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Structure of bryozoan communities in an Antarctic glacial fjord (Admiralty Bay, South Shetlands)

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Abstract Bryozoans are among the most important groups of the Southern Ocean benthic macrofauna, both in terms of species richness and abundance. However, there is a considerable lack of ecological research focused on their distribution patterns and species richness on smaller scale, especially in the soft bottom habitats of Antarctic glacial fjords. The aim of this study was to describe those patterns in the Admiralty Bay. Forty-nine Van Veen grab samples were collected at the depth range from 15 to 265 m, in the summer season of 1979/1980, at three sites distributed along the main axis of the fjord. Among 53 identified species of bryozoans, 32 were recorded in the Admiralty Bay for the first time. The most common and abundant species were *Himantozoum antarcticum, Inversiula nutrix* and *Nematoflustra flagellata.* Genera such as *Arachnopusia*, *Cellarinella* and *Osthimosia* were the most speciose taxa. It was demonstrated that depth was important for the distribution of the bryozoans. More than half of the recorded species were found only below 70 m. An influence of glacial disturbance was reflected in the dominance structure of colony growth-forms. The inner region of the fjord was dominated almost entirely by encrusting species, while the diversity of bryozoan growth-forms in less disturbed areas was much higher. In those sites the highest percentage of branched, tuft like species represented by buguliform and flustriform zoaria was observed.

Keywords King George Island · Suspension feeders · Bryozoa · Sublittoral · Biomass · Distribution patterns

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Introduction

Antarctic sessile suspension feeding communities are characterized by a high species richness and diversity (Gili et al. 2006). Bryozoans, ascidians and sponges are a key element of energy transfer from the pelagic zone into the benthic realm of the Southern Ocean (Gili et al. 2001). At least some of the species are able to exploit even very low food concentrations, as those observed during the Antarctic winter (Barnes and Clarke 1995). Bryozoans are also among the most important biomass components of the Southern Ocean benthic communities (Brey and Gerdes 1997).

Suspension feeding macro- and megazoobenthic communities are patchily distributed on dropstones and other types of hard substrata (Gutt and Starmans 1998). Distribution of bryozoan aggregations is also shaped by mineral suspension inflow and iceberg scouring, resulting in lower diversity and abundance, especially in the shallow sublittoral zone (Gutt 2001; Pabis et al. 2011). At greater depths their reduced abundance is explained mostly by lower organic matter supply (Saiz-Salinas et al. 1998).

The total richness of the Southern Ocean bryozoan fauna was estimated at more than 400 species (De Broyer et al. 2011), among which cheilostomatous bryozoans were a dominant and highly endemic group (Griffiths 2010). Most of the research on Antarctic bryozoans were focused on the taxonomy, and the number of newly described species was continuously increasing for the last 30 years (e.g., Lopez Gappa 1986; Hayward 1995; Kukliński and Barnes 2009; Hayward and Winston 2011; Figuerola et al. 2013 and references therein). Some of the most important studies were dedicated to zoogeography (Moyano 2005; Barnes and Griffiths 2008; Barnes and Kukliński 2010), colonization and succession processes (Stanwell-Smith and Barnes 1997; Bowden et al. 2006), as well as biology of particular species (e.g., Barnes 1995a; Barnes and Clarke 1995; Barnes et al. 2006).

The studies concerning species richness and distribution patterns on smaller scale are still relatively scarce and limited to only few Antarctic locations, such as Signy Island (Barnes 1995b; Barnes and Clarke 1995), Terra Nova Bay (Rosso and Sanfilippo 2000) and Bouvet Island (Barnes 2006). Even the Antarctic Peninsula region, one of the most intensively sampled areas in the Antarctic suffers from the scarcity of research concerning bryozoan fauna (Moyano 1979; Winston and Heimberg 1988; Moyano and Cancino 2002; Figuerola et al. 2012). There is still a considerable lack of ecological studies based on the quantitative samples. Moreover, many of the previous research were focused on typical hard bottom rocky habitats. Bryozoans, as a lophophorate organisms, are sensitive to disturbance caused by glacial sedimentation. On the other hand, some of them are considered as robust and can benefit from recent climate-related changes in the Antarctic benthic communities (Barnes and Griffiths 2008). For this reason, there is a need for studies at the sites characterized by high inflow of mineral suspension, especially in glacial fjords, such as Admiralty Bay. This basin belongs to the most comprehensively studied areas in the Antarctic in respect to benthic macrofauna and can be treated as a model ecosystem and reference site for future monitoring activities in the area of the Antarctic Peninsula (Siciński et al. 2011), the region currently facing the most rapid temperature increase in the Southern Hemisphere (Clarke et al. 2007; Walsh 2009). Many groups of benthic fauna in this bay, including polychaetes (e.g., Siciński 2004; Petti et al. 2006; Pabis and Siciński 2010), peracarid crustaceans (e.g., Jażdżewski et al. 1991; Pabis and Błażewicz-Paszkowycz 2011) and echinoderms (e.g., Presler and Figielska 1997; Nonato et al. 2000), were thoroughly analyzed. In contrast, the bryozoans were only scarcely studied (Moyano 1979). Thorough taxonomic inventory of all important benthic groups of macrofauna, and evaluation of their distribution patterns at such sites is essential for further ecological and zoogeographic assessments. Therefore, the quantitative studies presented here fill a gap in the ecological research on this group of organisms, demonstrating their species richness, biomass and distribution, on the soft bottom of the Admiralty Bay.

Materials and methods

Study area

Admiralty Bay is a glacial fjord like embayment of tectonic origin, typical of the Antarctic Peninsula region. This basin covers the area of about 120 000 000 m^2. It is located at the south-western part of King George Island. Four main parts are distinguished within this bay, a central basin and three inlets—Ezcurra Inlet, Martel Inlet and MacKellar Inlet. Ezcurra Inlet is a narrow fjord with large glaciers distributed along its coastline (Fig. 1), especially in the innermost region (Braun and Grossmann 2002). Ice disturbance has not been recorded in this semi-closed basin. Smaller growlers affect the bottom only in the intertidal zone and in shallowest sublittoral (down to about 2 m), while icebergs do not enter these fjord. In contrast, the ice disturbance was observed in the central basin and in the Martel Inlet down to 30 m depth (Nonato et al. 2000; Echeverria et al. 2005; Pabis et al. 2011). The total amount of mineral suspension transported every day into the waters of Admiralty Bay was estimated at 2,000,000 kg (Pęcherzewski 1980). Its primary source is crushed clastic material transported into the bay by subglacial streams (Jonasz 1983). A steep gradient of mineral suspension content was observed along the main axis of Ezcurra Inlet. The highest amount of mineral suspension (>0.1 kg/m^3) was noted in the innermost parts, close to the glacial termini (in Goulden Cove and Cardozo Cove), and decreases along the axis of the fjord (Fig. 1) toward the mouth of Ezcurra Inlet (about 0.015 kg/m^3) and the central basin (even 0.0028 kg/m^3) (Pęcherzewski 1980). High water turbidity was recorded in Ezcurra Inlet, especially in the inner glacial bays, and it diminished toward the central basin (Lipski 1987). The sedimentation process was reflected in the character of the bottom sediments of the bay (Fig. 1). The inner, highly disturbed part of the Ezcurra Inlet is characterized by silty clay and clay silt sediments, while its middle and outer regions have sandy clay silt sediments as well as larger amount of the skeletal fractions. The proportion of sandy bottom deposits is higher in the shallow sublittoral of the central basin. In the central basin, more dropstones were also noted (Siciński 2004; Siciński et al. 2011).

The character of bottom deposits from samples used in this study was described by Jażdżewski et al. (1986). Their results are congruent with those presented by Siciński (2004). Section III was characterized mostly by muddy deposits. In the section II, sediments were also muddy; however, the number of stations with gravel and stones was higher than in section III. In the shallow sublittoral of central part of the bay (section I), the content of sandy sediments was higher than in two other sections, although gravel and stones were also important element of these bottom area (Table 1).

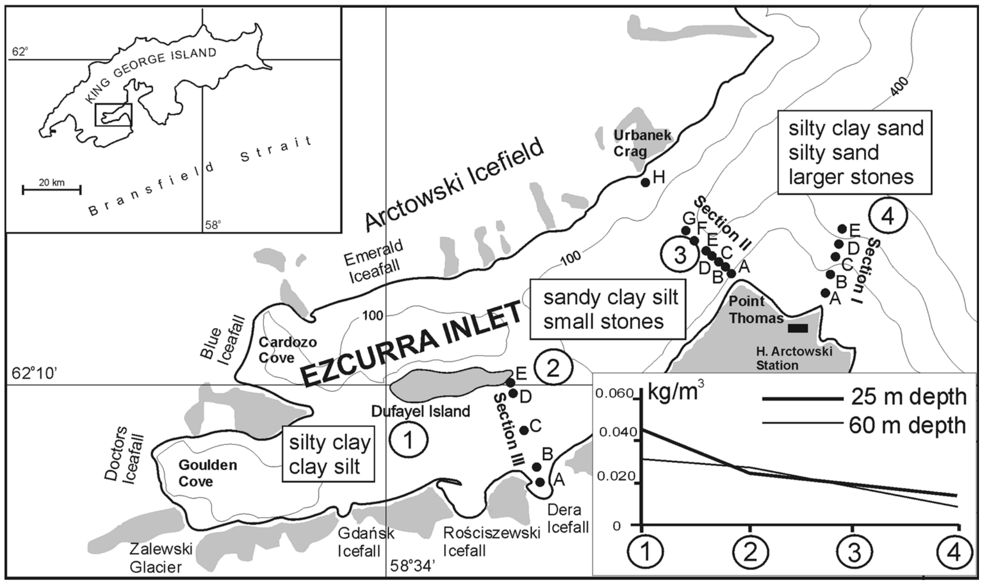

Fig. 1 Distribution of sampling stations in Admiralty Bay together with characteristics of sediments and suspended matter content in the investigated area. Data on sediments are derived from the analysis by Siciński (2004), while the diagram of mineral suspension content is constructed according to Pęcherzewski (1980)

The inner area of Ezcurra Inlet is characterized by intricate bottom configuration and is separated from the outer part by a conspicuous submerged sill. The outer area has a form of deep trough (Marsz 1983). Waters of this inlet had also lower values of chlorophyll-a content compared with the central basin where those values are very high (up to 0.22 kg/m^3). Those differences are especially noticeable from May to November. In the central part of the bay, larger concentrations of chlorophyll-a were found even below the euphotic zone (Tokarczyk 1986). Central basin is the deepest and less disturbed part of the bay that opens to the Bransfield Strait (Braun and Grossmann 2002). It is characterized by low water turbidity, low amount of mineral suspension and higher chlorophyll-a content (Pęcherzewski 1980; Tokarczyk 1986; Lipski 1987).

Sampling

Samples were collected in the 1979/80 austral summer during the 4th Antarctic Expedition of the Polish Academy of Sciences, with use of Van Veen grab (0.09 m^2). Forty-nine samples were collected at 18 stations, at depths ranging from 15 to 265 m. Three replicate samples were usually taken at each station, with exception of stations: SI D, SII A, SII E, SII F, SIII B and SIII E where two samples were collected, and SII B (four samples). Three sampling areas were selected. One site was located in the central basin of the bay, close to the Henryk Arctowski Station (section I—14 samples, 15–265 m). The second sampling area was situated in the outer part of Ezcurra Inlet, between Thomas Point and Urbanek Crag (section II—22 samples, 15–260 m). The third investigated area was located in the inner part of Ezcurra Inlet, between Dera Icefall and Dufayel Island (section III—13 samples, 15–70 m) (Fig. 1).

Samples were sieved on 0.5-mm mesh sieves and preserved in 5 % buffered formaldehyde. Bryozoa were identified to the species level, with use of SEM microscope (ZEISS LEO 1430). The samples were examined individually, and the wet weight of each bryozoan species was measured with the accuracy of 0.001 g using the analytical balance of Redwag WTB 200. Abundance and biomass of higher taxa from this set of samples were analyzed by Jażdżewski et al. (1986).

Data analysis

Biomass is an universal indicator of the community character, especially when colonial organisms, such as Bryozoa, are considered (Magurran 2004). For this reason, the analysis was based on the values of total wet weight of every species in each sample. Species richness (S) was also calculated for each sample (Magurran 2004). Differences between the species richness and total biomass values between sampling areas were tested using nonparametric Kruskal–Wallis test. Post hoc testing was done using Dunn's test in Statistica 6 package. Mean (*B*) with standard deviation (SD) and maximal (BMax) biomass values as well as frequency of occurrence (*F*—percentage of samples where a species was found in total number of samples) were calculated for each species in each area, and in the whole material. Frequency of occurrence of bryozoans as a whole and for each of the growth-form type was also calculated. The deepest station from section III was located at the depth of 70 m. To make the data fully comparable, we also compared the species richness and biomass on all three sites taking into account only the samples from the 15–70 m depth range. Each species was also assigned to a type of growth-form following the classification by Stach (1936) and Moyano

Table 1 Depth and sediment characteristics at the sampling stations

Stations	Depth (m)	Sediments
SI A	15	Sand/stones
SI B	30	Sand/gravel/stones
SI C	70–80	Gravel/mud
SI D	140–160	Mud/gravel
SI E	240–265	Mud
SII A	15	Sand/gravel/stones
SII B	25–45	Mud/gravel/stones
SII C	60–70	Mud/stones
SII D	90–100	Mud/gravel/stones
SII E	120	Mud/gravel
SII F	170	Mud
SII G	240–260	Mud
SII H	30–40	Mud/gravel/stones
SIII A	15	Mud
SIII B	30	Mud/stones
SIII C	70	Mud
SIII D	30–40	Mud/gravel
SIII E	15	Mud/stones

(1979, 2005). Dominance (percentage of the biomass of a particular group in a total biomass) was calculated for each type of growth-form, in each of the studied sites. Similarity between the samples was calculated using the Bray–Curtis index. Hierarchical agglomerative clustering was performed using group average method. Biomass values (wet weight g/0.09 m^2) of all species were square-root transformed before the analysis (Clarke and Warwick 1994).

Results

Species richness and biomass

Fifty-three species of Bryozoa from 24 families were found in the analyzed material. The majority of the species represents the order Cheilostomatida. Five species: *Tubulipora tubigera, Idmidronea atlantica, Mecynoecia* sp., *Disporella canaliculata* and *Favosipora* sp. belong to Cyclostomatida and one, *Alcyonidium* sp., to Ctenostomatida. Bryozoa were found in 29 of the 49 collected samples. Thirty-two species were recorded in Admiralty Bay for the first time (Table 2). Mean biomass values and frequency of all species were low. Relatively high values in the whole material were noted only for three species: *Himantozoum antarcticum* ($F = 20.4$ %, $B = 0.2 \pm 1.1$ g/0.09 m^2, BMax = 6.3 g/0.09 m^2), *Inversiula nutrix* ($F = 14.2$ %, $B = 0.08 \pm 0.5$ g/0.09 m^2, BMax = 3.5 g/0.09 m^2) and *Nematoflustra flagellata* ($F = 12.2$ %, $B = 0.04 \pm 0.1$ g/0.09 m^2, BMax = 1.02 g/0.09 m^2). Despite the relatively high number of species recorded in this study, the species richness values were low and did not exceed 10 species per sample. The highest mean species richness and biomass values were detected in section I (Fig. 2). Statistically significant differences for both values were found between sections III and II, as well as III and I (Kruskal–Wallis test, Dunn's test $p < 0.05$). The results were different in analysis of samples collected at 15–70 m depth range. Mean species richness and biomass were the highest in the section I (Fig. 2); however, no significant differences for both values between all the sites were observed (Kruskal–Wallis test, $p < 0.05$).

Thirty-three species were found in the central basin (section I). Seventeen of them were recorded only there (Table 1). This area was dominated by *H. antarcticum* ($F = 42.8$ %, $B = 0.8 \pm 2.1$ g/0.09 m^2) followed by *N. flagellata* ($F = 28.5$ %, $B = 0.1 \pm 0.3$ g/0.09 m^2) and *I. nutrix* ($F = 28.5$ %, $B = 0.2 \pm 0.9$ g/0.09 m^2). Two other species: *Osthimosia notialis* ($F = 21.4$ %, $B = 0.01 \pm 0.04$ g/0.09 m^2) and *Orthoporidra stenorhyncha* ($F = 21.4$ %, $B = 0.03 \pm 0.1$ g/0.09 m^2) had relatively high frequency in this area. The highest frequency of Bryozoa ($F = 85.7$ %) was also noted in this part of the bay.

Twenty-six species were found in outer region of Ezcurra Inlet (section II), including eleven species found exclusively here (Table 1). The most frequent and abundant species was *H. antarcticum* ($F = 18.1$ %, $B = 0.04 \pm 0.1$ g/0.09 m^2). Frequency of Bryozoa in this area was as high as 59.0 % (Table 2).

Only 14 species were found in the inner region of Ezcurra Inlet (section III), and all had very low biomass and frequency. The total frequency of Bryozoa in this area was low ($F = 46.1$ %). All species had very low biomass and frequency in this area. Seven of them were found only in this part of the bay (Table 2).

Bryozoan growth-forms

Bryozoans of Admiralty Bay were also characterized by a high diversity of the colonial forms (Fig. 3). Eight zoarial growth-forms have been distinguished including: membraniporiform (18 species), adeoniform (11 species), celleporiform (6 species), flustriform (4 species), buguliform (4 species), vinculariform (4 species), cellariform (3 species) and fungiform (3 species).

Central basin (section I) was characterized by a presence of all bryozoan growth-forms. The most important biomass component was buguliform bryozoans (56.4 %, $F = 42.8$ %), but only one species represented this growth-form. Encrusting (mebraniporiform) bryozoans had also high percentage of biomass and high frequency in this area (18.6 %, $F = 57.1$). Moreover, membraniporiform bryozoans had the highest species richness in this region. Eight species represented this

Table 2 Frequency of occurrence (*F*), mean (*B*) and maximal (BMax) biomass with SD of bryozoans in each of the studied areas and in the whole material together with growth-forms

Species/family	Section III		Section II		Section I		Total			Growth-form
	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	B Max (g/0.09 m^2)	
AETEIDAE										
**Aetea anguina* (Linnaeus, 1758)	–	–	–	–	7.1	0.00007 ± 0.0002	2	0.00002 ± 0.0001	0.001	membraniporiform
**Aetea* sp.	–	–	4.5	0.002 ± 0.01	–	–	2	0.001 ± 0.007	0.05	membraniporiform
ALCYONIDIIDAE										
Alcyonidium sp.	7.6	0.00008 ± 0.0002	–	–	–	–	2	0.00002 ± 0.0001	0.001	membraniporiform
ARACHNOPUSIIDAE										
**Arachnopusia aviculifera* (Hayward & Thorpe, 1988)	7.6	0.01 ± 0.03	4.5	0.001 ± 0.004	–	–	4	0.003 ± 0.02	0.14	membraniporiform
Arachnopusia columnaris (Hayward & Thorpe, 1988)	7.6	0.0001 ± 0.0005	–	–	–	–	2	0.00004 ± 0.0002	0.002	membraniporiform
**Arachnopusia decipiens* (Hayward & Thorpe, 1988)	–	–	4.5	0.002 ± 0.01	14.2	0.03 ± 0.1	6.1	0.01 ± 0.07	0.5	adeoniform
Arachnopusia sp.	–	–	4.5	0.00004 ± 0.0002	–	–	2	0.00002 ± 0.0001	0.001	membraniporiform
ASPIDOSTOMATIDAE										
**Aspidostoma* sp.	–	–	4.5	0.001 ± 0.007	–	–	2	0.0007 ± 0.005	0.03	adeoniform
BEANIIDAE										
Beania sp.	–	–	4.5	0.00004 ± 0.0002	–	–	2	0.00002 ± 0.0001	0.001	membraniporiform
BUFFONELLODIDAE										
**Aimulosia antarctica* (Powell, 1967)	7.6	0.0006 ± 0.002	–	–	–	–	2	0.0001 ± 0.001	0.009	membraniporiform
**Aimulosia australis* (Jullien, 1888)	15.3	0.00007 ± 0.0002	–	–	7.1	0.00007 ± 0.0002	2	0.00004 ± 0.0002	0.01	membraniporiform
BUGULIDAE										
Camptoplites retiformis (Kluge, 1914)	–	–	4.5	0.0007 ± 0.003	–	–	2	0.0003 ± 0.002	0.01	buguliform
**Himantozoum antarcticum* (Calvet, 1909)	–	–	18.1	0.04 ± 0.1	42.8	0.8 ± 2.1	20.4	0.2 ± 1.1	6.3	buguliform
CALLOPORIDAE										
Ellisina antarctica (Hastings, 1945)	7.6	0.005 ± 0.01	–	–	–	–	2	0.001 ± 0.01	0.07	membraniporiform
**Xylochotridens rangifer* (Hayward & Thorpe, 1989)	–	–	–	–	7.1	0.003 ± 0.01	2	0.0009 ± 0.006	0.04	membraniporiform

Table 2 continued

Species/family	Section III		Section II		Section I		Total			Growth-form
	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	B Max (g/0.09 m^2)	
CANDIDAE										
Caberea darwinii (Busk, 1884)	–	–	9	0.002 ± 0.01	14.2	0.008 ± 0.03	8.1	0.003 ± 0.01	0.1	buguliform
Notoplites drygalskii (Kluge, 1914)	7.6	0.001 ± 0.003	4.5	0.08 ± 0.3	–	–	4	0.03 ± 0.2	1.8	buguliform
CELLARIIDAE										
Cellaria diversa (Livingstone, 1928)	–	–	–	–	14.2	0.05 ± 0.1	4	0.01 ± 0.09	0.6	cellariform
**Cellaria malvinensis* (Busk, 1884)	–	–	–	–	7.1	0.0001 ± 0.0005	2	0.00004 ± 0.0002	0.002	cellariform
**Larvapora mawsoni* (Livingstone, 1928)	–	–	–	–	7.1	0.001 ± 0.004	2	0.0003 ± 0.002	0.01	adeoniform
Melicerita flabellifera (Hayward and Winston, 1994)	–	–	4.5	0.002 ± 0.01	7.1	0.0003 ± 0.001	4	0.001 ± 0.008	0.06	cellariform
CELLEPORIDAE										
Favosthimosia milleporoides (Calvet, 1909)	–	–	–	–	7.1	0.006 ± 0.02	2	0.001 ± 0.01	0.08	celleporiform
**Osthimosia bicornis* (Busk, 1881)	–	–	4.5	0.00004 ± 0.0002	–	–	2	0.00002 ± 0.0001	0.001	celleporiform
**Osthimosia curtioscula* (Hayward, 1992)	–	–	4.5	0.0002 ± 0.001	–	–	2	0.0001 ± 0.0007	0.005	celleporiform
**Osthimosia fusticula* (Hayward, 1992)	–	–	–	–	14.2	0.001 ± 0.006	4	0.0005 ± 0.003	0.02	celleporiform
Osthimosia malingae (Hayward, 1992)	–	–	–	–	14.2	0.005 ± 0.01	2	0.001 ± 0.01	0.07	celleporiform
**Osthimosia notialis* (Hayward, 1992)	–	–	–	–	21.4	0.01 ± 0.04	6.1	0.003 ± 0.02	0.1	celleporiform
DENSIPORIDAE										
**Favosipora* sp.	7.6	0.001 ± 0.003	–	–	–	–	2	0.0002 ± 0.002	0.01	fungiform
ELECTRIDAE										
* *Harpecia spinosissima* (Calvet, 1904a)	7.6	0.002 ± 0.009	–	–	14.2	0.003 ± 0.01	6.1	0.001 ± 0.008	0.05	membraniporiform
ENTALOPHORIDAE										
**Mecynoecia* sp.	–	–	–	–	7.1	0.001 ± 0.004	2	0.0003 ± 0.002	0.01	vinculariform
EXOCHELLIDAE										

Table 2 continued

Species/family	Section III		Section II		Section I		Total			Growth-form
	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	B Max (g/0.09 m^2)	
**Escharoides tridens* (Calvet, 1909)	7.6	0.00007 ± 0.0002	–	–	–	–	2	0.00002 ± 0.0001	0.001	membraniporiform
FLUSTRIDAE										
Nematoflustra flagellata (Waters, 1904)	–	–	9	0.003 ± 0.01	28.5	0.1 ± 0.3	12.2	0.04 ± 0.1	1.02	flustriform
HIPPOTHOIDAE										
Antarctothoa antarctica (Moyano and Gordon, 1980)	7.6	0.001 ± 0.006	4.5	0.001 ± 0.005	14.2	0.001 ± 0.004	8.1	0.001 ± 0.005	0.02	membraniporiform
* *Antarctothoa bougainvillei* (d'Orbigny, 1842)	–	–	–	–	14.2	0.009 ± 0.02	4	0.002 ± 0.01	0.1	membraniporiform
**Hippothoa flagellum* (Manzoni, 1870)	–	–	–	–	7.1	0.00007 ± 0.0002	2	0.00002 ± 0.0001	0.001	membraniporiform
INVERSIULIDAE										
Inversiula nutrix (Jullien, 1888)	7.6	0.00007 ± 0.0002	9	0.01 ± 0.06	28.5	0.2 ± 0.9	14.2	0.08 ± 0.5	3.5	membraniporiform
LACERNIDAE										
**Lacerna eatoni* (Busk, 1876)	7.6	0.0006 ± 0.002	–	–	–	–	2	0.0001 ± 0.001	0.008	membraniporiform
LEKYTHOPORIDAE										
**Orthoporidra stenorhyncha* (Moyano, 1985)	–	–	4.5	0.01 ± 0.04	21.4	0.03 ± 0.1	8.1	0.01 ± 0.07	0.4	vinculariform
LICHENOPORIDAE										
Disporella canaliculata (Busk, 1876)	7.6	0.0008 ± 0.003	–	–	7.1	0.0004 ± 0.001	4	0.0003 ± 0.001	0.01	fungiform
SCLERODOMIDAE										
Cellarinella latilaminata (Moyano, 1974)	–	–	4.5	0.01 ± 0.07	–	–	2	0.006 ± 0.04	0.3	adeoniform
**Cellarinella laytoni* (Rogick, 1956)	–	–	4.5	0.004 ± 0.01	7.1	0.001 ± 0.005	4	0.002 ± 0.01	0.09	vinculariform
**Cellarinella nodulata* (Waters, 1904)	–	–	4.5	0.003 ± 0.01	7.1	0.001 ± 0.004	4	0.001 ± 0.01	0.08	adeoniform
**Cellarinella rogickae* (Moyano, 1965)	–	–	–	–	7.1	0.005 ± 0.01	2	0.001 ± 0.01	0.07	adeoniform

Table 2 continued

Species/family	Section III		Section II		Section I		Total			Growth-form
	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	F (%)	B (g/0.09 m^2)	B Max (g/0.09 m^2)	
**Cellarinella terminata* (Hayward & Winston, 1994)	–	–	–	–	14.2	0.02 ± 0.08	4	0.006 ± 0.04	0.3	adeoniform
**Cellarinella watersi* (Calvet, 1909)	–	–	4.5	0.004 ± 0.01	7.1	0.02 ± 0.1	4	0.01 ± 0.05	0.4	adeoniform
**Cellarinelloides crassus* (Moyano, 1970)	–	–	–	–	7.1	0.02 ± 0.08	2	0.006 ± 0.04	0.3	adeoniform
SMITTINIDAE										
**Smittina antarctica* (Waters, 1904)	–	–	4.5	0.005 ± 0.02	–	–	2	0.002 ± 0.01	0.1	adeoniform
**Thrypticocirrus contortuplicata* (Calvet, 1909)	–	–	–	–	7.1	0.01 ± 0.04	2	0.003 ± 0.02	0.1	adeoniform
TUBULIPORIDAE										
Idmidronea atlantica (Forbes, in Johnston, 1847)	–	–	4.5	0.002 ± 0.01	–	–	2	0.001 ± 0.007	0.05	vinculariform
Tubulipora tubigera (Busk, 1886)	–	–	4.5	0.004 ± 0.02	7.1	0.01 ± 0.06	4	0.006 ± 0.03	0.2	fungiform
INCERTE SEDIS										
Austroflustra vulgaris (Kluge, 1914)	–	–	9	0.004 ± 0.02	–	–	4	0.002 ± 0.01	0.09	flustriform
Klugeflustra antarctica (Hastings, 1943)	–	–	–	–	7.1	0.001 ± 0.004	2	0.0003 ± 0.0023	0.01	flustriform
* *Klugeflustra vanhoeffeni* (Kluge, 1914)	–	–	9	0.06 ± 0.2	7.1	0.05 ± 0.2	6.1	0.04 ± 0.1	1.1	flustriform
Bryozoa total	46.1	0.02 ± 0.07	59.0	0.2 ± 0.4	85.7	1.6 ± 2.7	59.1	0.5 ± 1.6	9.2	

* Species and genera recorded in Admiralty Bay for the first time

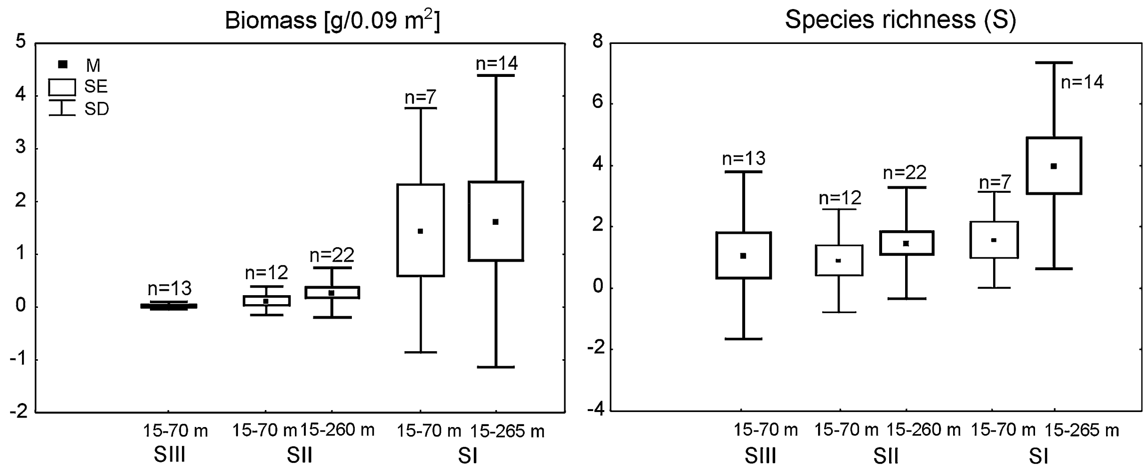

Fig. 2 Bryozoan biomass and species richness in three studied areas. *M* mean, *SE* standard error, *SD* standard deviation. (In section I and II, values are calculated also for the 15–70 m depth range)

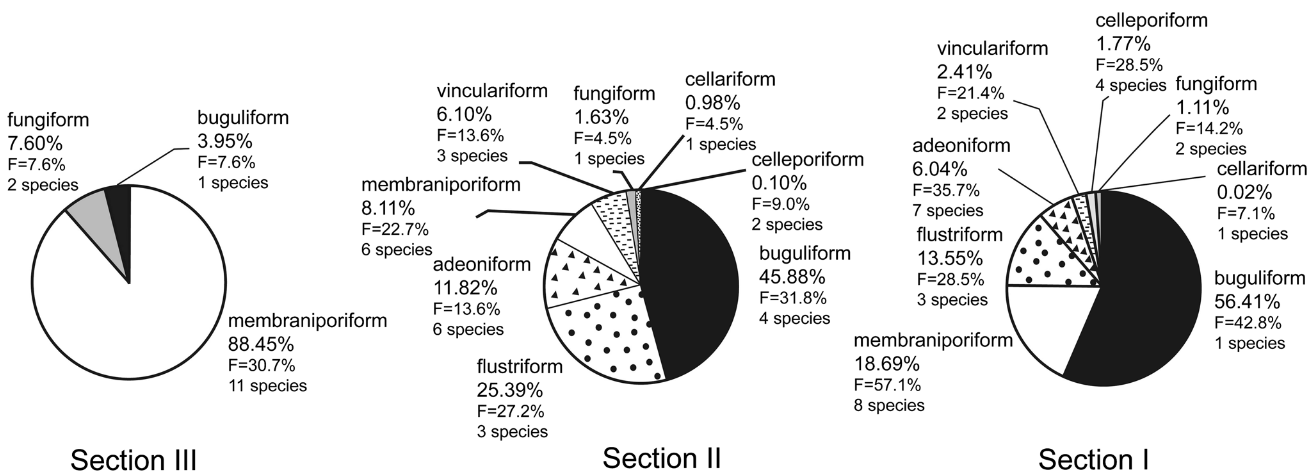

Fig. 3 Dominance structure of bryozoan growth-forms at three studied sites together with species richness and frequency of occurrence (*F*)

growth-form. In the section II, diversity of growth-forms was similar. All types found in Admiralty Bay were recorded here. The highest number of species was found for membraniporiform (6 species) and adeoniform form (6 species), followed by a buguliform type (4 species). Buguliform (45.8 %, $F = 31.8$ %) and flustriform (25.3 %, $F = 27.2$ %) bryozoans dominated the biomass and had the highest frequency in this part of the fjord. Section III was dominated by encrusting species (Fig. 3). Eleven of 14 species found in this area belong to the membraniporiform growth-form. This group constituted 88.4 % of the biomass and had relatively high frequency ($F = 30.7$ %).

At the 15–70 m depth range, the total number of species is decreasing along the axis of the fjord from the section III to section I. The number of encrusting species is very high in the inner area (section III) and much lower in other two areas where diversity of the growth-forms was higher (Fig. 4).

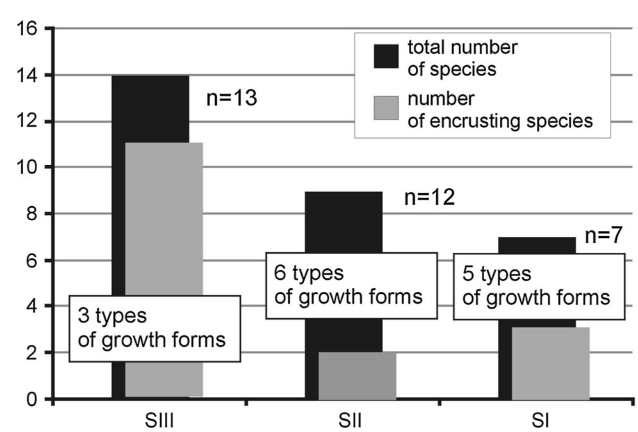

Fig. 4 Number of species and types of growth-forms at three studied sites in the 15–70 m depth range

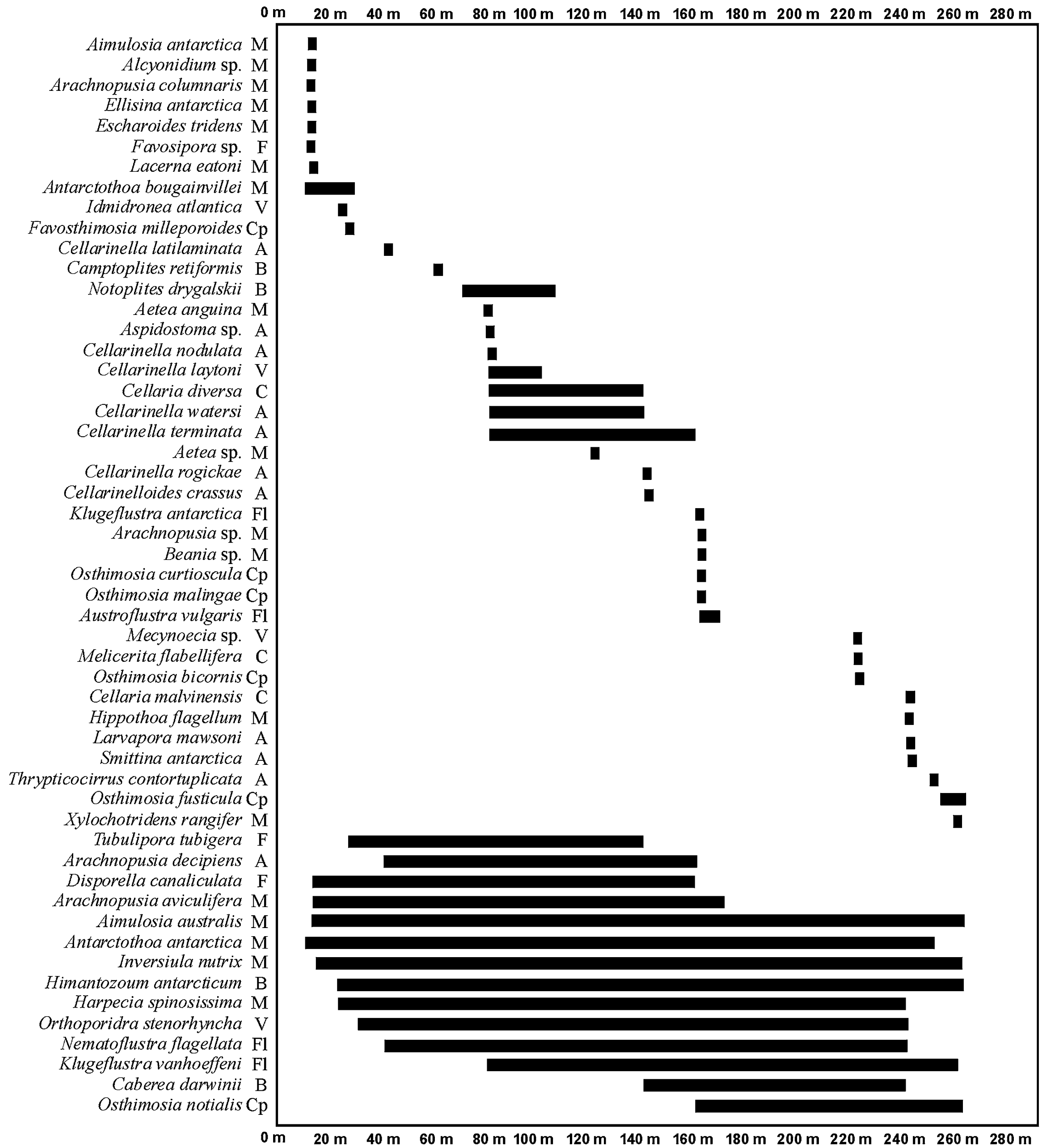

Fig. 5 Depth ranges of species in the studied material with information on type of growth-form (*A* adeoniform, *B* buguliform, *C* cellariform, *Cp* celleporiform, *F* fungiform, *Fl* flustriform, *M* membraniporiform, *V* vinculariform)

Bathymetric distribution

The majority of collected bryozoan species were recorded in single samples, and it was difficult to describe their depth range in Admiralty Bay. Some taxa occurred patchily in the studied depth range (Fig. 5). The species with the widest bathymetrical range were as follows: *Aimulosia australis, Antarctothoa antarctica, I. nutrix, H. antarcticum, Harpecia spinosissima, O. stenorhyncha* and *N. flagellata*. Ten species were found only in shallow sublittoral, down to 40 m. Among the species found only in the shallowest areas, seven were assigned to membraniporiform growth-form. This growth-form was also characteristic of three species with the widest bathymetric range: *A. australis, A. antarctica* and *I. nutrix*. Ten species were recorded only in the deeper sublittoral, below 220 m (Fig. 5).

Similarity of fauna

No faunal groupings were observed in Admiralty Bay (Fig. 6). Samples taken from different depths and sampling areas were mixed in the analysis. Even if some groups were

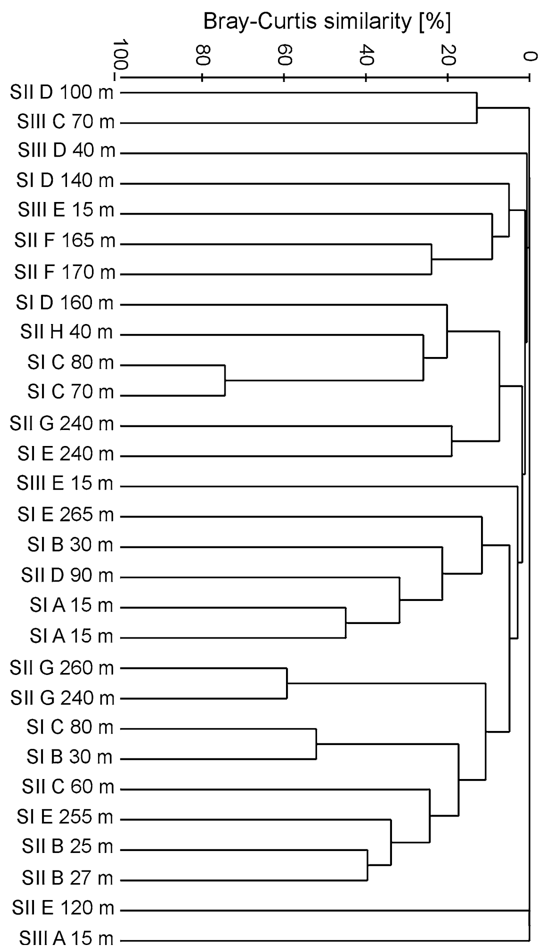

Fig. 6 Dendrogram of samples, Bray–Curtis similarity, square-root transformed data and group average grouping method

distinguished, the similarity was very low (about 10 %). Samples from section III were clustered within different groups or did not grouped with any other sample.

Discussion

Environmental gradients associated with intensity of glacial disturbance (high sedimentation rates, silting of bottom sediments) and the depth are typical of the polar fjords (Görlich et al. 1987; Siciński 2004; Włodarska-Kowalczuk and Pearson 2004; Grzelak and Kotwicki 2011). However, the distribution patterns of particular taxonomic groups of macrofauna can differ even in the same basin (Siciński 2004; Pabis and Błażewicz-Paszkowycz 2011). Those differences can be highly pronounced when various ecological groups are compared, e.g., small size, burrowing infauna versus large, filter-feeding epibenthos (Jażdżewski et al. 1986; Siciński 2004).

It was unexpected that at the depth range from 15 to 70 m, which is more vulnerable to disturbance, there was no significant difference in bryozoan species richness for the investigated sites. An increase in biodiversity along the fjord axis from the inner part to the central basin was observed for polychaetes, and peracarid crustaceans in Ezcurra Inlet (Siciński 2004; Pabis and Błażewicz-Paszkowycz 2011; Jażdżewska unpublished results). Difference in community structure between the investigated sites was found only in the species richness of bryozoan growth-forms. Encrusting species strongly dominated the inner area (section III). Distribution and composition of bryozoan growth-forms can be a good indicator of environmental conditions (Amini et al. 2004). High dominance of encrusting (membraniporiform) bryozoans in the disturbed inner region of Ezcurra Inlet, as well as low diversity of growth-forms can be explained by an influence of sedimentation inflow of glacial origin. Those bryozoans are considered the most opportunistic ones, and they can be found on various types of substrates (Amini et al. 2004). Encrusting species are very common in the shallow, intertidal rocky areas, influenced by wave action and other types of disturbance (Kukliński 2009). Moyano (1979) noted high dominance of encrusting forms at sites affected by volcanic disturbance in Port Foster. Branching bryozoans (adeoniform species) or bushy tufts (buguliform and flustriform species) are more vulnerable to high amount of inorganic suspension. Their abundance often increases with depth and with the increasing distance from the source of disturbance (Boyer et al. 1990; Barnes 1995b; Rosso and Sanfilippo 2000; Kukliński et al. 2005). Higher content of inorganic suspension in the waters around section III (Pęcherzewski 1980) can clog their filtering apparatus (Moore 1977).

Depth was also important for the distribution of bryozoans in Admiralty Bay. Most of the species (Fig. 5) were found only below 70 m. Kukliński et al. (2005) pointed that aside glacial disturbance in the Arctic fjords, the depth was also influencing bryozoan assemblages. However, Antarctic bryozoans are mostly eurybathic (Barnes 1995c; Lopez-Fe 2005; Barnes and Kukliński 2010; Figuerola et al. 2013). This fact might be associated with a deep-water origin of that fauna (Barnes and Kukliński 2010). Nevertheless, on smaller scale, in the semi-closed fjords and glacial bays, the bathymetric distribution of many species can be different and might be shaped by sedimentation inflow and other factors influencing bottom communities in the shallower areas. Deeper sublittoral of Admiralty Bay is characterized by relatively stable environmental conditions what support a higher richness and diversity of benthic communities (Siciński et al. 2011). Higher species richness of bryozoans in the sections I and II, which are deeper and less disturbed than the section III, could also result from the higher microhabitat diversity created by branching forms of Bryozoa, which may constitute an additional, three-dimensional substrate for the other bryozoan species (Barnes 1994). *H. antarcticum* and *N. flagellata* serve as a substrate for many other species recorded in South Bay (Moyano and Cancino 2002). The number of larger dropstones available for colonization and growth of branched bryozoans is clearly low in the section III (Fig. 1; Table 1), and stones can be buried due to higher sedimentation.

Clearly defined faunal assemblages of bivalves, polychaetes or amphipods were often described in the polar fjords and can be associated with depth, distance from the glaciers or sediment type (Siciński 2004; Włodarska-Kowalczuk and Pearson 2004; Jażdżewska unpublished results). Similar patterns were also found for the bryozoan fauna in the Svalbard fjords, where species composition was associated with depth and distance from the glaciers (Kukliński et al. 2005). High level of patchiness resulted in a lack of well-defined assemblages of bryozoan fauna in Admiralty Bay. Most of the species recorded during our study had very low frequency of occurrence. The distribution of particular species is highly irregular. Many bryozoans occurred in only a single patch. This pattern can be associated with recruitment and colonization processes in a glacial fjord like the Admiralty Bay. The only possible substrate for the sessile species in the studied soft bottom is various size stones, randomly distributed, mainly in the less disturbed central part of the bay (Marsz 1983; Siciński 2004). It was most probably the main reason for the lack of apparent zonation in the distribution of bryozoans species in the Admiralty Bay. The distribution of many species might be explained by a single colonization of the dropstones. These dropstones may be treated as stepping stones in colonization of the muddy sediments which are otherwise unsuitable for sessile species (Kukliński 2005) and a founder effect can occur here. Competition for a very limited space is also high in such environment (Barnes and Kukliński 2005).

In the material studied by us, most of the species were rare and only a few of them were widely distributed in the investigated sites, as well as in wide bathymetric range. Species such as *H. antarcticum* and *N. flagellata* can feed even during winter when food concentration is minimal (Barnes and Clarke 1994; Sanderson et al. 1994; Barnes and Clarke 1995). This ability can explain their relatively wide distribution in the Admiralty Bay. Moreover, *N. flagellata* is a fast growing species and probably does not show seasonal changes in growth rate (Barnes 1995a).

Generally, the biomass values recorded in our study were very low. This result surprised, especially if compared with the bryozoan biomass values recorded in the central basin of the Admiralty Bay, in 40–380 m depth range (Pabis et al. 2011; Pabis and Siciński 2012). Moreover, bryozoans can constitute up to 14 % of the macrozoobenthos biomass at some Southern Ocean sites (Winston and Heimberg 1988). Although, the biomass of sessile suspension feeders in the earlier studies done in the inner and middle part of Ezcurra Inlet was very low (Pabis et al. 2011). In our study, higher biomass was noted only in central basin of the bay (section I); however, the mean value was still low 1.6 ± 2.7 g/0.09 m^2. Nevertheless, this value of bryozoan biomass, higher than in two other sections could be linked with a very low mineral suspension content (Pęcherzewski 1980) and a higher food availability in this area (Tokarczyk 1986); however, differences between three studied areas at the depth range from 15 to 70 m were not statistically significant. Relatively low bryozoan biomass in shallower areas of section I could be associated with an influence of ice disturbance, which creates an important boundary for sessile benthos in the central basin of Admiralty Bay at depth of about 30 m (Nonato et al. 2000; Echeverria et al. 2005; Pabis et al. 2011).

Conclusions

This study is the first analysis of the bryozoan community of the Antarctic glacial fjord based on the large set of quantitative samples. It demonstrates that depth is important in shaping the bryozoan community in this basin. Almost 55 % of all species recorded were found only below 70 m. In shallower sublittoral (15–70 m depth), which is the most vulnerable to disturbance, there was no difference in species richness between all three sites located along the axis of the fjord. The influence of glacial disturbance was visible only in the dominance structure and diversity of the bryozoan growth-forms. The inner area characterized by silty clay sediments and high mineral suspension content in water was strongly dominated by encrusting species. It showed that the composition of bryozoan growth-forms can be a better indicator of glacial disturbance than species richness itself. The distribution of the bryozoan species in Admiralty Bay was characterized by a strong patchiness. In the soft bottom habitat of this fjord, those sessile suspension feeders can colonize only randomly distributed dropstones, what explains lack of clearly defined assemblages of bryozoan fauna.

Further studies of bryozoan communities from Antarctic fjords should be focused on the influence of suspension inflow on the community structure and should cover wider bathymetric range, as well as include the glacial bays located in the innermost part of the fjords. There is also a need for studies on colonization and succession processes in these disturbed bottom areas. Subsequent research should also address the problem of temporal changes in the diversity and species richness of the bryozoan communities. Repeated sampling at appropriate time scales (20–30 years) can be useful for detection of possible temporal variability associated with a climate change. Similar studies have already been done for some Arctic sites (Kędra et al. 2010; Węsławski et al. 2010) and demonstrated significant changes in the benthic community structure and diversity. Bryozoans are important ecological indicators and can be used in the assessments of the long-term environmental changes. Climate-related changes in the bryozoan growth rates have been recently noted in the Southern Ocean (Barnes et al. 2006, 2011), and we can also expect shifts in the distribution patterns and diversity of their communities. Such research should be planned in locations characterized by comprehensive benthic studies and availability of data collected in the period when climate warming was not so strongly pronounced as nowadays, in the 1970s and 1980s of the twentieth century. Admiralty Bay as a model fjord basin and because of its extensive research history of benthic fauna offers the possibility for such comparisons.

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Conflict of interest None of the co-authors have any sort of concern in the submission of this manuscript to the journal Polar Biology. There is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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