POLISH POLAR RESEARCH
vol. 26, no. 4, pp. 287–297, 2005

Species diversity of Arctic gravel beach: case study for species poor habitats

Marta RONOWICZ

Instytut Oceanologii, Polska Akademia Nauk, Powstańców Warszawy 55, 81-712 Sopot, Poland
< martigor1@o2.pl>

Abstract: Intertidal zone of four gravel beaches in Hornsund Fjord (West Spitsbergen) were investigated in order to study macrofaunal distribution and diversity in these poor habitats. A total of 12 macrofaunal taxa were found in the collected material. The most frequent and the most abundant taxon was *Lumbricillus* sp. (Oligochaeta). The next most numerous group were juvenile *Gammarus* spp. juv. The fauna included also polychaetes, molluscs and other crustaceans. The diversity measured with Shannon-Weaver index was low and varied from 0 to 1.4. The analysis revealed that there were no statistically important differences in macrofaunal distribution among stations in fjord. However there were significant differences among various tidal mark zones and high patchiness in animals abundance at each station. Also species composition, density and biomass were diversified along the tide level profile.

Key words: Arctic, Spitsbergen, Hornsund Fjord, gravel beach, macrofauna, biodiversity.

Introduction

Littoral or intertidal zone is defined as the area between low and high water marks and constitutes a unique marine environment because of a regular exposure to the air. Strong environmental stress has an important impact on the macrofauna living in this area. Except of all factors which influence organisms in littoral zones all around the world (desiccation, wave energy impact, wide temperature range, salinity fluctuations, competition for space), communities of tidal range in Arctic must additionally deal with a half year lasting night, short period of productivity, ice scouring and very low temperature (Węsławski *et al.* 1991). Nevertheless, investigations of a vast Svalbard area revealed that the Arctic littoral can be fairly rich in many localities. Studies conducted during many expeditions allowed to present an ecological inventory of the littoral and to map the most biologically important intertidal areas on the Svalbard Archipelago (Węsławski *et al.* 1993). Distribution and ecology of particular faunal communities and different taxa within a tidal range were described in many papers during last years (Ambrose and Leinaas 1990; Węsławski *et al.* 1992, 1993; Gruszczyński and Różycki 1994).

Studies of the Arctic littoral have recently started to be very important for various reasons. General warming-up in the Arctic region in last few decades has a strong influence on changes in hydrology with increasing volume of freshwater and glacier-induced sedimentation (Węsławski *et al.* 1992; Holte *et al.* 1996) as well as on macrofaunal distribution (Blacker 1957; Görlich *et al.* 1987). Also expanding oil drilling industry and potential threats of oil spills have resulted in investigations defining vulnerability of Arctic coasts for oil spills (Węsławski *et al.* 1997a).

Despite extensive studies of Svalbard intertidal areas little is known about settlement on gravel beaches. It is not only the case for the Arctic. In general, just few, mostly faunistic studies on gravel substrata exist .

The aim of this study is to describe the spatial patterns of littoral macrofaunal distribution and community structure on the gravel beaches in Hornsund Fjord. Such beaches are the most common and least diverse type of habitat on Svalbard coast (Węsławski *et al.* 1992). Four chosen sites differ in open ocean wave exposure, distance from active glaciers resulting in salinity fluctuations, iceberg scouring frequencies and level of inorganic sedimentation. Moreover the faunal distribution in tide level profile is taken into account.

The basic hypothesis was that the poorest and most stressed of Arctic habitats show uniform pattern of faunal occurrence and diversity. The well recognized zonation of fjord fauna would not be present, and variability among stations should be negligible.

Study area

The 30 km-long Hornsund Fjord is the southernmost fjord on Spitsbergen Island (Svalbard Archipelago, 74–81°N, 10–35°E).

South Spitsbergen is under the influence of the two water masses: the warmer West Spitsbergen Current and colder Sorrkap Current (Swerpel 1985). The coastline of the fjord is dominated by numerous bays surrounded by skjerras. Gravel beaches are among the most common types of habitat occurring in Svalbard coast (Węsławski *et al* 1997a). The tidal zone is about 5 m wide in the investigated area. Tides are regular, semidiurnal, with an amplitude reaching 0.8–1.8 m (Siwecki and Swerpel 1979).

Intertidal zone is covered with ice foot from autumn to late June. Wind often brings growlers and pieces of icebergs to the shore in summer.

Four sites in Hornsund Fjord were chosen because of occurrence of similar habitat (presence of skjerras, wave energy, type of substrate, tidal range) in slightly

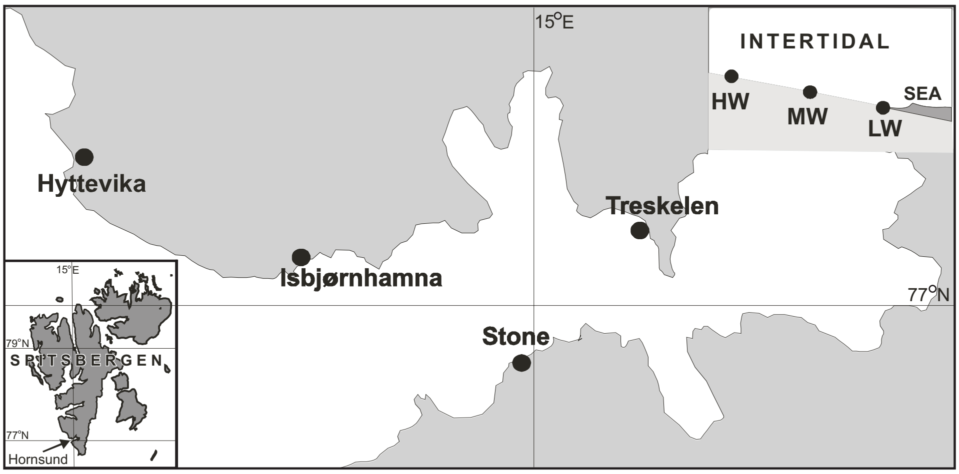

Fig. 1. Sampling stations in Hornsund Fjord and points of profile on the beach.

different location. These are: Hyttevika (situated outside the fjord), Isbjørnhamna, Stone, Treskelen (Fig. 1). Factors, such as: water temperature, salinity, ice presence, concentration of suspended matter, varied between these positions (Table 1).

Table 1

Physical parameters at stations in Hornsund Fjord

Station	Salinity (PSU)	Tempera-ture (°C)	Inorganic suspension (mg/l)	Presence of glacial ice	Grain size (after Wenthworth 1922)
Hyttevika	>34,5	>3	<20	–	Coarse sand – medium gravel 1 μm–8 mm
Stone	>34	1–3	<20	–	Medium – very coarse gravel 8–32 mm
Isbjørnhamna	22–30	>3	30–70	+	Coarse gravel – small boulders 16–128 mm
Treskelen	25–33	1–3	20–50	+	Very coarse gravel – very small boulders 32–64 mm

Material and methods

Material was collected in July 2002 and in July 2003. Samples were taken at four bays: Isbjørnhamna (July, 2002), Stonehengesteinane (= Stone) (July, 2003), Adriabukta-Treskelen (July, 2003) and Hyttevika (July, 2003) (Fig. 1).

Nine samples were collected at each bay, during low tide: three at low water mark zone (LW), three at high water mark (HW), and three in the mid-intertidal zone (MW), except of Isbjørnhamna, where 4 samples were taken at low water mark and 5 at high and mid water mark. 5 cm layer of sediment from a square of 30 × 30 cm were dug out with a spade, sieved on a 0.5 mm mesh size screen and preserved in 4% formaldehyd solution.

The species composition, abundance and biomass (wet formalin weight) were determined in the laboratory. Mollusca were weighed with shells. Planktonic organisms and those not classified as macrofauna were disregarded: *Syllidae* sp. juv., *Proceraea cornuta, Sagitta elegans*, Nematoda, Ostracoda, Copepoda, Harpacticoida, Foraminifera, Acarina, Decapoda larvae. All bryozoans, hydrozoans, ascidians and poriferans specimens were not attached to the substrate but probably pulled out and brougt to the intertidal zone by water masses. They were excluded from the analysis.

The frequency (F – the percentage of samples containing specimens of a given taxon) and the dominance (D – the percentage of particular taxon in the total abundance of macrofauna) were calculated for each species.

Faunal diversity of each sample was calculated using the Shannon-Weaver index (log e). Primer package (Clarke and Warwick 1994) was used to examine the relationship among the sites. Multivariate analysis was carried out on the basis of the Bray-Curtis coefficient calculated from a square-root transformed species abundance data. Ordination (non-metric multidimentional scaling – MDS plot) and classification (dendrogram) using group average linking were performed. One-way and two-way nested ANOSIM was used to test for significant differences among sites and between tide marks.

Results

A total of 12 taxa of macrofauna were identified (Table 2). It is necessary to emphasize that macrofauna was present in each sample.

The mean density of macrofauna in the area was 6649 ind./m^2 with the range from 22 ind./m^2 to 113733 ind./m^2. An oligochaete *Lumbricillus* sp. was the major component of gravel beach assemblage (found in 95% of samples, with a mean density 4896 ind./m^2). The next most numerous group were juveniles of *Gammarus setosus* and/or *Gammarus oceanicus* defined as *Gammarus* spp. juv. (present in 78% of samples with an average density of 1228 ind./m^2) (Table 2). 6 species: *Phyllodoce groenlandica, Harmothoe imbricata, Gammarellus homari* juv., *Ischyrocerus* sp., *Onisimus litoralis*, and *Musculus discors* were found only in less than 5% of samples and made up less than 0.1% of total macrofaunal abundance.

The mean biomass of macrofauna was 31 g w.w./m^2 with the range from 0.0016 g w.w./m^2 to 500 g w.w./m^2. The biomass was dominated by large, adult amphipods – *Gammarus setosus*.

Fauna of Isbjørnhamna was dominated, both in abundance and biomass, by *Lumbricillus* sp. (Figs 2, 3). The most numerous group of macrofauna in Hyttevika

Table 2

Species composition, dominance and frequency of occurrence of particular taxa at studied stations (*Gammarus* spp. juv. are *G. setosus* and/or *G. oceanicus*)

Taxon	Isbjornhamna N = 14		Hyttevika N = 0		Stone N = 9		Treskelen N = 9		LW N = 13		MW N = 14		HW N = 14	
	D%	F%	D%	F%	D%	F%	D%	F%	D%	F%	D%	F%	D%	F%
Bivalvia														
Musculus discors (Linnaeus, 1767)	0.01	7	0.07	11	0	0	0	0	0.05	15	0	0	0	0
Gastropoda														
Margarites helicinus (Phipps, 1774)	0.09	36	0	0	0.05	11	0.04	11	0.07	23	0.52	14	0.033	14
Polychaeta														
Phyllodoce groenlandica Oersted, 1842	0.01	14	0	0	0	0	0	0	0.01	8	0.09	7	0	0
Harmothoe imbricata (Linnaeus, 1767)	0	0	0	0	0.05	11	0	0	0.01	8	0	0	0	0
Spio sp.	0.09	14	0.36	56	1.30	22	8.01	56	2.57	69	1.91	29	0.007	7
Polynoidae larvae	0	0	0	0	0.09	22	33.19	44	8.53	23	3.12	21	0	0
Crustacea														
Gammarus setosus Dementieva, 1931	0	0	7.27	33	0.60	22	20.35	22	9.20	54	0	0	0	0
Gammarus oceanicus Segerstrale, 1947	0	0	3.53	33	0	0	0	0	1.70	15	0.17	7	0	0
Gammarus spp. juv.	2.87	86	37.27	78	85.33	89	31.19	56	52.83	100	7.63	93	0.053	43
Onisimus litoralis Krøyer, 1845	0.01	7	0.02	11	0	0	0	0	0	0	0.09	7	0.007	7
Gammarellus homari (Fabricius, 1779)	0.01	7	0	0	0	0	0	0	0.01	8	0	0	0	0
Ischyrocerus sp.	0.01	7	0	0	0	0	0	0	0	0	0.09	7	0	0
Oligochaeta														
Lumbricillus sp.	96.91	100	51.47	100	12.56	89	7.21	89	25.01	92	86.40	93	99.90	100

were also oligochaetes, but biomass was dominated by *Gammarus setosus* and *Gammarus oceanicus.* The latter was found only in Hyttevika. The similar situation was found in Stone, where oligochaetes dominated in abundance, whereas *Gammarus setosus* – in biomass. In Treskelen Polychaeta together (Polynoidae larvae, *Spio* sp.) made up about 40% of the total abundance. *Gammarus setosus* dominated in biomass (96%).

Mean densities ranged from 2653 ind./m^2 in Stone to 12709 ind./m^2 in Isbjørnhamna. The lowest mean biomass – 7 g w.w./m^2 characterized Isbjørnhamna, the highest value – 66 g w.w./m^2 – Treskelen.

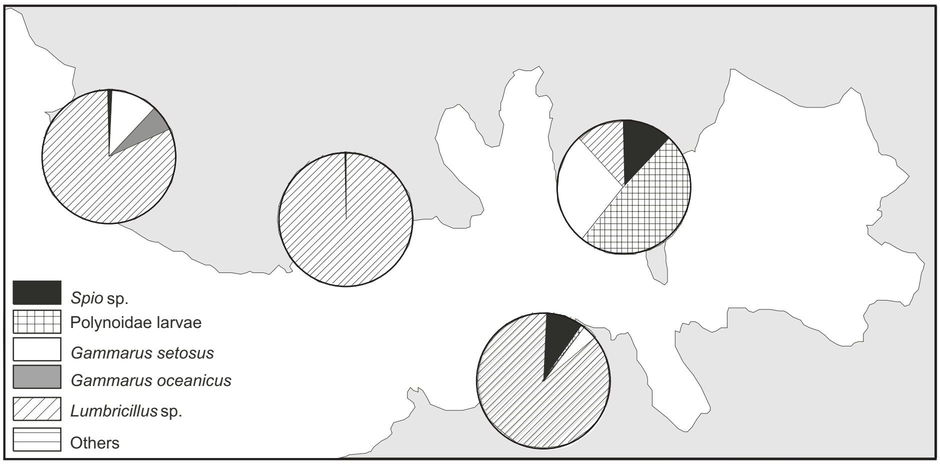

Fig. 2. Percentage of the average abundance of particular taxa in particular stations.

Fig. 3. Percentage of the average biomass of particular taxa in particular stations.

Oligochaetes dominated high and mid-water mark zone both in abundance and biomass. At low water mark zone *Gammarus* spp. juv. was the dominant species in term of abundance and *Gammarus setosus* in term of biomass.

The density and biomass were highly diversified among the points of the profile in the tidal zone. Mean density of macrofauna ranged from 916 ind./m^2 at mid water mark zone to 11894 ind./m^2 at high water mark zone. The absolute range of density was from 33 ind./m^2 in Treskelen at high water mark zone to 113 733 ind./m^2 in Isbjørnhamna also at high water mark zone. Mean macrofauna biomass varied from 1.3 g w.w./m^2 at mid water mark zone to 88 g w.w./m^2 at low water mark zone. The absolute biomass range was from 0.0012 g w.w./m^2 in Treskelen at mid water mark zone to 580 g w.w./m^2 in Treskelen at low water mark zone.

Table 3

Number of samples, number of taxa, mean macrofaunal density and biomass and mean Shannon-Weaver index at studied stations and points of profile in tidal range

Stations	Number of samples	Mean number of taxa (range)	Mean density (ind./m^2) (±SD)	Mean biomass (g w.w./m^2) (±SD)	Mean diversity H' (±SD)
Isbjørnhamna	14	2.78 (2–5)	12709 (±29651)	7.2 (±11.9)	0.36 (±0.38)
Hyttevika	9	3.22 (1–5)	5075 (±6275)	54.5 (±148.7)	0.45 (±0.42)
Stone	9	2.66 (1–6)	2653 (±4640)	14.4 (±29.5)	0.18 (±0.12)
Treskelen	9	2.77 (1–6)	2790 (±7036)	66.2 (±193.2)	0.68 (±0.58)
Tidal zones					
Low water	13	4.15 (2–6)	7173 (±7310)	87.9 (±192.1)	0.64 (±0.41)
Middle water	14	2.85 (2–4)	916 (±782)	1.28 (±1.66)	0.55 (±0.43)
High water	14	1.71 (1–3)	11894 (±29909)	11.2 (±25.4)	0.05 (±0.09)

The diversity measured by Shannon-Weaver index H' varied from 0.0 in Stone, Treskelen and Hyttevika at high water mark zones (where one species was found) to 1.4 in Treskelen at low water mark zone. Station with the highest mean diversity – 0.68 was Treskelen (Table 3). The lowest mean diversity was recorded in Stone – 0.18.

Both cluster analysis and MDS did not reveal any clear pattern of similarity among samples (Fig. 4, 5). Two-way nested ANOSIM showed no significant differences between site groups using tide groups as samples (R = 0.06, ρ = 25%).

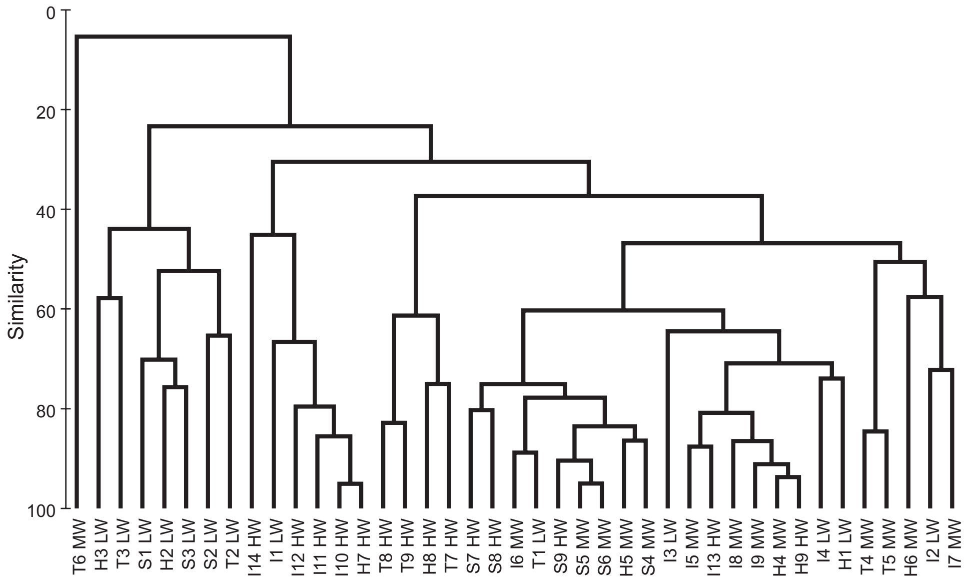

Fig. 4. Dendrogram resulting from cluster analysis of samples: I Isbjørnhamna, H Hyttevika, T Treskelen, S Stone; HW high water, MW mid water, LW low water. Numbers of particular replicate are also indicated.

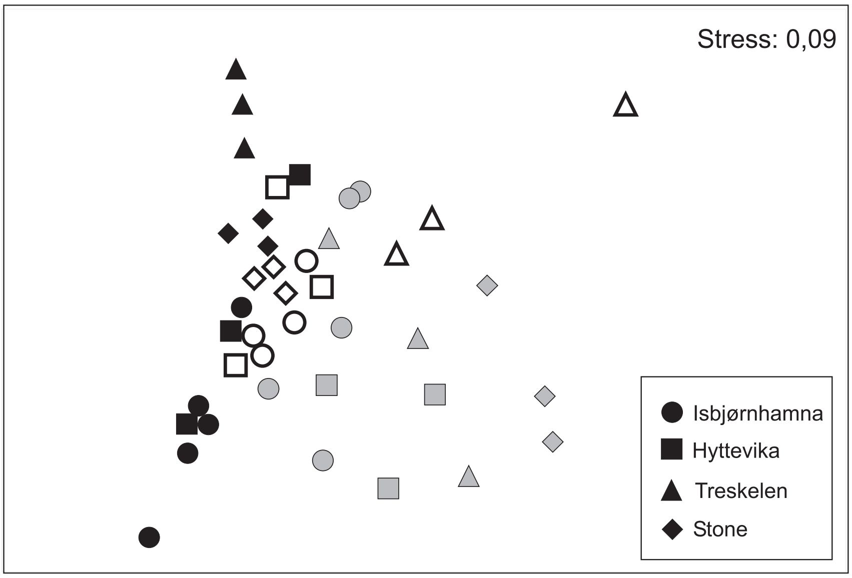

Fig. 5. MDS plot resulting from ordination of samples: Isbjørnhamna, Hyttevika, Treskelen, Stone; black – high water, white – mid water, grey – low water.

Differences tested for macrofaunal distribution at different tidal mark zones (one-way ANOSIM) were important in two cases: low and middle water mark zones ($R = 0.08$, $\rho = 4.9\%$) and low and high water mark zones ($R = 0.1$, $\rho = 2.4\%$). Middle and high water mark zones did not differ significantly ($R = 0.05$, $\rho = 9.7$).

Discussion

The intertidal zone of Svalbard is recognized as very poorly inhabited by macrofaunal organisms (Gulliksen 1979; Różycki 1987; Hansen and Haugen 1989; Włodarska-Kowalczuk *et al.* 1999). The environment of gravel beaches in comparison with other intertidals is especially rough due to the water movements, scouring of ice and pebbles, rolling of rocks, grinding effect of grains (Gauci *et al.* 2005).

The list of species identified in this study (Table 2) is much poorer than the checklist for the intertidal zone presented by other authors. Węsławski *et al.* (1993) noted 37 taxa of macrofauna from Svalbard littoral. However, that research covered larger area and more diversified habitats. On the other hand, Węsławski *et al.* (1990) and Włodarska-Kowalczuk *et al.* (1999) who studied gravel intertidals in Isfjorden (Spitsbergen) did not find any macrofaunal inhabitants.

Lack of attached epifaunal representatives can be explained by the effect of wave action, causing the rolling movements of sand and pebbles, or by the ice-related phenomena. Such physical disturbances were described by Gulliksen (1979) and Kukliński and Barnes (2004).

Six species, *Phyllodoce groenlandica, Harmothoe imbricata, Gammarellus homari* juv., *Ischyrocerus* sp., *Onisimus litoralis* and *Musculus discors,* that were found only in less than 5% of samples and made up less than 0.1% of total macrofaunal abundance, are not typical inhabitants of gravel beach biotopes. They are just occasional visitors and drifters from neighbouring habitats.

Mean density of macrobenthos in the study area is suprisingly high and exceeds densities noted for the Svalbard intertidal by Węsławski *et al.* (1993) and Węsławski *et al.* (1997b). It is due to the high abundance of Oligochaeta and *Gammarus* spp. juv. in collected material. The highest faunal densities occurring in Isbjørnhamna and Hyttevika is linked with the presence of kelps wracks on the beaches. Appearance of washed-up seaweed drastically increases the number of oligochaetes (Rossi and Underwood 2002). These deposit feeders find here a lot of food and a favourable habitat to reproduce and to reach such a high abundance. *Gammarus oceanicus* occured only at one station – Hyttevika, located outside the fjord. This species is described as Atlantic species and its distribution is linked with the range of warm West Spitsbergen Current (Węsławski 1994).

In respect to the species composition, gravel beach assemblage appeared to be uniform in different locations in fjord. Despite the variability of environmental conditions, such as: temperature, salinity, glacier fresh water outflow, turbidity and inorganic sedimentation rate, the assemblage structure of gravel beaches was rather similar with predominance of *Lumbricillus* sp. and *Gammarus* spp. juv. However, slightly different situation occurred at Treskelen, where macrofauna was dominated by polychaete larvae.

A high standard deviation values of indices presented in Table 3 reflect the patchy distribution of gravel beaches macrofauna. This high patchiness, together with rather uniform species composition of fjord beaches differing in physical conditions, indicate that the community dynamics may not be controlled by these physical factors only. More likely it seems that also microhabitats characteristics (food resources, shelter, competition for space) play important role in colonization. The patchiness and low biodiversity level are the main consequences of environmental disturbance (Clarke and Warwick 1994, Włodarska-Kowalczuk *et al.* 1996). Intertidals in Arctic are frozen during winter and intensively scoured by sea ice during the summer season. Under these conditions macrofauna is expected to be removed from tidal zone (Dale *et al*. 1989; Węsławski and Szymelfenig 1999). Each time after such a disturbance organisms must quickly recolonize the most favourable microhabitats.

The average littoral biomass – 60 g w.w./m^2 is low when compared to Bjørnoya sheltered skjerras (2000 w.w./m^2, Węsławski *et al.* 1997b). At the stations where macrofauna is dominated by species of small body sizes, biomass is much lower (Włodarska-Kowalczuk *et al.* 1998). High ratio of oligochaetes to amphipods is accompanied with lower values of biomass. That is a case for Isbjørnhamna and

Stone. Higher values noted in Hyttevika and Treskelen come from the presence of large, adult amphipods.

The low water mark zone is characterized by a higher number of species. The same was observed on sandy beaches by McLachlan and Jaramillo (1995).The mid and high littoral zones are dominated by oligochaetes. This is connected with the belt of kelp wracks that cover mid and high tidal range. There is a general trend that the number of *Gammarus* spp. juv. decreased up the tide level. This pattern of distribution is due to the tidal migrations of mobile crustaceans up and down the shore with the tides (McLachlan and Jaramillo 1995).

Acknowledgements. — I would like to thank Dr. Marek Zajączkowski for providing facilities for the field trip to Hornsund Fjord in 2003 and for his help during the fieldwork. Also I wish to thank Prof. Jan Marcin Węsławski for his valuable comments and advices on the manuscript. I am grateful to Dr. Lech Kotwicki who collected samples from Isbjørnhamna in 2002 and helped me during the laboratory work.

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Received 18 October 2004
Accepted 11 October 2005