

# Macrozoobenthos of two Antarctic glacial coves: a comparison with non-disturbed bottom areas

Jacek Siciński · Krzysztof Pabis ·  
Krzysztof Jażdżewski · Alicja Konopacka ·  
Magdalena Błazewicz-Paszkowycz

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**Abstract** There are only few studies on shallow Antarctic benthic communities associated with habitats affected by intense mineral sedimentation inflow. The analysis of macrofaunal communities associated with two shallow, isolated glacial coves was performed in Admiralty Bay (King George Island) and compared with non-disturbed sites. Multivariate analyses (hierarchical classification, nMDS) clearly separated glacial cove communities (two assemblages) from the sites situated outside both basins (two assemblages). The community influenced by the streamflow of glacial discharge of meltwater situated in the area with sandy–clay–silt sediments had a very low species richness, diversity and abundance. It was dominated by eurytopic, motile deposit feeding polychaetes such as *Mesospio moorei*, *Tharyx cincinnatus* and *Leitoscoloplos kerguelensis* as well as the bivalve *Yoldia eightsi*. The second glacial community of the area located at a greater distance from the outlet of the stream was characterized by sandy–clay–silt and clay–silt deposits and showed also a low diversity and species richness. The most abundant here

were peracarid crustaceans, with the dominant opportunistic feeder *Cheirimedon femoratus*. Community from the non-disturbed area with silty–clay–sand, and silty–sand sediments had higher species richness and diversity. The assemblage of fauna from the sandy bottom has values of those two indexes similar to those found in the disturbed areas.

**Keywords** West Antarctic · South Shetland Islands · Soft bottom · Macrozoobenthos · Environmental gradients

## Introduction

Polar regions are affected by a high level of disturbance associated with iceberg scour and glacial sedimentation (Barnes 1999; Gutt 2001; Smale and Barnes 2008); however, not all aspects of these problems were studied equally in the Arctic and in the Antarctic. While ice scour disturbance was intensively studied in both polar regions (Conlan et al. 1998; Gutt and Piepenburg 2003; Brown et al. 2004; Conlan and Kvitek 2005; Gerdes et al. 2008; Smale 2008a), it was recently emphasized by Smale and Barnes (2008) that studies on benthic communities affected by mineral suspension inflow are still lacking from the Southern Ocean.

Arctic benthic communities inhabiting shallow glacial bays were intensively studied, mostly on Spitsbergen (Włodarska et al. 1996; Włodarska-Kowalczyk et al. 1998, 1999; Włodarska-Kowalczyk and Wesławski 2001). In the Antarctic, similar studies are still scarce and often are based on higher taxa abundance and photographic surveys or are focused on only one group of invertebrates (Richardson and Hedgpeth 1977; Siciński et al. 1996; Gambi et al. 1997; Sahade et al. 1998; Siciński 2004; Brown et al. 2004; Bowden 2005).

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J. Siciński · K. Pabis (✉) · M. Błazewicz-Paszkowycz  
Laboratory of Polar Biology and Oceanobiology,  
University of Lodz, Banacha 12/16, 90-237 Lodz, Poland  
e-mail: cataclysta@wp.pl

J. Siciński  
e-mail: sicinski@biol.uni.lodz.pl

M. Błazewicz-Paszkowycz  
e-mail: magdab@biol.uni.lodz.pl

K. Jażdżewski · A. Konopacka  
Laboratory of Biogeography and Invertebrate Ecology,  
University of Lodz, Banacha 12/16, 90-237 Lodz, Poland  
e-mail: kryjaz@biol.uni.lodz.pl

A. Konopacka  
e-mail: alikon@biol.uni.lodz.pl

Shallow glacial bays are considered to be very peculiar habitats inhabited mostly by opportunistic, motile species, living under the influence of very serious and long-lasting disturbance (Wlodarska-Kowalczyk et al. 1998, 1999). Among the key factors shaping those habitats are the high rate of mineral sedimentation, low sediment stability, high water turbidity and low primary production. These conditions are accompanied by an increase in freshwater inflow, resulting in temperature and salinity oscillations. This may have a great influence on benthic fauna, especially on sessile suspension feeders, affecting their feeding abilities and/or reproduction (Rhoads 1974; Moore 1977).

The ongoing climate warming observed in the West Antarctic Peninsula region (Walsh 2009), which resulted in strong retreat of glaciers during the last 60 years (Cook et al. 2005), may change the structure of Antarctic benthic communities (Smale and Barnes 2008). According to predictions for both polar regions, the rate of suspension matter inflow driven by climate change will significantly increase in a short period of time (Syvitski and Andrews 1994; Smale and Barnes 2008) and will be especially pronounced in the Antarctic. The main reason for these expectations is the relative unimportance of this factor in the evolution of Southern Ocean shelf benthic communities, which are isolated and dominated by large sessile suspension feeders (Smale and Barnes 2008). It was also observed that some benthic invertebrates are even more sensitive to glacial sedimentation than to the direct impact of ice (Slattery and Bockus 1997). In this context, the studies of shallow glacial basins from the Antarctic, especially from the West Antarctic Peninsula region, are important, because the basic knowledge will be needed to assess possible future changes in those communities.

The aim of this study is to describe and compare benthic, macrofaunal communities associated with two different glacial coves with those from the sites located outside both basins. The first one (Ecology Glacier lagoon) is a very shallow, young glacial cove located in the vicinity of the large tidewater glacier, and the second one (Herve Cove) is deeper and affected by relatively small glacier with tidewater cliff.

## Materials and methods

### Study area

Admiralty Bay is a fjord-like embayment of King George Island. It consists of a central basin and three inlets: Ezcurra Inlet, Martel Inlet and MacKellar Inlet (Fig. 1). The central basin is the deepest part of the bay and it is open to the Bransfield Strait. Glacier cover is distributed mainly along the eastern coast of central basin and in the inlets

(Braun and Grossmann 2002). Shores geomorphology of Ezcurra Inlet was described by Marsz (1983). The highest rates of suspended matter in Admiralty Bay were measured in the inner parts of Ezcurra Inlet and in small coves and lagoons located in front of the glaciers (Pecherzewski 1980). In Admiralty Bay, several small glacial coves of different age can be found (Marsz 1983). Herve Cove and Ecology Glacier lagoon are two basins characterized by different stages of development as well as by differences in hydrography and hydrology. Both are to some degree isolated from the open waters of Admiralty Bay (Marsz 1983) (Table 1; Fig. 1).

Herve Cove is a small glacial cove located on the southern coast of Ezcurra Inlet. It is influenced by the shallow tidewater glacier (littoral–shallowest sublittoral)—the edge of the steep outlet glacier (Dera Icefall) (Fig. 1). Mean annual content of suspended matter in the waters of this cove was estimated as 46 mg/dm<sup>3</sup>. The highest values were noted in the areas located near the outlet of the streamflow of glacial discharge of meltwater. Quantities of mineral suspended matter in this part of Herve Cove reached 270 mg/dm<sup>3</sup> (Rakusa-Suszczewski 1995; Sicinski et al. 1996).

Ecology Glacier lagoon is a recently formed glacial cove located on the western shore of central basin in front of the shallow tidewater glacier (littoral–shallowest sublittoral)—the edge of the outlet glacier (Ecology Glacier) (Fig. 1). The amount of suspended matter in Ecology Glacier lagoon reaches the highest values recorded for Admiralty Bay. While the average quantity of suspended matter in open waters of Admiralty Bay was estimated as 12.4 mg/dm<sup>3</sup>, such values in front of the Ecology Glacier exceeded 150 mg/dm<sup>3</sup> (Pecherzewski 1980).

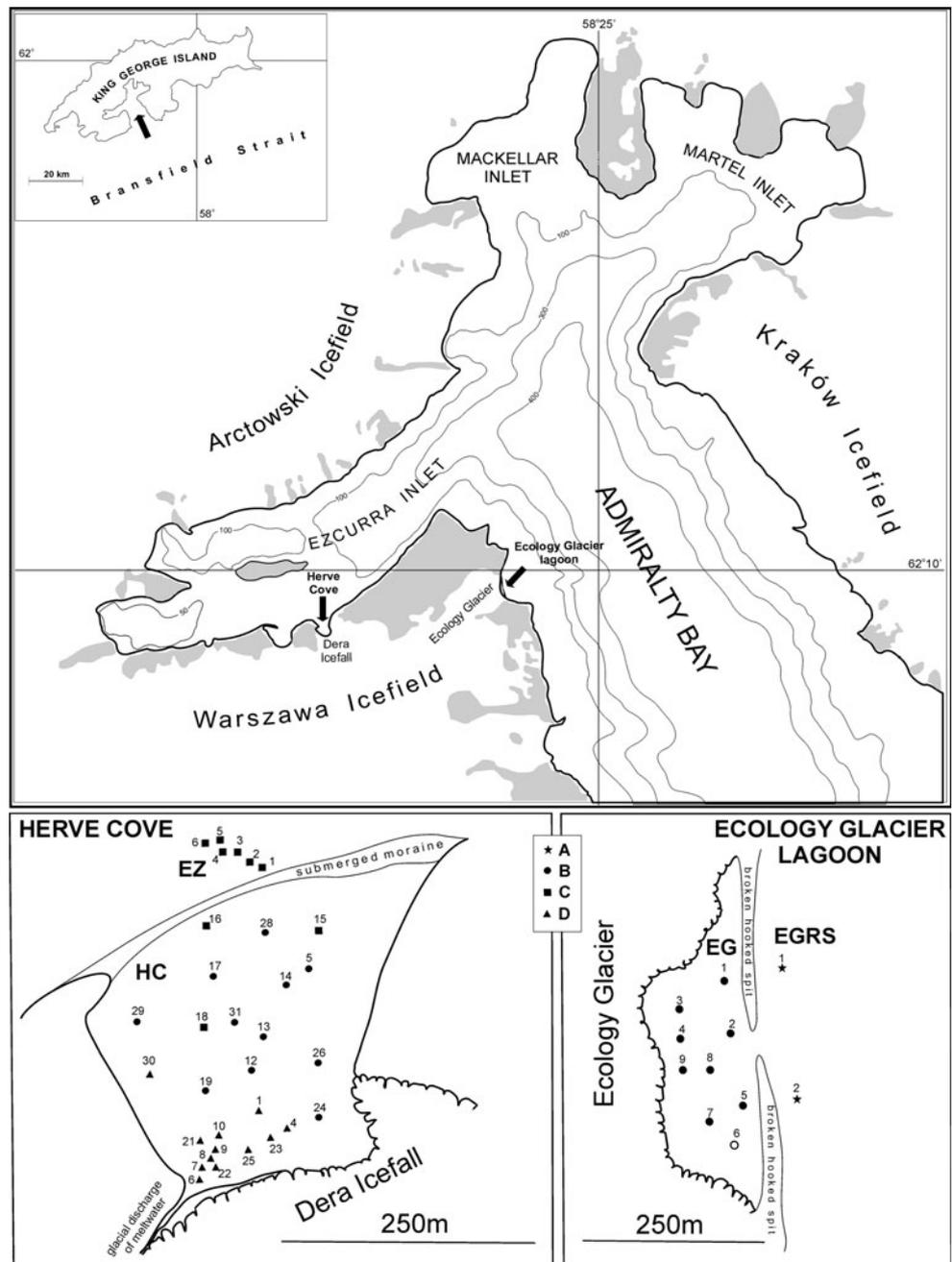
### Sampling

Forty-four samples were collected in the summer season of 1993/94 including twenty-seven samples from Herve Cove (HC), six samples from Ezcurra Inlet (EZ) (reference site for Herve Cove), nine samples from Ecology Glacier lagoon (EG) and two samples from the shallow sublittoral outside this basin (EGRS) (reference site for Ecology Glacier lagoon) (Fig. 1).

Samples from Herve Cove were collected using a van Veen grab (0.1 m<sup>2</sup>). Samples from the shallowest parts of the bottom (all samples from Ecology Glacier lagoon and both reference sites) were collected with the Tvärminne sampler (565 cm<sup>2</sup>) (Kangas 1972). Abundance values from those samples were converted to 0.1 m<sup>2</sup> surface area. All samples were sieved on a 0.5-mm mesh sieve.

Preliminary results from the same set of samples collected in Herve Cove (from HC1 to HC31) were already published by Sicinski et al. (1996). That study was based

**Fig. 1** Distribution of samples from the distinguished assemblages. (HC Herve Cove, EZ Ezcurra Inlet, EG Ecology Glacier lagoon, EGRS Ecology Glacier reference site). Samples are specified by signs representing the four groups distinguished in multivariate analysis (Figs. 3, 4)



on the abundance and biomass values mostly of higher taxa (altogether 24 taxa, 11 taxa (mostly polychaetes) of which were identified to the species level) and did not include the sediment analysis. The samples in the present study have the same numeration as used in the paper by Sicinski et al. (1996).

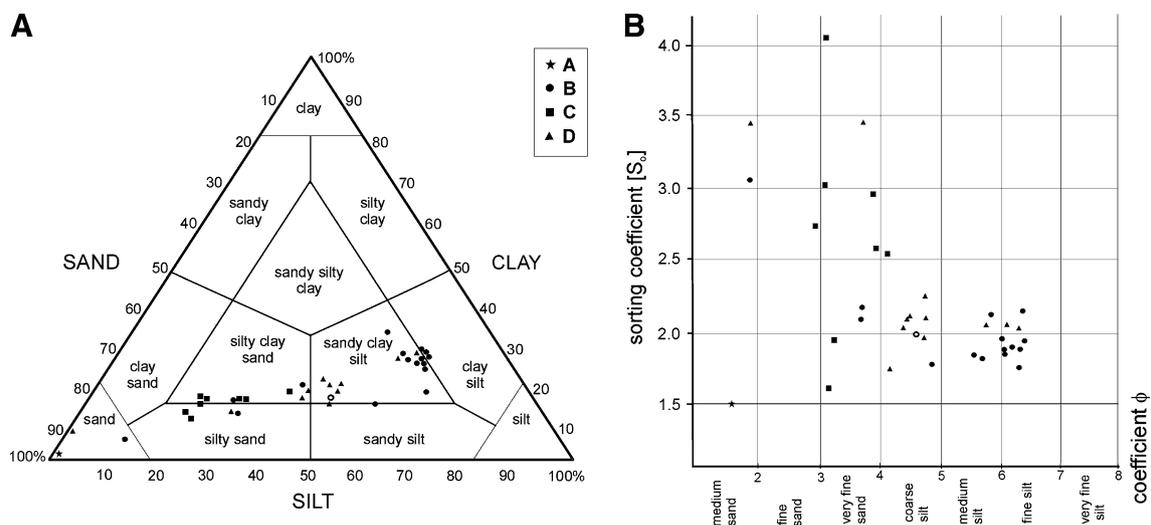
**Granulometric analysis**

Subsamples for granulometric analysis were taken from 38 out of the 44 collected. The analysis of sediments was

carried out using an areometric method. Sediment was sieved on a 1-mm mesh size sieve to separate the skeletal fraction. Fractions with grain diameter below 1 mm were further sorted. On the basis of this analysis, the cumulative curves of granulation were constructed. The content of sand, silt and clay fractions was measured. The classification and nomenclature of sediments proposed by Shepard (1954) (Fig. 2) were used as particularly useful for weakly sorted sediments. The sorting coefficient (So) and median of grain diameter expressed in the units of Md coefficient  $\phi = -\log_2 d$  ( $d$ —median grain size in

**Table 1** Characteristics of both bays

	Herve Cove	Ecology Glacier lagoon
Location	Inner part of Ezcurra Inlet	Western coast of central basin
Maximal depth	20 m	6 m
Bottom deposits	Very heterogenous, sand in some nearshore areas, silty–clay–sand and sandy–clay–silt in areas influenced by glacial stream; sandy–clay–silt and clay–silt in the predominate bottom areas (see also Fig. 2)	Very heterogenous, mostly medium sand, silty–sand and some sandy–silt (see also Fig. 2)
Surface area	ca 14 ha	ca 5 ha
Isolation	Submerged arc of terminal moraine	Kind of shore ridge—broken hooked spits
Type of glacier	Outlet glacier, tidewater glacier	Outlet glacier, tide water glacier
Bottom configuration	Diversified, complex bottom relief—many hollows and shallows	Monotonous
References	Pecherzewski (1980), Marsz (1983), Rakusa-Suszczewski (1995), Sicinski et al. (1996), Sicinski (2004)	Pecherzewski (1980), Marsz (1983), Rakusa-Suszczewski (1995)

**Fig. 2** Characteristics of bottom sediments based on the proportion of sand, silt and clay (**a**) and the relationship between Md  $\phi$  coefficient and sorting coefficient (So) (**b**). Samples are specified by signs representing the four groups distinguished in multivariate analysis (Figs. 3, 4)

millimeters) were also calculated (Krumbein 1934). Those values were used to locate the samples in the coordinate system represented by the sorting coefficient and Md coefficient (Fig. 2).

#### Data analysis

Bray–Curtis similarity index was used to calculate the similarities between the samples on the basis of density (ind./0.1 m<sup>2</sup>) of 78 taxa in 44 samples. Hierarchical agglomerative clustering was performed using the group-average method. Non-metric multidimensional scaling (nMDS) was used for sample ordination. Data were square-root-transformed to reduce the influence of dominant species upon the results of the analysis (Clarke and Warwick 1994). Indices of species

richness (Margalef  $d = (S-1)/\log N$ ), species diversity (Shannon index  $H' = -\sum p_i \ln p_i$ ) as well as evenness (Pielou  $J' = H'/\ln S$ ) were measured for each sample (Magurran 2004). The PRIMER package v. 6 was used for this analysis.

Mean values with standard errors and standard deviations were calculated for density values and all richness and diversity indices in each assemblage. Differences between these indices in the distinguished groups were tested using one-way ANOVA. Levene's test was used to estimate the homogeneity of variance. Tukey's test for groups with unequal number of replications was used for post hoc multiple comparisons using the STATISTICA 6 package. The group A that contains only 2 samples was excluded from the testing.

## Results

Seventy-seven species (26,513 individuals) were recorded in the investigated area (Table 2). Four assemblages were distinguished in the cluster analysis (Fig. 3). Similar pattern was found on the nMDS plot. The relatively low stress value indicates a good two-dimensional representation of multidimensional space (Fig. 4).

### Assemblage A

This assemblage represents the shallow bottom areas from the Ecology Glacier lagoon reference site (only 2 samples, both from 6 m depth) (Figs. 1, 3, 4). Only 10 species were found in this assemblage. The most abundant were amphipods: *Hippomedon kergueleni* ( $260.0 \pm 70.7$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ), *Cardenio paurodactylus* ( $96.0 \pm 0.0$  ind./ $0.1 \text{ m}^2$ ,  $F = 100$ ) and *Monoculodes scabriculosus* ( $29.0 \pm 2.8$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ). The polychaete *Travisia kerguelensis* ( $27.0 \pm 9.8$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ) was also an important element of this assemblage and the only non-crustacean member of the group (Table 2). The bottom was characterized by sandy deposits (Fig. 2).

### Assemblage B

Samples grouped in this cluster were distributed in Ecology Glacier lagoon and in a part of Herve Cove situated in a greater distance from the outlet of streamflow of glacial discharge of meltwater (Figs. 1, 3, 4). This assemblage consists of 40 species. Most of them were amphipod crustaceans with *Cheirimedon femoratus* ( $599.9 \pm 544.9$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ), *Djerboa furcipes* ( $176.2 \pm 457.1$  ind./ $0.1 \text{ m}^2$ ,  $F = 47.4$ ) and *Orchomenella* cf. *ultima* ( $16.3 \pm 40.7$  ind./ $0.1 \text{ m}^2$ ,  $F = 57.9$ ) being the most abundant and frequent taxa. The sea anemone *Edwardsia* sp. was also an important element of these group ( $19.2 \pm 45.1$  ind./ $0.1 \text{ m}^2$ ,  $F = 47.4$ ) (Table 2). The assemblage is characterized by lowest mean richness, diversity and evenness values (Fig. 5). The sediments were mostly sandy–clay–silt and clay–silt (Fig. 2).

### Assemblage C

This cluster grouped the samples from the reference site in Ezcurra Inlet as well as three samples from Herve Cove located close to the submerged moraine (Figs. 1, 3, 4). Fifty-nine species were found in this assemblage (Table 2). It is the group with highest densities, species richness and diversity values (Fig. 5). The most abundant and frequent species were crustaceans *Typhlotanais grahami* ( $176.4 \pm 160.9$  ind./ $0.1 \text{ m}^2$ ,  $F = 77.7$ ), *Eudorella splendida* ( $37.7 \pm 37.6$  ind./ $0.1 \text{ m}^2$ ,  $F = 88.8$ ), *Heterophoxus videns* ( $48.1 \pm 57.6$

ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ) and *Philomedes charcoti* ( $66.3 \pm 144.5$  ind./ $0.1 \text{ m}^2$ ,  $F = 77.7$ ), polychaetes: *Apistobranthus gudrunae* ( $60.4 \pm 99.6$  ind./ $0.1 \text{ m}^2$ ,  $F = 66.6$ ), *Ceratonereis* (C.) *antarctica* ( $56.2 \pm 62.6$  ind./ $0.1 \text{ m}^2$ ,  $F = 55.5$ ), *Tharyx cincinnatus* ( $75.5 \pm 133.4$  ind./ $0.1 \text{ m}^2$ ,  $F = 88.8$ ) and *Rhodine intermedia* ( $60.8 \pm 82.0$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ) as well as the bivalve *Yoldia eightsi* ( $35.4 \pm 44.7$  ind./ $0.1 \text{ m}^2$ ,  $F = 100.0$ ). The sediments in this group of samples can be described as silty–clay–sand and silty–sand (Fig. 2).

### Assemblage D

This cluster grouped the samples from a part of Herve Cove situated in a vicinity of the glacial discharge of meltwater outlet (Figs. 1, 3, 4). It is an assemblage with the lowest mean density value. Also, the richness and diversity were relatively low in this group (Fig. 5). Twenty-nine species were found in this assemblage (Table 2). The most abundant and frequent were *Mesospio moorei* ( $35.8 \pm 52.5$  ind./ $0.1 \text{ m}^2$ ,  $F = 83.3$ ), *Yoldia eightsi* ( $14.1 \pm 25.4$  ind./ $0.1 \text{ m}^2$ ,  $F = 66.6$ ), *Tharyx cincinnaus* ( $10.8 \pm 14.1$  ind./ $0.1 \text{ m}^2$ ,  $F = 66.6$ ) and *Leitoscoloplos kerguelensis* ( $7.3 \pm 14.2$  ind./ $0.1 \text{ m}^2$ ,  $F = 83.3$ ). The sediments are mostly sandy–clay–silt (Fig. 2).

There were significant differences between the three groups (B, C and D) in respect to Shannon index and Margalef index. Evenness values were significantly different between groups B/C and B/D (Tukey's test,  $P < 0.05$ ). No significant differences were found in the pair C/D. Density values were significantly different in pairs B/D and C/D, whereas there were no differences for the pair B/C (Tukey's test,  $P < 0.05$ ).

## Discussion

Macrobenthic fauna associated with habitats of dynamic sedimentation was not an object of intensive studies in the Antarctic. Only 13% of the Antarctic coast line is covered by glaciers with tidewater cliffs and those sites are scattered all over the continent (Gutt 2001). Besides, in the West Antarctic, the terrigenous sediment deposition originates mostly from grounded and floating ice shelves (Anderson et al. 1982). It was stressed that benthic fauna of the Southern Ocean has not evolved under a strong pressure of the mineral sedimentation inflow and thus may be sensitive to any increase in such processes (Smale and Barnes 2008). On the Antarctic islands, like South Shetlands archipelago, the influence of sedimentation on benthos was already described in the fjords and it is an important mechanism shaping the bottom communities (Sicinski 2004; Momo et al. 2008; Pabis et al. 2011). The

**Table 2** Mean densities [ind./0.1 m<sup>2</sup>] with standard deviation and frequency values [%] for each distinguished assemblage

	Species	A		B		C		D	
		mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]
Amp	<i>Cheirimedon femoratus</i>	-	-	<b>599.9 ± 544.9</b>	<b>100.0</b>	0.4 ± 0.8	22.2	1.0 ± 1.6	41.6
Amp	<i>Djerboa furcipes</i>	-	-	<b>176.2 ± 457.1</b>	<b>47.4</b>	-	-	-	-
Pol	<i>Mesospio moorei</i>	-	-	1.7 ± 5.7	26.3	-	-	<b>35.8 ± 52.5</b>	<b>83.3</b>
Act	<i>Edwardsia</i> sp.	-	-	<b>19.2 ± 45.1</b>	<b>47.4</b>	0.1 ± 0.3	11.1	3.4 ± 7.8	58.3
Amp	<i>Orchomenella</i> cf. <i>ultima</i>	-	-	<b>16.3 ± 40.7</b>	<b>57.9</b>	-	-	-	-
Amp	<i>Oradarea bidentata</i>	-	-	-	-	-	-	0.3 ± 1.1	8.3
Amp	<i>Oediceroides macrodactyla</i>	-	-	-	-	-	-	0.1 ± 0.5	8.3
Pol	<i>Aricidea</i> (A.) <i>antarctica</i>	-	-	-	-	-	-	0.1 ± 0.3	8.3
Pol	<i>Ampharete kerguelensis</i>	-	-	-	-	-	-	0.1 ± 0.5	8.3
Amp	<i>Gondogeneia antarctica</i>	-	-	2.9 ± 6.4	26.3	0.2 ± 0.6	11.1	0.07 ± 0.2	8.3
Amp	<i>Eurymera monticulosa</i>	-	-	0.3 ± 1.1	10.5	0.1 ± 0.3	11.1	-	-
Amp	<i>Paraperioculodes</i> sp.	-	-	0.1 ± 0.4	5.3	-	-	0.07 ± 0.2	8.3
Amp	<i>Bovallia gigantea</i>	-	-	0.1 ± 0.4	5.3	-	-	-	-
Iso	<i>Munna antarctica</i>	-	-	0.2 ± 0.9	5.3	-	-	-	-
Pol	<i>Capitella perarmata</i>	-	-	0.8 ± 3.6	5.3	-	-	0.3 ± 1.1	8.3
Amp	<i>Gondogeneia subantarctica</i>	-	-	0.9 ± 4.1	5.3	-	-	-	-
Amp	<i>Paramoera edouardi</i>	-	-	0.7 ± 2.6	10.5	-	-	-	-
Amp	<i>Protebbingia gracilis</i>	-	-	0.6 ± 1.4	21	-	-	-	-
Tan	<i>Typhlotanais grahami</i>	-	-	0.6 ± 2.7	5.3	<b>176.4 ± 160.9</b>	<b>77.7</b>	-	-
Pol	<i>Spiophanes tcherniai</i>	-	-	-	-	0.1 ± 0.3	11.1	-	-
Pol	<i>Scoloplos</i> (L.) <i>marginatus</i>	-	-	-	-	0.1 ± 0.3	11.1	-	-
Ast	<i>Odontaster validus</i>	-	-	-	-	0.1 ± 0.3	11.1	-	-
Amp	<i>Probolisca ovata</i>	-	-	-	-	0.2 ± 0.6	11.1	-	-
Amp	<i>Paradexamine fissicauda</i>	-	-	-	-	0.2 ± 0.6	11.1	-	-
Iso	<i>Austrofilius furcatus</i>	-	-	-	-	0.2 ± 0.6	11.1	-	-
Pol	<i>Brada villosa</i>	-	-	-	-	0.2 ± 0.6	11.1	-	-
Cum	<i>Eudorella gracilior</i>	-	-	-	-	0.2 ± 0.6	11.1	-	-
Pol	<i>Ophelia syringopyge</i>	-	-	0.05 ± 0.2	5.3	7.3 ± 12.1	77.7	0.9 ± 1.7	33.3
Iso	<i>Paraserolis polita</i>	1.0 ± 1.4	50.0	0.6 ± 1.9	21	3.6 ± 7.1	33.3	0.6 ± 1.5	25.0
Pol	<i>Capitella</i> sp.	-	-	0.3 ± 1.6	5.3	1.7 ± 1.7	66.6	-	-
Pri	<i>Priapulus</i> sp.	-	-	0.3 ± 0.8	21	3.7 ± 3.4	66.6	0.3 ± 0.5	41.6
Biv	<i>Laternula elliptica</i>	-	-	-	-	1.0 ± 1.3	55.5	1.8 ± 3.6	41.6
Tan	<i>Tanaopsis gallardoi</i>	-	-	-	-	0.5 ± 1.6	11.1	-	-
Iso	<i>Austrosignum globifrons</i>	-	-	0.6 ± 2.7	5.3	4.4 ± 6.7	44.4	-	-
Iso	<i>Munna neglecta</i>	-	-	0.2 ± 0.8	10.5	4.2 ± 10.9	22.2	-	-
Amp	<i>Schraderia gracilis</i>	-	-	0.2 ± 0.6	10.5	5.0 ± 8.4	44.4	-	-
Amp	<i>Oradarea edentata</i>	-	-	0.2 ± 0.9	5.3	5.4 ± 7.8	55.5	-	-
Ost	<i>Scleroconcha gallardoi</i>	-	-	-	-	4.7 ± 4.9	55.5	-	-
Pol	<i>Amphicteis gunneri antarctica</i>	-	-	0.05 ± 0.2	5.3	3.1 ± 5.1	33.3	-	-
Amp	<i>Schraderia</i> cf. <i>dubia</i>	-	-	-	-	3.3 ± 6.6	22.2	-	-
Ech	<i>Sterechinus neumayeri</i>	-	-	-	-	0.8 ± 1.7	22.2	-	-
Pol	<i>Eupraxillella antarctica</i>	-	-	-	-	2.2 ± 6.6	11.1	-	-
Pol	<i>Barrukia cristata</i>	-	-	-	-	2.1 ± 1.6	77.7	-	-
Amp	<i>Oradarea</i> cf. <i>ocellata</i>	-	-	-	-	1.2 ± 3.6	11.1	-	-
Gas	<i>Nacella concinna</i>	-	-	-	-	1.3 ± 1.7	44.4	-	-
Tan	<i>Paraeospinosus pushkini</i>	-	-	-	-	1.5 ± 4.6	11.1	-	-
Iso	<i>Paramunna rostrata</i>	-	-	-	-	1.4 ± 2.5	33.3	-	-
Amp	<i>Gitanopsis squamosa</i>	-	-	-	-	1.2 ± 1.3	55.5	0.07 ± 0.2	8.3
Pol	<i>Dorvilleidae</i> gen. sp.	-	-	-	-	1.3 ± 2.6	33.3	0.3 ± 1.3	8.3
Pol	<i>Aglaophamus trissophyllus</i>	-	-	-	-	1.0 ± 0.7	77.7	0.6 ± 0.9	33.3
Iso	<i>Munna jazdzewskii</i>	-	-	-	-	<b>30.8 ± 56.2</b>	<b>66.6</b>	-	-
Cum	<i>Campylaspis maculata</i>	-	-	0.3 ± 1.6	5.3	<b>29.4 ± 33.5</b>	<b>77.7</b>	-	-
Amp	<i>Methalimedon nordenskjoldi</i>	-	-	0.1 ± 0.4	5.3	<b>27.3 ± 33.7</b>	<b>66.6</b>	-	-

**Table 2** continued

	Species	A		B		C		D	
		mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]	mean density [ind./0.1m <sup>2</sup> ] with SD	F[%]
Tan	<i>Nototanaeis antarcticus</i>	-	-	0.9 ± 2.0	31.6	<b>44.6 ± 131.3</b>	<b>33.3</b>	0.4 ± 1.1	16.6
Cum	<i>Eudorella splendida</i>	-	-	0.2 ± 0.9	10.5	<b>37.7 ± 37.6</b>	<b>88.8</b>	0.2 ± 0.8	8.3
Pol	<i>Ceratonereis (C.) antarctica</i>	-	-	-	-	<b>56.2 ± 62.6</b>	<b>55.5</b>	-	-
Amp	<i>Heterophoxus videns</i>	-	-	0.1 ± 0.3	10.5	<b>48.1 ± 57.6</b>	<b>100.0</b>	0.1 ± 0.3	16.6
Pol	<i>Apistobranchus glaciera</i>	-	-	-	-	<b>60.4 ± 99.6</b>	<b>66.6</b>	0.7 ± 1.3	33.3
Ost	<i>Philomedes charcoti</i>	-	-	0.2 ± 0.6	15.8	<b>66.3 ± 144.5</b>	<b>77.7</b>	-	-
Pol	<i>Rhodine intermedia</i>	-	-	0.3 ± 0.8	21	<b>60.8 ± 82.0</b>	<b>100</b>	0.1 ± 0.3	16.6
Amp	<i>Parhalimedes turqueti</i>	-	-	0.1 ± 0.3	10.5	11.1 ± 15.7	44.4	-	-
Cum	<i>Vaunthompsonia inermis</i>	-	-	0.2 ± 1.1	10.5	<b>18.0 ± 36.0</b>	<b>77.7</b>	-	-
Iso	<i>Austrosignum grande</i>	-	-	-	-	<b>18.3 ± 21.5</b>	<b>66.6</b>	-	-
Pol	<i>Cirrophorus brevicirratu</i>	-	-	-	-	16.0 ± 33.9	22.2	-	-
Pol	<i>Sphaerodoropsis</i> sp.	-	-	-	-	<b>14.3 ± 26.0</b>	<b>66.6</b>	-	-
Pol	<i>Tharyx cincinnatus</i>	-	-	-	-	<b>75.5 ± 133.4</b>	<b>88.8</b>	10.8 ± 14.1	66.6
Pol	<i>Leitoscoloplos kerguelensis</i>	-	-	0.8 ± 2.7	15.8	<b>24.4 ± 21.7</b>	<b>100.0</b>	7.3 ± 14.2	83.3
Biv	<i>Yoldia eightsi</i>	-	-	0.1 ± 0.4	5.3	<b>35.4 ± 44.7</b>	<b>100.0</b>	14.1 ± 25.4	66.6
Amp	<i>Hippomedon kergueleni</i>	<b>260.0 ± 70.7</b>	<b>100.0</b>	1.5 ± 2.4	52.6	2.0 ± 2.5	55.5	1.3 ± 3.0	25.0
Amp	<i>Monocolodes scabriculosus</i>	<b>29.0 ± 2.8</b>	<b>100.0</b>	1.6 ± 2.6	47.4	10.2 ± 12.3	88.8	7.8 ± 11.9	50.0
Amp	<i>Cardenio paurodactylus</i>	<b>96.0 ± 0.0</b>	<b>100.0</b>	0.1 ± 0.4	5.3	-	-	-	-
Pol	<i>Travisia kerguelensis</i>	<b>27.0 ± 9.8</b>	<b>100.0</b>	-	-	-	-	-	-
Amp	<i>Eophoxocephalopsis</i> sp.	<b>23.0 ± 2.8</b>	<b>100.0</b>	-	-	-	-	-	-
Amp	<i>Heterophoxus trichosus</i>	<b>16.0 ± 16.9</b>	<b>100.0</b>	-	-	0.2 ± 0.6	11.1	-	-
Iso	<i>Spinoserolis beddardi</i>	<b>16.0 ± 15.5</b>	<b>100.0</b>	-	-	-	-	-	-
Amp	<i>Prostebbingia brevicornis</i>	<b>13.5 ± 13.4</b>	<b>100.0</b>	3.9 ± 13.7	26.3	1.7 ± 3.9	33.3	0.3 ± 0.7	16.6
Amp	<i>Parharpinia rotundifrons</i>	4.5 ± 0.7	100.0	1.2 ± 2.8	21	0.1 ± 0.3	11.1	0.23 ± 0.5	16.6

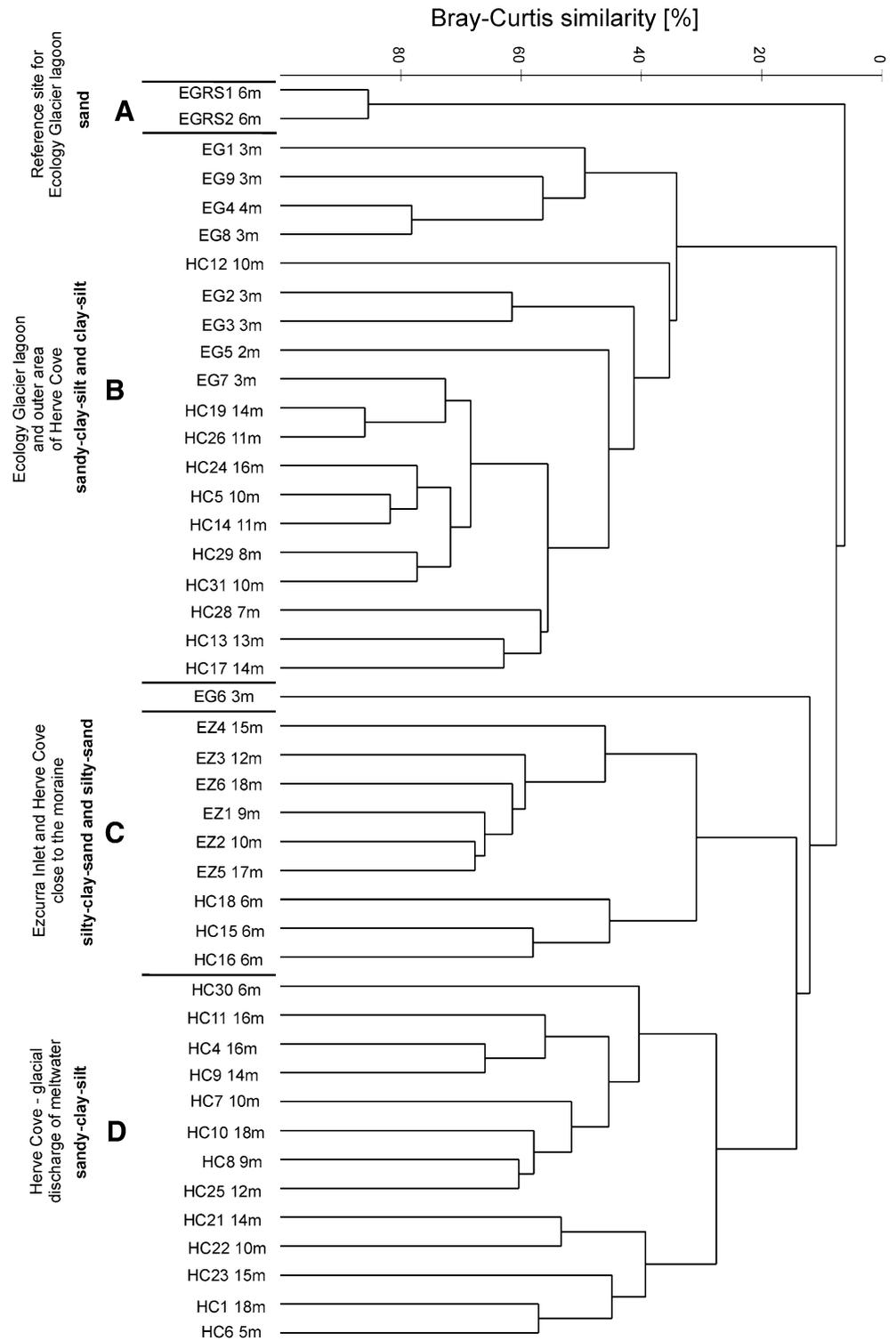
The order of species in table is based on the dendrogram of Bray–Curtis similarity between the species (square-root-transformed data of mean density values in each assemblage and single link grouping method) *Pol* Polychaeta, *Amp* Amphipoda, *Cum* Cumacea, *Tan* Tanaidacea, *Iso* Isopoda, *Ost* Ostracoda, *Act* Actiniaria, *Ast* Asteroidea, *Ech* Echinoidea, *Biv* Bivalvia, *Gas* Gastropoda, *Pri* Priapulida (species associated mostly with one assemblage are grouped in boxes, the most abundant and frequent species within the groups are marked with bold)

sedimentation inflow on a small spatial scale could have a great influence on the composition and diversity of the bottom fauna, especially in areas located close to the glacial termini (Włodarska-Kowalczyk et al. 1998, 1999; Włodarska-Kowalczyk and Weslawski 2001; Włodarska-Kowalczyk and Pearson 2004). The cluster analysis in the present study separated glacial cove communities (assemblages B and D) from the macrobenthic fauna associated with sites located outside both basins (assemblages A and C). The comparison of assemblage A with other groups and literature data may be difficult due to a very small number of samples collected in this bottom area. The outer assemblage of Herve Cove (C) unites the samples from both sides of the moraine. It shows possibility of fauna migration into the cove, as well as the influence of sedimentation, because some of the species building this assemblage are absent from the bottom areas located in the vicinity of the glacial discharge of meltwater (assemblage D). Those species are able to enter into the lagoon but are absent from the glacial assemblage. Both glacial cove communities had low species richness and diversity. The preliminary analysis by Sicinski et al. (1996) based on

abundance and biomass values of higher taxa showed similar patterns of benthos distribution in Herve Cove. The total biomass values were the lowest in the vicinity of a glacial discharge of meltwater and had the highest values in samples collected close to submerged moraine (HC15, HC16 and HC18— assemblage C). The benthic fauna from Ecology Glacier lagoon shows similarities with bottom communities in the middle part of Herve Cove even in its deeper part. In Herve Cove, the gradient of changes associated with the distance from the source of disturbance is more pronounced, and this basin seems to be a more complicated system, characterized by more heterogeneous bottom sediments and more diversified faunal groupings than a small and very shallow lagoon in the vicinity of Ecology Glacier.

The community associated with the area located close to the glacial stream (assemblage D) and characterized mostly by sandy–clay–silt deposits was dominated by eurytopic polychaetes: *Mesospio moorei*, *Tharyx cincinnatus* and *Leitoscoloplos kerguelensis*, as well as the bivalve *Yoldia eightsi*. The similar pattern was observed in the Arctic glacial bays and inner fjord areas with motile deposit

**Fig. 3** Dendrogram of samples (Bray–Curtis similarity of square-root-transformed density values, group-average grouping method) *HC* Herve Cove, *EZ* Ezcurra Inlet, *EG* Ecology Glacier lagoon, *EGRS* Ecology Glacier reference site



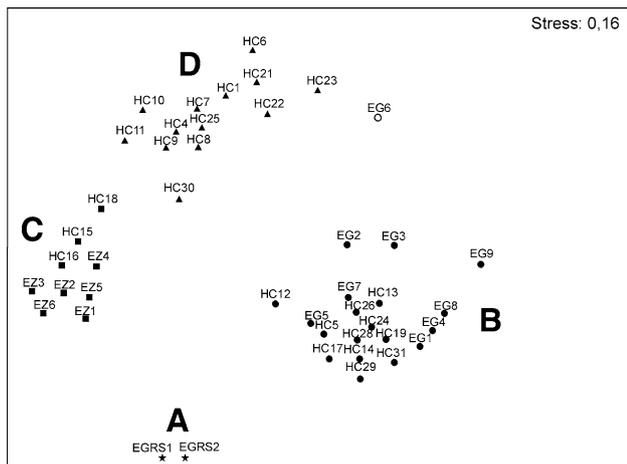
feeding polychaetes (*Tharyx*, *Leitoscoloplos*, *Cosssura*) and bivalves like Yoldiidae and Thyasiridae as the important members of the communities (Syvitski et al. 1989; Wlodarska-Kowalczyk et al. 1998, 1999; Wlodarska-Kowalczyk and Pearson 2004). Similar species composition was also observed in sites located close to the glaciers

in Arthur Harbor (Richardson and Hedgpeth 1977) and in the polychaete communities inhabiting the shallows of Chile Bay (Gallardo et al. 1988). Polychaetes, like *Leitoscoloplos* and *Tharyx*, were among the species colonizing the bottom after iceberg disturbance in the McMurdo Sound (Lenihan and Oliver 1995) and dominated the

shallow areas of Terra Nova Bay (Gambi et al. 1997). *Mesospio moorei* was also a dominant species in shallow parts of the Martel Inlet affected by ice scour disturbance (Bromberg et al. 2000) as well as in shallow areas of Borge Bay (Hardy 1972) and Morbihan Bay (Chardy et al. 1976).

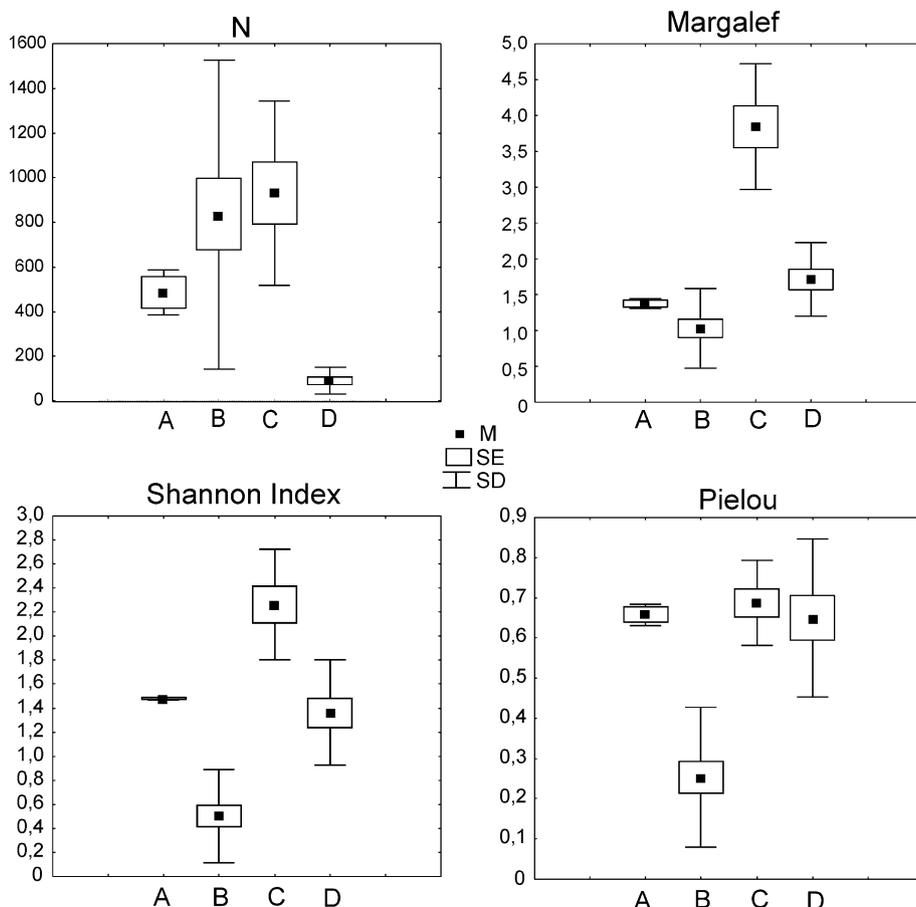
*Laternula elliptica* is sensitive to influence of meltwater streams (Mercuri et al. 2008). On the other hand, this species is able to reduce the metabolic rate under the influence of high sedimentation rate and it is to a certain degree adapted to the changing environmental conditions (Philipp et al. 2011). However, it was pointed out that *Y. eightsi*, the species adapted to high sedimentation rate, will be more abundant in disturbed sites and may take over the bottom areas of reduced abundance of *L. elliptica*. In consequence, it may lead to great changes in marine communities facing the ongoing climate warming because *L. elliptica* is a large, deep burrowing species that has a great influence upon benthic-pelagic carbon flux (Philipp et al. 2011). Results showing the distribution patterns of both species in the studied glacial coves strongly support these scenarios.

The second glacial cove assemblage (assemblage B) was dominated by motile epibenthic species (mostly amphipods), with the most abundant being *Cheirimedon femoratus* ( $599.9 \pm 544.9$ ,  $F = 100$ ). The most important polychaete species was *Mesospio moorei* ( $1.7 \pm 5.7$ ,  $F = 26.3$ ). *C. femoratus* is known to bury in bottom deposits during the day time, but it is also most probably a very good vertical swimmer (Bregazzi 1973). It was



**Fig. 4** nMDS plot (Bray–Curtis similarity of square-root-transformed density values) HC Herve Cove, EZ Ezcurra Inlet, EG Ecology Glacier lagoon, EGRS Ecology Glacier reference site

**Fig. 5** Comparison of density, diversity, species richness and evenness for four distinguished assemblages. *M* mean, *SE* standard error, *SD* standard deviation. (HC Herve Cove, EZ Ezcurra Inlet, EG Ecology Glacier lagoon, EGRS Ecology Glacier reference site)



observed as a species preferring sandy bottom (Bregazzi 1972), while in Herve Cove it was very abundant in the glacially affected area on the sandy–clay–silt and clay–silt sediments. On the other hand, *C. femoratus* occurred also in high numbers in stony uppermost sublittoral of Admiralty Bay (Jazdzewski et al. 2001). It is the species that was found commonly on animal carcasses, but it is also recognized as an opportunistic feeder (Presler 1986; Smale et al. 2007; Jazdzewska 2009). *Mesospio moorei* was also recorded as a dominant polychaete species in Herve Cove (Sicinski 2004) and together with *Leitoscoloplos kerguelensis*, *Tharyx cincinnatus* and *Rhodine intermedia*, it belongs to the most abundant and eurytopic species of polychaetes found in Admiralty Bay (Sicinski 2004). The high share of an amphipod *Djerboa furcipes* in assemblage B could be associated with the fragments of macroalgae that were observed inside small lagoons in Admiralty Bay (Rakusa-Suszczewski 1995). This species feeds on macroalgae (Obermüller et al. 2007) and was found in places with decaying macroalgal material (Richardson and Hedgpeth 1977). Generally, the high share of motile species and often secondary consumers (especially amphipods) in glacial coves is similar to general trends described by Smale (2008a) for the sites influenced by ice scour disturbance.

The sea anemone *Edwardsia* sp. was a dominant species in both glacial cove assemblages. Members of this genus burrow in muddy bottom sediments, and it was often observed in the Antarctic shallows (Williams 1981). Those infaunal anemones were found in polluted sediments around McMurdo Station together with polychaetes like *Tharyx* or *Ophryotrocha claparedei* (Lenihan et al. 1995). A closely related *Halacampoides* was very abundant in the sites affected by strong melt water runoff in Signy Island (Ansell and Peck 2000). This species, together with bivalves, represented also the core of the biomass in Herve Cove (Sicinski et al. 1996).

Almost complete absence of tanaids in both glacial assemblages studied may be due to the low mobility of these crustaceans. Species like *Nototanais antarcticus* live in the aggregations of tangled corridors, while typhlotanaids are known as tube-dwellers (Hassack and Holdich 1987; Blazewicz-Paszkowycz 2007).

While the highest sedimentation rates were observed in Herve Cove close to the glacial stream (over 200 mg/dm<sup>3</sup>) and in the proximity of Ecology Glacier (150 mg/dm<sup>3</sup>) (Pecherzewski 1980; Sicinski et al. 1996; Sicinski 2004) and the bottom deposits clearly reflect the influence of glacial sedimentation in both basins (Fig. 2), these are probably the most important factors structuring the benthos of two coves studied. Glacial stream could also influence the bottom fauna by changes in salinities. Although the surface salinities in a part of Herve Cove located close to

the stream outlet were often lower than in open waters of Admiralty Bay (22–26 PSU), on the bottom, even in shallow depth (2–3 m), salinity was again similar (over 34 PSU) to the values found in open waters (Szafranski and Lipski 1982; Kidawa *personal communication*). Moreover, both basins are isolated from the open waters of Admiralty Bay, and there is no influence of ice scour in these two areas of the bay, unlike as it was observed in Martel Inlet shallows (Echeverria et al. 2005).

The species composition and the patterns of distribution of bottom communities associated with glacial coves and the sites not affected by glacier runoff in Admiralty Bay show similarities with the stages of community recovery after iceberg or anchor ice disturbance (Lenihan and Oliver 1995; Conlan et al. 1998; Bromberg et al. 2000).

The species richness and diversity in assemblage C was higher than in glacial coves. Species composition of both undisturbed bottom areas showed many similarities with other non-disturbed sites in Admiralty Bay. Crustacean species like *Cardenio paurodactylus*, *Hippomedon kergueleni* or *Monoculodes scabriculosus* were among the most abundant inhabitants of shallow water bottom areas of Admiralty Bay central basin (Jazdzewski et al. 1991). The same concerns the polychaete *Travisia kerguelensis*, which was a very important element of sandy bottom communities in places located far from glaciers (Sicinski and Janowska 1993 and references therein).

In Antarctic larger coves or small basins, but with a direct connection with open waters, many large, sessile species were found, including such pioneer invertebrates, like a bryozoan *Fenestrulina rugula* and an ascidian *Molgula pedunculata* as well as some other members of the groups and common sea-urchin *Sterechinus neumayeri* (Sahade et al. 1998; Brown et al. 2004; Bowden 2005; Smale 2008b). In our study, there were no ascidians and bryozoans present. *S. neumayeri* was found only in assemblage C but in very small numbers and was absent in the glacial coves. This may be due to the hydrology and hydrography of Herve Cove and Ecology Glacier lagoon, which are both very sheltered and isolated basins. Moreover, large suspension feeders, which may survive the ice scour events in other sites, are also very sensitive to glacial sedimentation. On the other hand, those results may also be associated with differences in sampling methods: van Veen grab in this study and mostly photographic surveys in the others. However, the distribution patterns of megafaunal, suspension feeding communities are similar to results from this study, with the species richness and diversity increasing with the distance from the source of disturbance and almost complete absence of the large suspension feeders in the shallowest and most disturbed areas (Sahade et al. 1998; Smale 2008b). Similar patterns were also described by Barnes and Brockington (2003) at Adelaide Island with

increase in diversity and biomass along the depth gradient from 3 to 35 m as a pattern related to ice disturbance. In the same area, the number of encrusting species was 50% lower on site with higher ice scour frequency than on less disturbed site (Brown et al. 2004). The complete lack of similar invertebrates in Herve Cove and Ecology Glacier lagoon showed that the chronic disturbance associated with meltwater streams has even greater impact on those animals than the ice scour, which causes rather patchy distribution but not continuous zonation (Brown et al. 2004; Smale 2008b).

Although both investigated coves are more or less isolated from the open waters of Admiralty Bay, the migration of fauna into these basins is possible. Along with the transport of planktonic larvae and bottom migration of motile species, like some crustaceans or polychaetes, there can be at least two other important ways of fauna transport to these sites. Broken, hooked spits and submerged moraines anyway enable the exchange of cove water with open marine waters. It was also observed in the Ecology Glacier lagoon that marine water entering the cove carries large fragments of macroalgae (Rakusa-Suszczewski 1995). Holdfasts of those macroalgae can be an important vector of transport of animals into the cove (Edgar 1987). Polychaetes, like *Tharyx cincinnatus*, *Leitoscoloplos kerguelensis* and *Rhodine intermedia*, were among the most frequent and/or abundant species in the holdfasts of *Himantothallus grandifolius* in Admiralty Bay (Pabis and Sicinski 2010). Another vector could be associated with the transportation of animal carcasses into the lagoon together with the necrophagous invertebrates. In King George Bay, a large number of amphipods were found on a stranded fur seal carcass (Jazdzewska 2009), including species like *Cheirimedon femoratus* and *Hippomedon kergueleni* that were found in both glacial coves. Besides both of those species and *Orchomenella cf. ultima* were very abundant in the shallow sublittoral of Admiralty Bay, especially in the central basin (Jazdzewski et al. 1991, 2001).

Analysis of bottom communities associated with glacial coves shows a clear gradient from the non-disturbed bottom areas to the highly disturbed sites with decrease in species richness and abundance as well as the increasing dominance of mostly motile, highly eurytopic species. This pattern may reflect the possible changes in Antarctic communities associated with the climate change. Similar observations were done in the Arctic (Wlodarska-Kowalczyk and Weslawski 2001). This effect could become more pronounced when climate warming will increase the glacier activity. It may lead to substantial homogenization of shallow bottom habitats and cause larger-scale changes in the richness, diversity and trophic structure of bottom communities in the Arctic as well as in the region of Antarctic Peninsula (Smale and Barnes 2008; Weslawski et al. 2011).

To evaluate properly possible future changes, the baseline knowledge on the bottom fauna associated with sedimentary environments is needed. Particularly small, isolated glacial coves are good sites for studying the influence of sedimentation on benthic fauna. Future studies should be focused on those types of basins in various regions of the Antarctic. Repeated monitoring of sites in several years periods could help to answer further questions concerning the influence of climate change and glacier retreat upon the bottom fauna of the West Antarctic Peninsula region.

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