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Seasonal variability of meiobenthic assemblages inhabiting the Nottinghambukta tidal flat, SW Spitsbergen

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Abstract: The aim of the work was to describe the variability of a group of meiobenthos inhabiting a tidal flat in Nottinghambukta which is influenced by the diverse conditions of a seasonal as well as multi-annual cyclicity. Samples were collected in five series, i.e. during the Arctic spring (2001), summer (2000 and 2001) and autumn (2001). The material for qualitative analysis was collected from sites with different hydrological characteristics. The following major meiobenthic taxa were found: Metazoa, i.e. Nematoda and Crustacea (Ostracoda and Copepoda-Harpacticoida), and Foraminifera. Unstable conditions in the bay result in a seasonal variability in the species composition as well as an uneven colonisation of the Nottinghambukta area by meiobenthos. The lowest taxonomic diversity occurs in summer, but it increases in autumn when the land runoff ceases. Based on the conducted analysis, it can be concluded that the inflow of seawater in autumn brings on the occurrence of new taxa, which probably inhabit the bay temporarily until the summer season during which the highly variable conditions cause a change in the species composition. For the series of samples collected in July 2000 and 2001, the species composition for Harpacticoida was determined. The taxonomic diversity of the harpacticoid assemblage inhabiting the bay was observed in the two subsequent years. Moreover, during the study duration a considerable decrease was observed in the abundance of Ostracoda in Nottinghambukta.

Key words: meiobenthos, Nottinghambukta, Spitsbergen, seasonal variability, Foraminifera, Harpacticoida, Ostracoda

Introduction

Meiobenthos (meiofauna) as a functional complex group of organisms is subject to further divisions, among others, to marine and freshwater units, as well as permanent (specimens belonging to a given group throughout their life cycle) and temporary components (juvenile stages of macrobenthos). According to some authors (Soltwedel 1997; Gal'tsova et al. 2004; Radziejewska et al. 2006; Brandt et al. 2007; Giere 2009), Metazoa and large Protista and Foraminifera in particular, are regarded as meiobenthos, while others restrict marine meiobenthos to Metazoa (Sommerfield and Warwick 1996; Schizas and Shirley 1996).

The literature concerning the issues related to the Spitsbergen groups of meiobenthos is not very comprehensive. Moreover, the studied problems concentrate mainly on quantitative aspects; includes Radziejewska and Stańkowska-Radziun 1979; Mokievsky 1992; Węsławski et al. 1995; Węsławski et al. 1999; Kotwicki et al. 2004. Papers related to the fauna of the Nottinghambukta tidal flat are also rather rare. Inventories of certain groups of organisms and taxa diversity were described in several papers (e.g. Legeżyńska et al. 1984; Różycki and Gruszczyński 1986, 1991; Wiśniewska 2001; Wojtasik and Kur 2007). However, the above mentioned papers dealt with only one group or chosen systematic groups of macrobenthos. A similarly small number of papers are devoted to issues of the species composition of Copepoda-Harpacticoida and Ostracoda. The descriptions of species composition usually concern inventories of large areas, such as the waters surrounding Spitsbergen (Kotwicki 2002), Kongsfjord (Bick and Arlt 2005), fjord Hornsund (Mackiewicz 2006), and the fjords of northern Spitsbergen (Hartmann 1992, 1993). To date, a small number of harpacticoid species have been reported from the waters of Spitsbergen, i.e. 22 (Kotwicki 2002) and 26 species

(Mielke 1974); and 10 species in Kongsfjorden (Bick and Arlt 2005). The phylum Ostracoda is represented in larger numbers: 44 (Mackiewicz 2006) and 29 species (Hartmann 1992). There is quite an extensive literature on the subject of the species composition of fjord- inhabiting Foraminifera (Korsun et al. 1995; Korsun and Hald 2000; Majewski and Zajaczkowski 2007). However, the species composition of tidal flats has not yet been analysed. A tidal flat is a special type of ecosystem due to significantly variable salinity and temperature that change on an annual scale as well as in particular areas of the bay (Sapota et al. 2009). Therefore, it should be expected that a group of meiobenthos inhabiting a tidal flat will be different from those already described from the fjords and/or shore zone outside the tidal flats (Radziejowska and Stankowska-Radziun 1979; Mokievsky 1992; Szymelfenig et al. 1995; Kotwicki et al. 2004; Bick and Arlt 2005).

The aim of this paper was, firstly, to describe the seasonal variability of meiobenthic assemblages from chosen sites within the bay, and secondly, to determine the species composition of Foraminifera, Ostracoda and Harpacticoida from the tidal flat which is a different living environment compared to the fjords studied so far by various authors.

Study area

Nottinghambukta is situated in SW Spitsbergen, north of Hornsund. The bay is partly separated from the Greenland Sea by the range of the Dunöyane islands and skerries, and it is bordered by the Kvartsitt islets situated at the inlet to the bay and the capes Kvislodden (in the north) and Kvartsittodden (in the south). The area of the bay is about 4 km². The southern shore of the bay is rocky and stony, while the northern one is sandy and stony. In the east, the bay is situated on the forefield of Werenskiold glacier, which discharges its waters into the bay via glacial rivers (Krawczyk et al. 1990; Krawczyk and Leszkiewicz 1995; Leszkiewicz and Pulina 1995). Nottinghambukta is also supplied by waters flowing from Lake Myrktjörn carried by the River Brattegga. The bed of Nottinghambukta is rocky, covered by silty sediments, and throughout the area of the bay there are numerous quartzite rocks and skerries. During low tides, a large part of the bay is completely uncovered. The wave height in Nottinghambukta does not exceed 30 cm because shoals, skerries and the Dun islands attenuate oceanic waving. Intensive mixing of waters in the bay is caused by semidiurnal tides, wind damming of water and its small depth (Różycki and Gruszczyński 1986, 1991; Wiktor et al. 1986; Styszyńska and Wiśniewska 2002; Wiśniewska-Wojtasik and Styszyńska 2004).

Hydrological conditions present in the bay are shaped by warm waters of the West Spitsbergen Current, cold waters of the Sorkapp Current as well as by fresh waters carried by glacial rivers, the Bratteggvelva and small periodic tundra streams. In the hydrological season of 2001, the bay was under the impact of warm waters of the West Spitsbergen Current (NOAA-CIRES Climate Diagnostics Center, http://www.cdc.noaa.gov/).

The temperature and salinity of the bay waters in winter are shaped by near-shore waters, whereas during a hydrological season they are characterised by high variability resulting from the mixing of seawater with freshwater originating from land. As a result of these intensive freshening events the temperature and salinity of water in the bay do not have a uniform character and reveal large fluctuations, i.e. in the case of temperature, from 1.5°C in the river channels to 12°C in dammed lakes with dark silty sediments. Salinity ranges from 0 psu in river channels to over 31 psu at the beginning and at the end of a hydrological season, especially in the NW area of the bay (Wiśniewska-Wojtasik and Styszyńska 2004).

The length of an ice season in the inner part of the bay is estimated at 25 to 34 weeks. In the season of 2000–2001, the ice cover started to form at the beginning of February. At the end of May and the beginning of June, stable ice covered less than half of the bay. At that time, the shelf of SW Spitsbergen was overflowed by warm Atlantic waters which freed the bay forefield from ice (Styszynska and Wisniewska 2002).

Another significant factor shaping the bay's ecosystem is the possible occurrence of the surface freezing of sediments. The necessary conditions for the freezing of the surface layer of bottom sediments is the intensive giving off of energy accumulated during summer which can occur in early autumn due to an inflow of cold waters of the Sorkapp Current (with sub-zero temperature) and very low air temperatures. In the season of 2000–2001, surface freezing of the bottom sediments in the bay was not observed (Wiśniewska 1999; Wiśniewska-Wojtasik and Styszyńska 2004).

Material and methods

Material for the research was collected in five series, i.e. on 2 July 2000 (9 samples, Arctic summer), 18 June 2001 (10 samples, Arctic spring), 15 July 2001 (7 samples, Arctic summer), 5 August 2001 (10 samples, Arctic summer) and 7 September 2001 (11 samples, Arctic autumn) from an inner and outer profile at sites characterized by different salinity, temperature and structure of bottom sediment. Sites 1 and 3 were situated in the channel of a river flowing through the bay; sites 2 and 4 near the river channels; sites 5 and 6 within skerries (in

Table 1. Characteristics of the sampling stations (St) according to temperature (T), salinity (S) and type of sediment

St	Sampling date										Type of sediment
	02.07.2000		18.06.2001		15.07.2001		05.08.2001		07.09.2001		
	S	T	S	T	S	T	S	T	S	T	
1	5.9–6.0	7.3–8.3	0–1.4	2.8–3.5	3.1	6.1	3.5	4.4	31.1–31.3	4.7–4.9	msd
2	–	–	29.0–30.5	3.0–3.3	31.5	5.0	6.4	3.2	31.8	4.1	ms
3	0	6.2–8.5	0	1.4–1.5	0	6.9	0.0–0.1	2.9–3.2	27–31.2	3.9–4.0	ms
4	19.6–31.9	8.2–8.6	0.9–23.1	2.1–3.3	31.4	4.3	5.7	5.1	31.8	3.9	ms
5	30.3–33.6	7.7–8.5	31.5	3.7	–	–	30.5	5.0	31.7	3.7	sk
6	13.8–16.9	9.0–9.1	27.0–27.2	5.6	30.5	5.4	5.6	5.8	31.8	3.7	sm
7	16.3–23.7	8.1–9.4	24.0–25.2	5.6–5.7	–	–	5.4	6.5	31.7–31.8	3.7	smg
8	13.7–32.2	10.3	8.1–18.4	4.9–5.9	–	–	–	–	31.6	3.9	smg
9	–	–	–	–	15.8	11.3	0	8.5	31.8–32.0	4.5–4.7	ms
10	0–5.8	10.0–11.4	0	1.1	10.0–15.0	7.2	0.0–1.3	6.0–7.5	0.2–0.3	3.5–3.8	ms
11	2.5–4.7	9.4–11.9	3.3–3.4	5.3–5.4	–	–	5.6	9.1	27.4–28.5	4.1	ms

ms – muddy-sandy (mud > sand), msd – muddy-sandy with detritus (mud > sand), sm – sandy-muddy (sand > mud), smg – sandy-muddy with gravels (sand > mud), sk – skerries.

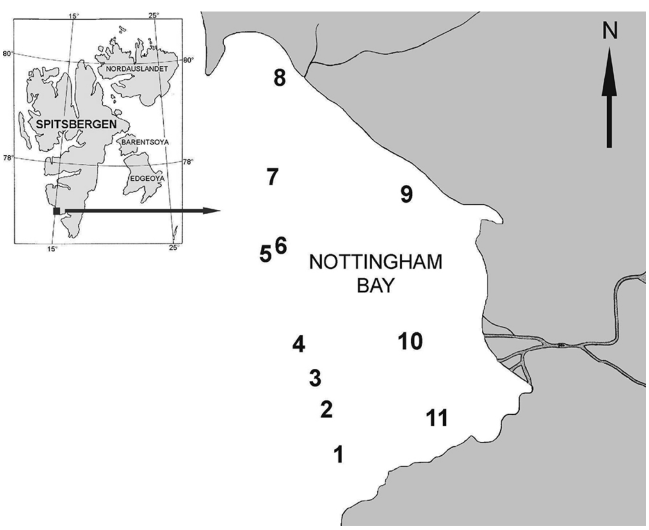

Fig. 1. Research area, sampling stations

the case of site 5, material was collected from the pools in the hollows of skerries); site 7 was between the belt of skerries and the northern shore of Nottinghambukta; and site 8 in the shore zone. Sites 9–11 were situated along the inner profile, while sites 10 and 11 in the seasonal river channel. The sampling sites are presented in Fig. 1, and the hydrological conditions in Table 1.

Field sample collection

Samples were collected with a hand scoop (30×20 cm metal frame with a 0.042 mm mesh) trawled through the 0–5 cm layer of sediment to cover a 100 cm^2 area per sample. The volume of each sample before preliminary rinsing was about 0.5 dm^3. In the case of skerries, the sample volume was smaller. The material was collected for the purpose of conducting a qualitative and semi-quantitative analysis of major meiobenthic taxa (Metazoan and Foraminifera) inhabiting Nottinghambukta. Samples were preserved in 70% ethanol and stained with Rose Bengal (Rose Bengal sodium salt, SIGMA nr R3877-5G). Thus, prepared material, after washing through a 0.042 mm sieve, underwent a detailed analysis with regard to the meiobenthic organisms present. The size of animals was assessed using, among others, scale pans with a 1×2 mm grid. Animals longer than 1 mm and whose width or thickness was equal or larger than 1 mm were classified as macrobenthos. Organisms whose size theoretically enabled them to pass through a 1 mm mesh were classified as meiobenthos.

Sediment samples were classified as follows: 1. muddy-sandy (ms): volume of mud > volume of sand; 2. sandy-muddy (sm): volume of sand > volume of mud; 3. muddy-sandy with detritus: volume of mud > volume of sand, with visible detritus; 4. sandy-muddy with stones or gravel: volume of sand > volume of mud > volume of gravel; and 5. skerries, i.e. samples were collected from skerries.

Taxonomic analysis

Taxonomic determinations of the genera Foraminifera were performed according to Loeblich and Tappan (1964), harpacticoids were identified according to the paper by Sars (1911), Lang (1948, 1965) and Bodin (1997), whereas Ostracoda were determined according to the papers by Sars (1922–1928), Athersuch et al. (1989), Huys et al. (1996) and Brouwers et al. (2000).

Ecological analysis MeioEco

MeioEco analyses were based on developed methodologies for assessing ecological status by the meiobenthos functional group (Wojtasik 2010, 2013a,b). 3D analyses were conducted for the relative scale taking into account the minimum, maximum on the parameters and arithmetic average calculated for maximum and minimum values (the boundaries of the intervals).

Parameters: N_{10} – the number of individuals per 10 cm², N_{taxa} – number of identified major meiobenthic taxa. The developed algorithm B_w (Wojtasik 2013a,b, 2018) was used to calculate the balance of taxa present in the assemblage. The B_w factor is described by the following formula:

$$B_w = 1 - \sum^{N}_{\substack{i,j\in(N) \\ nj \geq э0 \leq \ldots \leq э \leq nj \leq \ldots \leq nM \leq N \\ k = 1;2;\ldots;M-1}} \frac{(n_j - n_i)}{kN} \qquad [1]$$

where: N – the number of all individuals in a sample; n_i, n_j – the number of individuals of the i-th and j-th taxon $0 \leq \ldots \leq n_i \leq n_j \leq \ldots \leq n_M \leq N$, where M – the number of taxa in one sample.

The taxa are sorted in order of the increasing number of individuals in succeeding groups to distinguish them from N – the number of individuals, in this case (N) stands for natural numbers. k describes the taxa group in the following way:

- k = 1 for $(n_M - n_{M-1})$
- k = 2 for $(n_{M-1} - n_{M-2})$
- k = M – 1 for $(n_2 - n_1)$.

The B_w indicator assumes a maximum value equal to 1 when all the taxa present are represented by the same number of individuals. The lower the ratio, the stronger the dominance of one of the taxa. The value of the maximum and minimum B_W is the extent of our audit; the arithmetic average of the maximum and minimum values of the border ranges between equilibrium and its absence in the meiobentic assemblages.

Data analysis

For the purpose of analysis, the following methods and indices were used: constancy of occurrence which is the frequency (F) calculated for the whole material and for each sampling series separately; relative abundance (D) expressed as a percentage content (%); and Bray-Curtis faunistic similarity index calculated with the use of the PRIMER-E v.6 (Clarke and Gorley 2006) computer programme. Two types of analysis were performed, i.e. agglomeration of average connections and MDS multidimensional scaling. Additionally, the diversity of meiobenthic assemblages in the bay was presented as a 3D data extrapolation (Statistica v.8). For MeioEco analysis the computer application meioeco.pl (Wojtasik et al. 2016) was used.

Results and discussion

In the material collected in Nottinghambukta during five sampling series the following taxa specific for

Table 2. Number of individuals and relative abundance of major meiobenthic taxa

Date	Taxa	Station / Number of individuals											F
		1	2	3	4	5	6	7	8	9	10	11	
02.07.2000	Fo	32	–	0	4	8	4	15	0	–	4	14	0.78
	Ne	33	–	6	12	29	23	44	0	–	2	0	0.78
	Os	1	–	0	0	32	6	51	0	–	0	0	0.44
	Ha	0	–	5	5	6	0	7	0	–	60	2	0.67
18.06.2001	Fo	167	20	117	28	7	25	111	4	–	0	12	0.90
	Ne	52	0	40	24	868	1310	328	91	–	41	258	0.90
	Os	3	0	5	0	3	7	17	0	–	0	0	0.50
	Ha	1	1	0	0	111	8	0	0	–	26	25	0.60
15.07.2001	Fo	0	9	1	0	–	14	–	–	4	0	–	0.57
	Ne	0	73	7	3	–	25	–	–	220	20	–	0.86
	Os	0	3	0	0	–	3	–	–	2	1	–	0.57
	Ha	0	12	0	0	–	22	–	–	69	4	–	0.57
05.08.2001	Fo	1	0	0	11	48	1	2	–	0	3	3	0.70
	Ne	28	87	24	68	13	193	68	–	73	0	78	0.90
	Os	0	0	0	1	3	45	5	–	0	0	0	0.40
	Ha	0	4	0	8	4	0	33	–	55	0	16	0.60
07.09.2001	Fo	8	3	32	12	22	71	36	36	13	43	3	1
	Ne	44	79	87	0	0	11	48	93	96	0	171	0.73
	Os	0	0	9	1	0	3	7	14	0	0	1	0.55
	Ha	0	0	48	23	0	19	17	0	38	11	53	0.64
All samples	Fo	208	32	150	55	85	115	164	40	17	50	32	1
	Ne	157	239	164	107	910	1562	488	184	389	63	507	1
	Os	4	3	14	2	38	64	80	14	2	1	1	1
	Ha	1	17	53	36	121	49	57	0	162	101	96	0.91

Fo – Foraminifera, Ne – Nematoda, Os – Ostracoda, Ha – Harpacticoida. Relative abundance (D): a dark gray cell (D >50%), a light gray cell (50% ≥ D > 25%), a white cell (D ≤ 25%); F – Frequency; minus (–) no data.

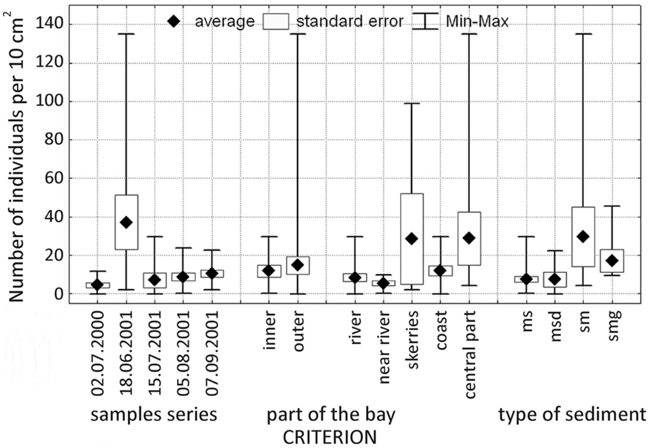

Fig. 2. Meiobenthic density (average, minimum, maximum)

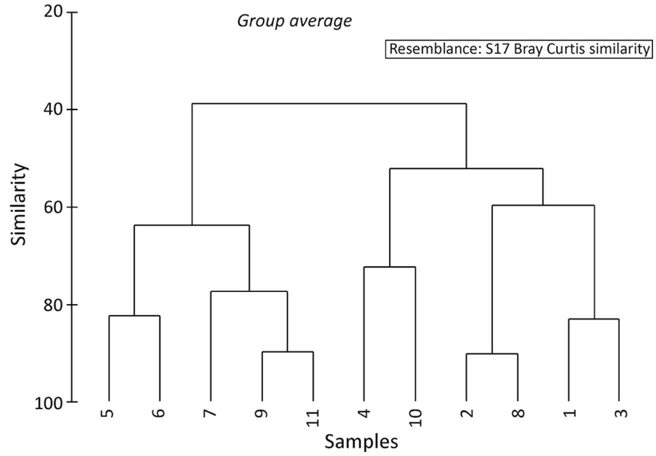

Fig. 3. Cluster dendogram of Bray-Curtis similarity of meiobenthic assemblages performed for four sampling series separately (2001)

meiobenthic assemblages were found: Foraminifera, Nematoda, Ostracoda and Copepoda-Harpacticoida. A total of 7017 specimens were isolated, namely, 1332 foraminiferans (including 384 empty shells), 4770 nematodes, 223 ostracods and 692 harpacticoids. Specimens of Polychaeta, Gammaridea and Oligochaeta were also found but due to their large size (length >1 mm) they were classified as macrobenthos.

The highest frequency among the sampling series was observed in Foraminifera and Nematoda, and the lowest in Ostracoda. For all the analyzed samples, the highest relative abundance was found in Nematoda (71.9%) and the lowest in Ostracoda (3.4%), while Foraminifera (14.3%) and Harpacticoida (10.4%) displayed medium values. Detailed data concerning the frequency and relative abundance for particular series of samples are presented in Table 2. Meiobenthic density (average, minimum, maximum) is presented in Fig. 2.

Nematoda were the dominant group in all the series of samples. Foraminifera constituted influents in spring and autumn, while in summer, they belonged to recedents. Harpacticoida were recedents in spring; in summer and autumn, their relative abundance grew to make them influents in the assemblage. Ostracoda were recedents in all the series of samples.

When considering particular series of samples and analysing relative abundance and the structure of domination (D>50%) for each site, a significant diversity was revealed regarding the area of the bay as well as seasonal variability for the same areas of Nottinghambukta. Foraminifera dominated in spring (June) in the SW area of the bay (four sites), and Nematoda in the NW and inner part (six sites). In samples collected in the summer period (July and August) Nematoda dominated at sites where previously Foraminifera were dominant in most cases. Moreover, Nematoda dominated at eight out of 10 sites. In autumn (September), Nematoda were not such a strong dominant (five sites out of 11), and the role of Foraminifera (dominant at three sites) and Harpacticoida (dominant at one site) grew. Changes in domination in autumn concerned mainly the NW and inner area of the bay. The SW area was still mainly inhabited by Nematoda, however, a decrease in the relative abundance of this taxon at particular sites had become visible. The area of the Ostracoda occurrence was limited to the western area of the bay (Table 2).

Statistical analysis of faunistic similarity between meiobenthic assemblages, performed to obtain: 1. the average of abundance for all series of samples (Fig. 3), 2. separately for all sampling series (Figs 4–5), revealed a significant variability. Clustering (Fig. 3) was revealed in two groups of sites. The first one was related to the area of the skerries (the site in the shore zone of the inner profile was also assigned here). The second subset consisted of meiobenthos from sites related to the SW area with river channels as well as site 8 in the shore zone of the northern part of the bay. The groups of meiobenthos from the river channels (sites 1 and 3) were interrelated, while sites 2 and 4, situated near the river channels, formed another subset. MDS analysis showed clearly that the character of meiobenthic assemblages changes during the hydrological season. The groups of meiobenthos that were quite diverse in spring and autumn acquired a homogeneous character in summer (except for site 10 represented by Foraminifera only). The similarity of the MDS diagrams of meiobenthos assemblages are presented in Figures 4 and 5. In the areas that undergo drastic environmental fluctuations (the temporary river channel and areas near river) the changes in meiobenthic assemblages mostly concern individuals/taxa abundance. In the areas characterized by more stable conditions the seasonal changes mainly affect the taxa domination in the assemblage (station No. 10). In small pools on the sker-

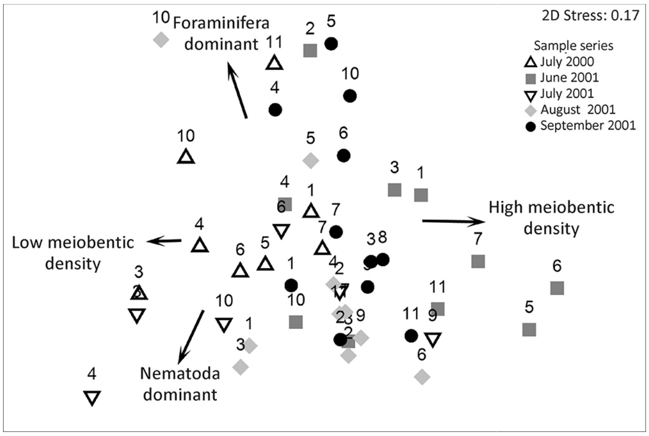

Fig. 4. S17 Bray-Curtis similarity multidimensional scaling (MDS) plot showing similarity of meiobenthic assemblages, all samples

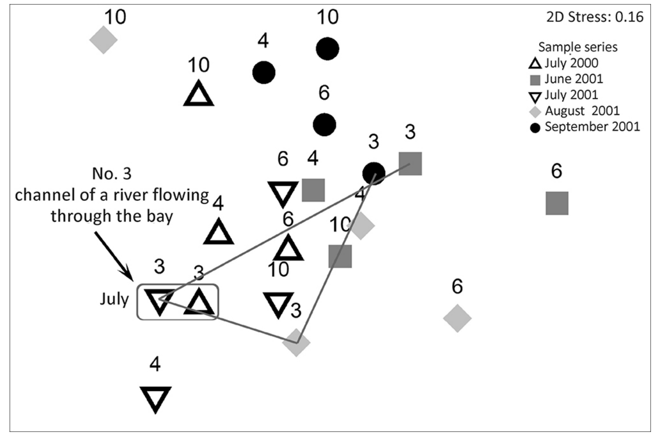

Fig. 5. S17 Bray-Curtis similarity multidimensional scaling (MDS) plot showing similarity of meiobenthic assemblages, changeability of meiobenthic assemblages for stations No. 3, 4, 6 and 10)

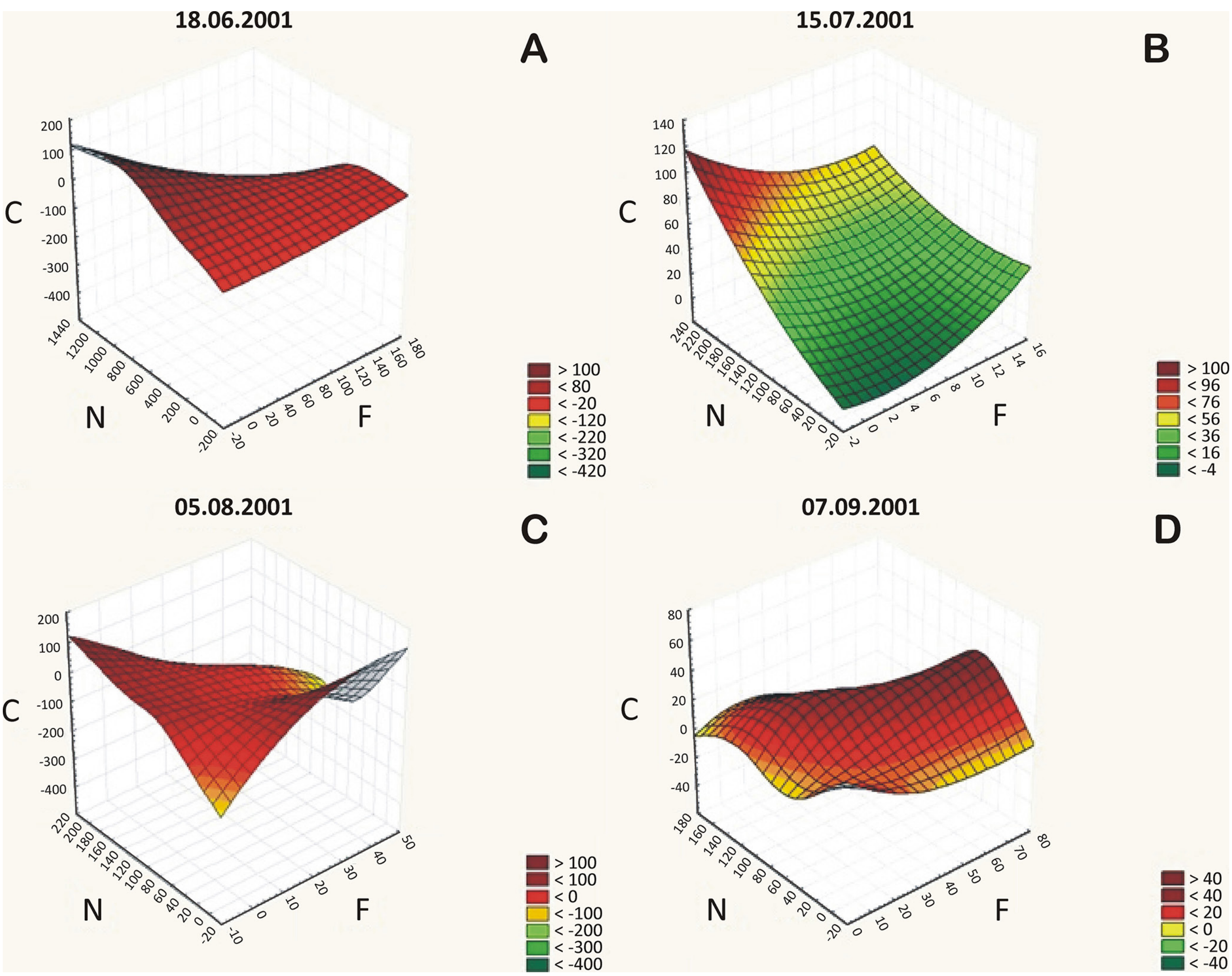

Fig. 6. 3D graph of meiobenthic assemblage variability

Explanation: axis X (F – Foraminifera), axis Y (N – Nematoda), axis Z (C – Crustacea: Ostracoda + Harpacticoida). Date of sampling: A – 18 JUN 2001, B – 15 JUL 2001, C – 05 AUG 2001, D – 07 SEP 2001.

ries (station No. 6) the changes concern the abundance of individuals and taxa domination. Additionally, a 3D graph depicting the variability of meiobenthic assemblages shows the values of abundance of Foraminifera (axis X), Nematoda (axis Y) and Crustacea (Ostracoda + Harpacticoida; axis Z) for the whole tidal flat in various sample series (Fig. 6). The obtained graphs indicate a significantly different character of the meiobenthos inhabiting the bay during summer. On the other hand, in spring, late summer and autumn the assemblage had similar characteristics.

The analysis of Foraminifera has revealed that Foraminifera were represented by four families, i.e. Islandiellidae (*Islandiella* sp.), Discorbidae (*Buccella* sp.), Elphididae (*Elphidium* spp.) and Nonionidae (*Nonionellina* sp.), with a suborder Nodosariacea (Species 1, Species 2). Based on the performed analysis, it was found that only individuals of *Elphidium* spp. were alive at the time of sample collection. The other taxa occurred as empty tests only. This may have resulted from unfavorable conditions in the tidal flat areas as well as from the deposits of tests in seawater inflowing regularly to the bays. No Foraminifera were observed at the two stations located in the vicinity of the glacial river. The stations in Nottingham Bay were situated at the equal distance from the open sea, therefore it can be concluded that the factor limiting the occurrence of these taxa was the freshening of the bay waters.

The analysis of the identified Foraminifera morphological types (Loeblich and Tappan 1964) suggested that the only individuals which had settled in the bay were planispiral-involute. In the case of empty tests, a greater shape diversity was observed, i.e. planispiral-involute, trochospiral, biserial and single chambered.

The taxonomic diversity of Foraminifera inhabiting the studied tidal flat was extremely poor as compared to that observed at the stations located in the deeper parts of the Spitsbergen fjords, as presented in the publications of Korsun et al. (1995), Korsun and Hald (2000), and Majewski and Zajaczkowski (2007).

Additional information concerning the seasonal variability of meiobenthos was obtained from the analysis of harpacticoids. In the analysed material, seven families were determined, namely, Ameiridae, Cletodidae (represented by *Nannopus palustris* (Brady 1880)), Ectinosomidae (represented by *Ectinosoma neglectum* Sars, 1904), Harpacticidae (represented by *Harpacticus uniremis* Kröyer 1842), Laophontidae, Tachididae (represented by *Microarthidion littorale* (Poppe 1881), *Tachidius discipes* (Giesbrecht 1881), *Tachidius* sp.), and Tisbidae (represented by *Tisbe gracilis* Scott, 1895). The most numerous family was Tachididae (394 specimens) as it was present in many sites in all three of the analysed sampling series. In the years 1993–1999, the occurrence of eight harpacticoid families was observed; besides the ones listed above, there were specimens belonging to the family Canthocamptidae which had not been reported in the more recent study (Wiśniewska 2001). The highest relative abundance was observed for Tachididae which were found at all the sites where Harpacticoida had been observed. Seasonal variability among harpacticoids was clearly visible. The lowest taxonomic variability was determined in Harpacticoida from the sample series collected in August. A relatively high taxonomic diversity was observed in samples from June and September. However, the frequency for the September sampling series was only slightly higher as compared to the frequencies for the other two series. These results indicate a significant relationship between the taxonomic diversity of Harpacticoida and the presence of seawater that inflows into the bay. Most likely, sparse representatives of Harpacticoida adapt to the very variable living conditions in the bay and inhabit this area despite extreme freshening of the bay waters. Greater taxonomic diversity lasts until the beginning of the hydrological season when the bay waters gradually start to be freshened, and after the cessation of land runoff. An additional finding which indicates a strong connection between the taxonomic diversity of Harpacticoida and the extent of bay freshening is the distribution of the taxa found within the bay. The largest taxonomic diversity among harpacticoids (six taxa at site 5; skerries) was observed in the NW area of Nottighambukta, which undergoes freshening during the arctic summer, in comparison to the southern part of the bay. On the other hand, in autumn, an increased diversity was observed at a larger number of sites, while the highest diversity for this sample series was observed in the same area (five taxa at site 6; near skerries). The

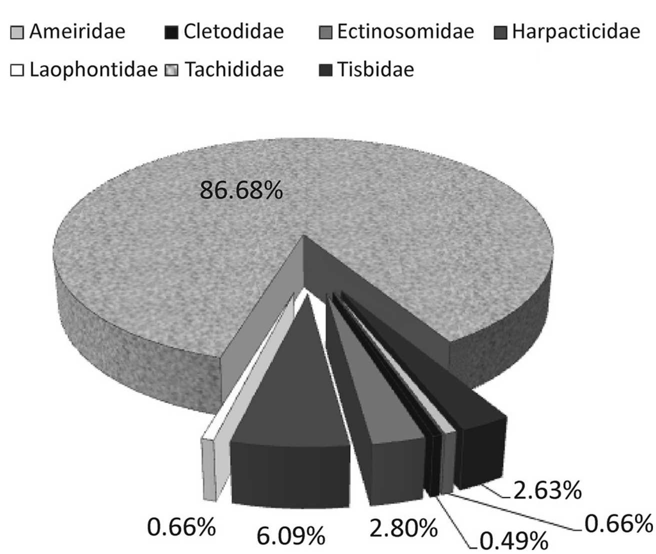

Fig. 7. Relative abundance of Harpacticoida taxa (all samples, 2001)

obtained results indicate the considerable instability of Harpacticoida which display seasonal variability as a result of the changing hydrological conditions in the bay. The relative abundance of the harpacticoid families is presented in Fig. 7 and the number of individuals in Fig. 8.

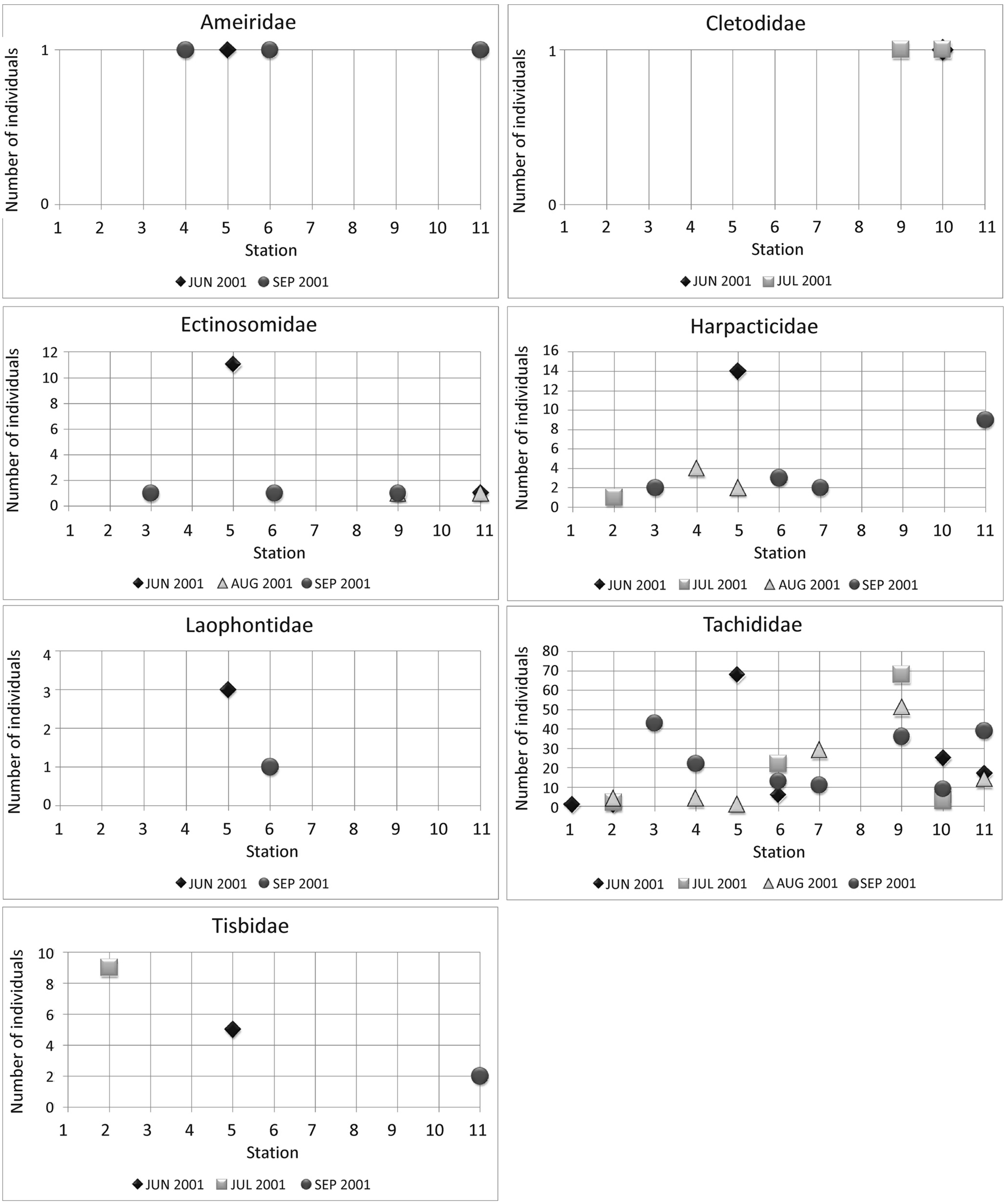

Fig. 8. Relative abundance of Harpacticoida taxa, stations and sample series (samples 2001)

Diversity of the Harpacticoida species composition

The Harpacticoida species composition was analysed for two sample series, i.e. July 2000 and July 2001. The following species were identified: *Tachidius discipes* (Giesbrecht 1881), *Microarthidion littorale* (Poppe 1881), *Tisbe gracilis* (Scott 1895), *Nannopus palustris* (Brady 1880), *Harpacticus uniremis* (Kröyer 1842) and *Stenhelia (Delavalia)* sp. In July 2000, some individuals of *T. discipes*, *M. littorale*, *N. palustris* and *Stenhelia (D.)* sp. were found, while in July 2001, the presence of *M. littorale*, *N. palustris*, *T. gracilis* and *H. uniremis* was reported (Table 3). The highest frequency in both sample series listed above was found for the species *M. littorale* (over 50%), while the remaining species occurred at few sites (Table 3). An MDS plot of Bray-Curtis similarity of Harpacticoida assemblages is presented in Fig. 9. The relative abundance of males, females and juvenile individuals of the Hapracticoida species is presented in Fig. 10.

In 2000, the species *N. palustris* occurred in the northern and inner part of the bay where salinity ranged from 0 to 5.6 psu. In 2001, *N. palustris* was observed in only one site located in the central part of the bay where salinity was 10–15 psu. From among the identified Copepods, the species *M. littorale* showed the highest tolerance with respect to salinity (0–33.6 psu in 2000, and 0–31.5 psu in 2001); it was present on silty and silty-sandy bottom. *T. dicipes* was recorded only in the year 2000 at a site in the north-western part of the bay where salinity was 0–5.8 psu. Individuals of *Stenhelia (D.)* sp. inhabited the bay only in the year 2000;

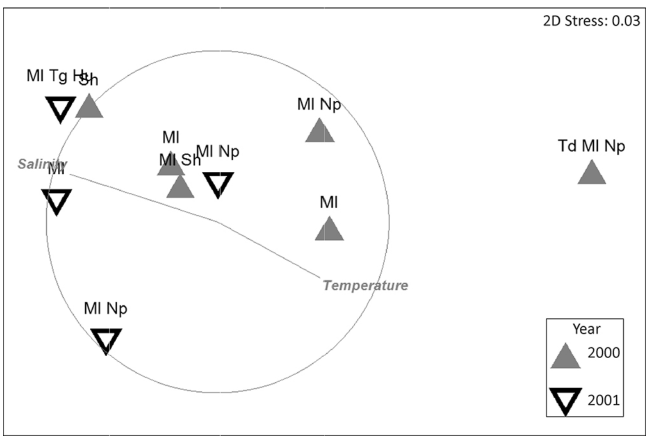

Fig. 9. S17 Bray-Curtis similarity multidimensional scaling (MDS) plot showing similarity of Harpacticoida assemblages
Hu – *H. uniremis*, Ml – *M. littorale*, Np – *N. palustris*, Sh – *Stenhelia (D.)* sp., Td – *T. disciples*, Tg – *T. gracilis*.

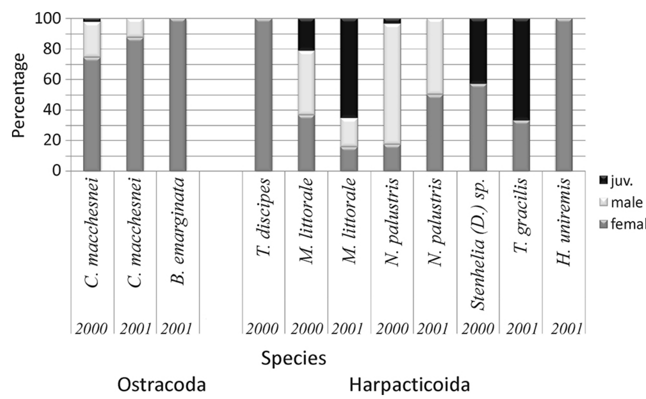

Fig. 10. Relative abundance of males, females and juvenile individuals of Ostracoda and Hapracticoida species

Table 3. Harpacticoida species abundance, temperature and salinity range, and ecological preferences

Season	Station	Harpacticoida species					
		T. discipes	*M. littorale*	*N. palustris*	*Stenhelia (D.)* sp.	*T. gracilis*	*H. uniremis*
02.07.2000	3	0	5	0	0	0	0
	4	0	5	0	0	0	0
	5	0	0	0	6	0	0
	7	0	6	0	1	0	0
	10	2	2	56	0	0	0
	11	0	1	1	0	0	0
15.07.2001	2	0	2	0	0	9	1
	6	0	22	0	0	0	0
	9	0	68	1	0	0	0
	10	0	3	1	0	0	0
Observed temperature min–max [°C]		10.0–11.4	5.0–11.9	7.2–11.9	7.7–9.4	5.0	5.0
Observed salinity min–max [psu]		0–5.8	0–31.9	0–15.8	16.3–33.6	31.5	31.5
Ecology environment[1, 2, 3, 4, 5]		m, b, et, eh, bA	m, b, in, et, eh, bA	m, b, f, t, et, eh, bA	–	m, et, bA	m, bA

m – marine, b – brackish, f – freshwater, t – terrestrial, in – intertidal, et – eurythermal, eh – euryhaline, bA– boreal-Arctic species.

[1]Sars G.O. 1903–1911, [2]Lang 1948, [3]Lang 1965, [4]Global Biodiversity Information Facility (http://data.gbif.org), [5]World of Copepods (http://www.marinespecies.org/copepoda).

they were found at a sandy-muddy site and in pools on the skerries where the salinity was relatively high (16.3–33.6 psu). The species *T. gracilis* occurred in 2001 in the south-western part of the bay where salinity was 31.5 psu. The last identified representative of Harpacticoida, i.e. *H. uniremis* also occurred in 2001 only and at the same site as the species *T. gracilis*. Due to the fact that only one specimen of *H. uniremis* was found its presence should be treated as incidental.

Among the Harpacticoida identified in Nottinghambukta, the species *N. palustris*, *H. uniremis* and *Stenhelia (D.)* sp. have been recorded for the first time; the remaining ones had already been reported in previous years (1993–1999), as follows: *E. neglectum*, *T. discipes*, *M. littorale*, *D. fusiformis* (Brady et Robertson, 1875), *D. typica* (Boeck, 1872), *Z. abbreviates* (Sars, 1904), *T. gracilis*, *A. minutus* (Claus, 1863), *P. hispida* (Brady, 1880), *A. longipes* (Boeck, 1864), *P. simplex* (Norman et T. Scott, 1905), *M. pygmea* (Claus, 1863), *H. minuta* (Boeck, 1872), *P. hyperborea* (Sars, 1909), and *Onychocamptus horridus* (Norman, 1876) (Wiśniewska 2001). The harpacticoid assemblages inhabiting Nottingham Bay were rather rich, however very variable. A previous study (Wiśniewska 2001) and the one presented here list 18 Harpacticoida species inhabiting Nottinghambukta. A rather low number of species were reported from the Svalbard area, i.e. 22 species identified by Kotwicki, 26 by Mielke and 49 by Gee and Huys (Kotwicki 2002). In Kongsfjorden 10 species were collected by Bick and Arlt (Bick and Arlt 2005).

In the 2001 season that covered spring, summer and autumn, the following representatives of Ostracoda were found: *Baffinicythere emarginata* (Sars, 1865) (2 specimens), *Roundstonia macchesneyi* (Brady et Crosskey, 1871) (119 specimens, including 13 juveniles) *Xestoleberis depressa* (Sars, 1866) (1 specimen) *Sclerochilus* sp. (2 specimens) and Paradoxostoma sp. (1 specimen). The dominant species throughout the whole season was *R. macchesneyi*. The occurrence of juvenile individuals may indicate the process of colo-

Table 4. Ostracoda species abundance, temperature and salinity range, and ecological preferences

Season	Station	Ostracoda species				
		B. emarginata	*C. macchesneyi*	*X. depressa*	*Sclerochilus sp.*	*Pontocypris sp.*
02.07.2000	1	0	1	0	0	0
	5	0	32	0	0	0
	6	0	6	0	0	0
	7	0	51	0	0	0
18.06.2001	1	0	3	0	0	0
	3	0	5	0	0	0
	5	0	3	0	0	1
	6	0	7	0	0	0
	7	0	17	0	0	0
15.07.2001	2	0	3	0	0	0
	6	0	3	0	0	0
	9	1	1	0	0	0
	10	0	1	0	0	0
05.08.2001	4	0	1	0	0	0
	5	0	3	0	0	0
	6	0	45	0	0	0
	7	0	5	0	0	0
07.09.2001	3	0	7	0	2	0
	4	0	1	0	0	0
	6	1	1	1	0	0
	7	1	6	0	0	0
	8	0	14	0	0	0
	11	0	1	0	0	0
Observed temperature min–max [°C]		3.7–11.3	1.4–11.3	3.7	4.1	3.7
Observed salinity min–max [psu]		15.8–31.8	0–33.6	31.8	31.8	31.5
Ecology environment[1, 2, 3]		m, il, e, NWAt, A	m, b, A	m, NWAt, A, Eu	–	–

m – marine, il – infralittoral of the Gulf, e – estuary, b – boreal, A – Arctic, NWAt – North West Atlantic, Eu – European waters.

[1]Sars G.O. 1886, [2]WoRMS (World Register of Marine Species), http://www.marinespecies.org/. [3]GBIF (Global Biodiversity Information Facility), http://data.gibf.org/species/.

nization of the bay by a given species. Ostracoda were most numerous in August at site 7, a location characterized by a relatively low salinity of 5.4 psu and a temperature of 6.5°C; they had the highest relative abundance for this taxon (18.8%). In spring, Ostracoda reached the highest percentage abundance at site 8 (4.6%). The lowest relative abundance of Ostracoda was observed in June in samples collected from sites with low salinity. Ostracoda occurred during all the sampling periods at some sites in the outer profile. These organisms did not inhabit the inner areas of Nottinghambukta (in all sample series only a few individuals were found at the sites 9–11). The abundance of the identified Ostracoda representatives for particular sites is presented in Table 4. The relative abundance of males, females and juvenile individuals of the Ostracoda species is presented in Fig. 8. In Svalbard *R. macchesneyi* was found in Liefdefjorden (Hartmann 1992, 1993) and in the glacial bays of Hornsund (Mackiewicz 2006) where salinity was typical for marine waters, i.e. >30 psu (Wiśniewska-Wojtasik 2005).

In Hornsund the occurrence of 44 Ostracoda species was noted by Mackiewicz (2006), while in the marine littoral of the Liefdefjorden 29 species were reported by Hartmann (1992). In Nottingham Bay only one ostracod species, namely, *R. macchesneyi* inhabited the area which is rich in numerous tidal flats.

MeioEco analysis, ecological status of the Nottingham Bay

The conducted MeioEco analyses indicate the diverse nature of the meiobenthos grouping, which is variable in time (series of tests) and in the bay area. The meiobenthos grouping is the richest in June, before the very intense runoff of glacial waters (Werenskiold's glacier) begins to flow into the bay. In July, during intensive runoff of glacial waters, the meiobenthos grouping becomes less numerous. It is the poorest in August and this especially concerns the area of the southern part of the bay, where during the hydrological season glacial rivers flow through the bay. In September, at the end of the hydrological season, when glacial runoff ceases, the meiobenthos grouping is rebuilt. As the obtained analyses indicate (Table 5, Fig. 11), the area most susceptible to degradation is the southern part of the bay. As a result of natural processes associated with the rapid runoff of glacial waters, the meiobenthos taxa withdraw from this region of the bay. The organisms begin to form a new group, rebuilt, at the end of the hydrological season, when the conditions in the bay stabilize. A different situation applies to the NW bay area. There, the grouping is relatively stable throughout the entire hydrological season. The inner part of the bay, the most sugared, which is subject to a continuous process of renewal of the meiobenthos assemblages, remains in a state of initial development due to the extremely difficult environment which is poor in organic matter. In this region there are large amounts of fresh terrigenous sediments, which are not demanding for aquatic organisms. A detailed description of the ecological status for Fig. 11 is provided in Table 6. The areas of different ecological characteristics are shown in Fig. 12.

Table 5. Parameters N_{10}, N_{taxa}, B_w of meiobenthic assemblages for station and series of collected samples from Nottinghambukta, NW Spitsbergen

Data/parameter	Station										
	1	2	3	4	5	6	7	8	9	10	11
18.06.2001											
N_{10}	22.3	2.1	16.2	5.2	98.9	135	45.6	9.5	–	6.7	29.5
N_{taxa}	4	2	3	2	4	4	3	2	–	2	3
B_w	0.371	0.095	0.417	0.923	0.181	0.042	0.421	0.084	–	0.776	0.188
15.07.2001											
N_{10}	0	9.6	0.8	0.3	–	6.4	–	–	29.5	2.5	–
N_{taxa}	0	4	2	1	–	4	–	–	4	3	–
B_w	-	0.323	0.25	0	–	0.833	–	–	0.376	0.300	–
05.08.2001											
N_{10}	2.9	9.1	2.4	8.8	6.8	23.9	10.8	–	12.8	0.3	9.7
N_{taxa}	2	2	1	4	4	3	4	–	2	1	3
B_w	0.069	0.088	0	0.309	0.414	0.289	0.537	–	0.859	0	0.294
07.09.2001											
N_{10}	5.2	8.2	17.6	3.6	2.2	10.4	10.8	14.3	14.7	5.4	22.8
N_{taxa}	2	2	4	3	1	4	4	3	3	2	4
B_w	0.308	0.073	0.689	0.542	0	0.436	0.77	0.524	0.52	0.407	0.370

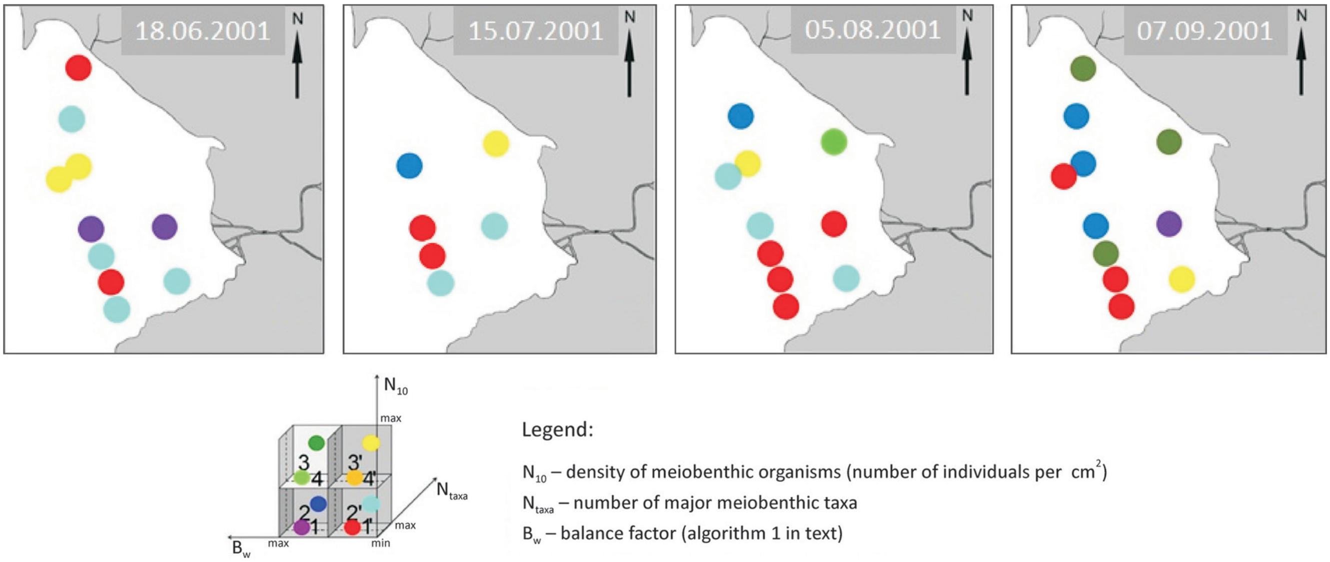

Fig. 11. MeioEco analysis of meiobenthic assemblages – different areas of ecological status

Table 6. Description of the MeioEco analysis presented in Figure 11

Symbol	N_{10}	N_{taxa}	B_w	Opis stanu ekologicznego
red	low	low	unbalance	degradation/initial development phase of trophy
purple	low	low	balance	degradation/initial development phase of trophy, area of re-colonisation
blue	low	high	balance	trophy increase
light blue	low	high	unbalance	trophy increase without taxonomic balance
dark green	high	high	balance	high trophy, maximum for the examined stations
green	high	low	balance	relatively high trophy, progressive degradation
yellow	high	high	unbalance	high trophy in the early stages of degradation

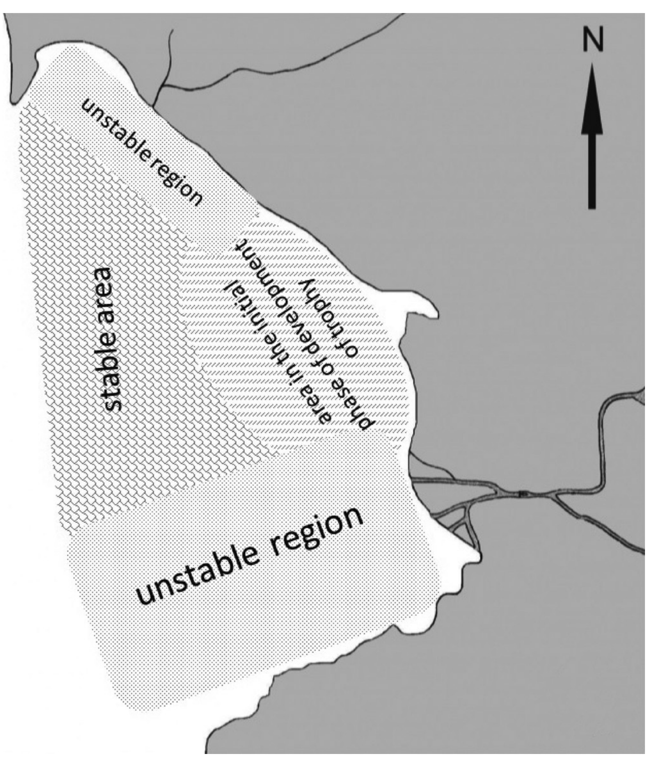

Fig. 12. Ecological status of selected area of Nottinghambukta

Conclusions

The performed research and zoocenological analyses indicate an uneven colonization of the Nottinghambukta tidal flat by meiobenthos. Taxonomic diversity of the major meiobenthic assemblages related to the specificity of certain areas of the bay (e.g. river channels and their edges, shore zone and skerries) as well as significant seasonal variability of assemblages at the same sites was revealed. During the study duration an increase in taxonomic diversity occurred in autumn which coincided with the cessation of land runoff. New organisms arrived with the seawater inflowing into the bay in autumn. The stabilizing effect of seawater inflow on the hydrological conditions in Nottinghambukta lasted until the next hydrological season.

The ecological characteristics of Nottingham Bay indicate three main zones: an unstable ecological zone with recolonization of meiobenthic assemblages after the rapid flow of glacier rivers, a stable zone and an inner zone with meiobenthic assemblages in the initial phase of development.

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