

## RESEARCH/REVIEW ARTICLE

# Microzooplankton along a transect from northern continental Norway to Svalbard

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**Keywords**

Microzooplankton; North Atlantic Current; Svalbard; tintinnids; dinoflagellates.

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E-mail: mmonti@inogs.it**Abstract**

In the framework of the Italian International Polar Year project entitled Evolution of a Glacial Arctic Continental Margin: the Southern Svalbard Ice Stream-dominated Sedimentary System, a study was carried out on microzooplankton distribution and biomass along a south-to-north transect extending from northern Norway to the Svalbard Archipelago, from 65° to 78°N. Tintinnids, heterotrophic dinoflagellates, aloricate ciliates and micrometazoans were the main groups observed in the samples collected at 17 surface stations from 9 to 13 July 2008. Total microzooplankton abundance ranged from 17 to 438 ind l<sup>-1</sup>. Tintinnids and heterotrophic dinoflagellates were the most abundant organisms, ranging from 1.5 to 292.5 ind l<sup>-1</sup> and from 0 to 232 ind l<sup>-1</sup>, respectively. Micrometazoans (mainly copepod nauplii) reached a maximum of 45.5 ind l<sup>-1</sup>, whereas aloricate ciliates were scarce at all stations. Microzooplankton carbon content ranged from 0.87 to 5.18 µg C l<sup>-1</sup>. In particular, tintinnids and micrometazoans made up the largest part of the microzooplankton biomass. *Parafavella denticulata*, *Parafavella gigantea*, *Acanthostomella norvegica* and *Ptychocylis obtusa* were the most common species among tintinnids, whereas *Leprotintinnus pellucidus* was recorded in only one station close to Svalbard. *Protoperidinium* was the most representative genus among heterotrophic dinoflagellates. The community of naked ciliates was dominated by *Strombidiidae* and *Holotrichia*. A clearly increasing gradient in both abundance and number of taxa was observed from south to north, with the temperature decreasing from 13.3 to 2.5°C.

During the last decades, it has been evident that microzooplankton (broadly heterotrophic planktonic organisms spanning 10–20 to 200 µm) play a significant role in the marine pelagic food web, relating primary producers to the higher trophic levels and transferring biomass and energy from the microbial to the grazing food web (Calbet & Landry 2004; Calbet 2008). Protozooplankton are potential grazers of bacteria, nanoflagellates, phytoplankton and other protozoa, and heterotrophic dinoflagellates are able to prey on organisms of the same dimensions or even larger (Hansen 1991; Jeong 1994; Jeong et al. 2004; Menden-Deuer et al. 2005). Heterotrophic dinoflagellates and ciliates are an important component of microzooplankton and they have been shown to have a control on the phytoplankton abundance at a station along the

Svalbard coast (Seuthe et al. 2011). During the summer period, tintinnids can consume up to 5% of the total primary production in the Barents Sea (Boltovskoy et al. 1991), and in the Greenland Sea microzooplankton plays an important role in recycling nitrogen (Smith et al. 1985).

Despite the importance of microzooplankton in the pelagic food web, little information is available about its community composition in the Barents and Greenland seas (Boltovskoy et al. 1991, 1995; Jensen & Hansen 2000; Seuthe et al. 2011). Hydrographic features of the area are dominated by southbound polar waters of the East Greenland Current, which have low temperatures and salinities, and by the warmer and more saline Norwegian Atlantic Current moving in the opposite

direction along the coast of Norway (Gyory et al. 2009). The northernmost extension of the Norwegian Atlantic Current is the West Spitsbergen Current that flows polewards along the west coast of Svalbard, splitting into two branches at 79°N. The Svalbard branch stays close to the continental shelf of Spitsbergen, travelling to the north and returning to the Atlantic with the East Greenland Current, whereas the Yermak branch flows more directly westward (Aagaard et al. 1987; Bourke et al. 1988).

The aim of this study is to describe the diversity and abundance of the microzooplankton community along a south-to-north transect affected by the North Atlantic Current.

### Materials and methods

Materials for this study were collected on 9–13 July 2008 during a cruise in the framework of the project Evolution of a Glacial Arctic Continental Margin: the Southern Svalbard Ice Stream-dominated Sedimentary System. An SBE 21 thermosalinograph (TSG; Sea-bird Electronics, Bellevue, WA, USA) was used to record surface-water temperature and conductivity. Salinity was calculated from the values measured by the SBE 21 sensor. By means of the pump connected to the TSG surface sea-water samples were collected every degree or half a degree along the south-to-north transect from 65 to 78°N (Fig. 1).

Water samples (5 l) were concentrated with a 10- $\mu$ m mesh, reduced to 250 ml and immediately fixed with buffered formaldehyde (4% final concentration). We are aware that naked ciliates have been underestimated because of the fixative chosen (Karayanni et al. 2004); otherwise, the amount of water sampled allowed us to feel confident that even rare organisms could have been detected in our samples.

Subsamples (100 cc) were examined in a settling chamber using a Leitz (now Leica Microsystems, Wetzlar, Germany) Labovert inverted microscope, equipped with phase contrast and bright-field illumination (magnitude:  $\times 200$ ), according to the Utermöhl method (1958). The entire surface of the chamber was examined.

Among the microzooplankton community, four main groups were considered: ciliates (naked and tintinnids), heterotrophic dinoflagellates, other protozoa and micro-metazoans.

Empty loricae of tintinnids were not differentiated from the filled ones because tintinnid protoplasts are attached to the lorica by a fragile strand, which detaches with ease during collection and fixation of the samples. The phototrophic ciliate *Mesodinium rubrum* is an obligate

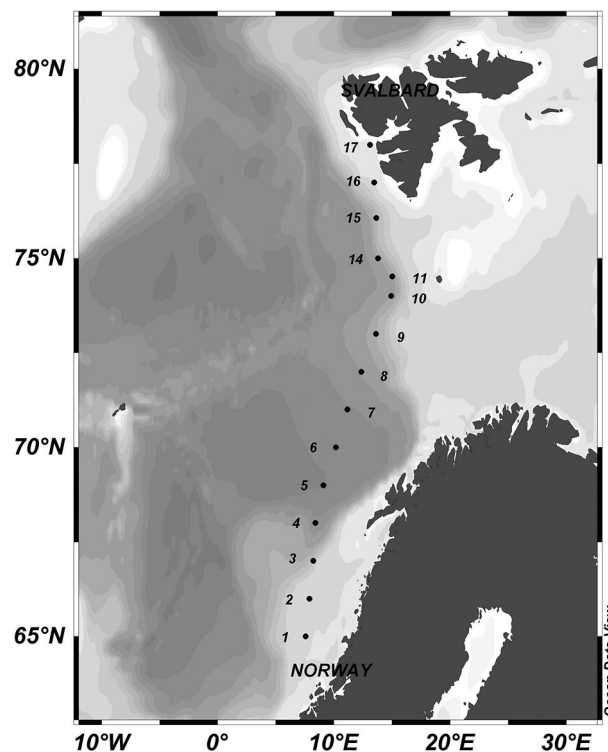


Fig. 1 Sampling stations along the south-to-north transect from continental Norway to Svalbard.

autotroph (Lindholm 1985), but it was considered to be in the list as it was only a minor part of the ciliates biomass. Dinoflagellates were considered heterotrophic based on the previous studies (Lessard 1991). Only species that belong to *Gyrodinium* genus could not be identified to species level and the contribution of autotrophy or mixotrophy could not be evaluated by this method but their contribution to total biomass was less than 1%.

For each taxon, biomasses were estimated by measuring the linear dimension of each organism with an eyepiece scale and equating shapes to standard geometric figures. Cell volumes were converted into carbon values using appropriate formulae or conversion factors, as follows—tintinnids:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.053 + 444.5$  (Verity & Langdon 1984); naked ciliates:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.14$  (Putt & Stoecker 1989); athecate dinoflagellates:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.11$  (Edler 1979); thecate dinoflagellates:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.13$  (Edler 1979); others:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.08$  (Beers & Stewart 1970); foraminifera:  $\text{pg C cell}^{-1} = \mu\text{m}^3 \times 0.089$  (Gifford & Caron 2000).

To test whether microzooplankton changed among stations, the cluster analyses and similarity percentage analyses (SIMPER) were performed using PRIMER software version 5. For the cluster analysis, square root

transformation of the data matrix and Bray–Curtis similarity with a complete linkage were applied (Clarke & Warwick 2001). To detect which microzooplanktonic groups were mainly responsible for the discrimination of subclusters, a SIMPER analysis was carried out. A percentage dissimilarity cut-off of 90% was applied.

To elucidate the relationship between biotic (total microzooplankton, naked ciliates, tintinnids, heterotrophic dinoflagellates, Foraminifera and micrometazoans) and abiotic variables (salinity and temperature), Spearman correlation analysis ( $R$ ) was performed using STATISTICA ( $P < 0.05^*$ ;  $P < 0.01^{**}$ ;  $P < 0.001^{***}$ ).

## Results

Temperatures ranged from 2.7°C (station 16) to 13.3°C (station 1) and salinity between 33.3 (station 16) and 35.2 (station 6). Temperature showed a clear south-to-north gradient; with the exception of station 16, with similar salinity values (Fig. 2).

The microzooplankton community was composed of heterotrophic dinoflagellates, foraminifers, ciliates (naked ciliates and tintinnids) and micrometazoans. In total, 27 taxa were counted (Table 1).

Total microzooplankton abundance ranged from 17 to 438 ind  $l^{-1}$ . Tintinnids and heterotrophic dinoflagellates were the most abundant organisms, ranging from 1.5 to 292.5 ind  $l^{-1}$  and from 0 to 232 ind  $l^{-1}$ , respectively (Fig. 3). An increasing gradient in both abundance (Fig. 3) and number of microzooplankton taxa (Fig. 4) was

observed from south to north, with temperature decreasing from 13 to 2°C.

Micrometazoans, mainly copepod nauplii and gastro-poda larvae, reached the maximum of 45.5 ind  $l^{-1}$  at station 7. Larval stages of the pteropod *Limacina helicina* were detected with a maximum of 5.5 ind  $l^{-1}$  (Table 1). Aloricate ciliates' abundance was always less than 50 ind  $l^{-1}$ ; no clear pattern with respect to the transect was discerned. Other protozoa, in this study constituted only by Foraminifera, were very scarce at all stations, with a maximum value of 1.4 ind  $l^{-1}$  (Table 1).

*Acanthostomella norvegica* (Daday), *Parafavella denticulata* (Ehrenberg), *Parafavella gigantea* (Brandt) and *Ptychocyclus obtusa* Brandt were the most common species among tintinnids (Fig. 5). *P. denticulata* and *A. norvegica* were the most abundant species, reaching their maxima at station 11 (227.5 ind  $l^{-1}$ ) and station 15 (146 ind  $l^{-1}$ ), respectively (Table 1). *A. norvegica* and *P. gigantea* were present all along the transect, whereas *P. denticulata*, *P. obtusa* and *Coxiella cf. pseudoannulata* were detected in the northern part of the transect. *Leprotintinnus pellucidus* (Cleve) (Fig. 5) was recorded only at station 17, close to Svalbard. The community of naked ciliates was dominated by *Strombididae* and *Holotrichia*. *Mesodinium rubrum* was always very scarce with a maximum value of 0.7 ind  $l^{-1}$ . *Protoperdinium* was the most representative genus among heterotrophic dinoflagellates. *P. bipes* (Paulsen) Balech, with a maximum of 116 ind  $l^{-1}$  at station 15, and *Dinophysis rotundata* Claparède and Lachmann were detected in the northern part of the transect, *P. cf. curtipes* in the southern part (Fig. 5).

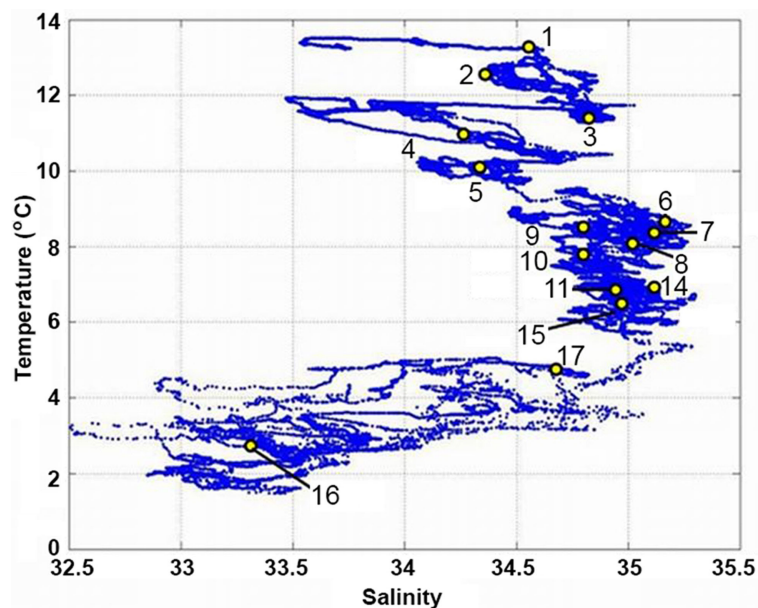


Fig. 2 Surface temperature and salinity data from the numbered stations along the transect.

**Table 1** List of the taxa with maximum abundance values.

	Max (ind l <sup>-1</sup> )
Dinophyceae	
<i>Dinophysis rotundata</i>	8.0
<i>Diplopsalis</i> group	20.0
<i>Gyrodinium</i> spp.	71.0
<i>Protoperidinium bipes</i>	116.0
<i>Protoperidinium</i> cf. <i>curtipes</i>	3.5
<i>Protoperidinium depressum</i>	14.0
<i>Protoperidinium</i> cf. <i>pallidum</i>	0.7
<i>Protoperidinium</i> spp.	142.0
Foraminifera	
Undet. Foraminifera	1.4
Ciliophora	
<i>Acanthostomella norvegica</i>	146.0
<i>Coxiella</i> cf. <i>pseudannulata</i>	11.0
<i>Leprotintinnus pellucidus</i>	11.0
<i>Parafavella denticulata</i>	227.5
<i>Parafavella gigantea</i>	14.5
<i>Ptychocyliis obtusa</i>	8.0
<i>Salpingella curta</i>	2.0
<i>Stenosemella nivalis</i>	0.5
<i>Tintinnopsis</i> spp.	2.0
Undet. Holotrichia	20.0
Undet. Oligotrichida	3.5
Undet. Strobilidiidae	3.5
Undet. Strombidiidae	49.0
Undet. Tintinnida	3.0
Undet. Ciliophora	6.0
<i>Mesodinium rubrum</i>	0.7
Metazoa	
Undet. eggs	14.5
Undet. larval forms	9.1
Mollusca	
Gastropoda	
<i>Limacina helicina</i>	5.5
Arthropoda	
Crustacea	
Copepoda	
Undet. nauplii	45.0

Cellular carbon content ranged from 0.87 to 5.18  $\mu\text{g C l}^{-1}$  (Fig. 6). Tintinnids and micrometazoa made up the largest part of the microzooplankton biomass with higher values at stations 10, 11 and 17 (Fig. 6). The high biomass of the tintinnids was due principally to genus *Parafavella*, consisting of large species such as *P. gigantea* and *P. denticulata*. Along the entire transect, micrometazoans showed quite constant carbon biomass values, due to copepoda nauplii and gastropoda larvae. The biomass of naked ciliates was dominated by *Strombidiidae* and *Holotrichia* that could not be identified to species mainly due to the fixative used. Dinoflagellates never formed the major part of carbon values, as they were mainly

constituted by small species from the genus *Protoperidinium*, such as *P. bipes*.

Cluster analysis divided the stations into two groups of stations with different microzooplanktonic communities (Fig. 7). The first group (south), which comprised stations 1–8, was characterized by low microzooplankton abundance. The second group (north) was characterized by stations with intermediate (stations 9 and 16) and high abundance (stations 10, 11, 14, 15 and 17). The SIMPER outputs showed an average dissimilarity between north and south groups of 76.51%. The main differences were due to tintinnids (45.20%) and dinoflagellates (22.68%), which were more abundant in the northern stations.

Highly significant negative correlations were observed between total microzooplankton ( $R = -0.88^{***}$ ), heterotrophic dinoflagellates ( $R = -0.87^{***}$ ), tintinnids ( $R = -0.86^{***}$ ) and temperature. No significant correlations were observed between microzooplankton abundances and salinity.

## Discussion

Temperature and salinity values measured during this study resembled what were found in the same area and season by other authors (Boltovskoy et al. 1991; Seuthe et al. 2011). Particularly, low temperature (2.7°C) and salinity (33.3) values recorded at station 16 could be related to the presence of colder fresh surface Arctic Water from the east (Cottier & Venables 2007). It was possible to identify three different types of density patterns. Stations 1–5, close to the Norwegian coast, presented temperatures between 10 and 13.3°C. For stations 6–17, between Norway and Svalbard, two subgroups were evident: stations 6–8 with temperature  $>8^{\circ}\text{C}$  and stations 10, 11, 14, 15 and 17 with temperature  $<8^{\circ}\text{C}$ . Stations 9 and 16, as suggested by cluster analysis, seemed to present particular characteristics. The former, with intermediate values of temperature and salinity, could be considered as the shifting from one situation (south) to another (north), while station 16 differed from all the rest for the minima of both temperature and salinity.

Tintinnids showed a south-to-north gradient, with highest abundance when the temperature was between 4 and 8°C (stations 10, 11, 14, 15 and 17).

The distribution of the most representative species showed a different pattern along the transect. *P. denticulata* appeared at station 7 and increased at stations 10–15. Even *P. obtusa* was present only in the northern stations with temperature  $<6^{\circ}\text{C}$ . Boltovskoy et al. (1991) found *P. obtusa* and *P. denticulata* 1.4–2 times more abundant in waters of Atlantic origin, in comparison to colder Arctic waters. Burkovskii (1976) reported that optimum

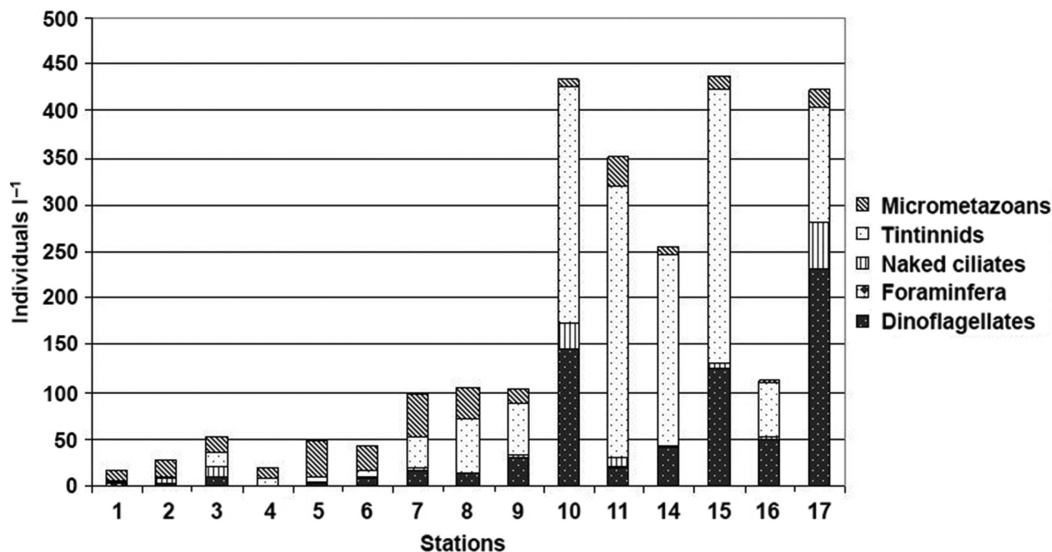


Fig. 3 Microzooplankton abundance data (ind l<sup>-1</sup>) along the transect.

temperature ranges for *P. denticulata* and *P. obtusa* were 8–16 and 6–11°C, respectively. In our samples, *P. denticulata* (Fig. 5) showed dimensions similar to the one found in Greenland samples by Boltovskoy et al. (1995). A comparison of the morphometric data for *P. denticulata* in the Greenland Sea vs. the Barents Sea showed a larger dimension of the oral diameter and bowl length in the Greenland Sea. The oral diameter of the specimens of *P. denticulata* in the Barents Sea was between 45 and 55 µm, while in the Greenland Sea it measured between 60 and 65 µm. Boltovskoy et al. (1995) argued that the difference between the mean size of *P. denticulata* in the two areas

was due to dissimilarities between the trophic status and thermic regimes of the two areas.

In this study, we found *P. gigantea* all along the transect, with a maximum of 14.5 ind l<sup>-1</sup>. In previous studies in nearby areas (Boltovskoy et al. 1991, 1995; Cordeiro & Sassi 1997; Cordeiro et al. 1997; Seuthe et al. 2011) *P. gigantea* was never recorded, not even at three stations close to the area considered in this study (stations 3, 11 and 12 in Boltovskoy et al. 1991). It was present in the central Barents Sea (Hansen & Jensen 2000) and off the west coast of Sweden (Hedin 1974, 1975). Hedin (1975) described *P. gigantea* as a summer species, most frequent

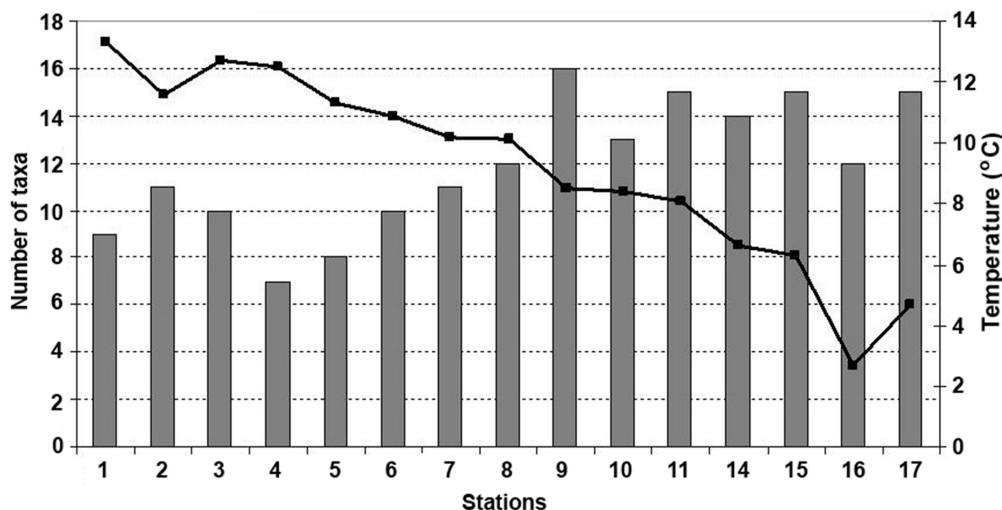
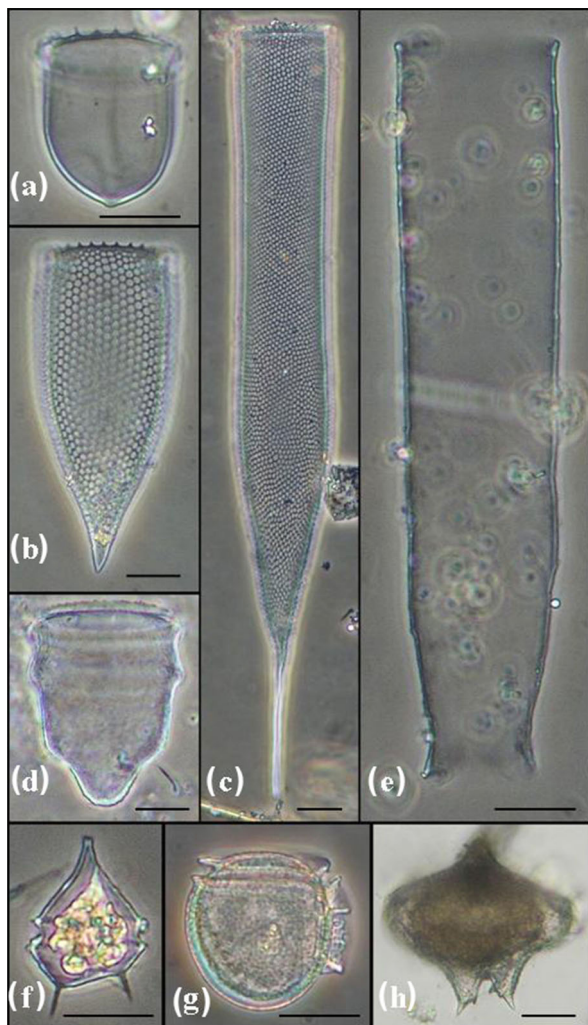


Fig. 4 Number of taxa observed along the transect and temperature values.



**Fig. 5** (a) *Acanthostomella norvegica*. (b) *Parafavella denticulata*. (c) *Parafavella gigantea*. (d) *Ptychocyclus obtusa*. (e) *Leprotintinnus pellucidus*. (f) *Protoperidinium bipes*. (g) *Dinophysis rotundata*. (h) *Protoperidinium cf. curtipes*. All scale bars are 20  $\mu\text{m}$  in length.

in surface waters with two peaks during the warmer months (April–June and October). Hedin (1974) reported dimensions varying from 211 to 265  $\mu\text{m}$ , while in Marshall (1969) length ranged from 200 to 750  $\mu\text{m}$ , which is closer to our findings (400–500  $\mu\text{m}$ ; Fig. 5c). This species is common in all northern seas, including the Arctic (Marshall 1969), and it is considered a boreal species by Pierce & Turner (1993). Recently, Hinder et al. (2012) observed a general increase of abundance of this species in the eastern North Atlantic, with more northern displacement towards Iceland and Greenland in less warm waters. These findings can explain the differences between our results and those of Boltovskoy et al. (1991), who did not report any *P. gigantea* in their samples.

We also found *A. norvegica* all along the transect, even if the abundance increased in the northern stations with a temperature below 8°C. Boltovskoy et al. (1991) found high values of this species at the stations dominated by Arctic waters, and Taniguchi (1983) reported peaks in colder waters along a transect across the Oyashio front. Other authors (Boltovskoy 1995; Cordeiro et al. 1997; Seuthe et al. 2011) reported high levels of abundance of this species in nearby areas and the absence in the samples counted by the continuous plankton recorder survey in the north-east Atlantic and North Sea was probably due to the counting method (Hinder et al. 2012). *A. norvegica* is considered cosmopolitan (Pierce & Turner 1993) and it was the only one present in both subpolar areas, as in the South Atlantic (Alder 1999), the Strait of Magellan (Fonda Umani et al. 2011), the Barents Sea and the Greenland Sea (Boltovskoy et al. 1991, 1995).

*L. pellucidus* was found only in the northernmost station sampled (station 17). Hedin (1975) considered this as a cold species most common in surface waters all through the year with the exception of summer and Boltovskoy et al. (1991) associated this species with waters of Atlantic origin.

The distribution patterns of tintinnids and dinoflagellates species found during the cruise showed a certain relationship with the circulation of waters within the Norwegian Atlantic Current and the West Spitsbergen Current.

It is not clear to us whether the biogeographic dissimilarities we report here are responses to differences in associated biological parameters or if they point to specific distributional preferences with respect to different water masses.

In previous studies in the Barents Sea (Boltovskoy et al. 1991), tintinnids ranged between <1 and 314 ind  $l^{-1}$ , with an average of 46 ind  $l^{-1}$  for the 0–50 m layer. In the Greenland Sea, tintinnid abundance was lower, not exceeding 135 ind  $l^{-1}$  (Boltovskoy et al. 1995).

*A. norvegica*, *P. denticulata* and *P. obtusa* accounted for almost 90% of the individuals in the Barents and Greenland seas (Boltovskoy et al. 1991, 1995). The Greenland Sea tintinnid assemblages were generally less diverse and had a lower equitability than those from the Barents Sea. Boltovskoy et al. suggested a direct relationship between lower temperature in the Greenland Sea (around 0–1°C) and lower diversity/higher dominance. In the study reported here, temperatures from 4 to 8°C were associated with higher abundance and diversity; at station 16, where the temperature fell to 2.5°C, abundance reduced.

Boltovskoy and coworkers found lower values for dinoflagellates in comparison to what we found in this

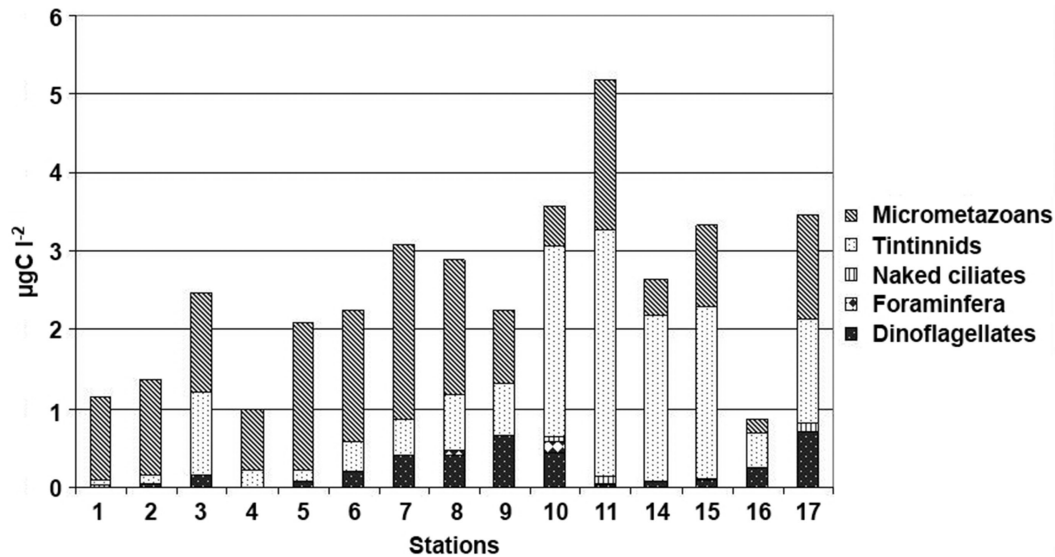


Fig. 6 Microzooplankton carbon content ( $\mu\text{g C l}^{-1}$ ) along the transect.

study, but they considered only large and thecate forms (Boltovskoy et al. 1991, 1995). In general, maximum concentrations for microzooplankton that occurred in the area were detected at or above 25 m (Boltovskoy et al. 1991, 1995). Recently, Seuthe et al. (2011) found dinoflagellate rather than aloricate ciliates dominating at one station located in a fjord on the west coast of Svalbard. In our study, aloricate ciliates never reached high abundance values and micrometazoans were higher than previously reported (Melle & Skjoldal 1989; Boltovskoy et al. 1991).

In terms of biomass, Boltovskoy et al. (1991) found for tintinnids a carbon average for the 0–50 m layer of  $0.33 \mu\text{g C l}^{-1}$ , with a maximum of  $2.1 \mu\text{g C l}^{-1}$ . In the central

Barents Sea, Jensen & Hansen (2000) analysed ciliates and heterotrophic dinoflagellates in the Marginal Ice Zone and they described a maximum biomass of tintinnids of  $1 \mu\text{g C l}^{-1}$ . The higher biomass in our results is principally due to the presence of *P. gigantea* and its larger dimensions, as the contribution to the total carbon amount of other frequent species, such as *A. norvegica* and *P. obtusa*, was never significant because of their small dimensions.

In conclusion, the microzooplankton community in the area affected by the North Atlantic Current seemed to be constituted principally by tintinnids and heterotrophic dinoflagellates. The abundance and the number of taxa changed along the south-to-north transect, with higher values at lower temperatures.

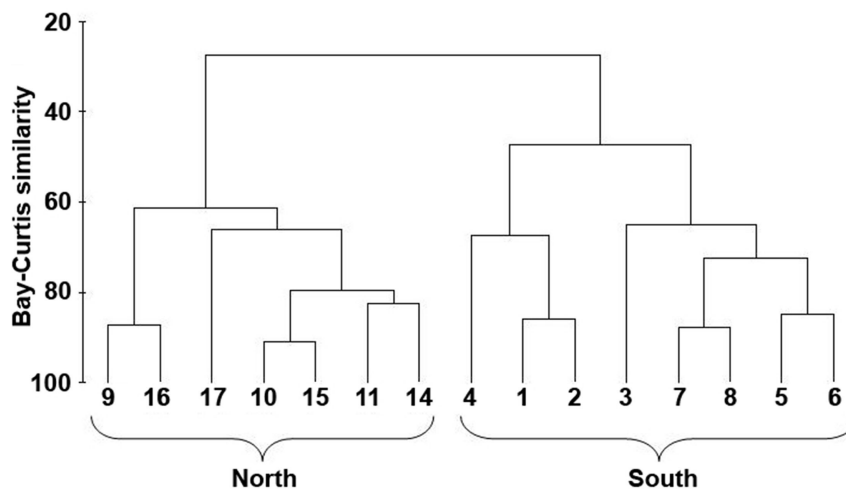


Fig. 7 Cluster analysis on the basis of samplings. The complete linkage was applied.

The forecasted warming of the Arctic could affect the geographical displacement of tintinnids cold species, which were significantly more abundant in the northernmost part of our transect, pushing them even further north and causing a reduction of both abundance and diversity in the southern part of the study area.

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