Polar Biol (1995) 15: 247–252

ORIGINAL PAPER

Julian Gutt

The occurrence of sub-ice algal aggregations off northeast Greenland

Received: 18 November 1993/Accepted: 24 July 1994

Abstract Massive growth of sub-ice algal assemblages was recorded at two stations under first-year ice off northeast Greenland using a Remotely Operated Vehicle equipped with cameras. The assemblages mainly consisted of the diatom *Melosira arctica* (Ehr.) Dickie. A station sampled at the beginning of June 1993 revealed two forms of growth, curtain-like and rope-like, but with many intermediate types along the entire 150 m transect. The algal distribution was patchy. No significant sympagic fauna was found close to the algal masses. At a station sampled in the middle of July, similar algal concentrations seemed to be disturbed by ice-melting processes. Two casts under multi-year ice flows failed to show any algal aggregations. The observation of algal assemblages under first-year ice is in contrast to earlier reports from the Barents Sea where they have been recorded exclusively under multi-year ice.

Introduction

One important compound of polar ecosystems is the sympagic community; this comprises plants and animals that live in association with sea ice for all or at least part of their lives. Sea ice algae are the primary energy source for a large number of invertebrate grazers at different water depths, such as amphipods or young polar cod in the Arctic (Carey 1985; Gulliksen and Lønne 1989), and krill in the Antarctic (O'Brien 1987). The latter harvest the ice in the early spring before the phytoplankton bloom in the water column.

The algae live in a number of communities that are generally classified according to their position in or under the ice (Horner et al. 1988, 1992). One such community occurs beneath the ice as mats or strands that may be loosely attached to the bottom surface of the ice, and it is referred to as the sub-ice community. The centric diatom *Melosira arctica* (Ehr.) Dickie has been shown to produce large, mucilaginous masses of long strands extending several meters beneath the bottom surface of Arctic ice (Mel'nikov and Bondarchuk 1987). This diatom has been reported at a number of places throughout the Arctic ocean (e.g. Usachev 1949; Hsiao 1983; Booth 1984; Syvertsen 1991), although detailed information about its distribution and biology is scarce.

The expedition ARK IX/2–3 of the German R/V "Polarstern" in June/July 1993 to the northeast Greenland coast, was part of the international, interdisciplinary Northeast Water Polynya project. Its goal was to investigate the physical mechanisms that generate and maintain the large annual polynya, and the ecological processes that are affected by it (Hirche and Kattner 1994). Within the framework of the project a Remotely Operated Vehicle (ROV) was used to determine the distribution of algal associations and the associated fauna in the polynya on an intermediate spatial scale, and to describe its different growth forms.

Materials and methods

The ROV (sprint 101) was equipped with two video cameras (monochrome, color), a still camera, a compass, five thrusters, lights, strobes, and a depth sensor. When the vehicle was operated approximately 20 cm below the ice at a standard distance of 1 m between the cameras and the observed objects, an optical resolution of the video image of less than 3 mm was obtained; that of the photographs was less than 1 mm. The vehicle had a maximum operating range of 200 m from the ship.

Observations below the approximately 300-cm-thick multi-year ice were made at stations 119 (2 July 1993) and 140 (6 July 1993).

J. Gutt
Alfred-Wegener-Institut für Polar- und Meeresforschung,
Columbusstrasse,
D-27568 Bremerhaven, Germany

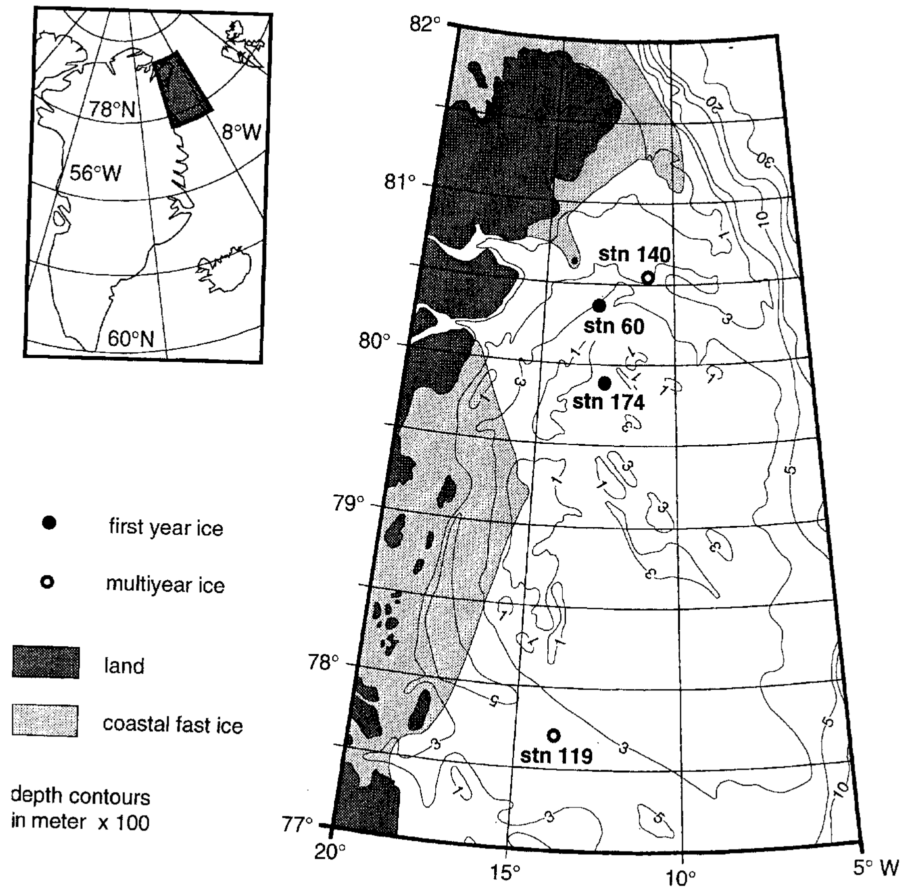

Fig. 1 Station map

Casts below 70- to 120-cm-thick first-year ice were made at stations 60 (9 June 1993) and 174 (13 July 1993; Fig. 1). The sea ice of an area 50 × 50 km around both stations 60 and 174 consisted exclusively of first-year ice with a coverage of 93% and 60% respectively. These data were taken from the SSM/I satellite. The ice at all stations was snow covered, although there were melt ponds at stations 140 and 174.

The distances covered by the ROV were estimated from the length of the tether cable lowered from the ship. Between ice floes, free-floating algal aggregations were collected occasionally using a bucket.

Results

The taxonomic determination (C. Hellum, personal communication) of the sampled algal aggregations showed that *Melosira arctica* made up most of the material in terms of biomass. A maximum relative abundance of 95% was estimated for this species, which resulted in an even higher percentage for biomass. The remaining cells were smaller diatom epiphytes such as *Synedra hyperborea*, *Pseudogomphonema arcticum* and *Gonioceros septentrionalis*.

The observations on the algal aggregations at stations 60 and 174, including type, size, and abundance, are given in Table 1.

No sub-ice assemblages were present under the multi-year ice at stations 140 and 119. No concentrations of macroplankton and no fish were observed directly under the ice at any station. Only a very few large copepods, other crustaceans, chaetognaths, and ctenophores were recorded.

Discussion

Dense aggregations of *Melosira arctica* have been reported from the northern Barents Sea where they were found attached to the undersurface of the ice (Usachev 1949; Syvertsen 1991). There are also indications that *M. arctica* dominates sub-ice assemblages in the central Arctic Ocean (Mel'nikov and Bondarchuk 1987; Syvertsen 1991). Hsiao (1983) listed many locations in the Canadian Arctic where *M. arctica* was collected. However, quantitative studies have shown that *M. arctica* can be rare or totally absent at other localities in the Arctic (Meguro et al. 1967; Bradstreet and Cross 1982; Booth 1984). There are other early reports from West Greenland (Vanhöffen 1897) and the Baltic Sea (Hustedt 1930).

The present data provide the first record of dense algal aggregations, dominated by *Melosira arctica*, for the area off northeast Greenland. The northernmost record so far from the Greenland coast was at 70°N (Østrup 1887). Although the two stations with massive

Table 1 Algal aggregations mainly consisting of *Melosira arctica* at stations 60 and 174 with its type, size, and abundance

Pieces of transects (m), counted from outset	Angle of transect to the ships heading	Type of aggregations	Size of aggregations	Abundance
Station 60				
0–15	90°	Open water		
15–65	90°	Flat, translucent, green-brown shreds, horizontally oriented as if attached to the lower ice surface (Fig. 2a)	Maximum: 20 × 20 cm	Mostly > 10/m²
65–165	90°	(1) Curtain-like type, very thin, flat, green-brownish, translucent beneath the ice at an angle between 80° and 20° to the surface apparently depending on the current. Shape varied from more or less rectangular to extremely irregular (Fig. 2b)	Maximum: 200 × 40 cm	1–5/10 m²
		(2) Solid rope-like type, hanging in a smooth curve beneath the ice (Fig. 2c). Most of the "ropes" were oriented in the same direction at an angle of roughly 30° due to the current. At their upper ends they were fixed to funnel-shaped indentations a few centimeters deep in the bottom of the ice. In some areas the undersurface of the ice was covered by a thin brownish layer aparently composed of other diatoms. The indentations were free of this brownish layer	Maximum length: 300 cm; diameter:1–2 cm, decreasing slightly toward the lower ends	Bunches of < 10/m²
		(3) Intermediate type, mostly consisting of the curtain-like growth hanging beneath the horizontally oriented rope-like structure and resembling a half-pulled-down roller blind. Similar structures appeared oriented at approximately 70° to the ice (Fig. 2d)	Smaller than "curtains"	1–5/10 m²
165–190	0°	All three types	See above	1/10 m²
190–290	170°	Changes between areas dominated by bunches of the rope-like and the intermediate type	See above	Bunches of "ropes": 10/5 m²; bunches patchy dispersed. Less intermediate types scattered in between
290–340	170°	Same as meters 15–65 from the ship at the beginning of the observations	See above	See above
340–355	170°	Open water		
Station 174				
0–20	80°	Small shreds of algae floating in open water	1–5 cm	
20–40	80°	Ridged ice perpendicular to the ships direction		
1–5 cm		Many shreds floating freely in the water a few meters beneath the ice, No significant amount of algal material was attached to the bottom of the ice	1–5 cm	
40–70	80°	Round or elongated fringed pieces	Minimum: 1 cm Average: 5 cm Maximum: 10 cm	< 50/m²; rare, denser in patches of an areal extent of ca. 4 m²; shreds uniformly dispersed;
		Short fringed, rope-like structures	< 30 cm long	< 5% of the total algal material
		Subsurface of ice slightly undulating with indentations a few centimeters deep		
70		Sharp border (crack?)		
70–90	80°	Almost no algal aggregations attached to the subsurface of the ice, substances smoother than before		
90–120		Patches chiefly composed of rope-like structures lying horizontally in contact with the ice	< 300 cm long with additional shorter pieces	Covered ca. 15% of the lower ice surface in the most concentrated areas

Table 1 (continued)

Pieces of transects (m), counted from outset	Angle of transect to the ships heading	Type of aggregations	Size of aggregations	Abundance
120–160		Similar to meters 40–70, though with smaller algal aggregations; some patches (of small scraps) withy partly distinct edges	Diameter: < 5 cm	< 30/m^2
		Rope-like structures present	See above	rare
160–190		Scraps;	Diameter: 2–20 cm	< 10/m^2
		rope-like structures	See above	< 1/10 m^2
190–380	260°	No observation on the way back to the ship		
0–70	40°	Ridged ice		
70–140	220°	No algal aggregations		

At each part of this transect the image was occasionally extremely blurred because of heavy schlieren caused by a sharp gradient between high and low salinity directly under the ice, which was disturbed by the thrusters of the ROV

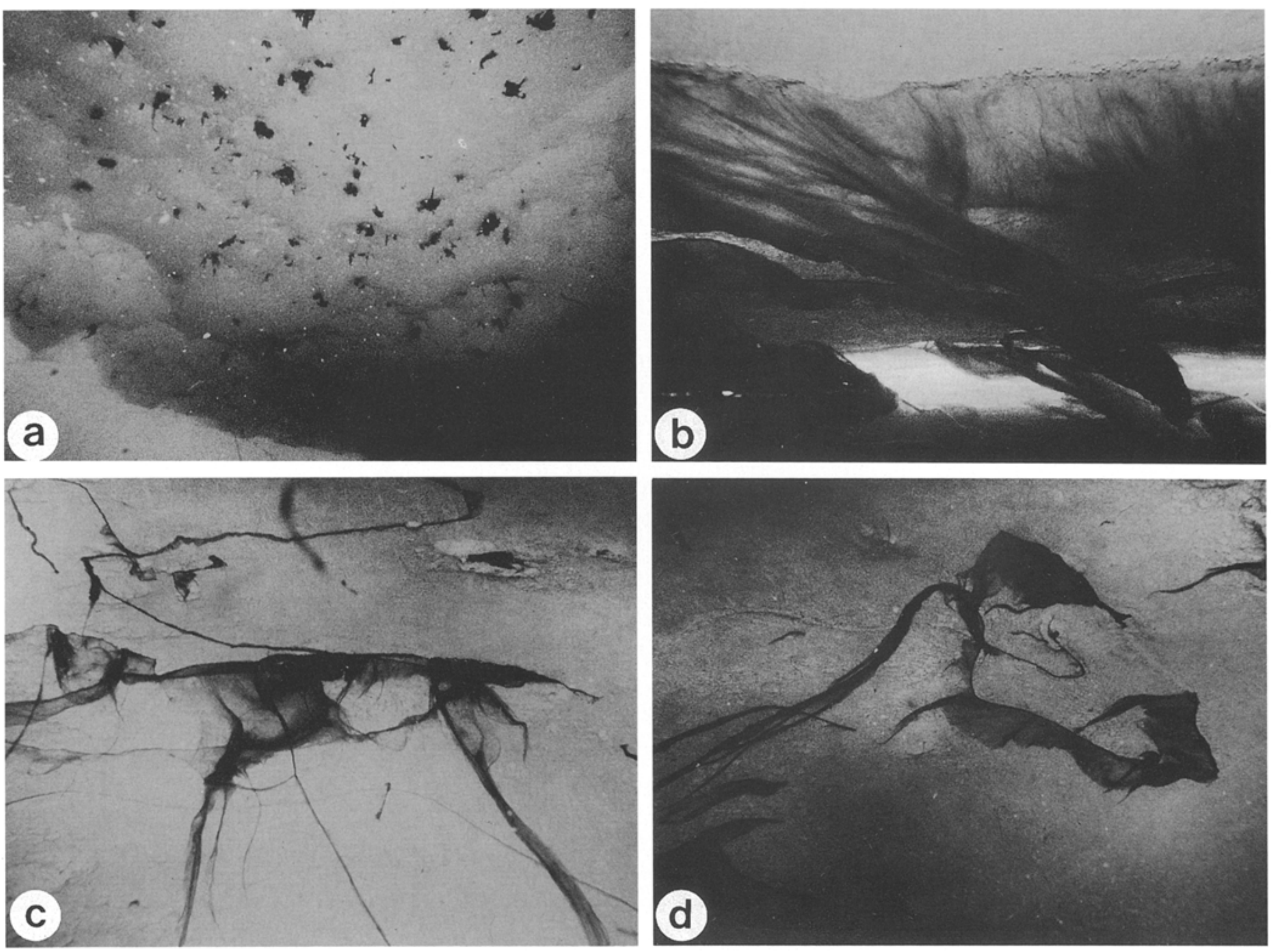

Fig. 2a–d Different morphological structures of algal aggregations dominated by *Melosira arctica* at station 60 under the first-year ice: **a** shreds that apparently result from mechanical disturbance or melting processes; **b** curtain-like structures; **c** rope-like structures; **d** intermediate forms between curtain- and rope-like structure

concentrations are of poor statistical value, the impression of a high abundance of large sub-ice assemblages beneath first-year ice was confirmed by observations from the ship when it broke through this ice. The same was true for the absence of such algal aggregations from beneath multi-year ice. The continuous observation by the ROV on a transect with a maximum length of 200 m (one station) had the advantage of illustrating that the algal aggregations were widespread on a relatively large spatial scale, but with a certain degree of patchiness. The areas without massive algal growth were no larger than a few square meters. The small shreds observed at the beginning of station 60 must have been disturbed by the propellers of the ship since they only occurred close to the ship. Similar shreds dominated station 174, and were probably influenced by the melting ice that was clearly seen as a shimmer directly under the ice. Most of these pieces were no longer attached to the ice and floated in the water. This was not observed earlier at station 60. Such remnants of sub-ice assemblages have also been described below the 2- to 4-m-thick ice in late summer to autumn in the Barents Sea (Syvertsen 1991). The growth forms (curtain-like and rope-like) reported here can only be explained as a mechanical rolling-up of the flat curtain-like material, or simple concentration and attachment by mucilaginous material. Colonies similar in shape were shown by Mel'nikov (1989) and described by Syvertsen (1991) for mainly *Nitzschia* and *Navicula* species in "older annual ice", and *M. arctica* on the "undersurface" of multi-year ice".

An association of *Melosira arctica* with the epiphytes *Synedra hyperborea*, *Pseudogomphonema arcticum* and *Gonioceros septentrionalis* was also reported by Horner et al. (1988) and Syvertsen (1991) for the central Arctic Ocean and Barents Sea. Additionally *Melosira* mats containing *Coscinodiscus* sp. and *Gymnodinium* sp. have been found in the Davis Strait (Horner 1985).

The algal aggregations, dominated by *Melosira arctica* beneath first-year ice are in contrast with earlier descriptions of its habitat. In the Barents Sea, *M. arctica* is known from multi-year ice up to 3-m thick in the north, and is missing in the 0- to 60-cm-thick first-year ice in the south. *M. arctica* also occurs under multi-year ice in the central Arctic Ocean (Horner et al. 1988; Mel'nikov 1989). Unfortunately, information on the thickness of the ice is missing from publications about sea ice biota in the Canadian Arctic and waters off Alaska. The absence of *M. arctica* under multi-year ice in the polynya off northeast Greenland can be explained by possible melting processes, or by dynamic ice growth during the Transpolar Drift. This may have disturbed the habitat to such a degree that permanent masses of sub-ice algae could not survive. This hypothesis fits with the observation of the ridged areas in the first-year ice at station 174 where algal aggregations were absent. Syvertsen (1991) showed a similar phenomenon for sub-ice assemblages in general.

The absence of a significant macrofauna associated with the diatom mats is remarkable, because there are several reports of complex relationships of a sympagic fauna mainly consisting of amphipods, other crustaceans, and polar cod (*Boreogadus saida*) under the sea ice (Bradstreet and Cross 1982; Cross 1982; Carey 1985; Gulliksen and Lønne 1989; Grainger and Hsiao 1990; Lønne and Gulliksen 1991). A possible reason might be the effect of avoidance of the noise of the ship's propellers or of the lights and the thrusters of the ROV itself. However, dense aggregations of crustaceans and single specimens of *Boreogadus saida* were observed in the same area close to the sea floor, which seemed to be totally undisturbed by the vehicle (unpublished observation). Investigations on trophic relationships showed that *Melosira arctica* does not play an important role as food for the sympagic fauna (Bradstreet and Cross 1982; Grainger and Hsiao 1990), and that the sub-ice fauna seems to be much less abundant below first-year ice than below multi-year ice (Lønne and Gulliksen 1991).

After the ice melt, *M. arctica* is supposed to sink rapidly to the sea bottom (Syvertsen 1991). Therefore this species can be considered as a big energy input to the shallow benthic systems. Investigations on metabolic processes of the benthos carried out during the Northeast Water Polynya project will elucidate the role of sub-ice assemblages for this part of the ecosystem. The results here show a more variable habitat preference than was previously thought. Future studies on its general biology, biomass and production, and role within trophic relationships, and a more intensive investigation on the distribution of *M. arctica* and its fate after the melting of the ice are needed.

Acknowledgements Thanks are due to C. Hellum for species determination, R. Ramseler and C. Garrity for information on sea-ice coverage, and G. Dieckmann, R. Crawford and D. Thomas for critical comments on the manuscript. This is publication No. 715 of the Alfred Wegener Institute.

References

Booth JA (1984) The epontic algal community of the ice edge zone and its significance to the Davis Strait ecosystem. Arctic 37:234–243
Bradstreet MSW, Cross WE (1982) Trophic relationships at high arctic ice edges. Arctic 35:1–12
Carey AG (1985) Marine ice fauna: Arctic. In: Horner RA (ed) Sea ice biota. CRC Press, Boca Raton, Fla, pp 173–190
Cross WE (1982) Under-ice biota at the Pond Inlet ice edge and in adjacent fast ice areas during spring. Arctic 35:13–27
Grainger EH, Hsiao IC (1990) Trophic relationships of the sea ice melofauna in Frobisher Bay, Arctic Canada. Polar Biol 10:283–292
Gulliksen B, Lønne OJ (1989) Distribution, abundance, and ecological importance of marine sympagic fauna in the Arctic, Rapp P-V Reun Cons Int Explor Mer 199:133–138
Hirche H-J, Kattner G (1994) The 1993 Northeast Water Expedition Scientific cruise report of RV "Polarstern" Arctic cruises ARK IX/2 and 3, USCG "Polar Sea" cruise NEWP and the NEWL and expedition. Ber Polarforsch 142:1–190
Horner RA (1985) Taxonomy of sea ice microalgae. In: Horner RA (ed) Sea ice biota. CRC Press, Boca Raton, Fla, pp 147–157
Horner RA, Syvertsen EE, Thomas DP, Lange C (1988) Proposed terminology and reporting units for sea ice algal assemblages. Polar Biol 8:249–253
Horner RA, Ackley SF, Dieckmann GS, Gulliksen B, Hoshiai T, Legendre L, Mel'nikov IA, Reeburgh WS, Spindler M, Sullivan

CW (1992) Ecology of sea ice biota 1. Habitat, terminology, and methodology. Polar Biol 12:417–427
Hsiao IC (1983) A checklist of marine phytoplankton and sea ice microalgae recorded from Arctic Canada. Nova Hedwigia 37:225–313
Hustedt F (1930) Die Kieselalgen Deutschalnds, Österreichs und der Schweiz mit Berücksichtigung der übrigen Länder Europas sowie der angrenzenden Meeresgeblete. In: Dr. L. Rabenhorst's Kryptogamen-Flora von Deutschland, Österreich und der Schweiz. Akademische Verlagsgesellschaft, Leipzig, vol VII
Lønne OJ, Gulliksen B (1991) Source, density and composition of sympagic fauna in the Barents Sea. Polar Res 10:289–294
Meguro H, Ito K, 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
Mel'nikov IA (1989) Ecosystem of the Arctic sea ice (in Russian, English summary). Academy of Sciences of the USSR, Moscow
Mel'nikov IA, Bondarchuk LL (1987) To the ecology of the mass aggregations of colonial diatom algae under the Arctic drifting sea ice (in Russian with English summary). Oceanologia 27:317–321
O'Brien DP (1987) Direct observations of the behavior of *Euphausia superba* and *Euphausia crystallorophias* (Crustacea: Euphausiacea) under pack ice during the Antarctic spring of 1985. J Crust Biol 7:437–448
Østrup E (1887) Kyst-Diatoméer fro Grøn land. Medd Grøn 15:305–362
Syvertsen EE (1991) Ice algae in the Barents Sea: types of assemblages, origin, fate and role in the ice-edge phytoplankton bloom. Polar Rec 10:277–287
Usachev PI (1949) The microflora of polar ice (in Russian). Tr Inst Okeanol Akad Nauk SSSR 3:216–259
Vanhöffen E (1987) Die Fauna und Flora Grönlands. Grönland Expedition der Gesellschaft für Erdkunde zu Berlin 1891–1893 2:1–383