antarctic Ocean south of Australia, contributions of nano- (<10 μm), micro- (10–60 μm) and netplankton (>60 μm) were determined by YAMAGUCHI and SHIBATA (1982). They demonstrated that the regional variation of phytoplankton concentration was attributed to the micro- and netplankton fluctuations, and nanoplankton was almost constant in this sea area.

The present study aims at obtaining more fundamental knowledge of surface and vertical distributions of chlorophyll standing stocks, and describing the relative contribution of nano- and microplankton fractions of phytoplankton in the Southern Ocean.

2. Materials and Methods

Surface water samplings for plant pigment determinations were carried out along the course of the icebreaker FUJI to and from Antarctica during the period from 30 November 1982 to 9 March 1983. Water samples were collected two or three times a day using a bucket at the surface. Vertical observations were also carried out at 10 stations along a transect from 68°59′S, 27°48′E to 40°22′S, 42°24′E, from 23 February to 5 March 1983. Water samples were taken from 0, 10, 20, 30, 50, 75, 100, 150 and 200 m depths with 2-*l* Nansen water bottles. An aliquot of water sample, usually one liter, was gently drawn through a 10 μm nylon plankton net (microplankton retained on the net) and the filtrate was then filtered through a Whatman GF/C glass fiber filter (nanoplankton retained on the filter). Both the plankton net and the filter samples were used to extract the chlorophyll pigments. The chlorophyll concentrations were determined by the fluorometric method (STRICKLAND and PARSONS, 1972) using a spectrofluorometer (Shimadzu model RF 500). The pigment analyses were performed usually within a week after the water sampling on board. The analyses of 13 filter samples for nanoplankton obtained from Stn. 83 to 95 had been delayed about two months after the samplings, because of trouble with the spectrofluorometer. Data on surface and vertical observations of total chlorophyll pigments (sum of nano- and microplankton chlorophyll) are listed in the Appendices 1 and 2, respectively. The surface concentrations obtained in the sea areas north of 20°S latitude are excluded in the present discussion.

Concurrently, temperature, salinity and nutrients were measured and the data will be published elsewhere (HANZAWA and IWAMOTO, 1984).

3. Results

Total chlorophyll *a* concentrations from 81 stations located south of 20°S latitude are shown in Fig. 1. Among them, 43 stations were occupied on the southward leg toward Syowa Station (69°00′S, 39°35′E) via Fremantle from 7 to 30 December 1982. After the FUJI left the ice edge off Syowa Station on 9 February 1983, surface observations and 10 vertical observations were performed on the northward leg from Syowa Station to Port Louis between 9 February and 9 March 1983.

Judging from the latitudinal changes of surface water temperature, salinity and nutrient salts, oceanic fronts such as the Subtropical Convergence (STC) and the Antarctic Convergence (AC) were roughly recognized. On the southward leg, the STC and the AC were located around 40°S and between 53°S and 56°S, respectively. On the northward leg, the AC and the STC were located around 53°S and between 42°S and 47°S, respectively.

Surface chlorophyll concentrations were higher in the eastern part of the Indian sector than those in the western part. On the southward leg, chlorophyll *a* concentrations in the seas adjacent to Western Australia were less than 0.2 mg/m^3 and they in-

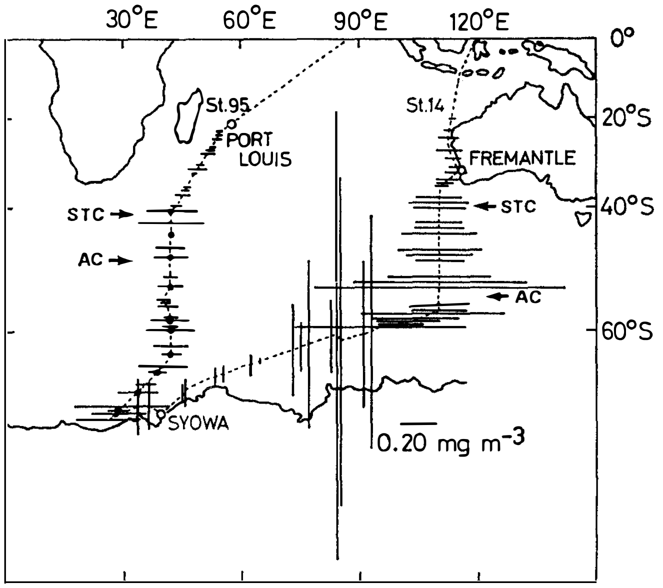

Fig. 1. *Cruise track of the icebreaker* FUJI *(dashed line) from December 1982 to March 1983 and distribution of total surface chlorophyll a concentration. Black circles indicate 10 stations of vertical water samplings. STC and AC denote approximate locations of the Subtropical and the Antarctic Convergences, respectively.*

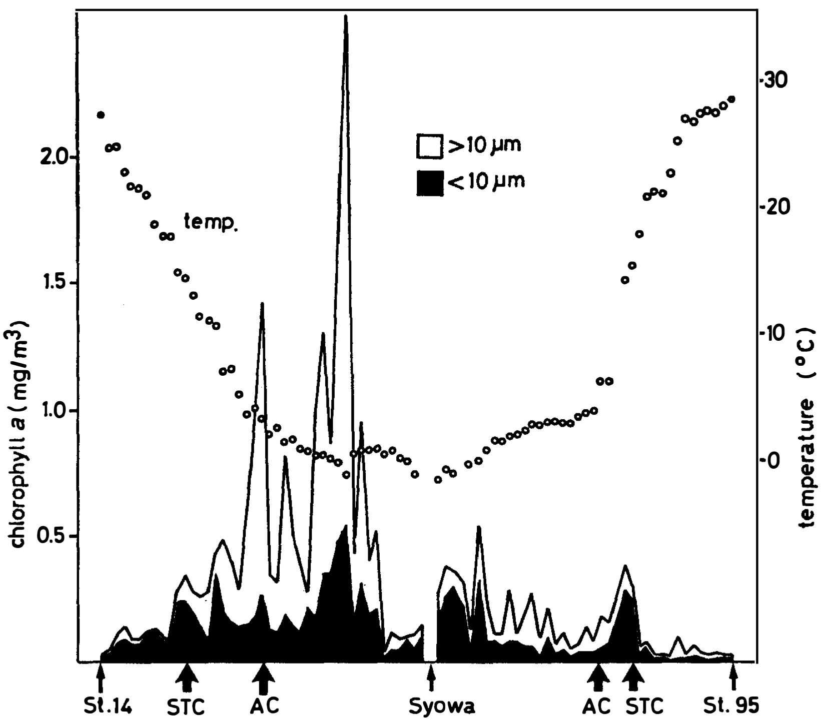

Fig. 2. *Distributions of nano- and microplankton chlorophyll a observed at the surface from Stn. 14 to 95 in the southern Indian Ocean. Circle indicates surface water temperatures at each station. AC and STC as in Fig. 1.*

creased to more than 0.2 mg/m^3 in the northern side of the STC. High concentrations were maintained toward about 70°E with some anomalously higher values (>1.0 mg/m^3) in the northern side of the AC and around 60°S. In the waters west of 70°E, surface chlorophyll stocks showed a rapid decrease to less than 0.2 mg/m^3. In February–March on the northward leg, concentrations were generally less than 0.3 mg/m^3, although, high values were found in the fast ice edge west of Syowa Station and around the STC.

Contributions of nano- and microplankton to the total chlorophyll standing stocks are illustrated in Fig. 2. Microplankton chlorophyll apparently fluctuated greater than nanoplankton did. Particularly in the Subantarctic and the Antarctic waters in December, marked peaks of more than 1.0 mg/m^3 in total concentration were evidently occupied by large amounts of microplankton.

Chlorophyll concentrations of two size fractions and total phytoplankton were classified into six groups according to differences in water masses and months (Table 1).

Table 1. Mean ($\bar{x}$), standard deviation (sd) of chlorophyll concentration (mg/m^3) and coefficient of variation (cv) for nano-, micro- and total phytoplankton in three different water masses on the southward leg (December) and the northward leg (February–March). Percentage contribution of microplankton to the total phytoplankton is indicated in the right column.

Month and area	N	Nanoplankton		Microplankton		Total		Micro (%)
		$\bar{x}$	sd (cv)	$\bar{x}$	sd (cv)	$\bar{x}$	sd (cv)	
December								
Subtropical	12	0.103	0.070 (0.68)	0.027	0.028 (1.04)	0.128	0.088 (0.69)	21.1
Subantarctic	10	0.19	0.08 (0.42)	0.35	0.36 (1.03)	0.54	0.38 (0.70)	64.8
Antarctic	21	0.19	0.14 (0.74)	0.42	0.51 (1.21)	0.61	0.65 (1.07)	68.9
February–March								
Antarctic	21	0.10	0.09 (0.90)	0.09	0.06 (0.67)	0.19	0.13 (0.68)	47.4
Subantarctic	4	0.17	0.12 (0.71)	0.08	0.03 (0.38)	0.25	0.10 (0.77)	32.8
Subtropical	13	0.024	0.016 (0.67)	0.022	0.019 (0.86)	0.046	0.026 (0.57)	47.8

Nanoplankton chlorophyll was virtually constant among groups with an exception for the subtropical waters in February–March. Chlorophylls of microplankton, however, showed remarkable differences among the groups. The mean microplankton concentrations in the Subantarctic and Antarctic waters in December were apparently higher than those in the other groups and also showed the larger standard deviations and coefficients of variation. The mean concentrations and standard deviations of total chlorophyll in the Subantarctic and Antarctic seas in December were also high, compared with the other groups in Table 1. The highest percentage contributions of microplankton were found in the same water masses, accounting for 64.8 and 68.9%, respectively, while these contributions reduced to less than 50% in February–March, primarily due to the decrease of microplankton chlorophyll. In the subtropical water, nanoplankton predominated in December (78.9%). In March, however, apparently low nanoplankton contribution (52.2%) was observed. This might be caused by the analytical error, because glass fiber filters were stored for about two months before analyses.

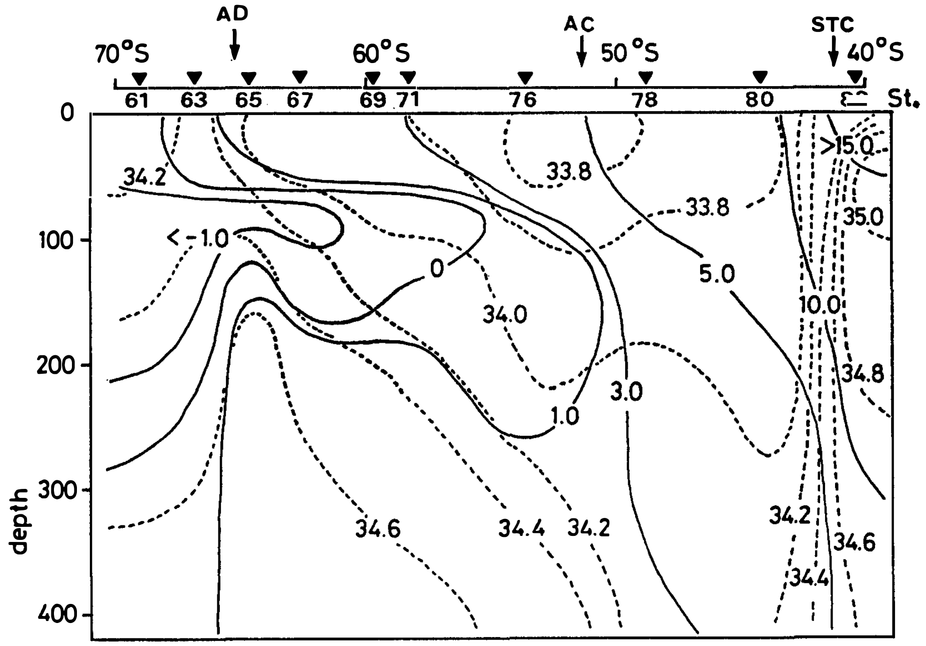

Fig. 3. Vertical sections of water temperature (°C) and salinity (practical salinity scale; dashed line) along 28°–40°E longitudes on the northward leg from 24 February to 5 March. Triangles indicate locations of 10 stations of vertical observations. AD denotes approximate location of the Antarctic Divergence. STC and AC as in Fig. 1.

According to the spatial distributions of temperature and salinity across ten stations of vertical observations (Fig. 3), an additional oceanic front, the Antarctic Divergence (AD), was roughly recognized around 65°S latitude. From 70° to 55°S, cold water with temperature below 0°C was observed between 75 and 150 m depth, which was carried from the south. Weak water stratifications were found around the AD (Stns. 65 and 67) and at Stn. 82.

Vertical profiles of nano- and total phytoplankton chlorophylls are shown in Fig. 4. Total phytoplankton distributed rather uniformly in the upper 100 m of the water column and the subsurface chlorophyll accumulation was less pronounced except for four stations of Stns. 63, 69, 71 and 82. Among them, three stations of Stns. 63, 69 and 71 were located in the south and the north of the AD and there were subsurface maxima of more than 0.3 mg/m^3 at the depth between 50 and 75 m. While in the midst of the AD (Stns. 65 and 67), weak increases (>0.2 mg/m^3) were found around or below 100 m depth. The concentration of nanoplankton generally varied within a small range below 0.2 mg/m^3 through the water column and a few marked peaks were observed at the subsurface maxima (Stns. 63 and 71) and at the surface of a subtropical sta-

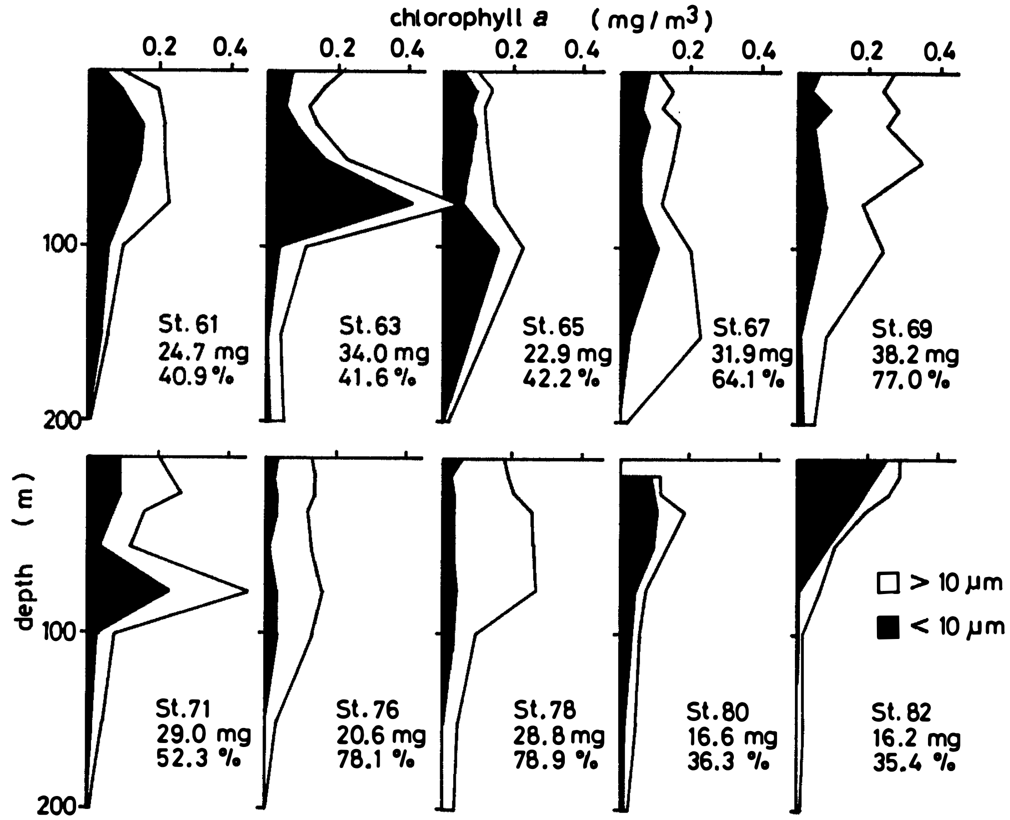

Fig. 4. Vertical profiles of nano- and microplankton chlorophyll a at ten stations on the northward leg from 23 February to 5 March. Integrated standing stocks of total chlorophyll (mg/m², 0–200 m) and percentage contributions (%) of microplankton chlorophyll to the stocks are also indicated.

tion (Stn. 82). Integrated chlorophyll stocks for the upper 200 m and the percentage contributions of microplankton are also shown in Fig. 4. Large integrated stocks of total chlorophyll (>30 mg/m²) were found at Stns. 63, 67 and 69, which were located at both south and north sides of the AD. The integrated value decreased to less than 20 mg/m² at Stns. 80 and 82. High contributions of microplankton (>50%) were observed in the sea areas between north of the AD and north of the AC (from Stns. 67 to 78). The microplankton proportion reduced to the lowest values of 35–36% around the STC (Stns. 80 and 82). In the Antarctic waters (from Stns. 61 to 76), a mean microplankton contribution to the total chlorophyll *a* at the surface layer was slightly lower (47.4%) than that of the water column (56.6%).

4. Discussion

Surface observations of chlorophyll *a* along the course of the FUJI revealed some characteristic features of phytoplankton distribution in the Indian sector of the Southern Ocean (Figs. 1 and 2, Table 1); (1) the average chlorophyll concentrations observed in December are higher than those observed in February–March, (2) the average concentrations in the Subantarctic and the Antarctic waters generally exceed those in the subtropical waters, and (3) the large horizontal fluctuations predominantly occur in the Antarctic surface waters in December. These general features are similar to those reported by FUKUCHI (1980) in the southern Indian Ocean. The average chlorophyll stocks for the six different groups are also in agreement with his results. FUKUCHI (1980) claimed that these features are a result of the seasonal periodicity of the phytoplankton standing stock. The present results also showed the distinctive predominance of chlorophyll stocks in December. The seasonal change would be the most likely explanation for the different phytoplankton stocks.

Most investigators emphasized the importance of nanoplankton, particularly, in the open ocean, primarily because of its high contribution to the total standing stock and productivity of phytoplankton (*e.g.* MALONE, 1971). HALLEGRAEFF (1981), however, observed the seasonal change of size-fractionated phytoplankton at a coastal station off Sydney and indicated that a sudden increase of total chlorophyll was due to the bloom of large-sized diatom, while nanoplankton abundance generally formed the constant background levels. Microplankton (>15 μm) accounted for 80–90% of the total phytoplankton when the diatom peaks occurred. FURNAS (1983) found that large-sized phytoplankton predominated in percentage contribution when a marked increase of total chlorophyll occurred in Narragansett Bay. According to these studies, a large standing stock of total chlorophyll is the result of high microplankton contribution. The present study shows that total phytoplankton stocks and contributions of microplankton in December were higher than those in February–March in the Southern Ocean (Table 1), and indicates that the former observations were made during more productive periods. This also supports the seasonal change of phytoplankton standing stock.

In the Antarctic Ocean, a few workers carried out size fractionation studies of phytoplankton (WALSH, 1969; FAY, 1973; YAMAGUCHI and SHIBATA, 1982). YAMAGUCHI and SHIBATA (1982) demonstrated that the mean percentage contributions of nano- (<10 μm), micro- (10–60 μm) and netplankton (>60 μm) to the total standing stock of chlorophyll *a* in the upper 200 m were 52.6, 25.1 and 22.3%, respectively. Although latitudinal variations on the relative proportions of each size group were not clear, they described the possible importance of the large size fraction to the regional variation of total phytoplankton. The present result revealed the regional differences in relative proportions of two size groups (Table 1). The mean contributions of microplankton (>10 μm) in the subtropical, the Subantarctic and the Antarctic waters in December were 24.1, 64.8 and 68.9%, respectively. The microplankton contribution varied latitudinally in accordance with the mean concentration of total chlorophyll. This suggests that the regional variation of total phytoplankton abundance approximately reflects the microplankton contribution. In February–March, however, there was not any clear relation between the microplankton contribution and the total phytoplankton standing stock.

The integrated stocks of chlorophyll from seven stations south of the AC (mean; 29 mg/m^2) are generally comparable to the previous reports observed in the western part of the Indian sector of the Antarctic Ocean in February–March. KURODA and FUKUCHI (1982) and WATANABE and NAKAJIMA (1982) estimated the mean integrated stocks of 21 and 32 mg/m^2, respectively. FUKUCHI and TAMURA (1982) reported a range of the integrated value, 17–39 mg/m^2. These workers demonstrated that integrated stocks in February–March were smaller than those observed in earlier periods of austral summer (December); the maximum value of more than 100 mg/m^2 was observed in middle-late December (KURODA and FUKUCHI, 1982).

Another typical feature of chlorophyll *a* distribution was that large standard deviations and coefficients of variation for micro- and total phytoplankton were found in the Antarctic Sea in December, indicating a remarkable discontinuity in horizontal distribution. FUKUCHI (1980) stated that a large fluctuation of surface chlorophyll in the Antarctic Ocean, especially south of 63°S, may be due to complicated hydrographic conditions including uneven distribution of pack ice or ice bergs. The highest chlorophyll concentration (2.56 mg/m^3) was actually observed near the pack ice edge with a high contribution of microplankton (78.5%). A sudden increase of total phytoplankton concentration in this area might be attributed to a microplankton increase caused by some preferable conditions associated with the ice.

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Appendix 1. Data on surface chlorophyll a and pheopigment concentrations of total phytoplankton observed in the Indian sector of the Southern Ocean in 1982–1983.

Stn. No.	Date			Time (LT)	Latitude	Longitude	Chl. *a* (mg/m³)	Pheopig. (mg/m³)
1	1982	Nov.	30	1700	10°40′N	128°26′E	0.07	0.33
2		Dec.	1	1800	5 24	125 51	0.05	0.27
3			2	0800	3 23	123 08	0.19	0.31
4			2	1800	2 15	121 23	0.31	0.14
5			3	0800	0 21	119 30	0.26	0.23
6			3	1800	1 44 S	118 51 E	0.35	0.28
7			4	0800	4 15	117 58	0.33	0.28
8			4	1800	6 14	116 46	0.29	0.59
9			5	0800	9 19	115 31	2.38	0.52
10			5	1800	11 18	115 05	0.06	0.21
11			6	0800	14 02	114 35	0.06	0.32
12			6	1800	15 48	114 17	0.22	0.44
13			7	0800	18 16	113 51	0.10	0.19
14			7	1800	20 13	113 28	0.03	0.24
15			8	0800	23 01	112 56	0.05	0.19
16			8	1800	24 57	112 33	0.11	0.22
17			9	0800	27 42	112 56	0.14	0.41
18			9	1800	29 27	113 45	0.09	0.30
19			10	0800	31 21	114 47	0.09	0.39
Fremantle								
20	1982	Dec.	16	1800	32°38′S	114°37′E	0.12	0.09
21			17	0800	34 12	112 27	0.13	0.14
22			17	1300	34 43	111 44	0.10	0.09
23			17	1800	35 15	110 55	0.08	0.16
24			18	0800	37 57	110 00	0.26	0.27
25			18	1300	38 59	109 60	0.34	0.30
26			18	1800	40 06	109 58	0.28	0.86
27			19	0800	42 51	110 02	0.26	0.64
28			19	1300	43 52	110 05	0.28	0.96
29			19	1800	44 54	110 09	0.43	0.52
30			20	0800	47 45	110 19	0.48	0.59
31			20	1300	48 41	110 03	0.39	1.57
32			20	1800	49 37	110 09	0.28	0.45
33			21	0800	52 14	110 14	0.58	0.54
34			21	1300	53 07	110 13	0.98	0.85
35			21	1800	53 58	110 18	1.42	0.92
36			22	0800	56 25	110 14	0.34	0.55
37			22	1300	57 17	109 53	0.31	0.58
38			22	1800	57 36	108 22	0.81	1.36
39			23	0800	58 22	104 10	0.49	0.31
40			23	1300	58 39	102 11	0.36	0.38
41			23	1800	58 56	100 18	0.26	0.41
42			24	0800	59 15	95 08	0.97	1.13
43			24	1300	60 01	92 57	1.32	1.26
44			24	1800	60 18	91 02	0.83	0.56
45			25	0800	61 06	84 57	1.87	1.01

Appendix 1. Continued.

Stn. No.	Date		Time (LT)	Latitude	Longitude	Chl. *a* (mg/m³)	Pheopig. (mg/m³)
46	1982 Dec.	25	1300	60°26′S	84°26′E	2.56	0.68
47		25	1800	60 31	82 24	0.41	0.90
48		26	0800	61 29	77 04	0.95	1.57
49		26	1300	61 50	75 02	0.28	0.57
50		26	1800	62 09	73 04	0.52	0.30
51		27	0800	63 29	66 38	0.02	0.37
52		27	1800	63 51	62 29	0.11	0.24
53		28	0800	64 55	55 37	0.09	0.14
54		28	1300	65 11	53 17	0.10	0.15
55		29	1800	66 48	45 12	0.11	0.49
56		30	1200	66 58	45 40	0.15	0.81
Ice edge off Syowa Station							
57	1983 Feb.	9	1300	68°09′S	36°20′E	0.27	0.32
58		9	1800	68 17	33 39	0.38	0.29
59		10	0800	69 30	26 16	0.36	0.15
60		22	1800	68 54	28 46	0.31	0.10
61		23	0800	68 59	27 48	0.10	0.49
62		23	1800	68 15	29 53	0.54	0.08
63		24	0800	66 50	33 40	0.22	0.37
64		24	1800	66 01	35 38	0.11	0.09
65		25	0800	64 37	38 41	0.10	0.34
66		25	1800	64 02	40 03	0.28	0.31
67		26	0800	62 35	42 05	0.11	0.00
68		26	1800	61 40	42 02	0.19	0.33
69		27	0800	59 41	42 00	0.27	0.13
70		27	1800	59 11	41 51	0.09	0.19
71		28	0800	58 17	41 26	0.21	0.10
72		28	1800	57 56	41 56	0.07	0.11
73	Mar.	1	0800	56 21	41 16	0.11	0.31
74		1	1300	55 56	40 44	0.05	0.28
75		1	1800	55 33	40 08	0.07	0.22
76		2	0800	53 39	42 04	0.14	0.09
77		2	1800	52 02	42 04	0.08	0.16
78		3	0800	48 51	42 09	0.18	0.06
79		3	1800	47 14	42 09	0.16	0.16
81		4	1800	42 48	42 18	0.38	0.32
82		5	0800	40 22	42 24	0.29	0.44
83		5	1800	39 21	43 44	0.06	0.07
84		6	0800	37 08	45 23	0.08	0.12
85		6	1300	36 11	45 49	0.03	0.08
86		6	1800	35 33	46 24	0.03	0.09
87		7	0800	32 32	48 15	0.02	0.07
88		7	1300	31 35	48 58	0.10	0.13
89		7	1800	30 38	49 42	0.03	0.11
90		8	0800	28 05	51 39	0.07	0.10
91		8	1300	27 16	52 15	0.04	0.11
92		8	1800	26 34	52 46	0.03	0.04
93		9	0800	24 25	54 09	0.04	0.05
94		9	1300	23 39	54 28	0.03	0.05
95		9	1800	22 57	54 41	0.03	0.04

Appendix 2. Data on vertical observation of chlorophyll a and pheopigments (total phytoplankton) at ten stations in February–March 1983.

Stn. No.	Data and time (LT)	Position	Depth (m)	Chl. *a* (mg/m³)	Pheopig.
61	1983 Feb. 23	68°59′S	0	0.10	0.49
	0800	27°48′E	10	0.20	0.69
			20	—	—
			30	0.22	0.41
			50	0.22	0.45
			75	0.23	0.56
			100	0.10	0.52
			150	0.06	0.30
			200	0.01	0.22
63	1983 Feb. 24	66°50′S	0	0.22	0.37
	0800	33°40′E	10	0.17	0.56
			20	0.13	0.80
			30	0.15	0.60
			50	0.23	0.69
			75	0.56	0.48
			100	0.12	0.46
			150	0.05	0.34
			200	0.06	0.16
65	1983 Feb. 25	64°37′S	0	0.10	0.34
	0800	38°41′E	10	0.14	0.21
			20	0.12	0.25
			30	0.12	0.24
			50	—	—
			75	0.15	0.28
			100	0.23	0.34
			150	—	—
			200	0.02	0.16
67	1983 Feb. 26	62°35′S	0	0.11	0.00
	0800	42°05′E	10	0.15	0.06
			20	0.12	0.01
			30	0.17	0.11
			50	0.15	0.68
			75	0.12	0.24
			100	0.20	0.36
			150	0.23	0.72
			200	0.02	0.07
69	1983 Feb. 27	59°41′S	0	0.27	0.13
	0800	42°00′E	10	0.24	0.39
			20	0.28	0.24
			30	0.25	0.42
			50	0.35	0.83
			75	0.18	0.44
			100	0.24	0.91
			150	0.08	0.25
			200	0.05	0.03

Appendix 2. Continued.

Stn. No.	Date and time (LT)	Position	Depth (m)	Chl. *a* (mg/m³)	Pheopig. (mg/m³)
71	1983 Feb. 28	58°17′S	5	0.21	0.10
	0800	41°26′E	10	—	—
			20	0.27	0.21
			30	0.17	0.15
			50	0.13	0.33
			75	0.46	0.31
			100	—	—
			150	0.05	0.39
			200	0.01	0.21
76	1983 Mar. 2	53°39′S	0	0.14	0.09
	0800	42°04′E	10	0.15	0.13
			20	0.15	0.10
			30	0.13	0.13
			50	0.14	0.14
			75	0.17	0.03
			100	0.14	0.10
			150	0.04	0.06
			200	0.01	0.03
78	1983 Mar. 3	48°51′S	0	0.18	0.06
	0800	42°09′E	10	0.19	0.09
			20	0.21	0.10
			30	0.26	0.21
			50	0.26	0.09
			75	0.27	0.09
			100	0.10	0.14
			150	0.05	0.09
			200	0.04	0.05
80	1983 Mar. 4	44°14′S	0	—	
	0800	42°09′E	10	0.12	0.19
			20	0.12	0.22
			30	0.19	0.17
			50	0.14	0.23
			75	0.08	0.30
			100	0.06	0.20
			150	0.05	0.12
			200	0.03	0.13
82	1983 Mar. 5	40°22′S	0	0.29	0.44
	0800	42°24′E	10	0.29	0.32
			20	0.26	0.36
			30	0.19	0.37
			50	0.11	0.28
			75	0.07	0.08
			100	0.02	0.15
			150	0.02	0.09
			200	0.01	0.11

—: no data