Mem. Natl Inst. Polar Res., Spec. Issue, **44**, 24-33, 1986

SURFACE CHLOROPHYLL *A* DISTRIBUTION IN MARGINAL ICE ZONE IN ANTARCTICA, 1984/85

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Abstract: Chlorophyll *a* concentrations of surface layer were measured at 108 stations in the Antarctic waters south of 63°S including the pack ice and the fast ice regions along the course of the SHIRASE during the 1984–85 austral summer. High chlorophyll *a* concentration was observed in the pack ice and the fast ice regions between late December and early January. This high value seems to be correlated with the release of so-called ice algae which proliferated at the bottom part of sea ice. After the disappearance of the sea ice, chlorophyll *a* concentration in the open water decreased abruptly and became low. After passing through a period of two or three months, the high concentration of chlorophyll *a* was observed again within Lützow-Holm Bay and Breid Bay. The growth of the planktonic algae seems to occur in these regions during the austral summer.

1. Introduction

Chlorophyll *a* distribution in the surface water along the cruise track of the Japanese Antarctic Research Expedition (JARE) was firstly investigated by HOSHIAI (1968). Subsequently, the routine measurement of the surface chlorophyll *a* concentration had been carried out every summer as a part of the research program of JARE. FUKUCHI (1980), summarizing the data between 1965 and 1976, discussed the regional distribution of surface chlorophyll *a* along the route of the FUJI. He suggested that the large deviation of chlorophyll *a* concentration in the Antarctic Surface Water south of 63°S was a true reflection of the widely variable surface chlorophyll stock in this water.

In the pack ice and the fast ice regions, the high value and large fluctuation of surface chlorophyll *a* concentrations were also observed by OHNO (1976), TANIMURA (1981), FUKUCHI and TAMURA (1982), WATANABE (1982) and WATANABE and NAKAJIMA (1983). TANIMURA (1981) and WATANABE (1982) suggested that the high chlorophyll *a* concentrations in the ice-associated regions (*i.e.*, pack ice and fast ice regions) were contributed by ice-algae released from the sea ice in spring and summer.

However, the analysis of temporal and spatial distributions of the surface chlorophyll *a* concentration in the marginal ice zone is still insufficient. In this paper, we discuss the small-scaled distribution of chlorophyll *a* in conjunction with the release of ice algae from the sea ice.

2. Materials and Methods

One liter of surface sea water was collected with a plastic bucket usually three times a day at 0700, 1200 and 1700 by local time along the course of the SHIRASE. One liter of the subsurface sea water which was pumped up from an intake on the hull (*ca.* 8 m in depth), was also subsampled. The water samples were filtered through a Whatman GF/C glass fiber filter (47 mm in diameter), and chlorophyll *a* was determined by the fluorometric method using a Shimadzu model RF-500 spectrofluorometer on board. Water temperature was measured at the same time.

3. Results

The concentrations of surface and subsurface chlorophyll *a* in the Antarctic waters south of 63°S and the relevant data are listed in Appendix 1. The relationship between the surface chlorophyll *a* and the subsurface chlorophyll *a* concentrations is shown in Fig. 1. The correlative equation acquired on the basis of 84 data sets is as follows:

$$Chl_s = -0.007 + 1.085\, Chl_{sub} \quad (r = 0.936),$$

where Chl_s and Chl_{sub} are concentrations of chlorophyll *a* at the surface and subsurface in mg/m^3, respectively. The positive correlation was clearly observed between the surface and subsurface values. Therefore, chlorophyll *a* concentrations referred to in the following sections do not distinguish two concentrations and the surface and subsurface data put together in the following sentences.

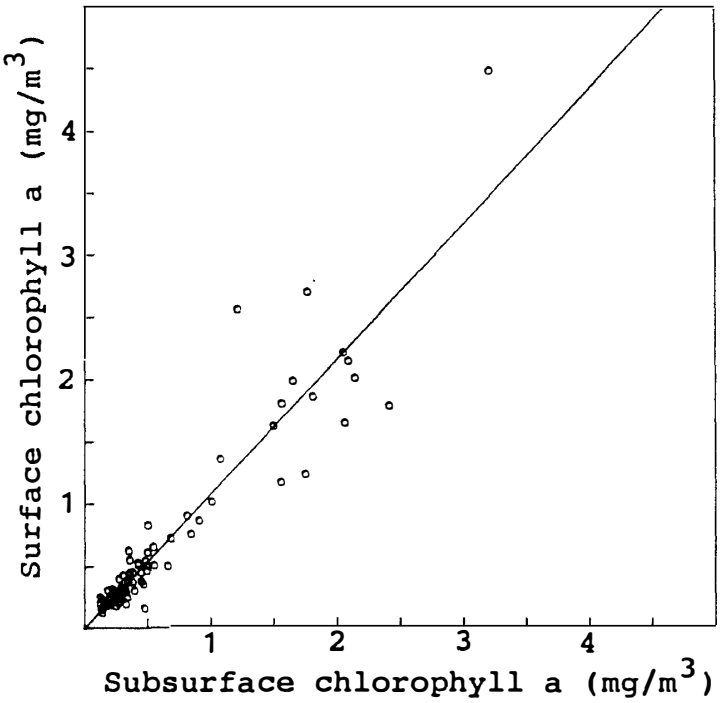

Fig. 1. Relationship between the surface chlorophyll a and the subsurface chlorophyll a concentrations in Antarctic water south of 63°S latitude.

3.1. Off Lützow-Holm Bay to Breid Bay (Stns. 1–12, Fig. 2)

Stations were all located in the pack ice region between 15 and 19 December 1984. The chlorophyll *a* concentrations at Stns. 1 and 2 were both 0.22 mg/m^3 and the coverage of ice was 5/10–8/10. The high values of chlorophyll *a* concentration were 0.50–0.73 mg/m^3 at Stns. 3–5 (coverage of ice: >8/10). The edge of the fast ice was situated along 67°50′S on 16 December 1984, which was 3 to 4 miles south of Stns. 3 and 4. Chlorophyll *a* concentrations between Stns. 6 and 12 fluctuated from 0.12 to 0.48 mg/m^3. The surface water temperature varied from −1.4° to −0.7°C.

3.2. Breid Bay to Syowa Station (Stns. 24–30, Fig. 2)

Stations 24–29 were located in the pack ice region, and Stn. 30 was situated in the fast ice region. The fast ice edge was located along 68°30′S on 3 January 1985. The lead (water) was located between Stns. 29 and 30. All stations were occupied between 1 and 3 January 1985. The chlorophyll *a* concentrations at Stns. 24 and 28 in the pack ice region (coverage of ice: >8/10) were as high as 0.75–0.85 and 1.08–1.35 mg/m^3, respectively. The highest concentration of chlorophyll *a* was found at Stn. 29 (2.70 mg/m^3) in the pack ice (coverage of ice: >9/10). Chlorophyll *a* concentration was high also at Stn. 30 (1.95 mg/m^3). The surface water temperature showed −1.0° to 0.8°C.

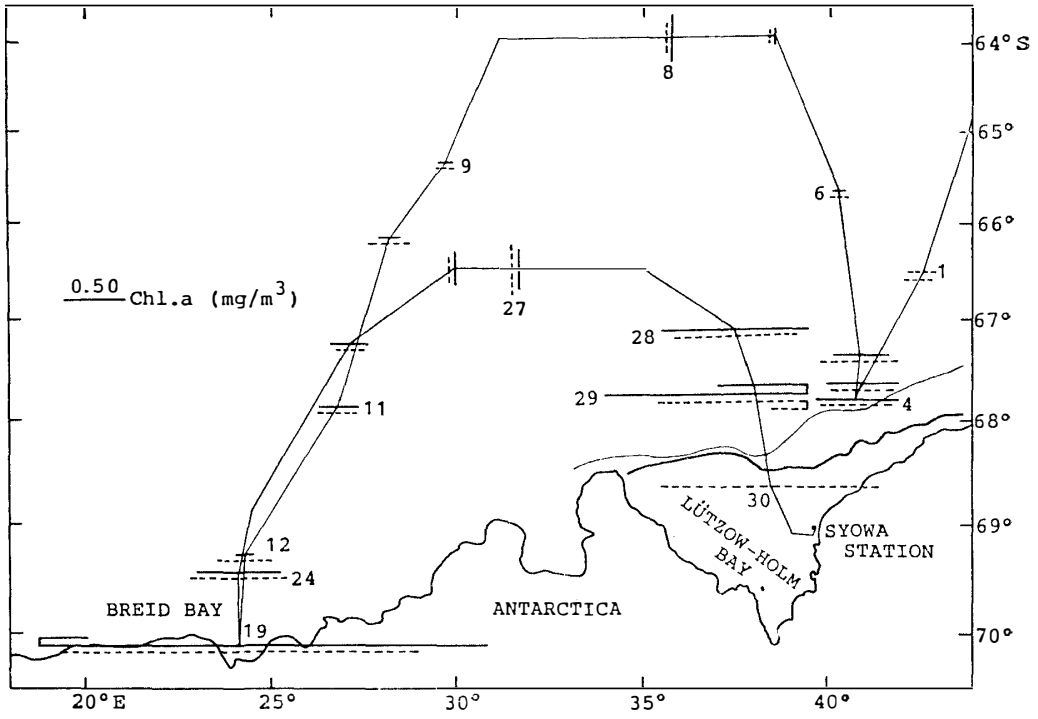

Fig. 2. Chlorophyll a (mg/m^3) distribution of surface (solid line) and subsurface (dashed line) waters along the course of the SHIRASE from 15 December 1984 to 3 January 1985. Numerals indicate serial numbers of sampling stations. The edges of the fast ice in Lützow-Holm Bay on 18 December 1984 and 3 January 1985 are illustrated by fine and bold curves, respectively.

3.3. Syowa Station to Breid Bay (Stns. 31–41, Fig. 3)

Edges of the fast ice and the pack ice in Lützow-Holm Bay were found along 68°40′S and 68°30′S, respectively. Stations 31–41 were all occupied in the Antarctic open water between 2 and 7 February 1985. Chlorophyll *a* concentrations fluctuated from 0.19 to 0.55 mg/m^3. However, the values of chlorophyll *a* at Stns. 31–33 were lower than those of the ice-associated regions (Stns. 28–30) in early January. The surface water temperature was from −1.0° to 1.2°C.

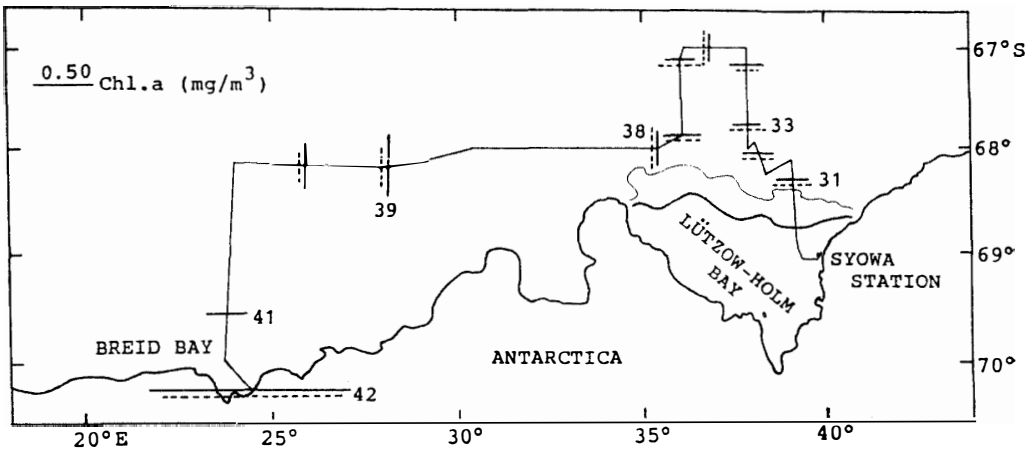

Fig. 3. Surface and subsurface chlorophyll a in 2–7 February 1985. Numerals and lines as in Fig. 2. The edges of the pack ice and the fast ice in Lützow-Holm Bay on 2 February 1985 are illustrated by fine and bold curves, respectively.

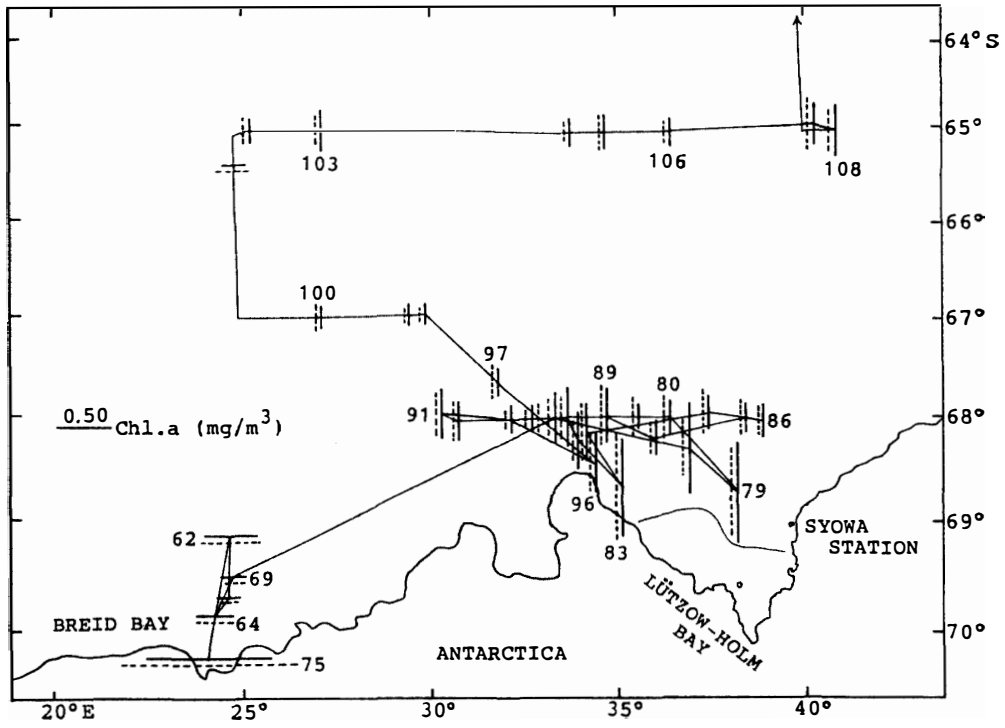

Fig. 4. Surface and subsurface chlorophyll a in 12 February–1 March 1985. Numerals and lines as in Fig. 2. Ice edge of the pack ice was observed on 20 February 1985 (as shown by a fine curve).

3.4. Breid Bay to Stn. 108 via Gunnerus Bank (Stns. 62–108, Fig. 4)

Stations 62–108 were occupied in the Antarctic open water between 12 February and 1 March 1985. Chlorophyll *a* concentrations off Breid Bay were in the range from 0.12 to 0.50mg/m^3 and lower than those within Breid Bay (1.50–2.42 mg/m^3) during mid-February (see the following sections).

Off Lützow-Holm Bay, chlorophyll *a* concentrations along the 68°S latitude were low, ranging from 0.13 to 0.51 mg/m^3. The chlorophyll *a* concentration increased toward the inside of Lützow-Holm Bay and the highest value was 0.91 mg/m^3 at Stn. 83. The values at Stns. 97–108 north of 68°S fluctuated from 0.14 to 0.45mg/m^3. The surface water temperature varied from −1.3° to 2.4°C.

3.5. The distribution of chlorophyll a concentrations in Breid Bay (Stns. 13–23, 42–61 and 75, Figs. 5 and 6)

In late December (29–30 December 1984), the distributions of the fast ice and the ice shelf are shown in Fig. 5. The high chlorophyll *a* concentrations were 2.49–4.48 mg/m^3 at Stns. 19, 20 and 23 within the fast ice region. The concentrations of chlorophyll *a* at Stns. 18 and 22 near the fast ice region were also high as much as 4.99 and 4.62mg/m^3, respectively. The other Stns. 13–17 and 21 in Breid Bay were located in the open water and the concentrations ranged from 1.62 to 2.82 mg/m^3. The range of temperature in the surface water was from 0.1° to 2.1°C in late December.

In middle February (7–17 February 1985), the fast ice completely disappeared from Breid Bay. The concentrations of chlorophyll *a* were from 0.76 to 2.54mg/m^3. The range of temperature in the surface water was between −1.0° and −0.3°C.

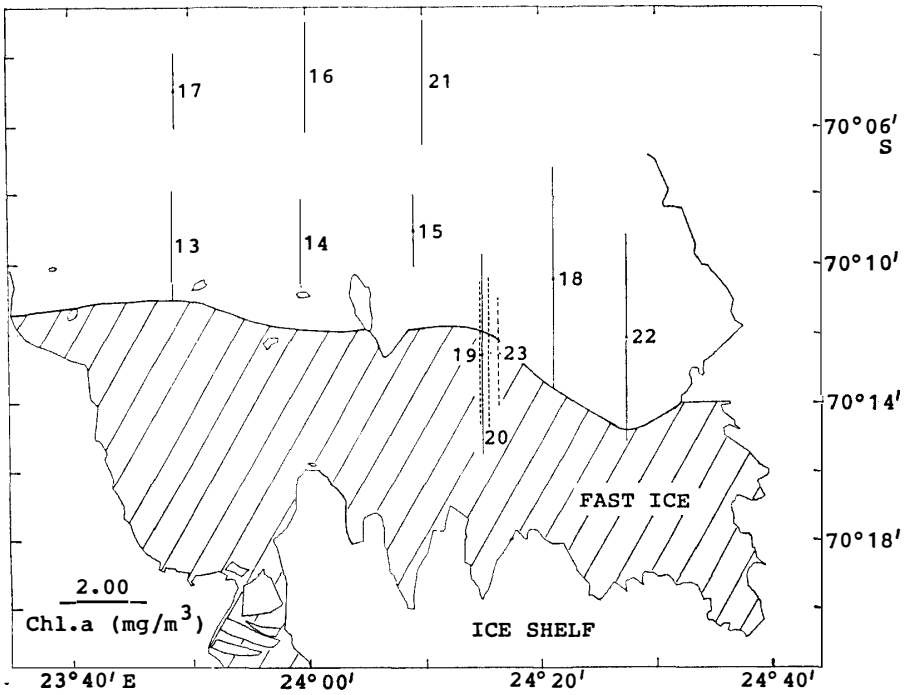

Fig. 5. Surface and subsurface chlorophyll a in Breid Bay, Antarctica from 29 to 30 December 1984. Numerals and lines as in Fig. 2. The fast ice region is illustrated by oblique solid lines.

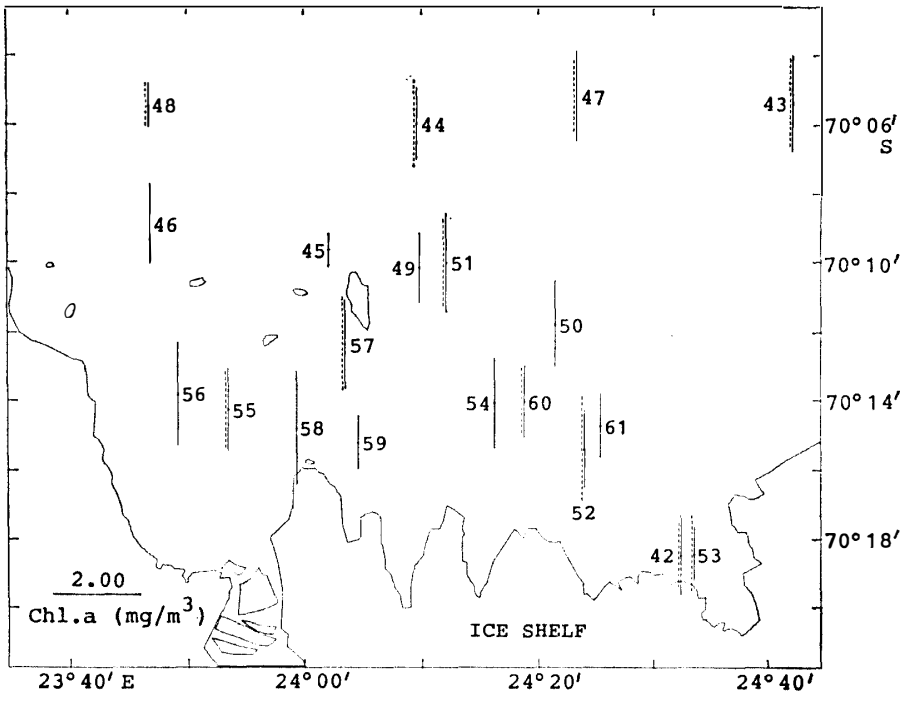

Fig. 6. Surface and subsurface chlorophyll a in Breid Bay, Antarctica from 7 to 17 February 1985. Numerals as in Fig. 2.

4. Discussion

In Lützow-Holm Bay, chlorophyll *a* values in the pack ice region near the fast ice at Stns. 3 (67°47′S latitude) and 4 (67°46′S latitude) were 0.54 to 0.73 mg/m^3 on 16 December 1984. On 3 January, eighteen days later, the high chlorophyll *a* concentrations were observed at Stn. 29 (67°43′S latitude). Values at Stn. 29 (1.77–2.70 mg/m^3) are four times greater than those of the previous values at Stns. 3 and 4. The chlorophyll *a* concentration at Stn. 30 was also high (1.95 mg/m^3) in the fast ice region (Fig. 2). HOSHIAI (1985) pointed out that a spring-summer proliferation of ice algae occurred extensively in ice-covered areas of the Antarctic. The high values at Stns. 29 and 30 in the ice-associated regions seem to be closely correlated with the proliferation of ice algae in summer. Especially, the influence of the thaw seems to be remarkable in the surface water during the summer (HOSHIAI, 1969). The edge of the ice-associated regions gradually retreated toward the south during the summer. And it may be presumed that the surface chlorophyll *a* concentration largely fluctuates with the retreat of the sea ice. After the sea ice disappeared in Lützow-Holm Bay, the chlorophyll *a* concentration in the open water at Stns. 31–33 decreased abruptly and the value became low (0.24 to 0.30 mg/m^3) (Fig. 3). After 16 to 18 days, the chlorophyll *a* concentration became relatively high again within the bay and low off the bay between 18 and 25 February (Fig. 4). The edge of the ice-associated regions retreated and was situated south of 69°S latitude on 24 February. After the sea ice disappeared, the growth of the planktonic algae seems to occur within the bay in late summer. Thus, the variation of chlorophyll *a* in Lützow-Holm Bay during the austral summer seems to be closely

correlated with the release of ice algae which increased at the bottom of the sea ice and the increase of planktonic algae in the water column.

In Breid Bay, the chlorophyll *a* concentrations at Stns. 18–23 (except Stn. 21) near and in the fast ice were high (2.49–4.99 mg/m^3) between 29 and 31 December 1984. These high values seem to be contributed by ice algae released from the sea ice, and are two times as much as the values at Stns. 29 and 30 in Lützow-Holm Bay. The chlorophyll *a* concentrations of all stations except Stns. 18–20 and 22–23 were about 2.00 mg/m^3 in open water within the bay (Fig. 5). In February, the fast ice had already disappeared and the high chlorophyll *a* concentration more than 3.00 mg/m^3 could not be observed. However, the chlorophyll *a* concentrations of all stations showed about 2.00 mg/m^3. These high values were restricted in open water within the bay and probably continued during the austral summer (Figs. 5 and 6). The growth of the planktonic algae in Breid Bay seems to occur in open water during the summer as well as in Lützow-Holm Bay. It is probable that this phenomenon is restricted within inlets of an indented Antarctic coastline during the austral summer.

Acknowledgments

We are grateful to Prof. S. KAWAGUCHI (National Institute of Polar Research), leader of the JARE-26 and his staff, especially to Messrs. K. IWANAMI and H. TOUJU (Hydrographic Department of Maritime Safety Agency), for their cooperation. Thanks are due to Prof. T. HOSHIAI and Messrs. A. TANIMURA and K. WATANABE (Natl Inst. Polar Res.) for their valuable advice and their help in various ways. Finally, we are indebted to Captain T. SATOU of the icebreaker SHIRASE and his officers and crew.

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(Received April 2, 1986; Revised manuscript received August 20, 1986)

Appendix 1. Chlorophyll a contents of surface layer in Antarctic water along the route of the SHIRASE between 15 December 1984 and 1 March 1985 (—: no data).

Station No.	Date	Time	Latitude	Longitude	Chlorophyll *a* (mg/m³)		Water temp. (°C)
					(Surface)	(Subsurface)	
	1984						
1	Dec. 15	1300	66 31 S	42 18E	—	0. 22	−1. 2
2		1700	66 32	42 18	—	0. 22	−1. 2
3	16	0700	67 47	40 41	0. 66	0. 54	−1. 3
4		1200	67 46	40 40	0. 73	0. 68	−1. 1
5		1700	67 24	40 56	0. 50	0. 66	−0. 8
6	17	0700	65 24	40 26	0. 18	0. 18	−1. 1
7		1200	63 58	38 34	0. 17	0. 15	−1. 0
8		1700	63 58	35 39	0. 43	0. 31	−1. 2
9	18	0700	65 26	29 36	0. 12	0. 14	−0. 9
10		1200	66 11	18 16	0. 19	0. 33	−0. 8
11		1700	66 57	26 50	0. 33	0. 32	−0. 7
12	19	0700	69 20	24 21	0. 16	0. 48	−1. 4
13	27	0958	70 09	23 48	2. 40	—	1. 9
14		1208	70 09	23 58	1. 98	—	2. 1
15		1455	70 09	24 09	1. 62	—	0. 5
16	29	0933	70 04	24 00	2. 47	—	1. 7
17		1201	70 05	23 48	1. 68	—	0. 5
18		1427	70 10	24 20	4. 99	—	0. 5
19		1500	70 12	24 11	4. 48	3. 22	—
20	30	0700	70 12	24 11	—	3. 39	0. 1
21		1115	70 05	24 10	2. 82	—	1. 6
22		1520	70 12	24 27	4. 62	—	0. 4
23		2119	70 12	24 11	—	2. 49	—
	1985						
24	Jan. 1	1900	69 26	24 12	0. 75	0. 85	0. 8
25	2	0700	67 18	27 12	0. 32	0. 22	−0. 1
26		1400	66 32	29 51	0. 25	0. 25	−0. 3
27		1800	66 30	31 35	0. 36	0. 47	−0. 4
28	3	0700	67 07	37 29	1. 35	1. 08	−0. 1
29		1200	67 43	38 01	2. 70	1. 77	−1. 0
30		1700	68 37	38 25	—	1. 95	—
31	Feb. 2	1700	68 17	38 10	0. 27	0. 29	−1. 0
32	3	0700	67 56	38 00	0. 27	0. 24	−0. 5
33		1200	67 48	38 01	0. 25	0. 30	0. 9
34	4	0700	67 11	38 01	0. 30	0. 19	1. 1
35		1515	67 01	36 27	0. 25	0. 28	1. 1
36	5	0700	67 10	36 04	0. 25	0. 34	1. 1
37		1200	67 54	36 01	0. 33	0. 30	1. 2
38		1700	68 02	35 31	0. 31	0. 40	1. 1
39	6	1200	68 13	28 06	0. 55	0. 36	0. 8
40		1700	68 13	26 04	0. 40	0. 27	0. 4
41	7	0730	69 37	23 55	0. 32	—	0. 1
42		1430	70 18	24 32	1. 80	1. 57	−0. 3
43		1700	70 03	24 42	2. 15	2. 09	−0. 3
44	8	0700	70 06	24 09	1. 64	2. 06	−0. 3
45		0905	70 09	24 01	0. 76	—	−0. 6

Appendix 1 (continued).

Station No.	Date	Time	Latitude	Longitude	Chlorophyll *a* (mg/m³) (Surface)	Chlorophyll *a* (mg/m³) (Subsurface)	Water temp. (°C)
	1985						
46	Feb. 8	1047	70 09 S	23 47 E	1. 79	—	−0. 5
47		1700	70 05	24 23	1. 99	1. 65	−0. 6
48	9	0700	70 05	23 46	1. 01	1. 01	−0. 7
49		0944	70 10	24 10	1. 58	—	−0. 5
50		1146	70 12	24 10	1. 96	—	−0. 7
51		1325	70 10	24 12	2. 22	2. 05	−0. 8
52		1700	70 15	24 24	1. 78	2. 42	−0. 6
53	10	1200	70 18	24 33	1. 23	1. 75	−0. 6
54		1517	70 14	24 16	2. 03	—	−0. 6
55		1700	70 14	23 53	1. 83	1. 81	−0. 7
56		1822	70 13	23 49	2. 31	—	−0. 4
57	11	0700	70 12	24 04	2. 01	2. 13	−1. 0
58		0854	70 14	23 59	2. 54	—	−0. 6
59		1034	70 15	24 04	1. 21	—	−1. 0
60		1300	70 14	24 18	1. 63	1. 50	−0. 9
61		1415	70 04	24 25	1. 44	—	−0. 8
62	12	0700	69 08	24 47	0. 47	0. 50	0. 5
63		1800	69 48	24 37	0. 19	0. 12	0. 3
64	13	0820	69 55	24 29	0. 30	0. 30	0. 2
65		1200	69 56	24 28	0. 38	0. 39	−0. 1
66		1930	69 57	24 30	0. 20	0. 20	−0. 1
67	14	0900	69 58	24 02	0. 32	0. 31	0. 2
68		1700	70 01	23 28	0. 19	0. 16	0. 3
69	15	0700	69 22	24 33	0. 22	0. 15	0. 3
70		1700	69 30	24 41	0. 25	0. 13	0. 7
71	16	0700	69 34	24 28	0. 63	0. 35	−0. 3
72		1200	69 47	24 15	0. 17	0. 25	0. 3
73		1700	69 59	24 16	0. 55	0. 49	0. 0
74	17	0700	70 01	23 43	0. 24	0. 21	−1. 3
75		1300	70 14	24 18	1. 16	1. 56	−0. 8
76		1700	69 28	24 49	0. 20	0. 27	0. 7
77	18	0700	68 00	33 17	0. 45	0. 36	0. 3
78		1300	68 10	37 06	0. 83	0. 51	−1. 1
79		1700	68 43	38 06	0. 90	0. 81	−1. 0
80	19	1200	67 59	36 19	0. 30	0. 32	0. 9
81		1700	68 00	33 45	0. 53	0. 43	0. 5
82	20	0700	68 11	34 08	0. 52	0. 42	0. 4
83		1200	68 31	35 03	0. 85	0. 91	0. 1
84		1700	68 07	34 08	0. 51	0. 55	−0. 2
85	21	0700	67 58	37 28	0. 29	0. 34	0. 8
86		1200	68 02	38 47	0. 29	0. 22	0. 6
87		1700	68 03	38 30	0. 27	0. 28	0. 5
88	22	0700	68 11	36 14	0. 31	0. 30	0. 5
89		1200	68 00	34 06	0. 51	0. 50	−0. 5
90		1700	67 59	32 32	0. 24	0. 21	0. 4
91	23	0700	67 57	30 17	0. 46	0. 45	0. 4
92		1200	67 59	30 45	0. 38	0. 35	0. 3

Appendix 1 (continued).

Station No.	Date	Time	Latitude	Longitude	Chlorophyll *a* (mg/m³)		Water temp. (°C)
					(Surface)	(Subsurface)	
	1985						
93	Feb. 23	2310	67 59 S	33 13E	—	0. 25	0. 3
94	24	0700	67 59	34 54	0. 23	0. 25	0. 6
95		1800	67 58	32 30	0. 26	0. 23	0. 7
96	25	0700	68 16	33 53	0. 61	0. 50	−0. 5
97		1700	67 37	32 03	0. 25	0. 28	0. 5
98	26	0700	66 57	29 57	0. 15	0. 14	1. 1
99		1200	66 59	29 31	0. 15	0. 14	1. 0
100		1700	66 58	26 49	0. 15	0. 15	0. 9
101	27	0700	65 07	25 01	0. 18	0. 20	1. 4
102		1200	64 57	25 18	0. 20	0. 18	1. 5
103		1700	64 56	27 19	0. 39	0. 34	1. 5
104	28	0700	65 00	33 45	0. 25	0. 21	1. 5
105		1200	65 07	34 46	0. 30	0. 25	1. 3
106		1700	64 59	36 30	0. 25	0. 21	2. 4
107	Mar. 1	1200	64 56	40 21	0. 38	0. 45	1. 0
108		1700	64 49	40 35	0. 45	0. 38	1. 1