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Monothalamous foraminifera from West Spitsbergen fjords, Svalbard: a brief overview

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Abstract: During the 2004 summer season, 14 sediment samples were collected in Kongsfjorden and Isfjorden, West Spitsbergen, from 6 down to 345 m water-depth (mwd). The samples yielded abundant assemblage of monothalamous foraminifera, belonging to almost 40 morphotypes. Our qualitative (>125 μm) and quantitative data (125–500 μm) allowed to distinguish three water-depth related assemblages in both Kongsfjorden and Adventfjorden (branch of Isfjorden), indicating that soft-walled monothalamous foraminifera show similar habitat gradation along fjord axis as calcareous and robust agglutinated taxa. Among the monothalamous foraminifera, the subtidal assemblage (6 mwd) was dominated by various unidentified allogromiids. The second, shallow-water assemblage (44–110 mwd) was dominated by *Psammophaga* sp. 1–3, *Hippocrepinella crassa*, *Hippocrepinella* cf. *hirudinea*, and large *Gloiogullmia* sp. 2. The deep-water (150–345 mwd) monothalamous assemblage was dominated by *Psammophaga* sp. 4, pear-shaped *Hippocrepina* sp., *Hippocrepina indivisa*, and long *Cylindrogullmia* sp. 2, as well as large agglutinated species *Hyperammina subnodosa* with attached *Tholosina bulla*, *Hyperammina fragilis* and *Lagenammina* sp.

Key words: Arctic, Spitsbergen, Foraminifera, Recent.

Introduction

Monothalamous (single-chambered) foraminifera are important but largely ignored component of Arctic and Antarctic meiofauna. These amoeboid protists include species with relatively simple, organic or agglutinated test, which size ranges from 50 to 500 microns, but may exceptionally reach up to several millimeters as in case of large agglutinated taxa (*e.g.* DeLaca *et al.* 1980). They are ubiquitous members of marine soft-bottom communities, particularly common in cold-water, deep-sea, and high-latitude settings (Gooday 1986, 2002; Gooday *et al.* 1996; Todo *et al.* 2005). In the Arctic, large agglutinated astrorhizids dominate the biomass of shelf foraminifera, reaching up to 3 g/m^2 in Barents and Kara Seas (Korsun *et al.* 1998; Korsun 2002), while small, organic-walled allogromiids prevail in habitats influenced by glacial melt-water (Korsun and Hald 1998).

Traditionally, the monothalamous foraminifera have been classified according to their test composition either in the organic-walled order Allogromiida or in the agglutinated order Astrorhizida (Loeblich and Tappan 1987; Sen Gupta 1999). This traditional point of view has been contradicted by molecular phylogenies, which consistently shown allogromiids and astrorhizids grouping together at the base of the foraminiferan tree, indicating that the agglutinated test was formed several times during the evolution of early Foraminifera (Pawlowski 2000; Pawlowski *et al.* 2002c, 2003; Flakowski *et al.* 2005). Molecular data has revealed high cryptic diversity of monothalamous foraminifera (Pawlowski *et al.* 2002a, b, 2005; Habura *et al.* 2004) and contributed to the description of several new species of polar allogromiids and astrorhizids (Pawlowski *et al.* 2002a; Gooday *et al.* 2004; Gooday and Pawlowski 2004; Sabbatini *et al*. 2004).

Morphological diversity of Arctic monothalamous foraminifera and gromiids, based on material collected in West Spitsbergen fjords in 2001, was recently described in Gooday *et al.* (2005). It was the first report on the diverse communities of small, mainly soft-walled monothalamous foraminifera in sublittoral Arctic waters. Here, we present the first quantitative data set of such fauna from two West Spitsbergen fjords, completed during the West Spitsbergen cruise of r/v *Oceania* during the summer of 2004.

Study area. — Our investigations focused on two areas: Kongsfjorden and the central part of Isfjorden including Adventfjorden (Fig. 1). Kongsfjorden runs from ESE to WNW and is 16 km long, up to 7 km wide, and up to 400 m deep. It lacks a sill at the mouth, but its bottom morphology is rather rough. The inner fjord (glacial bay) is partially isolated by the islands of Lovenoyane and Blomstrandoya and has relatively shallow water (< 100 mwd) and numerous shallows and hollows. The central part of the fjord is marked by a submarine deep > 400 mwd. The fjord bottom shallows to less than 300 mwd at its mouth and continues out into the shelf area as the submarine channel of Kongsfjordrenna. There are three tidewater glaciers in Kongsfjorden (Fig. 1). Kongsbreen is one of the most active glacier on Spitsbergen, supplying turbid water to the fjord all the year (Lefauconnier *et al.* 1994). The melting season of these glaciers peaks in July, when its melt-water outflow reaches 138 m^3 s^{-1} (Zajączkowski and Legeżyńska 2001). The other two glaciers, Blomstranbreen and Conwaybreen, are not as active and provide less turbid meltwater (Svendsen *et al.* 2002). According to Beszczyńska-Møller *et al.* (1997) all the glaciers introduce into Kongsfjorden 0.33 km^3 of melt-water per year. This

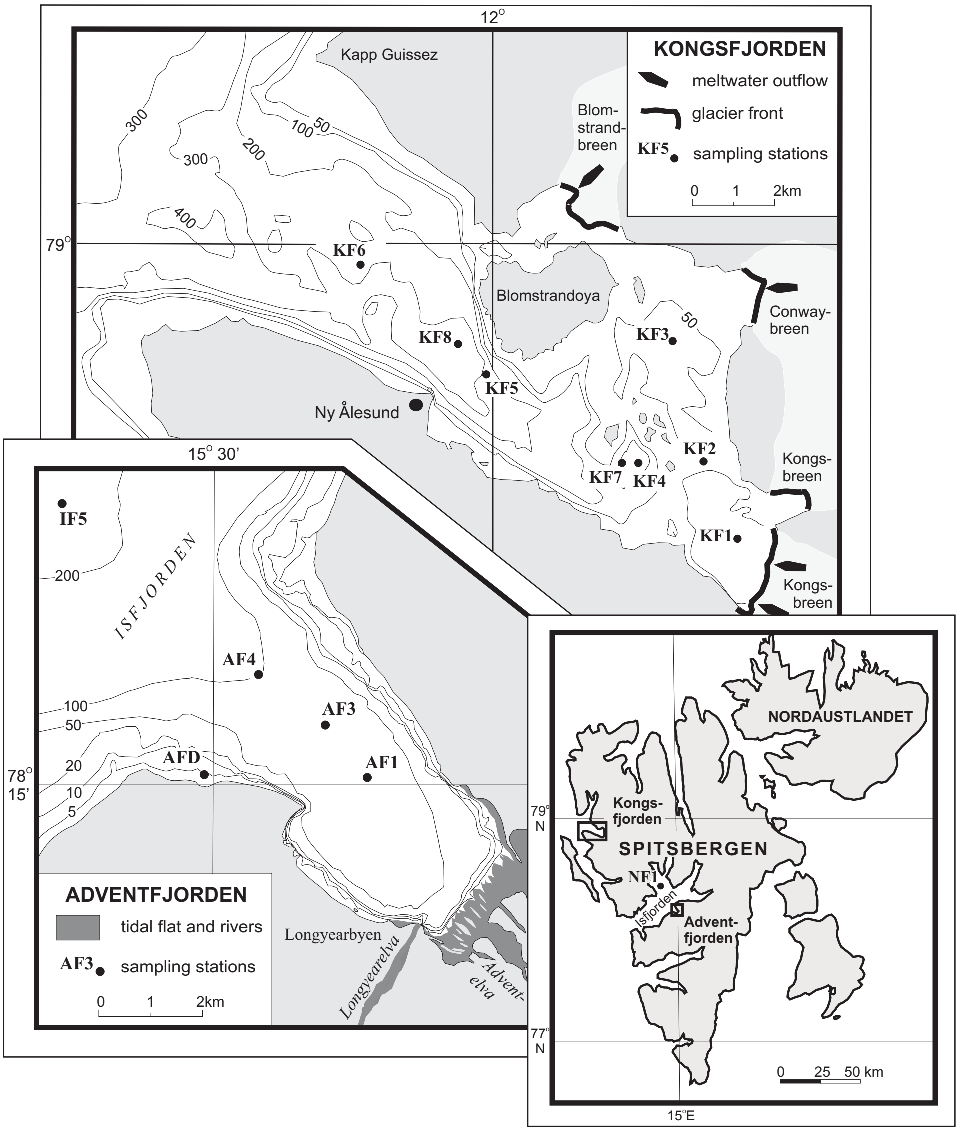

Fig. 1. The location of Kongsfjorden and Adventfjorden on West Spitsbergen. Note the positions of sampling stations.

turbid water supply creates steep environmental gradients in sedimentation and salinity along the Kongsfjorden axis (Hop *et al.* 2002).

Central Isfjorden is a basin up to 270 m deep split into Nordfjorden and Billefjorden to the north and Tempelfjorden to the east. It has extensive hydrographic communication with the open sea, which is reflected by the presence of Transformed Atlantic Water at the bottom (Hald and Korsun 1997). Adventfjorden is the southern, much smaller branch of Isfjorden and is only 8.3 km long and 3.4 km wide. It runs from SE and opens to NW. It is a natural harbour for Longyearbyen, the major Svalbard settlement. The fjord receives turbid water from two braided rivers Adventelva and Longyearelva. The rivers deliver melt water from the glaciers, which have retreated several kilometres inshore. The innermost part of Adventfjorden forms a tidal flat ~0.9 km wide, which ends in a steep slope that descends to the depth of 30 m. In the central and outer part, the fjord deepens steadily towards its mouth, where it reaches 100 m in depth. The inner fjord is strongly influenced by turbid water, what causes significant hydrologic stratification and flux of solids to the seafloor. Since Adventfjorden bottom is steep in the inner part, loose sediment is often resuspended, causing frequent increases in sediment concentration in the near-bottom water-zone (Zajączkowski 2002).

Thanks to the warm West Spitsbergen Current (WSC), the West Spitsbergen climate is very mild, considering its northern position (Hisdal 1985). The average annual air temperature is ~ –6°C. The warmest average summer temperatures are ~5–6°C, and the coldest winter ~ –15°C. The fjords of West Spitsbergen are strongly influenced by Transformed Atlantic Water (Beszczyńska-Møller *et al.* 1997), which is a mixture of Atlantic Water derived from the WSC and summer melt-water, which is local in origin.

During the melting season, which lasts for more than four months (Węsławski *et al.* 1999), the low-saline water coming from the glaciers and rivers is loaded with sediment. Shortly after entering the fjords' open water, it drops the suspended material (Majewski and Zajączkowski submitted). Then, the melt-water reaches far out into the shelf area, where it mixes with Atlantic Water (Beszczyńska-Møller *et al.* 1997). During the winter, the fjords are covered with *ca.* 1 m thick fast-ice. Dense and saline local water is produced. It often fills submarine depressions, where it may remain until the following winter season (Svendsen *et al.* 2002).

Methods

During late July to early August 2004, 14 sediment samples were collected from water-depths down to 345 m (Table 1). Thirteen of them were collected using a 14.5 × 14.5 cm box corer and one by scuba divers. Eight sampling stations were distributed throughout Kongsfjorden. Three samples were taken along Adventfjorden, one ~5 km in front of the fjord mouth (Fig. 1). One more sample was taken at the mouth of Nordfjorden. The last sample was taken by scuba divers next to Longyearbyen airport (Fig. 1) from 6 m water depth. Immediately after recovery, all samples were gently washed over 125 and 500 µm sieves with cold sea-water and stored at ~2°C temperature. Within a few days, the >500 µm and 125–500 µm residues were scanned for living monothalamous foraminifera. Soft-walled fresh-looking individuals, as well as robust agglutinated specimens showing cytoplasm when broken, were regarded as living, photographed (Figs 2–4), and preserved in

Table 1

List of sampling stations

Station	Water depth (m)	Distance from fresh-water source (km)	Latitude (°N)	Longitude (°W)
KF1	86	1.4	78.8983	12.4258
KF2	44	3.4	78.9211	12.4265
KF3	78	2.7	78.9671	12.3648
KF4	110	4.4	78.9209	12.2640
KF5	240	8.6	78.9570	11.9653
KF6	300	13.0	78.9828	11.6820
KF7	115	4.7	78.9180	12.2356
KF8	345	9.6	78.9599	11.9401
AF1	70	3.1	78.2401	15.6112
AF3	80	4.3	78.2560	15.5862
AF4	100	5.9	78.2699	15.5321
IF1	250	11.0	78.2955	15.3294
NF1	150	16.0	78.4924	14.9176
AFD	6	5.8	78.2529	15.4660

guanidine-based DNA extraction buffer. Our qualitative data are based on the immediate observations of living assemblage.

Unprocessed residues from 10 stations were fixed with 70% ethanol diluted in sea water, for quantitative study. After returning home, all or at least 300 specimens of monothalamous (organic or softly-agglutinated) foraminifera were picked from each of the fixed samples and placed by taxa in separate vials. At this stage, we did not attempt to distinguish the living specimens, and picked all specimens recognized.

Results

Table 2 presents our qualitative (*x* for present, *a* for abundant) and quantitative results expressed in percentages. During the initial investigation on board r/v *Oceania*, 1780 specimens were isolated and processed for DNA extraction, compared to 2653 specimens picked from the fixed samples after the cruise. The recognized foraminifera belong to ~40 morphotypes of various ranks (Figs 2–4). Unfortunately, the fixed samples showed a considerable degree of deterioration. Therefore, percentages of especially fragile organic-walled species (*Micrometula* sp., *Cylindrogullmia* sp. 2, *Nemogullmia longevariabilis*) have not been estimated. Nevertheless according to our qualitative results, two taxa, *Cylindrogullmia* sp. 2 and *Micrometula* sp., were abundant at several locations. Among the more robust agglutinated species, *Hyperammina subnodosa* was abundant but not included in our estimates, because it was found only in the fraction > 500 μm. Other more robust taxa,

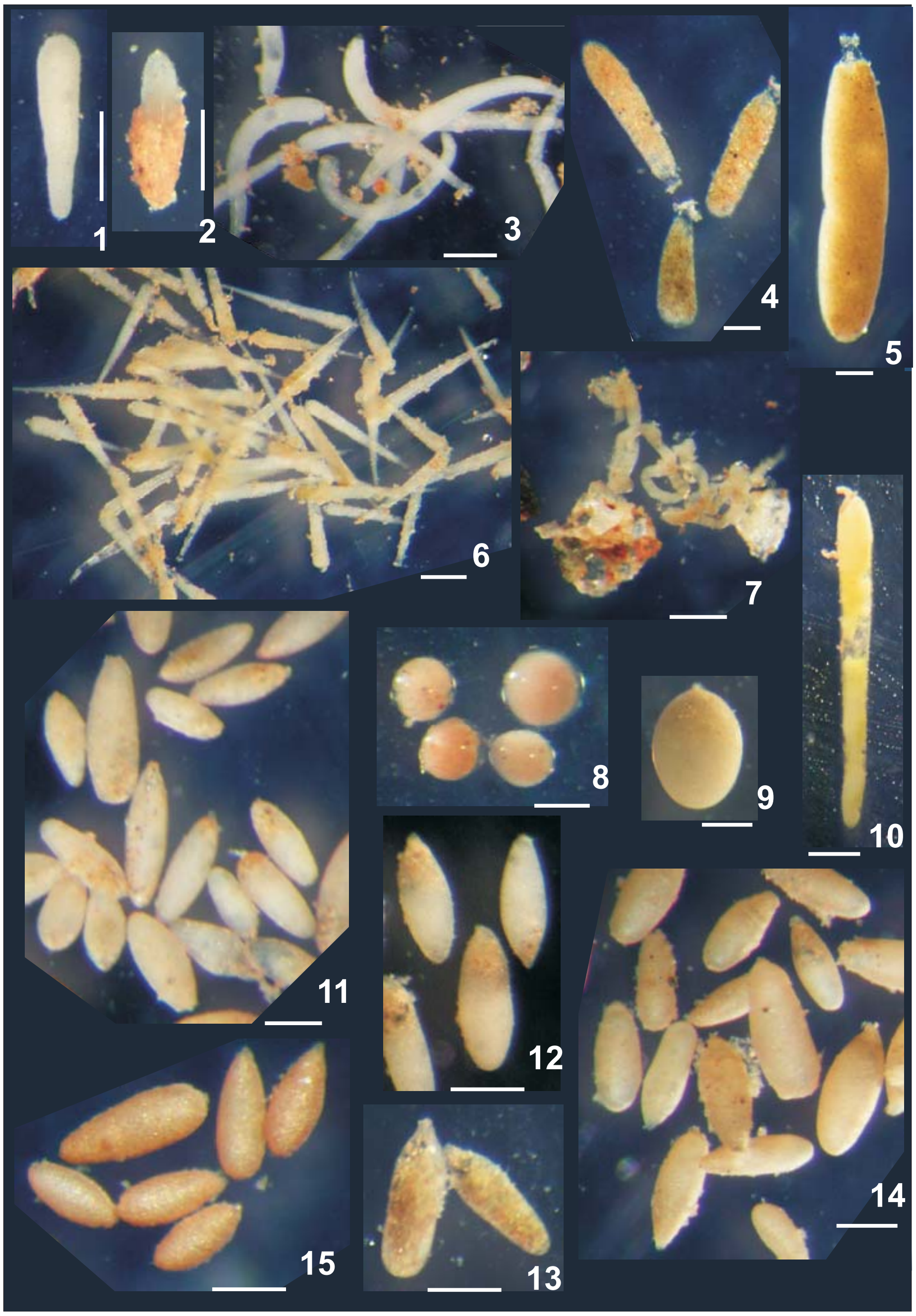

Fig. 2. **1–2**. *Cylidrogullmia* sp. 1, KF4, KF1. **3**. *Cylidrogullmia* sp. 2, KF8. **4**. *Gloiogullmia* sp. 1, KF4. **5**. *Gloiogullmia* sp. 2, AF1. **6**. *Micrometula* sp., AF1. **7**. *Nemogullmia longevariabilis* Nyholm, 1953, KF6. **8**. ?*Bathyallogromia*, KF4. **9**. *Allogromia* sp., AF3. **10**. Yellow allogromiid, KF4. **11–12**. *Psammophaga* sp. 1, KF4, AF3. **13**. *Psammophaga* sp. 2, KF4. **14**. *Psammophaga* sp. 3, AF3. **15**. *Psammophaga* sp. 4, KF5. All data bars equal 100 µm.

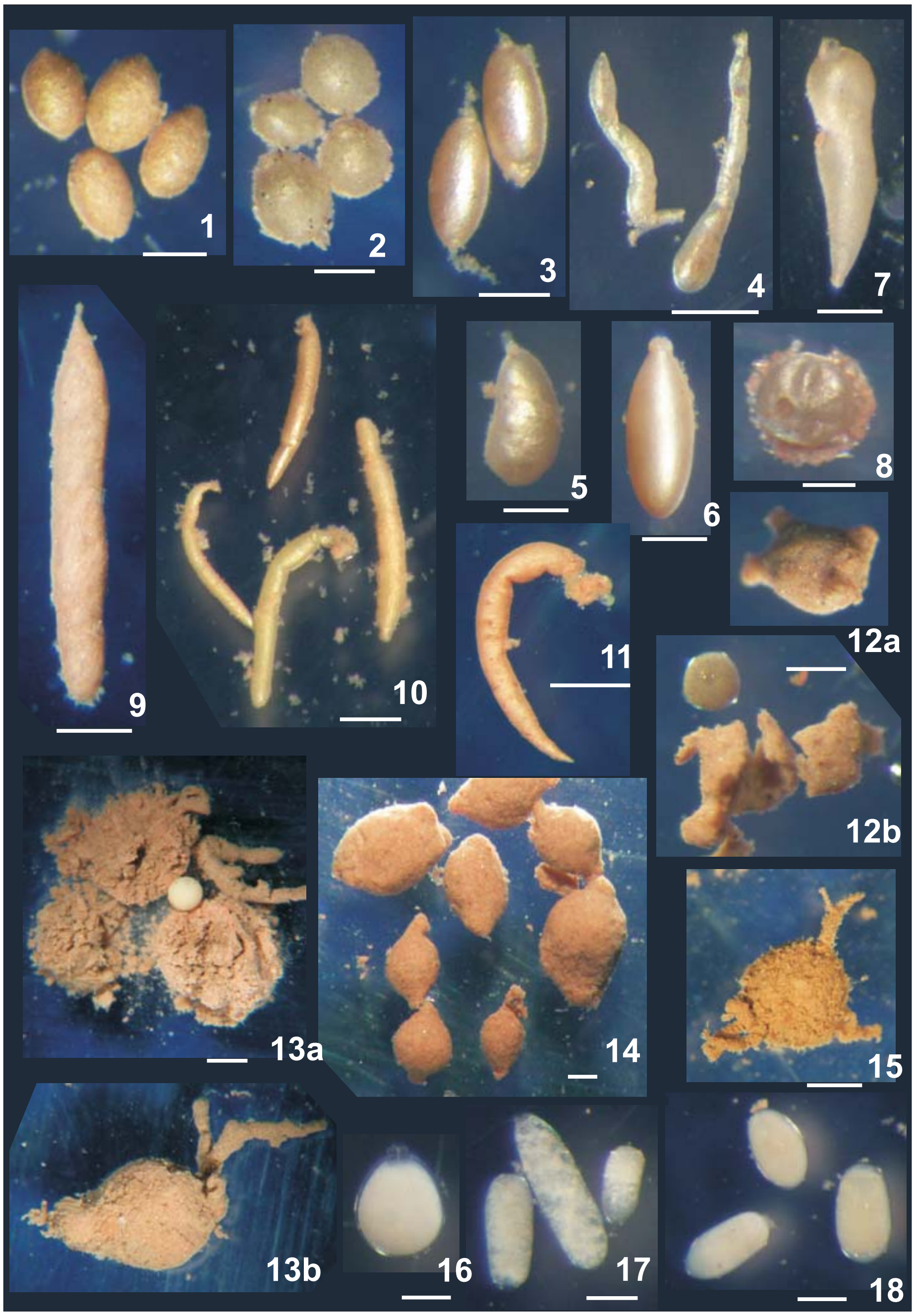

Fig. 3. **1–6**. Various silver saccamminids, KF6, AF3, KF5, IF1, NF1, KF1. **7**. *Phainogullmia* sp. 1, KF1. **8**. *Pilulina argentea* Höglund, 1947, KF2. **9**. *Phainogullmia* sp. 2, KF7. **10–11**. *Phainogullmia* sp. 3, KF6, KF7. **12**. *Pelosina* sp., NF1. **13–15**. *Pelosina sphaeriloculum* Höglund, 1947, KF5, KF2, NF1. **16–18**. Various allogromiids, IF1, IF1, KF7. All data bars equal 100 µm.

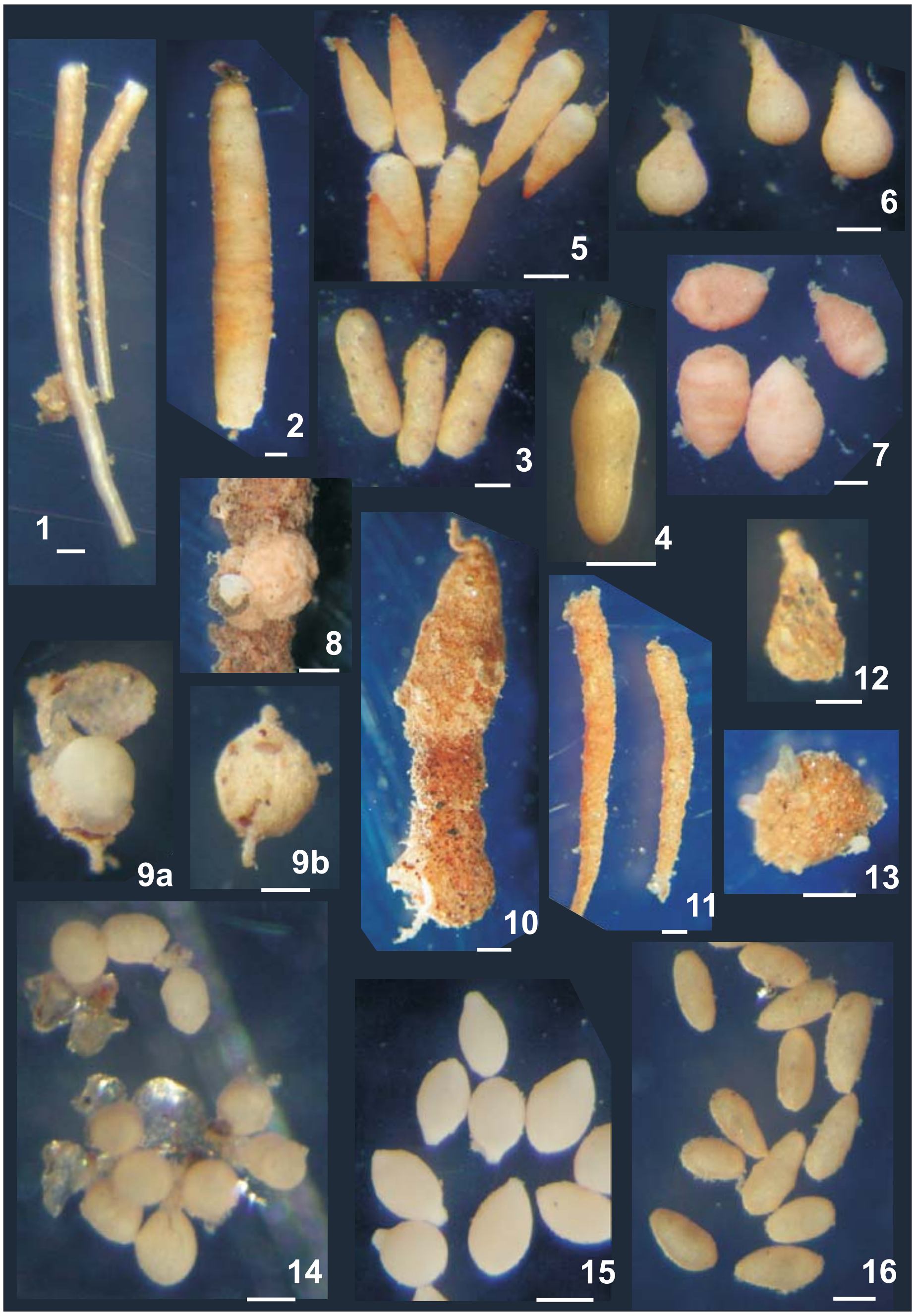

Fig. 4. **1**. *Bathysiphon argenteus* Heron-Allen *et* Earland, 1913, IF1. **2**. *Hippocrepinella hirudinea* Heron-Allen *et* Earland, 1932, NF1. **3**. *Hippocrepinella* cf. *hirudinea* Heron-Allen *et* Earland, 1932, KF6. **4**. ?*Hippocrepina*, IF1. **5**. *Hippocrepina indivisa* Parker, 1870, KF8. **6**. *Hippocrepina* sp., KF5. **7**. *Hippocrepina crassa* Heron-Allen *et* Earland, 1932, KF7. **8**. *Tholosina bulla* Rhumbler, 1935, AF1. **9**. *Armorella sphaerica* Heron-Allen *et* Earland, 1932, NF1. **10**. *Hyperammina subnodosa* →

Lagenammina sp. and *Hyperammina fragilis*, represented mixed subfossil and Recent populations and therefore were not included in quantitative investigations.

Monothalamous foraminiferal taxa

We found ~30 identified taxa and a large number of unidentified morphotypes (Table 2). Organic-walled monothalamous forms were represented mainly by short (Fig. 2.1–2) and elongate types (Fig. 2.3) of *Cylindrogullmia* (*Cylindrogullmia* sp. 1 and 2 respectively), *Micrometula* sp. (Fig. 2.6), and small (Fig. 2.4) and large types (Fig. 2.5) of *Gloiogullmia* (*Gloiogullmia* sp. 1 and 2). They were accompanied by a large number of unidentified spherical to ovoid morphotypes; some of them resembled *Bathyallogromia* (Fig. 2.8) or sarcodes (cell bodies) of *Pelosina* (Figs 3.12b, 13a) or other agglutinated large foraminifera. Other organic-walled genera, such as *Tinogullmia* and *Nemogullmia*, were rare in our samples.

One of most abundant allogromiids was the genus *Psammophaga.* It appeared in four morphotypes that differed in quantities of intracellular mineral particles, possibly crystals of barite (Arnold 1982), and wall transparency (from purely organic-walled to agglutinated). *Psammophaga* sp. 1 (Fig. 2.11–12) was bright, transparent with moderate number of crystals occurring only in the near-apertural portion of the cytoplasm. *Psammophaga* sp. 2 (Fig. 2.13) was also transparent but differed from *Psammophaga* sp. 1 in possessing an extremely large number of the mineral particles that fill practically the entire cell. *Psammophaga* sp. 3 (Fig. 2.14) was significantly less transparent than the two purely organic-walled forms of *Psammophaga* (sp. 1 and sp. 2). In fact, there were numerous intermediate forms between the three morphotypes, which could suggest that they represent variants of the same species. They all shared the same habitats between 70 and 110 mwd (Fig. 5). On the other hand, *Psammophaga* sp. 4 (Fig. 2.15) was practically opaque with an agglutinated wall. It appeared much more conservative in test shape and smaller in size than *Psammophaga* sp. 1–3. *Psammophaga* sp. 4 was abundant in deep (>115 mwd), outer-fjord settings (Fig. 5).

Agglutinated monothalamous forms were represented by frequently occurring and diverse forms of *Hippocrepinella* and *Hippocrepina*. They possessed an agglutinated test that was poorly cemented and flexible in life. We identified three well-described species: *Hippocrepinella hirudinea* (Fig. 4.2), *Hippocrepina crassa* (Fig. 4.7), and *Hippocrepina indivisa* (Fig. 4.5). Moreover, we distinguished a pear-shaped *Hippocrepina* sp. (Fig. 4.6), as well as *Hippocrepinella* cf. *hirudinea* (Fig. 4.3), which was much smaller than *H. hirudinea* and without transverse wrinkles.

Brady, 1884, AF1. **11**. *Hyperammina fragilis* Höglund, 1947, KF8. **12**. *Lagenammina* sp., NF1. **13**. *Psammosphaera fusca* Schulze, 1875, KF6. **14**. Unidentified saccamminid 1, AFD. **15**. Unidentified saccamminid 2, NF1. **16**. Unidentified saccamminid 3, AF1. All data bars equal 100 µm.

Table 2

The monothalamous foraminiferal chart with stations arranged with increasing water-depth. Note presence of qualitative (*x* for present, *a* for abundant) and quantitative data expressed in percentages. A star (*), placed next to station symbol, indicates qualitative data only.

Monothalamous foraminiferal assemblage	Sub-tidal	Shallow-water							?	Deep-water				
Station	AFD	KF2*	AF1	KF3	AF3	KF1*	AF4	KF4	KF7*	NF1	KF5*	IF1	KF6	KF8
Distance from fresh-water source (km)	5.8	3.4	3.1	2.7	4.3	1.4	5.9	4.4	4.7	16	8.6	11	13	9.6
Water depth (m)	6	44	70	78	80	86	100	110	115	150	240	250	300	345
?*Vellaria* sp.	×				x				x					
?*Bathyallogromia* sp.					x			x	x	x		x	x	
Cylindrogullmia sp. 1	1.3		2.3		0.9	x		0.3		x		0.7		
Cylindrogullmia sp. 2					x			x	a		a	a	1	a
Gloiogullmia sp. 1							0.3	2.1	x		x	2	x	0.4
Gloiogullmia sp. 2			41		1.8									
yellow allogromiid								x						
Nemogullmia longevariabilis													x	
Micrometula sp.	x		a	x	x	x		x	a	x		x		
Psammophaga sp. 1			0.7	5	17		24	36				0.7		
Psammophaga sp. 2					2.7		0.9	x						
Psammophaga sp. 3			6		22		11	7.4						
Psammophaga sp. 4									a	12	x	61	3.1	22
Allogromia sp.					x									
Psammosphaera fusca													x	
Armorella sphaerica								0.9		3.5				1.7
Pelosina sphaeriloculum		x	a				0.9	1.8	x	1	x	x	1	0.4
Hippocrepinella hirudinea							x			x		0.3	x	
Hippocrepinella cf. *hirudinea*							12	2.1	x	0.3		0.3	1	
Hippocrepina crassa		x		95	1.2	x	17	11	x	4.8		1		
Hippocrepina cf. *crassa*								4.2						0.4
Hippocrepina sp.										27	x	5.4	4.1	27
Hippocrepina indivisa			0.3							19		3.7	78	5.6
?*Hippocrepina* sp.										x		1.4		
Bathysiphon argenteus					1.5		0.6	3.3		0.6		0.3		
Phainogullmia sp. 1		x				x			x					
Phainogullmia sp. 2									x					
Phainogullmia sp. 3						x		1.8	x	x			x	
Pilulina argentea								x						

Table 2 continued

Monothalamous foraminiferal assemblage	Sub-tidal	Shallow-water							?	Deep-water				
Station	AFD	KF2*	AF1	KF3	AF3	KF1*	AF4	KF4	KF7*	NF1	KF5*	IF1	KF6	KF8
various silver saccamminids	5.4	x	2.7		6.6	x	1.9	13	x	1	x	4.1	3.1	3.5
unidentified saccamminid 1	68								x					
unidentified saccamminid 2										1.6				
unidentified saccamminid 3			47		46		30	14		28	x	17	5.2	39
various allogromiids	14	x	x		0.3	x	0.9	2.7	x	x	x	2	3.1	0.4
Lagenammina sp.										x		x	x	
Hyperammina subnodosa			x								x	x	x	x
Hyperammina fragilis									x	x			x	
Tholosina bulla			x							x	x	x	x	x
attached unidentified	11													
number of specimens counted for quantitative analysis	387		301	40	335		316	337		308		301	97	231

Among other agglutinated monothalamids, we found diverse specimens of the *Pelosina* (Fig. 3.12–15), mostly belonging to *Pelosina sphaeriloculum*. *Bathysiphon argenteus* (Fig. 4.1), *Armorella sphaerica* (Fig. 4.9), *Psammosphaera fusca* (Fig. 4.13), and the genus *Phainogullmia* also occurred. *Phainogullmia* was represented by at least three different morphotypes (Figs 3.7, 3.9–11). We also observed a large variety of small unidentified silver saccaminids (Fig. 3.1–6) with reflective test surfaces. These were present throughout the study area, in some locations in higher numbers (up to 14%). They demonstrated a good deal of morphological variability, from strongly elongated to sphaerical, having one or two apertures; some specimens were bifurcated.

A large proportion of the studied monothalamids was represented by small white to yellowish, oval to sphaerical saccamminids with fragile walls. Some of them were characteristic only for single localities. The grey-whitish, slightly angular saccamminid 1 (Fig. 4.14) was found in abundance, but only at the shallowest AFD site. Saccamminid 2, a snow-white form, oval in shape with a distinctive thick aperture (Fig. 4.15) was found only at the NF1 location. Saccamminid 3 (Fig. 4.16) was common in almost all samples. It had a yellowish, minute, ovoid test, without any clearly distinctive aperture.

At greater depths, we frequently found rigid, strongly cemented agglutinated taxa dominated by large *Hyperammina subnodosa* (Fig. 4.10), and to lesser degree by *Hyperammina fragilis* (Fig. 4.11) and *Lagenammina* sp. (Fig. 4.12). Numerous specimens of *H. subnodosa* possessed characteristic attached forms identified as *Tholosina bulla* (Fig. 4.8). Another unidentified foraminifer was found attached to sediment grains in the shallowest sample AFD.

Geographic distribution of monothalamous foraminifera

Adventfjorden. — Four samples (AFD, AF1, AF3, AF4) were collected between 6 and 100 mwd. The shallowest sample, collected by divers, contained a very specific assemblage dominated (68%) by an unidentified saccamminid 1, a few *Cylindrogullmia* sp. 1 and various unidentified allogromiids and saccamminids that were not found at any other locality. The sample AF1 from 70 mwd was dominated by *Gloiogullmia* sp. 2, *Micrometula* sp., *P. sphaeriloculum* and unidentified saccamminid 3. The last morphotype was abundant also in the samples AF3 and AF4, in which *Gloiogullmia* sp. and *Micrometula* sp. occurred in much lower numbers. In the samples AF3 and AF4, *Psammophaga* sp. 1–3 became an important component of total assemblages (36–37%), while *H.* cf. *hirudinea* and *H. crassa* appeared in abundance (together 29%) in AF4.

Isfjorden. — Two samples were taken at the entrance of the Adventfjorden (IF1) and near Nordfjorden (NF1) at 250 and 150 mwd, respectively. The sample IF1 was dominated by *Psammophaga* sp. 4 (59%). Both unidentified saccamminid 3 (17%) and *Cylindrogullmia* sp. 2 were also abundant. The similar morphotypes were found in the NF1 site, although here *Hippocrepina* sp. and *H. indivisa* were the dominant forms (46%).

Kongsfjorden. — Our data from this fjord are mostly qualitative. We have obtained good quantitative data for two samples only (KF4 and KF8). Sample KF4 (110 mwd) was dominated by *Psammophaga* sp. 1–3 (42%) whereas unidentified saccamminid 3, *H. crassa* and various silver saccamminids together accounted for 36%. The deepest sample, KF8 (345 mwd), was dominated by unidentified saccamminid 3 (39%), *Hippocrepina* sp. (27%), and *Psammophaga* sp. 4 (22%). Among the other samples, those from shallow water sites (<100 mwd) showed lower diversity than those from deeper ones, where *Cylindrogullmia* sp. 2 and *Psammophaga* sp. 4 were particularly abundant. *Micrometula* sp. was abundant at KF7 (115 mwd) but it was absent in all deeper Kongsfjorden samples. The KF6 was strongly dominated by *H. indivisa* (78%).

Depth-related monothalamous assemblages

Our qualitative and quantitative data allowed the distinction of three monothalamous foraminiferal assemblages that seemed to be most closely related to water-depth and/or distance from fresh-water source. The subtidal assemblage was represented by single sample AFD from 6 mwd. It shared only few species (short *Cylindrogullmia* sp. 1, *Micrometula* sp., ?*Vellaria* sp.) with other locations and was dominated by various unidentified allogromiids (Table 2).

The second, shallow-water assemblage comprised samples detained between 44 and 110 mwd. Characteristic components of this assemblage were the three forms of *Psammophaga,* characterized by a more or less transparent wall (*Psammophaga* sp. 1–3). These three forms were almost absent in deeper-water samples, where they were replaced by the non-transparent, finely agglutinated *Psammophaga* sp. 4 (Fig. 5). A similar taxonomic distinction between shallow- and deep-water assemblages was observed in the case of the *Hippocrepina/Hippocrepinella* group (Fig. 6). *Hippocrepinella crassa* and *Hippocrepinella* cf. *hirudinea* were much more abundant in shallow-water, than in deeper-water samples.

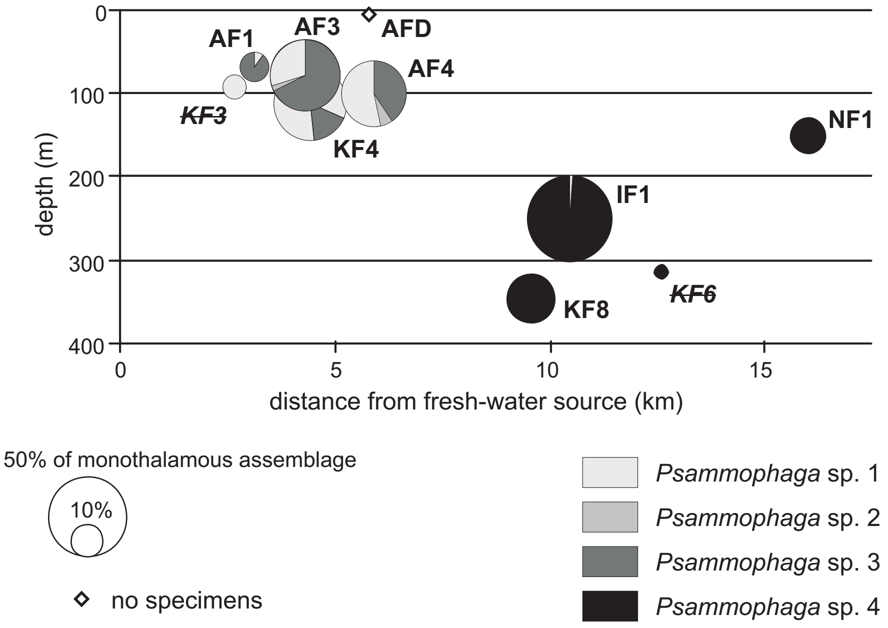

Fig. 5. Distribution of four forms of *Psammophaga* (*Psammophaga* sp. 1–4 from Fig. 2.11–15) in Kongsfjorden and Isfjorden. Vertical axis shows water depths, horizontal axis shows distance of the sample site from a major fresh water source inside the fjords. Crossed station symbols indicate poorly preserved, residual assemblages.

Deep-water (150–345 mwd) samples were characterised by large monothalamous agglutinated species (*Hyperammina subnodosa* with attached *Tholosina bulla*, *Hyperammina fragilis* and *Lagenammina* sp.) (Table 2). Moreover, our quantitative data indicate a high abundance of *Psammophaga* sp. 4, pear-shaped *Hippocrepina* sp., and *Hippocrepina indivisa* (Figs 5–6), which were absent in the shallower-water assemblages.

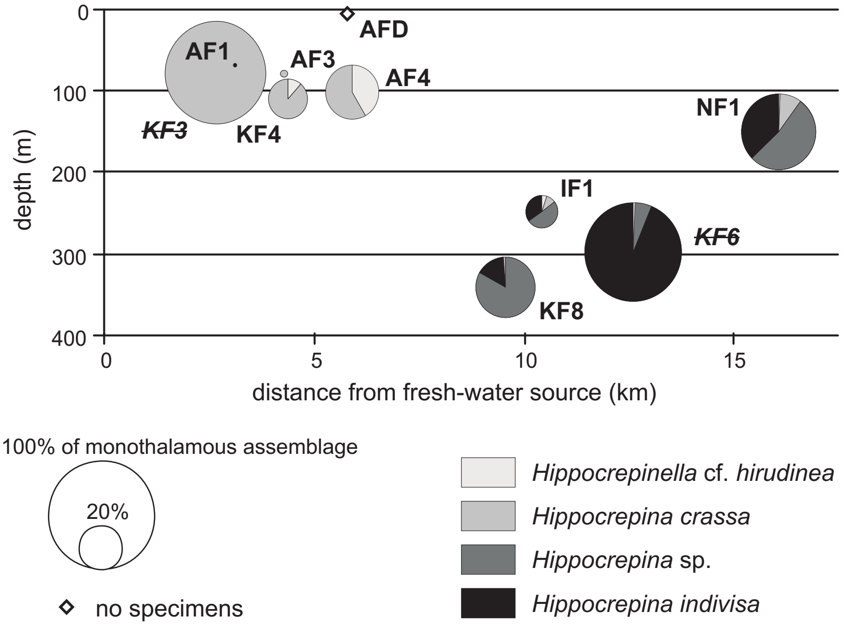

Fig. 6. Distribution of finely-agglutinated *Hippocrepinella* and *Hippocrepina* (see Fig. 4 for foraminiferal images) in Kongsfjorden and Isfjorden. Vertical axis shows water depths, horizontal axis shows distance of the sample site from a major fresh water source inside the fjords. Crossed station symbols indicate poorly preserved, residual assemblages.

Both shallow- and deep-water assemblages shared a number of organic-walled species, such as *Gloiogullmia* sp., *Micrometula* sp., *Cylindrogullmia* sp., agglutinated *Pelosina sphaeriloculum* and *Bathysiphon argenteus*. However, the large *Gloiogullmia* sp. 2 and the long *Cylindrogullmia* sp. 2 were more abundant in shallow- and deep-water samples respectively (Table 2). Various unidentified allogromiids and saccamiinids were present in all three assemblages (Table 2); however, they certainly represented a mixture of species, and we could not exclude the possibility that each of our assemblages was characterized by specific taxa.

Discussion and concluding remarks

The soft-walled monothalamous taxa were commonly overlooked by foraminiferal researchers. Nevertheless, some monothalamous agglutinated species as well as the soft-walled allogromiids were noted from deep-sea Arctic settings (see Gooday *et al.* 2005 for review). Moreover, Korsun and co-workers reported frequent occurrences of unidentified allogromiids from sublithoral Arctic sites off Novaya Zemlya (Korsun *et al.* 1995; Korsun and Hald 1998), River Ob estuary (Korsun 1999), Barents-Kara shelf (Korsun 2002), and Tempelfjorden in West

Spitsbergen (Korsun and Hald 2000). In both West Spitsbergen (Korsun and Hald 2000) and Novaya Zemlya fjords (Korsun and Hald 1998), several abundant unidentified allogromiid species were found to dominate the most glacier-proximal sites. Unfortunately, these reports were rather poorly documented.

Our recent results can be compared only with the Spitsbergen monothalamous foraminiferal data of Gooday *et al.* (2005). In that detailed morphological study, the authors compared Spitsbergen faunas with other monothalamous foraminiferal records from several locations around the world. We found most of the soft-walled species reported by Gooday *et al.* (2005). Among the more distinctive taxa, we have not found *Toxisarcon* sp., which could have been mechanically destroyed during the processing of our samples. We found only a single individual of the distinctive "yellow allogromiid" (Fig. 2.10), which was reported as common in Templefjorden (Gooday *et al.* 2005).

The distribution of calcareous and rigid agglutinated foraminifera in fjords of Svalbard has been intensely investigated (*e.g.* Hansen and Knudsen 1992, 1995; Hald and Korsun 1997; Korsun and Hald 1998, 2000; Korsun *et al.* 1995; and Majewski and Zajączkowski submitted). These studies indicated that there is a distinctive foraminiferal gradient along the axes of fjords from shallow-water, near-glacier inner-fjord, to the deeper-water outer-fjord. Our investigations of monothalamous foraminifera show similar succession, with three different monothalamous assemblages dominating subtidal, shallow-, and deep-water habitats in a similar manner in both Kongsfjorden and Adventfjorden.

A large proportion of unidentified allogromiids and saccamminids in our samples is consistent with previous reports of the high diversity of monothalamous foraminifera in Svalbard fjords (Korsun 2002; Gooday *et al.* 2005). Molecular analysis of similar assemblage from the Antarctic coastal waters (Explorers Cove, McMurdo Sound) showed that the majority of these unidentified forms represent new lineages of monothalamous foraminifera (Pawlowski *et al.* 2002b). This is confirmed by preliminary molecular data obtained for the material described here (Pawłowski, work in progress).

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References

BESZCZYŃSKA-MØLLER A., WĘSŁAWSKI J.M., WALCZOWSKI W. and M. ZAJĄCZKOWSKI. 1997. Estimation of glacial meltwater discharge into Svalbard coastal waters. *Oceanologia* 39 (3): 289–298.

DELACA T.E., LIPPS J.H. and HESSLER R.R. 1980. The morphology and ecology of a new large agglutinated Antarctic foraminifer (Textulariina: Notodendrodidae nov.). *Zoological Journal of the Linnean Society* 69: 205–224.

FLAKOWSKI J., BOLIVAR I., FAHRNI J. and PAWLOWSKI J. 2005. Actin phylogeny of Foraminifera. *Journal of Foraminiferal Research* 35: 93–102.

GOODAY A.J. 1986. Soft-shelled foraminifera in meiofaunal samples from the bathyal northeast Atlantic. *Sarsia* 71: 275–287.

GOODAY A.J. 2002. Organic-walled allogromiids: aspects of their occurrence, diversity and ecology in marine habitats. *Journal of Foraminiferal Research* 32: 384–399.

GOODAY A.J. and PAWLOWSKI J. 2004. *Conqueria laevis* gen. & sp. nov., a new soft-walled monothalamous foraminiferan from the deep Weddell Sea. *Journal of the Marine Biological Association of the United Kingdom* 84: 919–924.

GOODAY A.J., BOWSER S.S. and BERNHARD J.M. 1996. Benthic foraminiferal assemblages in Explorers Cove, Antarctica: a shallow-water site with deep-sea characteristics. *Progress in Oceanology* 37: 117–166.

GOODAY A.J., HOLZMANN M., GUIARD J., CORNELIUS N. and PAWLOWSKI J. 2004. A new monothalamous foraminiferan from 100–6300 m water depth in the Weddell Sea: morphological and molecular characterization. *Deep-Sea Research Part II* 51: 1603–1616.

GOODAY A.J., BOWSER S.S., CEDHAGEN T., CORNELIUS N., HALD M., KORSUN S. and PAWLOWSKI J. 2005. Monothalamous foraminiferans and gromiids (Protista) from western Svalbard: A preliminary survey. *Marine Biology Research* 1: 290–312.

HABURA A., PAWLOWSKI J., HANES S.D. and BOWSER S.S. 2004. Unexpected foraminiferal diversity revealed by small-subunit rDNA analysis of Antarctic sediment. *Journal of Eukaryotic Microbiology* 51: 173–179.

HALD M. and KORSUN S. 1997. Distribution of modern benthic foraminifera from fjords of Svalbard, European Arctic. *Journal of Foraminiferal Research* 27 (2): 101–122.

HANSEN A. and KNUDSEN K.L. 1992. Recent foraminifera in Freemansundet, eastern Svalbard. *LUNDQUA Reports* 35: 177–189.

HANSEN A. and KNUDSEN K.L. 1995. Recent foraminiferal distribution in Freemansundet and Early Holocene stratigraphy on Edgeøya, Svalbard. *Polar Research* 14 (2): 215–238.

HISDAL V. 1985. *Geography of Svalbard*. Norsk Polarinstitutt, Oslo; 75 pp.

HOP H., PEARSON T., HEGSETH E.N., KOVACS K., WIENCKE C., KWAŚNIEWSKI S., EIANE K., MEHLUM F., GULLIKSEN B., WŁODARSKA-KOWALCZUK M., LYDERSEN C., WĘSŁAWSKI J.M., COCHRANE S., GABRIELSEN G.W., LEAKEY R., LONNE O.J., ZAJĄCZKOWSKI M., FALK-PETERSEN S., KENDALL M., WANGBERG S.A., BISCHOF K., VORONKOV A.Y., KOVALTCHUK N.A., WIKTOR J., POLTERMAN M., DI PRISCO G., ESTOPPEY A., PAPUCCI C. and GERLAND S. 2002. The marine ecosystem of Kongsfjorden, Svalbard. *Polar Research* 21: 167–208.

KORSUN S. 1999. Benthic foraminifera of the Ob estuary, west Siberia. *Berichte zur Polarforschung* 300: 59–70.

KORSUN S. 2002. Allogromiids in foraminiferal assemblages on the Western Eurasian Arctic shelf. *Journal of Foraminiferal Research* 32: 400–413.

KORSUN S. and HALD M. 1998. Modern benthic foraminifera off Novaya Zemlya tidewater glaciers, Russian Arctic. *Arctic and Alpine Research* 30: 61–77.

KORSUN S. and HALD M. 2000. Seasonal dynamics of benthic foraminifera in glacially fed fjord of Svalbard, European Arctic. *Journal of Foraminiferal Research* 30 (4): 251–271.

KORSUN S.A., POGODINAI I.A., FORMAN S.L. and LUBINSKI D.J. 1995. Recent foraminifera in glaciomarine sediments from three arctic fjords of Novaya Zemlja and Svalbard. *Polar Research* 14 (1): 15–31.

KORSUN S., HALD M., PANTELEEVA N. and TARASOV G. 1998. Biomass of foraminifera in the St. Anna trough, Russian Arctic continental margin. *Sarsia* 83: 419–431.

LEFAUCONIER B., HAGEN J.O. and RUDANT J.P. 1994. Flow speed and calving rate of Kongsbreen Glacier, Svalbard, using SPOT images. *Polar Research* 13: 59–65.

LOEBLICH A.R. and TAPPAN H. 1987. Implication of wall composition and structure in agglutinated foraminifers. *Journal of Paleontology* 63: 769–777.

MAJEWSKI W. and ZAJĄCZKOWSKI M. (submitted). Benthic foraminiferal assemblages in Adventfjorden, Svalbard: The late 1980s – early 1990s high North Atlantic Oscillation (NAO) record. *Journal of Foraminiferal Research*.

PAWLOWSKI J. 2000. Introduction to the molecular systematics of foraminifera. *Micropaleontology* 46 (supplement 1): 1–12.

PAWLOWSKI J., FAHRNI J. and BOWSER S.S. 2002a. Phylogenetic analysis and genetic diversity of *Notodendrodes hyalinosphaira*. *Journal of Foraminiferal Research* 32: 173–176.

PAWLOWSKI J., FAHRNI J., BRYKCZYNSKA U., HABURA A. and BOWSER S.S. 2002b. Molecular data reveal high taxonomic diversity of allogromid foraminifera in Explorers Cove (McMurdo Sound, Antarctica). *Polar Biology* 25: 96–105.

PAWLOWSKI J., HOLZMANN M., FAHRNI J., CEDHAGEN T. and BOWSER S.S. 2002c. Phylogenetic position and diversity of allogromiid foraminifera inferred from rRNA gene sequences. *Journal of Foraminiferal Research* 32: 34–343.

PAWLOWSKI J., HOLZMANN M., BERNEY C., FAHRNI J., GOODAY A.J., CEDHAGEN T., HABURA A. and BOWSER S.S. 2003. Evolution of early foraminifera. *Proceedings of the National Academy of Sciences, USA* 100: 11494–11498.

PAWLOWSKI J., FAHRNI J.F., GUIARD J., KONLAN K., HARDECKER J., HABURA A. and BOWSER S.S. 2005. Allogromiid foraminifera and gromiids from under the Ross Ice Shelf: morphological and molecular diversity. *Polar Biology* 28: 514–522.

SABBATINI A., PAWLOWSKI J., GOODAY A.J., PIRAINO S., BOWSER S.S., MORIGI C. and NEGRI A. 2004. *Vellaria zucchellii* sp. nov., a new monothalamous foraminifer from Terra Nova Bay, Antarctica. *Antarctic Science* 16: 307–312.

SEN GUPTA B.K. 1999. Systematics of modern foraminifera. *In*: Sen Gupta B.K. (ed.) *Modern Foraminifera*. Kluwer Academic Publishers, Dordrecht, The Netherlands: 7–36.

SVENDSEN H, BESZCZYŃSKA-MØLLER A, HAGEN J.O., LEFAUCONNIER B., TVERBERG V., GERLAND S., ØRBÆK J.B., BISCHOF K., PAPUCCI C., ZAJĄCZKOWSKI M., AZZOLINI R., BRULAND O., WIENCKE Ch., WINTHER J. G. and DALLMANN W. 2002. Physical environment of Kongsfjorden, an Arctic fjord system in Svalbard. *Polar Research* 21 (1): 133–166.

TODO Y., KITAZATO H., HASHIMOTO J. and GOODAY A.J. 2005. Simple foraminifera flourish at the Ocean's deepest point. *Science* 307: 689.

WĘSŁAWSKI J.M., SZYMELFENIG M., ZAJĄCZKOWSKI M. and KECK A. 1999. Influence of salinity and suspended matter on benthos of an Arctic tidal flat. *ICES Journal of Marine Science* 56: 194–202.

ZAJĄCZKOWSKI M. and LEGEŻYŃSKA J. 2001. Estimation of zooplankton mortality caused by an Arctic glacier outflow. *Oceanologia* 43 (3): 341–351.

ZAJĄCZKOWSKI M. 2002, On the use of sediment traps in sedimentation measurements in glaciated fjords. *Polish Polar Research* 23 (2): 161–174.

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