# Sea Ice Colored by Ice Algae in a Lagoon, Lake Saroma, Hokkaido, Japan

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## サロマ湖（塩水湖）における Ice Algae による着色海氷

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**要旨**: 北海道オホーツク海岸の紋別において，流氷下端から，また，サロマ湖の湖氷下端からも，ice algae による着色層を見出した．サロマ湖は潟湖であり，湖内には 31‰ 以上の塩水が存在する．したがって，例年 1 月から 4 月へかけて湖面を覆う氷は，海氷と呼び得る性質のものである．

サロマ湖北西岸トエトコにおける観察の結果，冬季形成される海氷は，20～40 cm に達した後，ほとんど成長を止めることを知った．この時期，海氷下に褐色層が形成され，*Fragilariopsis, Nitzschia, Thalassiosira* などの珪藻を主とした ice algae が認められた．クロロフィル *a* は 25.88 $\mu g/l$ にも達した．

南北両極海では，海氷の下端付近で ice algae が繁殖し，着色現象が起こることが広く知られている．昭和基地付近では，2 月中旬に結氷がはじまり，3 月，海氷の厚さが 30 cm くらいになった後，1 カ月ほどその成長が停滞する．また，冬期間，1 m を越すほどに成長した海氷は，春 10 月以降ふたたび成長を止める．この二度の時期に，珪藻を主とした ice algae の増加が海氷下面付近で起こる．北海道で見られた ice algae による海氷の着色現象は，昭和基地で秋季に見られた現象とよく似ている．

サロマ湖においても，昭和基地においても，海氷下端で ice algae の繁殖が起こる時期には，海氷下の海水中のクロロフィル *a* 量は，それぞれ 0.09–0.23 $\mu g/l$, 0.05–0.13 $\mu g/l$ と低く，かつ減少傾向を示した．

サロマ湖は，海氷の着色が起こる，北半球における最も南の地域に位置していると思われる．

***Abstract***: The coloration of sea ice by the ice algae was studied at Mombetsu (44°20′N, 143°20′E) on the Okhotsk coast of Hokkaido and at Toetoko (44°11′N, 143°45′E) in a lagoon, Lake Saroma, which is also situated on the same coast, Hokkaido, Japan.

Lake Saroma is usually covered with the ice between middle January and early April. A brown layer was found at the bottom of the sea ice in February from 1977 through 1980. The 1977's results showed that *Fragilariopsis*, *Nitzschia*, *Thalassiosira* and other pennate diatoms were dominant components of the ice algal community. Chlorophyll *a* and phaeopigment were detected from top to bottom of the sea ice of 20 to 40 cm thick and concentrated at the bottom part. The level of plant pigment concentration (25.88 $\mu g$ chl $a/l$) in the sea ice was

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higher than that of the sea water (0.09 $\mu$g chl $a/l$). The increase of plant pigments with the lapse of time was observed, when the growth rate of the sea ice extremely decreased at ice thickness of 20 to 40 cm. The present results agreed with the data obtained at Syowa Station, Antarctica, on the development of ice algal community.

## 1. Introduction

Ecological investigations on the brown colored layer which is formed by proliferation of such microorganisms as diatoms, flagellates and ciliates in the sea ice have been carried out mainly in the polar oceans (HORNER, 1977; BRADFORD, 1978; ALEXANDER, 1979). Other than the polar oceans, MCROY *et al.* (1972) and MCROY and GOERING (1974) studied ice algae of the Bering Sea. HORNER (1977) mentioned that the ice biota was also seen in the Baltic Sea as well as in the Bering Sea. Recently, DUNBAR (1979) has reported that chlorophyll *a* was also detected from the sea ice of the Gulf of St. Lawrence, Canada.

In Japan, there were popular narratives that the drift ice on the northeastern coast of Hokkaido which faces the Sea of Okhotsk contained colored parts. MATSUDAIRA (1932) and TAMURA (1951) investigated microorganisms which inhabit the drift ice and the sea water under the ice. They found that population of microorganisms was composed mainly of diatoms and they thought that the diatoms of the sea ice were derived from the sea water, when the sea water froze. However, careful attentions were not paied to the causes and processes of coloration.

Based on the data obtained by the senior author at Syowa Station, Antarctica, and the information acquired by other investigators in the polar oceans, the present authors had a prospect that the colored part of the sea ice in Hokkaido might have been formed through the same process as that of the polar oceans. To confirm their prospect, they carried out field observations on the occurrence of ice algae on the Okhotsk coast of Hokkaido in the last four years from 1977 to 1980. In this report, however, they deal with the data of three winters except 1979, because the analysis of data of 1979 is in process at present.

## 2. Materials and Methods

Location of Lake Saroma and sampling sites is shown in Fig. 1. Geographical position of Lake Saroma is a little south of the Gulf of St. Lawrence, which extends between about 46° to 52°N and 56° to 68°W. The drift ice usually approaches the Okhotsk coast of Hokkaido in the middle of January and recesses in early April. During this period, Lake Saroma is also covered with the ice. Lake Saroma was connected with the Sea of Okhotsk through a channel and the characteristics of the

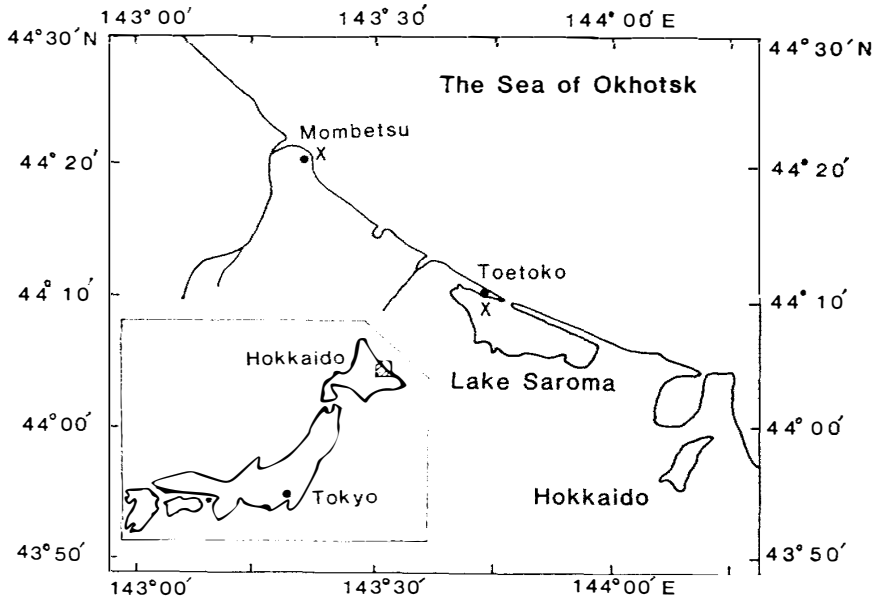


*Fig. 1. Location of sampling sites ( ).*

lake water can be regarded to be the same as the sea water, as considered from the oceanographic data shown in Table 1. Accordingly, the term of "sea ice" can be applied to the ice formed in the lake.

Preliminary observations were carried out at Mombetsu (44°20′N, 143°20′E) of the Okhotsk coast and at Toetoko (44°11′N, 143°45′E) of Lake Saroma in 1977. After 1978, observations were made only at Toetoko. The observation sites of Toetoko were selected in the area less than 200 m distant from the pier of the Toetoko harbor toward offshore, where the sea ice thickness was 20 to 40 cm and the depth of seabed was about 5 to 15 m.

Cores were taken with a SIPRE ice corer, 7.5 cm in diameter. A core was divided into three or four pieces in the field based on the difference of the color, transparency and hardness of the ice. Preparatory processing of samples, such as melting and filtration, was done at room temperature at the Sea Ice Research Laboratory, Institute of

*Table 1. Oceanographic conditions of sea water under the ice, Toetoko, February 7, 1978.*

| Depth | Chl *a* | Phaeo-p | Water temp. | Salinity | pH | $PO_4$-P | $SiO_3$-Si | $NO_2$-N | $NO_3$-N | $NH_4$-N |
|---|---|---|---|---|---|---|---|---|---|---|
| m | μg/*l* | | °C | ‰ | | μg-at/*l* | | | | |
| 0 | 0.09 | 0.01 | −1.4 | 31.09 | 8.15 | 0.71 | 15.32 | 0.18 | 6.24 | 2.72 |
| 0.5 | 0.09 | 0.08 | −1.3 | 31.47 | 8.15 | 0.75 | 9.17 | 0.21 | 6.35 | 2.64 |
| 1.0 | 0.09 | 0.09 | −1.5 | 31.76 | 8.20 | 0.78 | 8.41 | 0.24 | 6.58 | 3.08 |
| 2.0 | 0.09 | 0.12 | −1.3 | 31.78 | 8.20 | 0.74 | 8.53 | 0.27 | 6.21 | 4.62 |
| 4.0 | 0.14 | 0.17 | −1.4 | 31.87 | 8.10 | 0.72 | 9.60 | 0.16 | 5.83 | 3.46 |
| 6.0 | 0.09 | 0.15 | −1.3 | 31.93 | 8.10 | 0.72 | 6.87 | 0.15 | 5.70 | 1.74 |

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Measurement of chlorophyll *a* and phaeopigment was made by a fluorometric method using a Hitachi Spectrophotometer 139 incorporated with fluorometry attachment. It was done within a couple of days after sampling at the Plankton Laboratory, Faculty of Fisheries, Hokkaido University, Hakodate. Salinity was determined by an inductive salinometer, Auto-Lab Model 601 MKII at the same Plankton Laboratory. Phosphate-P, silicate-Si, nitrate-N and nitrite-N were determined after the methods of STRICKLAND and PARSONS (1968). Ammonia-N determination was made according to SOLORZANO (1969). Determination of nutrients was carried out at the Hokkaido Abashiri Fisheries Experimental Station in 1978 and at the Plankton Laboratory, Faculty of Fisheries, Hokkaido University, in 1980.

At Syowa Station, Antarctica, determination of chlorophyll *a* and phaeopigment was made fluorometrically with a Hitachi FPL fluorometer installed with a red sensitive photomultiplier in 1970.

## 3. Results and Discussion

### 3. 1. Discovery of a brown layer in 1977

In order to know whether the colored layer occurred in the sea ice, field surveys were done at both Mombetsu and Toetoko in the middle of February 1977. A light brown colored layer of 0.5 cm was recognized at the bottom part of drift ice which was distributed off Mombetsu connecting with the outer margin of the coastal ice zone. The thickness of drift ice was about 20 cm and the depth of snow accumulated on the ice was 5 cm. *Fragilariopsis*, *Nitzschia*, *Thalassiosira*, other pennate diatoms and small flagellates were found at the colored part. Density of diatoms was $2.72\times10^6$ cells/*l*.

A brown layer was also found at the bottom part of the sea ice of Toetoko, which was formed there. The thickness of the ice was 38 cm and that of brown layer was 3 cm. The depth of snow accumulation was 7 cm on the sea ice. *Fragilariopsis*, *Nitzschia frigida*, *Thalassiosira*, other diatoms and flagellates including *Peridinium* are inhabitants of the brown layer. The density of diatoms and peridinian was $130\times10^6$ cells/*l*. The prominent genera of diatoms observed were common to the dominant genera reported by TAMURA (1951) but MATSUDAIRA (1932) recorded *Biddulphia aurita* as the dominant species.

It is difficult to know the locality where the drift ice was formed and to identify the environmental conditions under which the microorganisms of the drift ice increased. On the contrary, the sea ice of Lake Saroma is usually stationary. Therefore, it is able to consider that the oceanographic and climatic conditions of Lake Saroma brought

the proliferation of microalgae of sea ice during January and early February.

### 3. 2. Chlorophyll *a* distribution in 1978

To know the distribution of algal biomass in the sea ice, an observation was carried out in early February of 1978. There were two different ice fields which adjoined in front of the Toetoko pier. One of them was formed in early January and the other was formed toward the end of January.

Two cores were taken at each of the distinguished two ice fields on February 8. A brown layer was recognized at the bottom part of the old ice of 29 cm thick but no colored layer was found in the young ice of 20 cm thick. As shown in Table 2, chloro-

*Table 2. Chlorophyll a and phaeopigment in the sea ice formed at different times, Toetoko, February 8, 1978.*

| Ice formed in late January | | | | | Ice formed in early January | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Distance from sea ice bottom | St. 1 | | St. 2 | | Distance from sea ice bottom | St. 6 | | Distance from sea ice bottom | St. 7 | |
| | Chl *a* | Phaeo-p | Chl *a* | Phaeo-p | | Chl *a* | Phaeo-p | | Chl *a* | Phaeo-p |
| cm | *μg/l* | | | | cm | *μg/l* | | cm | *μg/l* | |
| | | | | | 17–29 | 0.56 | 0.55 | 15–27.5 | 0.84 | 0.58 |
| 11–20 | 0.05 | 0.10 | 0.05 | 0.09 | 10–17 | 0.51 | 0.34 | 9–15 | 1.40 | 0.69 |
| 3–11 | 0.08 | 0.10 | 0.08 | 0.11 | 3–10 | 0.64 | 0.49 | 3– 9 | 1.14 | 0.77 |
| 0– 3 | 0.88 | 0.57 | 0.78 | 0.43 | 0– 3 | 25.26 | 8.02 | 0– 3 | 25.88 | 34.16 |

phyll *a* and phaeopigment were detected from top to bottom of the sea ice and concentrated at the bottom. The concentration of the plant pigments was higher in the old ice than in the young ice. The pigment concentrations of the colored part of the old ice were 33.28 *μg/l* and 60.04 *μg/l*. The order of these figures are comparable to that of the chlorophyll *a* concentration (86.35 *μg/l*) detected from the brown layer of Syowa Station on March 27, 1970 (see Table 4).

### 3. 3. Chlorophyll *a* and nutrients distribution in 1980

Location and method of sampling in 1980 were the same as in the preceding years. A light brown layer was seen at the bottom of the sea ice. Analysis of nutrient salts contained in the sea ice and in the sea water under the ice was made as well as the plant pigment analysis in late February. The results obtained are shown in Table 3.

The present figures of nutrients are comparable to the data given by HORNER (1972) from Barrow, Alaska. Concentration of plant pigments was higher at the bottom of the ice than that in the sea water just beneath the ice. On the contrary, nutrients were high in the sea water. Concentration of nutrients was low in the middle part in the sea ice. In particular, silicate-Si was low just above the bottom layer of the ice. However, further studies are needed to discuss the nutrients distribution and the relation between algal biomass and nutrient salts in the sea ice.

*Table 3. Chlorophyll a, phaeopigment and nutrients in the sea ice and the sea water under the ice, Toetoko, February 23, 1980.*

| Ice core | Distance from sea ice bottom | Chl *a* | Phaeo-p | $PO_4$-P | $SiO_3$-Si | $NO_2$-N | $NO_3$-N | Salinity |
|---|---|---|---|---|---|---|---|---|
| | cm | $\mu g/l$ | | $\mu g$-at/$l$ | | | | ‰ |
| No. 1 | 14–26 | 0.37 | 0.22 | 0.12 | 5.0 | 0.05 | 2.13 | |
| | 9–14 | 0.52 | 0.23 | 0.10 | 5.0 | 0.05 | 1.45 | |
| | 3– 9 | 0.89 | 0.34 | 0.20 | 1.8 | 0.05 | 1.44 | |
| | 0– 3 | 11.37 | 4.80 | 0.64 | 5.1 | 0.15 | 5.58 | |
| No. 2 | 14–24 | 0.37 | 0.21 | 0.11 | 5.5 | 0.07 | 2.04 | |
| | 9–14 | 0.57 | 0.27 | 0.06 | 4.5 | 0.05 | 1.48 | |
| | 3– 9 | 0.83 | 0.34 | 0.12 | 3.4 | 0.05 | 2.04 | |
| | 0– 3 | 12.83 | 5.29 | 0.44 | 10.5 | 0.15 | 5.49 | |
| Sea water under the ice | Depth (m) | | | | | | | |
| | 1 | 0.20 | 0.13 | 0.91 | 16.1 | 0.20 | 8.02 | 31.93 |
| | 2.5 | 0.23 | 0.19 | 0.87 | 15.6 | 0.19 | 7.50 | 31.93 |
| | 4.0 | 0.21 | 0.16 | 0.89 | 14.6 | 0.19 | 7.60 | 31.94 |

### 3. 4. Comparison between the present results and the data of Syowa Station

The seasonal variation of chlorophyll *a* and phaeopigment in the sea ice was investigated at Syowa Station, Antarctica (HOSHIAI, 1977). According to his observations, the proliferations of ice algae occurred twice a year, in autumn and spring.

By late March, austral autumn, thickness of the sea ice which was newly formed in the middle of February had become 30 cm but thereafter it hardly grew until the end of April. After the growth of sea ice in winter, it stopped growing from late September to summer, when the ice thickness was more than 1 meter. The coloration at the sea ice bottom occurred in the two periods. The coloration of the sea ice in Lake Saroma seems to be comparable to the autumnal coloration in the Syowa Station area, taking into account the ice thickness and solar radiation, which will be dealt with on another occasion.

In the Syowa Station area, a brown-colored layer was found at the bottom of the sea ice on March 27, 1970 and the concentration of chlorophyll *a* was 86.35 $\mu g/l$ (Table 4). Thereafter, chlorophyll *a* and phaeopigment increased and reached a peak in the middle of April. Then the pigments began to decrease. Chlorophyll *a* and phaeopigment were also recognized at the bottom part of the sea ice formed in a small pool which was opened on March 20, 1970 by the senior author. Concentrations of chlorophyll *a* and phaeopigment became 67.56 $\mu g/l$ and 6.24 $\mu g/l$ on April 9 and 290.88 $\mu g/l$ and 30.42 $\mu g/l$ on April 16, respectively. These figures were lower than those found in the sea ice shown in Table 4, which was formed in the middle of February 1970. The difference in the pigment concentration seemed to be one of the results of the temporal difference in start of the increase of ice algae. Compared with the young ice, high concentration of plant pigments in the old ice of Toetoko

*Table 4. Seasonal changes of chlorophyll a and phaeopigment at the bottom part of sea ice, Syowa Station, 1970.*

| Date | Mar. 27 | Apr. 3 | Apr. 9 | Apr. 16 | Apr. 23 | May 1 |
|---|---|---|---|---|---|---|
| Chl *a* ($\mu g/l$) | 86.35 | 138.12 | 829.15 | 921.25 | 403.27 | 177.13 |
| Phaeo-p ($\mu g/l$) | 0 | 0 | 5.03 | 73.09 | 52.15 | 13.20 |

*Table 5. Seasonal changes of chlorophyll a and phaeopigment in the sea water under the ice, Syowa Station, 1970.*

| Date | Mar. 16 | Mar. 24 | Apr. 1 | Apr. 11 | Apr. 27 |
|---|---|---|---|---|---|
| Chl *a* ($\mu g/l$) | 0.13 | 0.08 | 0.05 | 0.10 | 0.07 |
| Phaeo-p ($\mu g/l$) | 0.30 | 0.09 | 0.05 | 0.09 | 0.05 |

indicates the possible presence of the same process of ice algal proliferation in Lake Saroma as in the Syowa Station area.

The concentration of plant pigments in the sea water did not fluctuate and remained at low level (0.10–0.43 $\mu g/l$) at Syowa Station (Table 5) and at the level of 0.10 to 0.42 $\mu g/l$ at Toetoko (Tables 1 and 3). This fact shows that ice algal community develops independent of the phytoplankton community of the sea water under the ice, though parts of the constituent species are common to both habitats.

Therefore, it is concluded that the prospect suggested by the present authors is supported by the results obtained at both Toetoko and Syowa Station.

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