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Distribution and Developmental Processes of Sea-ice Algal Communities

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Abstract : Information on the distribution and developmental processes of ice algal communities in the Antarctic was reviewed. Although efforts were done in the ecological research of ice algae, data acquired were insufficient to make realistic estimation of biomass and primary productivity of ice algae in the Antarctic Ocean. Need for synoptic observations on distribution and developmental processes of ice algal communities was suggested to fill the gaps in the present knowledge of the ecology of ice algae.

Key words : Antarctic Ocean, chlorophyll, ecosystem, ice algae, primary productivity

Introduction

In the ice-covered Antarctic waters, ice algae have attracted attentions of biologists because of the brownish colour of their assemblages in the sea-ice, their autotrophic character and their possible contributions as primary producers to the ecosystems. The ice algae are considered to be important primary producers in the ice-covered regions as well as phytoplankton in the water column beneath the sea-ice. Since the 1960's many biologists have conducted investigations on the ecology of ice algae and obtained valuable information on their biomass, productivity and interrelationship with other organisms of a higher trophic level (Horner, 1985; Garrison et al., 1986). However, research efforts were concentrated in some selected localities and in the spring-summer season due to the convenience in obtaining logistic supports. Consequently information acquired is still insufficient to give a general explanation on such basic questions as "How and when does colonization by ice algae take place?"and"What are the spatial and temporal patterns of ice community distribution and development?", which were argued together with other specified research items of ice algal ecology in the SCAR /SCOR workshop on Ecology of the Antarctic Sea-Ice zone at Trondheim, Norway in May 1990. This means that synoptic investigations on the distribution of ice algae and the development of ice algal communities are needed as the first step to fill the gaps in our present knowledge on the ecology of ice algae.

Sea-ice Communities and Their Developmental Processes

The sea-ice provides ice algae a substratum to which they attach and also such microhabitats as brine pockets and interstices between ice crystals. Although ice algal communities were discovered on the vertical walls of tide-cracks and ice bergs (Whitaker, 1977), it is generally accepted that sea-ice communities develop in the snow-ice interface infiltrated with sea water, the interior part and the bottom part of the sea-ice (Ackley et al., 1979).

1. Surface Community

Ice algal communities formed in the snow-ice interface are named the surface community and reported from the northern part of Lutzow-Holm Bay (Meguro, 1962) and the Antarctic Peninsula area (Burkholder and Mandelli, 1965). Meguro(1962) speculated that the surface community is inoculated by the seeds contained in the sea water penetrated laterally into the snow-ice interface. Penetration of sea water is induced by the depress of ice floe with the accumulated snow during winter and the algae begin to increase when receiving solar radiation in spring and summer. This process seems to occur more commonly in the pack ice zone than in the fast ice zone (Clarke and Ackley, 1984). Sea water infiltrations followed by the algal bloom were observed along the tide crack (Whitaker, 1977), pressure ridge and in the depression formed in the sea-ice surface with the accumulated snow in the pack ice zone of Weddell Sea (Ackley, 1986). Along the approaching course of the Japanese Antarctic Research Ships to the continent, the surface communities were observed in the northern part of the ice-covered area, in the pack ice zone (Meguro et al., in press). The similar tendency in horizontal distribution of surface community was observed by the present author.

The surface community was formed in the field of fast ice. According to Watanabe and Satoh (1987), at their Station 3, the lower part of the snow accumulated to more than 70 cm in depth and became consolidated by freezing with the infiltrated sea water, and chlorophyll *a* concentration in this part began to increase in September. The chlorophyll *a* concentration was high in the uppermost part of the consolidated layer between mid-November and mid-December (Fig. 1). A maximum of chlorophyll *a* concentration was 25.44 mg m^{-3} on 18 December. They hypothesized that the seeds of this surface community came from the interior and/or bottom community through brine channels and capillaries in the sea-ice.

The values of chlorophyll *a* concentration reported by Meguro (1962) and Burkholder and Mandelli (1965) were 670 mg m^{-3} and 407 mg m^{-3} respectively, though that of Clarke and Ackley (1984) was 43 mg m^{-3}.

2. Interior Community

Algal cells are distributed through the interior part of the sea-ice and form chlorophyll *a* rich layers (Ackley et al., 1979). They mentioned that algal cells were incorporated with the nucleation and scavenging by fragile ice in the process of new ice formation and ice growth. Ackley et al. (1979) observed discolored pancake ice. Algal populations in these new ice floes were considered formed with initial incorporation of algal cells by scavenging of fragile ice and with successive enhancement by pumping of sea water, which was induced by wave action, into the pancake ice (Ackley et al., 1987). The incorporation of algal cells by fragile ice is considered as a common mechanism for the interior community formation in the pack ice zone, in particular in the Weddell Sea region. In general, however, chlorophyll *a* of this community is lower than the other two communities and mostly below ten mg m^{-3} (Garrison and Buck, 1982; Clarke and Ackley, 1984).

Algae increased at a layer in which nutrients contained in the surface of the sea-ice were concentrated with the downward drainage of brine due to warming of the surface (Ackley et al., 1979). This layer appeared to be formed near the sea surface, freeboard.

In the fast ice region, the incorporation of algal cells in the initial stage of ice formation was observed (Watanabe and Satoh, 1987). Break-up of the fast ice followed by freezing of sea water occurred in early May 1983.

Algal cells and flocks of algal colonies were incorporated in the grease ice (Figs. 1 and 2) and chlorophyll *a* concentrations were in the order of the magnitude of 10 mg m^{-3}. A high chlorophyll *a* layer was formed at the bottom part of sea-ice through downward shifting of algae at the early stage of ice formation, but the chlorophyll *a* concentration in the interior part decreased gradually with the progress of time. Although Watanabe and Satoh (1987) could not identify the origin of algal cells' incorporation, they considered the communities which developed at the bottom part of the over-summered sea-ice as one of the origins.

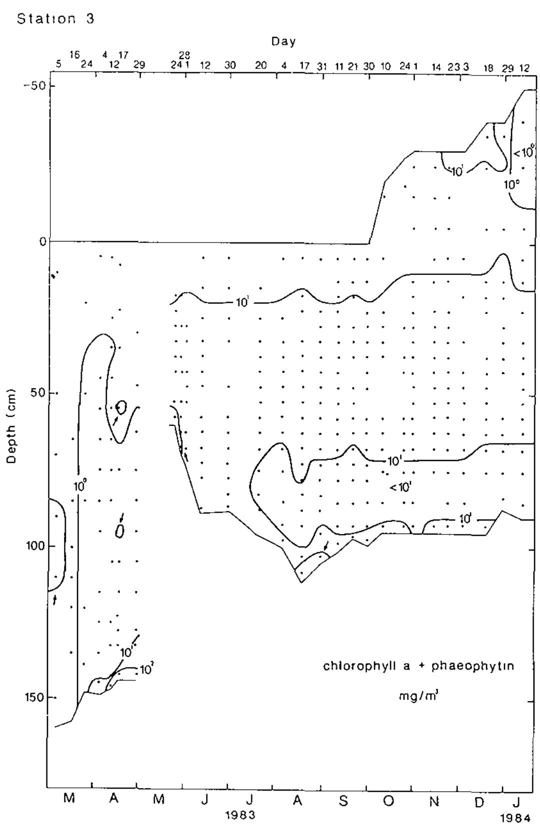

Fig. 1. Distribution and seasonal change of plant pigments in the sea-ice at Station 3 of Watanabe and Satoh (1987). Break-up of the over-summered sea-ice occurred on 2-3 May 1983. Autumnal and spring-summer bottom communities and the surface community are observed.

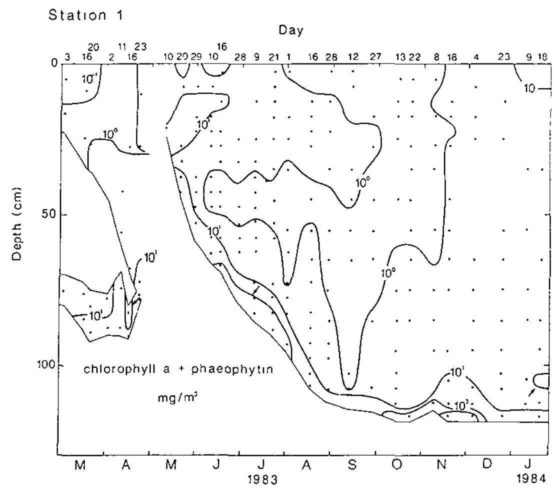

Fig. 2. Distribution and seasonal change of plant pigments in the sea-ice at Station 1 of Watanabe and Satoh (1987). Break-up of the over-summered sea-ice occurred on 2-3 May 1983. Autumnal and spring-summer bottom communities are formed.

It was reported that algal communities which developed at the bottom of newly formed sea-ice in autumn remained in the interior part of sea-ice through the winter (Buinitsky, 1977; Hoshiai, 1977 and 1981; McConville and Wetherbee, 1983; Watanabe and Satoh, 1987). The chlorophyll *a* concentration was high in the initial stage of community development as mentioned in the next section but in the relict community it decreased gradually with the advance of time.

3. Bottom Community

The bottom community in the fast ice region develops comprehensively. The distribution of this community is probably circumpolar because it has been reported from McMurdo (Bunt and Wood, 1963; Palmisano and Sullivan, 1983), Casey, Davis and Mawson (McConville and Wetherbee, 1983), Molodezhnaya (Buinitsky,

1977) and Syowa (Hoshiai, 1977 and 1981; Watanabe and Satoh, 1987). According to the observations at Syowa, blooming of the bottom community occurred in autumn and spring-summer. The autumnal increase of ice algae occurred at the bottom of new ice. The spatial extent of the autumnal community was limited and the chlorophyll *a* concentration fluctuated from year to year in comparison to the spring-summer community (Hoshiai, 1985). The chlorophyll *a* concentration of the autumnal community reached 944 mg m^{-3} in the 1970 autumn (Hoshiai, 1981). The autumnal proliferation of algae occurred at the bottom part of over-summered sea-ice as illustrated in Figures 1 and 2 as well as in the newly formed sea-ice shown in Figures 1, 2 and 3. The autumnal community was reported from Casey, Davis and Mawson (McConville and Wetherbee, 1983) and Molodezhnaya (Buinitsky, 1977) other than Syowa.

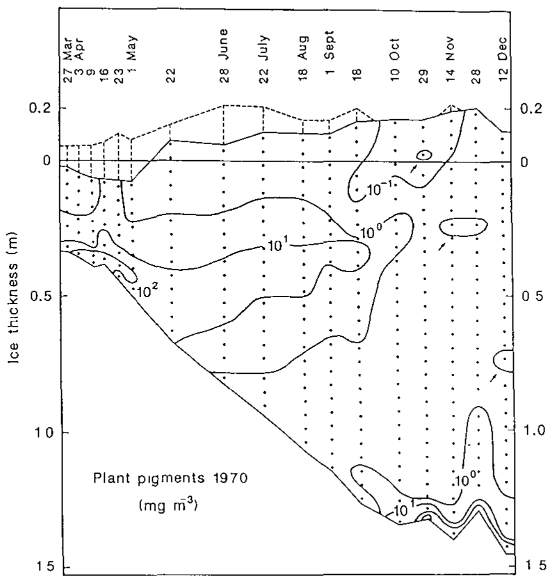

Fig. 3. Distribution and seasonal change of plant pigments in the new sea-ice at the site near Station 1 of Watanabe and Satoh (1987) in 1970 (Referred to Hoshiai, 1981).

The ecology of the spring-summer bottom community was intensively investigated in the McMurdo Sound area. The biomass, productivity and physiological response to the physical environment were studied by Bunt and Lee (1970) and Sullivan and his co-workers (cf. Sullivan et al., 1985). In the Syowa Station area the increase of chlorophyll *a* concentration at the bottom part of the sea-ice began in late August, when the solar radiation increased and the growth of sea-ice became slow, and reached a peak between late October and early December (Hoshiai, 1981; Watanabe and Satoh, 1987). The values of chlorophyll *a* content at its peak were beyond 10^3 mg m^{-3}.

In addition to the bottom community the algal community in the platelet ice layer formed just beneath the sea-ice in McMurdo Sound (Dayton et al., 1969) and the sub-ice microalgal strands which were suspended from the undersurface of the sea-ice at McMurdo (Sullivan et al., 1982), Davis (McConville et al., 1985) and Syowa (Watanabe, 1988).

Concluding Remarks

Recognition of the importance of the Antarctic Ocean in the global change of environment is increasing as a sink of carbon and nitrogen, and as a sensor to monitor global change because the Antarctic is sensitive in responding to the global change. To evaluate capacity of the Antarctic Ocean as the carbon and nitrogen sink, it is necessary to understand how and to what extent carbon and nitrogen are fixed and reserved in the Antarctic Ocean through physical, chemical and biological processes. The biomass of primary producers and the primary productivity are of the fundamental importance in getting a better understanding of the sink. There are two major groups of primary producers in the Antarctic Ocean, phytoplankton and ice algae. In this paper, the focus was put on the ice algae.

Although progress has been done in the ecological research of ice algae, questions still remain to be answered in order to give general figures of biomass and productivity of ice algae. Although the biomass and productivity of the surface community and the autumnal bottom community are seemed to be high, the horizontal extent of the two communities is unknown. As for the interior community, there is no accurate information as to whether the algae are able to grow and increase and where they come from. Although the chlorophyll *a* concentration of algae in the interior community is not high, the extent of the pack ice zone which contains the interior community is extremely wide. Estimation of biomass and productivity of the interior community is necessary. Ecological data on the spring-summer bottom community are intensively collected but still regional. To solve the above questions it is necessary to conduct synoptic observations on the distribution and development of the ice algal communities concurrently with the deeper research on specific topics of physiology and biochemistry of ice algae. Also, it is desired that the synoptic observations cover all the seasons of the year. Comparable data obtained through synoptic observations will contribute to the deep and comprehensive understanding of the ecological role of ice algae in the Antarctic Ocean.

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