

SEA ICE DIATOMS AND ICE EDGE PLANKTONIC  
DIATOMS AT THE NORTHERN LIMIT OF THE  
WEDDELL SEA PACK ICE

Ryszard LIGOWSKI<sup>1</sup>, Mirosław GODLEWSKI<sup>2</sup>  
and Aleksy ŁUKOWSKI<sup>3</sup>

<sup>1</sup>Laboratory of Polar Biology, Department of Invertebrate Zoology and  
Hydrobiology, University of Łódź, Banacha 12/16, 90–237  
Łódź, Poland

<sup>2</sup>Department of Plant Cytology and Cytochemistry, Institute of Physiology  
and Cytology, University of Łódź, Banacha 12/16,  
90–237 Łódź, Poland

<sup>3</sup>Department of Zoology and Ecology, Institute of Zoology, University  
of Warsaw, Krakowskie Przedmieście 26/28, 00–325  
Warszawa, Poland

**Abstract:** Drifting brash ice and phytoplankton were collected between Elephant Island and South Orkney Islands during the period from late December 1988 to mid-January 1989. In diatom assemblages from the sea ice, the highest occurrence was displayed by *Nitzschia curta*, *N. cylindrus* and *N. neglecta*. In phytoplankton assemblages the highest occurrence was shown by *Nitzschia curta*, *Actinocyclus actinochilus*, *Chaetoceros criophilum*, *Corethron criophilum*, *Thalassiothrix antarctica* and *Nitzschia cylindrus*. In the dendrogram of similarities of species composition, two groups of stations were distinguished. The first one was composed of the phytoplankton stations and the second one was composed of the sea ice stations. Microautoradiographic analysis revealed photosynthesis in diatoms from plankton and no photosynthesis in diatoms from brash ice after ice melting. Therefore, the sea ice diatoms could not be regarded as an inoculum for the phytoplankton diatoms in the area studied.

## 1. Introduction

The importance of ice edge phytoplankton bloom is well proved both in the Arctic Ocean (MÜLLER-KARGER and ALEXANDER, 1987; ALEXANDER and NIEBAUER, 1989; NIEBAUER and SMITH, 1989) and in the Antarctic Ocean (EL-SAYED and TAGUCHI, 1981; SMITH and NELSON, 1985, 1986; NELSON *et al.*, 1987; SULLIVAN *et al.*, 1988; see also review by SMITH, 1987). SMITH and NELSON (1986) calculated that including ice edge production of the Southern Ocean, its total productivity increases by more than 60%. Influence of sea ice is particularly significant in the Weddell Sea where the ice coverage in mid-winter, September, extends up to 80% of the sea (GARRISON *et al.*, 1986).

One of the possible causes of the ice edge phytoplankton bloom is the release of living ice algal cells into water column and growth of selected species in stable surface meltwater of low salinity (SMITH and NELSON, 1986). In the Antarctic, microalgal communities in sea ice are reported to develop in spring, summer and fall (HORNER,

1985a, 1990) and, at northern sites, also in winter (WHITAKER, 1977; KREBS, 1983; LIGOWSKI, 1987). Algal cells can be released from the ice for a long period of time and be an inoculum for phytoplankton. In the Weddell Sea ice edge a constant dispersion of cells occurs (ACKLEY *et al.*, 1979). Information is still limited on the fate of the sea ice algae after their release from the melting ice (HORNER, 1984, 1985a). Some investigations indicate that ice algal cells were alive and could grow in the water column in both nearshore (KREBS, 1983) and open ocean Antarctic ecosystems (WILSON *et al.*, 1986; GARRISON *et al.*, 1987). Some seasonal studies of inshore ice diatoms do not confirm this hypothesis (MC CONVILLE *et al.*, 1985; LIGOWSKI, 1986).

At the ice edge in the Weddell Sea, GARRISON *et al.* (1983) and GARRISON and BUCK (1985) found high similarity between diatom assemblages in young sea ice and water samples in late summer and lower similarity between species composition of old ice floes and plankton. The study of GARRISON *et al.* (1987) that was carried out on ice edge in the Weddell Sea in austral spring, confirmed the similarity between ice and planktonic algal assemblages. At northern boundary of the Weddell-Scotia Confluence the highest similarities of algal species occurred in discoloured brash ice, lower in the uncoloured sea ice and the lowest in surrounding water (LIGOWSKI *et al.*, 1988). In the northern part of the Weddell Sea the ice edge blooms were reported near the Weddell-Scotia Confluence (NELSON *et al.*, 1987; FRYXELL and KENDRICK, 1988).

Our study area was situated in the Weddell-Scotia Confluence (PATTERSON and SIEVERS, 1980). The western part of the area investigated (west of 53°30'W) was occupied by surface water of the Bellingshausen Sea origin and the Weddell Sea surface water was found in the central and eastern parts (east of 53°30'W) of the area (TOKARCZYK *et al.*, 1991).

The aim of the present study is to compare the occurrence of diatom species and their photosynthetic activity in sea ice and water column in marginal ice zone along the northern boundary of the Weddell Sea. Detailed data on diatom species composition, density and dominant species in net phytoplankton samples (LIGOWSKI and KOPCZYŃSKA, 1991) and in sea ice samples (LIGOWSKI, 1991) are presented elsewhere.

## 2. Materials and Methods

Investigations were conducted during a Polish Ice-sea Zone Expedition on board R. V. Prof. SIEDLECKI. Samples of the pack ice and net phytoplankton were collected between Elephant Island and South Orkney Islands (61°44'S–59°44'S and 54°01'W–46°26'W) (Fig. 1) during the period from December 29, 1988 to January 13, 1989. Detailed data on stations are presented by RAKUSA-SUSZCZEWSKI (1991).

Ice samples were taken at the northern boundary of the pack ice. Ice cores and bottom parts of pack ice were collected by divers. Smaller pieces of brash ice were taken directly from the sea surface. Pieces of sea ice were washed in filtered (GF/C) sea water to remove plankton cells. 50 ml subsamples of sea ice were taken from the ice using a 2.5 cm diameter ice auger. A total of 30 subsamples of sea ice from 8 stations (Fig. 1) was collected. The subsamples of ice were melted at temperature of about

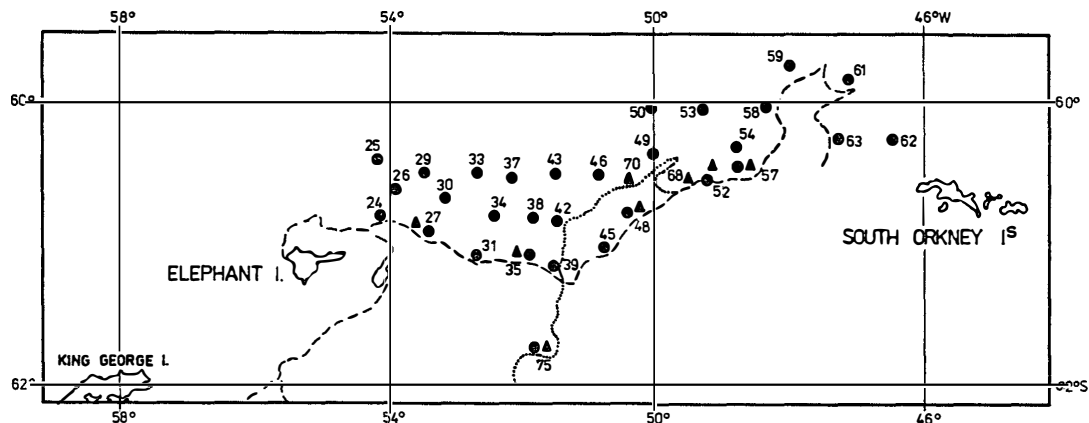


Fig. 1. Location of sampling stations. ●, net phytoplankton stations; ▲, sea ice stations. Dashed line indicates ice edge during eastward cruise (December 29, 1988–January 8, 1989), dotted line indicates ice edge during westward cruise (January 8, 1989–January 13, 1989).

0°C in filtered sea water (500 ml) to reduce osmotic stress (GARRISON and BUCK, 1986). On melting the solution was delicately shaken to avoid formation of fresh-water lenses beneath the ice.

Net phytoplankton were collected within 30 nautical miles from the ice edge. Vertical net hauls from 100 m depth to the surface were carried out with a Copenhagen net with a mouth opening of 0.196 m<sup>2</sup>, and 55 μm mesh size. Thirty samples of net phytoplankton (Fig. 1) were obtained.

Part of both sea ice and phytoplankton samples were fixed with 2% formalin (final concentration) and cleaned using chromic acid mixture (SIEMIŃSKA, 1964). Diatom frustules were mounted in pleurax slides. Diatoms were identified using an Amplival type Carl Zeiss microscope with immersion objectives using a Nomarski type phase interference attachment. Taxa found in net phytoplankton or sea ice in ≥50% of samples were distinguished as constant species (TISCHLER, 1976). To compare the species composition of the diatom assemblages Jaccard's similarity coefficient was used (ABBOTT *et al.*, 1985).

At Stns. 48, 70 and 75 situated in the central part of the study area, autoradiography experiments were performed on nine samples from sea ice and eighteen samples from phytoplankton during the period from January 4 to January 13, 1989. Ice samples were taken from the delicate brown coloured brash ice at Stns. 48, 70 and 75 with chl. *a* content of 52.75, 24.0 and 34.8 mg m<sup>-3</sup>, respectively (method after JEFFREY and HUMPHREY, 1975). Sea ice samples of 100 ml were melted in 500 ml filtered sea water and final salinity about 28.5‰ were obtained. Samples of net phytoplankton were taken, (a) at the ice edge using a net of 35 μm mesh size (0.196 m<sup>2</sup> opening mouth area) with a bucket from the water columns 50–20 m and 20–0 m, and (b) by divers just beneath the sea ice using a diver-operated push net (KIRKWOOD and BURTON, 1987) with a 35 μm mesh size. Three subsamples of 50 ml volume each from any ice and plankton sample were exposed in the ship's laboratory to <sup>14</sup>C labelled bicarbonate (NaHCO<sub>3</sub>) of 5 μCi ml<sup>-1</sup> for 4 hours at 2°C under artificial light of ≈40 μEm<sup>-2</sup> s<sup>-1</sup>. These cultures were fixed with 2% formalin (final concentration), which would not

Table 1. Occurrence (%) of diatoms in 30 samples of sea ice (I) and 30 samples of net phytoplankton (II) collected between Elephant Island and South Orkney Islands (December 1988–January 1989).

Taxa	I	II
<i>Actinocyclus actinochilius</i> (EHRENBERG) SIMONSEN	73±16	100
<i>Amphipleura rutilans</i> (TRENTEPOHL ex ROTH) CLEVE	10±11	0
<i>Amphipleura</i> sp.	7±9	0
<i>Amphiprora kjellmanii</i> CLEVE	50±18	10±11
<i>A. kufferathii</i> MANGUIN	63±17	0
<i>A. oestrupii</i> VAN HEURCK	63±17	23±15
<i>Amphiprora</i> sp.	3±6	0
<i>Amphora barreii</i> MANGUIN	50±18	10±11
<i>Amphora</i> sp.	7±9	0
<i>Asteromphalus hookerii</i> EHRENBERG	3±6	7±9
<i>Auricula compacta</i> (HUSTEDT) MEDLIN	10±11	0
<i>Azpeitia tabularis</i> (GRUNOW) FRYXELL et SIMS	0	3±6
<i>Banquisia belgicae</i> (VAN HEURCK) PADDOCK	57±18	3±6
<i>Chaetoceros aequatorale</i> CLEVE	3±6	0
<i>C. atlanticus</i> CLEVE	13±12	13±12
<i>C. convolutus</i> CASTRACANE	0	13±12
<i>C. criophilum</i> CASTRACANE	13±12	97±6
<i>C. dictyota</i> EHRENBERG	3±6	20±14
<i>C. flexuosus</i> MANGIN	0	3±6
<i>C. neglectus</i> KARSTEN	3±6	33±17
<i>C. neogracile</i> VAN LANDINGHAM	48±18	0
<i>Chaetoceros</i> sp.	27±16	3±6
<i>Chaetoceros</i> sp. resting spores	63±17	0
<i>Cocconeis costata</i> GREGORY	3±6	10±11
<i>C. costata</i> var. <i>hexagona</i> GRUNOW	3±6	0
<i>C. antiqua</i> var. <i>tenuistriata</i> VAN HEURCK	0	3±6
<i>C. illustris</i> SCHMIDT	0	7±9
<i>C. melchiorii</i> FRENGUELLI	0	3±6
<i>C. orbicularis</i> FRENGUELLI and ORLANDO	0	3±6
<i>Corethron criophilum</i> CASTRACANE	43±18	97±6
<i>Coscinodiscus bouvet</i> KARSTEN	13±12	13±12
<i>C. oculoides</i> KARSTEN	10±11	3±6
<i>C. oculus-iridis</i> EHRENBERG	17±13	67±17
<i>Cymbella</i> sp.	13±12	0
<i>Dactyliosolen tenuijunctus</i> (MANGUIN) HASLE	0	23±15
<i>Eucampia antarctica</i> CASTRACANE	37±17	37±17
<i>Gomphonema</i> sp.	13±12	0
<i>Gyrosigma</i> sp.	3±6	0
<i>Haslea trompii</i> (CLEVE) SIMONSEN	20±14	3±6
<i>Licmophora abbreviata</i> AGARDH	3±6	0
<i>Manguinea fusiformis</i> (MANGUIN) PADDOCK	53±18	0
<i>Membraneis challengerii</i> (GRUN. in CLEVE et GRUNOW) PADDOCK	7±9	0
<i>Navicula antarctica</i> FRENGUELLI	10±11	0
<i>N. concellata</i> DONKIN	3±6	0
<i>N. directa</i> (WM. SMITH) RALFS	27±16	7±9
<i>N. glaciei</i> VAN HEURCK	50±18	3±6
<i>N. jejunoides</i> VAN HEURCK	27±16	3±6
<i>Navicula</i> sp.	3±6	0

Table 1. (continued).

Taxa	I	II
<i>Nitzschia adeliانا</i> var. <i>major</i> MANGUIN	10±11	0
<i>N. angulata</i> HASLE	20±14	43±18
<i>N. barbieri</i> PERAGALLO	3±6	3±6
<i>N. closterium</i> (EHRENBERG) WM. SMITH	57±18	0
<i>N. curta</i> (VAN HEURCK) HASLE	100	100
<i>N. cylindrus</i> (GRUNOW) HASLE	100	90±11
<i>N. decipiens</i> HUSTEDT	40±18	3±6
<i>N. kerguelensis</i> (O'MEARA) HASLE	17±13	33±17
<i>N. lecointei</i> VAN HEURCK	73±16	17±13
<i>N. lineata</i> (CASTRACANE) HASLE	7±9	0
<i>N. neglecta</i> HUSTEDT	93±9	20±14
<i>N. obliquecostata</i> (VAN HEURCK) HASLE	47±18	33±17
<i>N. pseudonana</i> HASLE	7±9	0
<i>N. ritscherii</i> (HUSTEDT) HASLE	47±18	47±18
<i>N. separanda</i> (HUSTEDT) HASLE	3±6	0
<i>N. stellata</i> MANGUIN	7±9	0
<i>N. subcurvata</i> HASLE	60±18	0
<i>N. sublineata</i> HASLE	70±16	77±15
<i>N. turgiduloides</i> HASLE	47±18	43±18
<i>N. vanheurckii</i> (PERAGALLO) HASLE	63±17	23±15
<i>Odontella litigiosa</i> (VAN HEURCK) HOBAN	3±6	3±6
<i>O. weissflogii</i> (JANISCH) GRUNOW	20±14	33±17
<i>Pinnularia quatratarea</i> var. <i>constricta</i> ØSTRUP.	23±15	0
<i>Pleurosigma antarcticum</i> HEIDEN et KOLBE	23±15	3±6
<i>P. directum</i> GRUNOW	7±9	0
<i>Porosira glacialis</i> (GRUNOW) JORGENSEN	30±16	27±16
<i>P. pseudodenticulata</i> (HUSTEDT) JOUSÉ	67±17	73±16
<i>Proboscia alata</i> (BRIGHTWELL) SUNDSTRÖM	47±18	27±16
<i>Rhizosolenia inermis</i> CASTRACANE	3±6	37±17
<i>R. hebetata</i> f. <i>semispina</i> (HENSEN) GRAN	27±16	83±13
<i>R. sima</i> Castracane	3±6	3±6
<i>R. simplex</i> KARSTEN	0	3±6
<i>Stellarima microtrias</i> (EHRENBERG) HASLE et SIMS	67±17	87±12
<i>Synedropsis</i> sp. 1	53±18	0
<i>Synedropsis</i> sp. 2	17±13	0
<i>Thalassionema elegans</i> HUSTEDT	10±11	3±6
<i>T. nitzschiioides</i> GRUNOW	7±9	10±11
<i>Thalassiosira antarctica</i> COMBER	23±15	3±6
<i>T. australis</i> PERAGALLO	10±11	3±6
<i>T. dichotomica</i> (KOZLOVA) FRYXELL et HASLE	7±9	3±6
<i>T. frenguelli</i> KOZLOVA	7±9	0
<i>T. frenguelliopsis</i> FRYXELL et JOHANSEN	7±9	3±6
<i>T. gracilis</i> (KARSTEN) HUSTEDT	13±12	27±16
<i>T. gracilis</i> var. <i>expecta</i> (VLAND.) FRYXELL et HASLE	17±13	17±13
<i>T. gravida</i> CLEVE	3±6	0
<i>T. kozlovii</i> (KOZLOVA) MAKAROVA	3±6	0
<i>T. lentiginosa</i> (JANISCH) FRYXELL	7±9	20±14
<i>T. maculata</i> FRYXELL et JOHANSEN	7±9	7±9
<i>T. perpusilla</i> KOZLOVA	0	3±6
<i>T. ritscherii</i> (HUSTEDT) HASLE	57±18	17±13

Table 1. (continued).

Taxa	I	II
<i>T. tumida</i> (JANISCH) HASLE	40±18	57±18
<i>Thalassiothrix antarctica</i> SCHIMPER ex KARSTEN	27±16	90±11
<i>Triceratium</i> sp.	3±6	0
<i>Trichotoxon reinboldii</i> (VAN HEURCK) REID et ROUND	23±15	27±16
<i>Tropidoneis</i> sp. 1	17±13	0
<i>Tropidoneis</i> sp. 2	13±12	3±6
<i>Tropidoneis</i> sp. 3	17±13	0
<i>Tropidoneis</i> sp. 4	37±17	0
<i>Tropidoneis</i> sp. 5	33±17	0
<i>Tropidoneis</i> sp. 6	3±6	0

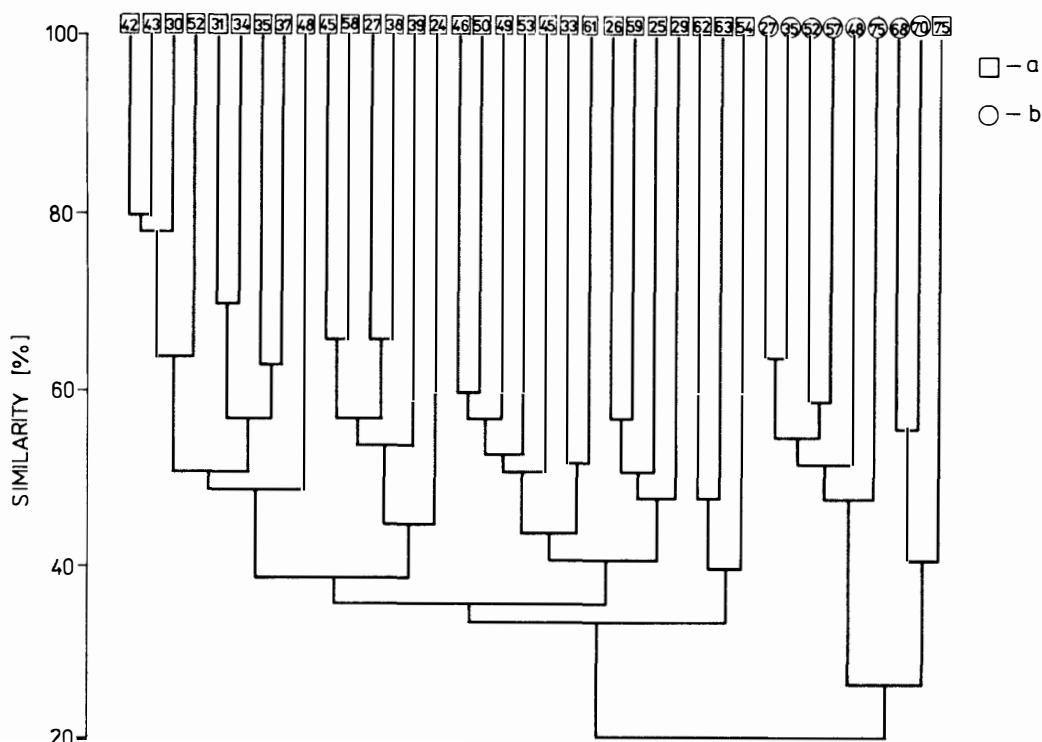


Fig. 2. Dendrogram of diatom species similarity coefficient. a, for net phytoplankton stations; b, for sea ice stations.

affect the results for distinguishing the incorporation of labelled bicarbonate into microalgal cells or not. In a university laboratory a few drops of washed samples were placed on a glass. Dried diatoms on slides were covered with liquid Ilford K-2 nuclear emulsion and exposed for 1 month at 4–6°C. Samples were mounted with Canada balsam for microscopical analysis with the immersion lens.

### 3. Results

A total of 108 diatom taxa was identified in the present study. Among them 98 taxa were recorded from 30 samples of sea ice and 69 taxa from 30 phytoplankton samples from the ice edge (Table 1).

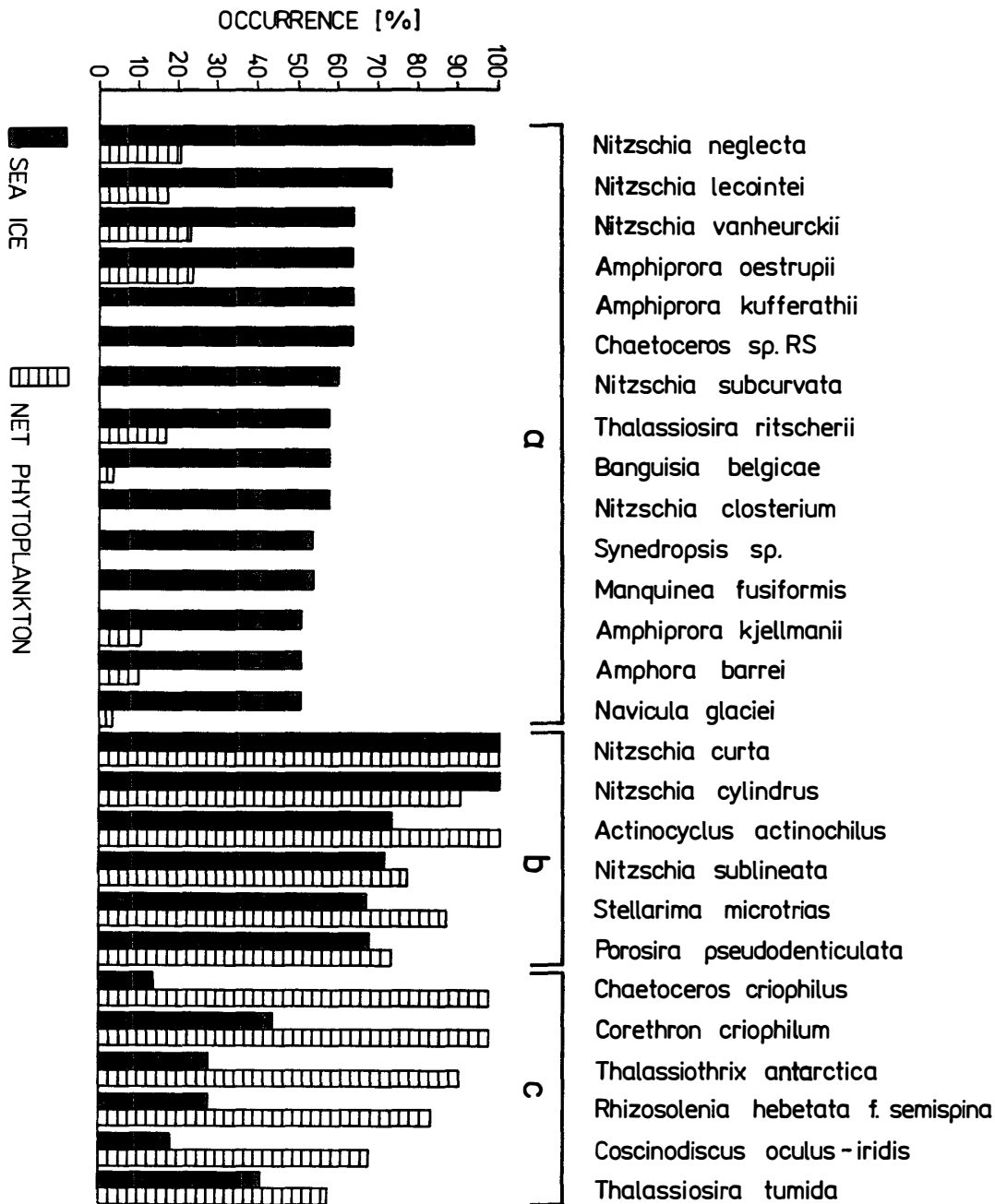


Fig. 3. Occurrence of diatom species constant (relative abundance  $\geq 50\%$ ) in 30 phytoplankton and/or 30 sea ice samples.

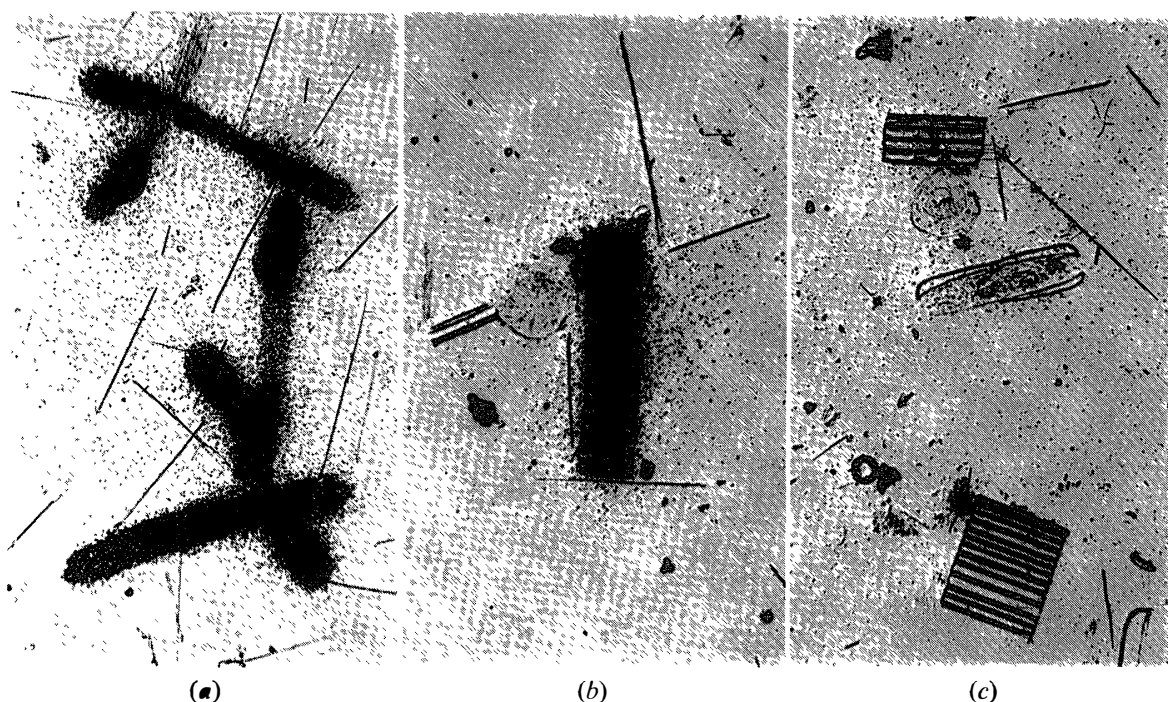


Fig. 4. Autoradiographs of incorporation of  $^{14}\text{C}$  into diatom cells. a: *Corethron criophilum* from phytoplankton at station No. 48. b: *Nitzschia* sp. from phytoplankton at Stn. 70. c: *Nitzschia* sp. and *Amphiprora* sp. from sea ice at stn. 70.

Two groups of stations were distinguished in the dendrogram of similarities of species composition constructed for both net phytoplankton and sea ice diatoms (Fig. 2). The first group was composed of the net phytoplankton stations; the second group consisted of the sea ice stations. Only one net phytoplankton station, Stn. 75 had higher similarity to the sea ice stations than others.

Fifteen species occurred  $\geq 50\%$  in sea ice samples but not so in net samples (group "a" in Fig. 3). On the other hand, six species occurred  $\geq 50\%$  in net phytoplankton samples, but not so in ice samples (group "c" in Fig. 3), six species occurred constantly in both the net and ice samples (group "b" in Fig. 3). Altogether 27 of constant (occurring in  $\geq 50\%$  samples) algal taxa in sea ice and/or in phytoplankton were distinguished (Fig. 3).

The species occurring most frequently in the sea ice were *Nitzschia curta*, *N. cylindrus*, *N. neglecta*, *N. lecointei*, *Actinocyclus actinochilus* and *Nitzschia sublineata*. In the net phytoplankton the highest frequency was observed in such species as *Nitzschia curta*, *Actinocyclus actinochilus*, *Chaetoceros criophilum*, *Corethron criophilum*, *Thalassiothrix antarctica*, *Nitzschia cylindrus*, *Stellarima microtrias* and *Rhizosolenia hebetata* var. *semispina* (Fig. 3). In phytoplankton exposed to  $^{14}\text{C}$  labelled bicarbonate the cells of *Corethron criophilum* mostly gave evidence of a high intensity of isotope incorporation (Fig. 4a). Cells of the *Nitzschia* species from plankton that incorporated the tracers were rarely observed. When the tracers were incorporated their density was very high (Fig. 4b). Autoradiographs of sea ice diatoms consist of similar density of tracer in both cells and background (Fig. 4c). These facts indicate the lack of  $^{14}\text{C}$  incorporation in cells. Hence sea ice diatoms did not give evidence of



photosynthetic activity in experimental conditions.

#### 4. Discussion

Similarity of species composition, dominant species and the viability of cells based on the autoradiographic experiment were taken into consideration for the comparison between sea ice and planktonic diatoms assemblages.

Water samples taken at the ice edge during the expedition were dominated by microflagellates and only about 10 taxa of diatoms could be found (KOPCZYŃSKA, 1991). For this reason species composition of sea ice diatoms were compared with that of net phytoplankton diatoms.

The higher similarity of phytoplankton species composition at Stn. 75 to sea ice species composition indicates that the community of sea ice origin occurred in water. Station No. 75 was the southernmost in the area studied, where the phytoplankton were predominantly algae released from melted sea ice (LIGOWSKI and KOPCZYŃSKA, 1991). A similar phenomenon was found by MARRA *et al.* (1982), who recorded species characteristic of sea ice beneath the pack ice and plankton assemblage at the ice edge was dominated by *Chaetoceros* sp. and *Corethron* sp. Also in the nearshore waters of Arthur Harbor, KREBS (1983) differentiated spring bloom of phytoplankton caused by sea ice algae and later summer phytoplankton bloom. Station No. 75 was occupied by winter-spring assemblage and the rest of stations were occupied by summer phytoplankton assemblage (LIGOWSKI and KOPCZYŃSKA, 1991).

Environment of the sea ice area can change in the range of less than a kilometer to hundreds of kilometers (SMITH and NELSON, 1985; NELSON *et al.*, 1987; FRYXELL and KENDRICK, 1988; BARTSCH, 1989). Environmental changes are caused mainly by the presence of less saline surface meltwater. In our study the presence of warmer and less saline water was observed at stations in the eastern part of the study area, although the oceanographic analysis indicated presence of water of summer modification (TOKARCZYK *et al.*, 1991). At the eastern stations (east of 49°W) dominant species did not indicate any large number of diatom cells of sea ice origin either in water or net phytoplankton samples. In sea ice *Nitzschia cylindrus* mostly dominated, rarely in association with *N. curta*, *N. lecointei*, *N. sublineata* or *Chaetoceros neogracile* (LIGOWSKI, 1991). In the western part of the area investigated, *Nitzschia cylindrus* was present in a low percentage in water samples (KOPCZYŃSKA, 1991). Net phytoplankton were dominated by *Chaetoceros criophilum* in the western part of the investigated area and by *Corethron criophilum* in the other parts of the area (LIGOWSKI and KOPCZYŃSKA, 1991).

Most frequent diatom species were *Nitzschia cylindrus* and *N. curta* in both sea ice and phytoplankton. In the Weddell Sea these species are characteristic of ice edge regions (NÖTHIG, 1988). *Nitzschia curta* and *N. cylindrus* were frequently observed in sea ice (HORNER, 1985b). These species were abundant in both sea ice and the water of the Weddell Sea (ACKLEY *et al.*, 1978) and in Lützow-Holm Bay (TANIMURA *et al.*, 1990). In the Ross Sea WILSON *et al.* (1986) found that *Nitzschia curta* released from sea ice selectively seeded shallow lens of low salinity and low density water. According to these authors microautoradiographic study indicated photosynthetic

activity of *Nitzschia curta*. Sea ice organisms in the Weddell Sea showed chlorophyll autofluorescence and hydrolyzed fluorescein diacetate, which indicated their viability (GARRISON *et al.*, 1987). Light intensity in autoradiographic experiments was above light-limited value for both *Corethron criophilum* (TILZER *et al.*, 1986, MORTRAIN-BERTRAND, 1989; FIALA and ORIOL, 1990) dominating in phytoplankton and *Nitzschia cylindrus* (PALMISANO and SULLIVAN, 1982; FIALA and ORIOL, 1990) dominating in sea ice. Diatoms for microautoradiographic analysis were taken from the water of the Weddell Sea origin with temperature from  $-0.2^{\circ}\text{C}$  to  $-1.0^{\circ}\text{C}$  (TOKARCZYK *et al.*, 1991). FIALA and ORIOL (1990) showed that temperature of  $2^{\circ}\text{C}$  is not harmful for the growth of *Corethron criophilum* and several sea ice diatom species. According to VARGO *et al.* (1986), some ice diatom species, including *Nitzschia cylindrus*, were grown at salinities from 11.5‰ to 34‰. Therefore, final light, temperature and salinity in our experiment was suitable for ice diatom.

Amount of chl. *a* and specific diatom assemblage indicate that diatoms had grown in brash ice (LIGOWSKI, 1991). However, in our study photosynthesis by sea ice diatoms after melting of ice was not recorded or scarcely recorded. Our study area was further north than that of studies in the Ross Sea (WILSON *et al.*, 1986) and the season was later than investigations in the Weddell Sea (GARRISON *et al.*, 1987). The lack of photosynthesis in sea ice algae could be explained by environmental factors caused by summer season and location of northern site occupied by the present study.

It is clear that diatom cells released from the sea ice should be found in water. Diatoms can be recognized relatively easily. Their occurrence can be a good indicator of the origin of a community. The analysis of autoradiographs and the frequency of different algae reflect the fact that the cells of sea ice diatoms in the summer of such a northern area are in a very poor physiological condition and are relatively rarely found in water. Our study confirms the opinion (HORNER, 1984, 1985a; SMITH, 1987) that the fate of algae released from sea ice depends on the ice habitat and surrounding environment.

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