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Author(s)	IINUMA, Tomoaki; IMAI, Keiri; ODATE, Tsuneo; MAITA, Yoshiaki
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5. Fluctuations of Nutrients and Primary Production Structure during Winter and Spring in Funka Bay

Tomoaki IINUMA, Keiri IMAI, Tsuneo ODATE[1] and Yoshiaki MAITA

Faculty of Fisheries, Hokkaido University, Hakodate, Hokkaido 041-8611, Japan
[1] *Present address: National Institute of Polar Research 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173, Japan*

Introduction

Prominent phytoplankton blooms, dominated by a diatom community, occur in the vicinity of Funka Bay in early spring, when an oceanic water mass, the Oyashio water, flows into the bay (Nishihama et al., 1976; Nishihama and Kawamada, 1979; Nakata, 1982). The inflow of the Oyashio water is believed to affect the physical and chemical environment of the water column of this bay (Ohtani and Akiba, 1970; Tanaka, 1984). In this paper, we further discuss the functional roles of the Oyashio water in the development of phytoplankton blooms in Funka Bay, based on observations made during the spring of 1996 and 1997. The data show the temporal and spatial changes of chlorophyll *a* and nutrients.

Materials and Methods

Oceanographic observations and sea water sampling were conducted between January and April 1996 and 1997, using the R/V *Ushio Maru*. Sea water samples at ten meter intervals from the surface to the bottom were collected using Niskin bottles at three stations (outside, the mouth, and inside the bay). Chlorophyll *a* concentrations were determined fluorometrically using a Turner Design Model 10R Fluorometer (Parsons et al., 1984). A 100 ml aliquot from each depth was frozen for later analysis for nitrate (plus nitrite) using an AutoAnalyzer II (Technicon Co.). Salinity and temperature were determined using a CTD (Sea-Bird SBE 19). Definition of water masses followed that of Ohtani and Kido (1980). Water temperature and salinity characteristics of the water masses are as follows: winter Funka Bay water (Fw) is >3°C and >33.3, Oyashio water (Ow) is 2-3 °C and 33.0-33.3, and Coastal Oyashio Water diluted with ice melting water (Oi) is <2°C and <33.0.

Results

Oceanographic Structure

Figure 1 shows a vertical section of salinity for the 1996 sampling period. The Ow was observed in the top 60 m (outside) on February 8, and reached in the top 20 m at the mouth of the bay on February 20. The inflow of the Ow into the bay occurred in the top 5 m between February 20 and March 6. On the other hand, the Oi was observed in the top 20 m (outside) on February 20 and in the top 20 m (inside) on March 6. The vertical section of

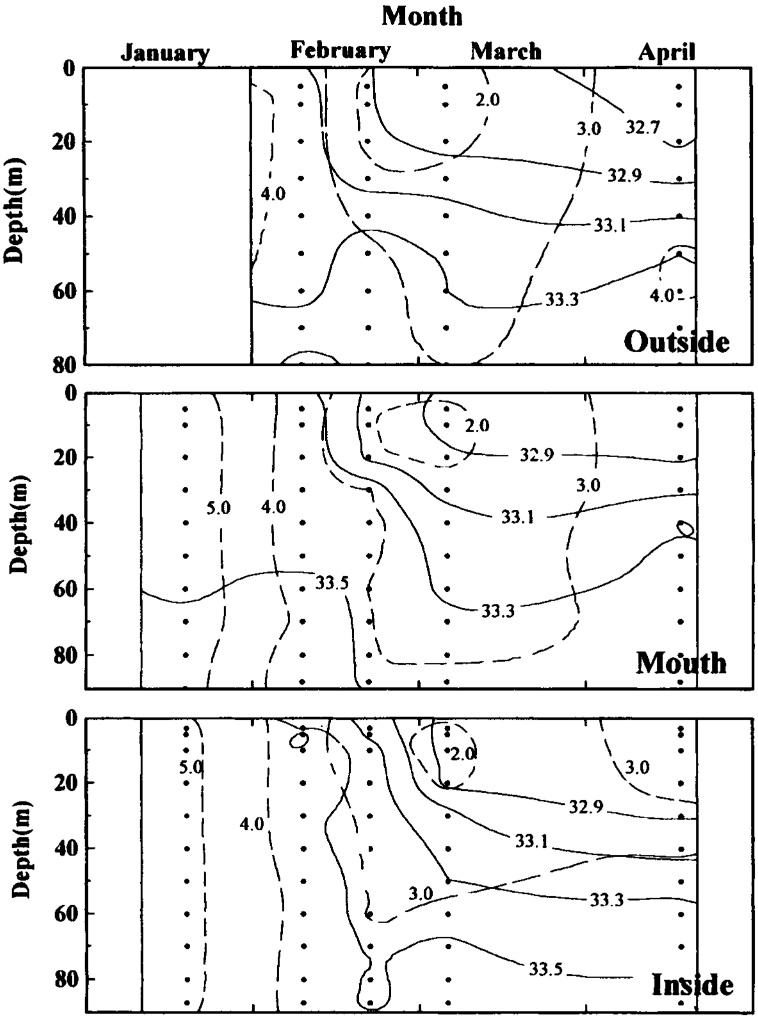

Fig.1. Vertical distributions of salinity and temperature at 3 stations (outside, mouth and inside the bay) from January to April in 1996. (thin line: salinity, broken line: temperature).

temperature and salinity for the 1997 sampling period is shown in Fig. 2. On February 27, 1997, the Ow was first observed in the top 70 m (outside) and 40 m (mouth). The Ow was observed in the top 30 m (inside) on March 17. The timing of the Ow inflow was about two weeks later in 1997 than in 1996. The Oi was not observed during the 1997 sampling period.

Distribution of Nutrients

The nitrate concentration gradually decreased during the 1996 sampling period. The concentration of nitrate (plus nitrite) exceeded 10.0 μM on January 18, 1996, throughout the

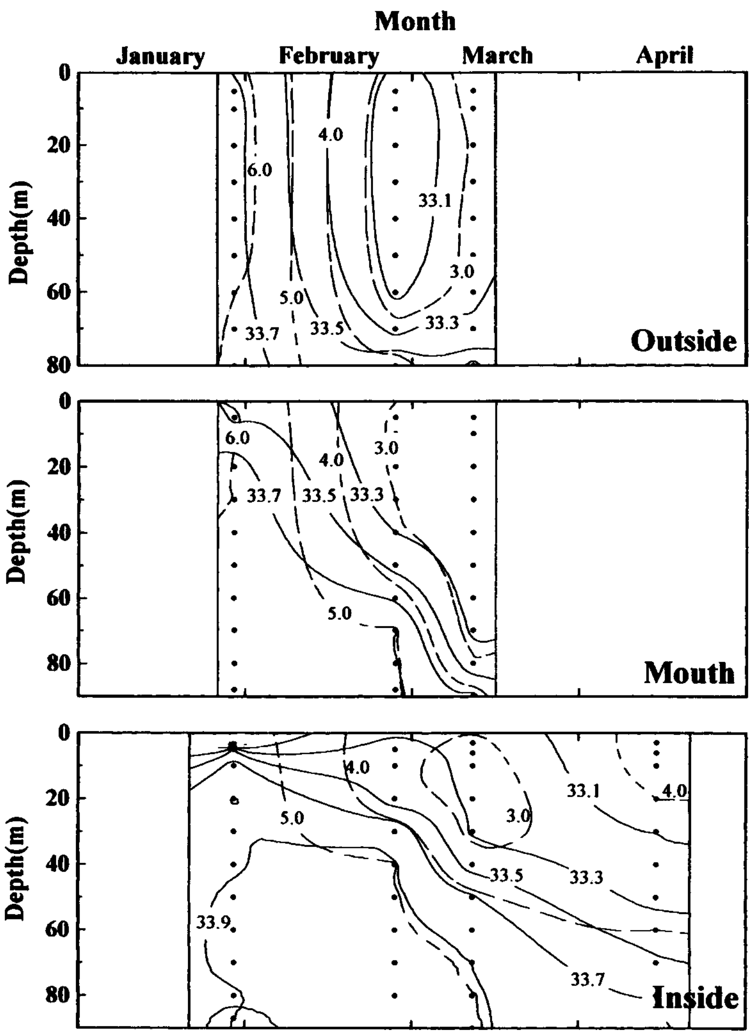

Fig. 2. Same as Fig. 1 except for in 1997.

water column at all stations. On February 8, the concentration was about 11.0 μM in the top 60 m (outside), between 7.0 and 9.0 μM in the top 50 m (mouth), 7.0 μM in the top 60 m (inside). On February 20, the concentration was similar to that found in the previous sampling period at all stations. On March 6, the concentration was 10.0 μM in the top 60 m (outside), between 5.0 and 7.0 μM in the top 30 m (mouth), and between 5.0 and 7.0 μM in the top 30 m (inside). Nitrate concentration was more than 10.0 μM on January 28, 1997, throughout the water column at all stations. This concentration was similar to last year's observation. On February 26, the concentration was 12.0 μM throughout the water columns (outside), 13.0 μM in the top 50 m (mouth), and between 9.0 and 10.0 μM in the top 50 m (inside). On March 17, the concentration decreased to 5.0 and 8.0 μM in the top 30 m at all stations.

Distribution of Chlorophyll a

The chlorophyll *a* concentration gradually increased during the sampling period of 1996. On February 8, 1996, chlorophyll *a* concentration was between 1.5 and 2.5μg/*l* at all stations. The concentration exceeded 2.0μg/*l* inside the bay. On February 20, chlorophyll *a* maximum layer occurred at 30 m depth in the Ow (3.1μg/*l*) (outside). At the same time, the maximum layer, with a higher concentration than found outside, occurred at 30 m depth in Ow (6.0μg/*l*) (mouth) and at 20 m depth in the Fw (7.4μg/*l*) (inside). On March 6, the maximum concentration increased to 7.0μg/*l* (outside), 18.0μg/*l* (mouth) and 11.3μg/*l* (inside). These layers of maximum concentration occurred in the Ow or Oi. For the 1997 sampling, low chlorophyll *a* concentrations (< 1.0μg/*l*) were found at all stations on January 28 and February 26. On March 17, the concentration of chlorophyll *a* rapidly increased. The highest concentration was 5.0μg/*l* (outside), 9.5μg/*l* (mouth) and 3.4 (inside). Chlorophyll *a* concentrations increased tenfold at the mouth of the bay, but only doubled in the subsurface at the center of the bay. The peak of the bloom occurred later in 1997 than in 1996.

Chlorophyll a *and Nutrients*

The relationship between concentration of chlorophyll *a* and nitrate in the euphotic zone is shown in Fig.3. Correlation analyses revealed that the relationship between the concentration of chlorophyll *a* and nitrate was significant in the Fw in 1996 ($P < 0.05$, $r=-0.728$, $n = 27$), but not in 1997 ($P > 0.05$, $r = -0.321$, $n = 17$). In the Ow, the relationships were also significant for both years ($P < 0.05$, $r = -0.653$, $n = 11$ (1996); $P < 0.05$, $r = -0.817$, $n = 27$ (1997)). The slope was -0.79 and -0.86, respectively. A significant relationship was revealed in the Oi based on the data in 1996 ($P < 0.05$, $r = -0.854$, $n = 25$). Both slope of the Ow and Oi were significant ($P < 0.05$). It appears that phytoplankton abundance increased in the Fw, Ow, and Oi in 1996, but only in Ow in 1997.

Discussion

In general, spring blooms of phytoplankton occur in the water column when surface temperature has increased and thermal stratification develops. In the vicinity of Funka Bay, inflow of the less saline Oyashio water results in the stratification of water column triggering a phytoplankton bloom (Tanaka, 1984). The present study also showed that phytoplankton abundance increased in both water masses of the Ow and Oi. In 1996, the increase of phytoplankton abundance was also observed inside of the bay where the Fw had remained in early February. The first and second phytoplankton blooms developed in Ow and Oi, respectively. There was consequently a relatively high abundance of phytoplankton occurred in the bay from February to March. On the other hand, a phytoplankton bloom developed in

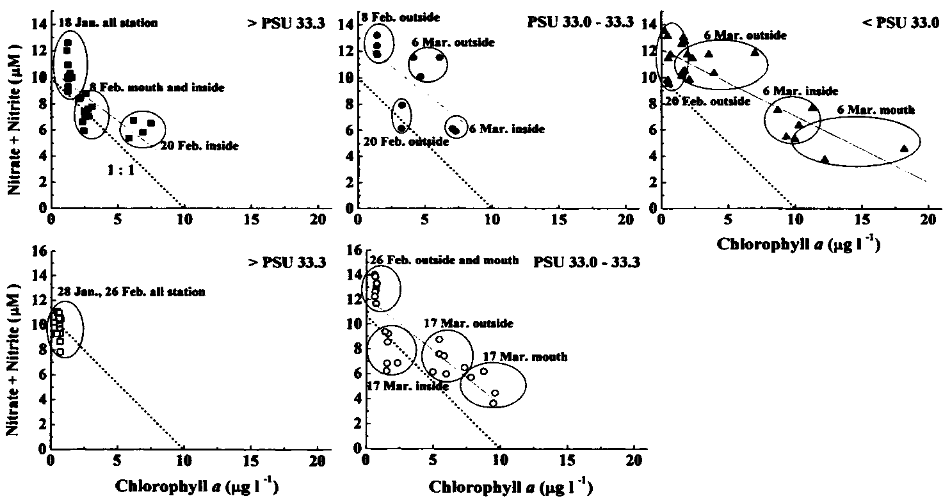

Fig.3. Relationship between nitrate plus nitrite and chlorophyll *a* in upper 40 m from January to March in both 1996 and 1997.

the Ow during the spring period of 1997, as it flowed into the bay in early March. The duration of high phytoplankton abundance was shorter in 1997 than in 1996. The relationship between standing stock of chlorophyll *a* and nitrate is generally 1:1, based on experimental field and laboratory studies with growing populations of diatoms (Parsons et al., 1978). The slope of temporal change of nutrients plotted against chlorophyll *a* is close to one in the Ow, but not in the Oi. This may be explained by a difference in phytoplankton activity or nutrient flux between Ow and Oi. Previous studies have shown that in spring, phytoplankton abundance begins to increase from inshore to offshore and from inside to outside of the bay (Yokouchi, 1984; Odate, 1987). These observations seem to agree with characteristics of the bloom in the Fw. The present study, however, showed that the Ow and Oi flowed into the bay, and phytoplankton abundance increased in both water masses. As a result, phytoplankton abundance was relatively high in the bay, where the water column had been stratified for some time, compared to outside the bay, where the water column had only just stratified. In the Funka Bay area, nutrient-rich Ow and Oi sequentially flow into the bay, so that the nutrient concentrations in the euphotic zone in the bay are maintained at high levels. The Ow and Oi inflow created suitable chemical and physical conditions for phytoplankton growth. Clearly, annual fluctuations in nutrients and the winter and spring primary production regimes are strongly affected by the inflow of the Ow and Oi into the bay.

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