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ORIGINAL ARTICLE

Recent benthic foraminifera in the Arctic Ocean and Kara Sea continental margin

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Abstract Living (stained) and dead (unstained) benthic foraminifera from the Arctic Ocean and Kara Sea continental margin have been investigated to extend the knowledge on modern living and dead benthic foraminifera in the Arctic Ocean. Three living and three dead benthic foraminiferal fauna assemblages have been distinguished based on Q-mode cluster analysis. In the seasonally ice-free Nansen Basin, a living assemblage consisting of *Ioanella tumidula–Stetsonia horvarthi* assemblage has been established. On the permanently ice covered Lomonosov Ridge and Alpha Ridge in addition to the seasonally ice-free Nansen Basin, the living assemblage is characterized by *I. tumidula–Oridorsalis tener–S. horvarthi* assemblage. The seasonally ice-free and relatively shallow Kara Sea continental margin displays a living fauna assemblage with agglutinated *Reophax* species in addition to the calcareous species *Cassidulina neoteretis*, *Epistominella nipponica*, and *Islandiella helenae*. The dead assemblages from Alpha Ridge, Lomonosov Ridge and Nansen Basin with assemblages characterized by *I. tumidula*, *O. tener* and *S. horvathi* reflect the living assemblages well. The dead fauna assemblage from the Kara Sea continental margin differs from the corresponding living assemblage by showing less agglutinated specimens and dominance by *C. neoteretis*. However, there is also a relatively good potential reconstructing paleoenvironmental change from the Kara Sea continental margin, when it is taken into account that the agglutinated species are not well preserved in the dead assemblages.

Keywords Foraminifera · Environmental parameters · Modern distribution · Paleoceanography · Arctic Ocean · Kara Sea

Introduction

The Arctic Ocean is situated on top of the northern hemisphere and is the smallest ocean of the world oceans. Most of the Arctic Ocean is perennially covered by sea ice, and only minor areas are seasonally ice-free. During the winter, the region receives no sunlight and during summer, it is exposed to midnight sun. The Arctic Ocean is key component in the global climate-ocean system, as it is an oceanic gateway from the Pacific to the North Atlantic. However, our knowledge about this ocean in the past and present is still very limited due to the logistic challenges investigating this area. The need for knowledge is pressing as the Arctic Ocean and surrounding Arctic region, has undergone large changes last decades with reduction of sea ice and increasing temperatures of the inflowing water masses (e.g., [3, 42]). To understand the mechanisms and effects of this warming, it is crucial to obtain long records of the climate changes in the past to assess the natural limits of Arctic Ocean climate system. To obtain oceanographic data (e.g., on temperature, salinity, density, acidification, nutrition, etc.) in the water masses from the past when prior to instrumental measurements of these factors, we study micro-flora and micro-fauna in the sediments in addition to geochemical parameters. The fossil flora and

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fauna depends on environmental factors such as temperature and salinity of the seawater or nutrition, thus showing how the marine environment and water masses were back in time (paleoclimatic proxy data). Previous investigations of Quaternary sediments in the Arctic Ocean have shown that siliceous fossils as diatoms are poorly preserved (e.g., [6]). Further, some calcareous fossils as coccoliths are limited to certain time intervals. However, calcareous foraminifera appear more consistently throughout the Quaternary period (Darby et al. [6]) in this region and are considered one of the most useful proxy to reconstruct past ocean environments.

To understand the fossil foraminiferal record, it is necessary to understand the modern distribution patterns of the foraminifera in the Arctic Ocean. A limited amount of studies of benthic foraminifera in surface sediments in the Arctic Ocean and adjoining seas have been carried out the last forty years: Lagoe [21], Schröder-Adams et al. [37], Scott and Vilks [35], Bergsten [2], Hald and Steinsund [11], Ishman and Foley [15], Wollenburg and Mackensen [43], Osterman et al. [25], Wollenburg and Kuhnt [44], Scott et al. [36] and Saher et al. [30, 31]. Sediment samples investigated in these studies have been collected in different ways using grab samplers, gravity coring, box coring or multi coring. Thus, the quality of the surface sediments samples may vary, and some of the samples such as core tops from gravity cores and grab samples might not reflect the upper few centimeters of sea floor surface. Different size fractions have also been investigated in the previous studies of modern benthic foraminifera in the Arctic Ocean. Mainly, the >63 μm size fraction has been used analyzing benthic foraminifera [2, 21, 35, 37, 43, 44]. However, in paleoceanographic reconstructions from the Arctic Ocean, most studies have used >125 or >150 μm (e.g., [16, 17, 25, 29]). Additionally Wollenburg et al. [45] and Cronin et al. [5] used >63 μm size fraction. Staining of the living specimens has only been performed in some of the studies of modern benthic foraminifera: Schröder-Adams et al. [37], Bergsten [2], Hald and Steinsund [11], Wollenburg and Mackensen [43], Wollenburg and Kuhnt [44], Scott et al. [36] and Saher et al. [30, 31] Furthermore, only some of these studies have distinguished between stained (living) and not stained (dead) fauna assemblages counting at least 300 specimens from each group (e.g., Wollenburg and Mackensen [43], Wollenburg and Kuhnt [44]. The studies found that environmental parameters such as water depth, type of substrate and water mass characteristics are not the main factors ruling the distribution of modern benthic foraminifera. Some species and assemblages are, however, mainly controlled by food availability [43, 44].

The overall aim of this study is to extend the knowledge on modern benthic foraminifera in the Arctic Ocean distinguishing between living and dead fauna assemblages on the >100 μm size fraction.

Study area

Overall, the Arctic Ocean consists of two large basins; the Amerasian and Eurasian Basins which are separated by the Lomonosov Ridge reaching a maximum depth of ca 1870 m [19]. The Amundsen and Nansen Basins are found within the Eurasian Basin separated by the Gakkel Ridge (Figs. 1, 2). In the Amerasian Basin, an additional ridge, the Alpha Ridge is situated (Fig. 2). The basins are more than 3000 m deep. The Arctic Ocean is surrounded by shelf seas, and the Fram Strait is the only deep connection to the Arctic Ocean (e.g., [18]). The Arctic Ocean is perennially covered by sea ice except for large parts of the Fram Strait region and the southern Nansen Basin that are ice-free in summer (Fig. 1). This is due to the inflow of warm Atlantic water masses entering the Arctic Ocean through the Fram Strait and the Barents Sea (e.g., [1, 34]). There are generally three main water masses in the Arctic Ocean. The surface water masses that are homogenized during winter

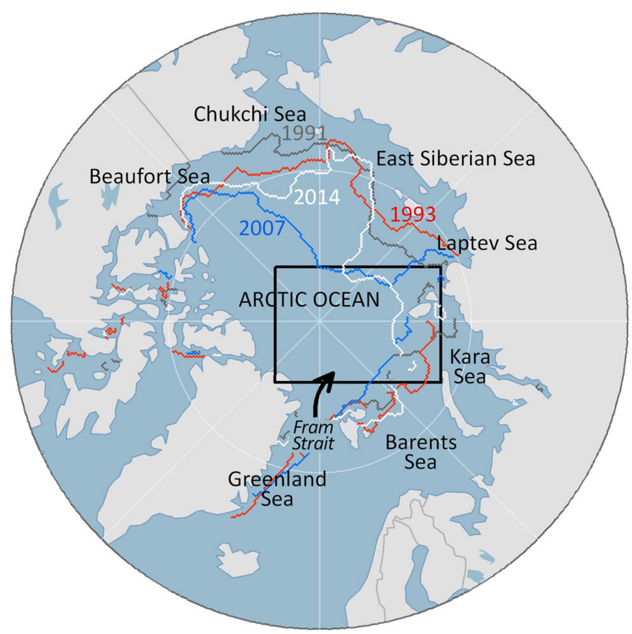


Fig. 1 Map of the Arctic Ocean and adjoining seas. *Black square* the investigation area that are shown in Figs. 2 and 5. *Black arrow* the inflow of Atlantic water to the Arctic Ocean. The sea ice extent in September from various years is also shown; 2014 (*white line*), 2007 (*blue line*), 1993 (*red line*), and 1991 (*gray line*). The sea ice extent is based on data from National Snow and Ice Data Center (NSIDC). These years were chosen as they are the sampling year of the current study (2007) and the sampling years (1991, 1993) of Wollenburg and Mackensen [43]

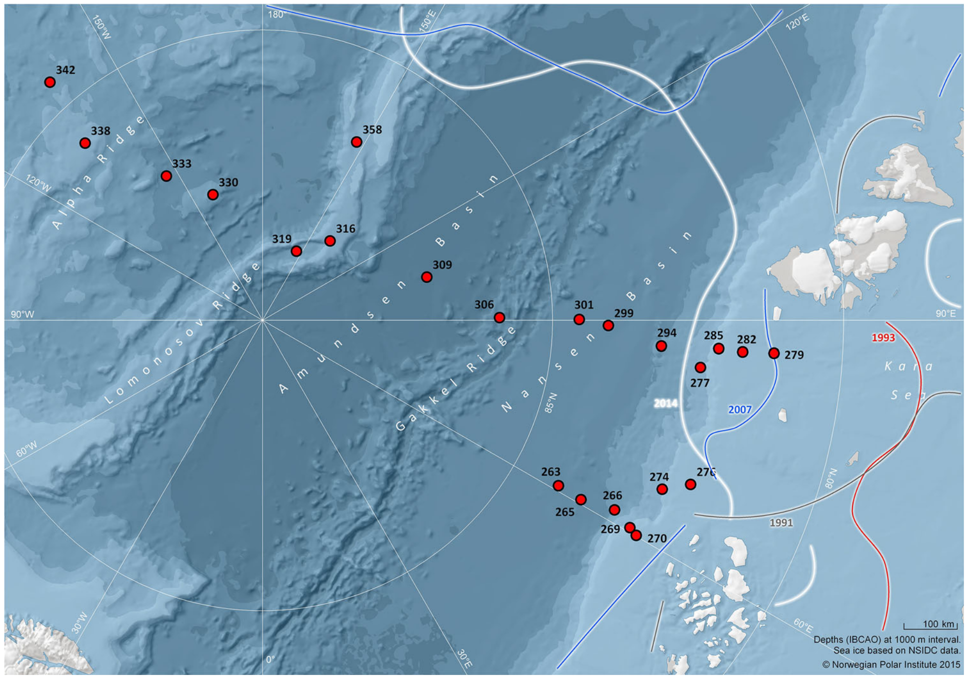


Fig. 2 Bathymetric map showing the positions of the sampling stations in addition to the September sea ice extent from 2014 (*white line*), 2007 (*blue line*), 1993 (*red line*), and 1991 (*gray line*). The sea ice extent is based on data from National Snow and Ice Data Center (NSIDC)

by freezing and brine release and during the summer are stratified by seasonal melt water (e.g., [26]). Below the surface water masses is the intermediate water masses of warmer and more saline Atlantic water. Underneath these water masses is the bottom waters in the basins [26]. The surface water masses are cold (−2 to 0 °C) and less saline (32–34 psu). The temperatures of the intermediate water masses are between 0 and 2 °C with a salinity from 34.7 to 35 psu [28]. The bottom water masses found deeper than 600–800 m show temperatures from −0.9 to 0 °C and a salinity around 34.9 psu [28].

Materials and methods

Twenty-three surface sediment samples were collected with RV "Polarstern" in August and September 2007 using a giant box corer during the ARK XXII-2 cruise in 2007 (Table 1). The upper 0–1 cm was sampled and preserved in unbuffered ethanol (96 %) with Rosa Bengal stain in cold storage for at least 14 days before further preparation. A separate bulk sample was also taken from the upper 0–1 cm of the box core to determine the content of organic (TOC) and total carbon ($CaCO_3$) in addition to grain size (Fig. 3). The samples were wet sieved at the >1 mm, >100 and >63 µm size fractions and dried at room temperature for 24 h. Only specimens with at least one clearly stained chamber were identified as stained specimens. The foraminiferal samples were counted at the size fraction 0.1–1.0 mm enabling direct comparisons with previous studies of recent foraminifera from Svalbard and the adjoining Barents Sea [11, 12, 30] in addition to ensure a robust taxonomy which may be difficult to obtain using the >63 µm size fraction. At least 300 living specimens and at least 300 dead specimens were identified and counted for each sample. Both living and dead assemblages are presented to investigate the living foraminifera and their modern environmental preferences in addition to identify any post-mortem changes of the fauna. In samples where it was not possible to obtain 300 specimens, only samples containing at least 100 living or 100 dead specimens were included when calculating relative and quantitative abundances (Appendix 1). Only species constituting at least 1 % of the total fauna in at least two samples were included in an unweighted pair-group average R-mode clustering analysis using Euclidean distance (Fig. 4). The species diversity was investigated using the Fisher alpha diversity index [9] in addition to the Shannon–Wiener diversity index H(S) [14, 38]). The cluster analysis and calculation of the diversity indices were carried out using the PAST software, version 2.17c [13].

Results

Surface sediments

The sediment samples consist of mainly clay and silt that constitute an average value of 90 % (Fig. 3). Two stations from Alpha Ridge (338, 342) differ from the others containing, respectively, 65 and 62 % clay and silt. The sampling stations differ with regard to the content of

Table 1 List of the stations and their geographical coordinates and water depth in addition to the bottom water temperature and salinity [33]

Area	St.	Latitude	Longitude	Water depth (m)	Bottom water temp (°C)	Salinity (psu)	LFA	DFA
Nansen Basin	263	84°09.45′N	60°51.42′E	3700	−0.9	34.9	1	2
Nansen Basin	265	83°42.17 N	60°39.26′E	3538	No data	No data	1	2
Nansen Basin	266	83°06.62′N	61°43.92′E	2995	−0.9	34.9	1	Outlier
Kara Sea continental margin	269	82°44.01′N	60°35.96′E	864.1	0.7	34.9	3	3
Kara Sea continental margin	270	82°34.45'N	60°06.78′E	324.9	0.3	34.9	3	3
Kara Sea continental margin	274	82°31.54′N	67°07.18′E	1187	−0.5	34.9	3	3
Kara Sea continental margin	276	82°06.18′N	69°04.00′E	686.9	0.3	34.9	Outlier	3
Kara Sea continental margin	277	82°24.57′N	83°52.21′E	1564	−0.7	34.9	Outlier	Outlier
Kara Sea continental margin	279	81°10.38′N	86°18.98′E	309.4	−0.4	34.9	3	3
Kara Sea continental margin	282	81°42.72′N	86°13.68′E	361.9	−0.4	34.9	3	3
Kara Sea continental margin	285	82°07.47′N	86°27.05′E	677.2	−0.4	34.9	3	3
Nansen Basin	294	83°06.65′N	86°17.95′E	3148	−0.9	34.9	1	2
Nansen Basin	299	84°02.22′N	89°06.07′E	3696	−0.9	34.9	2	2
Nansen Basin	301	84°32.31′N	90°07.17′E	3762	−0.9	34.9	2	2
Gakkel Ridge	306	85°54.71′N	90°36.13′E	4079	−0.9	34.9	Na	Na
Amundsen Basin	309	87°04.18′N	104°39.56′E	4443	−0.9	34.9	Outlier	2
Lomonosov Ridge	316	88°12.24′N	139°27.58′E	1335	−0.4	34.9	2	1
Lomonosov Ridge	319	88°40.51′N	153°44.06′E	2746	−0.7	34.9	2	Outlier
Alpha Ridge	330	87°40.49′N	158°26.95′W	2460	No data	No data	2	1
Alpha Ridge	333	87°00.82′N	146°17.49′W	3368	−0.5	34.9	Outlier	1
Alpha Ridge	338	85°40.92′N	134°54.90′W	1567	−0.5	34.9	Na	1
Alpha Ridge	342	84°30.24′N	138°12.84′W	2262	−0.5	34.9	Na	1
Lomonosov Ridge	358	86°31.54′N	152°05.98′E	1467	−0.4	34.9	2	1

It is also shown which assemblages the station belongs to (LFA/DFA)

Na not applicable due to too few specimens

$CaCO_3$ that fluctuates between 1 and 24 % (Fig. 3). The highest values from 14 to 24 % are found on Alpha Ridge (stations 330, 333, 338, 342). The other sampling stations show variating values regardless of the water depths. The content of total organic carbon (TOC) is between 0.2 and 1.4 %. The sampling stations show an overall trend of decreasing TOC values from the Kara Sea Shelf across the Nansen and Amundsen Basins towards the Alpha Ridge (Fig. 3). The stations on Alpha Ridge show the lowest values of TOC found in this study (0.2–0.4 %).

Foraminifera

Twenty-three samples were analyzed with regard to living and benthic foraminifera. Three sampling stations contained less than 100 living (stained) specimens, but all sampling stations except St. 306 contained more than 100 dead specimens (Appendix 1). The living fauna showed 5–38 species and the dead fauna 8–41 species (Table 2). The benthic foraminiferal concentration varies from 61 to 1274 specimens/10 cm^3 sediment for the living fauna to 225–21030 spec./10 cm^3 sed. for the dead fauna (Table 2). Three living and three dead fauna assemblages were identified using cluster analysis (Fig. 4). The clusters of living and dead assemblages are relatively similar, yet with some differences. The living fauna assemblages encompass larger geographical areas, whereas the dead fauna assemblages are more restricted (Fig. 5).

Living fauna

The cluster analysis of the living benthic foraminiferal fauna recognized three clusters and four outliers (Figs. 4a, 5a). The first cluster (1) consists of four stations from the Nansen Basin (stations 263, 265, 266 and 294), The cluster (1) is dominated by *Ioanella tumidula* with up to 39 % (Fig. 6a). Other frequent species with more than 10 % abundance are *Stetsonia horvathi*, *Reophax fusiformis* and *Jaculella* sp. (Fig. 6a; Appendix 1). Cluster 1 contains between 14 and 23 species. The diversity indices Fisher alpha and H(S) are between 4–10 and 2, respectively (Table 2). Cluster 2 is found in Nansen Basin and on the Alpha Ridge in addition to

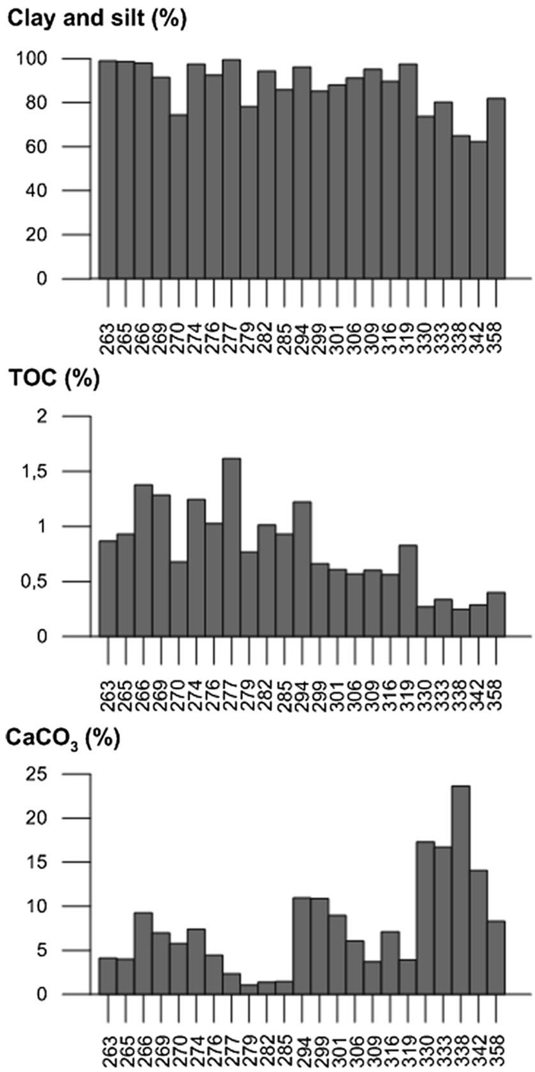


Fig. 3 Sedimentological parameters

Lomonosov Ridge (stations 299, 301, 316, 319, 330, 358). This cluster is heavily dominated of *I. tumidula* (38–68 %). *Oridorsalis tener* constitutes between 2 and 23 %, whereas *S. horvathi* constitutes zero to 13 % (Fig. 6a). The number of species is 5–16. Fisher alpha is 1–5 and H(S) is 1 (Table 2). One outlier is found in Amundsen Basin, station 309, and is characterized by *Aschemonella* sp. 1 (Fig. 4a; Appendix 1). The fourth outlier is found on Alpha Ridge (station 333) and is dominated by *I. tumidula* and *O. tener*. Cluster 3 contains 6 stations from the Kara Sea continental margin (stations 269, 270, 274, 279, 282, 285). Cluster 3 differs from cluster 1 by being dominated by *Reophax* spp. which variates between 6 and 34 % (Figs. 4a, 6b). *R. guttifer* and *Sacamminna atlantica* are also abundant with average frequencies around 4 %. *C. neoteretis* also characterizes cluster 3 with an average abundance around 7 % (Fig. 6a). Other characteristic calcareous species are *Epistominella nipponica* and *Islandiella helenae* with average abundances between 3 and 4 %

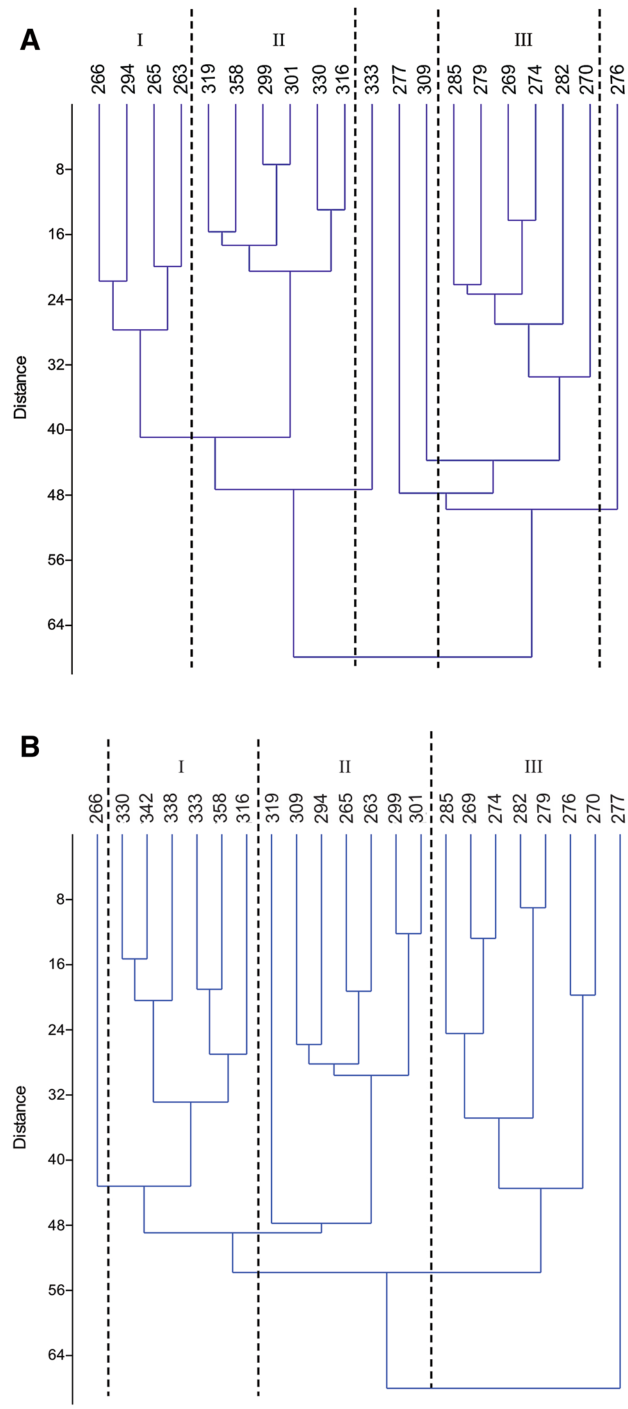


Fig. 4 **a** Q-mode cluster analysis of the living fauna assemblages. The numbers on the *x* axis are referring to the station numbers, and the roman numbers (*I, II, II*) refer to the cluster. The samples outside the clusters are outliers. **b** Q-mode cluster analysis of the dead fauna assemblages. The numbers on the *x* axis are referring to the station numbers, and the roman numbers (*I, II, II*) refer to the cluster. The samples outside the clusters are outliers

(Appendix 1). The diversity indices are different from cluster 1 by a higher number of species (28–38). The diversity indices also increase to 13–24 for Fisher alpha and 2–3 for

Table 2 Overview of benthic foraminiferal concentration (specimens/10cm^3), number of species and the diversity indices Fisher alpha and H(S) for each sample (both living and dead assemblages)

Area	St.	Living				Dead			
		Spec./10 cm^3	No. of species	Fisher alpha	H(S)	Spec./10 cm^3	No. of species	Fisher alpha	H(S)
Nansen Basin	263	126	18	6	2	326	27	12	2
Nansen Basin	265	61	14	4	2	534	20	8	2
Nansen Basin	266	120	17	6	2	225	20	8	2
Kara Sea continental margin	269	459	32	17	3	3238	35	24	3
Kara Sea continental margin	270	1274	30	16	3	21,030	41	29	2
Kara Sea continental margin	274	173	38	24	3	1656	36	22	2
Kara Sea continental margin	276	124	12	4	2	1100	11	3	2
Kara Sea continental margin	277	466	24	10	2	460	22	9	2
Kara Sea continental margin	279	254	30	16	3	968	34	19	3
Kara Sea continental margin	282	177	28	15	3	374	33	18	3
Kara Sea continental margin	285	680	28	13	2	1472	34	20	3
Nansen Basin	294	154	23	10	2	762	25	12	3
Nansen Basin	299	130	11	3	1	1269	28	13	2
Nansen Basin	301	212	10	3	1	1257	21	8	2
Gakkel Ridge	306	4	Na	Na	Na	140	Na	Na	Na
Amundsen Basin	309	65	17	6	2	272	18	7	2
Lomonosov Ridge	316	465	13	4	1	1311	25	11	3
Lomonosov Ridge	319	140	16	5	1	512	23	10	2
Alpha Ridge	330	187	5	1	1	6528	14	5	2
Alpha Ridge	333	111	11	3	1	1018	16	5	2
Alpha Ridge	338	24	Na	Na	Na	2703	8	2	1
Alpha Ridge	342	0	Na	Na	Na	1437	10	3	1
Lomonosov Ridge	358	259	8	2	1	2208	14	4	2

Na not applicable due to too few specimens

H(S) (Table 2). The remaining two stations from the Kara Sea Margin (stations 276 and 277) were identified as outliers (Fig. 4a), and they are each strongly dominated by two different species: *Cassidulina neoteretis* (40 %) and *Hormosinella guttifera* (41 %).

Dead fauna

Three clusters and three outliers were identified when the cluster analysis was performed on the dead benthic foraminiferal fauna (Figs. 4b, 5b). Cluster 1 includes only stations from the Lomonosov Ridge and Alpha Ridge (stations 316, 330, 333, 338, 342, and 358). Cluster 1 is distinguished by *I. tumidula* and *O. tener* with average abundances of 28 and 26 % (Fig. 6a). *Cibicides wuellerstorfi* is also very frequent with 2–30 %. The number of species varies between 8 and 25. Fisher alpha and H(S) are 2–11 and 1–3. An outlier, station 319, is situated on Lomonosov Ridge and is dominated by *Epistominella arctica*. The next cluster (2) includes the stations from Nansen Basin and Amundsen Basin (stations 263, 265, 294, 299, 301, and 309). This cluster (2) is characterized by *S. horvathi* (17–34 %) in addition to *I. tumidula* and *Triloculina frigida* that both occur with an average abundance of 9 % (Figs. 4a, 6a). Different *Aschemonella* species are also relatively frequent in this cluster. The number of species varies from 20 to 27. Fisher alpha is 7–12 and H(S) is 2–3. The outliers from the Kara Sea continental margin (stations 266 and 277) are dominated by *Adercotryma glomeratum* and *R. guttifer* (Fig. 6b). The last cluster (3) is restricted to stations on the Kara Sea continental margin (stations 269, 270, 274, 276, 279, 282, 285). This cluster is mainly dominated by *C. neoteretis* with an average frequency around 29 %. The cluster is also defined by *R. guttifer* and *S. atlantica* with average abundances of 10 and 6 % (Fig. 6a, b). Another frequent species are *Placopsilinella aurantiaca*, *I. helenae* and *Reophax* spp. reaching up to 8, 9 and 17 %, respectively. This cluster (3) is also characterized by 11–41 species. The diversity indices Fisher alpha and H(S) are 3–29 and 2–3, respectively (Table 2).

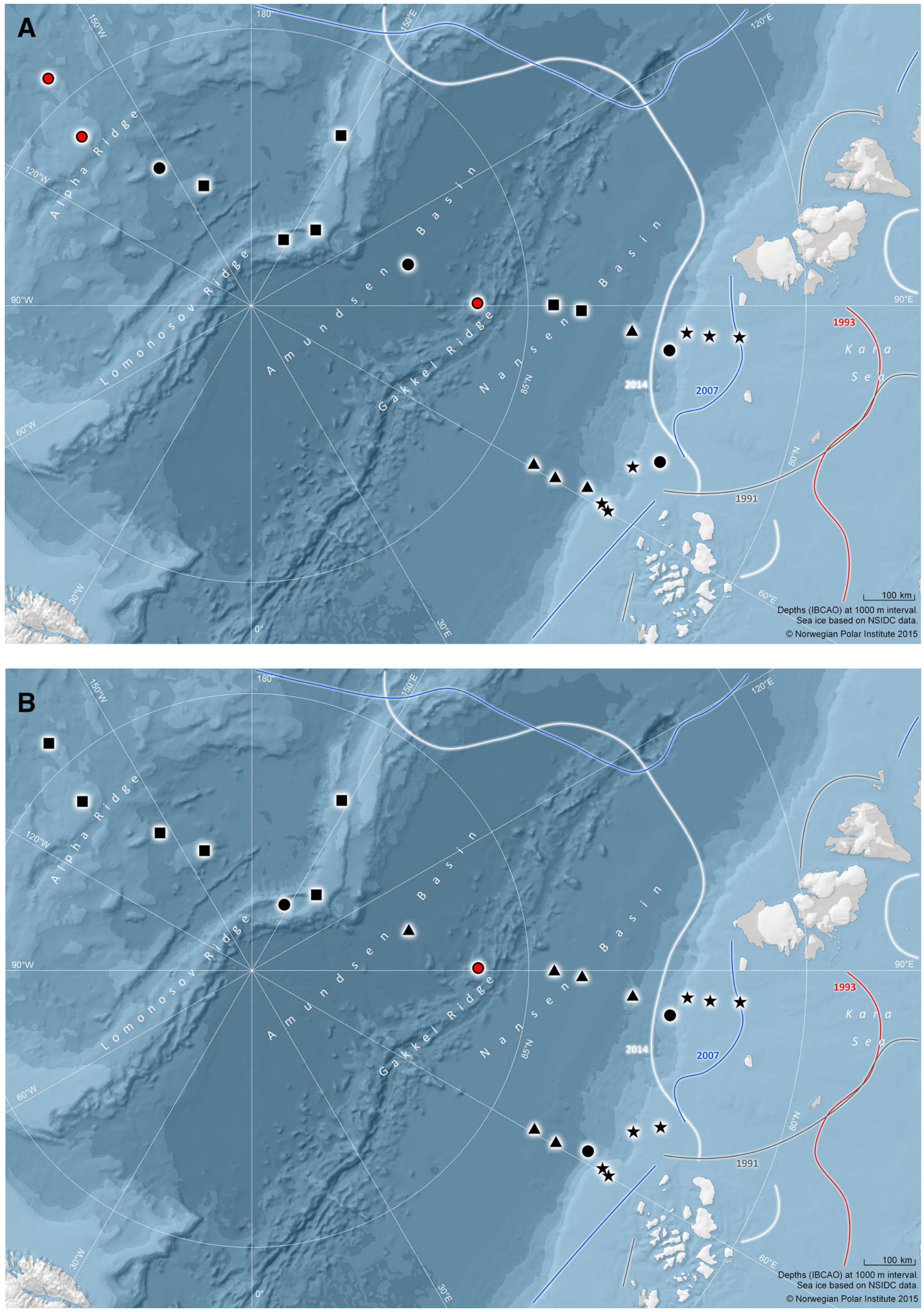


Fig. 5 **a** Bathymetric map showing the positions of the sampling stations and indicating which clusters they belong to (living fauna assemblages). *Red circles* the stations that were not included in the cluster analysis due to too few specimens (<100 specimens). *Black filled circles* the outliers. *Triangles* living foraminiferal (LF) assemblage LFA1; *filled squares* assemblage LFA2; *asterisks* assemblage LFA3. September sea ice extent from 2014 (*white line*), 2007 (*blue line*), 1993 (*red line*), and 1991 (*gray line*) are also shown. The sea ice extent is based on data from National Snow and Ice Data Center (NSIDC). **b** Bathymetric map showing the positions of the sampling stations and indicating which clusters they belong to (dead fauna assemblages). *Red circle* the station that was not included in the cluster analysis due to too few specimens (<100 specimens). *Black filled circles* the outliers. *Filled squares* dead foraminiferal (DF) assemblage DFA1; *triangles* assemblage DFA2; *asterisks* assemblage DFA3. September sea ice extent from 2014 (*white line*), 2007 (*blue line*), 1993 (*red line*), and 1991 (*gray line*) are also shown. The sea ice extent is based on data from National Snow and Ice Data Center (NSIDC)

Discussion

Three living fauna assemblages (LFA1, 2, 3) and three dead fauna assemblages (DFA1, 2, 3) have been identified. In this paragraph, the distribution of living fauna assemblages will be discussed with regard to the modern environmental parameters, and the dead fauna assemblages will be compared to the living assemblages discussing their potential use in paleoceanographic reconstructions.

Living fauna assemblages and modern environmental parameters

The bottom water temperature at the sampling stations varies between −0.9 and −0.4 °C, except one measurement from the Kara Sea continental shelf at 0.7 °C (Table 1). The salinity of the bottom water masses is very stable at 34.9 psu for all stations. Hence, the different fauna assemblages, with the Kara Sea continental shelf as a

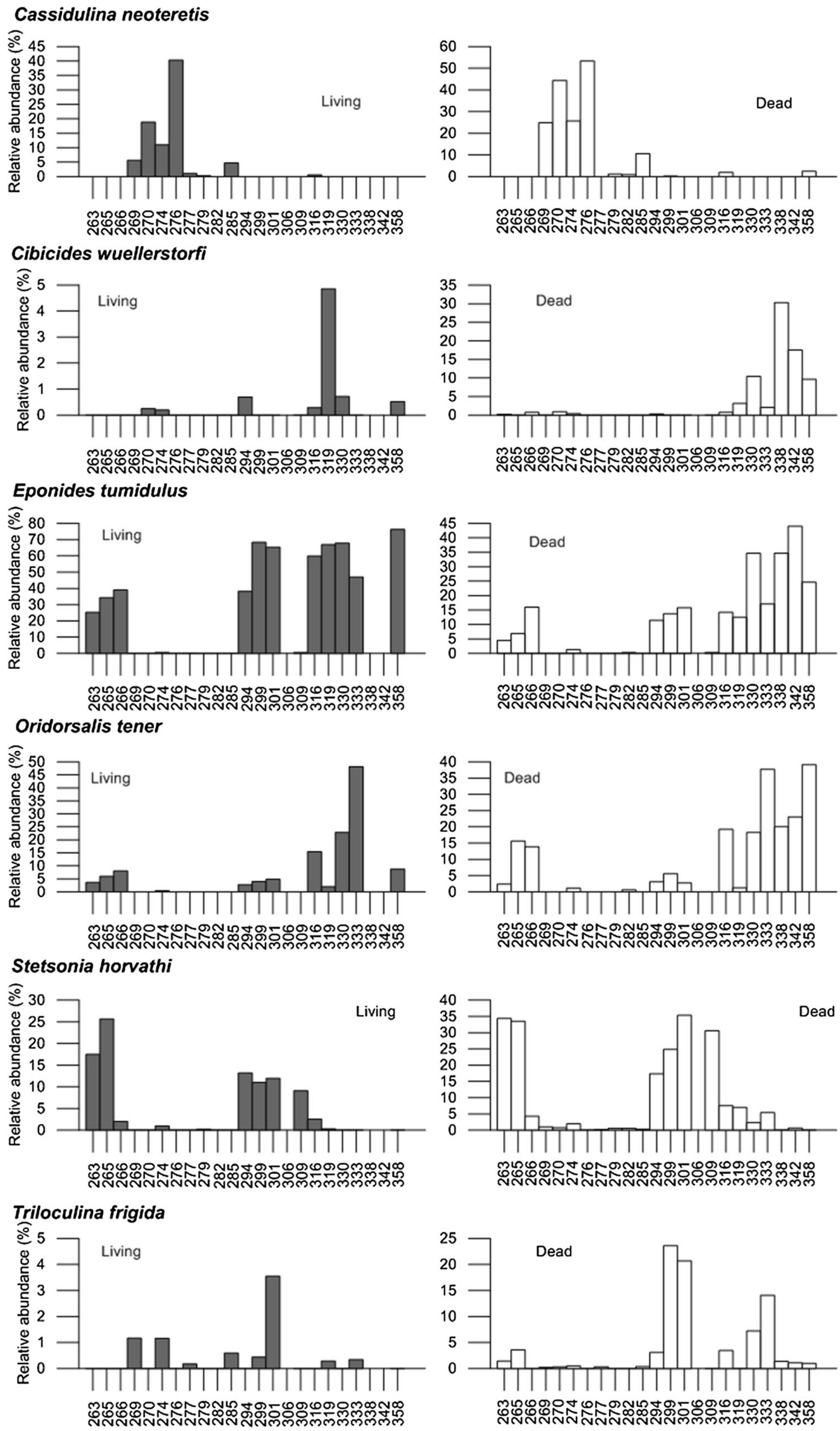
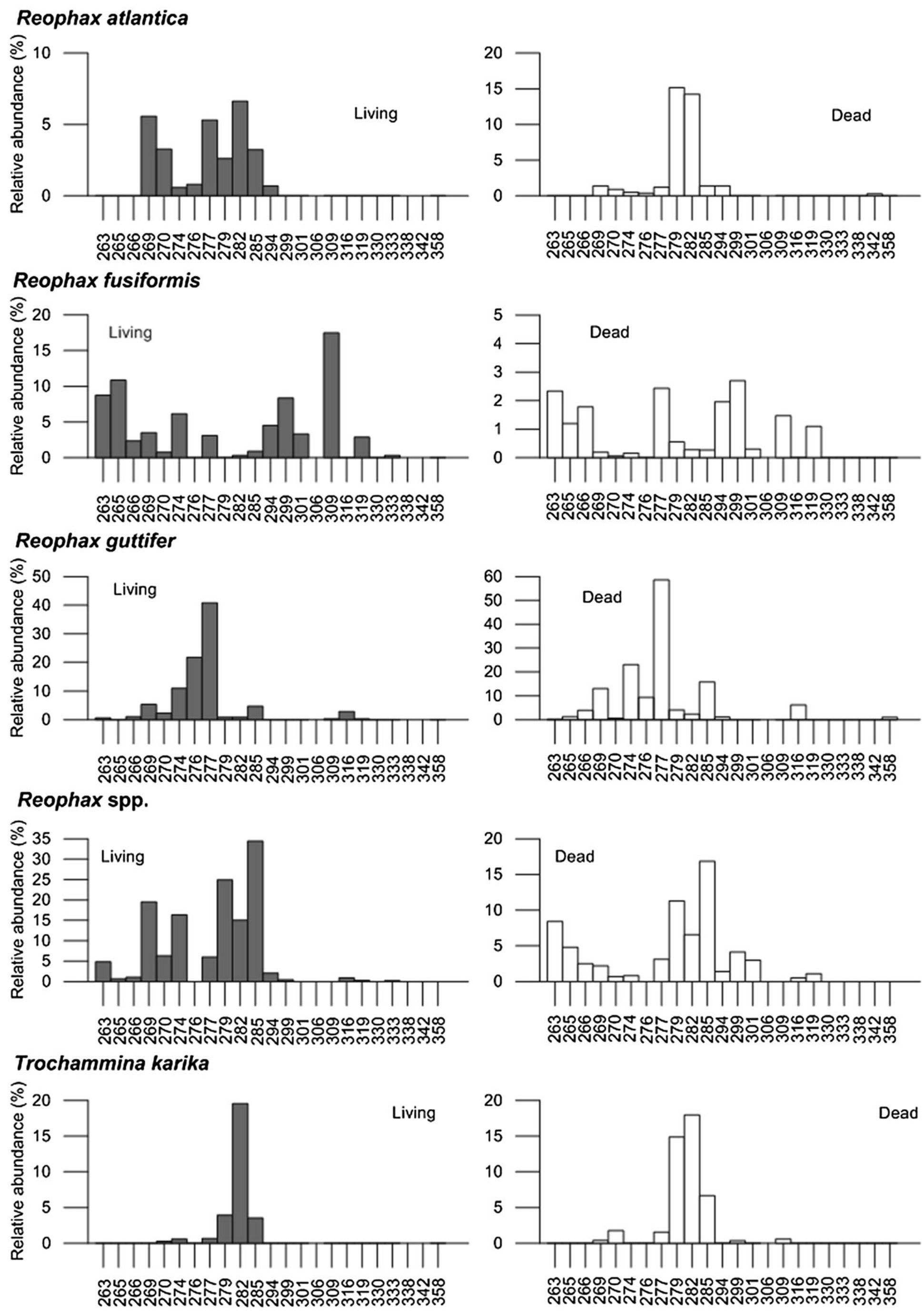


Fig. 6 **a** The relative abundance of the most frequent calcareous species living and dead. The selected species occur with 10 % in at least two stations. **b** The relative abundance of the most frequent agglutinated species living and dead. The selected species occur with 10 % in at least two stations

Fig. 6 continued



possible exception, seem not to be ruled by different temperatures or salinities. The sediment at the sampling stations is dominated by clay and silt except stations 338 and 342. Those stations containing very few living foraminifera are the sampling time, and it was not possible to carry out quantitative robust analysis of these two stations. This was feasible with the dead fauna; however, the stations do not differ with regard to fauna from stations dominated by clay and silt (Fig. 3). The three living assemblages are found within three partially different water depth intervals; 3000–3700 m (LFA1), 1300–3700 m (LFA2), and 300–1200 m (LFA3). Furthermore, the TOC content also show partial differences between the three living fauna assemblages. LFA1 is characterized by a TOC content from 0.9 to 1.4 %, whereas LFA2 show 0.3–0.7 % and LFA3 0.7–1.3 % (Fig. 2). The content of TOC in the sediments of the Arctic Ocean does usually not reflect the primary production of the water masses due to the large input of terrestrial organic from the surrounding shelf and coastal seas to the Arctic Ocean (e.g., [39, 40]); however, we chose to display these values as part of the other environmental parameters for each foraminiferal assemblage. The first living fauna assemblage 1 (LFA1) is found in the Nansen Basin in water depths from ca. 3000 to 3700 m and an average TOC content of ca. 1 %. The most abundant species *I. tumidula* has previously been found at shallower water depths between 1500 and 3000 m in seasonally ice-free areas and even shallower under permanent ice cover by Wollenburg and Mackensen [43], yet its current occurrence is within seasonally ice-free areas as well (Figs. 2, 5a). It is important to note that the current study investigated a different size fraction than Wollenburg and Mackensen [43]. The latter investigated both the 63–125 and >125 µm size fractions using >125 mm size fraction for discussing the living foraminifera. Hence, direct comparisons of the >100 µm size fraction (this study) may not be robust. The other frequent species *S. horvarthi* was reported by Wollenburg and Mackensen [43] as only occurring in permanent ice covered areas and below 2700 m.

LFA2 is found on Lomonosov Ridge, Alpha Ridge, and in the Nansen Basin in water depths from ca 1300 to 3700 m. The average TOC content is ca. 0.6 %. LFA2 is also dominated by *I. tumidula* as LFA1, yet in LFA2 *I. tumidula* dominates together with *O. tener* and *S. horvarthi*. These findings of *E. tumidulus* and *S. horvathi* in LFA2 are in accordance with the findings by Wollenburg and Mackensen [43] as the shallow stations are under permanent ice cover and the deepest stations are within seasonally ice-free areas in the Nansen Basin (Figs. 2, 5a). Wollenburg and Mackensen [43] have observed the additional frequent species *O. tener* in nearly the same water depths as the current fauna assemblage. They assumed that *O. tener* is better adapted to oligotrophic conditions than *I. tumidula*, and food availability and competition seemed to be ruling the occurrence and frequency of *O. tener* [43]. The current study may also seem to indicate this as the stations of LFA2 contain slightly lower values of TOC than LFA1. Wollenburg and Mackensen [43] found that in general the living foraminiferal assemblages in the Arctic Ocean to be ruled by food availability and competition for food.

The last living fauna assemblage (LFA3) is confined to the seasonally ice-free Kara Sea continental margin (300–1200 m water depth) showing an average TOC value of ca. 1.0 %. One station shows relatively warmer bottom water temperatures (St. 269) than the others in LFA3 (Table 1), yet the fauna does not differ from the other colder stations (Appendix 1). LFA3 is dominated by agglutinated species, namely several *Reophax* species. The *Reophax* species are generally found in many different environments; however, they belong to a morphogroup (C1 cf. [23]) that is mainly found in marginal marine and shelf to upper slope marine environments [23]. This is in accordance with the current study, where the *Reophax* species are found on the shelf and upper slope (Fig. 5a). The calcareous species *C. neoteretis*, *E. nipponica*, and *I. helenae* are also found living in this assemblage. The same assemblage is also found living in the adjoining Barents Sea in seasonally ice-free areas. Here, *C. neoteretis* is linked to inflow of cooled Atlantic water [41]. It has also been found to thrive in areas with pulses of fresh phytodetritus [10]. *E. nipponica* has been characterized as a "warm" species [11]; however, it is morphologically very similar to *Alabaminella weddellensis*. This species has a wide temperature range, but it is similar to *C. neoteretis* preferring pulses of fresh phytodetritus [10]. *I. helenae* and *Islandiella norcross* (not differentiated as individual species) have also been linked to the sea ice margin together with in the Barents Sea where there is a high food supply [11]. Hence, this fauna assemblage is most probably ruled by the high food supply facilitated by nearby marginal ice zones and the associated high biological productivity [32].

Dead vs living fauna assemblages

The three dead fauna assemblages are also found within three partially different water depth intervals; 1300–3400 m (DFA1), 3100–4400 m (DFA2), and 300–1200 m (DFA3). The TOC values also differ somewhat between the assemblages. They are on average 0.3 % (DFA1), 4.4 % (DFA2), and 1.0 % (DFA3).

The first dead fauna assemblage (DFA1) is found on the Lomonosov Ridge and Alpha Ridge, and is characterized by *I. tumidula* and *O. tener* in addition to *C. wuellerstorfi* (Fig. 5b; Appendix 1). *I. tumidula* and *O. tener* are also found in the living fauna assemblage (LFA2) in these areas except *S. horvathi* is reduced and *C. wuellerstorfi* is more prominent in the dead assemblage than in the living one. This can be due to the time of sampling (August and September 2007) which represents a snapshot of the yearlong assemblage. It could also be due to reworking and accumulation of dead *C. wuellerstorfi*.

In Amundsen Basin and Nansen Basin, the dead fauna assemblage 2 (DFA2) consists of *S. horvathi* and *I. tumidula* which are found in the two living fauna assemblages from these basins (LFA1, LFA2). The abundances of the most frequent species differ though between dead and living fauna assemblages resulting in different clusters. The abundance of *T. frigida* has increased in the dead fauna assemblage compared to the living assemblages making it one of the most frequent species in DFA2. This species has been found living found together with *S. horvathi* and *I. tumidula* in low productivity areas in the Arctic Ocean where it is believed to be influenced by food availability and competition [43]. Several different *Aschemonella* species also occur in higher numbers dead than living in the Amundsen Basin and Nansen Basin. These "primitive" species were also found living by Wollenburg and Mackensen [43] in permanently ice covered oligotrophic areas below depths of 3000 m that is in accordance with the current study.

The last dead fauna assemblage 3 (DFA3) is restricted to the Kara Sea continental margin (Fig. 5b) and encompasses the same stations as LFA3 (except station 276 which is an outlier in the living fauna assemblages). The difference between DFA3 and LFA3 is that the calcareous *C. neoteretis* is now the most frequent species, and the *Reophax* species are second. This is probable due to the low preservation potential of agglutinated species when dead (e.g., [7]). When comparing DFA3 and LFA3, *P. aurantiaca* appears more frequently in the dead fauna assemblage compared to the living fauna assemblage. This species has been found living in the Arctic Ocean in permanently ice covered areas in water depths from 1000 to 4000 m [43]. The current results are from seasonally ice-free areas and water depths from 1200 to 300 m water depth. *P. aurantiaca* was associated with local increased primary production in the Peru Trench [27] which could explain its presence on the Kara Sea continental margin with a higher primary production.

Conclusions

Twenty-three samples from the Arctic Ocean and Kara Sea continental margin have been investigated with regard to living (stained) and dead (unstained) benthic foraminifera. A high abundance of well-preserved dead benthic foraminifera and a relatively high number of living benthic foraminifera have been found. Using Q-mode cluster analysis of living and dead benthic foraminifera, three living and three dead benthic foraminiferal fauna assemblages have been identified. The different assemblages are not distinguished by different water mass temperatures nor salinities but probably food supply (cf. [43, 44]). In the seasonally ice-free Nansen Basin between ca. 3000 and 3700 m water depth, the *I. tumidula–S. horvarthi* assemblage (LFA1) has been observed. On the permanently ice covered Lomonosov Ridge and Alpha Ridge in addition to the seasonally ice-free Nansen Basin, the assemblage changes to the *I. tumidula–O. tener–S. horvarthi* assemblage (LFA2). The seasonally ice-free and relatively shallow Kara Sea continental margin (300–1200 m water depth) is characterized by a living fauna assemblage (LFA3) consisting of agglutinated *Reophax* species in addition to the calcareous species *C. neoteretis*, *E. nipponica*, and *I. helenae*. This fauna assemblage probably reflects a high food supply associated with the sea ice margin.

The dead assemblages (DFA1 and DFA2) reflect the living assemblages from Alpha Ridge, Lomonosov Ridge and Nansen Basin with assemblages characterized by *I. tumidula*, *O. tener* and *S. horvathi*. This suggests that there is a good potential for robust paleoenvironmental reconstruction from Alpha Ridge, Lomonosov Ridge and Nansen Basin. The dead fauna assemblage (DFA3) from the Kara Sea continental margin differs from the corresponding living assemblage (LFA3) by showing less agglutinated specimens and is dominated by *C. neoteretis*. However, there is also a relatively good potential for reconstructing paleoenvironmental changes from the Kara Sea continental margin, when it is taken into account that the agglutinated species are not well preserved in the dead assemblages.

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Appendix 1

See Tables 3 and 4.

Table 3 Living (stained) foraminiferal abundances (>1%)

Station	263	265	266	269	270	274	276	277	279	282	285	294	299
Adercotryma glomerata	0.3	0.3	16.3	0.2	0.0	0.4	0.0	2.4	4.7	5.7	1.2	3.5	0.0
Adercotryma abyssorum	0.6	0.0	0.0	0.7	0.0	2.9	0.0	14.9	0.0	0.9	1.5	2.8	0.9
Aschemonella sp. 1	3.6	3.9	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
Aschemonella sp. 2	0.0	0.3	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.3	0.0	7.6	0.0
Aschemonella sp. 3	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Buccella frigida	0.0	0.0	0.0	1.6	1.5	0.0	0.0	0.0	4.2	0.3	1.2	0.0	0.0
Buccella tenerrima	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0
Cassidulina laevigata	0.0	0.0	0.0	0.0	0.3	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3 continued

Station	263	265	266	269	270	274	276	277	279	282	285	294	299
Cassidulina neoteretis	0.0	0.0	0.0	5.6	18.8	11.0	40.3	1.0	0.3	0.0	4.7	0.0	0.0
Cassidulina reniforme	0.0	0.0	0.0	1.2	3.0	0.0	3.2	0.5	1.0	0.6	2.6	0.0	0.0
Cibicides lobatulus	0.0	0.0	3.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cibicides wuellerstorfi	0.0	0.0	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Deuterammina grisea	0.6	1.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.6	0.0	0.3	2.6
Elphidium excavatum f. *clavata*	0.0	0.0	0.0	0.0	1.0	0.2	0.0	0.0	6.6	5.1	0.0	0.0	0.0
Epistominella arctica	0.6	0.0	0.0	0.5	0.0	0.8	2.4	0.3	1.0	0.6	0.0	2.1	0.9
Epistominella nipponica	0.0	0.3	0.0	6.0	16.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haplophragmoides subglobosum	0.0	0.0	2.3	0.7	0.5	0.6	4.8	0.3	0.0	0.0	0.0	0.0	0.0
Hippocrepinella hirudinea	0.0	0.0	0.0	0.5	0.5	1.2	0.0	0.0	0.0	4.5	0.9	0.0	0.0
Hormosinella distans	0.0	0.0	0.0	0.0	0.0	1.0	2.4	2.1	0.0	0.0	0.3	0.0	0.0
Ioanella tumidula	25.3	34.2	39.0	0.0	0.0	0.6	0.0	0.2	0.0	0.0	0.0	38.2	68.3
Islandiella helenae	0.0	0.0	0.0	4.4	7.5	2.9	0.0	0.0	0.3	0.0	6.5	0.0	0.0
Islandiella islandica	0.0	0.0	0.0	0.9	10.1	0.8	0.0	0.0	0.5	0.6	0.0	0.0	0.0
Islandiella norcrossi	0.0	0.0	0.0	0.5	1.3	0.0	6.5	0.0	0.3	0.0	0.3	0.0	0.0
Jaculella sp.	14.8	5.9	0.7	4.2	0.5	4.6	0.0	0.9	0.8	4.8	0.9	1.4	0.0
Oridorsalis tener	3.6	5.9	8.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.8	4.0
Psammosphaera fusca	0.6	0.0	1.3	2.3	0.3	2.7	2.4	0.0	4.7	2.7	0.3	0.7	0.0
Pullenia bulloides	0.0	0.0	0.0	3.7	1.8	1.5	0.8	0.5	0.3	0.3	2.6	0.0	0.0
Pyrgo rotalaria	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Quinqueloculina akneriana	2.4	0.3	3.7	0.0	0.3	0.2	0.0	0.0	0.3	0.6	0.0	0.7	0.0
Reophax atlantica	0.0	0.0	0.0	5.6	3.3	0.6	0.8	5.3	2.6	6.6	3.2	0.7	0.0
Reophax curtus	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	3.1	3.0	3.5	0.0	0.0
Reophax fusiformis	8.7	10.9	2.3	3.5	0.8	6.2	0.0	3.1	0.0	0.3	0.9	4.5	8.4
Reophax guttifer	0.6	0.0	1.0	5.3	2.3	11.0	21.8	40.8	0.8	0.9	4.7	0.0	0.0
Reophax scorpiurus	0.0	0.0	0.0	7.2	2.0	5.0	9.7	2.2	3.4	2.1	0.0	0.0	0.0
Reophax subfusiformis	0.0	0.0	0.0	0.0	5.8	1.3	0.0	0.5	1.0	1.2	8.5	0.0	0.0
Reophax spp.	4.8	0.7	1.0	19.5	6.3	16.3	0.0	6.0	24.9	15.1	34.4	2.1	0.4
Robertina arctica	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	2.4	0.9	0.3	0.0	0.0
Saccamina sp.	0.0	6.9	1.7	5.1	1.0	5.0	0.0	5.3	0.3	0.6	6.5	1.7	1.3
Saccamminidae spp.	0.3	0.0	0.0	0.0	0.3	0.0	0.0	2.2	0.0	0.0	0.6	0.0	0.0
Sorosphaera sp.	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.5	0.0
Spiroplectammina biformis	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	7.1	0.9	0.0	0.0	0.0
Stetsonia horvathi	17.5	25.7	2.0	0.0	0.0	1.0	0.0	0.0	0.3	0.0	0.0	13.2	11.0
Subreophax aduncus	5.4	1.6	0.0	0.7	0.0	1.5	0.0	0.0	0.0	0.0	1.2	1.0	0.4
Triloculina frigida	0.0	0.0	0.0	1.2	0.0	1.2	0.0	0.2	0.0	0.0	0.6	0.0	0.4
Triloculina trihedra	0.0	0.0	3.3	2.8	2.3	1.2	0.0	0.0	7.1	1.2	1.5	0.0	0.0
Trochammina karika	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.7	3.9	19.6	3.5	0.0	0.0
Trochamminella bullata	0.0	0.0	1.0	1.9	0.3	3.5	0.0	0.2	1.3	2.1	2.1	0.0	0.0
Trochamminella lomonosoviensis	0.0	0.0	0.0	1.4	0.5	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No of specimens counted	332	304	300	430	398	520	124	583	381	332	340	288	227
Specimens/10cm^3	126	61	120	459	1274	173	124	466	254	177	680	154	130

Station	301	306	309	316	319	330	333	338	342	358
Adercotryma glomerata	0.0	Na	0.0	1.1	1.4	0.0	0.0	Na	Na	4.1
Adercotryma abyssorum	2.2	Na	0.0	0.0	0.6	0.0	0.0	Na	Na	0.0
Aschemonella sp. 1	0.0	Na	4.4	0.0	0.0	0.0	0.2	Na	Na	0.0
Aschemonella sp. 2	0.0	Na	24.6	0.0	0.0	0.0	0.0	Na	Na	0.0

Table 3 continued

Station	301	306	309	316	319	330	333	338	342	358
Aschemonella sp. 3	0.0	Na	2.2	0.0	0.0	0.0	0.0	Na	Na	0.0
Buccella frigida	0.0	Na	0.2	0.0	0.0	0.0	0.0	Na	Na	0.0
Buccella tenerrima	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Cassidulina laevigata	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Cassidulina neoteretis	0.0	Na	0.0	0.6	0.0	0.0	0.0	Na	Na	0.0
Cassidulina reniforme	0.0	Na	0.5	0.0	0.0	0.0	0.0	Na	Na	0.0
Cibicides lobatulus	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Cibicides wuellerstorfi	0.0	Na	0.0	0.3	4.9	0.7	0.0	Na	Na	0.5
Deuterammina grisea	1.3	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Elphidium excavatum f. *clavata*	0.0	Na	0.2	0.0	0.0	0.0	0.0	Na	Na	0.0
Epistominella arctica	2.2	Na	0.2	4.6	6.0	7.1	1.7	Na	Na	0.0
Epistominella nipponica	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Eponides tumidulus	65.4	Na	0.5	59.9	66.9	67.9	47.1	Na	Na	76.3
Haplophragmoides subglobosum	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Hippocrepinella hirudinea	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Islandiella helenae	0.0	Na	0.0	2.0	0.0	0.0	0.0	Na	Na	0.0
Islandiella islandica	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Islandiella norcrossi	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Jaculella sp.	0.0	Na	6.9	0.0	0.0	0.0	0.0	Na	Na	0.0
Oridorsalis tener	4.9	Na	0.0	15.5	2.0	22.9	48.1	Na	Na	8.8
Psammosphaera fusca	0.0	Na	4.7	0.0	1.4	0.0	0.0	Na	Na	0.0
Pullenia bulloides	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Pyrgo rotalaria	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Quinqueloculina akneriana	0.0	Na	0.2	4.6	7.7	0.0	1.2	Na	Na	2.6
Reophax curtus	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Reophax distans	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Reophax fusiformis	3.3	Na	17.5	0.0	2.9	0.0	0.3	Na	Na	0.0
Reophax guttifer	0.0	Na	0.2	2.9	0.3	0.0	0.0	Na	Na	0.0
Reophax scorpiurus	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Reophax subfusiformis	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Reophax spp.	0.0	Na	0.0	0.9	0.3	0.0	0.2	Na	Na	0.0
Robertina arctica	0.0	Na	0.0	0.0	0.3	0.0	0.0	Na	Na	0.0
Saccaminna atlantica	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Saccamina sp.	1.3	Na	10.1	0.0	2.3	0.0	0.2	Na	Na	2.1
Saccamminidae spp.	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Sorosphaera sp.	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Spiroplectammina biformis	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Stetsonia horvathi	12.0	Na	9.1	2.6	0.3	0.0	0.0	Na	Na	0.0
Subreophax aduncus	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Triloculina frigida	3.5	Na	0.0	0.0	0.3	0.0	0.3	Na	Na	0.0
Triloculina trihedra	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Trochammina karika	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Trochamminella bullata	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
Trochamminella lomonosoviensis	0.0	Na	0.0	0.0	0.0	0.0	0.0	Na	Na	0.0
No of specimens counted	451	1	406	349	350	140	582	8	0	194
Specimens/10cm^3	212	Na	65	465	140	187	111	Na	Na	259

Na not applicable due to too few specimens

Table 4 Dead (unstained) foraminiferal abundances (>1%)

Station	263	265	266	269	270	274	276	277	279	282	285	294	299	301	306	309	316	319	330	333	338	342	358
Adercotryma glomerata	0.2	1.2	29.2	0.0	0.1	1.0	0.0	4.2	2.8	2.6	1.2	5.6	0.0	0.0	Na	0.0	1.8	3.0	0.0	0.3	0.0	0.0	0.0
Adercotryma abyssorum	1.2	0.0	0.0	1.2	0.0	3.1	0.0	12.5	0.0	0.3	1.1	7.8	2.0	1.5	Na	0.0	0.0	5.6	0.7	0.0	0.0	0.0	0.0
Ashemonella sp. 1	17.3	5.4	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.2	0.0	Na	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0
Ashemonella sp. 2	0.0	1.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	5.9	0.0	0.0	Na	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ashemonella sp. 3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Na	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ashemonella spp.	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.9	1.8	Na	2.1	0.0	0.0	0.0	0.6	0.0	0.0	4.3
Astrononion gallowayi	0.0	0.0	0.4	0.0	1.0	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Buccella frigida	0.0	0.0	0.0	0.2	1.2	0.0	0.0	0.0	0.3	0.9	0.4	0.0	0.4	0.6	Na	1.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Cibicides wuellerstorfi	0.2	0.0	0.7	0.0	0.9	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	Na	0.0	0.7	3.1	10.5	2.1	30.3	17.5	9.7
Cibicides lobatulus	0.0	0.0	1.8	2.0	3.4	0.0	0.0	1.2	0.3	0.0	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Deuterammina grisea	6.8	9.9	0.4	0.4	0.1	0.2	0.0	0.2	0.3	0.9	1.4	1.4	5.4	4.5	Na	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Elphidiidae spp.	0.5	0.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.8	Na	3.8	0.1	0.2	0.0	0.3	0.0	0.0	0.0
Elphidium subarcticum	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.6	0.1	0.0	2.5	1.2	Na	7.1	0.7	0.9	0.0	1.2	0.0	0.0	1.0
E. excavatum f. *clavata*	0.0	0.0	0.4	0.2	1.1	0.0	0.0	0.0	2.5	3.1	0.0	0.0	0.2	0.3	Na	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Cassidulina reniforme	0.5	0.0	0.4	1.4	4.6	1.0	6.2	0.2	3.0	1.7	6.8	0.0	0.2	0.3	Na	0.9	0.1	0.0	0.3	0.0	0.0	0.0	0.0
Cassidulina teretis	0.0	0.0	0.0	24.9	44.4	25.6	53.4	0.0	1.1	0.9	10.6	0.0	0.2	0.0	Na	0.0	1.9	0.0	0.0	0.0	0.0	0.0	2.4
Cassidulina laevigata	0.0	0.0	0.0	0.0	1.4	0.0	8.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceratobulimina arctica	0.0	0.3	0.0	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	Na	0.0	2.4	0.3	3.3	0.0	0.7	0.3	0.5
Epistominella arctica	0.7	0.6	3.2	0.2	1.0	5.2	3.3	0.3	0.8	0.0	0.1	2.8	1.1	0.3	Na	0.0	4.8	35.2	8.2	2.7	0.0	4.9	4.8
Epistominella nipponica	0.0	0.0	0.0	1.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gordiospira sp.	0.0	0.0	0.4	1.0	0.4	0.2	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haynesina orbiculare	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.9	1.2	Na	4.1	0.0	0.0	0.3	0.6	0.0	0.0	0.0
Hormosinella distans	0.2	0.0	0.0	1.4	0.2	1.6	2.1	1.9	0.0	0.6	0.3	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hormosinella guttifera	0.2	1.2	3.9	13.0	0.5	23.0	9.4	58.6	4.1	2.3	15.9	1.1	0.0	0.0	Na	0.0	6.2	0.0	0.0	0.0	0.0	0.0	1.0
Hyperammina elongata	0.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.6	0.0	0.6	Na	2.4	0.0	0.0	0.3	0.3	0.0	0.0	0.0
Ioanella tumidula	4.4	6.9	16.0	0.0	0.0	1.3	0.0	0.0	0.0	0.3	0.0	11.5	13.7	15.9	Na	0.3	14.2	12.5	34.6	17.1	34.7	44.0	24.6
Islandiella norcrossi	0.2	0.0	0.0	1.2	1.3	0.5	5.3	0.0	0.0	0.3	0.3	0.0	0.2	0.0	Na	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Islandiella helenae	0.0	0.0	0.0	4.0	9.2	5.2	0.0	0.0	1.1	0.9	5.4	0.3	0.0	0.0	Na	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0
Islandiella islandica	0.0	0.0	0.0	0.2	3.5	0.3	0.0	1.2	1.1	1.1	0.0	0.0	0.0	0.0	Na	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0
Miliolinella irregularis	0.5	0.3	0.0	2.0	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.0	Na	0.0	4.9	0.5	0.3	2.4	0.0	0.0	0.0
Oridorsalis tener	2.3	15.6	13.9	0.0	0.0	1.1	0.0	0.0	0.0	0.6	0.0	3.1	5.6	2.7	Na	0.0	19.2	1.3	18.3	37.7	20.1	23.1	39.1
Placopsinella aurantiaca	0.0	0.0	0.0	5.3	0.9	8.1	5.5	0.0	4.1	6.0	5.0	0.0	0.2	0.3	Na	0.0	0.0	7.8	0.0	5.4	0.0	2.4	4.8
Psammosphaera fusca	0.5	0.0	0.0	2.0	0.4	1.4	0.5	0.0	3.9	3.4	1.4	5.3	1.3	0.0	Na	3.2	0.0	1.3	0.0	0.0	0.0	0.0	0.0
Quinqueloculina akneriana	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.3	0.1	1.1	0.0	0.0	Na	0.0	6.7	4.5	6.2	5.1	9.4	3.6	1.9
Quinqueloculina spp	0.0	0.0	0.0	1.8	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Na	0.0	2.8	0.3	0.0	0.0	0.1	0.0	0.0
Reophax curtus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.4	0.3	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reophax fusiformis	2.3	1.2	1.8	0.2	0.1	0.2	0.0	2.4	0.6	0.3	0.3	2.0	2.7	0.3	Na	1.5	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Reophax scorpiurus	0.0	0.0	0.0	0.8	1.1	1.3	2.6	1.0	5.5	7.1	0.4	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4 continued

Station	263	265	266	269	270	274	276	277	279	282	285	294	299	301	306	309	316	319	330	333	338	342	358
Reophax spp.	8.4	4.8	2.5	2.2	0.7	0.8	0.0	3.1	11.3	6.6	16.8	1.4	4.1	3.0	Na	0.0	0.5	1.1	0.0	0.0	0.0	0.0	0.0
Rhabdammina spp.	0.0	0.3	0.4	0.0	0.1	0.3	0.0	0.0	0.6	1.1	0.1	1.1	0.2	0.0	Na	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.5
Saccaminna atlantica	0.0	0.0	0.0	1.4	0.9	0.5	0.4	1.2	15.2	14.2	1.4	1.4	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Sorosphaera sp.	4.7	4.5	0.0	0.6	0.0	0.6	0.0	0.0	0.3	0.0	0.0	0.0	2.2	0.9	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spiroplectammina biformis	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	4.7	3.1	0.8	0.3	0.2	0.0	Na	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stetsonia horvathi	34.3	33.5	4.3	1.0	0.8	1.9	0.0	0.2	0.6	0.6	0.3	17.4	24.9	35.3	Na	30.6	7.5	7.0	2.3	5.4	0.0	0.7	0.0
Subreophax aduncus	6.8	3.6	0.0	0.8	0.0	0.6	0.0	0.0	0.0	0.0	0.7	3.4	1.4	0.9	Na	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Textularia earlandi	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.3	2.8	2.3	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Triloculina trihedra	0.7	0.9	13.9	1.0	1.4	0.0	0.0	0.0	1.1	0.0	0.8	0.0	0.0	0.0	Na	0.0	0.0	5.6	0.3	0.0	0.0	0.0	0.0
Triloculina frigida	1.4	3.6	0.0	0.2	0.3	0.5	0.0	0.3	0.0	0.0	0.4	3.1	23.6	20.7	Na	0.0	3.5	0.0	7.2	14.1	1.4	1.1	1.0
Trochammina karika	0.0	0.0	0.0	0.4	1.8	0.0	0.0	1.6	14.9	17.9	6.7	0.0	0.4	0.0	Na	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trochamminella atlantica	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2	2.5	4.0	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T. globigeriniformis	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	1.7	3.4	0.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trochamminella bullata	0.0	0.0	0.7	2.4	0.6	1.1	0.0	0.3	0.6	4.3	3.0	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T. lomonosoviensis	0.0	0.0	0.0	1.6	0.1	1.9	0.0	0.0	0.6	0.0	0.3	0.0	0.0	0.0	Na	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trochaminopsis pusillus	0.0	0.0	0.0	0.6	0.9	0.3	0.0	0.9	3.0	0.0	1.4	0.0	0.0	0.0	Na	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Valvulineria arctica	0.0	0.0	0.0	1.8	0.6	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	Na	0.0	3.1	0.0	0.0	0.0	0.6	0.0	1.0
No of specimens counted	428	334	281	506	1643	621	1100	575	363	351	736	357	555	334	35	340	983	640	306	334	887	741	207
Specimens/10 cm^3	326	534	225	3238	21030	1656	1100	460	968	374	1472	762	1269	1257	Na	272	1311	512	6528	1018	2703	1437	2208

Na not applicable due to too few specimens

Appendix 2

The foraminiferal species are listed alphabetically by genus names. *Aschemonellinae* has been placed in the order Foraminiferida and not in the class *Xenophyophorea*. Otherwise, the genus names follow Ellis and Messina (1940–1978) and Loeblich and Tappan (1987)

Species list

Adercotryma glomerata (Brady, 1878)
Adercotryma abyssorum Saidova, 1975
Aschemonella spp. Brady, 1879
Buccella frigida (Cushman, 1921)
Cassidulina laevigata d'Orbigny, 1826
Cassidulina neoteretis Seidenkrantz, 1995
Cassidulina reniforme Nørvang, 1945
Ceratobulimina arctica Green, 1959
Cibicides lobatulus (Walker and Jacob, 1798)
Cibicides wuellerstorfi (Schwager, 1866)
Deuterammina grisea Earland, 1934
Elphidiidae spp. Galloway, 1933
Elphidium excavatum (Terquem) f. *clavata* (Cushman, 1944)
Elphidium hallandense Brotzen, 1943
Epistominella arctica Green, 1960
Epistominella nipponica (Kuwano, 1962)
Ioanella tumidula (Brady, 1884)
Haynesina orbiculare (Brady, 1881)
Hyperammina elongata Brady, 1878
Islandiella norcrossi (Cushman, 1933)
Islandiella helenae Feyling-Hanssen and Buzas, 1976.
Oridorsalis tener (Brady, 1884)
Placopsilinella aurantiaca Earland, 1934
Psammosphaera fusca Schulze, 1875
Quinqueloculina akneriana d'Orbigny, 1846
Saccaminna atlantica (Cushman, 1944)
Reophax curtus Cushman, 1920
Hormosinella distans (Brady, 1881)
Reophax fusiformis Williamson, 1858
Hormosinella guttifera (Brady, 1881)
Reophax scorpiurus de Montfort, 1808
Reophax spp. de Montfort, 1808
Rhabdammina spp Sars, 1869
Sorosphaera sp. Brady, 1879
Spiroplectammina biformis (Parker and Jones, 1865)
Stetsonia horvathi Green, 1960
Subreophax aduncus Brady, 1882
Trochammina karika Shchedrina, 1946
Trochamminella atlantica Parker, 1952
Trochamminella globigeriniformis (Parker and Jones, 1865)
Trochamminella bullata Høglund, 1947
Textularia earlandi Parker, 1952
Triloculina trihedra Loeblich and Tappan, 1953
Triloculina frigida Lagoe, 1977
Valvulineria arctica Green, 1959

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