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Sea ice microalgae at the northern boundary of the pack ice between Elephant Island and South Orkney Islands (December 1988 – January 1989)

ABSTRACT: At the northern border of pack ice the study on chlorophyll *a* content, density of cells, species composition and domination in samples from the drifting ice floes and from brash ice was carried out. 102 taxa of algae were found in the pack ice. In the study area algal taxa were rather uniformly distributed. In different ice layers the qualitative composition of diatom assemblages was similar and usually the diatom *Nitzschia cylindrus* was dominant and most frequent. Chlorophyll *a* content (from 0.12 to 334.5 mg m^{-3}) and the density of cells (from 0.3 to 362×10^6 cm^{-3}) varied strongly in various habitats. Ice floes near the northern pack ice border contained low values of chlorophyll *a* (mean value 0.50 ± 0.28 mg m^{-3}). However, brash sea ice originating from ice floes, contained 142.4 ± 117.5 mg m^{-3} of chlorophyll *a* in visibly discoloured and 30.1 ± 24.3 mg m^{-3} of chlorophyll *a* in not visibly discoloured parts on average. The range of chlorophyll *a* content and the presence of characteristic species allow to distinguish brash sea ice infiltration assemblage of diatoms.

Key words: Antractic algae, diatoms, pack ice, Weddell Sea, chlorophyll *a*.

Introduction

In the Southern Hemisphere sea ice covers maximally about 20×10^6 km^2. As sea ice less than one year old dominates in the Antarctic, about 16×10^6 km^2 of ice melts at the end of austral summer (Squire 1990). Weddell Sea is the region in Antarctic where the changes in the ice cover during the year are the largest (Bartsch 1989). According to Ropelewski (1983) the surface of the Weddell Sea covered with sea ice is 4.36×106 km^2 in August and 1.14 km^2 in February. The contribution of frazil ice in the Weddell Sea ice is considerable and reaches 50–70% (Clarke and Ackley 1981). It is probably due to the waves and winds acting during ice formation (Squire 1990). Frazil ice may also arise in Antarctic fast ice (Dayton, Robilliard and Devries 1969). The domination of congelation ice is typical for fast ice on the contrary to the drifting pack ice in the Weddell Sea where frazil ice is more common (Garrison, Sullivan and Ackley 1986). Frazil ice during its formation accumulates algae that are present in water (see Garrison, Close and Reimnitz 1989). Therefore, unicellular algae are always present in sea ice, although their intense growth is seasonal. The differences in formation and occurrence of various structure of ice in fast ice and pack ice also result in different ice biota distribution. In fast ice the development maximum of chlorophyll *a* usually appears in the lower part of ice; in pack ice – in central or surface parts (see Garrison, Sullivan and Ackley 1986) of ice. Species composition of algae, mainly diatoms, in sea ice of different origin is similar. However, it is possible to distinguish evident assemblages (Horner 1990, Garrison 1991) in particular microhabitats depending on the place of their formation in the sea ice column (Horner *et al.* 1988).

More accurate, seasonal studies on ice biota were carried out in Antarctic sea ice near research stations (see Horner 1985a). The data on ice biota in pack ice, however, are still not complete (Garrison and Buck 1989). Investigations of algae in pack ice of the Weddell Sea were carried out: near the ice pack edge at the Antarctic Peninsula (Ackley, Taguchi and Buck 1978, Garrison, Ackley and Buck 1983, Garrison and Buck 1985), in its southern (Gersonde 1986) and eastern (Clarke and Ackley 1984, Bartsch 1989) parts, at the northern edge of pack ice (Garrison, Buck and Fryxell 1987, Ligowski, Lipski and Zieliński 1988) and in Weddell Gyre (Nikolaev 1991). In the pack ice of Weddell Sea and of the Antarctic Peninsula region representatives of various groups of autotrophs and heterotrophs were found (Garrison and Buck 1989). However, only diatoms are recognized enough to compare the communities of different habitats (Garrison, Sullivan and Ackley 1986, Garrison 1991).

During the Sea-Ice Zone Expedition of Polish Academy of Sciences in December 1988 and January 1989 oceanographical investigations were carried out near the northern ice edge in the Weddell Sea between Elephant Island and the South Orkney Islands. Two types of water masses in this region were observed: west of 48.5°W – waters coming from the Drake Passage and the Bransfield Strait, and east of this meridian – waters of the Weddell Sea origin (Tokarczyk *et al.* 1991). Investigations encompassed, among others, the study on the distribution of bottle phytoplankton (Kopczyńska 1991) and chlorophyll *a* content (Lipski 1991). The present work is a successive paper concerning the primary production in this region and contains data on chlorophyll *a* content, density of cells, species composition and dominant species of algae in the drifting pack ice floes and pieces of brash ice.

Material and methods

Samples from the drifting ice floes and pieces of brash ice were collected between Elephant Island and the South Orkney Islands from the northern boundary of the Weddell Sea pack ice, from December 30, 1988 to January 13, 1989. More detailed data on stations, where the study was carried out, are presented in the work of Rakusa-Suszczewski (1991). The ice cores and samples from the bottom of ice floes were collected by divers. Smaller pieces of brash ice were taken directly on a motor-boat or on the ship's board. The surface of ice samples was rinsed with sea water filtered through GF/C filter in order to remove cells coming from phytoplankton. At 8 stations a total of 30 samples were taken (Fig. 1). Content of chlorophyll *a* in sea ice was measured spectro-

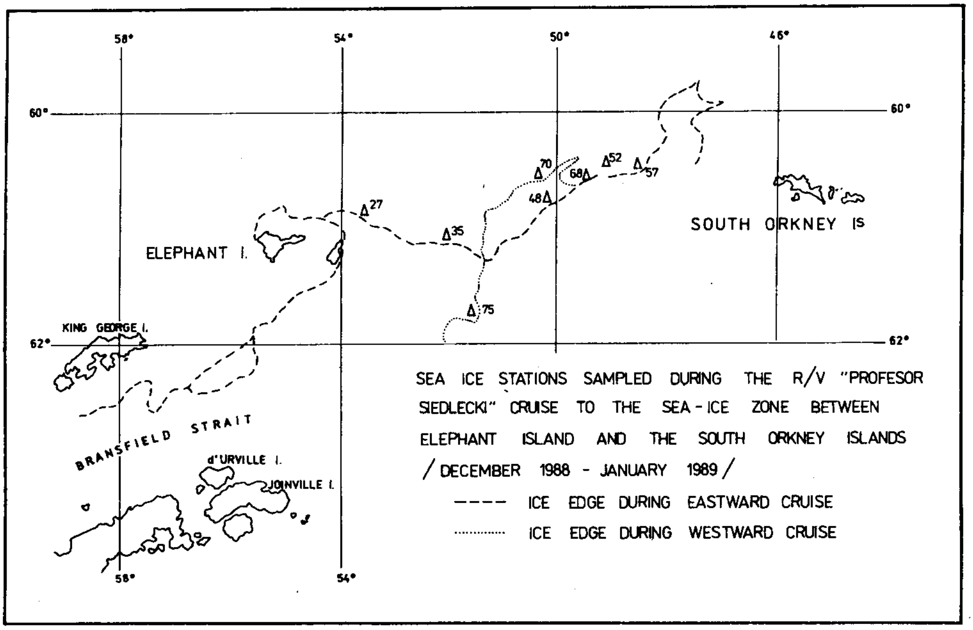

Fig. 1. Study area and stations of sea ice algae collections

photometrically (Jeffrey and Humphrey 1975) after ice melting at 0°C. Ice subsamples of equal volume of 50 cm^3 were taken with ice coring auger 2.5 cm in diameter from all samples of ice. Subsamples of ice were melted in 500 cm^3 of filtered sea water (similarly to Garrison and Buck 1986) in temperature of about 2°C. To prevent formation of fresh water layer under the melting ice, the solution was smoothly moved. Two permanent slides were made from each sample. To determine algal density a part (20 cm^3) of each sample was filtered on the Synpor membrane filter of 0.4 μm pore diameter. Dry filter was made translucent using xylene and mounted in Canada balsam. Diatom taxa were identified in permanent slides in pleurax after cleaning organic material with chromic acid mixture. For identification an immersion lens Amplival microscope (Carl Zeiss) was used and Nomarski type phase interference techniques.

The species constituting more than 5% of cells in the sample were recognized as dominant ones. Jaccard's similarity coefficient (Abbott, Bisby and Rogers 1985) was used to compare the qualitative content of the samples. Results were presented in a dendrogram.

Results

Chlorophyll *a* content

The mean chlorophyll *a* content in all 30 samples was 64.8±99.0 mg m^{-3} and varied from 0.12 to 334.5 mg m^{-3}. The lowest values of chlorophyll *a* (from 0.12 to 0.83 mg m^{-3}) were observed in ice cores of pack ice floes in all distinguished layers of the ice column. The mean value of chlorophyll *a* in pack ice floes (6 samples) was 0.53±0.28 mg m^{-3}.

In the brash ice pieces chlorophyll *a* contents varied from 2.36 to 335.5 mg m^{-3}; the mean value was 92.3±107.1 mg m^{-3}. This value in the western part of the investigated area (west of 48.5°W) was 8.7±6.4 mg m^{-3} on average, in the rest of the area — 106.3±110.0 mg m^{-3}. In visible discoloured pieces of ice mean chlorophyll *a* content was 142.4±117.5 mg m^{-3} and in not visible discoloured ones — 30.1±24.3 mg m^{-3}. Range of chlorophyll *a* content in different sea ice algal assemblages is presented in Fig. 2.

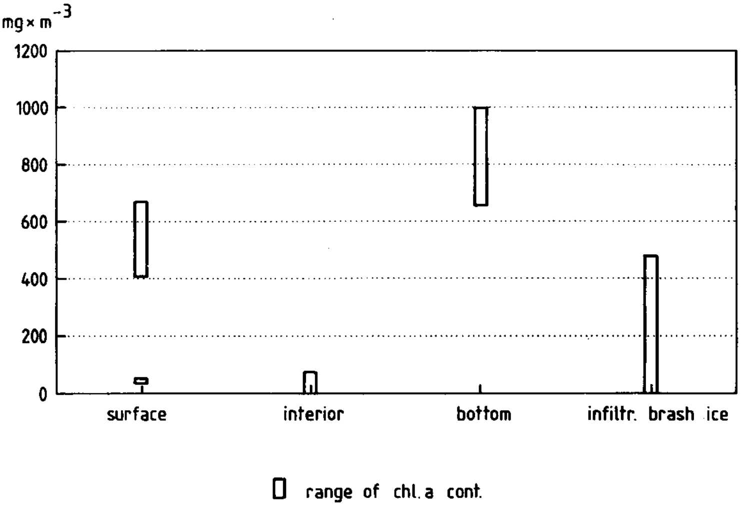

Fig. 2. Chlorophyll *a* content in different sea ice assemblages in Antarctica after: Ackley, Buck and Taguchi (1979), Bartsch (1989), Burkholder and Mandelli (1965), Clarke and Ackley (1984), Garrison (1990), Garrison and Buck (1989), Garrison, Ackley and Buck (1983), Garrison, Sullivan and Ackley (1986), Hoshai (1977, 1981), Ligowski, Lipski and Zieliński (1988), Meguro (1962), Palmisano and Sullivan (1983) and present data

Density of cells

The mean density of cells in 30 samples was $128.0 \pm 115.8 \times 10^3$ cm^{-3}. For the samples taken west of 53.5° W the mean density of cells was $68.9 \pm 108.0 \times 10^3$ cm^{-3}, for these taken east of 53.5°W it was $158.0 \pm 110.2 \times 10^3$ cm^{-3}.

Species composition

102 taxa of algae were determined in the samples. They were 98 taxa of diatoms, two species of siliceous cysts, *Dictyocha speculum* and *Phaeocystis pouchetii* (Tab. 1). Similarity of species composition in particular samples is presented in dendrogram (Fig. 3). 23 taxa of algae (22 of them — diatoms) were species of high frequency occurring in more than half of the total number of samples.

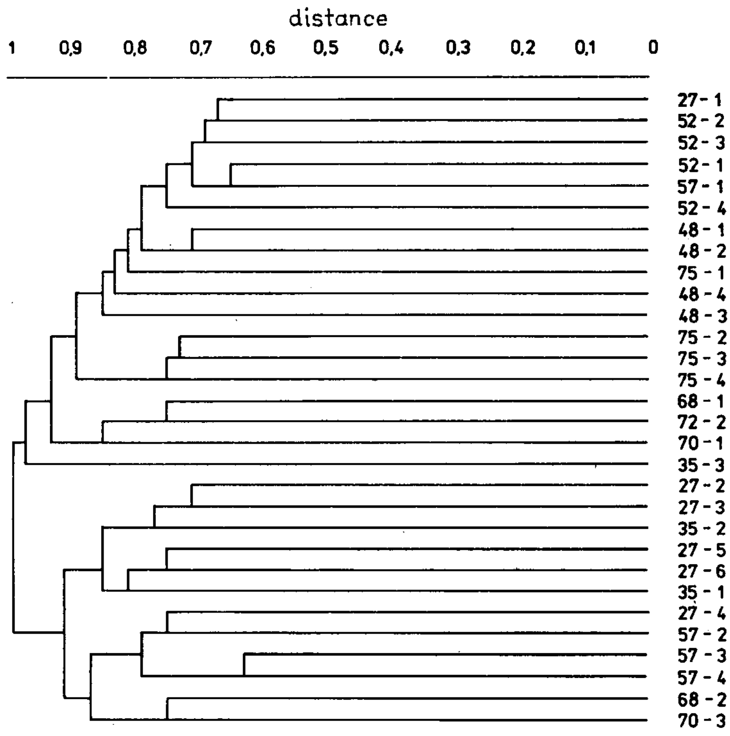

Fig. 3. Dendrogram of similarity coefficients of algal species composition in samples of sea ice

Dominant species

12 species were dominant in at least one sample (Tab. 1). These were 10 species of diatoms (number of samples in which the species dominated is given in brackets): *Nitzschia cylindrus* (30), *N. curta* (15), *N. sublineata* (4), *Chaetoce-*

Algae species composition of sea ice collected between Elephant
Percentage share in number of cells of only

Taxa										Sta	
	27						35			48	
										Sam	
	1	2	3	4	5	6	1	2	3	1	2
Actinocyclus actinochilus (Ehrenberg) Simonsen	+	+	+	+		+	+	+		+	+
Amphipleura rutilans (Trentepohl) Cleve							+	+			
Amphipleura sp.							+				
Amphiprora kjellmanii Cleve	+				+	+	+			+	
A. kufferathii Manguin	+				+	+	+			+	+
A. oestrupii Van Heurck	+	+	+			+	+			+	+
Amphiprora sp.								+			
Amphora barrei Manguin	+		+			+	+	+	+	+	+
Amphora sp.											
Asteromphalus hookerii Ehrenberg											
Auricula compacta (Hustedt) Medlin											
Banquisia belgicae (Van Heurck) Paddock	+	+	+		+	+	+	+			
Chaetoceros aequatorale Cleve							+				
Ch. atlanticus Cleve	+				+		+				+
Ch. criophilus Castracâne			+				+		+		+
Ch. dichaeta Ehrenberg										+	
Ch. neglectus Karsten				+							
Ch. neogracile Van Landingham			+	54	18	+		+		+	
Chaetoceros sp.					+					+	
Chaetoceros sp. RS	+	+		+	+					+	+
Cocconeis costata Gregory											
C. costata var. *hexagona* Grunow											
Corethron criophilum Castracane	+	+	+					+		+	+
Coscinodiscus bouvet Karsten											+
C. oculoides Karsten										+	+
C. oculus-iridis Ehrenberg											+
Cymbella sp.											+
Eucampia antarctica Castracane					+					+	+
Gomphonema sp.							+	+			
Gyrosigma sp.	+										
Haslea trompii (Cleve) Simonsen	+				+		+	+			
Licmophora abbreviata Agardh			+								
Manguinea fusiformis (Manguin) Paddock	+	+		+	+	+	+	+		+	+
Membraneis challengerii (Grun. in Cleve et Grunow) Paddock						+		+			
Navicula antarctica Frenguelli	+				+		+				
N. concellata Donkin											
N. glaciei Van Heurck	+	+		+		+	+	+			
N. jejunoides Van Heurck	+								+		
N. directa (W. Sm.) Ralfs	+	+					+	+		+	+
Navicula sp.											

Table 1

Island and South Orkney Islands (December 1988 - January 1989)
dominant species in particular sample is given

tions																		
48		52				57				68		70			75			
ple																		
3	4	1	2	3	4	1	2	3	4	1	2	1	2	3	1	2	3	4
+	+	+	+	+	+	+	+						+		+	+	+	+
+																		
	+																	
+		+	+	+	+	+	+	+	+									+
	+	+	+	+		+	+			+		14	+		+	+	+	+
+			+	+	+	+	+			+	+			+	+	+		+
	+	+	+	+	+												+	+
	+																	+
				+														
																+	+	+
+		+	+	+	+	+					+			+		+	+	
		58				+	+	+	+	+							+	
		+			+	+		+				+					+	
+		+	+	+	+	+	+	+	+		+	+			+		+	
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	+																	
	+	+	+		+											+	+	+
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+	+		+		+		+								+	+	+	
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			+		+													
		+	+	7		+	+	+	+									
		+																
			+	+	+	+	+								+	+	+	+
+			+												+	+	+	+
				+		+												
																		+

	27						35			48	
	1	2	3	4	5	6	1	2	3	1	2
Nitzschia adeliana var. *maior* Manguin											
N. angulata Hasle		+				+			+	+	
N. barbieri Peragallo											
N. closterium (Ehrenberg) Wm. Smith	+	+	+	+	+	+	+	+		+	
N. curta (Van Heurck) Hasle	+	+	+	+	+	+	+	7	+	22	33
N. cylindrus (Grunow) Hasle	98	94	87	41	59	28	83	84	78	70	51
N. decipiens Hustedt	+			+	+	+	+	+			+
N. kerguelensis (O'Meara) Hasle					+				+		
N. lecointei Van Heurck	+	+	+	+	+	+	+			+	
N. lineata Grunow							+	+			
N. neglecta Hustedt	+	+		+	+	22	+	+	+	+	+
N. obliquecostata (Van Heurck) Hasle	+		+	+				+			
N. pseudonana (Hasle) Hasle						+					
N. ritscherii (Hustedt) Hasle	+		+		+		+	+			
N. separanda (Hustedt) Hasle					+						
N. stellata Manguin											
N. subcurvata Hasle				+	+	+	+		+	+	+
N. sublineata Hasle	+				+	+	+	+			+
N. turgiduloides Hasle	+	+			+						+
N. vanheurckii (M. Peragallo) Hasle	+	+	+		+			+		+	+
Odontella litigiosa (Van Heurck) Hoban											+
O. weissflogii (Janisch) Grunow										+	
Pinnularia quatratarea (W. Schmidt) Cleve	+	+					+	+			
Pleurosigma antarcticum Heiden et Kolbe								+			
P. directum Grunow			+				+				
Porosira glacialis (Grunow) Jørgensen		+								+	+
P. pseudodenticulata (Hustedt) Jousé	+	+			+	+		+		+	+
Proboscia alata (Brightwell) Sundström	+				+	+				+	+
Proboscia inermis (Castracane) Jordan et Ligowski											
Rh. hebetata f. *semispina* (Hensen) Gran	+	+	+	+	+	+		+			+
Rh. sima Castracane											+
Stellarima microtrias (Ehrenberg) Hasle et Sims	+	+	+		+			+		+	+
Synedropsis sp. 1				+	+	+			+	+	+
Synedropsis sp. 2										+	+
Thalassionema elegans Hustedt											
Th. nitzschioides Grunow											
Thalassiosira antarctica Comber				+				+			+
Th. australis Peragallo										+	+
Th. dichotomica (Kozlova) Fryxell et Hasle									+		
Th. frenquellii Kozlova					+					+	

Table 1 cont.

48		52				57				68		70			75			
3	4	1	2	3	4	1	2	3	4	1	2	1	2	3	1	2	3	4
	+				+												+	
																+	+	
																	+	
+	+	+			+	+	+	+	+									
+	+	+	13	13	11	12	7	5	7	26	42	17	5	5	21	55	25	+
16	64	41	45	50	57	87	81	90	80	72	7	50	93	93	77	9	74	79
						+			+		+			+		+		
				+												+		+
70	24	+	+	+	+	+	+					+		+	+	+	+	+
+	+		+	+	+	+	+	+	6	+	+	7	+	+	+	+	+	+
	+	+		+	+	+	+				+				+		+	+
						+												
		+	+	+		+	+							+	+		+	+
											+							+
	+	+	+		+	+	+	+	+		+	+			+			
	+	+	31	25	22	+	+	+		+	38		+	+	+	+	+	
+		+	+	+	+	+				+	+				+	+		
+		+	+	+		+	+			+	+			+	+	+	+	
			+	+											+	+	+	
			+													+		+
+		+	+		+	+												+
		+	+	+							+	+					+	
	+	+	+	+	+	+	+				+	+			+	+	+	+
	+	+	+	+	+	+				+					+	+		
																+		
5	+	+	+	+	+	+				+		+			+	+	+	20
+	+	+	+	+		+	+				+				+		+	
+				+		+												
+											+					+		
	+			+														
					+	+									+			
																	+	
				+														

	27						35			48	
	1	2	3	4	5	6	1	2	3	1	2
Th. frenquelliopsis Fryxell et Johansen										+	+
Th. gracilis (Karsten) Hustedt		+					+			+	
Th. gracilis var. *expecta* (Van Land.) Fryxell et Hasle				+							+
Th. gravida Cleve											
Th. kozlovii (Kozlova) Makarova										+	
Th. lentiginosa (Janisch) Fryxell					+						
Th. maculata Fryxell et Johansen											+
Th. ritscherii (Hustedt) Hasle	+	+		+			+			+	+
Th. tumida (Janisch) Hasle								+		+	+
Thalassiothrix antarctica Schimper et Karsten	+		+	+		+	+				+
Trigonium sp.											
Trichotoxon reinboldii (Van Heurck) Reid et Round		+					+				
Tropidoneis sp. 1	+				+						
Tropidoneis sp. 2	+										
Tropidoneis sp. 3	+						+				
Tropidoneis sp. 4	+	+			+	27	+	+	+	+	
Tropidoneis sp. 5		+	+	+				+			
Dictyocha speculum Ehrenberg	+									+	
Phaeocystis pouchetii (Hariot) Lagerheim											
Siliceous cysts 1	+		6			+		+			
Siliceous cysts 2	+	+	6	+	8	+	+	+		+	+

ros neogracile (4), *Nitzschia neglecta* (3), *N. lecointei* (2), *N. closterium* (1), *Amphiprora kufferathii* (1), *Stellarima microtrias* (1), *Tropidoneis* sp. (1); and two species of siliceous cysts (1 each).

Discussion

The mean value of chlorophyll *a* in ice floes — 0.53 mg m^{-3} is similar to the amount of chlorophyll *a* in the surrounding water (Lipski 1991). The content of chlorophyll *a* from about one to several mg m^{-3} is typical of internal layer communities occurring in pack ice floes also in other regions of the Weddell Sea (Ackley, Buck and Taguchi 1979, Garrison, Buck and Silver 1982, Clarke and Ackley 1984, Bartsch 1989, Garrison and Buck 1989). The similar value of chlorophyll *a* was found in not visible discoloured parts of ice floes north of Elephant Island (Ligowski, Lipski and Zieliński 1988). Garrison, Ackley and Buck (1983), who noted the accumulation of algae in sea ice, have found in newly created frazil ice in the Weddell Sea 7.9 ± 6.7 mg m^{-3} of chlorophyll *a* and 0.5 ± 0.3 mg m^{-3} in the surrounding water (on an average). In the inshore

Table 1 cont.

48		52				57				68		70			75			
3	4	1	2	3	4	1	2	3	4	1	2	1	2	3	1	2	3	4
					+													
					+										+		+	
																	+	
																	+	
																	+	
+	+	+	+	+	+	+	+									+	+	+
			+	+	+	+	+								+	+	+	+
				+	+													
			+															
					+	+	+									+	+	+
			+	+	+													
			+				+										+	
															+		+	+
	+		+	+														
	+	+				+	+	+	+									
		+	+	+	+										+			
		+																
+		+		+		+									+	+	+	
+		+	+	+		+		+		+	+	+	+			+	+	+

regions the chlorophyll *a* content found in interior assemblages was also similar (Hoshai 1977, Palmisano and Sullivan 1983), despite the fact that in fast ice usually congelation ice dominates and in pack ice frazil ice dominates (Maykut 1985, Garrison, Sullivan and Ackley 1986). If we assume that during ours study and study of Garrison, Ackley and Buck (1983), the content of chlorophyll *a* in water during formation of investigated floes was similar, there was no accumulation of algae during formation at least of part of sea ice.

In not visible discoloured pieces of brash ice a characteristic amount of chlorophyll *a* (mean 30.1 mg m^{-3}) was found. In visible discoloured pieces it was 142.4 mg m^{-3} on average. The pieces of ice occurring at the northern border of pack ice during spring and summer might have originated from crushed ice floes of pack ice. They might have originated from fast ice as well, but it is less probable. The dark colour of ice, caused by high concentration of diatoms, results in higher heat absorption by floes, which leads to their quicker disintegration (Bujnickij 1968). It is worth noticing, however, that chlorophyll *a* content is evidently higher in not visible discoloured pieces of ice (60 times) and in visible discoloured pieces of ice (285 times) than in ice floes found in this region. Algae appear in ice floes in three main layers: upper surface, interior and bottom one (Horner *et al.* 1988). However, in the open ocean of the Weddell Sea algal assemblages occur mainly in the interior and surface layers (Garrison, Sullivan and Ackley 1986). Furthermore, the amounts of chlorophyll *a* found in pieces of brash ice were much lower than these for bottom layer of fast ice (Hoshai 1977, 1981, Palmisano and Sullivan 1983, Watanabe and Satoh 1987, Bartsch 1989). Also the species recognized as characteristic for bottom layer assemblages were absent in the brash ice. The amount of chlorophyll *a* in visible discoloured brash ice reached values similar to these found in surface layer of ice floes at the end of winter (Clarke and Ackley 1984) and in spring (Garrison, Sullivan and Ackley 1986), and in interior layer during the spring development of algae (Garrison, Sullivan and Ackley 1986, Ligowski, Lipski and Zieliński 1988). Therefore, the information on the amount of chlorophyll *a* alone does not allow to find out whether the brash ice comes from the surface or the interior layer of ice floes. In the surface layer algae develop mainly in the upper layer of ice 20–30 cm (Horner 1985b, Garrison and Buck 1989) or 15–100 cm (Burkholder and Mandelli 1965). Pieces of brash ice uniformly inhabited by algae can attain larger thickness. Many species of algae characteristic for the surface layer of pack ice, for example: *Phaeocystis pouchetii*, *Gymnodinium* sp., *Thalassiosira gracilis* (Garrison, Buck and Fryxell 1987, Garrison 1991), were not observed among algae occurring in the pieces of ice. However the species composition and domination in brash ice was very similar to that reported for interior layer by Ackley, Buck and Taguchi (1979), Garrison, Ackley and Buck (1983), Garrison and Buck (1985), Gersonde (1986), Ligowski, Lipski and Zieliński (1988) and Bartsch (1989). This leads to the conclusion that the pieces of ice originated from the central part of ice floes, which in the Weddell Sea consist mainly of frazil ice reaching 4 m of thickness (Maykut 1985) and this type of ice often accumulates algae during its formation (Garrison, Ackley and Buck 1983, Garrison, Close and Reimnitz 1989). Further development of these algae takes place in sea ice (Gersonde 1986, Smetacek, Scharek and Nöthig 1990, Ligowski 1991). Ice floes less inhabited by algae, and therefore uncoloured, are more solid (Bujnickij 1968) and more resistant to melting. Therefore it is evident that in the given region the chlorophyll *a* content in sea ice may vary from values similar to those found in surrounding sea water to values higher by several orders of magnitude. But if the brash ice originated from ice floes with similar population the question arises: what does the difference in algae population in visible discoloured and not visible discoloured ice floe result from? Unfortunately, there are no investigations on brash ice structure. It is possible only to draw a hypothesis that uncoloured brash ice comes from uncoloured parts of ice floes and that the visible discoloured one – from discoloured parts of ice floes. Light, temperature, nutrients, size of cells and salinity influence the primary production in sea ice (Palmisano and Sullivan 1985). Almost submerged brash ice creates more favourable abiotic conditions for algae than those present in the ice floes column. These conditions are similar to the conditions existing in surface assemblages in ice floes such as similar temperature of water, better light penetration, possibility of sea water infiltration supplementing possible lack of nutrients and increasing salinity. Therefore, an intense growth of algae in brash ice takes place. This assumption is confirmed by similar chlorophyll *a* content in pack ice surface assemblages in spring — about 40 mg $\times 10^{-3}$ (Clarke and Ackley 1984, Garrison 1990) and in uncoloured brash ice 30 mg m^{-3}. Comparable amount of chlorophyll *a* is also present in ice surface assemblages in summer — 305–407 mg m^{-3} (Burkholder and Mandelli 1965) and 670 mg m^{-3} (Meguro 1962) as well as in visible discolored brash ice — 32–335 mg m^{-3} and 117–470 mg m^{-3} (Ligowski, Lipski and Zieliński 1988; Fig. 2). Therefore, the brash ice originated from ice floes is inhabited by „infiltration brash ice assemblages" with high chlorophyll *a* content characteristic for ice surface infiltration assemblages and with species composition characteristic for ice interior assemblages. The brash ice constitutes a large part of sea ice near the northern border of pack ice. Since the chlorophyll *a* content is higher there that in ice floes the „infiltration brash ice assemblages" play an important role in the investigated area. The algae growing in brash ice are easily accessible for animals and get relatively quickly into water because of good surface area volume ratio of brash ice. Similar conditions for algal growth as those in brash ice probably influence the algal growth in sea ice observed by Smetacek, Scharek and Nöthig (1990) after rafting and ridging of ice floes; that could result in abundant krill appearance under ridged ice (Marschall 1988). The species occurring in brash ice were present in big amounts in gut content of krill caught in the ice edge region (Ligowski, unpubl. data); although in the culture their photosynthetic activity was not observed (Ligowski, Godlewski and Łukowski 1990).

Among organisms occurring in pack ice of the Weddell Sea the species composition of diatoms is best known. From 236 species of diatoms reported from Antarctic sea ice also by early authors (Horner 1985c) a part of determinations is synonymic or out-dated. Garrison (1991) reports 125 species of diatoms occurring in ice on the basis of works from last ten years. This list includes also species typical for fast ice. In the Weddell Sea pack ice Clarke, Ackley and Kumai (1984) identified 33 taxa, Garrison and Buck (1985) — 80 taxa, Gersonde (1986) — 86 taxa, Ligowski, Lipski and Zieliński (1988) — 64 taxa, Garrison and Buck (1989) — 63 taxa, Bartsch (1989) — 67 taxa (together with diatoms in fast ice). Nikolaev (1991) supposes that the winter flora of the Weddell Sea ice includes 80–90 species of diatoms. Therefore, it seems that 98 species of diatoms found in ice during present investigation at the ice edge is a comprehensive list of diatom species. The comparison of the qualitative composition of individual samples does not provide the basis for drawing conclusions on differences in their geographical distribution and distribution in ice column.

Pennatae diatom *Nitzschia cylindrus* usually dominating in sea water — is a species characteristic mainly for the Weddell Sea pack ice (Clarke and Ackley 1984, Garrison and Buck 1985, Gersonde 1986, Ligowski, Lipski and Zieliński 1988, Bartsch 1989). *N. curta* — the other species relatively often dominating in the investigated ice is not so often reported as dominant (Garrison, Buck and

Fryxell 1987). The abundance of *N. curta* in ice floes from the Weddell Sea is lower than in young ice, whereas abundance of *N. cylindrus* increases with the age of ice (Garrison and Buck 1985). It is possible that the increase of *N. cylindrus* dominance with the decrease of sea ice salinity during its getting older (Garrison, Sullivan and Ackley 1986) is related to the fact that in low salinity it has the highest growth rates among several other sea ice diatoms (Vargo *et al.* 1986). Sea ice algae assemblages are regarded as „shade adapted", but this concerns mainly ice bottom assemblages. Algae living mainly at the surface and in infiltration ice are rather „sun adapted" (Palmisano and Sullivan 1985). Algal assemblages of the brash ice both in Antarctic (Burkholder and Mandelli 1965, Bunt and Lee 1970) and in Arctic (Alexander and Chapman 1981) were adapted to high intensity. Laboratory experiments show that *N. cylindrus* dominating in brash ice during this investigation, as well as some other diatoms occurring in ice are „sun adapted" (Palmisano and Sullivan 1982, Fiala and Oriol 1990). Probably the development of the assemblage with *N. cylindrus* dominance was influenced by favourable for this species temperature and light (Fiala and Oriol 1990) and as well as low salinity (Vargo *et al.* 1986). In the spatial distribution of *N. curta* in the investigated area rather characteristic its lower contribution in all samples of ice collected in stations 27 and 35 (Tab. 1). Moreover, only at the station 27 *Tropidoneis* sp. and siliceous cysts dominated. In the ice from stations 27 and 35 chlorophyll *a* content and density of cells in volume unit were lower. Station 27 was located in waters of the Drake Passage and the Bransfield Strait origin (Tokarczyk *et al.* 1991), and station 35 in the mixing zone (Ligowski and Kopczyńska 1991). Furthermore, in the region of stations 27 and 35 geostrophic currents flowed in the north-eastern direction (Grelowski and Wojewódzki, unpubl. data). The ice at stations 27 and 35 might have been of different origin. It might have drifted away also from the northern direction and stayed in unfavourable environmental conditions zone longer than pack ice from other stations. That might have been a reason why it is not so densely populated by algae.

The observations carried out from the ship, motor-boat and by SCUBA divers showed that at the northern border of the Weddell Sea pack ice in summer only low percent of ice was visible discoloured by algal bloom. Present investigations and seasonal observations of drifting sea ice at the similar latitude in the Admiralty Bay, South Shetland Islands (Ligowski 1987) confirm the observations of Bujnickij (1968), that the ice covering Antarctic is populated by diatoms very irregularly. This fact makes the assessment of the total algal biomass in pack ice difficult. Subsequent extensive regional investigations concerning distribution of intense growth of sea ice algal in pack ice are still necessary.

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References

Abbott L.A., Bisby F.A. and Rogers D.J. 1985. Taxonomic analysis in biology — Columbia Univ. Press. New York; 336 pp.

Ackley S.F., Buck K.R. and Taguchi S. 1979. Standing crop of algae in the sea ice of the Weddell Sea region. — Deep-Sea Res., 26: 269–282.

Ackley S.F., Taguchi S. and Buck K.R. 1978. Primary productivity in sea ice of the Weddell region. — CREL Report 78–79: 17 pp.

Alexander V. and Chapman T. 1981. The role of epontic algal communities in Bering Sea. *In*: D.W.Hood and J.A.Calder (eds.), The Eastern Bering Sea Shelf: Oceanography and Resources, vol. 2. Washington Univ. Press. Seattle; 773.

Bartsch A. 1989. Eisalganeflora des Weddellmeeres (Antarktis): Artenzusammensetzung und biomasse sowie Ökophysiologie ausgewählter Arten. — Ber. Polarforsch., 63: 110 pp.

Bujnickij V.K. 1968. Vljanie mikroskopičeskich vodoroslej na stroenie i pročnost' morskich antarktičeskich l'dov. — Okeanologija, 8: 971–979.

Bunt J.S. and Lee C.C. 1970. Seasonal primary production in Antarctic sea ice at McMurdo Sound in 1967. — J. Mar. Res., 1(28): 304–320.

Burkholder P.R. and Mandelli E.F. 1965. Productivity of microalgae in Antarctic sea ice. — Science, 149: 872–874.

Clarke D.L. and Ackley S.F. 1981. Physical, chemical and biological properties of winter sea ice in the Weddell Sea. — Antarct. J. U.S., 17: 107–109.

Clarke D.L. and Ackley S.F. 1984. Sea ice structure and biological activity in the Antarctic marginal ice zone. — J. Geophys. Res., 89: 2087–2095.

Clarke D.B., Ackley S.F. and Kumai M. 1984. Morphology and ecology of diatoms in sea ice from the Weddell Sea. — CREL Report, 84–85; 41 pp.

Dayton P.K., Robilliard G.A. and Devries A.L. 1969. Anchor ice formation in McMurdo Sound. Antarctica and its biological effects. — Science, 163: 273–274.

Fiala M. and Oriol L. 1990. Light-temperature interactions on the growth of Antarctic diatoms. — Polar Biol., 10: 629–636.

Garrison D.L. 1990. Development of surface layer sea ice assemblages in Antarctic pack ice during the austral spring. — Abstr. of the Thirteenth Symp. on Polar Biology, December 5 and 6, 1990; Nat. Inst. Pol. Res., Tokyo; 19.

Garrison D.L. 1991. Antarctic sea ice biota. — Amer. Zool., 31: 17–33.

Garrison D.L. and Buck K.R. 1985. Sea-ice algal communities in the Weddell Sea: species composition in ice and plankton assemblages. *In*: J.D.Gray and M.E.Christiansen (eds.), Marine Biology of Polar Regions and Effects of Stress on Marine Organisms. — John Willey and Sons Ltd.; 103–122.

Garrison D.L. and Buck K.R. 1986. Organism losses during ice melting: a serious bias in sea ice community studies. — Polar Biol., 6: 237–239.

Garrison D.L. and Buck K.R. 1989. The biota of Antarctic pack ice in the Weddell Sea and Antarctic Peninsula regions. — Polar Biol., 10: 211–219.

Garrison D.L., Ackley S.F. and Buck K.R. 1983. A physical mechanism for establishing algal population in frazil ice. — Nature, 306: 363–365.

Garrison D.L., Buck K.R. and Fryxell G.A. 1987. Algal assemblages in Antarctic pack ice and in ice edge plankton. — J. Phycol., 23: 564–572.

Garrison D.L., Buck K.R. and Silver M.W. 1982. Ice algal communities in the Weddell Sea. — Ant. J. U.S., 17: 157–159.

Garrison D.L., Close A.R. and Reimnitz E. 1989. Algae concentrated by frazil ice: evidence from laboratory experiments and fields measurements. — Antarctic Science, 1: 313–316.

Garrison D.L., Sullivan C.W. and Ackley S.F. 1986. Sea ice microbial communities in Antarctica. — BioScience, 36: 343–250.

Gersonde R. 1986. Siliceous microorganisms in sea ice and their record in sediments in the southern Weddell Sea (Antarctica). *In*: M.Ricard (ed.), Proceedings of the Eight International Diatom Symposium, Paris 1984, Koeltz, Koenigstein; 549–566.

Horner R. 1985a. History of ice algal investigations. *In*: R.Horner (ed.), Sea ice biota. — CRC Press, Inc., Boca Raton; 1–19.

Horner R. 1985b. Ecology of sea ice microalgae. *In*: R.Horner (ed.), Sea ice biota. — CRC Press. Inc., Boca Raton; 83–103.

Horner R. 1985c. Appendix. Algal species reported from sea ice. *In*: R.Horner (ed.), Sea ice biota. CRC Press, Inc., Boca Raton; 191–203.

Horner R. 1990. Ice-associated ecosystems. *In*: L.K.Medlin and J.Priddle (eds.), Polar Marine Diatoms. — Brit. Antarct. Surv., Cambridge; 9–14.

Horner R.A., Syvertsen E.E., Thomas D.P. and Lange C. 1988. Proposed terminology and reporting units for sea ice algal assemblages. — Polar Biol., 8: 249–253.

Hoshai T. 1977. Seasonal change of ice communities in the sea ice near Syowa Station, Antarctica. *In*: M.J.Dunbar (ed.), Polar Oceans. — Arctic Inst. of North America, Calgary; 307–317.

Hoshai T. 1981. Profileration of ice algae in the Syowa Station area, Antarctica. — Mem. natl. Inst. Polar Res., Ser. E, 34: 1–12.

Jeffrey S.W. and Humphrey G.F. 1975. New spectrophotometric equations for determining chlorophylls *a*, *b*, c_1 and c_2 in higher plants, algae and natural phytoplantkon. — Biochem. Physiol. Pflanzen, 167: 191–194.

Kopczyńska E.E. 1991. Distribution of microflagellates and diatoms in the sea-ice zone between Elephant Island and the South Orkney Islands (December 1988 - January 1989). — Pol. Polar Res., 12: 515–528.

Ligowski R. 1987. Sea ice microalgae community of the floating ice in the Admiralty Bay (South Shetland Islands). — Pol. Polar Res., 8: 367–380.

Ligowski R. 1991. Plankton and sea ice diatoms in the vicinity of the South Shetland Islands. *In*: M.Poulin (ed.), Proceedings of the Third Polar Diatom Colloquium, Canadian Museum of Nature, Ottawa, Ontario, August 5–10, 1990, — Can. Tech. Rep. Fish. Aquat. Sci., 1781: 27–28.

Ligowski R. and Kopczyńska E.E. 1991. Distribution of net phytoplankton in the sea-ice zone between Elephant Island and the South Orkney Islands (December 1988 - January 1989). — Pol. Polar Res., 12: 529–546.

Ligowski R., Godlewski M. and Łukowski A. 1990. Sea ice diatoms and ice edge planktonic diatoms at northern boundary of the Weddell Sea pack ice. — Abstr. of the Thirteenth Symp. on Polar Biology. December 5 and 6, 1990; Nat. Inst. Polar Res., Tokyo; 43.

Ligowski R., Lipski M. and Zieliński K. 1988. Algae of drifting sea ice north of Elephant Island (BIOMASS III, October 1986). — Pol. Polar Res., 9; 217–229.

Lipski M. 1991. Environmental conditions and phytoplankton standing crop near pack-ice in the Scotia Sea (December 1988 - January 1989). — Pol. Polar Res., 12; 507–513.

Marschall H.-P. 1988. The overwintering strategy of Antarctic krill under the pack ice of the Weddell Sea. — Polar Biol., 9: 129–139.

Maykut G.A. 1985. The ice environment. *In*: R.Horner (ed.), Sea ice biota. — CRC Press, Inc., Boca Raton; 21–82.

Meguro H. 1962. Plankton ice in the Antarctic Ocean. — Antarct. Record, 14: 72–79.

Nikolaev V.A. 1991. Communities of ice algae from Antarctica. *In*: M.Poulin (ed.), Proceedings of the Third Polar Diatom Colloquium, Canadian Museum of Nature, Ottawa, Ontario, August 5–10, 1990. — Can. Tech. Rep. Fish. Aquat. Sci., 1781: 81.

Palmisano A.C. and Sullivan C.W. 1982. Physiology of sea ice diatoms. 1. Response of three polar diatoms to a simulated summer-winter transition. — J. Phycol., 18: 489–498.

Palmisano A.C. and Sullivan C.W. 1983. Sea ice microbial communities (SIMCO). 1. Distribution, abundance and primary production of sea ice microalgae in McMurdo Sound, Antarctica in 1980. — Polar Biol., 2: 171–177.

Palmisano A.C. and Sullivan C.W. 1985. Growth, metabolism and survival in sea ice microalgae. *In*: R.Horner (ed.), Sea ice biota. — CRC Press, Inc., Boca Raton; 131–146.
Rakusa-Suszczewski S. 1991. Report on the Antarctic Expedition of the r/v „Profesor Siedlecki" to the Sea-Ice Zone, 1988–1989. — Pol. Polar. Res., 12: 485–494.
Ropelewski C.F. 1983. Spatial and temporal variations in Antarctic sea-ice (1973–1982). — J. Clim. Appl. Met., 22: 470–473.
Smetacek V., Scharek R. and Nöthig E.-M. 1990. Seasonal and regional variation in the pelagial and the relationship to the life history cycle of krill. — Proceedings of 5th SCAR Symposium on Antarctic Biology, Hobart 1988.
Squire V.A. 1990. Sea ice: its formation, distribution and properties. *In*: L.K.Medlin and J.Priddle (eds.), Polar Marine Diatoms. — Brit. Antarct. Surv., Cambridge; 3–8.
Tokarczyk R., Lipski M., Perez F.F. and Reboredo R.P. 1991. Hydrology and hydrochemistry of the surface water layer near the sea-ice edge in the Scotia Sea (December 1988 – January 1989). — Pol. Polar Res., 12: 495–505.
Vargo G.A., Fanning K., Heil C. and Bell L. 1986. Growth rates and the salinity response of an Antarctic ice microflora community. — Polar Biol., 5: 241–247.
Watanabe K. and Satoh H. 1987. Seasonal variations of ice algal standing crop near Syowa Station, East Antarctica in 1983/84. — Bull. Plankton Soc. Japan, 34: 143–164.

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Streszczenie

W czasie wyprawy PAN w grudniu 1988 i styczniu 1989 w rejonie krawędzi lodu morskiego między Wyspą Elephant a Południowymi Orkadami badano zawartość chlorofilu *a*, zagęszczenie komórek glonów, skład gatunkowy i dominację glonów zasiedlających występujące w paku lodowym kry lodowe i pochodzący z pokruszonych kier gruz lodu morskiego. Ogółem zidentyfikowano 102 taksony glonów występujących w lodzie morskim. Ich rozmieszczenie geograficzne i w kolumnie lodu było równomierne. W lodzie morskim zarówno zawartość chlorofilu *a* ($0.12-334.5$ mg m^{-3}), jak i zagęszczenie komórek glonów ($0.3-362\times10^6$ cm^{-3}) wahały się znacznie. Wartości te były małe w krach lodowych, a znacznie wyższe w gruzie lodowym. W lodzie występującym w masach wodnych Morza Bellingshausena wartości chlorofilu *a* i zagęszczenia komórek były w lodzie niższe niż w lodzie występującym w masach wodnych Morza Weddella. W składzie ilościowym dominowały okrzemki, głównie *Nitzschia cylindrus*, a współdominantami były *N. curta, N. sublineata, Chaetoceros neogracile, N. neglecta, N. lecointei, N. closterium, Amphiprora kufferathii, Stellarima microtrias* i *Tropidoneis* sp. oraz 2 typy krzemionkowych cyst. Występujący w kawałkach lodu zakres zawartości chlorofilu *a* oraz charakterystyczne gatunki pozwalają wyróżnić infiltrujące zbiorowisko okrzemek gruzu lodowego.