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Sea ice microalgae community of the floating ice in the Admiralty Bay (South Shetland Islands)

ABSTRACT: Density, composition and domination structure of the sea ice microalgae in the Admiralty Bay (South Shetland Islands) were investigated in 1983. Algae were recorded both in discoloured and in colourless sea ice from June to October. The highest algae density, amounting to 5×10^5 cells in 1 cm^3 was observed till the end of August, the diatoms *Nitzschia cylindrus* and *N. curta* being the dominant species. A total of 95 algal taxa, mostly diatoms, were recorded. Air temperature seems to be an important factor influencing the development of algae in sea ice.

Key words: Antarctica, King George Island, sea ice microalgae.

1. Introduction

Diatoms inhabiting and colouring the sea ice in polar zones were first mentioned as early as in the nineteenth century. Diatoms from the sea ice of the Arctic Ocean were described for the first time by Ehrenberg (1841, 1847) and those in Antarctica by Hooker (1847) (according to Horner 1976). In their phytoplankton studies, Heiden and Kolbe (1928) and Hart (1934) recorded diatom species living in the sea ice. Hendey (1937) investigated diatom species in samples of melted sea ice from the Bellingshausen Sea.

Detailed investigations of the flora inhabiting the sea ice started in the sixties of XX-th century. Three types of communities in respect to their location in the ice were distinguished (Ackley, Buck and Taguchi 1979): 1) surface ones (Burkholder and Mandelli 1965, Whitaker 1977), 2) internal ones at medium depths (Ackley, Buck and Taguchi 1979) and 3) bottom ones (Bunt and Wood 1963). These communities occur both in fast ice and in drifting ice (Ackley, Buck and Taguchi 1979). Diatoms dominate in sea ice, but other algae (Ackley, Buck and Taguchi 1979) as well as bacteria (Sullivan and Palmisano 1981, Marra, Ducklow and Burckley, 1982) also occur there.

Seasonal sea ice of Antarctica occurs in an area of 15—18 millions km^2, hence the role of the ice flora is very important (Tranter 1982, Voronina 1984). It seems that about 2.6 millions km^2 of ice around Antarctica are intensely overgrown by algae (Burkholder and Mandelli 1965). In this time the phytoplankton is sparse (Bunt 1963, Voronina 1984), hence any production in sea ice in this period may be crucial for the survival of herbivorous animals (Andrijašev 1967, Rakusa-Suszczewski 1972, Richardson and Whitaker 1979, Hamner et al. 1983, Tanimura et al 1984). Besides its high importance in Antarctica's primary production (Burkholder and Mandelli 1965, Tranter 1982) the ice flora is supposed to play an important role as an inoculum for plankton (Hasle 1969), however other data do not support this view (McConville, Mitchell and Wetherbee 1985, Ligowski 1986).

Algae live in ice in rather extreme temperature and light conditions (McGrath, Grossi and Sullivan 1984). The ice temperature is intermediate between those of the sea water and the air (Palmisano and Sullivan 1983). The compensation level for algal photosynthesis in ice may occur at 0.1%—0.06% of sunlight and not at 1%, which is usually considered the lower limit of the euphotic zone (Raymond 1980). This results from the adaptation of the ice algae to live in the darkness (Palmisano, SooHoo and Sullivan 1984, Müller-Hackiel 1985).

The aim of the present study was to determine the changes in the density, composition and domination structure of algae associated with sea ice settled at the shore of Admiralty Bay.

2. Material and methods

Samples of sea ice were collected near Polish Antarctic Station "H. Arctowski" (62°10'S, 58°28'W) situated on King George Island (South Shetlands), along a 14 km shore line section from the inner part of the Admiralty Bay (Italian Valley) to the Bransfield Strait (Demay Point). In winter 1983 the Admiralty Bay was not covered with fast ice. The samples were taken from forming frazil ice of the salinity of about 25‰, pancake ice (salinity about 10‰) and ice cake settled on the shore (salinity auout 5—12‰). This samples were taken both from coloured ice and from randomly chosen colourless ice. Samples of surface water were taken close to the ice. The ice samples were melted and then processed as the water samples.

To determine algal density a part of the sample ranging from 1 cm^3 to 20 cm^3 (up to 100 cm^3 at very low densities) was filtered on the Synpor membrane filters of 0.4 μm pore diameter. After drying the filter was made translucent using xylene and a microscopic slide in Canada balsam was prepared. Slides obtained with this technique enabled the use of immersion lens for quantitative analysis. Slides were also prepared in pleurax after elimination of organic parts with H_2O_2 and ultraviolet radiation (Swift 1967). In quantitative analysis over 300 cells in a sample were counted (Cholnoky 1968) or, at their low density, cells in one hundredth part of a slide. Results obtained were recalculated to obtain the number of cells per 1 cm^3 of melted ice. Species whose abundances exceeded 5% were considered the dominant ones.

3. Results

3.1. Density

The density of algal cells in sea ice varied widely. The minimal values amounted to several dozens of cells in 1 cm^3, the maximal ones to over 500×10^3 cells in 1 cm^3 of melted ice (Table 1). In winter 1983 first yellow-brown ice-cakes coloured by rich growth of diatoms were observed in 15 June (Table 1). Till the end of June several coloured ice-floes were recorded along the whole observed coast, from the Ezcurra Inlet to the Bransfield Strait. At the beginning of July, after several days of northern winds and after an increase of temperature above 0°C, most of ice-cakes settled on the shore were brownish. In this period the maximal cell number in 1 cm^3 (553×10^3) was recorded (Table 1). Cell densities over 100×10^3 in 1 cm^3 occurred only till the end of August. Sea ice algae were observed till the mid October, however in September and October the number of algal cells in sea ice was low (Table 1).

Algal cells density in surface water layers did not fluctuate significantly in the period from June to October and was from 0.02×10^3 to 0.09×10^3 per 1 cm^3.

3.2. Domination structure

15 species were dominant in at least one sample (Table 1). *Nitzschia cylindrus* was the most frequent dominant. It occurred in the highest number of cells till the end of August. *Nitzschia curta*, usually present

Table 1.

Total density of algal cells and the density of dominant diatom species in the sea ice of the Admiralty Bay in 1983

Number of samples	Date	Development of sea ice	Number of cells ($10^3 \cdot cm^{-3}$)	Percent of dominant taxa						
				Nitzschia cylindrus	*Nitzschia curta*	*Thalassiosira antarctica*	*Navicula glaciei*	*Navicula criophila*	*Nitzschia lecointei*	*Gomphonema* sp.
1	2	3	4	5	6	7	8	9	10	11
176	15.06.	ice cake	401		99					
187	27.06.	–,,–	31				66			30
195	2.07.	–,,–	267	90	5					
197a	2.07.	–,,–	49	39	37			10		
197b	2.07.	–,,–	149	98						
198	2.07.	–,,–	43	81	15					
199a	2.07	–,,–	187	84	7					
199b	2.07.	–,,–	98	76	14					
200	2.07.	–,,–	533		99					
201	2.07.	–,,–	322		99					
202a	2.07.	–,,–	138	12	11				58	
202b	2.07.	–,,–	167	81					12	
204	3.07.	–,,–	14	89					9	
205	3.07.	–,,–	79	71					18	
207	3.07.	–,,–	16	78	15					
208	3.07.	–,,–	114	77	5				8	
209	3.07.	–,,–	4	67	27					
210	5.07.	–,,–	79	74	12					
211	5.07.	–,,–	84	53	34					
212	5.07.	–,,–	6	52	30					

Table 1 — continued

1	2	3	4	5	6	7	8	9	10	11
236	16.07.	ice cake	0.40	90	11					
237	16.07.	–„–	0.20	82						
238	16.07.	frazil ice	0.80	21	51		13			
239	16.07.	pancake ice	0.80	36	24	12		17		
240	16.07.	ice cake	75	73	23					
258a	28.07.	–„–	107	55	9			5	14	
258b	28.07.	–„–	158	9	8				81	
267	29.07.	–„–	10	97						
269	30.07.	–„–	0.60	16	9	64				
270	30.07.	–„–	0.03	13			47			
273	8.08.	–„–	329	99						
274	8.08.	–„–	43	70	10				5	
277	11.08.	–„–	511	98						
278	11.08.	–„–	354	96						
279	11.08.	–„–	321	99						
283	22.08.	–„–	225	94	5					
284	25.08.	–„–	102	98						
285	25.08.	–„–	36	54	12				6	
287	26.08.	–„–	70					99		
288	26.08.	–„–	13	27		25		40		
290	26.08.	frazil ice	7	17	16	56				
293	26.08.	–„–	0.60	29	14	43		5		
294a	26.08.	ice cake	76	93						
294b	26.08.	–„–	43	83	6					
295	27.08.	–„–	20	57						
298	28.08.	frazil ice	0.40	31	9		23	16		

Table 1 — continued

1	2	3	4	5	6	7	8	9	10	11
299	28.08.	ice cake	0.06	27	10		40			
301	29.08.	frazil ice	0.03				20	13		
303	29.08.	–„–	0.05			38	15			11
306	30.08.	pancake ice	0.09	9		10	56	15		
309	4.09.	ice cake	12			14	36	48		
313	6.09.	–„–	31	74					21	
319	10.09.	–„–	0.20				63	5		6
320	10.09.	pancake ice	0.10	16		32	30			
321	10.09.	frazil ice	0.10	9	18	22	24			6
324	12.09.	–„–	0.10	17		13	65			
325	12.09.	pancake ice	0.05	30		20	20			
326	14.09.	ice cake	0.50			12	44	9		12
327	14.09.	–„–	3	26		39		18		
328	14.09.	–„–	1	7		52	18	19		
329	14.09.	–„–	0.60	9		52	11	19		
330	16.09.	frazil ice	0.20	19		25	27			
331	16.09.	pancake ice	0.20	19		38	39			
350	7.10.	ice cake	0.01	15		20	17	10		
380	19.10.	–„–	1	29		35				

Dominants in simple samples: *Chaetoceros* sp., *Gomphonema* sp., *Nitzschia neglecta*, *N. turgiduloides*, *Porosira glacialis*, *Tropidoneis* sp., *Thalassiothrix antarctica*, unidentifid flagellates.

together with *N. cylindrus* but in a lower cell abundance, was the second dominant in respect to frequency. In September and October the percentage of species of the genus Nitzschia was lower, while those of the genera Navicula and Gomphonema were higher (Table 1).

3.3. Species composition

A total of 95 taxa were distinguished in 65 samples of the sea ice (Table 2). Diatoms constituted most of taxa. *Dictyocha speculum* of Silicoflagellatae and an unknown number of unidentified flagellate species represented other taxonomic groups.

Table 2

List of taxa of the sea ice algae
of the Admiralty Bay in 1983

1. *Achnanthes groenlandica* (Cleve) Grunow
2. *Actinocyclus actinochilus* (Ehr.) Simonsen
3. *Amphiprora kjelmanii* Cleve
4. *A. kjelmanii* var. *subtilissima* Van Heurck
5. *A. oestrupii* Van Heurck
6. *Amphiprora* sp.
7. *Amphora antarctica* Hustedt
8. *Asteromphalus hookerii* Ehrenberg
9. *A. parvulus* Karsten
10. *Chaetoceros atlanticus* Cleve
11. *Ch. criophilum* Castracane
12. *Ch. dichaeta* Ehrenberg
13. *Ch. gaussii* Heiden et Kolbe
14. *Chaetoceros* sp.
15. *Cocconeis antiqua* var. *tenuistriata* Van Heurck
16. *C. costata* Cregory
17. *C. costata* var. *hexagona* Grunow
18. *C. imperathrix* A. Schmidt
19. *C. melchiorii* Frenquelli
20. *C. orbicularis* Frenquelli
21. *Corethron criophilum* Castracane
22. *Coscinodiscus bouvete* Karsten
23. *C. gyratus* Janish
24. *C. oculoides* Karsten
25. *C. tabularis* Grunow
26. *Coscinodiscus* sp. 1
27. *Coscinodiscus* sp. 2
28. *Cymbella* sp.
29. *Eucampia balaustium* Castracane
30. *Fragilaria californica* var. *antarctica* Peragallo
31. *Gomphonema* sp. 1

32. *Gomphonema* sp. 2
33. *Haslea trompii* (Cleve) Simonsen
34. *Melosira sol* (Ehrenberg) Kützing
35. *Navicula criophila* Manguin
36. *N. directa* W. Schmidt
37. *N. glaciei* Van Heurck
38. *N. muticopsis* Van Heurck
39. *Navicula* sp. 1
40. *Navicula* sp. 2
41. *Navicula* sp. 3
42. *Nitzschia angulata* Hasle
43. *N. compacta* Hustedt
44. *N. curta* (Van Heurck) Hasle
45. *N. cylindrus* (Grunow) Hasle
46. *N. decipiens* Hustedt
47. *N. distansoides* Hustedt
48. *N. heimii* Manguin
49. *N. lecointei* Van Heurck
50. *N. neglecta* Hustedt
51. *N. obliquecostata* (Van Heurck) Hasle
52. *N. ritscherii* (Hustedt) Hasle
53. *N. separanda* (Hustedt) Hasle
54. *N. subcurvata* Hasle
55. *N. sublineata* Hasle
56. *N. turgiduloides* Hasle
57. *N. vanheurckii* (Peragallo) Hasle
58. *Nitzschia* sp. 1
59. *Nitzschia* sp. 2
60. *Odontella weissflogii* (Janish) Grunow
61. *Pleurosigma directum* Grunow
62. *Porosira glacialis* (Grunow) Jørgensen
63. *P. pseudodenticulata* (Hustedt) Jouse
64. *Rhizosolenia alata* Brightwell
65. *Rh. hebetata* f. *semispina* (Hensen) Gran
66. *Rh. hebetata* f. *hiemalis* Gran
67. *Rh. truncata* Karsten
68. *Rhizosolenia* sima Castracane
69. *Rhizosolenia* sp.
70. *Symbolophora furcata* (Karsten) Nikolaev
71. *S. microtrias* Ehrenberg
72. *Thalassionema nitzschioides* Grunow
73. *Thalassionema* sp.
74. *Thalassiosira antarctica* Comber
75. *Th. australis* Peragallo
76. *Th. eccentrica* (Ehrenberg) Cleve
77. *Th. gracilis* (Karsten) Hustedt
78. *Th. gracilis* var. *expecta* (Van Landingham) Fryxell and Hasle
79. *Th. kozlovii* (Kozlova) Makarova
80. *Th. lentiginosa* (Janish) Fryxell
81. *Th. maculata* Fryxell and Johansen
82. *Th. ritscherii* (Hustedt) Kozlova

83. *Th. scotia* Fryxell and Hoban
84. *Th. tumida* (Janish) Hasle
85. *Thalassiosira* sp.
86. *Trachyneis aspera* (Ehrenberg) Cleve
87. *Tropidoneis antarctica* (Grunow) Cleve
88. *T. belgicae* var. *major* Van Heurck
89. *T. gaussii* Heiden et Kolbe
90. *T. glacialis* Heiden
91. *T. fusiformis* Manguin
92. *Tropidoneis* sp.
93. *Thallassiothrix antarctica* (Cleve et Grunow) Schimper
94. *Dictyocha speculum Ehrenberg*
95. Unidentified flagellates

In 12 samples of surface plankton 62 algal taxa were noted. 26 of these were not recorded in samples of sea ice.

4. Discussion

The period of the occurrence of algae in sea ice of the Admitalty Bay is similar to that observed on Signy Island of South Orkneys (60°42'S, 45°36'W), where algae in ice were recorded in 1973 from June till the end of November (Richardson and Whitaker 1979). At the Mirnyj Station, which is situated farther to the south (66°33'S) the period of the occurrence of microscopic algae in fast ice was longer and covered the period from 20 April 1968 to 11 January 1969 (Bujnickij 1974). At a similar latitude (66°47'S) of the Bellingshausen Sea Hendey (1937) investigated diatoms in a sample of the sea ice from 30 December 1930. In the Alašev Bay (about 67°40'S) Rakusa-Suszczewski (1972) observed algal development from the middle of August till the end of February. At the Mawson Station (67°36'S) and Davis Station (68°38'S) the spring development of algae began at the end of September, reached its maximal peak in November and ended at the beginning of December (McConville and Wetherbee 1983). At the Syowa Station (69°00'S) colouring of sea ice caused by algae appeared first in spring and lasted till October, while another algal growth period in the ice occurred in autumn (Hoshiai 1977). In a number of sites, algae in ice were recorded in summer: in Lützow-Holm Bay at 68°48'S in January 1983 (Sasaki and Watanabe 1984), at Prince Olaf Coast (68°20'S) on 18 January 1961, at Cape Bird (77°12'S) on December 1971 (Watanabe 1982), at McMurdo Sound (77°51'S) in November and December (Kottmeier et al. 1984). Bunt and Wood (1963) collected sea ice algae close to the McMurdo Station from 18 December 1962 till 7 January 1963 and Littlepage (1965) recorded there the development of algae in ice from September to the end of December, its maximum occurring from October to December.

The change in the period of algal development in sea ice from the winter period at the latitudes of 60°—62°S to the autum-winter-spring period at the latitude of about 66°S and to the summer period at the latitudes of 68—78°S does not seem to support the idea that light is a factor limiting algal development in ice. In the above comparison the absorption of light by ice or snow layers was not taken into account. However, it may be assumed that along with light (Hoshiai 1981, Sullivan et al. 1983, Kottmeier et al. 1984) and nutrients (McConville, Mitchell and Wetherbee 1985) the temperature is one of the limiting factors for algal growth in ice as it was observed by Ackley, Buck and Taquchi (1979). An increase in the abundance of brown coloured ice cake in the Admiralty Bay in winter 1983, after periods in which the mean daily temperature was above 0°C (Adamowski and Marszczek, unpubl. data), supports this assumption.

The highest densities of algal cells in the sea ice of the Admiralty Bay were higher than those noted by other authors. Bunt (1963) recorded algal cells densities ranging from 4.5×10^3 to 16.8×10^3 in 1 cm^3, Bujnickij (1974) recorded values ranging from 51×10^3 to 76×10^3 in 1 cm^3, and Gersonde (1984) — the values above 10^3 in 1 cm^3. In the Admiralty Bay the highest algal density in ice occurred in the first period of their development (till the end of August), the small cells of *Nitzschia curta* and *N. cylindrus* being the dominant ones.

The number of algal cells developing in sea ice was observed to be many times higher than that in the surrounding water (Bujnickij 1974, Ackley, Taguchi and Buck 1978), the chlorophyll contents in the former case being also higher (Garrison, Ackley and Buck 1983, Palmisano and Sullivan 1983). In comparison with the data of the above authors, the difference between the abundance of cells in brown sea ice and that in the surrounding water in the Admiralty Bay was much higher ($\pm 2500 \times$), while the number of cells in colourless ice was about 5 times higher then the number of cells in the surrounding water of the bay. It is to be mentioned that sea ice formed in the zone influenced by the suspended matter flushed from land may be of a colour similar to that of ice overgrown by diatoms, despite the fact that no algae are recorded in the former. The dominant diatom species in the sea ice in the initial period of the development (till the end of August) were *Nitzschia cylindrus* and *N. curta*. These species are typical of this environment frequently dominating there (Hasle 1965, Garrison and Buck 1985). *Nitzschia cylindrus* occurs in large quantities in the plankton of Antarctic Zone, the number of its cells increasing from the north to south (Hasle 1965). *Nitzschia cylindrus* was frequently proved to be a dominant species of Antarctic sea ice (Bujnickij 1968, Ackley, Taguchi and Buck 1978, Garrison and Buck 1985). *Nitzschia curta*, the second most frequent dominant species of the Admiralty Bay ice, is distributed in Antarctica similarly to *N. cylindrus* (Hasle 1965). *N. curta* was frequently found to be a dominant species in plankton at the shelf ice (Manguin 1960, Kozlova 1962, Steyaert 1974, Ligowski 1983, Wilson and Smith 1984). In sea ice this species was recorded by Hendey (1937), Burkholder and Mandelli (1965), Ackley, Taguchi and Buck (1978) and Garrison and Buck (1985).

Beginning from late August in the sea ice settled at the shore one of the dominants was *Navicula glaciei;* it would suggest that this ice has originated from the shore ice (Whitaker 1977).

Species occurring most abundantly in ice samples were dominant in samples of surface water collected in the Admiralty Bay close to the ice samples. Similar share of algal species occurring in water and in young ice were determined by Garrison, Ackley and Buck (1983) and Garrison and Buck (1985). A high number of 24 days with mean air temperatures above 0°C recorded at Arctowski Station in 1983 (Adamowski and Marszczek, unpubl. data) during the period of sea ice algae development might have caused periodical transfer of diatom cells from ice to the water of Admiralty Bay.

Garrison and Buck (1985) recorded 80 species of algae in the sea ice of the Weddell Sea, Bunt and Wood (1963) — 32 species in the vicinity of the McMurdo Station, Kozyrenko (Bujnickij 1974) — 103 species in the vicinity of the Mirnyj Station, and Nikolajev (Bujnickij 1974) — 78 species in the ice of the Alašev Bay.

The number of algal taxa found in the sea ice of the Admiralty Bay, the northernmost locality out of these all localities, is similar. The majority of species given from the sea ice from different localities were common for all of them. A higher share of benthic taxa was a distinctive feature of the composition of the microalgae sea ice community of the Admiralty Bay in comparison with the other localities. Samples of net phytoplankton from the Admiralty Bay collected in autumn and spring 1983 were richer in species and included 163 algal taxa (Ligowski 1986).

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6. Streszczenie

W 65 próbach pływającego lodu morskiego, pobranych w 1983 r. w Zatoce Admiralicji (Wyspa Króla Jerzego, Archipelag Szetlandów Południowych), w okolicy stacji im. H. Arctowskiego (62°10'S, 58°28'W) stwierdzono rozwój glonów od połowy czerwca do połowy października (Tabela 1). W pierwszym okresie (do końca sierpnia) liczba komórek glonów w 1 cm³ roztopionego lodu była największa i maksymalnie wynosiła $5,33 \times 10^5$, przy dominacji okrzemek *Nitzschia cylindrus* i *Nitzschia curta*. Dane z literatury wskazują, że rozwój glonów w lodzie na około 60°S ograniczony był do okresu zimy, na stacjach położonych na około 66°S okres ten ulega przedłużeniu na wiosnę i jesień, a na 68°S — 78°S — ograniczony jest do lata. Można przypuszczać, że jednym z czynników limitujących rozwój glonów w lodzie morskim jest temperatura. W wodzie zagęszczenie glonów było wielokrotnie ($\pm 2500 \times$) mniejsze niż w lodzie zabarwionym na brązowo i kilkakrotnie mniejsze od obserwowanego w lodzie bezbarwnym. Ogółem wyróżniono 95 taksonów glonów występujących w lodzie morskim (Tabela 2). Jest to liczba mniejsza od liczby taksonów (163) stwierdzonej w fitoplanktonie sieciowym Zatoki Admiralicji, również w 1983 roku.