Spatial Variability in Photosynthetic Characteristics of Ice Algae in Saroma-ko Lagoon, Hokkaido

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[Introduction]

Sea ice ecosystem consists of snow, sea ice, and sea water. In the sea ice ecosystem, brine channels in the sea ice are utilized as fundamental habitats of phytoplankton including different types of algal communities. Those trapped communities are developed as ice algal communities. Ice algal habitats are characterized by the physical structure of sea ice and also consistently vary in accordance with the development of sea ice.

The brine channels are formed in the sea ice during the formation of sea ice. The salinity and nutrient concentration in the brine channels at the bottom surface layer are several times higher than those in the underlying sea water. Light through snow and sea ice is much reduced and varied spatially due to heterogeneous distribution of brine channels. Ice algae can grow by acclimating to low irradiance to an extremely high biomass in the brine channels with high concentration of nutrients. The species composition, biomass, and the photosynthetic characteristics of ice algae can be highly variable due to the heterogeneous distribution of brine channels in the sea ice.

Saroma-ko Lagoon located on the southern limits of the Sea of Okhotsk. The seasonal sea ice is formed every year in Saroma-ko Lagoon in February and March. The ice season of an ice algal community is less than 3 months at most (Taguchi and Takahashi 1993). The size of horizontal patch of ice algal biomass has been reported as about 1 m^2 based on the analysis of chlorophyll *a* (Ronineau et al. 1997).

The objectives of the present study are to determine the spatial variability in the photosynthetic characteristics in relation to the species composition and biomass of an ice algal community and the environmental variables within in 1m^2.

[Material & Methods]

Samplings were conducted in the morning on March 5, 2010 at the station off Sakae-Ura, the east of Saroma-ko Lagoon, Hokkaido. A whole ice core of about 40 cm long was taken by a CRREL core samplar (Rand and Mellor 1985) at the four corners (St. A, B, C, and D) of 1 m^2 surface area. Each ice core was cut every 3 cm from the bottom of ice core to 9 cm long. Sliced ice core subsamples were melted in 300 ml of the filtered sea water.

Water temperature, salinity, and nutrients concentration were measured as the environmental variables. Water temperature and salinity were determined with a thermometer and salinometer, respectively. Nutrients were determined by using Auto Analyzer by a modification of the methods of Parsons et al. (1984).

Chlorophyll *a* concentration, enumeration, and identification of an ice algal community were examined as indexes of biomass of the ice algal community. Chlorophyll *a* was measured by HPLC (Head and Horne 1992, Suzuki and Ishimaru 1990). Enumeration and identification of the ice algal community were conducted by using counting chamber and an inverted microscope (Hasle 1978).

Chlorophyll *a* fluorescence was determined to study on the photosynthetic characteristics of an ice algal community by using a Water Pulse Amplitude Modulation (Water-PAM) (Heinz Walz GmbH, Effeltrich, Germany) (Serodio et al. 2005). PAM enables to measure maximum quantum yield (F_v / F_m) of photosystem II (PSII). Minimum and maximum fluorescences were defined as F_0 and F_m, respectively. A ratio of F_v to F_m of PSII was calculated from a following formula:
$F_v / F_m = (F_m - F_0) / F_m$ (Bulter & Kitajima 1975).

[Results & Discussions]

The spatial variabilities of chlorophyll *a* concentration and F_v/F_m in 1 m^2 area were analyzed in 3D graphs (Figs. 1, 2). Letters of A, B, C and D on X axis correspond the four corners (St. A, B, C, and D) of 1 m^2 respectively. The highest salinity and nutrient concentration were observed at the bottom sea ice. The highest salinity was 24.5‰ at the bottom of ice core at St. C. The highest concentration of NO_3, SiO_2, and PO_4 was 9.07μM at the bottom of ice core at St. B, 9.50μM at the bottom of ice core at St.C, and 0.30μM at the middle of ice core at St. B and D respectively (data are not shown). The highest chlorophyll *a* concentration was 18.0 mg・m^{-3} at St. D whereas the lowest concentration was 7.23 mg・m^{-3}at St. A (Fig. 1). The highest biomass of chlorophyll *a* was observed in accordance with the highest salinity and concentration of nutrients at the bottom surface layer of sea ice. Diatoms were the most dominant group of an ice algal community at four stations.

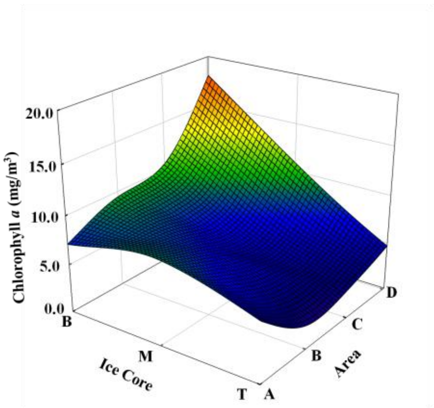

Figure 1. Spatial distribution of chlorophyll *a* concentration in the ice layers (Top, Middle, and Bottom) at the four corners (St. A, B, C, and D) of 1 m^2.

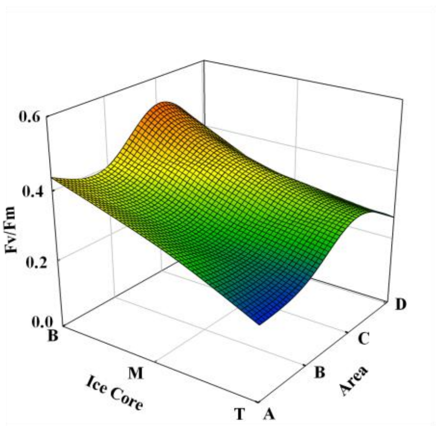

Figure 2. Spatial distribution of F_v/F_m in the ice layers (Top, Middle, and Bottom) at the four corners (St. A, B, C, and D) of 1 m^2.

Table 1. Analysis of correlation among salinity (Sal), nitrate (NO_3), chlorophyll *a* (Chl *a*) concentration, and F_v/F_m observed at the bottom surface layer of ice core. * and ** indicate a significance level at 0.05 and 0.01, respectively.

	Sal	NO_3	Chl *a*	F_v/F_m
Sal		0.40	0.82**	0.39
NO_3			0.56*	0.002
Chl *a*				0.12

The maximum quantum yield also indicated the maximum at the bottom surface layer of sea ice (Fig. 2). Among four stations, F_v/F_m was the highest (0.523) at St. C and the lowest (0.381) at St. D. Analyses of simple correlation among salinity, nitrate concentration, chlorophyll *a* concentration, and F_v/F_m indicate that F_v/F_m is least related with other variables (Table 1) although ice algal biomass can be controlled significantly by salinity and nitrate, which can be related with volume of brine as suggested by Nomura et al (2009). Based on the analysis by coefficient of variation, the highest variability was found in the spatial distribution of chlorophyll *a* concentration (0.382) whereas the lowest variability was observed in the spatial distribution of F_v/F_m (0.139).

In conclusion, the spatial variability in ice algal biomass can be high even within area of 1m^2, which can be caused by the heterogeneous distribution of brine volume in the sea ice. To the contrary to the high variability in ice algal biomass, the spatial variability in the F_v/F_m of diatom-dominant ice algal community seems to be reduced to less degree because the potential photosynthetic characteristics are likely controlled by the photo-acclimation to the ambient irradiance as long as other environmental variables are not limiting factors (Obata and Taguchi 2009). The spatial variability in the ambient irradiance at the ice algal layer is clearly an area that warrants significant research in the future.

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