Proc. NIPR Symp. Polar Biol., 2, 9–15, 1989

A PHYTOPLANKTON BLOOM UNDER SEA ICE RECORDED WITH A MOORED SYSTEM IN LAGOON SAROMA KO, HOKKAIDO, JAPAN

Mitsuo FUKUCHI[1], Kentaro WATANABE[1], Atsushi TANIMURA[1], Takao HOSHIAI[1], Hiroshi SASAKI[2], Hiroo SATOH[3] and Yukuya YAMAGUCHI[4]

[1]*National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173*
[2]*Faculty of Agriculture, Tohoku University, 1–1, Tsutsumidori-Amamiyamachi, Sendai 980*
[3]*Tokyo University of Fisheries, 5–7, Konan 4-chome, Minato-ku, Tokyo 108*
[4]*College of Liberal Arts, Saitama University, 255, Shimo-Ookubo, Urawa 338*

Abstract: A phytoplankton bloom under the fast ice formed in a lagoon, Saroma Ko, Hokkaido, Japan, was recorded with a long-term chlorophyll-measuring buoy moored at 3 m of water depth of 6 m for 161 days from December 1986 to May 1987. A total of 1938 sets of time series data (*in situ* chlorophyll *a*, temperature and depth) at two-hour intervals were obtained. Chlorophyll *a* was low (less than 1 μg/*l*) under cold temperature below -1.5°C until middle March. From middle March to middle April, when the fast ice still covered the lagoon surface, chlorophyll *a* increased greatly to 4–5 μg/*l*. Thereafter it decreased to 2 μg/*l*.

1. Introduction

Lagoon Saroma Ko is located on the Okhotsk coast of Hokkaido, Japan, which is known as the southernmost area of seasonal sea ice distribution in the northern hemisphere. Lagoon Saroma Ko is also known as one of the intensive aquaculture areas for oyster and scallop. Extensive investigations on the phytoplankton productivity estimation of lagoon water have been carried out by Hokkaido Abashiri Experimental Fisheries Station. These works, however, are mostly concentrated on spring-summer-autumn seasons, when the seasonal sea ice is not formed. A year-round observation on chlorophyll *a* abundance is essential to evaluate the annual productivity of the lagoon. In the past winters, however, only a few works by HOSHIAI and FUKUCHI (1981) and SATOH *et al.* (1989) were done dealing with the colored layer of fast ice.

Recently, FUKUCHI *et al.* (1988) succeeded in observing a time series variation of chlorophyll *a* concentration for 47 days with a chlorophyll-measuring buoy in antarctic waters. We deployed the same buoy for continuous measurement of chlorophyll *a* in lagoon Saroma Ko throughout the ice-forming period and detected the early spring bloom of phytoplankton before the sea ice melting.

2. Materials and Methods

A prototype of the chlorophyll-measuring bouy was capable of operating for 3 months at one-hour intervals (see FUKUCHI and HATTORI, 1988; FUKUCHI *et al.*, 1988). A minor modification in sampling intervals, *e.g.* 2 h, enables the bouy to operate for 6 months. The buoy was equipped with 3 sensors of fluorescence, temperature and pressure.

The modified buoy was deployed at Station A off Toetoko in lagoon Saroma Ko (see Fig. 1 in SATOH *et al.*, 1989) on December 9, 1986. The bouy was directly tied on a ground rope, which was a part of scallop-farming facilities (Fig. 1). Water depth at Station 1 is 6–7 m and the sensors of the buoy are positioned at 3–4 m depth. The buoy was recovered on 20 May 1987.

Lagoon surface was completely covered with fast ice on January 16, 1987, and opened completely on April 17, 1987. These date were read from the records by the Nakayubetsu Fisheries Cooperative located beside lagoon Saroma Ko.

In addition to the buoy observations, water samplings were also carried out on the days of buoy deployment and recovery, 3 times during the fast ice coverage (February 12, 21–22 and March 7–8, 1987). Chlorophyll *a* and phaeopigment concentrations were measured with a fluorometric method (STRICKLAND and PARSONS, 1972), using a HITACHI model 320 spectrofluorometer. Pigment ratio was calculated as a percentage of chlorophyll *a* to the sum of chlorophyll *a* and phaeopigments. An aliquot of each water sample was preserved in 1% buffered formalin sea water for the later analysis of phytoplankton species composition.

Fluorescence intensity recorded by the buoy was converted into chlorophyll *a* concentration based on the following equation, which was established by comparisons

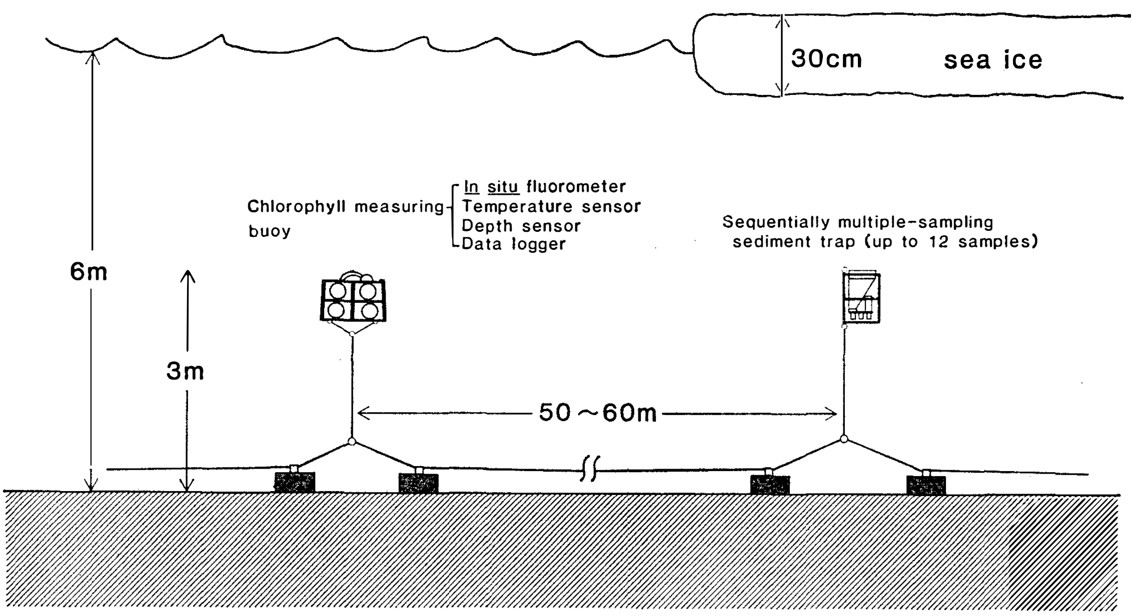

Fig. 1. Mooring array of the chlorophyll-measuring buoy and the sediment trap in a lagoon, Saroma Ko, Hokkaido, Japan.

of *in vivo* fluorescence values with actual chlorophyll *a* concentrations of the lagoon water in May 1987:

$$\text{chl. } a = 10^{(0.415V-1.133)},$$

where chl. *a* is chlorophyll *a* concentration in μg/*l* and *V* is fluorescence intensity expressed in volts.

The samples obtained with the traps deployed concurrently as seen in Fig. 1 will be dealt with in a separate paper.

3. Results and Discussion

Chlorophyll *a* concentration and pigment ratio determined on water samples are summarized in Table 1. Chlorophyll *a* concentrations were less than 1 μg/*l* except for one value of 1.37 μg/*l* at 6 m depth on February 12. On December 9, chlorophyll *a* values were about 0.6 μg/*l* from 0 to 6 m depths. Throughout the fast ice forming period from February 12 to March 8, chlorophyll *a* values ranged in 0.2–0.6 μg/*l*. After the fast ice melted, chlorophyll *a* were 0.4–0.8 μg/*l* on May 20.

HOSHIAI and FUKUCHI (1981) also reported low chlorophyll *a* values of 0.1–0.2 μg/*l* in February of 1978 and 1980. While the present results are slightly higher than those in 1978 and 1980, any conspicuous increase of chlorophyll *a* concentration could not be read in Table 1.

Electricity of the buoy, though prepared for 6 months operation, expired on May 19, one day prior to the recovery on May 20. Therefore, the buoy recorded 1939 sets of data at two-hour intervals from 1000 local time (LT) on December 9, 1986, to 2000 LT on May 19, 1987. Those data recorded over 161 days on depth, temperature and chlorophyll *a* are shown in Fig. 2, in which the dates of water samplings as well as the period of fast ice coverage are also illustrated.

Continuous observations on chlorophyll with moored instruments were firstly carried out by WHITLEDGE and WIRICK (1983, 1986) for 6–11 days off Long Island, New York. FUKUCHI *et al.* (1988) succeeded in obtaining time series data over 47 days in Breid Bay, Antarctica. The present record over 161 days thus appears to extend the operable range of the moored fluorometer.

Table 1. Chlorophyll a concentration (μg/l) at Station 1 in lagoon Saroma Ko. Pigment ratio percentage of chlorophyll a *to the sum of chlorophyll* a *and phaeopigment is in parentheses.*

Depth (m)	Dec. 9 1986	Feb. 12 1987	Feb. 21–22 1987	Mar. 7–8 1987	May 20 1987
0	0.63 (53)	0.22 (43)	0.46 (61)	0.60 (81)	0.43 (56)
1.5	—	—	—	0.63 (82)	—
3.0	0.61 (55)	0.26 (50)	0.30 (54)	0.39 (76)	0.48 (54)
6.0	0.61 (58)	1.37 (79)	0.16 (44)	0.22 (58)	0.75 (62)

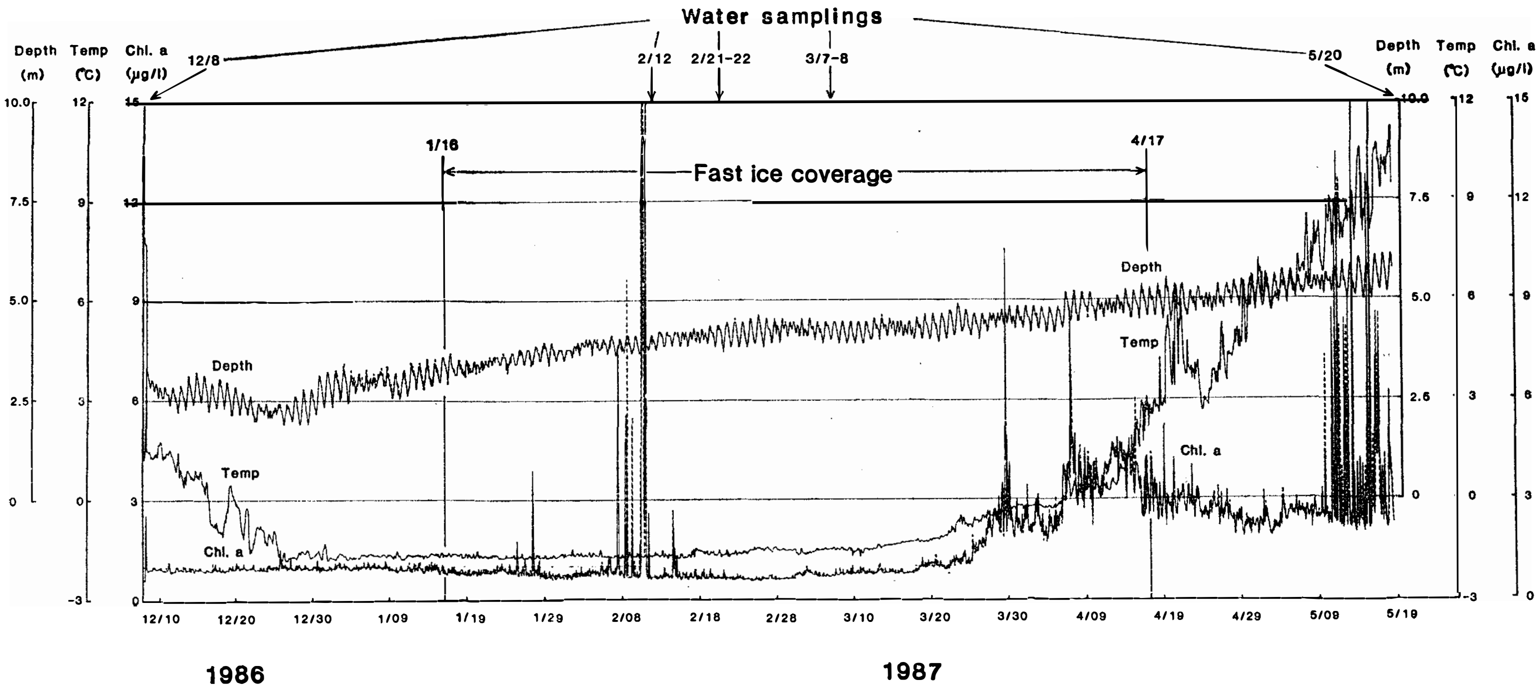

Fig. 2. Time series data over 161 days on depth, temperature and chlorophyll a *between 1000, 9 December 1986 and 2000, 19 May 1987 in a lagoon, Saroma Ko, Hokkaido, Japan.*

The depth of the buoy changed periodically. Its daily range was within 1.0 m and might be caused by tidal movements. The shift of average depth from 3 m in December to 6 m in May does not mean the actual deepening of the buoy, but it seems to be due to an electrical drift of the pressure transducer itself, because the electric circuit of the pressure transducer was adjusted to the deep water (0–300 m range) for the last experiment in the Antarctic.

Water temperature was about +1.5°C on December 9 and decreased to about −1.5°C in late December. On the decreasing course, temperature fluctuated widely; it changed 1.0°C within a day on December 18 and 21. Temperature showed stable as low as less than −1.7°C in January and early February. From middle February, temperature started to increase gradually to −1.5°C in middle March. Thereafter, it increased steadily to −0.5°C in late March and to 0°C in early April. Water temperature rose above 0°C prior to the complete disappearance of fast ice. After the fast ice melting, temperature increased steeply to 11°C in middle May, while temperature showed again a large variability on the last course.

Among lower chlorophyll *a* concentrations less than 1.0 μg/*l* during the period from the beginning of mooring experiment to middle March, some extraordinarily high values were recorded around late January and early-middle February.

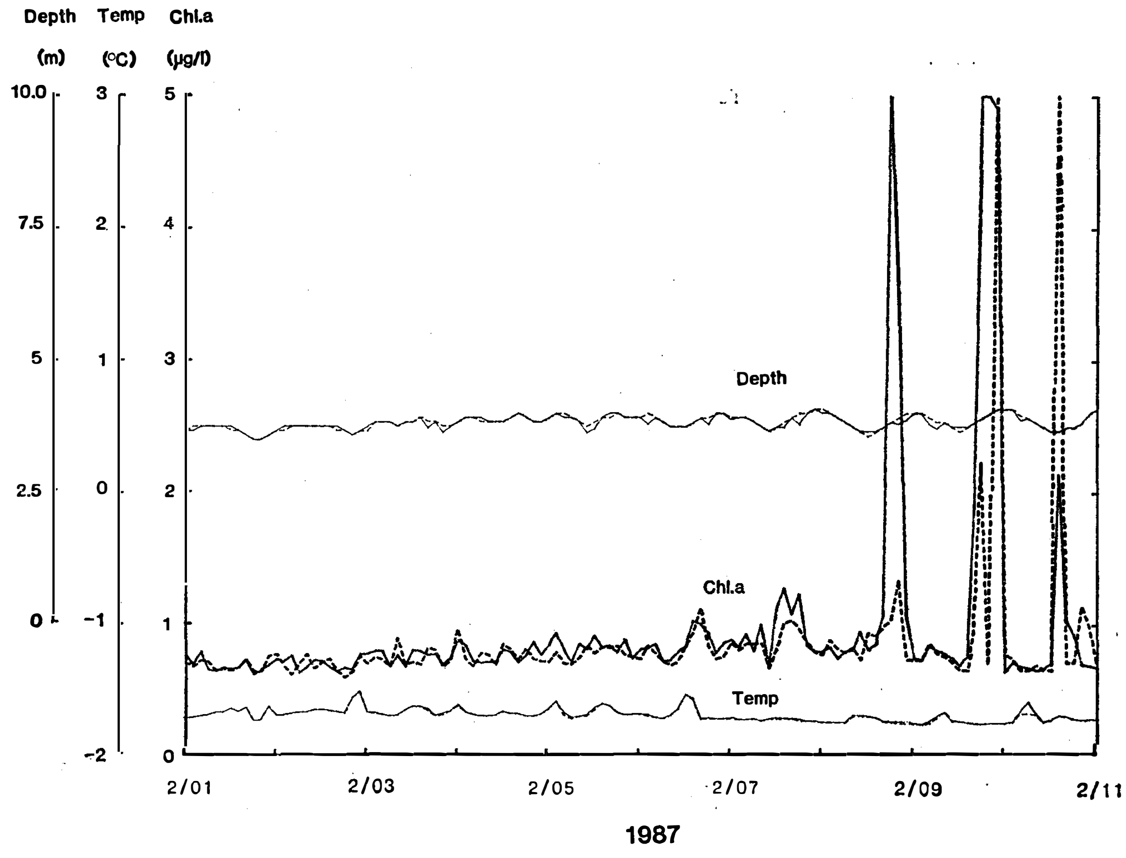

Fig. 3. Time series data over 10 days on depth, temperature and chlorophyll a between 1 and 10 February 1987 in lagoon Saroma Ko, Hokkaido, Japan. Data obtained before, and after, washing the window of fluorometer are shown by strait, and dashed lines, respectively.

Time series data for a 10-day period in early February is reproduced in Fig. 3 to show examples of these very high values. Three high values are seen between February 8 and 11. Data obtained before and after washing of the window of fluorometer are shown by strait and dashed lines, respectively. In the case of a high value on February 8, the chlorophyll *a* concentration decreased to the preceding level after the window was washed. Therefore, it is easy to consider that the high value caused by some fouling organisms was decreased after the elimination of organisms by washing. On the other hand, in the case of the other high value on February 10, a much higher value was still recorded after washing.

At present, we do not know why those extraordinarily high values were recorded. The epontic algae are known to grow on the surface of eelgrass at the bottom of the lagoon, as well as around the farming facilities. Also, the surface of the buoy was coated with these algae when the buoy was recovered in May. These algae might have interfered temporally the normal fluorometric measurement.

From middle March, chlorophyll *a* concentration started to increase rapidly to about 3.0 μg/*l* at the end of March and reached 4–5 μg/*l* in early-middle April. Thereafter, it decreased slightly to 2 μg/*l* toward the end of April. In May, many spikes of the extraordinarily high values were recorded but their general tendency and reason were again not clearly determined. Excluding those spikes, however, it is obviously seen in the background values that a bloom-like increase of chlorophyll *a* occurred from late March to middle April while the lagoon surface was still covered with the fast ice (Fig. 2).

In the antarctic fast ice area, FUKUCHI *et al.* (1984) obsreved phytoplankton bloom under the fast ice and reported the maximum chlorophyll *a* concentration was as much as 2.0–11.3 μg/*l*. Comparing to these values, values observed in the blooming period in lagoon Saroma Ko are small.

Acknowledgments

We express our sincere thanks to Prof. M. AOTA of the Sea Ice Research Laboratory, Hokkaido University, for his kind support to the present work. We also thank Mr. M. OOTOMO and Mr. MIURA of Nakayubetsu Fisheries Cooperative for providing logistic support.

References

FUKUCHI, M. and HATTORI, H. (1988): Continuous recording of chlorophyll *a* with a moored buoy system in Breid Bay, Antarctica, December 1985–February 1986. JARE Data Rep., **136** (Mar. Biol. 12), 30 p.

FUKUCHI, M., TANIMURA, A. and OHTSUKA H. (1984): Seasonal change of chlorophyll *a* under fast ice in Lützow-Holm Bay, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **32**, 51–59.

FUKUCHI, M., HATTORI, H., SASAKI, H. and HOSHIAI, T. (1988): A phytoplankton bloom and associated processes observed with a long-term moored system in antarctic waters. Mar. Ecol., Prog. Ser., **45**, 279–288.

HOSHIAI, T. and FUKUCHI, M. (1981): Sea ice colored by ice algae in a lagoon, Lake Saroma, Hokkaido, Japan. Nankyoku Shiryô (Antarct. Rec.), **71**, 113–120.

SATOH, H., YAMAGUCHI, Y., WATANABE, K., TANIMURA, A., FUKUCHI, M. and ARUGA, Y. (1989): Photosynthetic nature of ice algae and their contribution to the primary production in lagoon Saroma Ko, Hokkaido, Japan. Proc. NIPR Symp. Polar Biol., **2**, 1–8.

STRICKLAND, J. D. H. and PARSONS, T. R. (1972): A practical handbook of seawater analysis, 2nd ed. Fish. Res. Bd. Can. Bull., **167**, 310 p.

WHITLEDGE, T. E. and WIRICK, C. D. (1983): Observations of chlorophyll concentrations off Long Island from a moored *in situ* fluorometer. Deep-Sea Res., **30** (3A), 297–309.

WHITLEDGE, T. E. and WIRICK C. D. (1986): Development of a moored *in situ* fluorometer for phytoplankton studies. Lecture Notes on Coastal and Estuarine Studies, 17. Tidal Mixing and Plankton Dynamics, ed. by T. BOWMAN *et al.* Berlin, Springer, 449–462.

(*Received May 31, 1988; Revised manuscript received September 24, 1988*)