—研究ノート—
Scientific Note

Vertical flux of chlorophyll *a* under fast ice near Syowa Station, Antarctica, in austral summer, 1991/1992

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1991/1992年夏季の南極昭和基地周辺の定着氷下における クロロフィル*a*の鉛直フラックス

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要旨: 1992年1月6日から2月6日の期間，南極昭和基地周辺の定着氷下の水深25あるいは30 mにセジメントトラップを設置し，沈降する粒子を補足した．得られた試料を基に，クロロフィル*a*（Chl *a*）のフラックスを見積もり，夏季の植物プランクトン大増殖後の現存量低下に対する，沈降による除去の寄与率を評価した．セジメントトラップより上層の積算Chl *a*濃度は，1月中旬に最大に達した．Chl *a*フラックスは，Chl *a*濃度が最大に達した後に高くなった．上層のChl *a*濃度減少期における，1日当りの減少率は，8.71–10.4 mg Chl *a* $m^{-2}day^{-1}$であった．この時，Chl *a*フラックスは，上層で起こったChl *a*減少率の3.6–4.0%に過ぎなかった．このことは，植物プランクトンの沈降が，大増殖後にみられる現存量低下の大きな要因ではないことを示す．

Abstract: Sinking particles were collected using sediment traps, which were deployed at depths of 25 or 30 m under fast ice near Syowa Station, Antarctica, from January 6 to February 6, 1992. Using the samples, fluxes of chlorophyll *a* (Chl *a*) were estimated and the contribution of algal sinking to the decrease of phytoplankton biomass after the summer bloom was evaluated. The Chl *a* concentration, integrated above the depths at which the sediment traps were deployed, reached a maximum in mid-January. The Chl *a* flux became high after the maximum of the concentration was recorded. In the Chl *a* decreasing phase, daily decreasing rates of the Chl *a* concentrations in the water columns were 8.71–10.4 mg Chl *a* $m^{-2}day^{-1}$. During this period the Chl *a* fluxes accounted for only 3.6–4.0% of the decreasing rates. These observations imply that algal sinking is not the major process of phytoplankton biomass decrease after the summer bloom.

1. Introduction

In polar regions, ice algae and phytoplankton achieve maximum primary production in summer when incident irradiation is at its highest. In mid to late summer, when

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ice algal biomass declines, phytoplankton production is a major food source for pelagic herbivores in the ecosystem under the fast ice (Smith and Sakshaug, 1990). Temporal changes in phytoplankton abundance under the fast ice near Syowa Station (69°00′S, 38°35′E) in summer have been investigated by several authors (Hoshiai, 1969; Fukuchi *et al*., 1984; Satoh *et al*., 1986, 1991; Odate and Fukuchi, 1996; Ishikawa *et al*., 2001). They showed that phytoplankton biomass usually reaches a maximum in mid-January or early February and decreases by mid-February or March. However, it is not obvious what processes cause the decrease in phytoplankton biomass after summer blooms in polar regions. One of the possible processes is the sinking loss of phytoplankton cells from the surface layer. The present study aims to evaluate the contribution of algal sinking to decrease of phytoplankton biomass in the surface layer, based on sediment trap samples collected in the austral summer of 1991/1992.

2. Materials and methods

Sinking particles were collected using sediment traps, which were deployed at the depths of 10, 30, 50, and 200 m at Site A, 10, 25, 30 m at Site B, and 10, 20, and 25 m at Site C (Fig. 1). The opening of the trap was 186 cm^2. The detailed dimensions of the trap have been described by Ishikawa *et al.* (2001). The sea surface of the sampling area was covered with fast ice during the observation period. The thickness of sea-ice was 2.0 m at Site A on January 6, 2.7 m at Site B on January 9, and 2.5 m at Site C on January 7. Recovery and redeployment were conducted at 4–10 day intervals

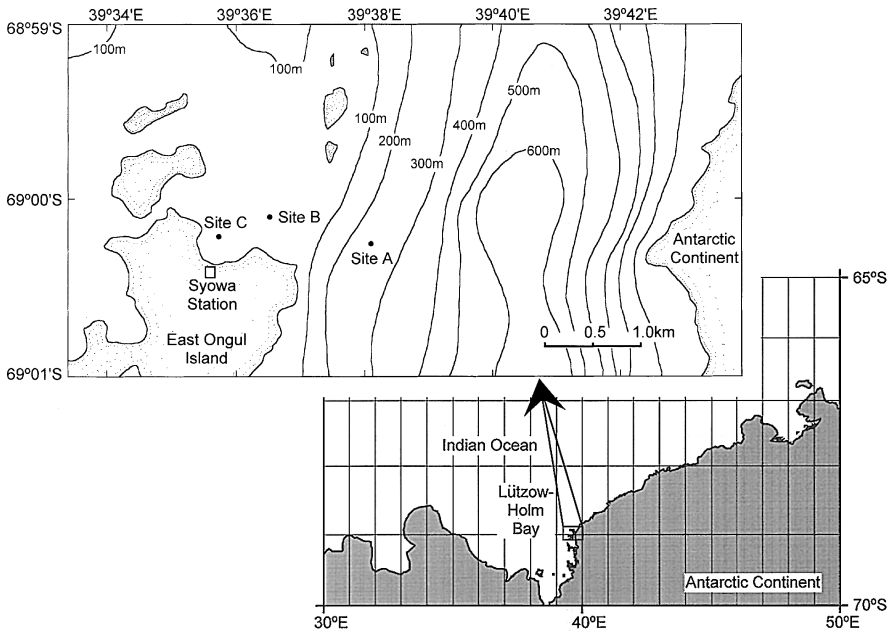

Fig. 1. Location of sampling sites in Lützow-Holm Bay, Antarctica. Submarine topography is redrawn after Fujiwara (1971).

between January 6 and February 6, 1992. In the present study samples from 30 m at Site A, 25 m at Site B, and 25 m at Site C were used. The other samples were provided for determination of particulate organic carbon (POC) fluxes, which have been published by Suzuki *et al.* (1998).

Three subsamples (20–100 m*l*) from the sample bottle (500 m*l*) were filtered through Whatman GF/F filters (25 mm diameter) with less than 100 mm Hg of vacuum pressure. The filter was put into a glass vial, which contained 6 m*l* of N,N-dimethylformamide (Suzuki and Ishimaru, 1990), and pigments were extracted in the dark at -20°C. The concentration of chlorophyll *a* (Chl *a*) was determined fluorometrically using a Turner Design Model 10R Fluorometer (Parsons *et al*., 1984), which had been calibrated with pure Chl *a* (Sigma Chemical Co.). The concentration in the sample bottle was converted into the total amount of Chl *a* flux (mg $m^{-2}day^{-1}$). Temporal variations of Chl *a* concentration in the water columns have been shown by Odate and Fukuchi (1996).

3. Results and Discussion

Our previous study (Odate and Fukuchi, 1996) has revealed that a considerable increase of Chl *a* concentration occurred at <30 m depth. Consequently, sediment traps deployed at depth of 25 or 30 m could collect the sinking phytoplankton during a bloom in the upper layers. In the present study, the observation periods are divided into four phases, depending upon the temporal variations in the depth-integrated Chl *a* concentrations: Phase I, with constant Chl *a* concentration before increase (~January 12 at Site A and ~January 16 at Site B); Phase II, with increasing Chl *a* (January 12–17 at Site A and January 16–23 at Site B); Phase III, with decreasing Chl *a* (January 17–28 at Site A and January 23–28 at Site B); and Phase IV, with constant Chl *a* after decrease (January 28~ at Sites A and B) (Fig. 2).

At the beginning of the observations (Phase I) the Chl *a* fluxes were 0.07 mg m^{-2} day^{-1} at Site A and 0.04 mg $m^{-2}day^{-1}$ at Site B (Fig. 2). These daily amounts corresponded to 0.1% or less of the depth-integrated Chl *a* concentration. Similar low flux (0.04 mg $m^{-2}day^{-1}$) was noted at Site C from January 7 to 13, though the results are not shown in Fig. 2 because the sediment trap was deployed only between January 7 and 13.

The Chl *a* flux became four to 15-fold larger in Phase II than in Phase I (Fig. 2). The mean Chl *a* fluxes were 0.26 mg $m^{-2}day^{-1}$ at Site A and 0.34 mg $m^{-2}day^{-1}$ at Site B. The daily amounts of sinking loss corresponded to less than 0.5% of the depth-integrated Chl *a* concentration in Phase II.

During Phase III the mean Chl *a* fluxes were 0.31 mg $m^{-2}day^{-1}$ at Site A and 0.42 mg $m^{-2}day^{-1}$ at Site B (Table 1), which were larger than those in Phase II although the depth-integrated Chl *a* concentrations decreased. It was estimated that less than 0.5% of the depth-integrated Chl *a* concentration sank from the surface water columns every day in Phase III.

In the present study the highest flux occurred in Phase IV. That is, 0.38 mg m^{-2} day^{-1} at Site A between January 27 and February 1 and 0.93 mg $m^{-2}day^{-1}$ at Site B between January 31 and February 6. These fluxes were observed about 10 days after the days when the maximum depth-integrated Chl *a* concentration occurred. During

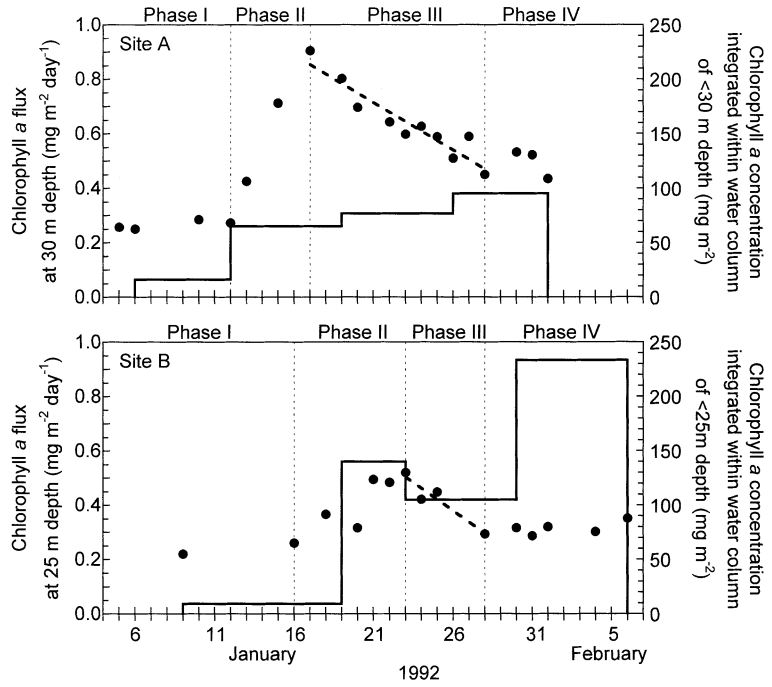

Fig. 2. Temporal variations in vertical fluxes at the depths of 30 m at Site A and 25 m at Site B (histogram). Depth- integrated concentrations of chlorophyll a *within the water columns are shown at Sites A (<30 m) and B (<25 m) (closed circles). Data on chlorophyll* a *concentrations were obtained from Odate and Fukuchi (1996). Depending on the temporal variations of chlorophyll* a *concentrations, the observation periods are divided into Phases I–IV (see text). The broken line indicates the regression line between chlorophyll* a *concentration and day for each site.*

Table 1. Mean chlorophyll a *fluxes at the depths of 30 m (Site A) and 25 m (Site B) during the decreasing period (Phase III in Fig. 2) and mean daily decrease of chlorophyll* a *concentration in the surface water columns (<30 m at Site A and <25 m at Site B) (slopes of broken lines in Fig. 2).*

Site	Decreasing period	Flux (mg Chl *a* $m^{-2}day^{-1}$)	Decrease (mg Chl *a* $m^{-2}day^{-1}$)	Flux/Decrease
A	January 17–28, 1992	0.31	8.71	3.6%
B	January 23–28, 1992	0.42	10.4	4.0%

Phase IV the Chl *a* concentrations integrated within the water columns did not decrease (109–133 mg m^{-2} at Site A and 72–88 mg m^{-2} at Site B). The daily Chl *a* fluxes accounted for about 0.3% (Site A) and 1.0% (Site B) of the depth-integrated Chl *a* concentrations in Phase IV on the average.

The present Chl *a* fluxes were slightly lower than previously reported for Lützow-Holm Bay (Sasaki and Hoshiai, 1986). Suzuki *et al.* (1998) reported POC fluxes at

depths of 10 and 50 m at Site A and 10 and 30 m at Site B. Interpolated POC fluxes were 12–24 mgC $m^{-2}day^{-1}$ at 30 m depth at Site A and 7–24 mgC $m^{-2}day^{-1}$ at 25 m depth at Site B. Comparing the interpolated POC fluxes to our Chl *a* fluxes, the POC: Chl *a* ratio became 184–190 when the depth-integrated Chl *a* concentration was low in Phase I and the ratios were between 29 and 90 when Chl *a* concentration increased. Since similar POC: Chl *a* ratios were reported for sinking particles collected under sea-ice in the Weddell Sea by Thomas *et al.* (2001), the present Chl *a* flux values do not seem to be low, considering the magnitude of the POC flux. Indeed, one to two orders of magnitude lower Chl *a* fluxes than those in the present study have been observed in Terra Nova Bay (Pusceddu *et al*., 1999). The regional and interannual variations may result from differences of environmental conditions as well as the structure of the pelagic community.

Decrease of the depth-integrated Chl *a* concentration in the surface water column during Phase III indicated the termination of the phytoplankton bloom. In this phase the depth-integrated Chl *a* concentrations decreased at 8.71 mg $m^{-2}day^{-1}$ at Site A and 10.4 mg $m^{-2}day^{-1}$ at Site B (Table 1), which were slopes of regression lines (broken lines in Fig. 2). During the same period the mean Chl *a* fluxes were 0.31 mg $m^{-2}day^{-1}$ at Site A and 0.42 mg $m^{-2}day^{-1}$ at Site B (Table 1). These fluxes accounted for 3.6 and 4.0% of decreases of Chl *a* concentration in the surface water columns of Sites A and B, respectively. These results imply that sinking loss of phytoplankton cells is not the major process for the decrease of phytoplankton biomass in the late phase of blooms, suggesting that other processes are important for decrease of the phytoplankton biomass; specifically, grazing by zooplankton (DiTullio and Smith, 1996; Dunbar *et al*., 1998) and/or horizontal advection (Bunt, 1968) are considered important.

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