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Review

A BRIEF HISTORY OF SEA ICE BIOTA STUDIES AT SYOWA STATION AND ITS VICINITY

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Abstract: A history of sea ice biota studies which were carried out at Syowa Station (69°00′S, 39°35′E) and its vicinity is outlined. The process of the surface community formation in ice floes, the bimodal proliferation of ice algae in the bottom layer of fast ice and the algae-copepod-fish link associated with fast ice were mainly investigated. Based on the results obtained from the Syowa Station area and those from other locations, the distribution of ice algal communities, the seasonality in formation of the ice algal community and the food chain associated with sea ice are discussed. Finally, a need for comparative research on Arctic and Antarctic ecosystems is suggested.

1. Introduction

The importance of ice algae as one of the primary producers in the ecosystem of ice-covered seas has been widely recognized (Alexander, 1974; Horner, 1985; Smith and Sakshaug, 1990; Knox, 1994). Japanese scientists who have participated in the Japanese Antarctic Research Expedition (JARE) have been interested in ice algae since the early stage of JARE activity which commenced in 1956 to cooperate with the scientific research of the International Geophysical Year (IGY). Accordingly, field studies on the ice algae by Japanese scientists have been mainly carried out in the vicinity of Syowa Station (69°00′S, 39°35′E), Antarctica, and some comparative studies were done in the Arctic (Meguro *et al.*, 1967) and along the northeastern coast of Hokkaido, Japan, facing the Sea of Okhotsk (Hoshiai and Fukuchi, 1981; Takahashi, 1981). As an extension of the above-mentioned activities, field studies on sea ice biota, both plants and animals, associated with sea ice, started in 1992 in Saroma-ko lagoon, Hokkaido, northern Japan and in the Resolute Passage, Northwest Territories, Canada, as part of the Japan-Canada Complementary Study (Fukuchi *et al.*, 1995).

In this report, we outline the history of ice algae studies carried out by Japanese scientists to provide some basic information on the sea ice biota to glaciologists and meteorologists whose cooperation with biologists is essential to further ecological understanding of sea ice biota.

2. Ecological Research in the Syowa Station Area

In the early stage of the JARE, biologists noted brown-colored sea ice *en route* to Syowa Station. It was reported that microorganisms were observed in the colored ice (Matsuda, 1961; Fukushima, 1961) and pioneering work was done by Meguro (1962). He detected such a high chlorophyll *a* standing stock as 97 mg/m^2 in the brown layer stained by diatoms in the lowermost part of the snow accumulated on sea ice floes. Based on the fact that the brown layer was formed at the level corresponding to the sea water surface, he assumed discoloration process as follows. The sea ice was depressed by snow which fell during winter. The lowermost part of the snow layer was immersed in sea water which contained seeds of micro-algae. In spring to summer, the inoculated seeds grew to stain the snow brown, absorbing solar radiation supplied through the snow layer. In mid-summer, the brown layer was broken and the algae returned to the water column surrounding the floe. This scheme of seasonal cycle of the ice algal community has been widely accepted (*e.g.* HORNER, 1985). HOSHIAI and KATO (1962) examined the species composition of diatom communities in the ice floe sampled north of Syowa Station and made a comparison with that of phytoplankton communities in the water column. The species composition of the former was different from that of the latter, though some species were common to both habitats.

In 1965, the investigation of ice algae in the fast ice area became possible due to the commissioning of the new powerful icebreaking research vessel, FUJI. FUKUSHIMA and MEGURO (1966) discovered another brown layer at the bottom of the fast ice north of Syowa Station. They named it "bottom type plankton ice", distinguishing it from the brown layer formed between snow and ice, "surface type plankton ice". HOSHIAI (1977, 1981) observed the distribution of ice algal biomass in terms of chlorophyll *a* and phaeopigments with chlorinity and pH of the ice melt water and their seasonal changes throughout the 1970 winter season after preliminary winter research on the formation of the ice algal community in 1967 (HOSHIAI, 1969). The conclusions in his report were that the extremes in ice algal biomass occurred twice a year, in autumn and spring-summer, at the sea ice bottom; that the algal biomass of autumn and spring-summer communities were comparable, about 30 and 35 mg chl.a/m^2, respectively; that the chlorinity was high just above and below the layers in which algae bloomed; that the pH value was high in the whole layer of sea ice in autumn, decreased in winter and recovered in spring-summer. The seasonal variation of pH was interpreted as a result of photosynthesis of ice algae. Autumnal and the spring-summer increases of ice algae were observed in 1968 by NARUSE *et al.* (1971) and in 1983 by WATANABE and SATOH (1987) in the Syowa Station area. In addition, WATANABE and SATOH (1987) reported the notable increase of diatoms at the interface of snow and ice in the spring-summer of 1983. They assumed that the inoculumn of diatoms came up from the interior community based on the similarity of species composition in both communities (WATANABE *et al.*, 1990).

A considerable proportion of diatom species which appeared in the brown layer were composed of colonial species. They adhere to ice crystals or become suspended in the interstices between ice crystals. When they grow up, the colonies overflow the interstices and extend out of the undersurface of sea ice and hang as strands from the sea ice bottom. WATANABE (1988) reported that algal strands 10–15 cm in length in early November grew up to 50–60 cm by early December in 1983. Various sized fragments of strands were tangled with the towing rope of a plankton net in spring-summer. SASAKI and HOSHIAI (1986) mentioned that they might settle immediately on the sea floor.

The naupliar larva of a calanoid copepod, *Paralabidocera antarctica*, occurred in the brown layer of sea ice in autumn and resided there during winter (HOSHIAI, 1981). They grew slightly in autumn, stopped growing in mid-winter and restarted growth in spring-summer, feeding on ice algae (HOSHIAI *et al.*, 1987). Furthermore, it was clarified that the larva was one of the major winter foods of the young of a nototheniid fish, *Pagothenia borchgrevinki* (HOSHIAI *et al.*, 1991). Harpacticoid copepods were also common constituents of the sea ice meiofauna throughout the year but their number was less than that of *P. antarctica*. Due to taxonomical difficulty, detailed information on the ecology of harpacticoids has not been acquired.

3. Discussion

3.1. Distribution of ice algal communities

In the early stage of ecological research on the sea ice biota, it was thought that the surface community formed at the snow-ice interface was distributed in the pack ice in summer (MEGURO, 1962; BURKHOLDER and MANDELLI, 1965). ACKLEY *et al.* (1979) reported later that ice algae were widely distributed not only in the surface and the bottom parts but also in the interior part of ice floes in the pack ice area of the Weddell Sea. ACKLEY (1982) ascribed the mechanism of interior community formation to the incorporation of microorganisms accompanied by the floating and aggregating frazil ice in the pack ice region. However, the distribution of chlorophyll *a* in the interior part was shown extensively in the fast ice area (HOSHIAI, 1981) as well. The interior part of this ice might be composed of columnar ice. Further studies are necessary to draw out conclusive explanation for the interior community formation. It was a popular understanding that the bottom community was ubiquitous in the fast ice area in contrast to the surface community (BUNT, 1968; GRUZOV, 1977; HOSHIAI, 1981). WHITAKER (1977) reported ice algal communities at various parts of sea ice in the coastal area of Signy Island. Recently, ACKLEY and SULLIVAN (1994) surveyed ice algal communities in relation to their habitats. According to two previous reports, it seems that any part of sea ice may be potentially a habitat of a dense population of ice algae because physical and chemical conditions are suitable for their growth.

3.2. Seasonality in the formation of the ice algal community

MEGURO (1962) speculated that the surface community might be formed in spring-summer on ice floes. BARSDATE and ALEXANDER (1977) observed remarkable algal growth in floes newly formed in autumn near Biscoe Islands (66°S, 66.5°W). GARRISON and CLOSE (1993) reported that the ice algae were concentrated in the bottom of ice floes 30 to 50 cm thick in the period between mid-June and early July in the region surrounded by 59°S, 61.5°S latitude and 40°W, 49°W longitude in the Weddell Sea. FRITSEN *et al.* (1994) observed the autumnal ice algal communities formed in the freeboard layer of drifting pack ice in February to June between 71.4°S and 65.8°S along 53°W longitude in the Weddell Sea.

As mentioned above, the bottom community was common in the fast ice area. Although one peak in algal biomass in summer had been observed in McMurdo Sound where SULLIVAN and his coworkers had done intensive field work on the ecology and physiology of ice algae, two peaks were observed at Mirny (BUINITSKY, 1977; GRUZOV, 1977), Casey (MCCONVILLE and WETHERBEE, 1983) and Davis (PERRIN *et al.*, 1987) in addition to Syowa Station (HOSHIAI, 1981; WATANABE and SATOH, 1987). The autumnal increase of ice algae was observed in the new bottom ice layer in May 1983 (Watanabe and Satoh, 1987) but Hoshiai (1981) discovered the algal blooming in the bottom layer of summer-persisting ice in the Syowa area.

As reported by Hoshiai (1985), the growing season of ice algae is longer than that presumed in the early stage of ecological research on ice algae. This implies that the role of ice algae as one of primary producers is more important to the ecosystems in the ice-covered seas than presumed before.

3.3. Possible sources of ice algae in floes in the pack ice area

In the Syowa Station area, the break-up of land fast ice sometimes occurs in late autumn. The breaking-up of the marginal part of the fast ice area is normal. Relatively extensive break-up of the fast ice field occurs frequently, and almost complete break-up occurs sometimes in late autumn. When the broken chips of fast ice flow out, they transport many algal cells, mostly concentrated in the bottom part, into the pack ice area (Fig. 1). There, they collide with each other and are disbanded into smaller fragments with ice algae, that could release micro-algae into the water column. Immediately after disbanding, aggregation of ice with the algae occurs to form new floes in the sea surface, when the water temperature is at the freezing point.

In the newly formed ice floe in the pack ice area, increase of ice algae occurs in the bottom part as observed by Garrison and Close (1993) and in such new ice floes the occurrence of a similar process of disbanding and freezing is expected. Watanabe observed, from an aircraft, brown colored small ice floes and slush among the floes spreading extensively in the pack ice zone north of Syowa Station in March–April, 1994. The brown color was thought to show the growth of diatoms in and/or attached to sea ice. In addition to the algal cells incorporated into the interior parts of ice floes with nucleation and scavenging by frazil ice (Ackley, 1982), the algal cells proliferated in the sea ice and recycled in the sea surface layer are considered as an important inoculumn of sea ice

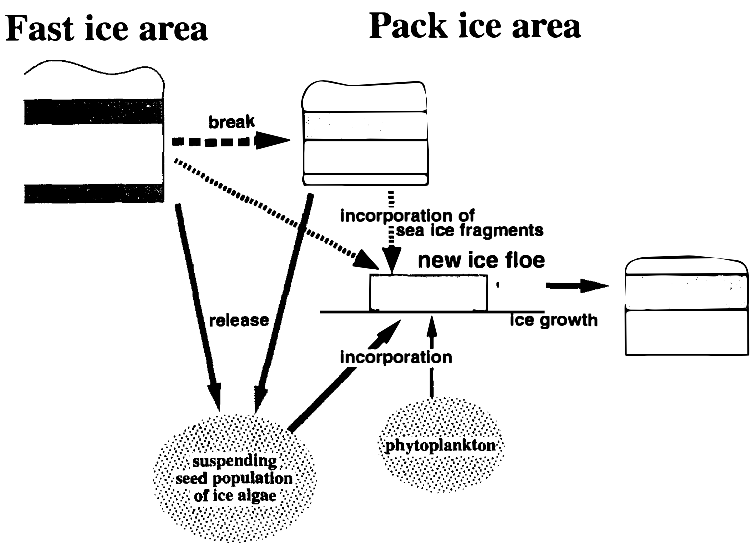

Fig. 1. Schematic representation of formation processes of ice algal assemblage in the Antarctic pack ice area.

communities in the pack ice area.

3.4. *Food chain associated with sea ice*

To evaluate the importance of ice algae in the ecosystem of an ice-covered sea, we should consider their high abundance, their concentrated distribution in the particular parts of sea ice and their presence in winter, when the primary production by phytoplankton is very little. The dense population of algae is beneficial for the feeding of such consumers as amphipods (Rakusa-Suszczewski, 1972; Richardson and Whitaker, 1979), euphausiids (Marschall, 1988; Daly 1990) and copepods (Dahms and Dieckmann, 1987; Hoshiai *et al.*, 1991; Kurbjeweit *et al.*, 1993; Menshenina and Melnikov, 1995). As the algal cells which grow in autumn are retained in the sea ice throughout the winter, amphipods and euphausiids feed on them at the undersurface of the sea ice and/or pockets in the sea ice and copepods feed within the interstices at the bottom. The above-mentioned crustacean herbivores are food for secondary consumers such as fish, birds and mammals.

3.5. *Bipolar comparison of ice associated ecosystems*

Field work on the ecology of sea ice biota in both polar seas has been carried out in some limited regions but the comparison of the results obtained from both seas has been purely conceptual, based on such general knowledge as the assumption that the majority of the Antarctic sea ice is first year but that of the Arctic sea ice is multi-year. In fact, however, there is a first year ice in the coastal waters of the Arctic and multi-year ice in the coastal areas of the Antarctic. The precise comparison of the structure and function of ecosystems in both polar seas is essential to identify the similarity and dissimilarity between the ecosystems, taking into account the temporal and spatial environmental variations of the research area. Andriashev (1968) examined the ice-associated ecosystems in the Arctic and the Antarctic seas and pointed out their similarity, which has been comprehensively accepted.

In 1974, a conference was held at McGill University, Canada, in which the necessity of coordinating research in both polar oceans was stressed. At present, however, as Hoshiai *et al.* (1996) mentioned, the comparison of the winter survival of copepods in the sea ice of both seas is difficult, because of the lack of winter data in the Arctic. Accurately comparable studies are indispensable to further our understanding of the polar sea ecosystems.

References

Ackley, S.F. (1982): Ice scavenging and nucleation: Two mechanisms for the incorporation of algae into newly forming sea ice. EOS: Trans., **63**, 65.

Ackley, S.F. and Sullivan, C.W. (1994): Physical controls on the development and characteristics of Antarctic sea ice biological communities—A review and synthesis. Deep-Sea Res. I, **41**, 1583–1604.

Ackley, S.F., Buck, K.R. and Taguchi, S. (1979): Standing crop of algae in the sea ice of the Weddell Sea region. Deep-Sea Res., **26**, 269–281.

Alexander, V. (1974): Primary productivity regimes of the nearshore Beaufort Sea, with reference to the potential role of ice biota. Coastal and Shelf of the Beaufort Sea, ed. by J.C. Reed and J.E. Sater. Arlington, Arctic Inst. North Am., 609–632.

ANDRIASHEV, A.P. (1968): The problem of the life community associated with the Antarctic fast ice. Symposium on Antarctic Oceanography, ed. by R.I. CURRIE. Cambridge, Scott Polar Res. Inst., 147–155.

BARSDATE, R.J. and ALEXANDER, V. (1977): Effects of ice faces on small scale oceanic phenomena : R/V Hero Cruise 77-1. Antarct. J. U. S., **12**(4), 21–22.

BUINITSKY, V.K. (1977): Organic life in sea ice. Polar Oceans, ed. by M. J. DUNBAR. Calgary, Arctic Inst. North Am., 301–306.

BUNT, J.S. (1968): Microalgae of the pack-ice zone. Symposium on Antarctic Oceanography, ed. by R. I. CURRIE, Cambridge, Scott Polar Res. Inst., 198–219.

BURKHOLDER, P.R. and MANDELLI, E.F. (1965): Productivity of microalgae in Antarctic sea ice. Science, **33**, 177–184.

DAHMS, H.U. and DIECKMANN, G.S. (1987): *Drescheriella glacialis* gen. nov., sp. nov. (Copepoda, Harpacticoida) from Antarctic sea ice. Polar Biol., **7**, 329–337.

DALY, K.L. (1990): Overwintering development, growth, and feeding of larval, *Euphausia superba* in the Antarctic marginal ice zone. Limnol. Oceanogr., **35**, 1564–1576.

FRITSEN, C.H., LYTLE, V.I., ACKLEY, S.F. and SULLIVAN, C.W. (1994): Autumnal bloom of Antarctic pack-ice algae. Science, **266**, 782–784.

FUKUCHI, M., TAKAHASHI, M., HOSHIAI, T. and LEGENDRE, L. (1995): Summary of the SARES project as a part of the Japan-Canada complementary study. Proc. NIPR Symp. Polar Biol., **8**, 1–4.

FUKUSHIMA, H. (1961): Preliminary reports of the biological studies on colored ocean ice. Nankyoku Shiryô (Antarct. Rec.), **11**, 164.

FUKUSHIMA, H. and MEGURO, H. (1966): The plankton ice as basic factor of the primary production in the Antarctic Ocean. Nankyoku Shiryô (Antarct. Rec.), **27**, 99–101.

GARRISON, D.L. and CLOSE, A.R. (1993): Winter ecology of the sea ice biota in Weddell Sea pack ice. Mar. Ecol. Prog. Ser., **96**, 17–31.

GRUZOV, E.N. (1977): Seasonal alteration in coastal communities in the Davis Sea. Adaptations within Antarctic Ecosystems. Proceedings of the Third SCAR Symposium on Antarctic Biology, ed. by G. A. LLANO. Washington, D.C., Smithsonian Institution, 263–278.

HORNER, R. A. (1985): History of ice algal investigations. Sea Ice Biota, ed. by R. A. HORNER. Boca Raton, CRC Press, 1–20.

HOSHIAI, T. (1969): Ecological observations of the colored layer of the sea ice at Syowa Station. Nankyoku Shiryô (Antarct. Rec.), **34**, 60–72 (in Japanese with English abstract).

HOSHIAI, T. (1977): Seasonal change of ice communities in the sea ice near Syowa Station Antarctica. Polar Oceans, ed. by M. J. DUNBAR. Calgary, Arctic Inst. North Am., 307–317.

HOSHIAI, T. (1981): Proliferation of sea ice algae in the Syowa Station area, Antarctica. Mem. Natl Inst. Polar Res., Ser. E (Biol. Med. Sci.), **34**, 1–12.

HOSHIAI, T. (1985): Autumnal proliferation of ice-algae in Antarctic sea-ice. Antarctic Nutrient Cycles and Food Webs, ed. by W. R. SIEGFRIED *et al.* Berlin, Springer, 89–92.

HOSHIAI, T. and FUKUCHI, M. (1981): Sea ice colored by ice algae in a lagoon, Lake Saroma, Hokkaido, Japan. Nankyoku Shiryô (Antarct. Rec.), **71**, 113–120.

HOSHIAI, T. and KATO, M. (1962): Ecological notes on the diatom community of the sea ice in Antarctica. Bull. Mar. Biol. Stn. Asamushi, Tohoku Univ., **10**, 221–230.

HOSHIAI, T., TANIMURA, A. and WATANABE, K. (1987): Ice algae as food of an Antarctic ice associated copepod, *Paralabidocera antarctica* (I.C. Thompson). Proc. NIPR Symp. Polar Biol., **1**, 105–111.

HOSHIAI, T., TANIMURA, A., WATANABE, K. and FUKUCHI, M. (1991): Algae-copepod-fish link associated with Antarctic sea ice. Marine Biology, Its Accomplishment and Future Prospect, ed. by J. MAUCHLINE and T. NEMOTO. Tokyo, Hokusen-sha, 237–246.

HOSHIAI, T., TANIMURA, A. and KUDOH, S. (1996): The significance of autumnal sea ice biota in the ecosystem of ice-covered polar seas. Proc. NIPR Symp. Polar Biol., **9**, 27–34.

KNOX, G.A. (1994): The Biology of the Southern Ocean. Cambridge, Cambridge Univ. Press, 1–444.

KURBJEWEIT, F., GRADINGER, R. and WEISSENBERGER, J. (1993): The life cycle of *Stephos longipes*—An example for cryopelagic coupling in the Weddell Sea (Antarctica). Mar. Ecol. Prog. Ser., **98**, 255–262.

MARSCHALL, H.P. (1988): The overwintering strategy of Antarctic krill under the pack ice of the Weddell Sea.

Polar Biol., **9**, 129–135.

MATSUDA, T. (1961): Biological investigation during Antarctic expedition voyage and at East and West Ongul Islands in Antarctica. Nankyoku Shiryô (Antarct. Rec.), **11**, 159.

McCONVILLE, M. J. and WETHERBEE, R. (1983): The bottom-ice microalgal community from annual ice in the inshore waters of East Antarctica. J. Phycol., **19**, 431–439.

MEGURO, H. (1962): Plankton ice in the Antarctic Ocean. Nankyoku Shiryô (Antarct. Rec.), **14**, 72–79.

MEGURO, H., ITO, K. and FUKUSHIMA, H. (1967): Ice flora (bottom type): A mechanism of primary production in polar seas and the growth of diatoms in sea ice. Arctic, **20**, 114–133.

MENSHENINA, L.L. and MELNIKOV, I.A. (1995): Under-ice zooplankton of the western Weddell Sea. Proc. NIPR Symp. Polar Biol., **8**, 126–138.

NARUSE, R., ENDO, Y., ISHIDA, T. and AGETA, Y. (1971): Observations of snow accumulation and sea ice at Syowa Station, Antarctica. Nankyoku Shiryô (Antarct. Rec.), **40**, 57–64.

PERRIN, R.A., LU, P. and MARCHANT, H.J. (1987): Seasonal variation in marine phytoplankton and ice algae at a shallow Antarctic coastal site. Hydrobiologia, **146**, 33–46.

RAKUSA-SUSZCZEWSKI, S. (1972): The biology of *Paramoera walkeri* STEBBING (Amphipoda) and the Antarctic sub-fast ice community. Pol. Arch. Hydrobiol., **19**, 11–36.

RICHARDSON, M.G. and WHITAKER, T.M. (1979): An Antarctic fast-ice food chain: Observations on the interaction of the amphipod *Pontogeneia antarctica* Chevreux with ice associated micro-algae. Br. Antarct. Surv. Bull., **17**, 107–115.

SASAKI, H. and HOSHIAI, T. (1986): Sedimentation of microalgae under the Antarctic fast ice in summer. Mem. Natl Inst. Polar Res., Spec. Issue, **40**, 45–55.

SMITH, W. O., Jr. and SAKSHAUG, E. (1990): Polar phytoplankton. Polar Oceanography, Part B: Chemistry, Biology and Geology, ed. by W. O. SMITH, Jr. San Diego, Academic Press, 477–525.

TAKAHASHI, E. (1981): Floristic study of ice algae in the sea ice of a lagoon, Lake Saroma, Hokkaido, Japan. Mem. Natl Inst. Polar Res., Ser. E (Biol. Med. Sci.), **34**, 49–56.

WATANABE, K. (1988): Sub-ice microalgal strands in the Antarctic coastal fast ice near Syowa Station. Jpn. J. Phycol., **36**, 221–229.

WATANABE, K. and SATOH, H. (1987): Seasonal variations of ice algal standing crop near Syowa Station, East Antarctica, in 1983/84. Bull. Plankton Soc. Jpn., **34**, 143–164.

WATANABE, K., SATOH, H. and HOSHIAI, T. (1990): Seasonal variation in ice algal assemblages in the fast ice near Syowa Station in 1983/84. Antarctic Ecosystems—Change and Conservation, ed. by K.R. KERRY and G. HEMPEL. Heidelberg, Springer, 136–142

WHITAKER, T.M. (1977): Sea ice habitats of Signy Island (South Orkneys) and their primary productivity. Adaptations within Antarctic Ecosystems: Proceedings of the Third SCAR Symposium on Antarctic Biology, ed. by G.A. LLANO. Washington, D.C., Smithsonian Institution, 75–82.

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