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ORIGINAL RESEARCH ARTICLE

Impact of shelf-transformed waters (STW) on foraminiferal assemblages in the outwash and glacial fjords of Adventfjorden and Hornsund, Svalbard

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Summary A new dataset of benthic foraminiferal assemblages from Adventfjorden (tributary fjord of Isfjorden, West Spitsbergen) was compared with the results of a study conducted by Zajączkowski et al. (2010) in Hornsund (West Spitsbergen). According to Nilsen et al. (2016), Atlantic water inflow to the Isfjorden Trough occurs more readily than to anywhere else along the shelf of Spitsbergen; thus, we compared the foraminiferal assemblages of the outwash Adventfjorden fjord, located in the Isfjorden system, with glacial Hornsund, located in southwest Spitsbergen. Despite the juxtaposition of Adventfjorden and Hornsund the data revealed varying impacts of shelf-transformed water (STW) on the benthic foraminiferal assemblages. Outer and central Adventfjorden was dominated by *Adercotryma glomerata*, *Recurvoides turbinata* and *Spiroplectammina* sp., reflecting the presence of STW, while abundant *Melonis barleeanus* in the central area of the fjord indicated a large flux of unaltered organic matter. Only the head of the fjord was dominated by the glaciomarine taxa *Cassidulina reniforme* and *Elphidium clavatum*. Foraminiferal fauna characteristic of STW-influenced environments (i.e., *Nonionellina labradorica* and *R. turbinata*) were also observed in outer Hornsund. However, the glacier-proximal taxa *E. clavatum* and *C. reniforme* were dominant throughout the fjord, demonstrating the impacts of meltwater and high sedimentation. Therefore, it is likely that in Hornsund, glacial impact is a major environmental factor, which is stronger than the influence of STW.

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1. Introduction

Foraminifera are widely used in micropaleontology in the reconstruction of diverse past and present marine ecosystems owing to their sensitivity to environmental parameters and the preservation of their hard shells throughout geological time (Murray, 2006). The geochemical composition (e.g., $\delta^{13}C$, $\delta^{18}O$) of foraminifera tests and the changes in foraminiferal assemblages, abundance and diversity are used as proxies of temperature, salinity, oxygen availability and water mass properties (e.g., Hald et al., 2007; Rasmussen et al., 2012; Ślubowska-Woldengen et al., 2008).

The climate and oceanography of West Spitsbergen are shaped primarily by Atlantic water (AW) inflow. A recent study conducted by Nilsen et al. (2016) found that AW flows into the Isfjorden Trough more easily than anywhere else along the shelf of Spitsbergen. They conclude that barotropic water movement in the Spitsbergen shelf depends on January—February wind stress, which accelerates and expands the WSC over its average flow layer of 500-m-long isobaths. Further transport of warm and saline water to Isfjorden is topographically guided. Therefore, Isfjorden is potentially the most AW-impacted fjord of West Spitsbergen, and AW may reach its innermost inlets, including Adventfjorden. Fjords south of Isfjorden, such as Hornsund, receive less AW and thus experience Arctic-like conditions. According to Nilsen et al. (2016), the inflow of AW to Hornsund is limited by the depth of the mouth of the fjord and wind stress that is weaker than that in Isfjorden Trough. In contrast, Adventfjorden is the outwash arm of Isfjorden, with a wide and relatively deep entrance; thus, rapid water exchange with the Spitsbergen shelf occurs.

In the recent years, a growing influence of Atlantic Water on the hydrographic regime of the European Arctic was observed (Arthun et al., 2012). This phenomenon, so-called 'atlantification', affects the functional properties of the Arctic ecosystems (Carmack and Wassmann, 2006). In the light of the latest findings of Nilsen et al. (2016), Adventfjorden may serve as a fjord model for studying the correlation between foraminiferal assemblages and the outreach of STW. Despite the fact that foraminiferal assemblages in the fjords of European Arctic have been widely studied (e.g., Hald and Korsun, 1997; Korsun and Hald, 2000; Skirbekk et al., 2016), there is a need to validate and refine the results of these studies, in the context of contemporary hydrographic and environmental changes.

Previous studies conducted in Adventfjorden have revealed high sensitivity of the fjord to climatic (Zajączkowski et al., 2004) and ecological changes (Pawłowska et al., 2011) and have shown that benthic foraminiferal assemblages reflect past and present environmental variability, largely steered by the inflow of AW (Majewski and Zajączkowski, 2007). However, according to Beszczyńska-Möller et al. (1997), water formed over the Spitsbergen shelf is a mixture of AW, Arctic water (ArW) transported from the Barents Sea and local glacial meltwater that has reached the shelf area, termed shelf-transformed water (STW). Recent changes in AW inflow and associated heat transport to West Spitsbergen have resulted in the creation of large ice-free areas in northern and western Svalbard (Cottier et al., 2007), leading to changes in the productivity and biodiversity of the Arctic ecosystems (Pawłowska et al., 2011). Therefore, linking faunal changes with local oceanographic data may aid in understanding and predicting environmental responses to the changing climate. The aim of this study is to investigate the impact of STW inflow on the foraminiferal assemblages in a glacial (Hornsund) and an outwash (Adventfjorden) fjord. In these two types of fjords, the location of glacial or glaciofluvial outflow in the inner fjord causes environmental gradients in turbidity, suspended organic matter concentration and sediment stability (Syvitski et al., 1987). According to Zajączkowski (2008), the sedimentological regime is consistent between these two types of fjords, however, outwash fjords exhibit more pronounced horizontal gradients in water density than do glacial fjords. Herein, we have compared a new dataset of foraminiferal assemblages from Adventfjorden with the results of a study conducted by Zajączkowski et al. (2010) in Hornsund. Analysed were datasets from late summer (August), for which there are recent, well-developed foraminiferal tests, representing the average conditions of the studied fjords.

2. Study area

The oceanographic regime off West Spitsbergen is shaped by two coastal currents: the West Spitsbergen Current (WSC), carrying AW and the East Spitsbergen Current (ESC), carrying a mixture of Arctic (ArW) and Polar waters (PW; e.g., Cottier et al., 2005). The classification of water masses proposed by Swift (1986) and Hopkins (1991) defines the temperature and salinity of AW as $>3°C$ and >34.9, respectively. The ArW is fresher and colder than AW; however, its temperature and salinity vary according to the outflow from land. In the shelf off West Spitsbergen, AW, ArW and glacial water converge and mix, forming STW over the AW and ArW mixing line (Cottier et al., 2005). Based on the intensities of AW and ArW inflow, the waters on the shelf and in the adjacent fjords shift from Arctic to Atlantic dominance in annual cycles (e.g., Aagard et al., 1987; Svendsen et al., 2002).

This study was conducted in Adventfjorden, one of the southern arms of Isfjorden located on the west coast of Spitsbergen (Svalbard; Fig. 1). The wide and more than 100 m deep entrance of Adventfjorden allows for water exchange with the central part of Isfjorden, the largest fjord system on Spitsbergen. Adventfjorden is 8.3 km long and 3.4 km wide and is located between 78°13′ and 78°17′N and 15°25′ and 15°46′E. In the innermost area, there is a 0.7-km-wide tidal flat. The tides are semidiurnal and have a range of 159 cm (Zajączkowski and Włodarska-Kowalczuk, 2007).

The fjord is a marine coastal system, receiving freshwater and terrigenous material of primarily glacial origin. The Adventelva and Longyearelva rivers are the greatest contributors of sediment and freshwater. Freshwater discharge in summer is $3.18\ m^3\ s^{-1}$, with a sediment load of 131—151 mg dm^{-3}. Because the rivers remain frozen in winter, this water supply is cut off for 243 days of the year. Sediment accumulation decreases down-fjord from 1.87 to 0.87 cm $year^{-1}$ (Węsławski et al., 1999; Zajączkowski et al., 2004).

The water salinity is approximately 6 near the tidal flat, and at 1.5 km from the flat, it reaches 28. Since 2005, the fjord has remained ice-free during the winter (Zajączkowski et al., 2010). The climate of the region is warmer than expected from its high latitude owing to the influence of

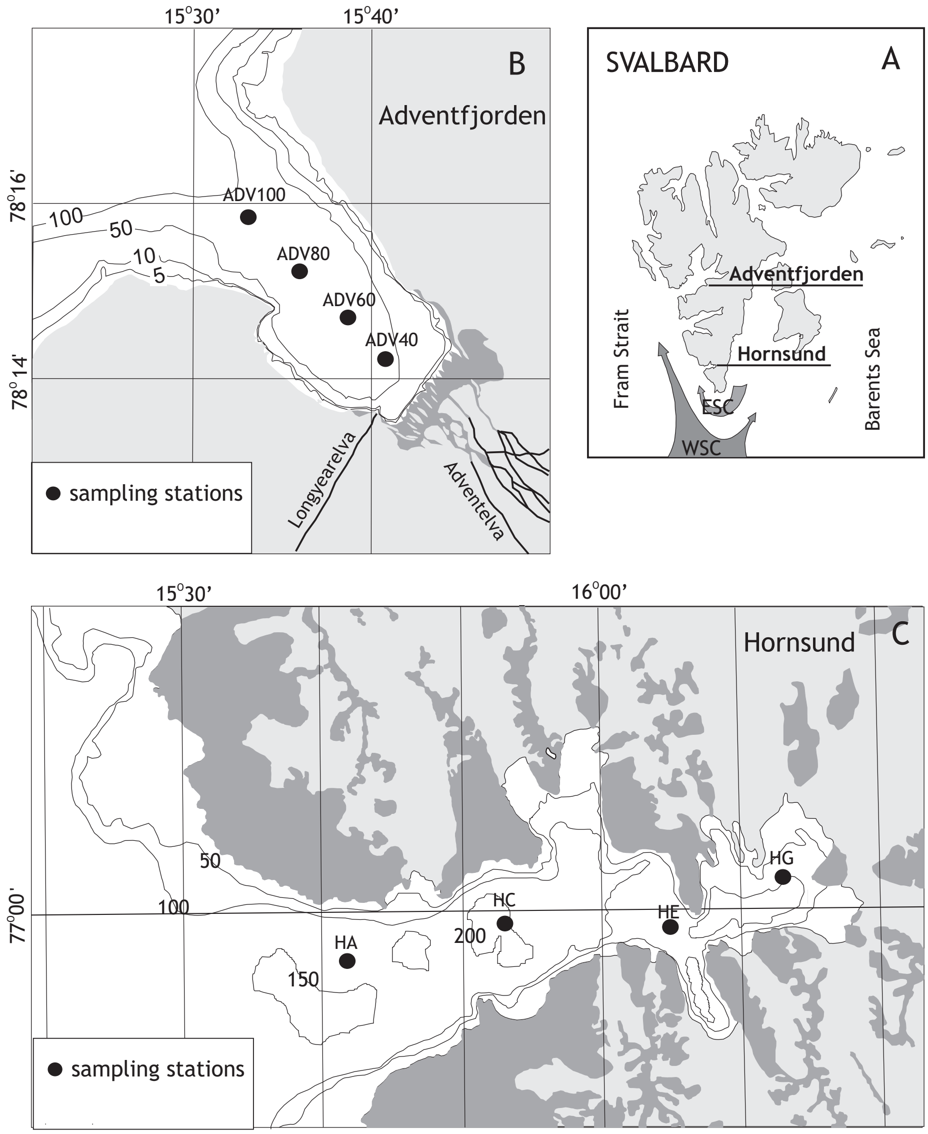

Figure 1 Location of studied fjords (A) and sampling stations in Adventfjorden (B) and Hornsund (C). Sampling stations in Hornsund are from Zajączkowski et al. (2010). WSC — West Spitsbergen Current, ESC — East Spitsbergen Current.

WSC, which transports warm and saline AW northwards. Progressive warming of the WSC over the last decade, as reported by Walczowski and Piechura (2007), has increased the temperature of the STW. In the Isfjorden system, the influence of STW is strongly related to coastal wind stress and the occurrence of winter cyclones in the Fram Strait (Nilsen et al., 2016).

Hornsund is the southernmost fjord of Spitsbergen, located between 77°05′ and 76°53′N and 15°27′ and 16°38′E. The coastline of the fjord encompasses several glacier-proximal basins with depths ranging from 55 to 180 m (Görlich et al., 1987). The fjord is under the influence of STW, with a temperature and salinity of 1°C and 34.7, respectively. STW primarily occupies the central and outer areas of the fjord, whereas the innermost basins are occupied by cold (below 0°C) and saline (35) winter-cooled water (WCW). WCW is produced by salt rejection during sea-ice formation in winter (Beszczyńska-Möller et al., 1997). Hornsund is the most glaciated of the Spitsbergen fjords, as almost 70% of its drainage area is covered by glaciers and 13 tidewater glaciers enter the fjord (Błaszczyk et al., 2013; Hagen et al., 1993). According to Węsławski et al. (1991), up to 12% of the water mass in Hornsund originates from glacial meltwater runoff. Sediment enters through meltwater discharge from the tidewater glaciers. The suspended sediment concentration is the highest in the innermost parts of the glacial bays (Brepollen, Burgerbukta, Isbjörhnamna and Samarinvågen). Sediment accumulation rates vary from 0.5 cm year^{-1} in the inner fjord to 0.7 cm year^{-1} in the mouth of the fjord (Szczuciński et al., 2006).

3. Benthic foraminiferal assemblages in Hornsund

Zajączkowski et al. (2010) investigated the foraminiferal assemblages and modern oceanography of Hornsund. The spatial variation in the foraminiferal assemblages reveals a zonation stemming from the impact of STW in the area surrounding the mouth of the fjord and glacial meltwater at the head of the fjord.

Outer Hornsund is dominated by a *Nonionellina labradorica* assemblage, with two accessory species, *Recurvoides turbinata* and *Elphidium selseyensis*. The greatest living foraminifera abundance in this part of the fjord is found 3—6 cm below the sediment surface.

In the centre of Hornsund, the boreal *E. selseyensis* is replaced by *Elphidium clavatum*, which is an opportunistic species well-adapted to unstable environments characterised by high sedimentation (Hald and Korsun, 1997). In this part of Hornsund, the *N. labradorica* assemblage is slightly less prevalent; however, it is still abundant in the sediment surface. The numbers of species and agglutinated specimens slightly decreases compared to those in the outer fjord; however, 20 species are still identified, with agglutinated species accounting for 7—30% of the total foraminiferal fauna. The greatest abundance of living foraminifera is found in the upper part of the sediment.

Two sediment cores from the head of Hornsund present proximal glacier conditions. Close to the glacier fronts, agglutinated species disappears completely, and the numbers of foraminiferal individuals and species decreased significantly. *E. clavatum* is dominant; however, the presence of *Cassidulina reniforme* and *N. labradorica* indicates seasonal STW inflow. Furthermore, the presence of *Bucella frigida* indicates sea ice formation during the winter. Most of the living specimens are found in the upper part of the sediment.

4. Methods

This study is based on the analysis of four sediment cores collected from the ship r/v *Oceania* during a sampling campaign in August 2015. A small gravity corer with a 7-cm diameter was used. The temperature and salinity of the water column were measured in 1-s intervals using a Mini CTD Sensordata SD202.

The sampling stations ADV40, ADV60, ADV80 and ADV100 were located along the fjord axis at depths of 40, 60, 80 and 100 m, respectively (Fig. 1). After collection, the 10-cm-long sediment cores were carefully transported to the laboratory in a vertical position and were then cut into 1-cm slices. Sediment was extruded using the piston. Samples were preserved with 70% ethanol solution with Rose Bengal. Rose Bengal allows differentiation between living and dead foraminifera by staining the living individuals. The study by Zajączkowski et al. (2010) of Hornsund found the majority of living foraminiferal individuals in the upper 10 cm of sediment. Therefore, in the present study, foraminiferal fauna from 10-cm-thick sediment was analysed. Next, samples were transported to the Institute of Oceanology PAN in Sopot. In the laboratory, samples were wet-sieved using 500- and 100-μm sieves and dried at 60°C. Samples containing a large number of specimens were divided using a dry microsplitter. When possible, at least 300 foraminiferal specimens were selected and placed on micropaleontological slides. Samples were quantitatively and qualitatively analysed using a microscope for species identification and counting of specimens. Species were identified according to Loeblich and Tappan (1987), and the collection of specimens was stored at the Institute of Oceanology PAN. According to Darling et al. (2016), the morphs traditionally identified as *Elphidium excavatum* f. *clavata* and *E. excavatum* f. *selseyensis* are of two distinct genetic types. Therefore, in the present dataset, the name *E. clavatum* refers to the previously termed *E. excavatum* f. *clavata*. *E. selseyensis* (formerly, *E. excavatum* f. *selseyensis*) is not present in the studied material. Foraminiferal counts are reported as the number of individuals per 10 cm^3 of sediment [ind. 10 cm^{-3}] and as a percent [%] of the total assemblage. Species composition was analysed using Q-mode principal component (PC) analysis of the quantity of living and dead foraminifera specimens. For this purpose, the SYSTAT 11 statistical package was used, and only taxa with an abundance of >1% in at least one sample was considered. Each PC is referred to as a foraminiferal assemblage (FA), named according to the taxa with highest PC scores. PC loadings exceeding 0.4 were regarded as statistically significant (Malmgren and Haq, 1982). Additionally, Shannon—Wiener Index (*H*) was used to express biodiversity. The index was calculated according to the following formula:

$$H = -\sum_{i=1}^{n} p_i \ln p_i,$$

where p_i is the proportion of each specimen belonging to the *i*th species, to the sum of all individuals (Spellerberg and Fedor, 2003).

5. Results

5.1. Adventfjorden oceanography

In the inner fjord (station ADV40), the salinity was lowest on the surface and steadily increased to a depth of 4 m. Four metres from the bottom, the salinity was 33. At the centre of the fjord, the thickness of the brackish surface layer decreased to 2 m and eventually 1 m, but the salinity of the layer was never less than 10. The water temperature exhibited smaller fluctuations than that of the salinity. The surface temperature oscillated around approximately 10°C at all the stations and fell below 3°C at the bottom of the fjord. At the head of the fjord, the temperature reached 5°C at the bottom (Fig. 2).

5.2. Foraminiferal assemblages

In the 40 samples, a total of 8886 specimens were counted, representing 38 species of both living and dead foraminifera. Agglutinated taxa were more abundant than calcareous taxa in the two outermost stations (ADV80 and ADV100; Figs. 3 and 4). At the same stations, dead specimens were dominant over living ones, while the opposite was true for the inner stations (ADV40 and ADV60, Fig. 5). The total counts and percentages of all foraminifera are presented in Appendix 1. The most abundant genus was *Spiroplectammina* sp. (3079 individuals in total), except for at station ADV40, where *E. clavatum* was dominant. *Spiroplectammina biformis* and *Cribrostomoides crassimargo* were the only two species to exceed 1000 specimens in the analysed material (Fig. 6). Clear increasing trends of the sum of living and dead foraminifera specimen

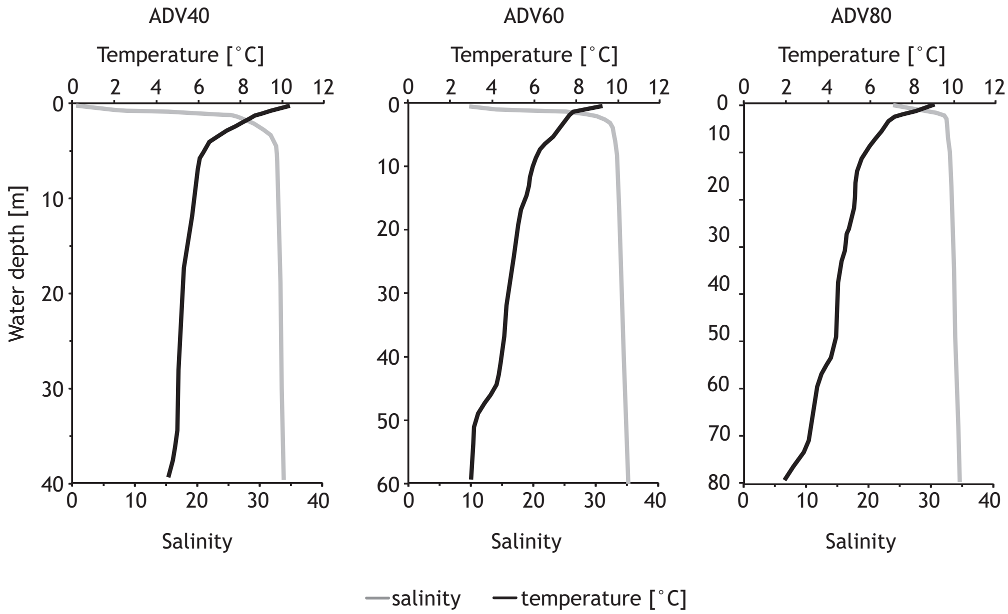

Figure 2 Salinity and temperature of Adventfjorden water in August 2015 measured at stations ADV40, ADV60 and ADV80.

and species richness towards the mouth of the fjord were observed (Figs. 3 and 6). The maximum number of specimens in each station was observed below 4 cm of sediment depth (Fig. 3). The sediment cores revealed great variability in biodiversity. The diversity varied between stations, as well as sediment depths at each station. Station ADV100 was characterised by high species diversity, with a maximum of 16 species found (at a sediment depth of 3 cm), and the Shannon—Wiener diversity index varied between 2 and 2.5 (Figs. 4 and 7). The highest species count of all cores was at station ADV80 at 10 cm in sediment depth, where the Shannon—Wiener diversity index reached its maximum of all samples at 2.8 (Fig. 7). A small number of species were found in stations at the head of the fjord (ADV40, ADV60; Fig. 4).

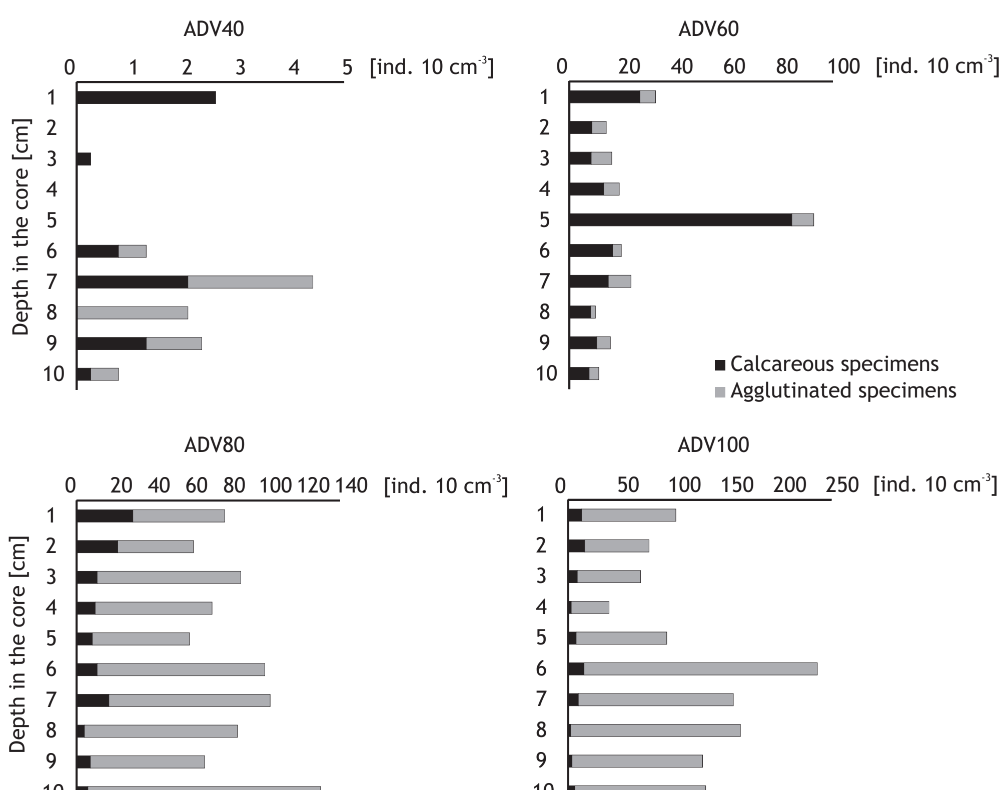

Figure 3 Distribution and quantity of foraminifera individuals, presented as specimens per 10 cm^3.

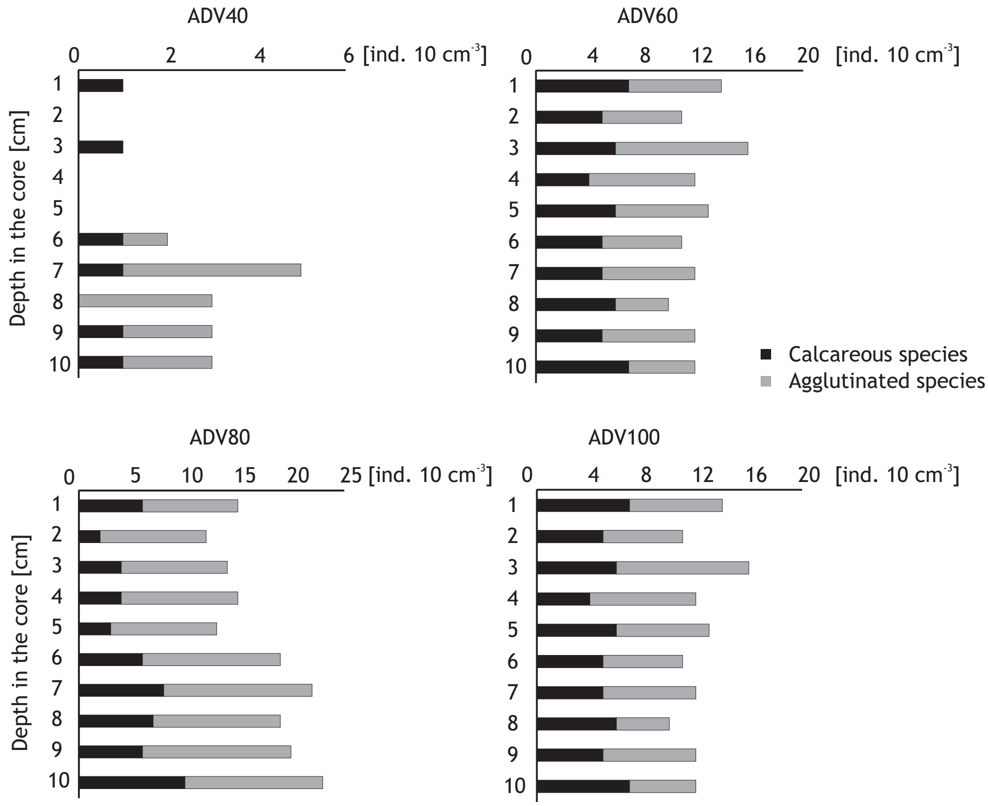

Figure 4 Distribution and quantity of foraminifera species, presented as species per 10 cm^3.

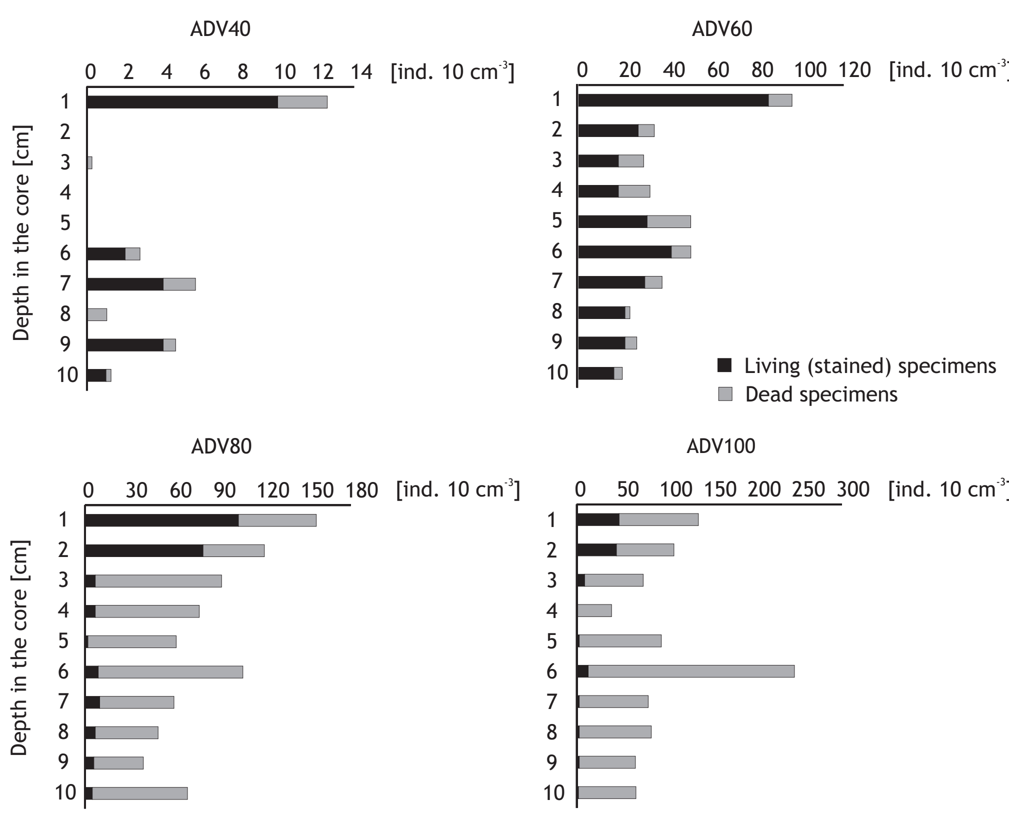

Figure 5 Distribution of living (stained) and dead (unstained) foraminifera specimens, presented as specimens per 10 cm^3.

The foraminiferal assemblage of station ADV100, located at the mouth of the fjord, was characterised by the greatest abundance of individuals, as well as noticeably high species diversity (Figs. 3 and 4). Altogether, 3475 individuals were counted in the core. The most abundant species, *S. biformis*, reached 37 specimens per 10 cm^3 (Fig. 6). Agglutinated taxa were more abundant than calcareous taxa in the two outermost stations (at depths of 80 and 100 m; Figs. 3 and 4). At the same stations, dead specimens were dominant over living ones, while the opposite was true for the inner stations (ADV 40 and ADV 60, Fig. 5). The foraminiferal assemblage at the station ADV 100 was also characterised by high number of living (stained) representatives of *N. labradorica*, especially in the two upper centimetres of sediment depth. Specimens of other species were in large majority found dead (Fig. 8). Most of the agglutinated individuals belonged to the genus

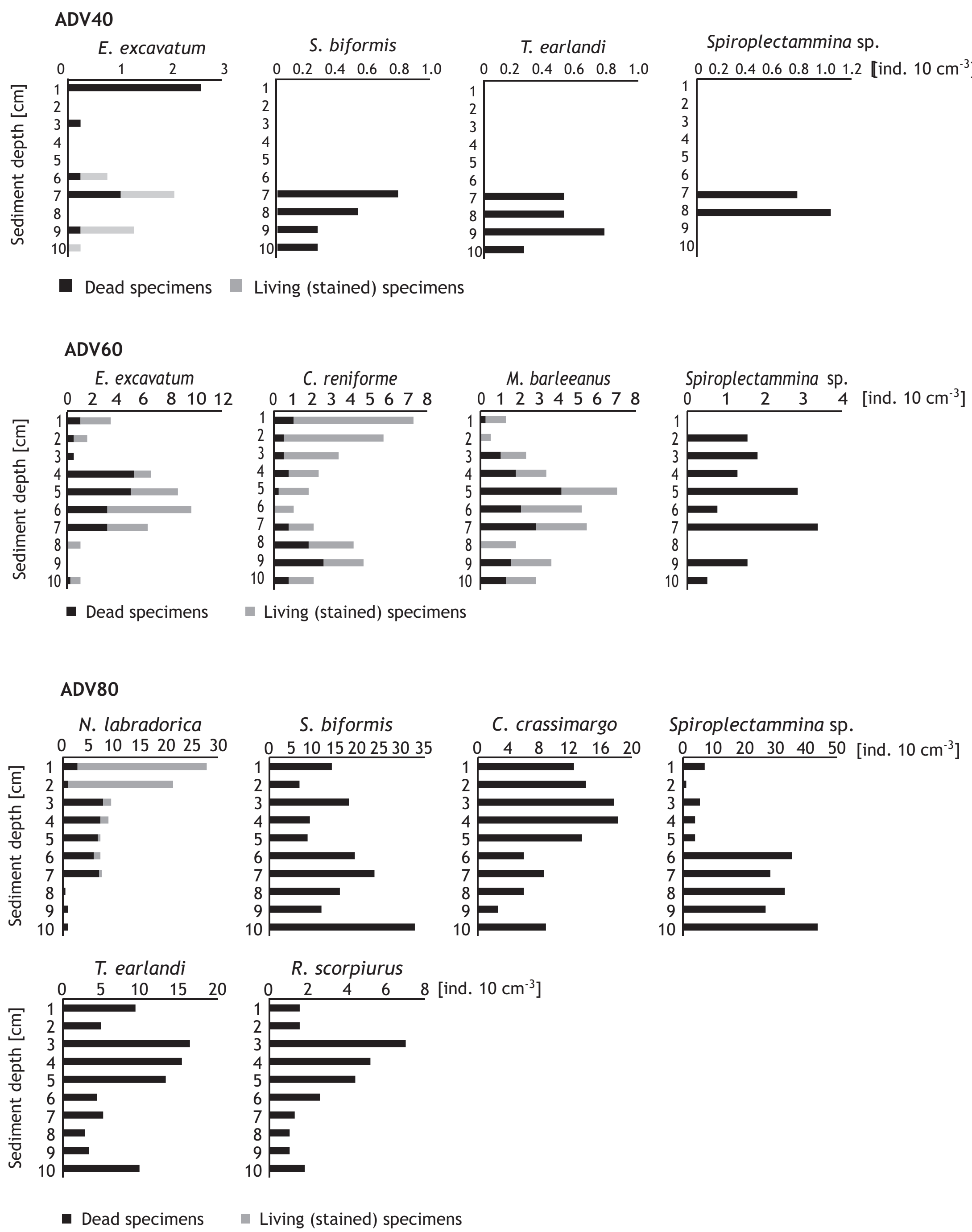

Figure 6 Occurrence of living and dead foraminiferal specimens of dominant foraminiferal taxa (*Elphidium excavatum*, *Spiroplectammina biformis*, *Textularia earlandi*, *Spiroplectammina sp.*, *Cassidulina reniforme*, *Melonis barleeanus*, *Nonionellina labradorica*, *Cribrostomoides crassimargo*, *Reophax scorpiurus*, *Recurvoides turbinata*, *Adercotryma glomerata*, *Ammotium cassis*, *Verneuilina advena*) at the four stations, presented as specimens per 10 cm^3. Taxa comprising more than 2% of total are presented.

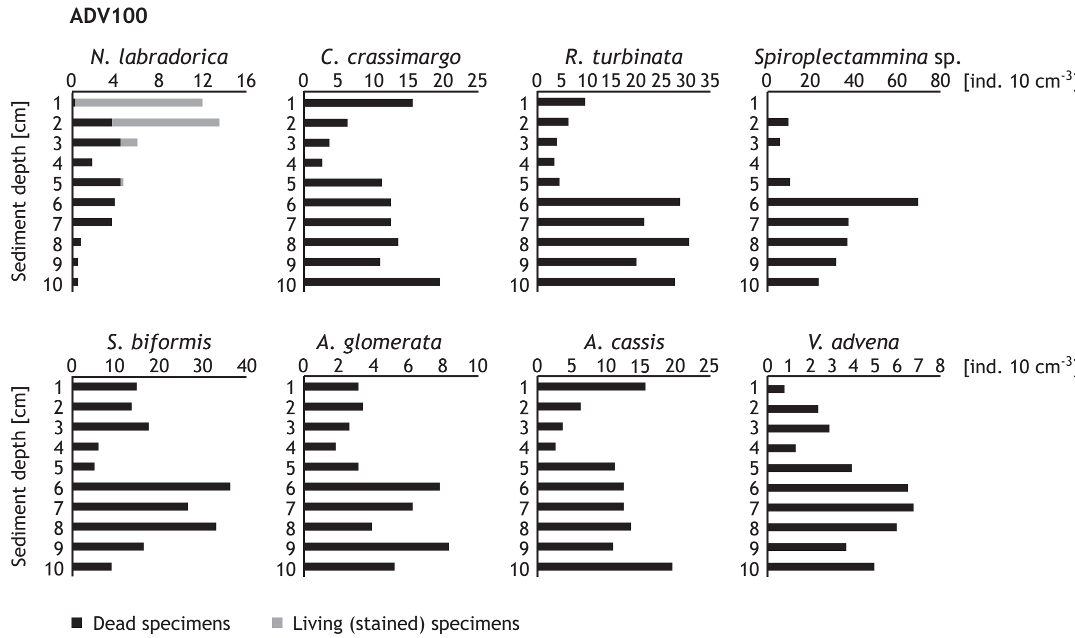

Figure 6 (*Continued*).

Spiroplectammina. The dominant calcareous species was *N. labradorica*, at more than 10 specimens per 10 cm^3 (Figs. 6 and 7). The Shannon—Wiener index was relatively stable, varying between 2 and 2.5 throughout the core (Fig. 7).

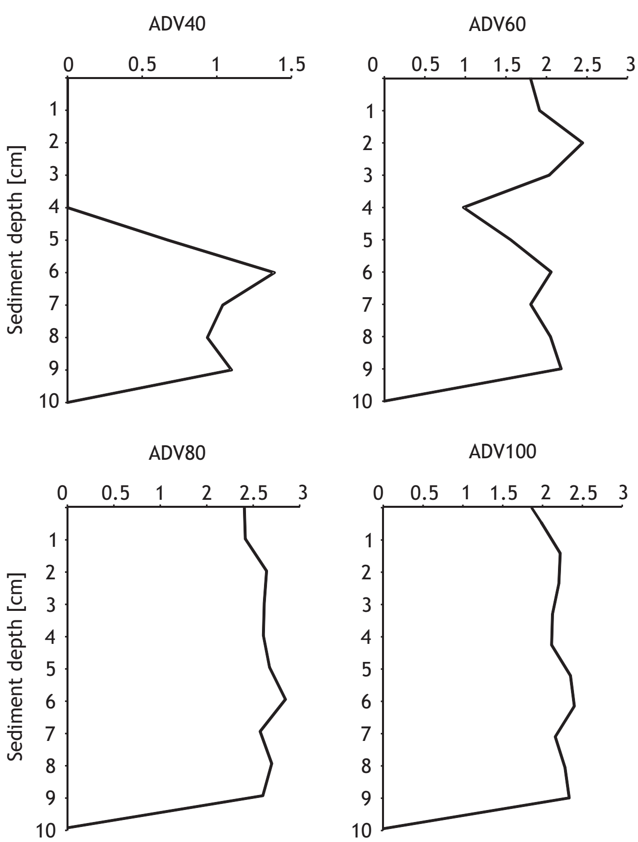

Figure 7 Shannon—Wiener index for foraminiferal assemblages at each station.

At sampling station ADV80, the genus *Spiroplectammina* was also highly abundant, especially at depths below 6 cm, and *S. biformis* reached 40 ind. 10 cm^{-3}. The second most abundant species, *N. labradorica*, reached almost 30 ind. 10 cm^{-3} and was the only calcareous species among the dominant species in ADV80. Generally, the quantity of foraminifera specimens peaked in the deepest part of the core (9—10 cm). The abundance of another calcifying foraminifera species, *E. clavatum*, was noticeably smaller than that of ADV40 and ADV60 (Fig. 3). Station ADV80 was characterised by the highest species Shannon—Wiener index, which reached 2.8 in 6 cm of sediment depth (Fig. 7). The number of living specimens was relatively low, with the exception of the representatives of *N. labradorica* on the sediment depth of 10 cm (100%, Fig. 8).

At sampling station ADV60 revealed a less diverse foraminiferal assemblage compared with those of ADV100 and ADV80. The quantity of specimens was noticeably smaller, although the abundance of *E. clavatum* increased (Fig. 6). The most abundant species in the ADV60 core was *Melonis barleeanus*, which reached 75 ind. 10 cm^{-3} at the depth of 5 cm (Fig. 6). The quantity of foraminifera clearly peaked at 5 cm, exceeding 90 ind. 10 cm^{-3} (Fig. 6). *C. reniforme* reached two abundance maxima at depths of 1 and 8 cm (up to 6 ind. 10 cm^{-3}). At 4 cm, *C. reniforme* abundance dropped noticeably in favour of *M. barleeanus* and *E. clavatum* (Fig. 6). Generally, station ADV60 had the highest percentage of living specimens (Fig. 6). The number of living (stained) specimens of *M. barleeanus* clearly exceeded the number of dead individuals (Fig. 8). The proportion of living specimens of *E. clavatum* reached almost 50% in 6 cm of depth (Fig. 8). Of the dominant calcareous species, *N. labradorica* had the highest percentage of living specimens at 100% at a depth of 2 cm (Figs. 6 and 8).

At the station located near the tidal flat (ADV40), the quantity of foraminifera was distinctly lower than at the other stations, and calcareous taxa were dominant over

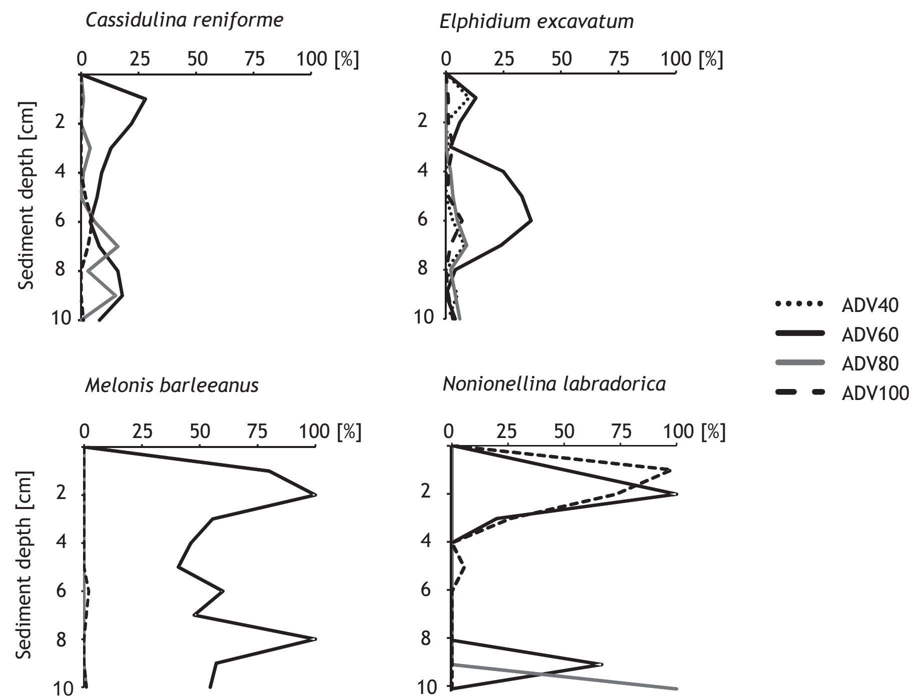

Figure 8 Distribution of the most abundant foraminiferal species as the percent of living (stained) specimens.

agglutinated (Fig. 4). The maximum quantity of foraminifera (5 ind. 10 cm^{-3}) was observed at a depth of 5 cm (Fig. 3). In the ADV40 core, only four species were present: *Cuneata arctica*, *E. clavatum*, *S. biformis* and *Textularia earlandi*. This resulted in the lowest species diversity of all stations and the Shannon—Wiener index peaking at only 1.5 (Fig. 7). *E. clavatum* was the most abundant species (2.5 ind. 10 cm^{-3}) and comprised 50% of the total count in most samples. Living (stained) specimens comprised 10% of the total count (Fig. 8), and these were almost exclusively

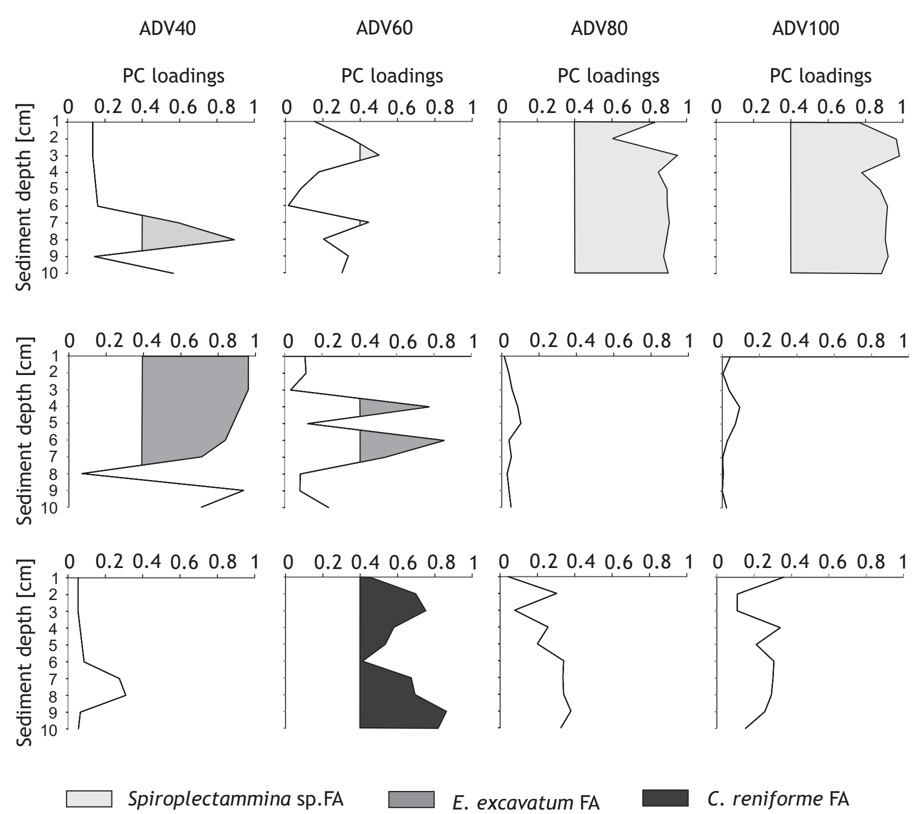

Figure 9 PC loading values for three foraminiferal assemblages. Statistically significant PC loadings are marked in shades of grey.

Table 1 PC scores and percentage of total variance explained by three-factor principal component analysis performed on the sum of living (stained) and dead foraminifera. The dominant taxa are underlined, and accessory species are bolded.

	PC1	PC2	PC3
Percent of total variance explained	48.4	16.8	16.4
Adercotryma glomerata	−0.14137	−0.30133	−0.38282
Ammotium cassis	0.235285	−0.27195	−0.71136
Cassidulina reniforme	−0.64349	−0.54897	<u>**2.699978**</u>
Cibicides lobatulus	−0.40159	−0.29933	−0.2124
Cribrostomoides crassimargo	**1.356035**	−0.02195	−**1.65839**
Cuneata arctica	−0.40037	0.192224	0.344879
Dentalina ittai	−0.42097	−0.2908	−0.24813
Elphidium clavatum	−0.64512	<u>**4.614105**</u>	0.257083
Guttulina dawsoni	−0.42028	−0.28976	−0.2512
Islandiella spp.	−0.42123	−0.29069	−0.24877
Melonis barleeanus	−0.71041	0.057422	**2.314409**
Nonionellina labradorica	0.590668	−0.2811	−0.81346
Quinqueloculina stalkeri	−0.38628	−0.26969	−0.16972
Recurvoides turbinata	0.292502	−0.3727	−0.00953
Reophax scorpiurus	−0.08445	−0.29288	−0.26008
Reophax spp.	−0.37996	−0.32396	−0.02342
Robertina arctica	−0.41299	−0.28574	−0.26516
Spiroplectammina sp.	<u>**4.131051**</u>	0.166076	**1.832678**
Stainforthia feylingi	−0.52469	−0.2965	0.592858
Stainforthia loeblichi	−0.40112	−0.28981	−0.26252
Textularia earlandi	**1.026791**	**0.867865**	−**1.64783**
Textularia torquata	−0.34442	−0.25739	−0.13618
Triloculina frigida	−0.4209	−0.29084	−0.24788
Trochammina nana	−0.35618	−0.32509	−0.17942
Verneuilina advena	−0.11651	−0.29721	−0.31362

representatives of the species *E. clavatum*. Three samples barren of foraminifera were noted at depths of 1—2 and 3—5 cm (Fig. 3).

5.3. Principal component analysis

The principal component analysis explained 89.17% of the total variance in the foraminifera data using a three-factor solution. Each PC was characterised by a dominant and an accessory species. Each PC was referred to as an FA. The assemblages were named after the dominant species (Fig. 9, Table 1).

The *Spiroplectammina* sp. FA with *C. crassimargo* and *T. earlandi* as accessory species explained 48.4% of the foraminiferal variance. All species were agglutinated taxa. The FA *Spiroplectammina* sp. was statistically significant throughout the ADV80 and ADV100 cores and at selected depths in the ADV40 and ADV60 cores (Fig. 9, Table 1).

The second assemblage was named after *E. clavatum*, with accessory species *T. earlandi*. It explained 16.8% of the foraminiferal variance and was abundant in the innermost stations (ADV40 and ADV60). It had a major impact on the sediment surface down to 7 cm in depth (Fig. 9, Table 1).

The *C. reniforme* FA with accessory species *M. barleeanus*, *T. earlandi* and *C. crassimargo* explained 16.4% of the total foraminiferal variance. This was the only FA that was significant at only one station (ADV60), and it was dominant throughout the core (Fig. 9, Table 1).

6. Discussion

6.1. The impact of STW on foraminiferal fauna

In the fjords of Svalbard, the foraminiferal assemblages impacted by STW have been primarily characterised by (i) relatively high biodiversity, (ii) a high abundance of agglutinated taxa and (iii) the presence of *N. labradorica* (e.g., Hald and Korsun, 1997; Zajączkowski et al., 2010). In the Spitsbergen fjords, the presence of *N. labradorica* is positively correlated with the presence of STW (Hald and Korsun, 1997). In the Barents Sea, *N. labradorica* is especially abundant near the highly productive frontal zones and the sea-ice edge (Hald and Steinsund, 1996). Moreover, the presence of *M. barleeanus* may reflect the influence of AW, as observed in the Spitsbergen shelf (Jernas et al., 2013) and modern Norwegian fjords (Husum and Hald, 2004).

In the outermost parts of Adventfjorden (i.e. stations ADV80 and ADV100), the foraminiferal assemblages match all the characteristics of STW-influenced assemblages. An overall increase in foraminiferal abundance and diversity towards the mouth of the fjord was observed. However, this may have resulted from a combination of the impact of STW in the outer fjord with the diminishing impact of the rivers (i.e. decreasing freshwater flux and suspension concentrations). Moreover, *N. labradorica* occurs abundantly in the outer parts of Adventfjorden, matching its general distribution in Arctic fjords. In Svalbard and Novaya Zemlya, peaks of

N. labradorica are characteristic of glacier-distal settings influenced by STW (Hald and Korsun, 1997; Korsun and Hald, 1998; Pogodina, 2005).

Generally, total and agglutinated foraminiferal abundance increased towards the mouth of the fjord, supporting previous findings for Adventfjorden (Majewski and Zajączkowski, 2007). Agglutinated specimens made up to 90% of all foraminiferal specimens in the outermost part of Adventfjorden. Majewski and Zajączkowski (2007) proposed several explanations for such high abundance of agglutinated foraminifera in Adventfjorden. This may partly be explained by a naturally low proportion of calcareous species, which is typical for seasonally ice-free areas (Wollenburg and Kuhnt, 2000). In addition, the dissolution of calcareous tests resulting from lowered pH due to a decay of organic matter may explain the high percentage of agglutinated specimens. The latter explanation is in accordance with the results of Pawłowska et al. (unpublished data — *under review*), which indicate that in Adventfjorden, an organic matter decay in sediments is more intensive in summer than in other seasons, and may possibly have an effect on carbonate preservation in the sediments.

Outer Adventfjorden was dominated by the *Spiroplectammina* sp. FA. The genus *Spiroplectammina* is present in Norwegian and Spitsbergen fjords, as well as on the shelf of Spitsbergen and in the Barents Sea, and it has been reported as the innermost and most shallow-dwelling agglutinated taxa in the shelf regions of the Canadian Arctic (Schröder-Adams et al., 1990) and fjords of Svalbard (Korsun and Hald, 2000). *S. biformis* is also abundantly found in the shallowest parts of northern Norwegian fjords (Murray, 2006). Moreover, the occurrence of *T. earlandi* and *S. biformis* is typical of glaciomarine habitats in the region, while other arenaceous taxa are absent or rare (Hald and Korsun, 1997; Korsun and Hald, 1998). However, data on the modern distribution of *Spiroplectammina* are scarce and geographically patchy and cannot be correlated with certain environmental conditions. For example, Hald and Korsun (1997) did not find a statistically significant correlation between the occurrence of *S. biformis* and any of the analysed environmental parameters.

The high abundance of *R. turbinata* and *Adercotryma glomerata* in outer Adventfjorden may have been related to the presence of STW. Both species are positively correlated with higher temperature and salinity, and their dominance increases towards the outer parts of the Spitsbergen fjords (Hald and Korsun, 1997).

In the inner fjord, the influence of STW on the foraminiferal assemblage was less pronounced and may be reflected by the presence of *N. labradorica*. Moreover, at station ADV60, a great abundance of *M. barleeanus* was noted. The species may be considered an indicator of STW (Jernas et al., 2013); however, its abundance at the other stations was low. The presence of *M. barleeanus* likely results from a large flux of unaltered organic matter on which the species feeds or from the presence of persistent currents at the bottom of the sampling station (Caralp, 1989; Jennings et al., 2004).

Adventfjorden is located relatively far from the Isfjorden Trough, which is the major pathway of water exchange between the Spitsbergen shelf and the central basin of Isfjorden. Because the STW penetrates Isfjorden more deeply than any other fjord along the Spitsbergen coast (Nilsen et al., 2016), the influence of STW is pronounced in Adventfjorden, especially in the outer areas. However, in the innermost part of the fjord, the influence of riverine input prevails over the STW influence on the environment, resulting in the presence of foraminiferal assemblages dominated by *E. clavatum* and *C. reniforme* (Fig. 5). Both taxa are so-called 'glaciomarine' species that thrive in settings with high turbidity and sediment accumulation rates. In Adventfjorden, *E. clavatum* and *C. reniforme* are dominant near the delta slope, which is characterised by high sedimentation rates and subsequent gravity flows and turbidity currents (Zajączkowski and Włodarska-Kowalczuk, 2007), creating environmental stressors that may affect benthic fauna (Wlodarska-Kowalczuk and Pearson, 2004).

Foraminiferal fauna characteristic of STW-influenced environments were also observed in the outer Hornsund. Łącka and Zajączkowski (2016) noted that increased inflow of STW to Hornsund resulted in greater biodiversity and a greater number of rare species. Moreover, they concluded that the presence of *N. labradorica* may be indicative of both STW and high foraminiferal biodiversity. According to Zajączkowski et al. (2010), the species richness was greatest in the outermost part of the fjord. *N. labradorica* and *R. turbinata* were present throughout the fjord, and their abundance decreased towards the head of the fjord. Moreover, the outer and central areas of the fjord were characterised by the presence of *N. labradorica* FA, whereas in the inner fjord, this FA was nearly absent. However, the foraminiferal assemblages in Hornsund were dominated by *C. reniforme* and *E. clavatum* throughout. *E. clavatum* and *C. reniforme* are commonly found in the Barents Sea and in the eastern Greenland shelf, and their occurrence is related to the presence of cold waters with variable salinity (Hald and Steinsund, 1996; Jennings and Helgadóttir, 1994). In the fjords of Svalbard, *C. reniforme* and *E. clavatum* are considered indicative of the influence of meltwater and high sedimentation rates (Hald and Korsun, 1997; Knudsen et al., 2012; Pogodina, 2005). In the Spitsbergen shelf and Nordic Seas, these species are used as ArW indicators (e.g., Ślubowska-Woldengen et al., 2008); however, in Hornsund, their presence may be connected to the presence of cold WCW, which forms in the inner glacial bays (Węsławski et al., 1991).

Hornsund is directly connected to the Spitsbergen shelf, and a wide, no-sill outlet enables direct water exchange. However, the foraminiferal fauna revealed the influence of STW only in the outermost part of the fjord. Central and inner Hornsund were dominated by calcareous, glaciomarine taxa, reflecting the strong influence of glacial meltwater and local waters (Zajączkowski et al., 2010). Therefore, the Hornsund environment is likely shaped by glaciers rather than STW.

6.2. The downcore distribution of foraminiferal fauna

The sampling depth most commonly advised for modern foraminifera studies is the upper 1—2 cm of sediment (Schonfeld et al., 2012), as the majority of living foraminifera is thought to be found there (Murray, 2006). However, according to recent studies, in the Hornsund fjord, living (Rose Bengal-stained) foraminifera appear in depths up to 21 cm, with natural abundance several centimetres below the sediment surface. This may be attributable to the vertical migration of foraminifera in search of food or oxygen, for example. On the other hand, sediment accumulation, which is relatively high in fjords, may influence the vertical distribution of foraminiferal fauna via the rapid burial of specimens.

The results of this study support the findings of Zajączkowski et al. (2010), as foraminiferal abundance maxima were observed below 4—5 cm in sediment depth. Moreover, previous studies on foraminiferal distribution concluded that there is no universal vertical distribution of species (Murray, 2006). In the case of certain species in the Spitsbergen fjords, the favourable sediment depth is likely fixed. For example, the maximum abundance of *E. clavatum* in both fjords occurred at 4—6 cm in depth, while the majority of *N. labradorica* specimens occurred in the upper 2 cm (see Zajączkowski et al., 2010, for comparison). However, further studies are needed to confirm this assumption.

7. Conclusion

Despite the juxtaposition of an outwash fjord-Adventfjorden and a glaciated fjord-Hornsund, the foraminiferal data revealed varying severity of STW impact on fjord environments. Outwash fjords filled with STW due to their deep entrance, reveal strong influence of STW even far from the inlet. In glacial fjords, the environment is mainly influenced by turbid meltwater and the impact of STW is recorded only in the outer parts of the fjords. Considering these findings, we conclude that studies on both horizontal and vertical distribution of foraminiferal assemblages can provide information on the intensity of STW impact on the fjord environment. Our results confirmed previous assumptions, that foraminiferal assemblages provide information on water mass inflows into fjord systems and thus may serve as a reference for studies on both past and present environmental changes.

Acknowledgements

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Appendix 1. Table containing all counted foraminifera species with their abundance and percentage at each sampling station

Sample	ADV40 0—1	ADV40 1—2	ADV40 2—3	ADV40 3—4	ADV40 4—5	ADV40 5—6	ADV40 6—7	ADV40 7—8	ADV40 8—9	ADV40 9—10	Sum in ADV40	% of ADV40 total sum
Astrononion gallowayi (Loeblich and Tapan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Bolivinellina pseudopunctata (Höglund, 1947)	0	0	0	0	0	0	0	0	0	0	0	0.0
Buccella frigida (Cushman, 1922)	0	0	0	0	0	0	0	0	0	0	0	0.0
Buccella tenerrima (Bandy, 1950)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cassidulina reniforme (Nørvag, 1945)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cibicides lobatulus (Walker and Jacob, 1798)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cornuspira involvens (Reuss, 1850)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cornuspira spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Dentalina ittai (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Elphidium clavatum (Terquem, 1875)	10	0	1	0	0	3	8	0	5	1	28	52.8
Elphidium spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Elphidium subarcticum (Weiss, 1954)	0	0	0	0	0	0	0	0	0	0	0	0.0
Fissurina marginata (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0
Globobulimina spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Guttulina dawsoni (Cushman and Ozawa, 1930)	0	0	0	0	0	0	0	0	0	0	0	0.0
Guttulina lactea (Walker and Jacob, 1798)	0	0	0	0	0	0	0	0	0	0	0	0.0
Islandiella helenae (Feyling—Hanssen and Buzas, 1976)	0	0	0	0	0	0	0	0	0	0	0	0.0
Islandiella spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Lagena gracillima (Seguenza, 1862)	0	0	0	0	0	0	0	0	0	0	0	0.0
Lagena mollis (Cushman, 1944)	0	0	0	0	0	0	0	0	0	0	0	0.0
Melonis barleeanus (Williamson, 1858)	0	0	0	0	0	0	0	0	0	0	0	0.0
Miliolina oblonga (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0
Nonionellina labradorica (Dowson, 1860)	0	0	0	0	0	0	0	0	0	0	0	0.0
Quinqueloculina seminulum (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0.0
Robertinoides charlottensis (Cushman, 1925)	0	0	0	0	0	0	0	0	0	0	0	0.0
Silicosigmoilina groenlandica (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Stainforthia feylingi (Knudsen and Seidenkrantz, 1994)	0	0	0	0	0	0	0	0	0	0	0	0.0
Stainforthia loeblichi (Feyling-Hanssen, 1954)	0	0	0	0	0	0	0	0	0	0	0	0.0
Triloculina frigida (Lagoe, 1977)	0	0	0	0	0	0	0	0	0	0	0	0.0
Uvigerina peregrina (Cushman, 1923)	0	0	0	0	0	0	0	0	0	0	0	0.0
Adercotryma glomerata (Brady, 1878)	0	0	0	0	0	0	0	0	0	0	0	0.0
Ammotium cassis (Parker, 1870)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cribrostomoides crassimargo (Norman, 1892)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cuneata arctica (Brady, 1881)	0	0	0	0	0	2	1	0	0	0	3	5.7
Quinqueloculina stalkeri (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Recurvoides turbinata (Brady, 1881)	0	0	0	0	0	0	0	0	0	0	0	0.0

Appendix 1. (*Continued*)

Sample	ADV40 0—1	ADV40 1—2	ADV40 2—3	ADV40 3—4	ADV40 4—5	ADV40 5—6	ADV40 6—7	ADV40 7—8	ADV40 8—9	ADV40 9—10	Sum in ADV40	% of ADV40 total sum
Reophax scorpiurus (Montfort, 1808)	0	0	0	0	0	0	0	0	0	0	0	0.0
Reophax spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Spiroplectammina biformis (Parker and Jones, 1865)	0	0	0	0	0	0	3	2	1	1	7	13.2
Spiroplectammina sp.	0	0	0	0	0	0	3	4	0	0	7	13.2
Textularia earlandi (Parker, 1952)	0	0	0	0	0	0	2	2	3	1	8	15.1
Textularia torquata (Parker, 1952)	0	0	0	0	0	0	0	0	0	0	0	0.0
Trochammina nana (Brady, 1881)	0	0	0	0	0	0	0	0	0	0	0	0.0
Verneuilina advena (Cushman, 1922)	0	0	0	0	0	0	0	0	0	0	0	0.0
Total sum	10	0	1	0	0	5	17	8	9	3	53	100.0

Sample	ADV60 0—1	ADV60 1—2	ADV60 2—3	ADV60 3—4	ADV60 4—5	ADV60 5—6	ADV60 6—7	ADV60 7—8	ADV60 8—9	ADV60 9—10	Sum in ADV60	% of total sum in ADV 60
Astrononion gallowayi (Loeblich and Tapan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Bolivinellina pseudopunctata (Höglund, 1947)	0	0	0	0	0	0	0	0	0	0	0	0.0
Buccella frigida (Cushman, 1922)	0	0	1	0	0	1	1	0	0	1	4	0.4
Buccella tenerrima (Bandy, 1950)	0	0	0	0	0	0	0	0	1	1	2	0.2
Cassidulina reniforme (Nørvag, 1945)	28	22	13	9	7	4	8	16	18	8	133	13.6
Cibicides lobatulus (Walker and Jacob, 1798)	0	0	0	0	0	0	0	1	0	0	1	0.1
Cornuspira involvens (Reuss, 1850)	0	0	0	0	0	0	0	1	0	0	1	0.1
Cornuspira spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Dentalina ittai (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Elphidium clavatum (Terquem, 1875)	13	6	2	25	33	37	24	4	0	4	148	15.1
Elphidium spp.	1	0	0	0	0	0	0	0	0	0	1	0.1
Elphidium subarcticum (Weiss, 1954)	0	0	0	0	0	0	0	0	0	0	0	0.0
Fissurina marginata (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0
Globobulimina spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Guttulina dawsoni (Cushman and Ozawa, 1930)	0	0	0	0	0	0	0	0	0	0	0	0.0
Guttulina lactea (Walker and Jacob, 1798)	0	0	0	0	0	0	0	0	0	0	0	0.0
Islandiella helenae (Feyling—Hanssen and Buzas, 1976)	0	0	0	0	0	0	0	0	0	0	0	0.0
Islandiella spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Lagena gracillima (Seguenza, 1862)	1	0	0	0	1	0	0	0	0	0	2	0.2
Lagena mollis (Cushman, 1944)	0	0	0	0	0	0	0	0	0	0	0	0.0
Melonis barleeanus (Williamson, 1858)	5	2	9	13	277	20	21	7	14	11	379	38.7
Miliolina oblonga (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0
Nonionellina labradorica (Dowson, 1860)	2	1	5	0	5	0	0	2	3	1	19	1.9
Quinqueloculina seminulum (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0.0
Robertinoides charlottensis (Cushman, 1925)	0	0	0	0	0	0	0	0	0	0	0	0.0
Silicosigmoilina groenlandica (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Stainforthia feylingi (Knudsen and Seidenkrantz, 1994)	53	2	2	3	2	1	3	0	4	3	73	7.4
Stainforthia loeblichi (Feyling-Hanssen, 1954)	0	0	0	0	0	0	0	0	0	0	0	0.0
Triloculina frigida (Lagoe, 1977)	0	0	0	0	0	0	0	0	0	0	0	0.0
Uvigerina peregrina (Cushman, 1923)	0	0	0	0	0	0	0	0	0	0	0	0.0
Adercotryma glomerata (Brady, 1878)	0	0	0	0	0	0	0	0	1	0	1	0.1
Ammotium cassis (Parker, 1870)	0	0	0	0	0	0	0	0	0	0	0	0.0
Cribrostomoides crassimargo (Norman, 1892)	0	3	2	2	3	2	0	0	0	0	12	1.2
Cuneata arctica (Brady, 1881)	10	1	7	5	2	1	5	0	2	3	36	3.7
Quinqueloculina stalkeri (Loeblich and Tappan, 1953)	1	0	1	1	3	0	2	1	0	0	9	0.9
Recurvoides turbinata (Brady, 1881)	1	6	0	2	0	2	2	3	5	1	22	2.2
Reophax scorpiurus (Montfort, 1808)	0	3	3	0	5	1	0	1	2	0	15	1.5
Reophax spp.	4	0	4	0	3	0	3	0	0	0	14	1.4
Spiroplectammina biformis (Parker and Jones, 1865)	4	2	2	4	5	4	6	0	3	5	35	3.6
Spiroplectammina sp.	0	6	7	5	11	3	13	0	6	2	53	5.4
Textularia earlandi (Parker, 1952)	2	0	2	1	0	0	0	0	1	3	9	0.9
Textularia torquata (Parker, 1952)	0	0	0	3	0	0	2	0	0	0	5	0.5
Trochammina nana (Brady, 1881)	0	0	1	0	0	0	0	0	0	0	1	0.1
Verneuilina advena (Cushman, 1922)	1	0	1	0	0	0	0	2	0	0	4	0.4
Total sum	126	55	62	73	357	76	90	38	60	43	980	100.0

Sample	ADV80 0—1	ADV80 1—2	ADV80 2—3	ADV80 3—4	ADV80 4—5	ADV80 5—6	ADV80 6—7	ADV80 7—8	ADV80 8—9	ADV80 9—10	Sum in ADV80	% of total sum ADV80
Astrononion gallowayi (Loeblich and Tapan, 1953)	1	0	0	0	0	0	0	0	0	2	3	0.1
Bolivinellina pseudopunctata (Höglund, 1947)	0	0	0	0	0	0	0	0	0	1	1	0.0
Buccella frigida (Cushman, 1922)	0	0	0	0	0	1	2	3	1	1	8	0.2
Buccella tenerrima (Bandy, 1950)	0	0	0	0	0	0	4	0	0	4	8	0.2
Cassidulina reniforme (Nørvag, 1945)	1	0	4	1	0	6	16	2	15	0	45	1.4
Cibicides lobatulus (Walker and Jacob, 1798)	0	0	0	0	0	0	4	2	3	2	11	0.3
Cornuspira involvens (Reuss, 1850)	0	2	0	0	0	0	0	0	0	0	2	0.1
Cornuspira spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Dentalina ittai (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	1	1	0.0
Elphidium clavatum (Terquem, 1875)	0	0	0	2	3	5	9	2	4	6	31	1.0
Elphidium spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Elphidium subarcticum (Weiss, 1954)	0	0	0	0	0	0	0	0	0	0	0	0.0
Fissurina marginata (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0
Globobulimina spp.	1	0	1	0	0	0	0	0	0	0	2	0.1
Guttulina dawsoni (Cushman and Ozawa, 1930)	0	0	0	0	0	0	0	0	0	0	0	0.0
Guttulina lactea (Walker and Jacob, 1798)	0	0	0	0	0	0	0	0	0	1	1	0.0
Islandiella helenae (Feyling—Hanssen and Buzas, 1976)	0	0	0	0	0	0	0	0	0	0	0	0.0

Appendix 1. (*Continued*)

Sample	ADV80 0—1	ADV80 1—2	ADV80 2—3	ADV80 3—4	ADV80 4—5	ADV80 5—6	ADV80 6—7	ADV80 7—8	ADV80 8—9	ADV80 9—10	Sum in ADV80	% of total sum ADV80
Islandiella spp.	0	0	0	0	0	0	0	0	0	0	0	0.0
Lagena gracillima (Seguenza, 1862)	0	0	0	0	0	0	0	0	0	0	0	0.0
Lagena mollis (Cushman, 1944)	0	0	0	0	0	1	1	0	0	0	2	0.1
Melonis barleeanus (Williamson, 1858)	0	0	0	0	0	0	0	0	0	1	1	0.0
Miliolina oblonga (Montagu, 1803)	0	0	0	0	0	1	0	0	0	0	1	0.0
Nonionellina labradorica (Dowson, 1860)	104	82	36	34	28	28	29	2	4	4	351	10.8
Quinqueloculina seminulum (Linnaeus, 1758)	2	0	1	0	0	0	0	0	0	0	3	0.1
Robertinoides charlottensis (Cushman, 1925)	0	0	0	0	0	0	0	0	0	0	0	0.0
Silicosigmoilina groenlandica (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	0	0	0	0.0
Stainforthia feylingi (Knudsen and Seidenkrantz, 1994)	0	0	0	0	0	0	0	4	0	0	4	0.1
Stainforthia loeblichi (Feyling-Hanssen, 1954)	6	0	0	1	1	0	0	0	1	0	9	0.3
Triloculina frigida (Lagoe, 1977)	0	0	0	0	0	0	1	0	0	0	1	0.0
Uvigerina peregrina (Cushman, 1923)	0	0	0	0	0	0	0	1	0	0	1	0.0
Adercotryma glomerata (Brady, 1878)	0	8	11	1	3	1	3	3	4	8	42	1.3
Ammotium cassis (Parker, 1870)	5	20	5	7	4	3	8	17	6	9	84	2.6
Cribrostomoides crassimargo (Norman, 1892)	48	54	68	70	52	23	33	23	10	34	415	12.7
Cuneata arctica (Brady, 1881)	0	0	0	6	2	19	16	8	9	16	76	2.3
Quinqueloculina stalkeri (Loeblich and Tappan, 1953)	2	2	4	2	0	0	2	0	2	4	18	0.6
Recurvoides turbinata (Brady, 1881)	9	14	12	8	10	14	8	25	6	21	127	3.9
Reophax scorpiurus (Montfort, 1808)	6	6	27	20	17	10	5	4	4	7	106	3.3
Reophax spp.	0	0	0	0	0	19	11	2	5	8	45	1.4
Spiroplectammina biformis (Parker and Jones, 1865)	54	26	69	35	33	74	91	61	45	126	614	18.9
Spiroplectammina sp.	27	4	21	15	15	136	109	127	103	168	725	22.3
Textularia earlandi (Parker, 1952)	36	19	63	59	51	17	20	11	13	38	327	10.0
Textularia torquata (Parker, 1952)	0	0	0	0	0	6	9	20	13	25	73	2.2
Trochammina nana (Brady, 1881)	0	0	0	0	0	10	10	0	6	0	26	0.8
Verneuilina advena (Cushman, 1922)	1	2	14	16	12	11	5	12	8	12	93	2.9
Total sum	303	239	336	277	231	385	396	329	262	499	3257	100.0

Sample	ADV100 0—1	ADV100 1—2	ADV100 2—3	ADV100 3—4	ADV100 4—5	ADV100 5—6	ADV100 6—7	ADV100 7—8	ADV100 8—9	ADV100 9—10	Sum in ADV100	% of total sum ADV100	Total sum of specimens in all samples	% of total sum of specimens in all samples
Astrononion gallowayi (Loeblich and Tapan, 1953)	0	0	0	0	0	3	0	0	0	0	3	0.1	6	0.1
Bolivinellina pseudopunctata (Höglund, 1947)	0	0	0	0	0	0	0	0	0	0	0	0.0	1	0.0
Buccella frigida (Cushman, 1922)	0	0	2	1	2	11	6	1	4	2	29	0.6	41	0.5
Buccella tenerrima (Bandy, 1950)	0	0	0	0	0	2	6	3	2	1	14	0.3	24	0.3
Cassidulina reniforme (Nørvag, 1945)	0	0	0	0	2	5	3	0	0	1	11	0.2	189	2.1
Cibicides lobatulus (Walker and Jacob, 1798)	0	0	4	1	1	2	0	2	3	3	16	0.3	28	0.3
Cornuspira involvens (Reuss, 1850)	0	0	0	0	0	1	0	0	0	0	1	0.0	4	0.0
Cornuspira spp.	0	0	0	0	0	0	1	0	0	0	1	0.0	1	0.0
Dentalina ittai (Loeblich and Tappan, 1953)	0	0	0	0	0	0	0	0	1	1	2	0.0	3	0.0
Elphidium clavatum (Terquem, 1875)	1	1	3	1	1	7	2	0	1	3	20	0.4	227	2.6
Elphidium spp.	0	0	0	0	0	0	0	0	0	0	0	0.0	1	0.0
Elphidium subarcticum (Weiss, 1954)	0	0	0	0	0	0	1	0	0	0	1	0.0	1	0.0
Fissurina marginata (Montagu, 1803)	0	0	0	0	0	0	0	0	0	1	1	0.0	1	0.0
Globobulimina spp.	0	0	0	0	0	0	0	0	0	0	0	0.0	2	0.0
Guttulina dawsoni (Cushman and Ozawa, 1930)	0	0	0	0	1	0	0	0	0	1	2	0.0	2	0.0
Guttulina lactea (Walker and Jacob, 1798)	0	0	0	0	0	0	0	0	0	1	1	0.0	2	0.0
Islandiella helenae (Feyling—Hanssen and Buzas, 1976)	0	0	0	0	0	0	0	0	1	0	1	0.0	1	0.0
Islandiella spp.	0	0	0	0	0	0	0	0	0	2	2	0.0	2	0.0
Lagena gracillima (Seguenza, 1862)	0	0	0	0	1	0	0	0	0	0	1	0.0	3	0.0
Lagena mollis (Cushman, 1944)	0	0	0	0	0	0	0	0	0	1	1	0.0	3	0.0
Melonis barleeanus (Williamson, 1858)	0	0	0	0	0	2	1	0	0	1	4	0.1	384	4.3
Miliolina oblonga (Montagu, 1803)	0	0	0	0	0	0	0	0	0	0	0	0.0	1	0.0
Nonionellina labradorica (Dowson, 1860)	46	52	23	7	18	15	14	3	2	2	182	4.0	552	6.2
Quinqueloculina seminulum (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	0	0	0.0	3	0.0
Robertinoides charlottensis (Cushman, 1925)	2	0	0	1	0	1	0	0	0	0	4	0.1	4	0.0
Silicosigmoilina groenlandica (Loeblich and Tappan, 1953)	0	0	0	0	0	1	0	0	0	0	1	0.0	1	0.0
Stainforthia feylingi (Knudsen and Seidenkrantz, 1994)	0	6	1	0	3	8	1	0	0	1	20	0.4	97	1.1
Stainforthia loeblichi (Feyling-Hanssen, 1954)	0	1	0	0	0	0	1	0	0	2	4	0.1	13	0.1
Triloculina frigida (Lagoe, 1977)	0	0	0	0	0	0	1	0	0	1	2	0.0	3	0.0
Uvigerina peregrina (Cushman, 1923)	0	0	0	0	0	0	0	0	0	0	0	0.0	1	0.0
Adercotryma glomerata (Brady, 1878)	12	13	10	7	12	30	24	15	32	20	175	3.8	218	2.5
Ammotium cassis (Parker, 1870)	60	24	14	10	43	48	48	52	42	75	416	9.1	500	5.6

Appendix 1. (*Continued*)

Sample	ADV100 0—1	ADV100 1—2	ADV100 2—3	ADV100 3—4	ADV100 4—5	ADV100 5—6	ADV100 6—7	ADV100 7—8	ADV100 8—9	ADV100 9—10	Sum in ADV100	% of total sum ADV100	Total sum of specimens in all samples	% of total sum of specimens in all samples
Cribrostomoides crassimargo (Norman, 1892)	86	42	49	32	101	87	52	52	63	80	644	14.0	1071	12.1
Cuneata arctica (Brady, 1881)	0	0	0	0	0	21	12	19	2	2	56	1.2	171	1.9
Quinqueloculina stalkeri (Loeblich and Tappan, 1953)	1	0	0	2	0	7	4	1	2	2	19	0.4	46	0.5
Recurvoides turbinata (Brady, 1881)	37	24	15	13	17	111	83	118	77	107	602	13.1	751	8.5
Reophax scorpiurus (Montfort, 1808)	6	7	14	7	3	9	13	6	8	10	83	1.8	204	2.3
Reophax spp.	0	0	0	0	0	11	7	5	4	1	28	0.6	87	1.0
Spiroplectammina biformis (Parker and Jones, 1865)	64	59	76	26	22	157	115	143	71	39	772	16.8	1428	16.1
Spiroplectammina sp.	0	37	22	0	40	268	144	142	122	91	866	18.8	1651	18.6
Textularia earlandi (Parker, 1952)	75	20	20	36	78	44	9	22	14	11	329	7.2	673	7.6
Textularia torquata (Parker, 1952)	0	0	0	0	0	9	14	9	11	11	54	1.2	132	1.5
Trochammina nana (Brady, 1881)	0	0	0	0	0	25	15	13	15	10	78	1.7	105	1.2
Verneuilina advena (Cushman, 1922)	3	9	11	5	15	25	26	23	14	19	150	3.3	247	2.8
Total sum	393	295	264	149	360	910	603	629	491	502	4596	100.0	8886	100.0

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