



Differences in taxonomic composition of summer phytoplankton in two fjords of West Spitsbergen, Svalbard

Józef WIKTOR and Katarzyna WOJCIECHOWSKA

Instytut Oceanologii, Polska Akademia Nauk, Powstańców Warszawy 55, 81-712 Sopot, Poland
<wiktork@iopan.gda.pl> <kasia_wojciechowska@hotmail.com>

Abstract: Fjords of West Spitsbergen are very dynamic in terms of hydrology. Here we tested whether the qualitative analysis of the taxonomic composition of phytoplankton may be useful as a fast method to assess the origin of the waters and whether it can give any additional information to hydrological data. Phytoplankton samples were collected along transects in Hornsund and Kongsfjord. Among total of 109 taxa identified, only 49 were common in both fjords. The assemblages in Hornsund implied that inflow of the cold waters of the Sørkapp Current had occurred some time before samples collection, while in Kongsfjord the taxonomic composition was typical for the summer and did not show any recent, unusual hydrological phenomenon. Concluding, the method can be useful in the surveys in which hydrological data are collected infrequently.

Key words: Arctic, Spitsbergen, summer phytoplankton, fjords, hydrology.

Introduction

The species composition of phytoplankton assemblages is specific for waters which the assemblage originate in. As phytoplankton constituents move within the water body, it is possible to trace where the water masses originated by a simple qualitative analysis of the phytoplankton. It is especially useful in areas where inflow of different water masses changes annually and seasonally. Due to mixing, water loses its characteristic physical and chemical features within a few days, but the taxonomic composition of phytoplankton assemblages and condition of the cells can still reflect the origin of water masses.

The Svalbard Archipelago (particularly its largest island Spitsbergen) is such a place with dynamic hydrological conditions (Svendsen *et al.* 2002). The western coast of the island is influenced by the relatively warm Atlantic waters advected in by the West Spitsbergen Current, which flows northwards along the coast up to the northern tip of the island. An example of a fjord influenced by this warm current is

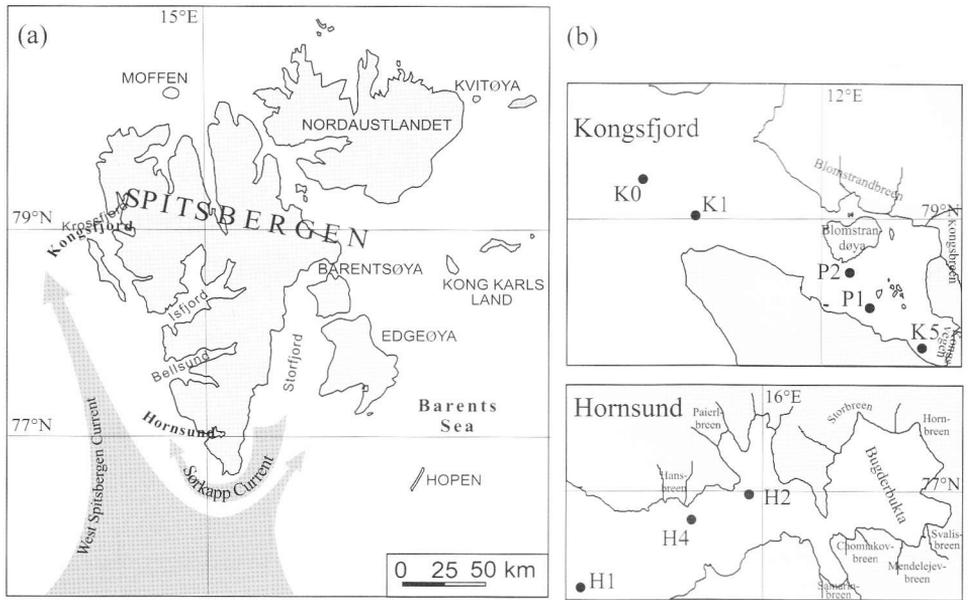


Fig. 1. (a) Map of the Svalbard Archipelago showing currents influencing fjords and location of the investigated fjords; (b) location of sampling stations in the fjords.

Kongsfjord. Its eastern coast is influenced by the southerly flow of the colder, less saline waters of Barents Sea (Fig. 1a). However, during the summer the southern part of the western coast of the Spitsbergen and its southernmost fjord – Hornsund, may be under the influence of either warm Atlantic waters or cold Arctic waters flowing as the Sørkapp Current (Swerpel 1985). In some years, the Sørkapp Current when entering the Hornsund, carries remnants of pack ice from the Barents Sea together with ice associated diatoms (Hegseth 1992). Depending on which water has advected in and whether with or without the pack ice, the different phytoplankton assemblages will be encountered.

In summer, fjords (especially their inner reaches) are also strongly influenced by the freshwater run off from the melting glaciers. The run off not only decreases the salinity of the upper water column but also increases the turbidity, and hence diminishes the vertical extent of the euphotic zone (Węśławski *et al.* 1995; Keck 1999; Keck *et al.* 1999). The lower salinities of the surface layer in the inner fjords form a barrier for many of the oceanic species, so they are present only in the outer reaches. These two factors, namely the inflow of seawater from the open ocean and the run off of freshwater from the melting glaciers, shape the taxonomic composition of phytoplankton assemblages in Spitsbergen fjords.

In this paper we aim to show that simple, qualitative analysis of the phytoplankton assemblages can be valuable as a fast method to assess the origin of waters in the hydrologically dynamic areas and can add some essential information to hy-

drological data. We noticed this when we were analysing the samples that initially were collected for quantitative analyses. These data will be published elsewhere.

Material and methods

Phytoplankton samples were collected along longitudinal transects (Fig.1b) during the summer cruise of *r/v Oceania* in 2002. In Hornsund, the sampling was carried out on 23–27 July at three stations and in Kongsfjord on 29–30 July at five stations. At each station a depth profile of six 10 dm³ samples was collected by Niskin bottle in the upper 50 m (Table 1). Subsamples (250 ml) were immediately fixed with Lugol's solution (final concentration of 2%). After 24 hours buffered formaldehyde was added (final concentration 2%).

Table 1

Sites of sampling

Station	Longitude	Latitude	Date	Layers at which samples were collected [m]
HORNSUND				
H1	76°55.32'N	15°16.46'E	23.07.2002	0, 5, 10, 50
H2	76°59.62'N	15°55.82'E	25 and 27.07.2002	0, 2, 5, 7, 10, 15
H4	76°58.63'N	15°43.74'E	25.07.2002	0, 5, 10, 15, 20, 25, 30
			23.07.2002	0, 5, 30
KONGSFJORD				
K0	79°02.62'N	11°07.91'E	29.07.2002	0, 20, 30, 50
K1	79°00.65'N	11°25.34'E	30.07.2002	0, 5, 7, 15, 50
K5	78°53.17'N	12°25.74'E	30.07.2002	0, 12, 40
P1	78°55.21'N	12°14.47'E	30.07.2002	0, 1, 2, 5, 7, 10, 15, 30
P2	78°56.83'N	12°07.13'E	30.07.2002	0, 3, 5, 7, 10, 15, 30

After the expedition, determinations and counts of 10ml subsamples were done in laboratory under inverted microscope Nikon TM-300 at magnifications of 100× and 400×, with use of the Utermöhl method (Utermöhl 1958). Diatoms and dinoflagellates were identified to the species or genus level. Individuals belonging to other groups were identified to the family level or remained unidentified.

An analysis of the dissimilarity between the stations was done with the software PRIMER 5. Calculation of Bray-Curtis dissimilarity was based on the data of presence or absence of the species.

Results

A total of 109 taxa belonging to seven phyla (Bacillariophyta, Cryptophyta, Dinophyta, Euglenophyta, Haptophyta, Heterokontophyta and Prasinophyta)

were identified, of them 61 were determined to a species level and 31 to a genus level. The occurrence of all identified taxa from both investigated fjords is shown in the Table 2.

Table 2

The occurrence of taxa at each station. H1–H4 – samples taken in Hornsund, K0–K5 and P1–P2 – samples taken in Kongsfjord

Taxon	Hornsund			Kongsfjord				
	H1	H2	H4	K0	K1	K5	P1	P2
<i>Amphidinium</i> sp. 3	•	•	•	•	•	•	•	•
Cryptomonad 8–25 µm	•	•	•	•	•	•	•	•
Cryptomonad < 8 µm	•	•	•	•	•	•	•	•
Flagellates < 3 µm	•	•	•	•	•	•	•	•
<i>Gymnodinium arcticum</i> Wulff, 1919	•	•	•	•	•	•	•	•
<i>Gymnodinium wulffii</i> Schiller, 1933	•	•	•	•	•	•	•	•
<i>Pseudonitzschia seriata</i> (Cleve) H. Peragallo, 1900	•	•	•	•	•	•	•	•
Flagellates > 7 µm	•	•	•	•	•		•	•
<i>Gymnodinium simplex</i> (Lochmann) Kofoid <i>et</i> Swezy, 1921	•	•	•	•	•		•	•
<i>Katodinium rotundatum</i> (Lohmann) Loebich III, 1965	•	•	•	•	•	•		•
<i>Phaeocystis pouchetii</i> (Hariot in Pouchet) Lagerheim, 1893	•	•	•	•	•	•		•
<i>Scrippsiella trochoidea</i> (Stein) Loebich III, 1973	•	•	•	•	•	•	•	
<i>Amphidinium crassum</i> Lohmann, 1908		•	•	•	•	•	•	•
<i>Amphidinium extensum</i> Wulff, 1916		•	•	•	•	•	•	•
<i>Amphidinium</i> sp. 5		•	•	•	•	•	•	•
<i>Gyrodinium fusiforme</i> Kofoid <i>et</i> Swezy, 1921		•	•	•	•	•	•	•
<i>Thalassiosira antarctica/gravida</i>	•	•	•	•	•			•
<i>Amphidinium sphaenoides</i> Wulff, 1916		•	•	•	•	•	•	•
<i>Chaetoceros decipiens</i> Cleve, 1873	•		•	•	•		•	•
<i>Microacanthodinium</i> sp.		•	•	•	•		•	•
<i>Chaetoceros socialis</i> Lauder, 1864	•	•	•	•	•			
<i>Chrysochromulina</i> sp.	•	•	•	•	•			
<i>Cylindrotheca closterium</i> (Ehrenberg) Reimann <i>et</i> Lewin, 1839	•	•	•	•				•
Flagellates 3–7 µm	•	•	•	•				•
Pedinellaceae non det.	•	•	•	•	•			
<i>Protoperidinium bipes</i> (Paulsen) Balech, 1974	•	•	•		•	•		
<i>Navicula</i> sp.	•	•		•	•			•
<i>Gyrodinium lachryma</i> (Meunier) Kofoid <i>et</i> Swezy, 1921	•	•	•	•				
<i>Pseudonitzschia delicatissima</i> (Cleve) Heiden, 1928	•	•	•					•
<i>Gymnodinium</i> sp. 2		•	•		•		•	•
<i>Gymnodinium</i> sp. 3	•	•			•		•	•
<i>Gymnodinium veris</i> Lindemann, 1925		•	•	•	•		•	
<i>Protoperidinium brevipes</i> (Paulsen) Balech, 1974		•	•	•		•	•	
<i>Pronoctiluca pelagica</i> Fabre-Domergue, 1889			•	•	•		•	•

Taxon	Hornsund			Kongsfjord				
	H1	H2	H4	K0	K1	K5	P1	P2
<i>Chaetoceros debilis</i> Cleve, 1894	•	•	•	•				
Prymnesiales non det.	•		•					•
<i>Rhizosolenia hebetata</i> Bailey, 1856	•		•		•			
<i>Alexandrium ostenfeldii</i> (Paulsen) Balech et Tangen, 1904		•	•		•			
<i>Gymnodinium</i> sp.		•	•		•			
<i>Gymnodinium</i> sp. 7		•	•		•			
<i>Navicula transitans</i> Cleve, 1880	•		•	•				
<i>Prorocentrum</i> sp.		•	•					
<i>Amphidinium</i> sp. 6			•	•			•	
<i>Gymnodinium</i> cf. <i>splendens</i> Lebour, 1925		•		•			•	
<i>Gonyaulax scrippsae</i> Kofoid, 1911	•						•	
Gymnodiniaceae 5		•			•			
<i>Gyrodinium</i> sp.			•		•			
<i>Navicula directa</i> (W. Smith) Ralfs in Pritchard, 1853		•					•	
unidentified algae		•		•				
<i>Bacteriosira bathyomphala</i> (Gran) Syvertsen et Hasle, 1993	•	•	•					
<i>Chaetoceros furcellatus</i> Bailey, 1856	•	•	•					
<i>Navicula vanhoeffenii</i> Gran, 1897	•	•	•					
<i>Pachysphaera pelagica</i> Ostenfeld, 1899	•	•	•					
Sphaerical not determined algae	•	•	•					
<i>Chaetoceros wighamii</i> Brightwell, 1856	•		•					
<i>Navicula pelagica</i> Cleve, 1896	•		•					
<i>Prorocentrum gracile</i> Schütt, 1895		•	•					
<i>Thalassiosira nordenskiöldii</i> Cleve, 1873	•		•					
<i>Thalassiosira</i> sp.	•		•					
<i>Alexandrium</i> sp.			•					
<i>Amphidinium</i> sp.			•					
<i>Chaetoceros furcellatus/socialis</i>			•					
<i>Chaetoceros</i> sp. resting spores			•					
<i>Eucampia groenlandica</i> Cleve, 1896	•	•	•					
<i>Cochlodinium</i> sp.		•						
<i>Diplopsalis lenticula</i> Bergh, 1881		•						
<i>Eutreptia</i> sp.		•						
<i>Fragilariopsis</i> cf. <i>oceanica</i> (Cleve) Hasle, 1965			•					
<i>Chaetoceros</i> sp.		•						
<i>Gonioceros septentrionalis</i> (Ostrup) Crawford, 1994			•					
<i>Fragilariopsis cylindrus</i> (Grunow) Krieger in Helmcke et Krieger, 1954			•					
<i>Fragilariopsis</i> sp.	•							

49 taxa were common to both fjords and most of them were dinoflagellates *e.g.* nanoplanktonic *Gymnodinium wulffii*, *G. arcticum*, *G. simplex*, *Katodinium rotundatum*, and heterotrophic *Protoperidinium bipes* and *P. brevipes*. Diatoms were also represented by many species, like *Nitzschia seriata*, *Cylindrotheca closterium* and *Chaetoceros socialis*. Nanoflagellates of different phylogenetic affiliations were also common to both fjords. Unfortunately, because of their delicate structures that get destroyed during fixation, their accurate taxonomic analysis was impossible. Some specimens were determined to generic (*e.g.* *Chrysochromulina* sp.) or to family level (*e.g.* Cryptomonadaceae). The only nanoflagellate species we determined was the colonial form of *Phaeocystis pouchetii*. The flagellated cells were of the size from 1 to 3 μm . Apart from these ubiquitous species, the phytoplankton assemblages inhabiting the two fjords differed significantly. There were about 30 species typical of each fjord.

On the basis of taxonomic composition three different zones were distinguished in Kongsfjord: (i) an outer basin (K0, K1, P2); (ii) an inner basin (P1) and (iii) a basin in the vicinity of the Kongsvegen/Kongsbreen glacier (K5). The outer zone was characterised by oceanic species, like *Protoperidinium pallidum*, *P. steinii*, *Phalacroma rotundatum* and *Rhizosolenia hebetata*. In the inner zone, the taxa with fragile cells were characteristic, determination of which was difficult due to applied fixatives. The taxa *Pachysphaera* sp. and *Eutreptiella* sp. could be regarded as typical. The assemblage in the basin in the vicinity of the glacier could be characterized solely by low species number (~20).

In Hornsund, the most typical taxa were cryopelagic diatoms, like *Bacteriosira bathyomphala*, *Navicula vanhoeffenii*, *Nitzschia delicatissima* and *Fragilariopsis cylindrus*. Species of *Chaetoceros* and *Thalassiosira* had formed resting spores. Among dinoflagellates, *Gyrodinium* cf. *nasutum* and *G. pellucidum* were unique for this fjord.

The differences between the basins and the fjords were confirmed by the dissimilarity analysis based on the occurrence of the taxa in the samples (Fig. 2).

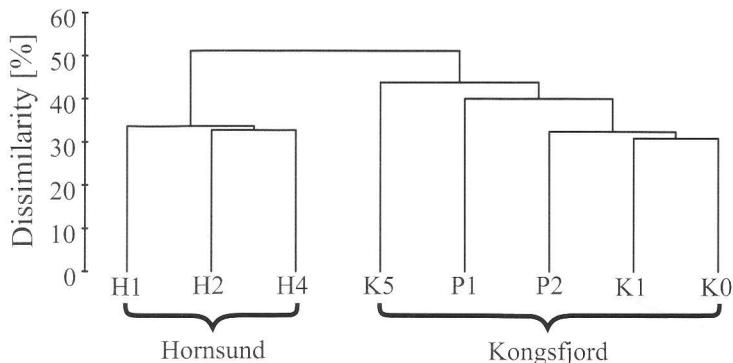


Fig. 2. Dissimilarity between the stations according to cluster analysis based on taxonomic composition (presence/absence method).

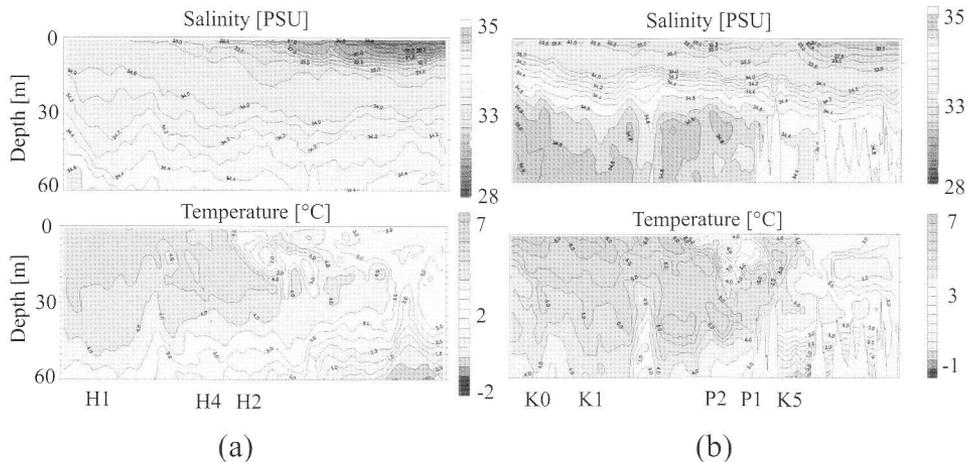


Fig. 3. STD cross-sections in Hornsund [23–25 July 2002] (a) and Kongsfjord [29–30 July 2002] (b). Courtesy of Piotr Wieczorek, Marine Hydrology Laboratory, Institute of Oceanology of the Polish Academy of Sciences.

Discussion

The common pattern observed in two fjords appears to be typical of summer-time assemblages, except of the absence of *Dinobryon balticum* (Eilersten *et al.* 1989; Hasle and Heimdal 1998; Keck *et al.* 1999; Okolodkov *et al.* 2000; Hop *et al.* 2002). It implies that the main environmental characteristics in both fjords are similar and do not change much from year to year.

The presence of the cryopelagic diatoms in Hornsund was unusual. They either may have been carried within the waters of the Sørkapp Current carrying the sea ice (Hegseth 1992) or may have grown from resting spores resuspended from the sediment. The latter phenomenon is known only from the spring season (Hegseth *et al.* 1995; Wiktor 2000). Nevertheless, the presence of the diatoms means that the inflow of cold water from the Barents Sea had taken place. However, in the hydrological graphs of Hornsund, such water masses are not visible (Fig. 3). If we consider the presence of the resting spores as an indicator that the environment was not suitable for the diatoms any more, we can conclude that the inflow had preceded the sampling for time long enough for the waters to be mixed. However, the inflow still could be revealed by the unusual taxonomic composition.

The presence of oceanic species in the phytoplankton assemblage in the outer part of Kongsfjord was consistent with the fact that the basin is influenced by West Spitsbergen Current (Hop *et al.* 2002; Svendsen *et al.* 2002). However, the Atlantic waters could not reach basins inside the fjord because of the sill situated on the bottom in the middle section of the fjord. These basins are under the influence of the freshwater run-off from the glaciers (Svendsen *et al.* 2002). The differences

between the outer and inner basins also resulted from the differences in the amounts of suspended matter. In the inner basins waters are highly turbid (Elverhøi *et al.* 1980, 1983, Zajaczkowski 2000). Such conditions favour mixo- and heterotrophic protists (Keck *et al.* 1999). The taxonomic composition of the phytoplankton in the inner basins reflected their hydrological situation (Fig. 3). As the assemblages were typical of the Kongsfjord in summertime (Halldal and Halldal 1973; Hasle and Heimdal 1998; Keck *et al.* 1999; Okolodkov *et al.* 2000; Hop *et al.* 2002), it seems unlikely that any unusual hydrological phenomenon had taken place.

Conclusion

The qualitative analysis has turned out helpful in hydrological investigation of the surface waters of the fjords of western coast of Spitsbergen. Its strongest point is that it can reveal the inflow of the different waters even after mixing, when there are no signs in terms of salinity and temperature. On the other hand, for the same reason it cannot be used in surveys that focus on sudden changes in water masses.

References

- EILERSTEN H.C., TAASEN J.P. and WĘŚLAWSKI J.M. 1989. Phytoplankton studies in the fjords of West Spitsbergen: physical environment and production in spring and summer. *Journal of Plankton Research* 11: 1245–1260.
- ELVERHØI A., LIESTØL O. and NAGY J. 1980. Glacial erosion, sedimentation and microfauna in the inner part of Kongsfjorden, Spitsbergen. *Norsk Polarinstitutt Skrifter* 172: 33–60.
- ELVERHØI A., LØNNE Ø. and SELAND R. 1983. Glaciomarine sedimentation in a modern fjord environment, Spitsbergen. *Polar Research* 1 n.s.: 127–149.
- HALLDAL P. and HALLDAL K. 1973. Phytoplankton, Chlorophyll and Submarine Light Conditions in Kings Bay, Spitsbergen, July 1971. *Norwegian Journal of Botany* 20: 99–108.
- HASLE G.R. and HEIMDAL B.R. 1998. The net phytoplankton in Kongsfjorden, Svalbard, July 1988, with general remarks on species composition of arctic phytoplankton. *Polar Research* 17: 31–52.
- HEGSETH E.N. 1992. Sub-ice assemblages of the Barents Sea: Species composition, chemical composition and growth rates. *Polar Biology* 12: 485–496.
- HEGSETH E.N., SVENDSEN H. and VON QUILLFELDT C.H. 1995. Phytoplankton in fjords and coastal waters of northern Norway: environmental conditions and dynamics of the spring bloom. In: H.R. Skjoldal, C.C.E. Hopkins, K.E. Erikstad and H.P. Leinaas (eds) *Ecology of Fjords and Coastal Waters* (Mare nor Proceedings), Elsevier Science B.V., Amsterdam: 45–72.
- HOP H., PEARSON T., HEGSETH E.N., KOVACS K.M., WIENCKE K., KWAŚNIEWSKI S., EIANE K., MEHLUM F., GULLIKSEN B., WŁODARSKA-KOWALCZUK M., LYDERSEN C., WĘŚLAWSKI J.M., COCHRANE S., GABRIELSEN G.W., LEAKEY R.J.G., LØNNE O.J., ZAJĄCZKOWSKI M., FALK-PETERSEN S. KENDALL. M., WÄNGBERG S.A., BISCHOF K., VORONKOV A.Y., KOVALTCHOUK N.A., WIKTOR J., POLTERMANN M., DI PRISCO G., PAPUCCI C. and GERLAND S. 2002. The marine ecosystem of Kongsfjorden, Svalbard. *Polar Research* 21: 167–208.

- KECK A. 1999. West Spitsbergen Fjords (Svalbard, Norwegian Arctic): Physical Settings and Sedimentation. *The Finnish Environment 263 (International Cooperation)*: 58–68.
- KECK A., WIKTOR J., HAPTER R. and NILSEN R. 1999. Phytoplankton assemblages related to physical gradients in an Arctic glacier-fed fjord in summer. *ICES Journal of Marine Science*, 56 Supplement: 203–214.
- OKOLODKOV Y.B., HAPTER R. and SEMOVSKI S.V. 2000. Phytoplankton in Kongsfjorden, Spitsbergen, July 1996. *Sarsia* 85: 345–352.
- SVENDSEN H., BESZCZYŃSKA-MØLLER A., HAGEN J.O., LEFAUCONNIER B., TVERBERG V., GERLAND S., ØRBÆK J.B., BISCHOF K., PAPUCCI C., ZAJĄCZKOWSKI M., AZZOLINI R., BRULAND O., WIENCKE C., WINTER J.-G. and DALLMANN W. 2002. The physical environment of Kongsfjorden-Krossfjorden, an Arctic fjord system in Svalbard. *Polar Research* 21: 133–166.
- SWERPEL S. 1985. The Hornsund Fiord: Water Masses. *Polish Polar Research* 6: 475–496.
- UTERMÖHL H. 1958. Zur Vervollkommung der quantitativen Phytoplankton Methodik. *Mitteilungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 9, 1–38.
- WĘSŁAWSKI J.M., KOSZTEYN J., ZAJĄCZKOWSKI M., WIKTOR J. and KWAŚNIEWSKI S. 1995. Freshwater in Svalbard fjord ecosystems. In: H.R. Skjoldal, C.C.E. Hopkins, K.E. Erikstad and H.P. Leinaas (eds) *Ecology of Fjords and Coastal Waters*. Elsevier Science, Amsterdam: 229–241.
- WIKTOR J. 2000. *Wiosenne zakwity mikroplanktonu w zalodzonych fiordach Arktyki*. PhD Thesis. Uniwersytet Gdański, Wydział Biologii, Geografii i Oceanologii; 1–91.
- ZAJĄCZKOWSKI M. 2000. *Dopływ i sedimentacja zawiesiny w wybranych fiordach zachodniego Spitsbergenu*. PhD Thesis. Uniwersytet Gdański, Wydział Biologii, Geografii i Oceanologii; 1–91.

Received 23 September 2004

Accepted 4 November 2005