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Algae of drifting sea ice north of Elephant Island (BIOMASS III, October 1986)

ABSTRACT: Chlorophyll *a* content and the density and species composition of algae were determined in drifting sea ice north of the Elephant Island (between 54—56°W and 60°30′—61°00′S) at the end of October 1986. In yellow--brownish pieces of brash ice the amount of chlorophyll *a* was on average 203.5 ± 149.9 mg m^{-3} at the density of algal cells of $255.7 \pm 137.8 \cdot 10^3$ in cm^3. In not visibly discoloured ice the respective values were about 80 times lower, and in surface water about 700 times lower. 69 algal taxa were recorded in the samples, almost all of which were diatoms. *Nitzschia cylindrus* dominated in all the samples. A comparison of species composition in the investigated habitats revealed that the highest species similarities occurred between samples collected in discoloured ice, lower in the uncoloured ice and the lowest ones in water.

Key words: Antarctica, sea ice algae, chlorophyll *a*, drifting ice, BIOMASS III.

1. Introduction

In polar regions microscopic algae living in sea water become trapped by sea ice and concentrated in this process (Garrison, Buck and Silver 1982; Garrison, Ackley and Buck 1983). Under favourable conditions these algae develop in the sea ice and the content of chlorophyll *a* in sea ice algae may then reach very high values, mainly in the bottom ice layer (Garrison, Sullivan and Ackley 1986); chlorophyll *a* content in surrounding water is many times lower (up to 2000 times) (Bunt 1963; Fukushima and Meguro 1966; Sullivan and Palmisano 1981; Palmisano and Sullivan 1983).

In the course of sea ice melting algae are released into water (Garrison, Buck and Silver 1982). Their fate then is not clearly determined. Algae growing on the ice bottom surface after being released are in a poor physiological condition and quickly sink (McConville and Wetherbee 1983; Sasaki and Watanabe 1984); some sea ice species of epontic algae under favourable conditions may grow abundantly in the lenticles of melted ice (Smith and Nelson 1985).

In the course of the BIOMASS III expedition r/v "Profesor Siedlecki" sailed north of Elephant Island across a drifting pack-ice field. From Stein's (1987) multiannual investigations of geostrophic currents it follows that the drifting pack-ice in this area could appear in waters of the Bellingshausen Sea origin in the southern Drake Passage, less probably in the Bransfield Strait. During the BIOMASS III investigation carried out between King George Island and Elephant Island, along the edge of the shelf, geostrophic currents carried water masses towards the north-west (Grelowski and Wojewódzki 1988).

The aim of the present study was to determine the chlorophyll *a* content in drifting pack-ice in comparison with the surrounding sea water.

2. Material and methods

Samples of drifting pack-ice were collected north of Elephant Island (Fig. 1) at the end of October 1986. Most of them were discoloured or not visibly discoloured small pieces of brash ice (cross section length up to 0.5 m). In oce case (samples B27—B29) samples were taken from an ice floe (cake ice, diameter below 20 m). Three samples were taken — each from different floe layer: B27 and B29 from the not visibly discoloured layers situated above and below the discoloured layer from where sample B28 was taken. After melting the ice at a temperature of several centigrades the sample was treated as a water sample. Samples of surface water were collected in the immediate vicinity of the ice pieces.

At the distance of about a dozen nautical miles south-west of the ice samples collecting area oceanographic studies were carried out in the polygon I of the BIOMASS III expedition (Rakusa-Suszczewski 1988). Salinity was measured using the Plessey 6230 laboratory salinometer. In total 5 samples from the not visibly discoloured ice, 6 samples from the discoloured ice and 5 water samples were taken. Water samples were filtered through a GF/C Whatman Glass-Fiber filter and chlorophyll *a* content was determined after Evans and O'Reilly (1980). For spectrophotometrical identifications a Beckmann 25 spectrophotometer was used. The chlorophyll content was calculated using a simplified equation of Jeffrey and Humphrey (1975).

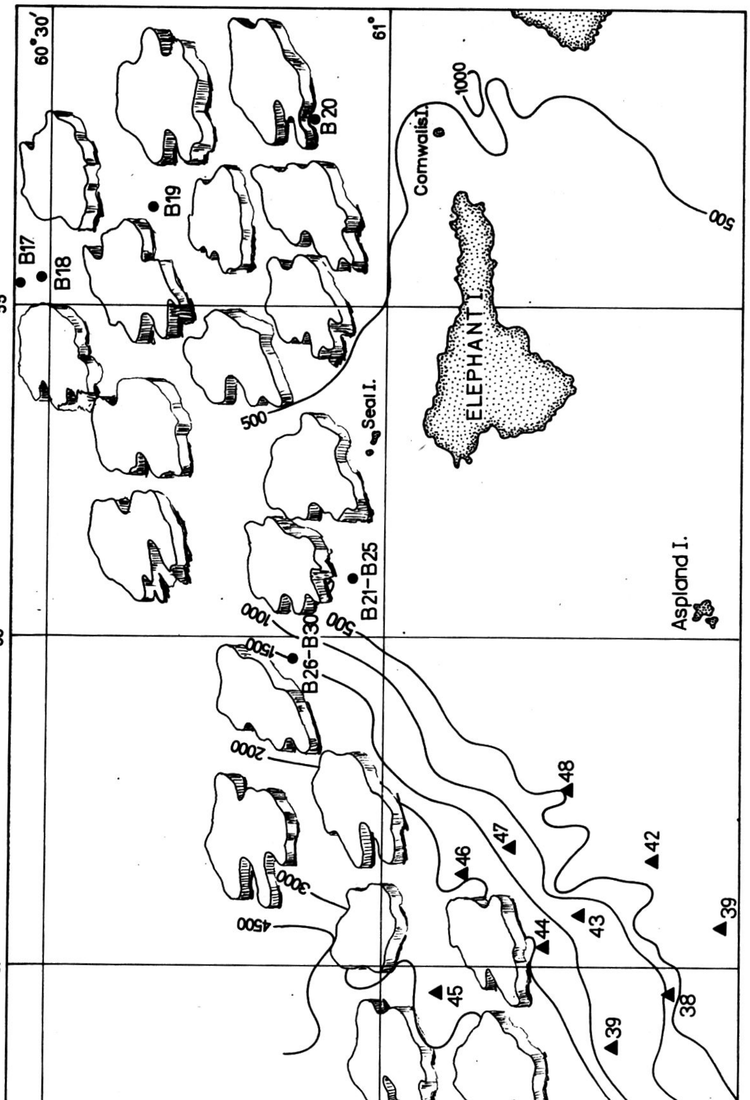

Fig. 1. Stations of surface water and drifting sea ice sampling (October 1986)

For algae countings and determinations surface water samples of 100 cm^3 each, melted colourless sea ice samples of 20 cm^3 each and melted discoloured sea ice samples of 1 cm^3 each were filtered through a Synpor membrane filter with 0.4 μm pores. After drying them up filters with sedimented algae were treated with xylene and mounted in Canada balsam to obtain permanent microscopic slides for quantitative studies. To determine the share of particular species over 300 cells in each sample were counted. To complement qualitative investigations organic parts of the samples were cleaned using chromic acid cleaning mixture and diatom frustules were mounted in pleurax slides. Algae were identified using an Amplival type of Carl Zeiss microscope with an immersion objective and using a Nomarski type phase interference technique. To compare the species compositions of samples Jaccrd's similarity coefficients was used $s = \frac{w}{a+b-w}$, where: s — similarity of two compared samples, w — number of species common for two samples, a — number of species in one of the samples, b — number of species in the other sample. Results are presented in a dendrogram.

3. Results

3.1. Contents of chlorophyll *a*

In surface waters of the salinity of abt. 34‰ the contents of chlorophyll *a* ranged from 0.24 to 0.38 mg m^{-3} (Tab. 1) and amounted on average to 0.32 ± 0.07 mg m^{-3}.

In not visibly discoloured ice of the salinity of 0.28 to 2.2‰ chlorophyll *a* contents ranged from 0.38 to 7.0 mg m^{-3} (Tab. 1), on average 2.68 ± 3.03 mg m^{-3}, which is 8.4 times more than in surface water.

In the discoloured ice (salinity of 3.7 to 5.12‰) the contents of chlorophyll *a* ranged from 53.2 to 474 mg m^{-3} (Tab. 1), on average 203.5 ± 149.9 mg m^{-3}, which is 636 times more than in surface water and 76 times more than in not visibly discoloured ice.

Of the samples taken from the non-discoloured ice the lowest chlorophyll *a* values were found in the non-discoloured layers of the ice floe situated above (B27) and below (B29) the discoloured layer (B28). Also, of the samples taken from the ice discoloured with diatoms bloom the lowest chlorophyll *a* amount occurred in this middle layer (B28) of the ice-floe.

3.2. Algal density

In surface water the number of algal cells in 1 cm^3 ranged from $0.04 \cdot 10^3$ to $0.9 \cdot 10^3$ (Tab. 1), on average $0.344 \pm 0.343 \cdot 10^3$.

Table 1

Chlorophyll *a* contents and algal cells densities in surface water (I), uncoloured ice (II) and discoloured ice (III) north of Elephant Island between 26 and 29 October 1986

	Sample number	Salinity (‰)	Number of cells ($\times 10^3$ cm^{-3})	Chlorophyll a (mg m^{-3})
I	B17		0.08	0.38
	B18		0.4	
	B20		0.9	
	B21	33.93	0.04	0.24
	B26	33.95	0.3	0.35
II	B17b		4.0	7.0
	B24	2.2	5.8	4.75
	B25	1.1	2.8	0.81
	B27	0.28	0.8	0.44
	B29	1.36	1.6	0.38
III	B17a		470.0	474.0
	B19		216.0	101.0
	B22	3.7	379.0	247.0
	B23	5.12	164.0	207.0
	B28	4.1	117.0	53.2
	B30		188.0	139.0

In the uncoloured ice the number of cells in 1 cm^3 ranged from $0.8 \cdot 10^3$ to $5.8 \cdot 10^3$ (Tab. 1), on average $3.0 \pm 2.0 \cdot 10^3$, which is 8.7 times more than in surface water.

In discoloured ice the number of algal cells in 1 cm^3 ranged from $117 \cdot 10^3$ to $470 \cdot 10^3$, on average $255.7 \pm 137.8 \cdot 10^3$, which value is 743 times higher than the average for surface water and 85 times higher than the average for uncoloured ice.

3.3 Species composition

69 algal taxa were encountered in the samples. Except of *Dictyocha speculum* and unidentified flagellates, all of them were diatoms. 54 taxa were recorded in surface water, 64 in the not visibly discoloured ice and 55 in discoloured ice (Tab. 2).

A comparison of species composition in particular types of samples (Fig. 2) indicated the highest similarity of species composition in yellow-brownish ice pieces of brash ice, a lower one in uncoloured pieces of brash ice and the lowest one in surface sea water. A comparison of species composition in samples of various layers of the single ice-floe (B27—B29) revealed low similarities between these layers.

Table 2

Algal species composition of sea ice and surface water collected near Elephant Island (BIOMASS III, October 1986) Percentage share in number of cells of only dominant species in particular sample is given.

Taxa	Samples															
	surface water					uncoloured sea ice					discoloured sea ice					
	B17	B18	B20	B21	B26	B17b	B24	B25	B27	B29	B17a	B19	B22	B23	B28	B30
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Actinocyclus actinochilus (Ehrenberg) Simonsen	+	+	+		+	+	+	3	+	+	+	2	+	2	+	+
Amphiprora kjelmanii Cleve			+	+		+	7	+			+	+	+	+	+	+
A. oestrupii Van Heurck		+				+	+				+	+	+	+		
Amphora antarctica Hustedt	+				+		+	+			+	+	+	+		+
Aateromphalus hookerii Ehrenberg			+													
A. parvulus Karsten	+		+					+								
Chaetoceros atlanticus Cleve		+	+	+	+	+	+	+			+		+	+		+
Ch. criophilum Castracane			+					+				+				
Ch. curvisetum Cleve						+										
Ch. flexuosum Manguin					+		+									
Ch. neglectum Karsten			+								+					
Chaetoceros sp. (resting spores)			+	2		+	+	+			3	+	13	3	+	1
Chaetoceros sp.						+										
Corethron criophilum Castracane	4	+	+	3	+	+	+	+	+	+	+	+	+	+	+	+
Coscinodiscus bouvet Karsten		+						+		+		+	+	+	+	+
C. oculoides Karsten						+		+		+	+	+	+	+		
C. tabularis Grunow								+							+	
Dactyliosolen antarcticus Castracane								+								
Eucampia balaustium Castracane			+		+	+		+			+	+	+		+	+
Gomphonema minusculum Cleve			+													
Haslea trompii (Cleve) Simonsen											+					
Licmophora sp.			+													
Navicula criophila Manguin						+								+		
N. directa W. Schmidt	+		+	+	+	+	+		+		+	+	+	+		+

Table 2 — continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
N. glaciei Van Heurck	+				+	+	+	+	+	5	+	+	+	2	+	+
N. jejunoides Van Heurck						+	+							+		
Navicula sp.			+			+										
Nitzschia angulata Hasle	+	+			+	+	+	4		+	+	+	+	+	+	+
N. curta (Van Heurck) Hasle	4	7	+	2	4	+	+	9	+		7	8	+	13	+	1
N. cylindrus (Grunow) Hasle	90	62	41	81	85	84	52	62	96	93	58	35	55	47	85	70
N. decipiens Haustedt		+			+		14	+	+		+	+	+	+	+	+
N. heimii Manguin				+												
N. kerguelensis (O'Meara) Hasle	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
N. lecointei Van Heurck		+	3	+	9	11	25	7	+	+	20	50	15	12	13	22
N. obliquecostata (Van Heurck) Hasle		+			+			+				+	+	+		+
N. neglecta Hustedt					+	+	+			+	+	+		+		
N. peragalli Hasle										+					+	
N. pseudonana (Hasle) Hasle								+								
N. ritscherii (Hustedt) Hasle					+		+			+	+			+		+
N. separanda (Hustedt) Hasle				+				+				+				
N. sublineata Hasle		+	+		+	+	+			+		2	+	5	+	
N. turgiduloides Hasle					+		+	+			+					
N. vanheurckii (M. Peragallo) Hasle		4		3	+	+	+	+		+	+	+	2	14	+	
Odontella weissloflogii (Janisch) Grunow			+		+	+	+	+			+	+	+	+		+
Pleurosigma antarcticum Heiden et Kolbe	+					+	+	+		+	+	+	+	+		
P. directum Grunow												+				
Porosira glacialis (Grunow) Jørgensen										+						
P. pseudodenticulata (Hustedt) Jouse		+	+		+	+		+	+		+	+		+		
Rhizosolenia alata Brightwell		+	+	+	+	+	+	+		+			+		+	+
R. hebetata f.*semispina* (Hensen) Gran		+		+						+		+		+		
R. sima Castracane	+					+		+			+	+	+	+		+
Stellarima microtrias (Ehrenb.) Hasle et Sims		+	+		+	+	+	3		+	+	+	+	2	+	+

Table 2 — continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Thalassionema nitzschioides Grunow						+	+	+				+		+	+	
Thalassiosira antarctica Comber	+	+	+	7	+		+			+		+		+	+	
T. australis Peragallo			+			+								+		
T. gracilis (Karsten) Hustedt			+				+	+		+	+					
T. gracilis var.*expecta* (Van Land.) Fryxell et Hasle	+							+		+					+	
T. gravida Cleve			+													
T. lentiginosa (Janisch) Fryxell			+				+			+		+		+	+	
T. oliveriana (O'Meara) Makarova et Nikolaev		+					+					+				
T. ritscherii (Hustedt) Hasle			+		+		+	+	+	+		+				
T. tumida (Janisch) Hasle	+		+		+	+	+	+		+	+	+	+	+		+
Thalassiothrix antarctica Schimper ex Karsten		+			+			+								
Tropidoneis belgicae (Van Heurck) Heiden	+		+		+	+	+	+			+	+	+	+		+
T. fusiformis Manguin				+	+	+	+		+			+	+	+		+
T. glacialis Heiden								+			+				+	
Tropidoneis sp.	+		+			+				+				+		
Dictyocha speculum Ehrenberg		+	+		+	+		+			+					
Flagellates		+	50	+	+		+			+	+	+	+			

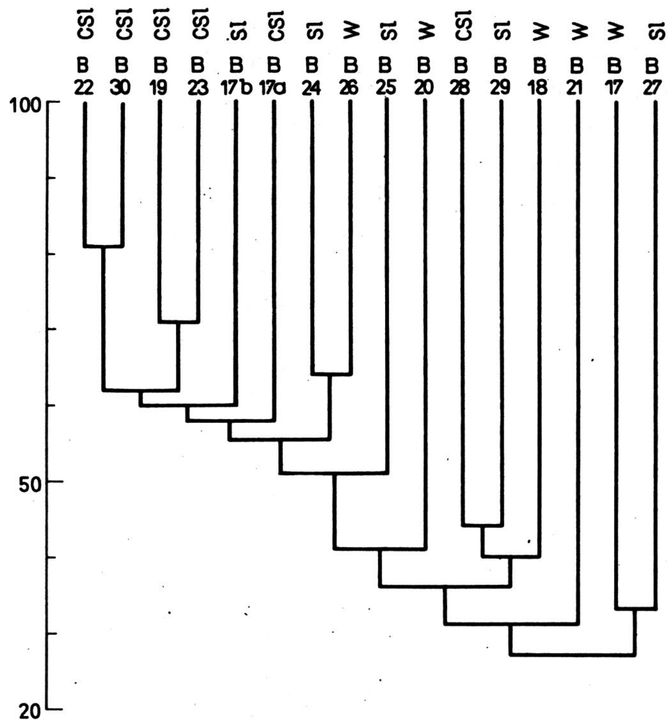

Fig. 2. Dendrogram of similarity coefficients of species compositions in discoloured ice (CSI), uncoloured ice (SI) and surface water (W) north of Elephant Island.

3.4. Dominant species

Nitzschia cylindrus clearly dominated in all samples of the studied habitats. It was accompanied, in lower share, by *Nitzschia lecointei*, which occured mainly in discoloured ice. *Nitzschia curta*, which occurred in lower share in all investigated samples, belonged also to the dominants. Some other species dominated in lower numbers of samples (Tab. 1).

4. Discussion

All investigated habitats (discoloured ice, not visibly discoloured ice and surface water) were inhabited by the community dominated by *Nitzschia cylindrus*. This species was already mentioned several times as a dominant one in the Antarctic sea ice (Bujnickij 1968; Ackley, Taguchi and Buck 1978; Garrison and Buck 1985; Ligowski 1987). A comparison of species compositions in these habitats indicated some differences. Fig. 2 shows that the most similar compositions occurred in samples taken from small pieces of discoloured, almost completely submerged brash sea ice and the least similar compositions in samples of surface water while samples of uncoloured ice were of intermediate similarity. This general pattern was distorted by samples taken from three layers of an ice-floe (B27, B28 and B29). Garrison and Buck (1985) recorded that in young sea ice and surrounding water the communities of algae were identical, whereas algal communities in older ice floes differed from those occurring in the pelagic zone.

A tendency of chlorophyll *a* contents and algal cells density to increase in the ice of higher salinity was also observed during the stratified investigations of an ice column (Ackley, Buck and Taguchi 1979). The correlation between the increase in salinity and the increase in the growth rate of ice microflora communities was also proved experimentally (Vargo et al. 1986). Ackley, Buck and Taguchi (1979) are of the opinion that a relation does exist between changes in ice salinity caused by increase in temperature and algal growth in ice. An increased algal growth at water temperature close to 0°C but at the air temperature above zero was observed in the Bransfield Strait (Ligowski 1987). Surface water temperature north of Elephant Island at the end of 1986 was close to the freezing point (Grelowski and Wojewódzki 1988) and air temperature was above 0°C.

Increase in chlorophyll *a* contents and algal density occurred together with an increase in bacteria density, which amounted to 10^8 cells cm^{-3} in the uncoloured ice, to 10^9 cells cm^{-3} in discoloured ice and 10^6 cells cm^{-3} in surface water (Zdanowski 1988).

From the present study it follows that the contents of chlorophyll *a* and algal cells density in discoloured ice were much higher (about 700 times) than those in surface water. Similar data were obtained in various parts of the Southern Ocean (Bunt 1963; Fukushima and Meguro 1966; Bujnickij 1974; Sullivan and Palmisano 1981; Palmisano and Sullivan 1983, Ligowski 1987). However, one should remember that in a water column of euphotic layer the total biomas of algae is usually higher than the total algae biomass in the comparatively thin sea ice column (Fukuchi and Sasaki 1981; Garrison, Buck and Silver 1982). The content of chlorophyll *a* estimated by the present authors in an ice column was about 20 mg m^{-2} and was also lower than the chlorophyll *a* amount in a 0—150 m water layer (60—150 mg m^{-2}) investigated in neighbouring oceanographic stations of the area I of the BIOMASS III expedition (Lipski and Zieliński 1988).

Burkholder and Mandelli (1965), Fukushima and Meguro (1966) and Ackley, Taguchi and Buck (1978) reported that in the sea ice and in the surrounding water the same algae species do occur. In the water layer below ice occur usually the species originating from ice (Fukuchi and Sasaki 1981; Garrison, Buck and Silver 1982; Marra, Burckle and Ducklow 1982); on the other hand in this water layer the species not occurring in ice can be met sometimes even as a dominant ones (Fryxell, Theriot and Buck 1984). Burkholder and Mandelli (1965) found several diatom species common to sea ice and sea water but they also noticed that small organisms occurred in higher percentages in the ice. Bunt and Wood (1963) distinguished clearly two communities: epontic and planktonic ones. Some algal species of ice origin may also develop in water at the ice edge, but their development is probably restricted to the stable water layer of the salinity lowered by melted ice; such a layer may extend along the distance of many kilometers (Smith and Nelson 1985).

Net phytoplankton in the area I of the BIOMASS III expedition situated about a dozen nautical miles south-west of the presently studied area was dominated mainly by *Corethron criophilum* (Ligowski 1988). Of course, in samples from the planktonic net the share of this diatom species was overestimated. In surface water samples from the presently investigated region *C. criophilum* always occurred, its single cells being also recorded in ice. Other dominants of net phytoplankton in area I of the BIOMASS III expedition were species of the genus *Nitzschia* of the *Fragilariopsis* group (Ligowski 1988). *Nitzschia cylindrus* and *N. curta*, also belonging to this group, as mentioned above were dominants in the ice. Kopczyńska (1988) has also recorded these species in her bottle phytoplankton samples taken in area I, mainly in stations situated close to the ice pack north of the Scotia Front zone.

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6. Streszczenie

W końcu października 1986, na północ od Scotia Front (Weddell Scotia Confluence) w rejonie Wyspy Elephant występowało pole lodowe dryfujące z południowego-zachodu. W dryfujących kawałkach lodu, w krze oraz w wodzie powierzchniowej badano zawartość chlorofilu *a*, zagęszczenie i skład glonów.

Średnio zawartość chlorofilu *a* i zagęszczenie glonów wynosiło odpowiednio: w lodzie zabarwionym przez zakwit okrzemek 203.5 ($\pm$149.9) mg chl. $a \cdot m^{-3}$ i 155.7 ($\pm$137.8)$\cdot 10^3$ komórek$\cdot cm^{-3}$, w lodzie o nie zmienionej barwie 2.68 ($\pm$3.03) mg chl. $a \cdot m^{-3}$ i 3.0 ($\pm$2.0)$\cdot 10^3$ komórek$\cdot cm^{-3}$, w wodzie powierzchniowej 0.32 ($\pm$0.07) mg chl. $a \cdot m^{-3}$ i 0.34 4(0.344)($\pm$0.345)$\cdot 10^3$ komórek$\cdot cm^{-3}$. W lodzie zabarwionym zawartość chlorofilu *a* i zagęszczenie komórek glonów są o około 80× większe, niż w lodzie nie zabarwionym i około 700× większe, niż w wodzie powierzchniowej.

Większa zawartość chlorofilu *a* i zagęszczenie glonów występuje w lodzie o większym zasoleniu. Stwierdzono większą zawartość glonów w drobnych odłamkach dryfującego lodu, niż w krze.

W próbach określono 69 taksonów glonów, głównie okrzemek. Porównanie składu gatunków w badanych siedliskach wyróżnia 3 grupy stanowisk: lód zabarwiony, lód nie zabarwiony, woda powierzchniowa. We wszystkich badanych siedliskach dominowały okrzemki, głównie *Nitzschia cylindrus*.