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Abundance, biomass and composition of spring ice algal and phytoplankton communities of the Laptev Sea (Arctic)

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Abstract Abundance, biomass and composition of the ice algal and phytoplankton communities were investigated in the southeastern Laptev Sea in spring 1999. Diatoms dominated the algal communities and pennate diatoms dominated the diatom population. 12 dominant algal species occurred within sea ice and underlying water column, including *Fragilariopsis oceanica*, *F. cylindrus*, *Nitzschia frigida*, *N. promare*, *Achnanthes taeniata*, *Nitzschia neofrigida*, *Navicula pelagica*, *N. vanhoeffenii*, *N. septentrionalis*, *Melosira arctica*, *Clindrotheca closterium* and *Pyramimonas* sp. The algal abundance of bottom 10 cm sea ice varied between 14.6 and 1562.2 $\times 10^4$ cells l^{-1} with an average of 639.0 $\times 10^4$ cells l^{-1}, and the algal biomass ranged from 7.89 to 2093.5 μg C l^{-1} with an average of 886.9 μg C l^{-1}, which were generally one order of magnitude higher than those of sub-bottom ice and two orders of magnitude higher than those of underlying surface water. The integrated algal abundance and biomass of lowermost 20 cm ice column were averagely 7.7 and 12.2 times as those of upper 20 m water column, respectively, suggesting that the ice algae might play an important role in maintaining the coastal marine ecosystem before the thawing of sea ice. Ice algae influenced the phytoplankton community of the underlying water column. However, the "seeding" of ice algae for phytoplankton bloom was negligible because of the low phytoplankton biomass within the underlying water column.

Key words ice algae, phytoplankton, biomass, Laptev Sea, Arctic.

The Laptev Sea, an important shelf area of the Arctic Ocean, is significant for the fresh water balance and temperature and salinity structure of the Arctic Ocean (Steele *et al.* 1996; Johnson and Polyakov 2001). As an important new ice forming area, the Laptev Sea exports sea ice and influences the sea ice and planktonic community structure of the Arctic Ocean due to the existence of the Transpolar Drift, which transported the pack ice through the central Arctic Ocean to the Greenland Sea (Wollenburg 1993; Eicken *et al.* 1997; Dethleff *et al.* 2000).

The southeastern Laptev Sea is a shallow water area with the water depths of less than 40 m in most area, and covers with sea ice between October and June or July in the next year. The water temperature near the sea bottom is below 0℃ in the whole year. The fresh water influx from Lena and Yana rivers, brings abundant nutrients, organic matters and phytoplankton to this area (e. g. Sorokin and Sorokin 1996; Kattner *et al*. 1999; Matthiessen *et al*. 2000). Consequently, the algal community structure of this area was mostly dominantly controled by the seasonal covering of sea ice and the influx of fresh water (Clark 1990).

Most researches of the spring ice algae and phytoplankton of the coastal seas were carried out in the Canadian Arctic seas (e. g. Hsiao 1980; Michel *et al*. 1993; Monti *et al*. 1996). In the Laptev Sea, several studies have been done mainly in summer and few in other seasons (e. g. Gran 1904; Kiselev 1932; Okolodkov 1992a, b; Heiskanen and Keck 1996; Soroki and Sorokin 1996; Cremer 1998). Juterzenka and Knickmeier (1999) and Tushling *et al*. (2000) reported the autumn chlorophyll a concentrations and micro-algal compositions within the sea ice and water column. Tushling (2000) compared the phytoplankton biomass and community structure of different seasons. No information was available for the spring ice algal community in this area.

The aim of this study is to describe the spring species composition, abundance and biomass both in the sea ice and underlying water column of Laptev Sea, to know further the ecological characteristic of ice algal community in this area, the relationship with phytoplankton and its significance to the marine ecosystem.

1 Materials and methods

1. 1 Sampling stations and sample collection

Samples were collected from 10 stations in the Laptev Sea between April 17 and May 6, 1999, and most of the stations located in the fast ice zone (Fig. 1). Samples were collected twice at Stn. 01 and stn. 05 (marked as stn. 01—I/stn. 01—II and stn. 05—I/stn. 05—II, respectively). At stn. 03, new ice with 20 cm thickness was also collected (marked as stn. 03—II).

Ice cores were collected using a CRREL ice auger, bottom 10 cm (lowermost 0～10 cm) and sub-bottom (10—20 cm) fragments of sea ice were cut down for algal observation. Each fragment was melted in seawater pre-filtered through a 0. 2 μm membrane to avoid osmotic stress (Garrison and Buck 1986). Underlying water samples were collected with a water sampler at 0 m, 5 m, 10 m and 20 m depths. 250 ml subsamples were collected using brown glass bottles, fixed with 0. 2 μm filtered borax-buffered formalin (1. 0% final concentration, v/v), preserved avoiding light and at 4℃ until algal counting.

1. 2 Counting and biomass conversion

50 ml of each fixed water sample was taken and algal cells were settled using a Hydro-bios sediment chamber according to the method of Utermöhl (1931), and

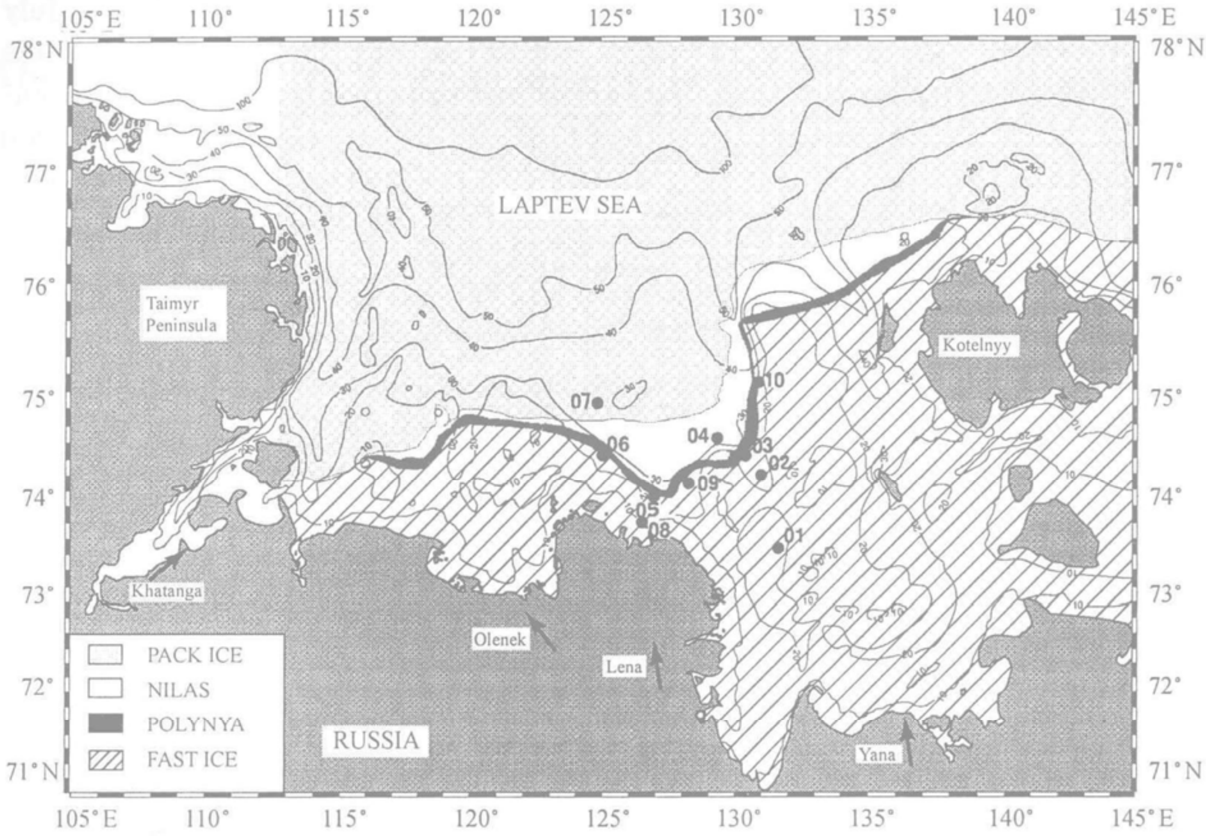

Fig. 1 The sampling stations in the southeastern Laptev Sea.

counted under a Zeiss Axiovert 135. One or two lines of algal cells were counted under a 40× objective lens and the total counting cells were not less than 400 per samples. Several lines, or even whole chamber of algal cells were counted for the phytoplankton samples because of the low abundance of phytoplankton. The cell size of protists was measured using a Porton G12 ocular micrometer (Graticiles Ltd. UK), and the bio-volume was calculated according to the method described by HELCOM (1989). Algal biomass was estimated by the bio-volume with a conversion factor of 0.11 pg C μm^{-3}, and for the armored dinoflagellates, a conversion factor of 0.13 pg C μm^{-3} was used (HELCOM 1989). Bray-Curtis similarity factor was used to describe the community similarity between those of bottom and sub-bottom ice, and of bottom ice and underlying surface water. The similarity factor was calculated according to Bray and Curtis (1957) with

$$C_N = 2J_N/(aN+bN)$$

Where aN and bN are species numbers of sample a and b, respectively. JN is the common species number occurred in both samples. Considering the considerable variation of algal abundance occurred among micro-habitats (bottom ice, sub-bottom ice and underlying surface water), algal species number other than algal abundance was adopted in the formula for the similarity estimation.

The species with the abundance percentage higher than 10% was regarded as dominant species.

2 Results

2. 1 *Ice algal abundance and biomass*

The ice algal abundance and biomass of the bottom and sub-bottom ice at each station were summarized in Table 1. Algal abundance of bottom ice ranged from 14. 6 to 1562. 2×10^4 cells l^{-1} with an average of 639. 0×10^4 cells l^{-1}, and algal abundance of sub-bottom ice varied between 5. 0 and 1170. 1×10^4 cells l^{-1}, with an average of 143. 2×10^4 cells l^{-1}. Biomass of bottom ice ranged from 7. 9 and 2093. 5 μg C l^{-1} with an average of 886. 9 μg C l^{-1}, and biomass of sub-bottom ice ranged from 5. 0 and 594. 5 μg C l^{-1}, with an average of 132. 4 μg C l^{-1}.

Except for stn. 03—II, the ice algal abundance and biomass of the bottom ice were higher than those of the sub-bottom ice, or even 2 orders of magnitude higher at some stations. At stn. 03—II, the total thickness of sea ice (new ice) was 20 cm, and the abundance and biomass of upper 10 cm ice section were 80 and 75 times higher than those of the downside 10 cm ice section, respectively. Stn. 07 was located in the pack ice zone, and no considerable variation was observed between stn. 07 and the stations located in the fast ice zone.

Table 1. Comparison of algal abundance and biomass among ice bottom (0—10 cm), sub-bottom (10—20 cm) and underling water surface

Stations		stn. 01—I	—II	stn. 02	stn. 03—I	—II	stn. 04	stn. 05—I	—II	stn. 06	stn. 07	stn. 08	stn. 09	stn. 10
Abundance	Sub-bottom ice	14. 6	15. 5	5. 0	9. 6	1170. 1	18. 1	55. 4	113. 6	34. 3	32. 2	8. 5	340. 1	44. 1
	Bottom ice	177. 2	884. 4	127. 3	1239. 4	14. 6	906. 1	74. 6	1273. 5	168. 5	595. 1	643. 5	641. 1	1562. 2
	Surface water	0. 1	1. 0	1. 0	0. 8	2. 3	1. 9	1. 7	26. 4	10. 6	1. 5	0. 4	24. 8	5. 26
Biomass	Sub-bottom ice	33. 4	35. 0	5. 0	24. 9	594. 5	35. 8	46. 0	237. 7	20. 0	52. 8	10. 5	579. 8	46. 2
	Bottom ice	292. 4	2093. 5	155. 4	1387. 0	7. 9	1448. 8	117. 6	1642. 8	104. 2	911. 2	971. 7	890. 3	1506. 4
	Surface water	0. 1	1. 5	1. 1	0. 3	3. 0	1. 2	1. 0	160. 1	4. 3	2. 2	0. 5	36. 0	9. 48

* The unit of abundance: 10^4 cells l^{-1}; the unit of biomass: μg C l^{-1}.

The integrated biomass within bottom 20 cm ice column ranged from 13. 0 to 160. 6×10^7 cells m^{-2}, with an average of 79. 9×10^7 cells m^{-2}. The integrated biomass varied between 12. 4 and 212. 8 mg C m^{-2}, with an average of 112. 0 mg C m^{-2} (Table 2).

Table 2. Comparison of integrated abundance and biomass of bottom 20 cm ice and underlying 20 m water column

Stations		stn. 01—II	stn. 02	stn. 03	stn. 04	stn. 05—I	—II	stn. 06	stn. 07	stn. 08	stn. 09	stn. 10	Average
Abundance	Sea ice	90. 0	13. 2	124. 9	92. 4	13. 0	138. 7	20. 3	62. 7	65. 2	98. 1	160. 6	79. 9
	Water column	6. 7	8. 3	6. 6	14. 8	13. 1	263. 5	72. 5	32. 1	1. 7	308. 7	63. 0	71. 9
	Ratio	13. 4	1. 6	18. 9	6. 2	1. 0	0. 5	0. 3	2. 0	38. 4	0. 3	2. 5	7. 7
Biomass	Sea ice	212. 8	16. 0	141. 2	148. 5	16. 4	188. 0	12. 4	96. 4	98. 2	147. 0	155. 3	112. 0
	Water column	10. 1	8. 5	4. 0	8. 7	6. 7	1781. 7	25. 2	34. 3	1. 9	270. 4	193. 1	213. 1
	Ratio	21. 1	1. 9	35. 3	17. 1	2. 4	0. 1	0. 5	2. 8	51. 7	0. 5	0. 8	12. 2

* The unit of abundance: 10^7 cells m^{-2}; the unit of biomass: mg C m^{-2}.

2. 2 *Phytoplankton abundance and biomass*

Phytoplankton abundance ranged from 0. 02 and 26. 4×10^4 cells l^{-1}, and the biomass was between 0. 03 and 324. 9 μg C l^{-1}. The maximum occurred at 5 m depth of stn. 05—II, and the minimum occurred at 20 m depths of stn. 02. The phytoplankton abundance and biomass decreased with the depth except for few stations, at which the maximum occurred at 5 m depth.

The phytoplankton abundance of underlying surface water ranged from 0. 1 to 26. 4$\times 10^4$ cells l^{-1} with an average of 6. 0$\times 10^4$ cells l^{-1}. The algal abundance varied between 0. 1 and 160. 1 μg C l^{-1} with an average of 17. 0 μg C l^{-1} (Table 1). The ratios of algal abundance and biomass between bottom ice and underlying surface water had high variability among stations. The minimum was at stn. 03—II (6. 3 and 2. 7, respectively), and the maximum was at stn. 03 with the ratios of 1609. 6 and 4203. 0, respectively. In general, the algal abundance and biomass of the underlying surface water were 2 orders of magnitude lower than those of bottom ice, and one order of magnitude lower than those of sub-bottom ice.

The integrated abundance of upper 20 m water column was between 1. 7 and 263. 5$\times 10^7$ cells m^{-2} with an average of 71. 9$\times 10^7$ cells m^{-2}, the integrated biomass ranged from 1. 9 to 1781. 7 mg C m^{-2}, with an average of 213. 1 mg C m^{-2}, suggesting that the integrated biomass of upper 20 m water column was even lower than that of the lowermost 20 cm ice column (Table 2).

2. 3 *Species composition of ice algae*

Table 3 lists the spring dominant species of ice algae in the Laptev Sea. The dominant species included *Achnanthes taeniata*, *Clindrotheca closterium*, *Fragilariopsis cylindrus*, *Fragilariopsis oceanica*, *Melosira arctica*, *Navicula pelagica*, *Navicula septentrionalis*, *Navicula vanhoeffenii*, *Nitzschia frigida*, *Nitzschia neofrigida and Nitzschia promarme*. Among which, *Fragilariopsis cylindrus*, *Fragilariopsis oceanica* and *Nitzschia frigida* were dominated in few station, and *Melosira arctica*, *N. septentrionalis* and *Clindrotheca closterium* dominated only at one station, respectively. The dominant species composition was variable among stations (Table 3).

The similarity factor of ice algal community between bottom and sub-bottom ice varied between 0. 37 and 0. 64 with an average of 0. 52, suggesting that similarity, in some extent, existed between these two communities.

2. 4 *Species composition of phytoplankton*

The dominant species of phytoplankton included *Achnanthes taeniata*, *Fragilariopsis cylindrus*, *Fragilariopsis oceanica*, *Melosira arctica*, *Navicula pelagica*, *Navicula septentrionalis*, *Nitzschia frigida*, and *Nitzschia promarme*. Among which, *Fragilariopsis cylindrus*, *Fragilariopsis oceanica*, *Nitzschia frigida* and *Pyramimonas* sp. , as dominant species, occurred only in one station. *Nitzschia neofrigida*, *Navicula vanhoeffenii* and *Clindrotheca closterium*, which were the dominant species within the ice, were not the dominant species in the water column. By contraries, *Pyramimonas* sp. dominated only in the water column (surface water at stn. 10).

The diatoms generally dominated the phytoplankton of the whole water column, except for stn. 10. In the surface water at stn. 10, phytoflagellates such as *Pyramimonas* sp. constituted 61% of total algal abundance and 14.4% of total biomass.

The similarity factor of algal community between underlying surface water and bottom ice ranged from 0.22 and 0.59 with an average of 0.41, which was lower than that between bottom and sub-bottom ice.

Table 3. List of dominant algal species (percentage abundance>10%) in bottom ice, sub-bottom ice and underlying surface water

Stations	Sub-bottom ice	Bottom ice	Underlying surface water
Stn. 01 −I	*N. frigida*(23.1), *N. neofrigida*(19.2), *F. cylidrus*(17.3), *N. vanhoeffenii*(15.8)	*F. cylindrus*(23.0), *N. frigida*(21.7), *C. closterium*(13.0) *N. noefrigida*(10.3)	*A. taeniata*(67.6), *N. frigida*(16.9), *F. oceanica*(11.3)
−II	*F. cylindrus*(50.3), *N. frigida*(22.7)	*N. frigida*(24.4), *A. taenicata*(16.9), *F. cylindrus*(16.0), *N. neofrigida*(13.1)	*A. taeniata*(22.7), *N. frigida*(14.6), *F. cylindrus*(12.7) *N. promare*(11.2), *F. oceanica*(10.4)
Stn. 02	*F. cylindrus*(40.3), *F. oceanica*(15.2), *N. arctica*(10.2)	*F. cylindrus*(43.1), *N. frigida*(11.8)	*F. cylindrus*(57.1)
Stn. 03 −I	*F. cylindrus*(23.0), *M. arctica*(21.5)	*F. oceanica*(30.4), *F. cylindrus*(22.8), *N. promare*(22.2)	*F. oceanica*(92.0)
−II	*F. oceanica*(57.9), *N. septentrionalis*(20.7), *A. taeniata*(11.2) *F. oceanica*(11.5)	*F. oceanica*(51.7), *F. cylindrus*(15.5), *F. cylindrus*(11.9)	*N. septentrionalis*(33.5), *M. arctica*(26.8),
Stn. 04	*F. frigida*(29.2), *F. cylindrus*(18.2), *N. plagica*(13.7), *S. radisonii*(13.0)	*N. frigida*(36.8), *N. plagica*(24.3)	*F. cylindrus*(41.7), *F. oceanica*(23.2)
Stn. 05 −I	*N. cylindrus*(52.6)	*N. frigida*(25.9), *N. pelgaica*(22.2)	*F. cylindrus*(56.4), *F. oceanica*(13.9)
−II	*N. frigida*(48.1), *N. promare*(24.0)	*N. frigida*(39.4), *N. promare*(39.1)	*M. arctica*(71.1), *F. cylindrus*(12.3)
Stn. 06	*F. oceanica*(89.4)	*F. oceanica*(86.6)	*F. oceanica*(64.4), *F. cylindrus*(14.8)
Stn. 07	*N. frigida*(49.7)	*N. frigida*(65.1)	*N. frigida*(52.8), *N. plagica*(13.0), *F. cylidrus*(10.1)
Stn. 08	*N. frigida*(29.5), *F. oceanica*(10.8)	*N. frigida*(37.5), *F. cylindrus*(15.0)	*N. frigida*(26.9), *A. taenicata*(10.8)
Stn. 09	*N. frigida*(20.8), *F. oceanica*(20.8), *A. taeniata*(18.3), *N. promera*(11.8), *M. arctica*(11.4)	*N. frigida*(28.5), *N. promare*(26.6), *N. vanhoefenii*(17.8), *M. arctica*(10.9)	*F. oceanica*(44.3), *N. frigida*(12.5)
Stn. 10	*F. cylindrus*(51.2), *N. promare*(27.8)	*N. promare*(47.0), *F. cylindrus*(42.9)	*Pyramimonas sp.*(26.8), *M. arctica*(19.3)

3 Discussion

3.1 *Spatial distribution*

The variation of algal communities among stations was considerable. For the bottom or sub-bottom ice, the maximum of variation between stations could be 2 orders of magnitude higher, and for the surface water, even 4 orders of magnitude higher. Tuschling *et al*. (2000) also reported the high biomass variations of new ice, surface water or water with 5 m depths at different stations. Previous researches suggested that in the Arctic estuary area, covering snow on the sea ice and the salinity of the ice-water interface were two crucial factors controling the ice algal abundance of the bottom ice (e. g. Monti *et al.* 1996).

The abundance and biomass within ice were high in contrast to those in the water column. Table 2 shows that the average ratios of integrated abundance and biomass between 20 cm of bottom ice and 20 m of underlying water column were 7. 7 and 12. 2, respectively, suggesting that in the southeastern Laptev Sea with the water depth of less than 40 m in most area, the algal biomass within ice column might be higher than those in the whole water column, and served as an important food source for a variety of the zooplankton in spring. Horner and Schrader (1982) reported that in the Beaufort Sea, ice algae contributed about 2/3 of the spring primary production in this area. No information was available for the grazing activity of zooplankton of spring Laptev Sea. However, Werner and Martinez Arbizu (1999) reported that in summer Laptev Sea, nauplii aggregated at the ice-water interface, and the abundance maximum could be 23911 individuals m^{-3}.

3. 2 *Relationship between ice algae and underlying phytoplankton*

Our present study shows that the similarity factor of algal community between underlying surface water and bottom ice ranges from 0. 22 and 0. 59 with an average of 0. 41. It was not high. However, species such as *N. frigida* and *F. cylindrus*, the typical ice algae, were common in the water column, suggesting that at least some of the dominant species in the water column came from bottom ice. The continuance and extent of the influence of spring ice algae to the underlying phytoplankton community was depended on the release velocity of ice algae. Fortier *et al.* (2002) proposed that covering snow was crucial for the ice algae release. Ice algae would release in a short period, if the rapid warming or precipitation led to the quick disappearance of covering snow.

Several researches in the Arctic coastal seas showed that ice algae could play as "seeding" of the spring phytoplankton bloom (Schandelmeir and Alexander 1981; Michel *et al.* 1993). Present study showed that the dominant species such as *F. cylindrus*, *F. oceanica* and *N. frigida* were all algal aggregates. When released from sea ice, these aggregates would be grazed easily by zooplankton or settled quickly to the sea floor (Sancetta 1981; Cremer 1999; Fortier *et al.* 2002), and therefore the role of these aggregated to the "seeding" was negligible. It has been reported that the summer phytoplankton community in the Laptev Sea affected considerably by the influx of fresh water (Clark 1990). However, in present study the phytoplankton biomass was low and most of the species were marine species, suggesting that the influence of fresh water algal species to the phytoplankton community did not emerge yet during the investigation period.

The algal community in the surface water at stn. 10 dominated with phytoflagellates other than diatom, which might be caused by the spring phytoflagellate bloom in the ice-water interface. Gradinger (1996) reported a summer *Pyramimonas* sp. bloom in the downside melting pond under pack ice of the Greenland Sea, and the abundance could be as high as 19.1×10^6 cells l^{-1}. Some fresh water species such as *Aulacosira sp. were observed in the bottom ice of stn. 03－I, suggesting that the bottom ice community might be influenced, in some extent, by the phytoplankton.*

3.3 Seasonal variation

No information for autumn ice algal abundance is available in the Laptev Sea because of the high sediments within ice and difficulty of cell counting under microscope (Tuschling 2000). Comparison of ice algal communities between of spring and autumn suggest that seasonal variation of species composition occurred (Tushling 2000; Krember and Angle 2001). This variation might be caused by physical or biological processes. In summer, influenced by fresh water influx, summer phytoplankton was dominated by fresh-brackish water species or brackish water-marine species (Cremer 1998; 1999). In autumn, in the processes of ice formation, ice crystal harvested phytoplankton from the upper water column (Ackley 1982, Garrison *et al.* 1983, He *et al.* 2003). Consequently, the autumn ice algal community would influenced by the phytoplankton community of the upper water column. Our present study showed that the spring phytoplankton abundance was low, suggesting that the high biomass of ice algae was caused by the biological process, the *in situ* growth of ice algae.

Marked seasonal variations of phytoplankton abundance and biomass were observed in the Laptev Sea. The spring phytoplankton abundance of the surface water ranged from 0.1 to 26.4×10^4 cells l^{-1}, and the biomass was between 0.1 and 160.1 μg C l^{-1}, which was higher than that from spring 1996 ($<$0.1－88.4 μg C l^{-1}, Tushling 2000), and much higher than that from autumn (351－33660 cells l^{-1}, 0.1 ~5.3 μg C l^{-1}, Tushling *et al.* 2000). The researches have shown that the maximum of algal biomass occurred in summer (Tushling 2000). Zernova *et al.* (2000) also reported that in the northern Laptev Sea, the vertical algal flux in summer were several hundreds higher than that in other seasons.

3.4 Comparison to other Arctic seas

The dominant species of spring Laptev Sea resembled to those of the coastal seas of Beaufort and Siberia Seas, and of Canadian Arctic seas. *F. cylindrus*, *F. oceanica* and *N. frigida* were common spring dominant species of Arctic coastal seas (Cross 1982; Horner and Schrader 1982; Okolodkov 1992a, 1993; Michel *et al.* 1993). The ice algal community had similarity, in some extent, with that of the first-year pack ice. However, there was obvious variation with that of multi-year pack ice in the high Arctic (Syvertsen 1990; Krember and Engel 2001). The percentage abundance of *Melosira arctica* in the bottom ice at stn. 09 was 10.9%. This species was commonly a dominant ice algal species of the multi-year pack ice of high Arctic, and the abundance maximum could be 11.57×10^6 cells l^{-1} in summer (Booth and Horner 1997). However, traditional view suggested that *Melosira arctica* was not important in the community of the fast ice (Hsiao 1980; Okolodkov 1992a), and has not been described as a dominant ice algal species of the fast ice before.

The spring phytoplankton abundance of underlying surface water was higher than that of Beaufort Sea, but lower than that of Canadian Arctic seas and Chukchi Sea (Hsiao 1980; Horner and Schrader 1982; Okolodkov 1992a).

The results from re-sampling station of stn. 01 and stn. 05 showed that the biomass of the bottom ice and underlying water column was increased during the investigation period. However, the observation of ice algal samples showed there were many diatom frustules, and most of dominant species had attached algae such as *Synedra hyperborean*, *Attheya septentrionalis* and *Pseudogomphonema arctica*, suggesting that the ice algae community was not healthy and the peak of algal biomass might not occur in the late May to early June, just before the thawing of sea ice, which usually occurred in other Arctic fast ice zone (Hsiao 1980; Horner and Schrader 1982).

4 Conclusion

There were some characteristics of the spring algal community of the southeastern Laptev Sea:

1) Algae aggregated mostly in the bottom of sea ice. In general, the abundance and biomass of the lowermost 10 cm sea ice were one order of magnitude higher than those of the sub-bottom 10 cm sea ice, and two orders of magnitude higher than those of the underlying surface water.

2) The variation of algal spatial distribution was considerable. The maximum of algal abundance and biomass could be 2 to 4 orders of magnitude as the minimum.

3) Ice algae community would influence the phytoplankton community during the investigation period, but the "seeding" role of ice algae to phytoplankton was negligible.

4) Although the spring ice algal biomass was lower than that of summer phytoplankton, the spring ice algal bloom occurred in the bottom of sea ice suggests that, ice algal community might be significant in the ecosystem at least in the special period when the phytoplankton in the water column was low.

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References

Ackley SF (1982) Ice scavenging and nucleation: Two mechanisms for incorporation of algae into newly forming sea ice. EOS, 63: 54 - 55.

Booth BC and Horner RA (1997): Microalgae on the Arctic Ocean Section, 1994: species abundance and biomass. Deep Sea Res. II, 44: 1607 - 1622.

Bray JR and Curtis JT (1957): An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr., 27: 325 - 349.

Clark DL (1990): Arctic Ocean ice cover; geologic history and climatic significance. In: Grantz A, Johnson L, Sweeney JF (ed.) The Arctic Ocean Region. The Geology of North America, Vol. L. The Geological Society of America, Boulder, CO: 53 - 62.

Cremer H (1998): Diatoms in the Laptev Sea (Arctic Ocean): Taxonomy and biogeographic distribution. Report Polar Res., 260:1—205 (in German with English abstract).

Cremer H (1999): Distribution patterns of diatom surface sediment assemblages in the Laptev Sea (Arctic Ocean). Mar. Micropaleontol., 38: 39 - 67.

Cross WE (1982): Under-ice biota at the Pond Inlet ice edge and in adjacent fast ice areas during spring. Arctic, 35(1):13 - 27.

Dethleff D, Rachold V, Tintelnot M *et al.* (2000): Sea-ice transport of riverine particles from the Laptev Sea to Fram Strait based on clay mineral studies. Int. J. Earth Sci., 89:496 - 502.

Eicken H, Reimnitz E, Alexandrov V *et al.* (1997): Sea-ice processes in the Laptev Sea and their importance for sediment export. Cont. Shelf Res., 17: 205 - 233.

Fortier M, Fortier L, Michel C *et al.* (2002): Climatic and biological forcing of the vertical flux of biogenic particles under seasonal Arctic sea ice. Mar. Ecol. Prog. Ser., 225: 1 - 16.

Garrison DL, Ackley SF, Buck KR (1983) A physical mechanism for establishing algal populations in frazil ice. Nature, 306, 363 - 365.

Garrison DL and Buck KR (1986): Organisms losses during ice melting: a serious bias in sea ice community studies. Polar Biol., 6: 237 - 239.

Gran HH (1904): Diatomaceae from the ice floes and plankton of the Arctic Ocean. XI. In: Nansen F (eds) The Norweigian North Polar Expedition 1893—1896, Scientific Results, 4: 1 - 85.

Gradinger R (1996): Occurrence of an algal bloom under Arctic pack ice. Mar. Ecol. Prog. Ser., 131: 301 - 305.

He J, Wang G, Li S *et al.* (2003): A review of the ice algal assemblages and their live history in the Antarctic sea-ice zone. Chinese Journal of Polar Research (Chinese Edition), 15(2):102 - 114(in Chinese with English abstract).

Heiskanen AS and Keck A (1996): Distribution and sinking rates of phytoplankton, detritus, and particulate biogenic silica in the Laptev Sea and Lena River (Arctic Siberia). Mar. Chem., 53: 229 - 245.

HELCOM (1989): Guidelines for the Baltic monitoring programme for the third stage. Part D. Biological determinands. Finn Governm Print Centre, Helsinki, 161.

Horner R and Schrader GC (1982): Relative contribution of ice algae, phytoplankton, and benthic microalgae to primary production in nearshore regions of the Beaufort Sea. Arctic, 35(4):485 - 503.

Hsiao SIC (1980): Quantitative composition, distribution, community structure and standing stock of sea ice microalgae in the Canadian Arctic. Arctic, 33(4): 768 - 793.

Johnson MA and Polyakov IV (2001): The Laptev Sea as a source for recent Arctic Ocean salinity Changes. Geophys. Res. Lett., 28(10): 2017 - 2020.

Juterzenka K and Knickneier K (1999): Chlorophyll a distribution in water column and sea ice during the Laptev Sea Freeze-Up Study in autumn1995. In: Bauch HA, Dmitrenko I, Eicken H *et al.* (ed) Land-ocean systems in the Siberian Arctic: Dynamics and history. Springer-Verlag, Berin, 153 - 160.

Kattner G, Lobbes JM, Fitznar HP *et al.* (1999): Tracing dissolved organic substances and nutrients from the Lena River through Laptev Sea (Arctic). Mar. Chem., 65 (1 - 2):25 - 39.

Kiselev IA (1932): Material po mikroflora gevostoshoi shasti more laptevish. Studies of the USSR Seas. State Hydrology Institute Publications, Leningrad, 67 - 103 (in Russian).

Krembs C and Engel A (2001): Abundance and variability of microorganisms and transparent exopolymer particles across the ice-water interface of melting first-year sea ice in the Laptev Sea (Arctic). Mar Biol., 138: 173 - 185.

Michel C, Legendre L, Therriault JC *et al.* (1993): Springtime coupling between ice algal and phytoplankton assemblages in southeastern Hudson Bay, Canadian Arctic. Polar Biol., 13: 441 - 449.

Monti D, Legendre L, Therriault J C *et al.* (1996): Horizontal distribution of sea-ice microalgae: environmental control and spatial processes (southeastern Hudson Bay, Canada). Mar. Ecol. Prog.

Ser. , 133: 229 - 240.

Okolodkov YB (1992a): Cryopelagic flora of Chucki-East Siberian and Laptev Seas. Proc. NIPR Symp. Polar Biol. , 5: 28 - 43.

Okolodkov YB (1992b): Vodorosli ldov moria Laptevykh (Algae of the Laptev Sea ice), Novosti systematiki nizschikh rastenii. 28, 29 - 31 (in Russian).

Okolodkov YB (1993): A checklist of algal species found in the East Siberian Sea in May 1987. Polar Biol. , 13:7 - 11.

Polyakova YI (1996): Diatoms of the Eurasian arctic seas and their distribution in surface sediments. Report Polar Res. , 212: 315 - 324 (in German with English abstract).

Sancetta C (1981): Oceanographic and ecologic significance of diatoms in surface sediments of the Bering and Okhotsk seas. Deep-Sea Res. , 28:789 - 817.

Schandelmeir L and Alexander V (1981): An analysis of the influence of ice on spring phytoplankton population structure in the southeastern Bering Sea. Limnol. Oceanogr. , 26: 935 - 943.

Sorokin YI and Sorokin PY (1996): Plankton and primary production in the Lena River Estuary and in the South-eastern Laptev Sea. Est. Coast. Shelf Sci. , 43: 399 - 418.

Steele M, Thomas D and Rothrock D (1996): A simple model study of Arctic Ocean freshwater balance, 1979 - 1985. J. Geophys. Res. , 101: 20833 - 20848.

Syvertsen EE (1990): Ice algae in the Barents Sea: types of assemblages, origin, fate and role in the ice edge phytoplankton bloom. Polar Res. , 10: 277 - 287.

Tuschling K (2000): Phytoplankton ecology in the arctic Laptev Sea: A comparison of three seasons. Report Polar Res. , 347: 1 - 144 (in German with English abstract).

Tuschling K, v. Juterzenka K, Okolodkov YB *et al.* (2000): Composition and distribution of the pelagic and sympagic algal assemblages in the Laptev Sea during autumnal freeze-up. J. Plankton. Res. , 22: 843 - 864.

Utermöhl H (1931): Neue Wege in der quantitativen Erfassung des Planktons. Verh. Int. Ver. Theor. Angew. Limnol. , 5: 567 - 596.

Werner I and Martinez Arbizu P (1999): The sub-ice fauna of the Laptev Sea and the adjacent Arctic Ocean in summer 1995. Polar Biol. , 21, 71 - 79.

Wollenburg I (1993): Sediment transport by Arctic sea ice: the recent load of lithogenic and biogenic material. Rep. Polar Res. , 127: 1 - 159.

Zernova VV, Nothig EM and Shevchenko VP (2000): Vertical microalga flux in the northern Laptev Sea (from the data collected by the yearlong sediment trap). Oceanology, 40(6): 801 - 808.