PROLIFERATION OF ICE ALGAE IN THE SYOWA STATION AREA, ANTARCTICA

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***Abstract*:** The distribution and seasonal variation of ice algae were investigated in the vicinity of Syowa Station (69°00′S, 39°35′E), Antarctica.

The plant pigments, chlorophyll *a* and phaeophytin, were detected from top to bottom of the sea ice. However, the proliferation of ice algae occurred significantly at the bottom of the sea ice to make it brown in autumn and spring. The autumnal outburst of algae was found in the more limited regions which were covered with the ice formed newly than the regions in which the spring proliferation occurred. The autumnal proliferation of algae also occurred in the wintered ice as well as in the new ice but algal biomass in the old ice was less than in the new ice.

The annual production of ice algae in the Syowa Station area was assumed as 1.50 to 3.25 gC/m^2 based on the present data of algal biomass.

These results show the potential importance of ice algae in the marine ecosystems of the polar regions.

1. Introduction

The ice algal communities or the ice biotas have been investigated during the recent two decades, 1960's and 1970's, because it was thought that they play an important role in the primary production of the polar ocean ecosystems (HORNER, 1977; BRADFORD, 1978; ALEXANDER, 1979). Most of the investigations were concentrated on the algal growth from spring to summer when remarkable proliferations of algae were seen in the broad areas of Arctic and Antarctic Oceans. BUINITSKY (1965, 1977) reported that higher concentration of diatoms was observed in the sea ice than in the sea water under the ice throughout a year in Alasheyev Bay, East Antarctica. The present author observed the proliferation of algae in the bottom layer of the Antarctic sea ice in autumn as well as in spring (HOSHIAI, 1977). However, available information on the autumnal proliferation and also the winter survival of ice algae is still limited. Therefore, the autumnal algal growth and successive seasonal change of algae in the sea ice which were observed in the vicinity of Syowa Station (69°00′S, 39°35′E) are described in this report.

2. Materials and Methods

Serial observations were carried out at intervals at one station of the Kita-no-seto Strait (Fig. 1) and two stations off Miharasi Peak in the Ongul Strait. For reference, ice core samplings were also made occasionally near the seasonal observation sites.

Sea ice cores were taken with a SIPRE ice coring auger. First, the sea ice thickness and the position and thickness of the colored layer were observed. Successively,

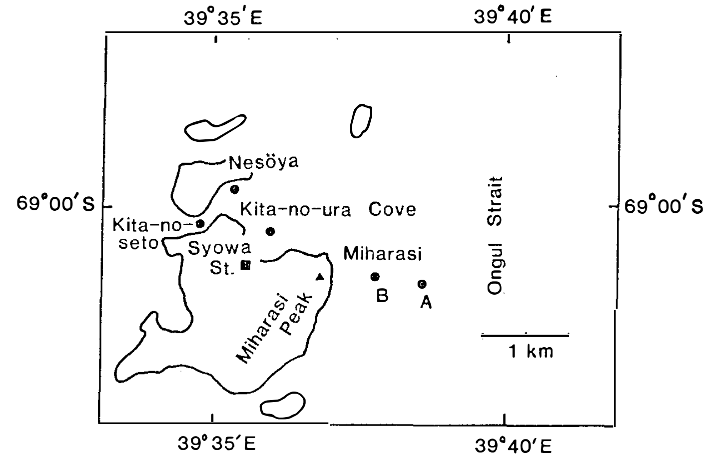

Fig. 1. Location of the sampling sites.

the ice core was sawed into several parts of uniform hardness, transparency and coloration. Furthermore, the middle part of the sea ice which was uniformly hard, transparent and colorless during winter was subdivided into pieces of about 10 cm thick to investigate the detailed algal distribution in it.

After melting of samples at room temperature of 20°C, chlorophyll *a*, phaeophytin, pH and chlorinity were determined. Chlorophyll *a* and phaeophytin were measured according to the method for quantitative determination of phytoplankton pigments by fluorescens (YENTSCH and MENZEL, 1963). The fluorometer used was Hitachi FPL-2 Type installed with a red sensitive photomultiplier (Hamamatsu Electric Co. Ltd., R-136). A Hitachi 436 mμ filter was used for excitation and a Toshiba 660 mμ filter was used for the measurement of the emission. The pH was measured by a glass electrode pH-meter, Model HM-5A, TOA Electronics Co. Ltd. Chlorinity was determined by titration with silver nitrate using uranin as the indicator. Since the volume of sample water was 5 m*l*, the accuracy of the results obtained was not so high but it seemed to be sufficient to represent the fluctuation of chlorinity in the sea ice.

3. Results and Discussion

3.1. Proliferation of ice algae at Kita-no-seto Strait

Freezing of the sea water at the Kita-no-seto Strait began in the middle of February. The sea ice became about 30 cm thick in the latter part of March and a brown layer was formed in the bottom part of sea ice. The brown layer extended upward and downward with the increase of the ice thickness through winter and its color faded gradually with time and became invisible by October. During winter the sea ice grew downward and a hard and transparent ice layer was formed below the brown layer. The sea ice growth became extremely slow after the middle of September and

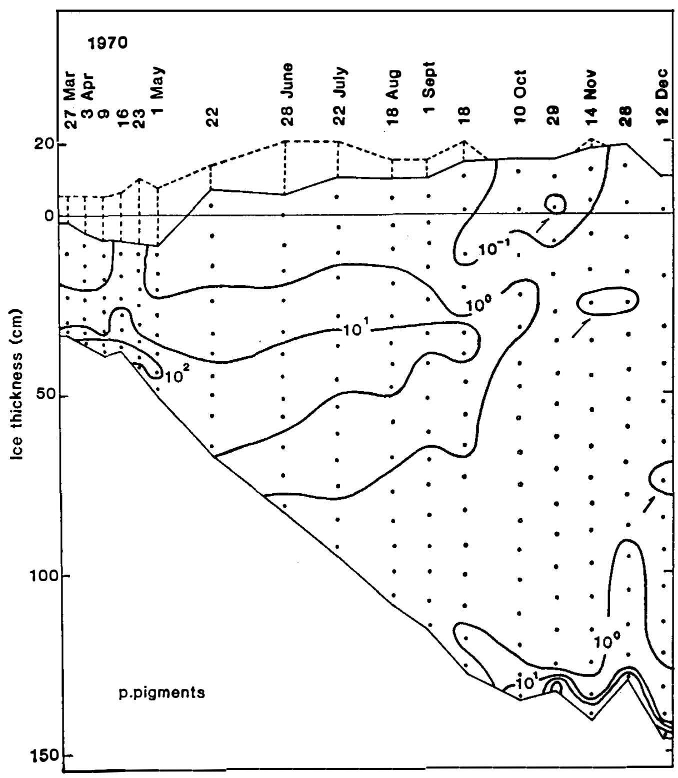

Fig. 2. Distribution and seasonal variation of plant pigments (mg/m³) in the sea ice, Kita-no-seto Strait, 1970. Snow cover is illustrated by dotted lines.

a second brown layer appeared at the bottom of sea ice in November. The color of the second brown layer became deeper and deeper until the end of December.

The distribution and seasonal variation of the plant pigment concentration which are shown as the sum of chlorophyll *a* and phaeophytin concentrations correspond to the behavior of the brown layers as described above (Fig. 2). The plant pigments concentrated in the brown layer and reached a peak of 994.3 mg/m³ on April 16. The pigments extended vertically and their concentration lowered to the same level as that of the colorless parts. The second remarkable increase of plant pigments occurred in the bottom part of sea ice from October and the highest value was 5319.6 mg/m³ on December 12. Such high chlorophyll *a* concentration as 7490 mg/m³ was also observed in the sea ice of Signy Island, South Orkney Islands (WHITAKER, 1977). The plant pigments concentration throughout winter was low being between 1.0 mg/m³ and 0.1 mg/m³. However, in terms of chlorophyll *a* concentration, the values in the sea ice were more than ten times that in sea water (0.01 mg/m³), which was reported from the Kita-no-seto Strait by HOSHIAI (1969).

The proportion of chlorophyll *a* to the sum of chlorophyll *a* and phaeophytin gives the active fraction in the plant pigments (YENTSCH, 1965). The vertical distribu-

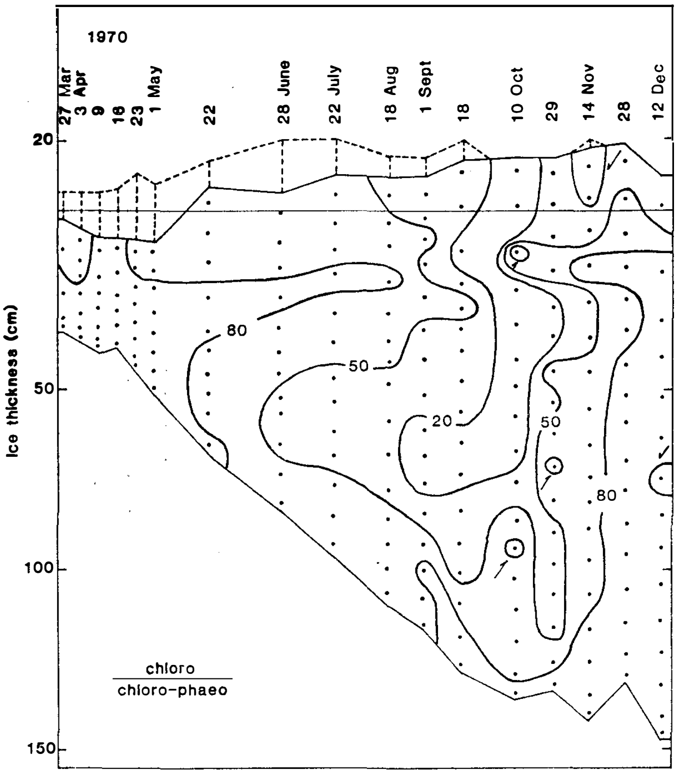

Fig. 3. Distribution and seasonal variation of the proportion of chlorophyll a (%) to the sum of chlorophyll a and phaeophytin in the sea ice, Kita-no-seto Strait, 1970.

tion and seasonal change of the proportion of chlorophyll *a* are illustrated in Fig. 3. Till the beginning of May, the proportion of chlorophyll *a* was higher than 80 per cent in most parts of the sea ice. The proportion of chlorophyll *a* decreased with the lapse of time and reached a minimal level below 20 per cent in the upper half of the ice between September and early October. On the contrary, in the bottom part, the increase of proportion of chlorophyll *a* occurred concurrently with the increase of plant pigments in September. The proportion of chlorophyll *a* in the whole parts of the sea ice increased abruptly after the middle of October and exceeded again 80 per cent in the latter of November.

The pH value was higher than 8.0 in the part above the autumnal brown layer (Fig. 4). In that part pH exceeded 9.0 in late April and between June and July. In the sea ice which grew in winter, however, the pH values were 7.3 to 8.0. After late October, pH values became again high in most parts of the sea ice. The distribution and seasonal change of pH seem to correspond to those of the proportion of chlorophyll *a*.

As shown in Fig. 5, chlorinity was high just above and in the bottom layer of the sea ice, in particular, chlorinity exceeded 4.0‰ in the brown layer in autumn and

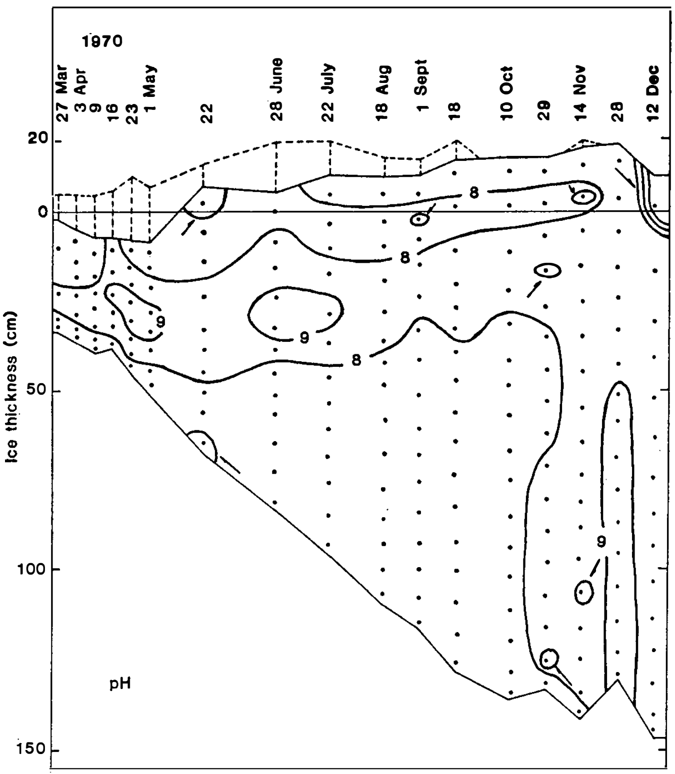

Fig. 4. Distribution and seasonal variation of the pH in the sea ice, Kita-no-seto, 1970.

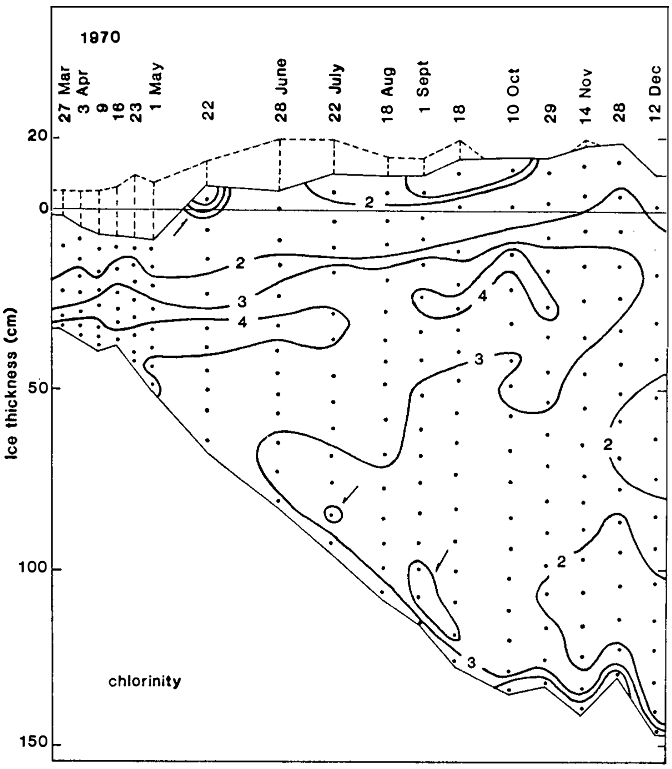

Fig. 5. Distribution and seasonal variation of the chlorinity (‰) in the sea ice, Kita-no-seto Strait, 1970.

spring when the growth of sea ice was slow. The coincidence between the high chlorinity layer and the high pigment concentration layer agreed with the description of ACKLEY *et al.* (1979) on the sea ice of the Weddell Sea region. However, the high chlorinity layer formed in autumn remained there till summer though its chlorinity lowered gradually. The present result in the chlorinity distribution differed from the conceptional model proposed by them.

3.2. Distribution of ice algae Miharasi stations

Freezing of the sea water of the Ongul Strait was delayed because of the stormy weather in the autumn of 1970. It began in the middle of March. Snow accumulated on the sea ice so heavily that it depressed the ice downward. Consequently, the lower part of snow accumulated was moistened and consolidated by the sea water soaked through the sea ice in winter. The consolidated snow layer was distinguished by its porous structure from the layer derived from the sea water.

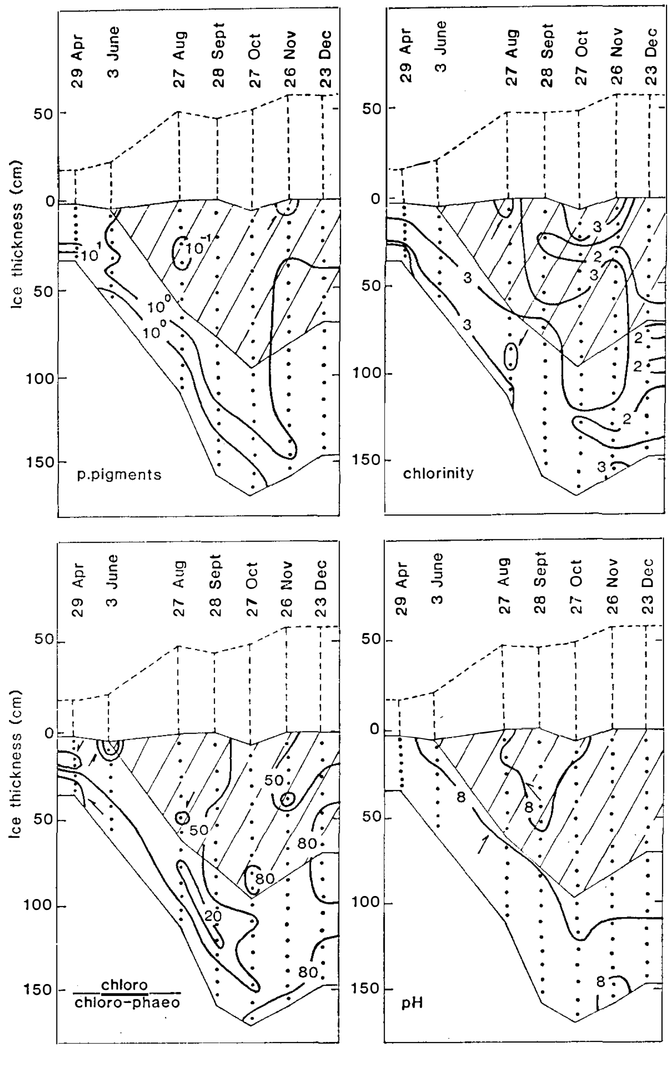

Fig. 6. Distribution and seasonal variation of plant pigments (mg/m³), proportion of chlorophyll a (%) to the sum of chlorophyll a and phaeophytin, chlorinity (‰) and pH, Miharasi A, 1970. Snow cover and consolidated snow layer are illustrated by dotted lines and oblique solid lines.

3.2.1. Miharasi A

The plant pigments were detected from top to bottom of the sea ice including the consolidated snow layer as shown in Fig. 6. The concentration of plant pigments was higher in the layer above the bottom than in the other layers but no colored layer was formed. The high pigment concentration layer which was formed in autumn remained until the end of November. The remarkable spring proliferation of algae was not observed in any layer but the pigment concentration in the lower part of the consolidated snow layer and the ice layer derived from the sea water slightly increased toward summer.

The proportion of chlorophyll *a* to the sum of chlorophyll *a* and phaeophytin was high at the bottom in autumn and spring. In late December the proportion of chlorophyll *a* increased in the boundary zone of snow and sea ice. The pH value exceeded 8.0 in most part of the consolidated snow layer and in the upper part of the sea ice. Any particular relation of pH to the pigment concentration or the proportion of chlorophyll *a* in the pigments was not found. Chlorinity was high in the

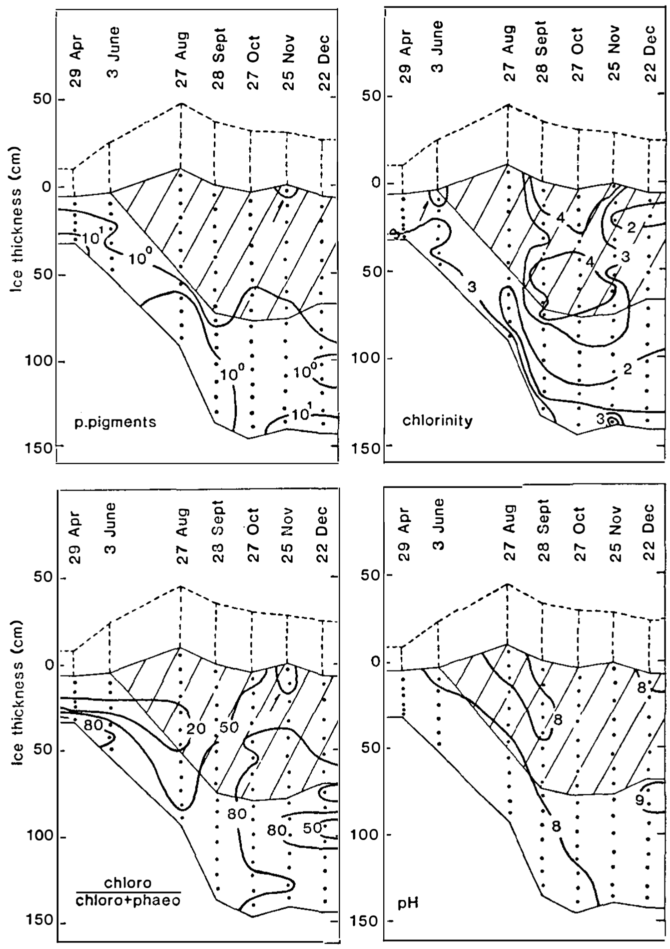

Fig. 7. Distribution and seasonal variation of plant pigments (mg/m³), proportion of chlorophyll a (%) to the sum of chlorophyll a and phaeophytin, chlorinity (‰) and pH, Miharasi B, 1970. Snow cover and consolidated snow layer are illustrated by dotted lines and oblique solid lines.

boundary part of consolidated snow and sea ice as the result of infiltration of the sea water. The increase of the proportion of chlorophyll *a* was observed as mentioned above but such remarkable increase of plant pigments as suggested by MEGURO (1962) was not recognized in this part.

3.2.2. Miharasi B

Two light brown layers were observed and the increases of plant pigments occurred twice in autumn and spring at the bottom of sea ice (Fig. 7). High proportion of chlorophyll *a* was also observed corresponding to the increase of plant pigments. The proportion of chlorophyll *a* increased with time in both lower part of consolidated snow and sea ice after October but decreased abruptly in the upper part of sea ice after late November. The distribution and seasonal variation of pH were substantially similar to those of Miharasi A but the high pH value exceeding 8.0 was found in the consolidated snow layer and the whole parts of sea ice in spring and summer. High chlorinity was found in the consolidated snow layer from September to November but the increase of plant pigments as Miharasi A was not recognized.

3.3. Algal proliferation in the old ice

It seemed that the autumnal proliferation of ice algae occurred in the wintered ice near Nesöya as well as the new ice. A light brown layer of about 20 cm thick was observed in the layer above the bottom of the wintered sea ice of 70 cm thick, lower part of which seemed to be melted and lost during summer. The maximum concentration of plant pigments was 149.5 mg/m^3 on April 20 (Fig. 8). Although the determinations of plant pigments, pH and chlorinity in the upper parts were not carried out, it may be said that the distribution of the plant pigments, the proportion of chlorophyll *a*, pH and chlorinity in the lower two-thirds of the sea ice resembled that of the new ice. For a comparative examination, parts of the results obtained at the Kita-no-seto Strait are cited in Fig. 8B. The seasonal variation of the plant pigments, the proportion of chlorophyll *a*, pH and chlorinity was also similar to that of the new ice of the Kita-no-seto Strait.

A light yellow layer was also found in the layer just above the bottom of the old ice of about 150 cm thick at the Kita-no-ura Cove (Fig. 1) on May 12, 1970. The pigment concentration was 40.6 mg/m^3. It seemed that the ice layer of a few centimeters at the bottom was formed in this autumn. The distribution and seasonal change of the plant pigment concentration and chlorinity were more complicated than those of the preceding two cases. Except the surface part of the sea ice, the proportion of chlorophyll *a* to the sum of chlorophyll *a* and phaeophytin and the pH value were high in May and October. The relation between chlorinity and plant pigments was also more complicated in the old ice than in the new ice in which plant pigments accumulated in or close to the high chlorinity layer. ACKLEY *et al.* (1979) also observed the complicated distribution of chlorinity and chlorophyll *a* in the shore-attached fast ice of the Weddell Sea.

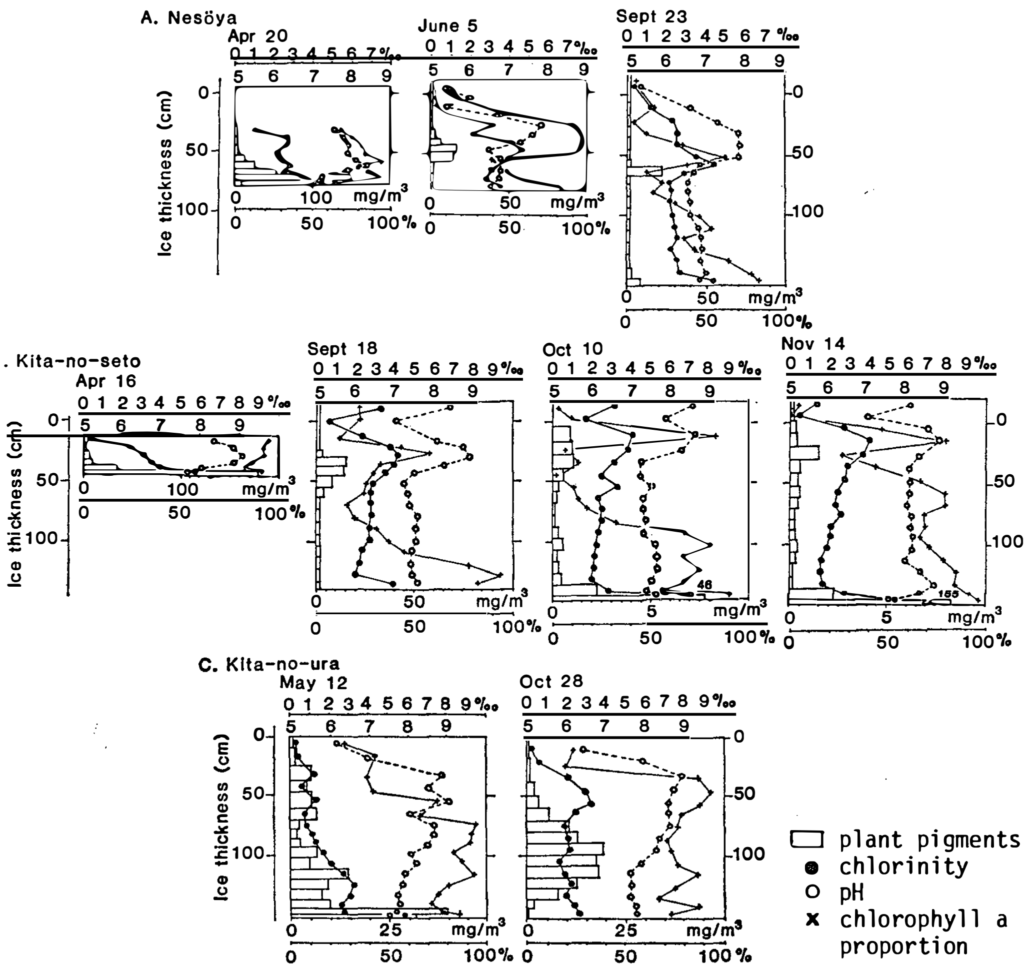

Fig. 8. Comparison between new ice and old ice in the distribution and seasonal change of plant pigments (mg/m³), proportion of chlorophyll a (%) to the sum of chlorophyll a and phaeophytin, pH and chlorinity (‰). New ice was sampled at Kita-no-seto and old ones were taken near Nesöya and at Kita-no-ura, 1970.

3.4. *Biomass of ice algae and their function in ecosystems*

From the present observations, it is concluded that ice algae are able to inhabit every stratum of the sea ice from top to bottom but their significant proliferations occur in the bottom part in the limited locations of polar seas in autumn and spring. It is also said that the degree of coloration of the sea ice depends only upon the density of ice algae. These show that the sea ice is one of the important substrata for the primary production of the polar ocean ecosystems.

Some investigators emphasized the importance of ice algae as the primary producers in the polar oceans (ANDRIASHEV, 1968, 1970; FUKUSHIMA and MEGURO, 1966). On the contrary, BUNT (1968) estimated that the contribution of ice algae to the primary production of the Antarctic Ocean might be less than 2 per cent. It is possi-

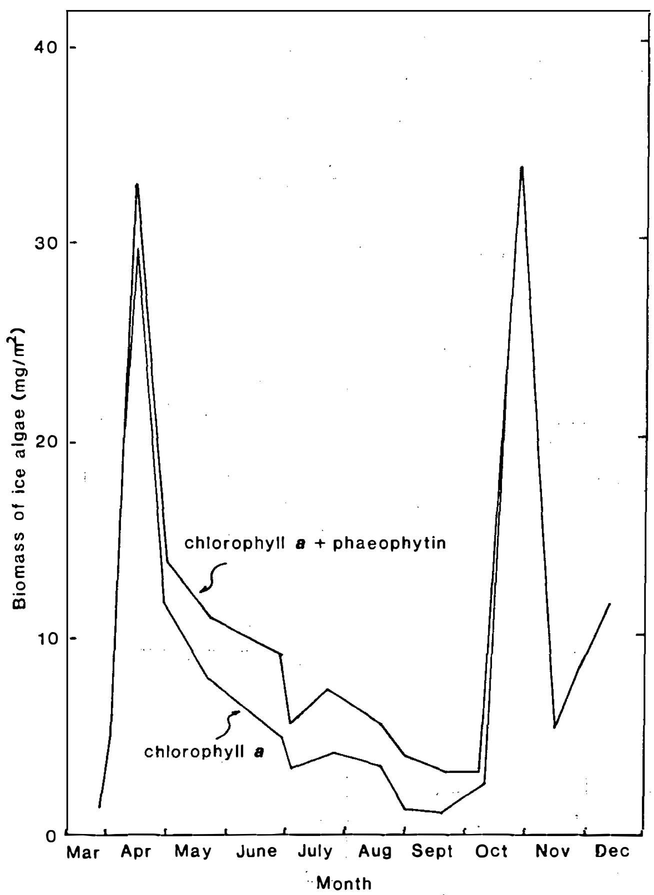

Fig. 9. Seasonal change of biomass of ice algae in the sea ice, Kita-no-seto Strait, 1970. Calculated from data presented in Fig. 2.

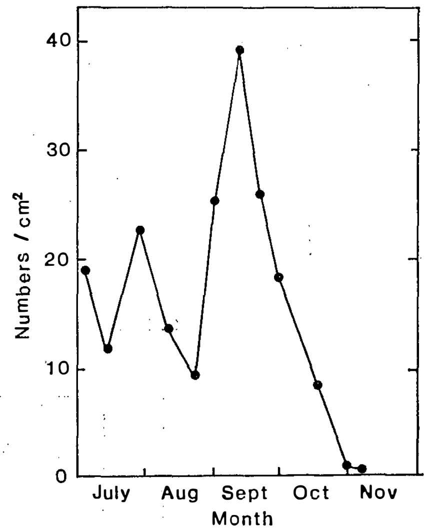

Fig. 10. Fluctuation of the density of copepod nauplius on the undersurface of the sea ice, Kita-no-seto, July to November 1975.

ble that algal cells which proliferated in the sea ice may have remained there for some time because they are sedentary or epontic as defined by BUNT and WOOD (1963) and are hardly moved by the current of the sea water. Therefore, it is possible to assume that the algal biomass, which is represented as the plant pigment concentration, approximately corresponds to the net production of ice algae. The integrated values of the algal biomass in the sea ice of the Kita-no-seto Strait are shown in Fig. 9. Two significant peaks appeared in autumn and spring. The two peaks of chlorophyll *a* were about 30 and 35 mg/m². Therefore, the annual production in the new ice in the Syowa Station area is in a range between 30 and 65 mg/m² in terms of chlorophyll *a*. Assuming a ratio of carbon to chlorophyll *a* as 50:1, these figures are converted to 1.50 to 3.25 gC/m². BURKHOLDER and BURKHOLDER (1967) suggested tentatively about 30 gC/m² as an annual production in the Antarctic Ocean. The figure obtained in the present work shows that the contribution of ice algae may be less than about 10 per cent.

However, it is noteworthy that the pigment concentration in the sea ice was ten times that in the sea water during winter as mentioned in 3.1. HOSHIAI and TANIMURA (1981) reported the presence of copepods, such as *Oithona similis* and *Oncaea curvata* in winter under the sea ice of the Kita-no-seto Strait. Although the grazing by copepods is expected, the relation of the copepods to the ice algae falling from the sea ice is uncertain. Further studies are needed to verify this relationship.

GRUZOV *et al.* (1967) described the fauna associated with the ice algae and RAKUSA-SUSZCZEWSKI (1972) reported the winter occurrence of an amphipod, *Paramoera walkeri*, on the undersurface of the Antarctic sea ice. In the vicinity of Syowa Station, the copepod nauplius was found on the bottom surface of the sea ice. The nauplii seemed to be swimming between ice crystals or on the surface of ice crystals in the bottom part of the sea ice because they were usually contained in the melted water of the bottom layer of ice cores sampled. The fluctuation of individual numbers of copepod nauplius is shown in Fig. 10. The density of nauplius was high in winter. However, the relation of nauplius to the sea ice and ice algae is still not clear. Further studies are expected to clarify the function of ice algae and to analyze the food relations in the Antarctic marine ecosystems.

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