Phytoplankton and water masses in the European subarctic Polar Front zone

OCEANOLOGIA, 40 (1), 1998.
pp. 51–64.

KEYWORDS
Phytoplankton
Arctic
Water masses
Polar front

Daniel Markowski
Department of Oceanography,
Sea Fisheries Institute,
Gdynia

Józef Wiktor
Institute of Oceanology,
Polish Academy of Sciences,
Sopot

Manuscript received January 26, 1998, in final form March 9, 1998.

Abstract

Phytoplankton and hydrological data were collected during the Greenland Sea Project between 74° and 76°N, 13° and 20°E, in July 1988 and 1991. The water masses were very different with regard to their hydrology in the two years, especially with regard to the displacement of the frontal zone. The phytoplankton community was similar in both years, however. Multivariate analyses have not shown any significant relationship between phytoplankton abundance, salinity, nutrients and temperature. It was assumed that the water mass as a single, comprehensive system influences phytoplankton occurrence, and its origin determines the phytoplankton recorded in the frontal zone.

1. Introduction

The influence of physical conditions on subarctic, pelagic biota has been studied by a number of researchers (Helland-Hansen and Nansen, 1909; Ryzhov, 1985; Ryzhov *et al.*, 1987; Loeng, 1989, 1991; Węsławski, 1993; Węsławski *et al.*, 1993). Employing qualitative methods, these studies dealt with the impact of hydrography on the occurrence of phytoplankton, zooplankton and fish. Studies using modern statistical techniques are rare. Marine currents, hydrographic fronts, water stability and upwellings are well-known factors influencing phytoplankton abundance in the sea, and it is quite common for particular water masses to be characterised by specific indicator species or their associations (Węsławski and Kwaśniewski, 1983).

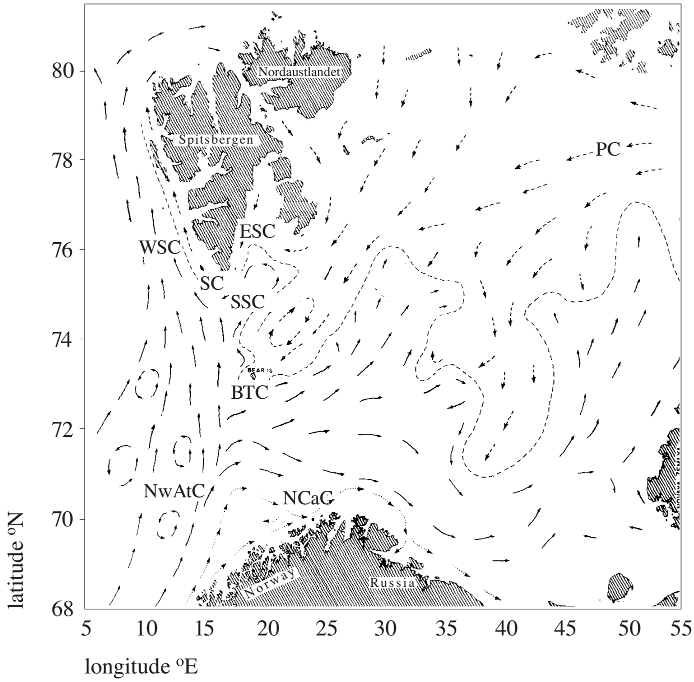

Fig. 1. Current distribution in the study area. NwAtC – North Atlantic Current, NCaC – North Cape Current, BTC – Bjornoya Trough Current, SSC – South Spitsbergen Current, WSC – West Spitsbergen Current, SC – Sörkapp Current, ESC – East Spitsbergen Current, PC – Persey Current (compiled after Hopkins, 1991; Sakshaug, 1992)

The Barents Sea shelf is an area with a high level of primary production (Sakshaug, 1992), one which is maintained by the continual supply of warm Atlantic waters mixed with cold, nutrient-rich waters from the Arctic (Fig. 1). Thorough vertical mixing in the autumn and winter makes for an even distribution of nutrients throughout the water column (Demel and Rutkowicz, 1958; Sakshaug, 1992). The single, intense phytoplankton bloom takes place typically in May–June, while post-bloom phytoplankton communities flourish in summer (July–August) (Ryzhov, 1985; Sakshaug, 1992). In some years a massive bloom of *Phaeocystis pouchetti* Lagerh. occurs when sea ice arrives with waters from the north (Rey and Loeng, 1985). In summer, mixed associations of spring and summer phytoplankton are noted in the SW Barents Sea, which usually contains waters originating from the Norwegian Sea (Owrid *et al.*, in preparation). Our study area straddled the borderline between the Norwegian and Barents Seas, where three different water masses (Tab. 1) give rise to a complex circulation system (Hopkins, 1991; Piechura, 1993).

Table 1. Water masses determined between Bjornoya and Spitsbergen (according to Hopkins, 1991)

Water mass	Symbol	Feature of water	Origin
Barents Sea Water	BrW	$-1>T>-3°C$ $S<34$	Persey Current, Bjornoya Current and Sörkapp Current waters
Barents Sea –Atlantic Water	BrAtW	$T = 2–5°C$ $S>34.7$	Bjornoya Current water mixed with Nordkapp Current water
Norwegian Sea –Atlantic Water	NwAtW	$T>2°C$ $S>35$	North Atlantic Current waters

The aim of the present study is to discover the correlation between phytoplankton occurrence and hydrological parameters. The hypothesis is that the variable surface water hydrography in the area exerts a decisive influence on the phytoplankton abundance and species composition.

2. Materials and methods

Data were collected at 19 sampling stations in July 1988 and 32 in June 1991 during cruises of r/v 'Oceania' conducted within the framework of the Greenland Sea Project (Druet, 1990). Salinity and temperature readings were obtained using CTD Guildline Instruments 8770. Nutrients were analysed according to the standard chemical methods recommended for seawater analysis. The phytoplankton was sampled with a bathometric rosette from depths of 1 m, the maximum fluorescence level (usually 5–10 m) and 50 m. 100 cm^2 samples were fixed in Lugol solution and analysed under an inverted microscope (Utermöhl method) six months later. The average number of cells per m^3 for each taxon was calculated by integrating subsample values for the whole water column and dividing them by the depth. The phytoplankton density at a station is given by the total number of cells under one square metre of a 50 m-deep water column. The similarity of stations is given as MDS (Multi Dimensional Scaling) and dendrograms calculated with the PRIMER v. 3.1 package. The Bray Curtis coefficient was used. Additionally, the correlation (Sperman) between phytoplankton occurrence and the main hydrological parameters was analysed statistically.

3. Results

Hydrology

The water temperature in the study area ranged from 2.49 to 8.34°C in 1988 and from 1.3 to 6.81°C in 1991 (Fig. 2).

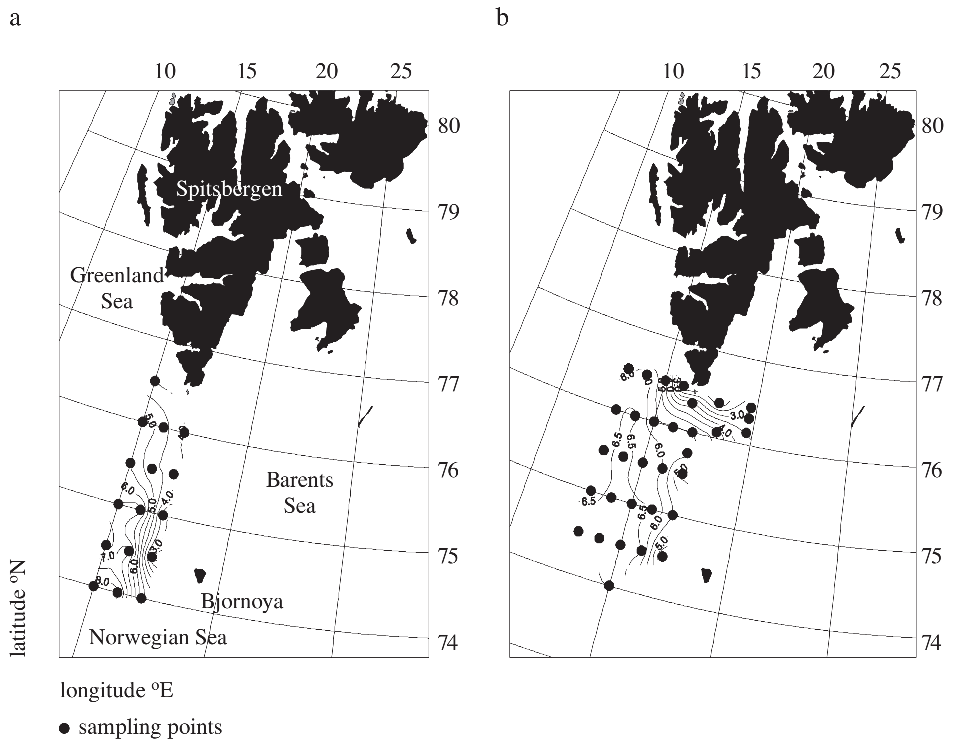

Fig. 2. Surface temperature distribution in 1988 (a) and 1991 (b)

The fronts in the isoline distribution in the two years are shaped differently. In 1988 the hydrographic front line ran longitudinally through the study area. The lack of Norwegian Sea (Atlantic) Water and the low salinity range (33.82 (76°N 17°E) – 34.93 (75°N 16°E)) indicate that water of Arctic origin, *i.e.* Barents Sea Water and Barents–Atlantic Water, had reached a long way south (Fig. 3).

In 1991, however, the front divided the NE part of the study area above 76°N. Here, Sörkapp Current waters mix with water masses transported by the East Spitsbergen Current (Adrov, 1959; Tantsiura, 1959; Sakshaug, 1992). The central part of the area was occupied by North Atlantic waters. Salinities below 35 PSU in the SW part indicate the influence of the Bjornoya Current. The high salinity (35.1 PSU) in the NW part of the area was probably due to the West Spitsbergen Current.

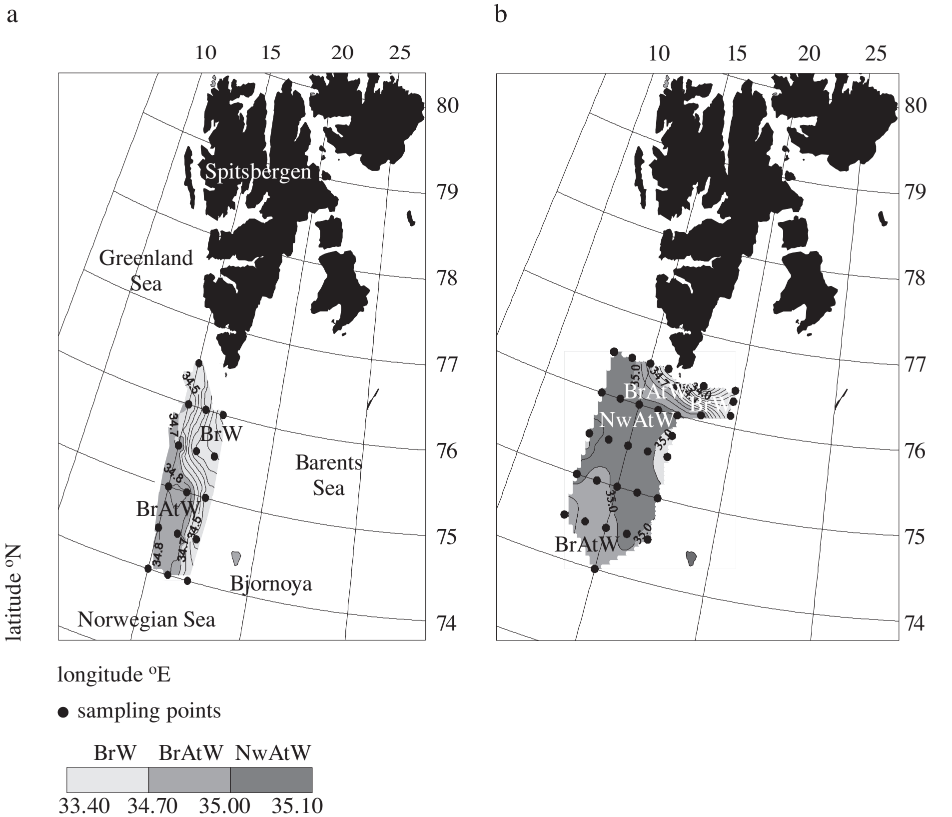

Fig. 3. Salinity distribution in the study area in 1988 (a) and 1991 (b)

Phytoplankton

In 1988, 65 phytoplankton taxa from eight taxonomic groups were found at five stations (Tab. 2). The family Bacillariophycae was most abundant in species and was represented by 32 taxa (almost 50% of all the phytoplankton cells). Barents–Atlantic and Barents Sea Waters contained the largest numbers of phytoplankton cells, and densities there were as high as 4×10^{10} cells m^{-2}. The numbers of cells decreased fivefold towards the NE. The low nutrient concentration and the species composition in 1988 suggest the final stage of the spring bloom or an early post-bloom situation: diatoms were being replaced by dinoflagellates. In 1991 63 taxa were found (Tab. 2), and again, the most abundant species were diatoms (23 taxa). As in 1988, Barents–Atlantic Waters were richest in phytoplankton, particularly at the front with Norwegian Sea–Atlantic Waters. At the station (74°30′N 15°E) west of Bjornoya, in waters supplied by the Bjornoya Current, the number of phytoplankton cells was in excess of 1.8×10^{10} cells m^{-2}.

Table 2. List of taxa identified during r/v 'Oceania' cruises in 1988 and 1991

Taxon	1988 Freq. [%]	1991 Freq. [%]
Dinophyceae		
Gymnodinium wulffii Schill.	40	6.25
Amphidinium sp. Clap. et Lachm.		6.25
Ceratium arcticum (Ehr.) Cl.		6.25
Dinophysis norvegica Clap. et Lachm.		6.25
Dinophyta l = 17 μm		12.5
Dinophyta diam = 20 μm		6.25
Dinophyta diam = 23 μm		6.25
Dinophyta l = 43 μm		6.25
Dinophyta diam = 15 μm		6.25
Dinophyta l = 12 μm		25
Peridinium pallidum Ostf.		6.25
Dinophyta		6.25
Gymnodinium sp. Stein diam = 18 μm		18.75
Gyrodinium sp. Kofoid et Swezy l = 12 μm		6.25
Gyrodinium sp. Kofoid et Swezy l = 100 μm		6.25
Diplopsalis lenticula Bergh	20	
Gymnodinium sp. Stein small	20	
Gymnodinium sp. Stein	80	
Gymnodinium cf. *lachrima*	20	
Gyrodinium cf. *aureolum*	20	
Gyrodinium fissum Kofoid et Swezy	80	
Gyrodinium cf. *glaucum*	20	
Gyrodinium lachryma Kofoid et Swezy	40	
Gymnodinium lochmanii Lemm.	40	
Minuscula bipes Lebour	60	
Gyrodinium sp. Kofoid et Swezy	20	
Protoperidinium pellucidum Bergh	20	
Peridinium sp. Echr.	40	
Gymnodinium simplex Kofoid et Swezy	20	
Scripsiella trochoidea Loeb.	40	
Bacillariophyceae		
Chaetoceros sp. Echr.	20	6.25
Ch. borealis Bail.	20	56.25
Ch. concavicornis Mangin	60	18.75
Ch. convolutus Castr.	20	25
Centriceae non det.		6.25
Centriceae l = 75 μm		6.25
Leptocylindrus danicus Cleve		6.25
Centriceae diam = 4 μm		12.5

Table 2. (continued)

Taxon	1988 Freq. [%]	1991 Freq. [%]
Centriceae diam = 48 μm		12.5
Centriceae diam = 15 μm		18.75
Centriceae diam = 35 μm		18.75
Centriceae diam = 10 μm		25
Centriceae		25
Centriceae diam = 13 μm		43.75
Centriceae diam = 8 μm		56.25
Achnanthes taeniata Cleve et Grunow	20	
Ch. atlanticus Cl.	40	
Ch. braevis Shütt	20	
Ch. constrictus Gran	20	
Ch. decipiens Cl.	40	
Ch. densus Cl.	20	
Ch. septentrionalis Östr.	20	
Ch. sp. small	20	
Ch. holsaticus Shütt	40	
Ch. debilis Cl.		50
Ch. cf. *fragilis*		6.25
Ch. teres Cl.		31.25
Corethron cryophyllum Castr.	60	56.25
Gonioceros septentrionalis Östr.		6.25
Cylindrotheca closterium Reiman et Levin		12.5
Eucampia groenlandica Cleve		12.5
Fragillariopsis oceanicus Hasle	20	18.75
Lauderia borealis Gran	20	
Lycmophora sp. Ag.	20	
Melosira arctica Dickie in Pritchard	20	
Navicula sp. Bory	40	
Nitzschia delicatissima Cleve	80	
Nitzschia longissima (Bréb) Ralfs	80	
N. seriata Cl.		6.25
Nitzschia sp. Hass	40	43.75
Pennatae >50 μm	20	75
Pennatae <50 μm	80	6.25
Rhizosolenia sp. Echr.	20	
R. setigaera Bright.	80	
R. styliformis Bright.	60	
Stauroneis sp. Echr.	40	
Skeletonemma costatum (Grev.) Cl.		12.5
Thalassiosira antarctica Comber	20	
Th. gravida Cl.	20	

Table 2. (continued)

Taxon	1988 Freq. [%]	1991 Freq. [%]
Th. levanderii Van Goor	20	6.25
Th. nordenskioeldii Cleve		6.25
Thalassiosira sp. Cl.	60	68.75
Chlorophyceae		
Pyramimonas sp. Schmarda	20	6.25
Oocystis submarina Lagerh.	20	
Scenedesmus quadricauda (Turp.) Bréb.	40	12.5
Cryptophyceae		
Cryptomonas cf. *pelagica*	20	6.25
Cryptomonas sp. Echr. <10 μm	20	12.5
Cryptomonas sp. Echr.		12.5
Cryptophyceae 10–25 μm		93.75
Chrysophyceae		
Chrysophyceae cysts		6.25
Emiliana huxlei Hay		6.25
Prymnesiophyceae		
Phaeocystis pouchetii Lagerh.	20	12.5
Flagellates		
Flagellatae non det. >7 μm	20	18.75
Flagellatae non det. 3 μm	20	12.5
Flagellatae non det. 3–7 μm	20	25
Cyanophyceae		
Aphanothece sp. Näg.	20	
Nodularia sp. Met. ex Born	20	
Cyanophyceae non det.		12.5
Unknown cysts	20	

Similar numbers of cells were found at the front between the cold, freshened waters of the Sörkapp Current and the warm, saline waters of the West Spitsbergen Current (76°04′N 18°11′E). Low numbers of phytoplankton were found in the N and NE parts occupied by Barents Sea Water (Fig. 4). The number of cells was 100 times less when compared with Barents Sea–Atlantic Water. Phytoplankton was less abundant along the eastern edge of the study area. The lower cell number and the higher nutrient concentrations indicate a post-bloom situation.

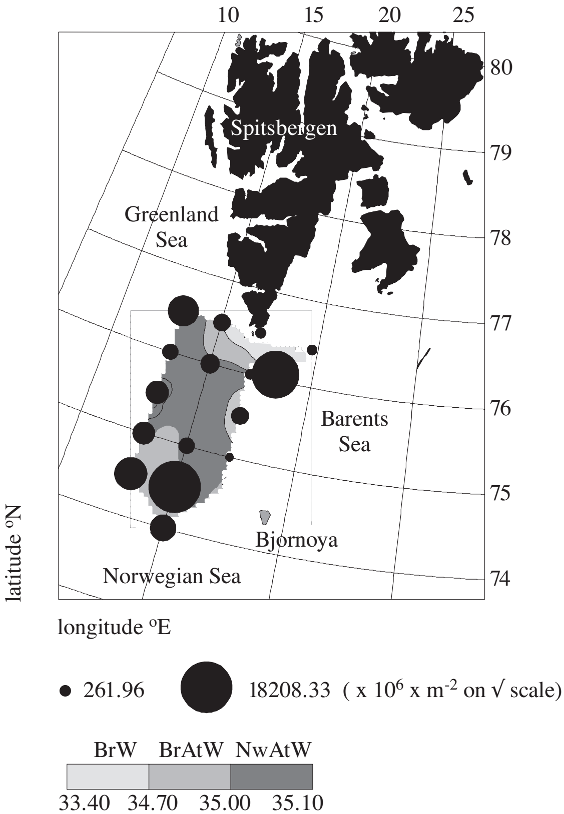

Fig. 4. Cell distribution in 1991 ($\times 10^6$ m^{-2} on $\sqrt{\ }$ scale) under square meter in 50th water column

The water masses were characterised on the basis of hydrological and phytoplankton features as follows:

Norwegian Sea–Atlantic Water

This water mass was largely dominated by Cryptophyta and diatoms (*Thalassiosira* sp. Cl., *Chaetoceros borealis* Bail., *Ch. teres* Cl., Pennatae, Centriceae 8 and 4 μm in diameter). Cell numbers in the euphotic zone (0–50 m): $304 \times 10^6 - 4839 \times 10^6$.

Barents Sea–Atlantic Water

Cell numbers ranged from 1068×10^6 to 18208×10^6 m^{-2} (0–50 m). This water mass was uncertain. In the S and SW parts of the study area it was probably influenced by the Bjornoya Current. Cell abundance and the number of species reached a maximum there; *Chaetoceros debilis*, *Ch. decipiens* Cl., *Thalassiosira* sp. Cl., Pennatae, *Cryptomonas* sp. (17 μm) and Centriceae (4 and 8 μm diameter) were the dominant

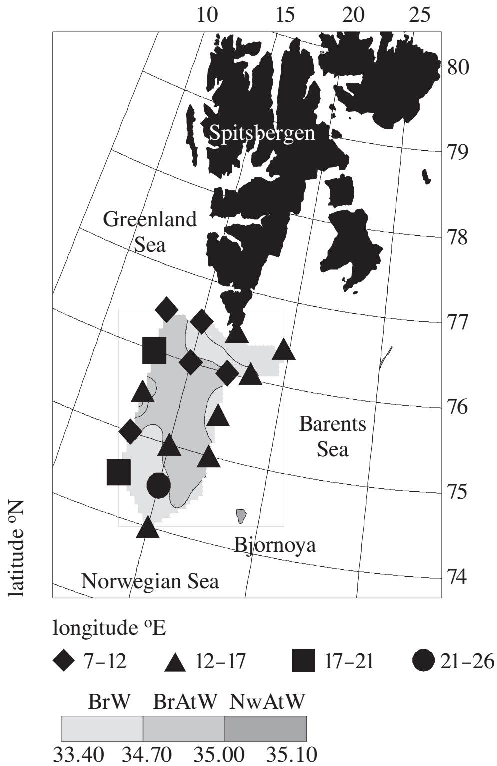

Fig. 5. Number of phytoplankton taxa at sampling points in summer 1991

taxa (Fig. 5). In the presence of Sörkapp Current waters, *Phaeocystis pouchetti*, unidentified Centriceae, autotrophic flagellates, Cryptophyta, *Chaetoceros debilis*, Chrysophyta (cysts) were predominant. Autotrophic flagellates were prevalent at stations with a low concentration of silicates and a high concentration of nitrates, which suggests a post-bloom event. A similar situation was recorded in 1981 by Rey and Loeng (1985). In Barents–Atlantic Water the number of phytoplankton taxa was low (6–13).

Barents Sea Water

Waters carried by the Sörkapp Current were found in the N and NW of the area. The species diversity was low here, and consisted mainly of Centriceae and Centriceae diam 8 μm, Cryptophyta, *Cheatoceros decipiens*; only 13–14 taxa were identified. The number of cells did not exceed 300×10^6 in the euphotic zone.

Statistical analysis

Correlation and MDS analyses suggest that the hydrological parameters have no direct influence on the abundance of phytoplankton (Tab. 3).

Table 3. Correlation coefficients between number of phytoplankton cells and given hydrological and hydrochemical parameters in 1991

Parameters	Spearman's correlation coefficient
salinity–phytoplankton	0.188
temperature–phytoplankton	0.512
density–phytoplankton	–0.009
PO_4–phytoplankton	–0.126
NO_3–phytoplankton	–0.071
NO_2–phytoplankton	0.018
SiO_3–phytoplankton	0.393

Any correlations are due to the origin of the water masses. Owing to the small number of stations in 1988, the multivariate analyses were performed only with the 1991 results. The three main groups are shown in Fig. 6.

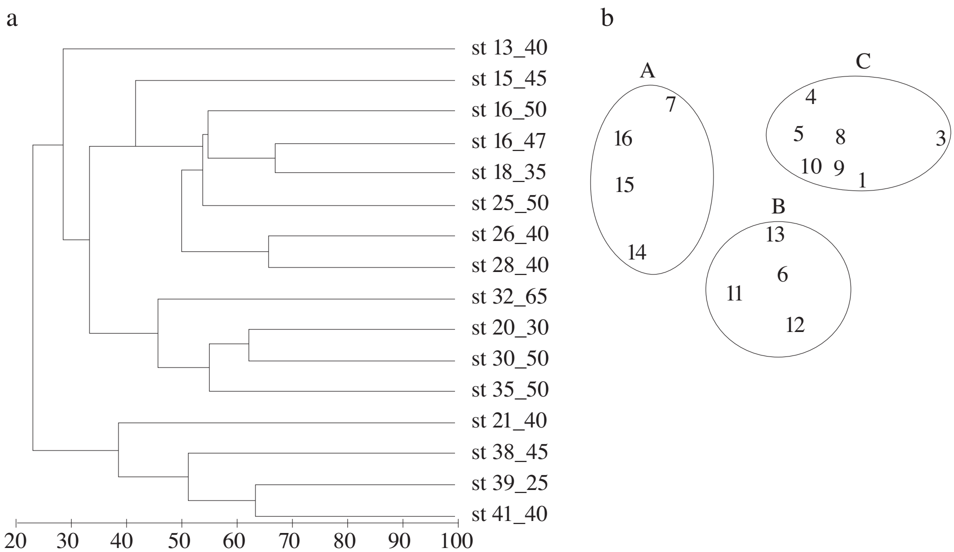

Fig. 6. Similarities between stations according to Cluster analysis (a) and MDS (b)

The first group of stations (A) are those along 76°30′N, where the Sörkapp Current arrives from the NE and reaches the West Spitsbergen Current. These stations represent different water masses with a poor species composition. Stations 14 and 15 were located right on the borderline between the two different water masses.

The stations in group (B), in the E and NE of the study area, along 17°E represent three different water masses: cold and freshened outflows from the East Spitsbergen and Bjornoya Currents, as well as the warm and more saline waters of the West Spitsbergen Current. The considerable dynamism of the area is not reflected in the phytoplankton species diversity: only 10–13 taxa were recorded here.

The last group (C) consists of stations in the W and SW parts of the area, which are influenced by the warm, saline waters of the North Atlantic Current superimposed by Norwegian Sea Waters.

Stations 3 (74°30′N 15°E) and 2 were exceptional: it was here that the highest phytoplankton species diversity with a high cell density was recorded.

4. Discussion

The three water masses described in this study (Norwegian Sea–Atlantic, Barents Sea–Atlantic, and Barents Sea Water) have been described in a number of other works (Adrov, 1959; Tantsiura, 1959; Petrov, 1985; Loeng, 1991). Although our classification of the phytoplankton species found in these waters is much the same as that in the literature (Matishov, 1985), species noted at particular stations were usually reported from a number of other localities elsewhere in the Barents Sea (Chlebovitsch, 1974; Matishov, 1985; Ryzhov, 1987; Węsławski and Kwaśniewski, 1993). This suggests that the observed links between the water masses and their phytoplankton are the result of seasonality differences in the places where these water masses originate. Flowing down from the north, the East Spitsbergen Current with large diatoms growing on 'new nutrients' displays a near-bloom situation, while Atlantic waters from the South that the phytoplankton is dominated by small species growing on regenerated nutrients. A similar pattern was found during the Pro Mare study in the Barents Sea (Sakshaug, 1992). The phytoplankton in our study area was 'imported' from distant regions, hence its occurrence in waters whose hydrological parameters differ from those in their areas of origin. The highly variable climate and hydrography of the Barents Sea (Sakshaug, 1992) may be responsible for the considerable interannual differences in the physical conditions for phytoplankton growth. The composition and abundance of phytoplankton in our study area were predetermined many months earlier in distant areas to the south and north of the actual study site. That is why the summer values of the hydrographic parameters display little correlation with the phytoplankton in this area of mixing water masses.

References

Adrov M. M., 1959, *New data on hydrology of the western part of Barents Sea*, Trudy PINRO, 11, 5–9, (in Russian).

Chlebovitsch T. V., 1974, *Quantitative and seasonal changes in the phytoplankton of Guba Czupa, White Sea*, Inv. of the Seas of USSR, 13 (21), 56–64, (in Russian).

Demel K., Rutkowicz S., 1958, *The Barents Sea*, Wyd. Mor., Gdynia, 310 pp.

Druet C., 1990, *The results of Polish oceanographic investigations focused on variability of the Greenland Sea energoactive zones*, General Rap. ICES, C. M 1990/C:13, Inst. Oceanol. PAS, Sopot, manuscript.

Helland-Hansen B., Nansen F., 1909, *The Norwegian Sea*, Fisk Dir. Skr. Ser. Hav. Unders., 2 (2), 1–360.

Hopkins T. S., 1991, *The GIN Sea – a synthesis of its physical oceanography and literature review 1972–1985*, Earth-Sci. Rev., 30, 175–358.

Loeng H., 1989, *Ecological features of the Barents Sea*, Proc. 6th Conf. of the Com. Arctique Int. 13–15 May, 1985, E. J. Brill (ed.), Leiden–New York–København, Köln, 327–365.

Loeng H., 1991, *Features of the physical oceanographic conditions of the Barents Sea*, Polar Res., 10 (1), 5–18.

Matishov G. G. (ed.), 1985, *Life and its environment in the pelagic realm of Barents Sea*, Murmansk. Mor. Biol. Inst. AN SSSR, Apatity, 230 pp., (in Russian).

Owrid G., Nothig E. M., Socal G., Luchetta A., Wiktor J., Andreassen I., Civitarese G., Shauer U., Sorensson F., Strass V., *Spatial variability of phytoplankton and new production in the waters around Svalbard in relation to hydrological and nutrient condition*, (in preparation).

Petrov V. S., 1985, *Physico-geographical characteristics of the Barents Sea*, [in:] *Life and its environment in the pelagic realm of Barents Sea*, G. G. Matishov (ed.), Murmansk. Mor. Biol. Inst. AN SSSR, Apatity, 11–14, (in Russian).

Piechura J., 1993, *Hydrological aspects of the Norwegian-Barents confluence zone*, Stud. i Mater. Oceanol., 65, 197–222.

PRIMER (Plymouth Routines in Multivariate Ecological Research), 1993, Package, Plymouth Mar. Lab., Plymouth, version 3.1.

Rey F., Loeng H., 1985, *The influence of ice and hydrographic conditions on the development of phytoplankton in the Barents Sea*, [in:] *Marine biology of polar regions and effects of stress on marine organisms*, J. S. Gray and M. E. Christiansen (eds.), John Wiley and Sons, Oslo, 49–64.

Ryzhov V. M., 1985, *Phytoplankton*, [in:] *Life and its environment in the pelagic realm of Barents Sea*, G. G. Matishov (ed.), Murmansk. Mor. Biol. Inst. AN SSSR, Apatity, 100–105, (in Russian).

Ryzhov V. M., 1987, *Phytoplankton in the Spitsbergen Bear Island area in relation to oceanographic characteristics of water masses of different origin*, ICES Symp., 105, 1–18.

Ryzhov V. M, Boytsov V. D., Shavykin A. A., 1987, *On chlorophyll concentration in the area of Barents Sea polar front in relation to oceanographic conditions*, ICES Symp., 72, 1–14.

Sakshaug E. (ed.), 1992 *Ecosystem of the Barents Sea*, Pro Mare, Heimdal AS, Trondheim, 304 pp., (in Norwegian).

Tantsiura A. I., 1959, *Currents of Barents Sea*, Trudy PINRO, 11, 35–53, (in Russian).

Węsławski J. M., 1993, *Sensitivity of Svalbard ecosystem to global climate change*, Rozpr. i monogr., Inst. Oceanol. PAN, Sopot, 3, 114 pp., (in Polish).

Węsławski J. M., Kwaśniewski S., 1983 *An attempt to use biological indicators to determine the reach and origin of South Spitsbergen Sea Currents*, Pol. Arch. Hydrobiol., 30, 189–197.

Węsławski J. M., Kwaśniewski S., Wiktor J., 1993, *Species, communities and concentration of plankton*, Stud. i Mater. Oceanol., 65, 181–196.