Spatial and seasonal changes in the sandy littoral zoobenthos of the Gulf of Gdańsk

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Abstract

The meiobenthos and macrobenthos of the sandy littoral (about 1 m depth) were studied monthly in 1993 at three localities on the Gulf of Gdańsk. The average abundance ranged from 0 to 15 159 indiv. m^{-2} for macrofauna and from 101 to 4193 indiv. 10^{-1} cm^{-2} for meiofauna. The respective average biomass ranged from 0 to 51.5 g m^{-2} and from 0.05 to 2.45 mg 10^{-1} cm^{-2}. The zoobenthos biomass and abundance show two distinct seasonal peaks in May and late September. The macrofauna was dominated by polychaetes (*Nereis diversicolor*), the meiofauna by Nematoda and Oligochaeta. Twenty-two macrobenthos taxa were found in the samples examined, which makes the littoral of the Gulf of Gdańsk highly diverse when compared to the open Baltic coast. The meiobenthos consisted of similar higher taxa known from other localities of the temperate zone.

1. Introduction

The Gulf of Gdańsk has often been the focus of Polish marine biological and hydrological research (see the reviews in Majewski, 1990; Korzeniewski, 1993). The shores of the Gulf of Gdańsk are among the most ideal recreational areas on the Polish coast. On the other hand, there is much industry (construction sites, harbours, fishery), and the heaviest discharge of pollutants (the river Vistula and the Tri-City urban complex) occurs here. Therefore, the HELCOM recommendations (1993), which emphasised the necessity for coastal studies in the Baltic, named the Gulf of Gdańsk among selected key areas (Andrulewicz, 1996). In spite of growing interest in the ecology of benthic fauna inhabiting sandy shores, quantitative studies have always been limited to the deeper regions of the Gulf of Gdańsk. As a result, our present knowledge of the macrobenthos of littoral sediments has remained restricted; indeed, where the interstitial meiobenthos is concerned, hardly any work at all has been done. The present study addresses the following questions, which, according to the published literature, have not been answered yet:

- What fauna inhabits the sandy littoral sediment within 10 m of the shoreline in the Gulf of Gdańsk?
- What is the abundance and biomass of the sandy littoral fauna in the Gulf of Gdańsk?
- What kind of seasonal changes is the littoral fauna subject to?
- How much do the individual localities within the Gulf of Gdańsk differ with respect to littoral zoobenthos?

2. Material and methods

The study was undertaken in the littoral zone (Hedgpeth, 1957) of the Gulf of Gdańsk at three localities: Jurata, Osłonino and Mikoszewo (Fig. 1). These localities were selected to represent the variety of sandy littoral habitats occurring within the Gulf of Gdańsk. The zoobenthos was sampled at these locations monthly from January to December 1993. Concurrently, water temperature and salinity were monitored and samples were collected for sediment analysis.

At each sampling locality, a sampling station consisting of three points A, B, C forming an equilateral triangle with 1 m sides was set down. It was situated approximately 10 m from the shoreline, so the water depth at the station was usually 0.8–1.0 m (Fig. 2).

A hand-operated sampler was used for collecting the zoobenthos and sediment. For the macrobenthos, a sample core of sediment 10 cm long and 10 cm in diameter was taken; for the meiobenthos, the sediment core was 10 cm long and 2.25 cm in diameter. Each sample was preserved in 10% formalin.

The sediment cores obtained from the centre of the A B C triangles were sliced horizontally into 3 layers – 0.0–1.0 cm, 1.1–3.0 cm

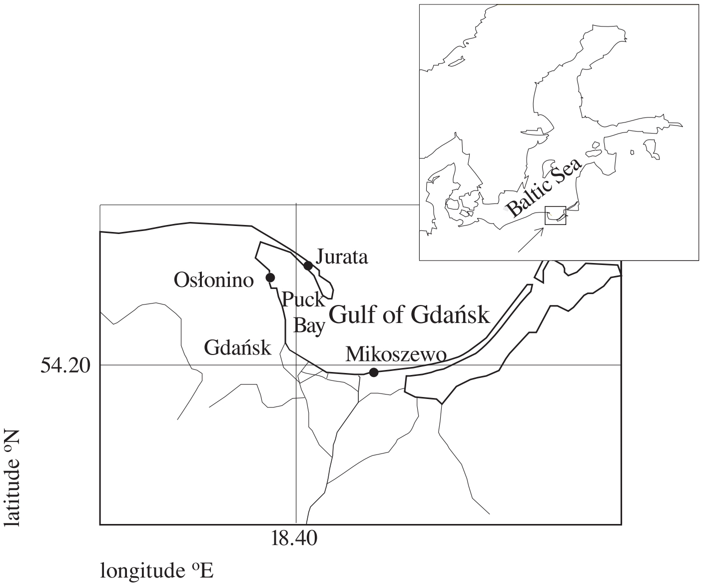

Fig. 1. The study area

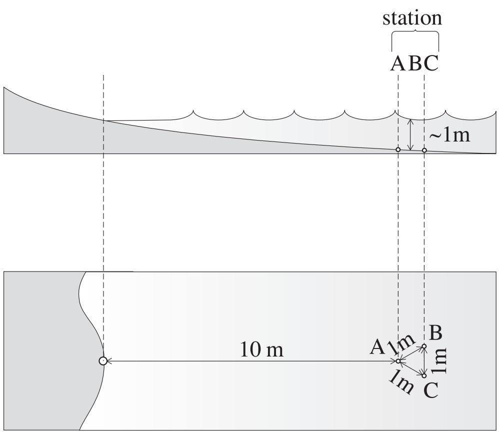

Fig. 2. The sampling strategy

and 3.1–5.0 cm – and kept frozen until the sediment analysis. Grain-size analyses of the sediment fractions were done by sieving, and the sediment type was determined using the standard Wentworth grain-size grade scale for sediments (Davis, 1972). The organic matter content in the sediment was measured by drying, combusting, and calculating differences in weights.

The macrobenthos sample was strained through a metal sieve of 0.5 mm mesh. Wherever possible, animals were identified to species level; in the case of juvenile specimens without the species-specific features, identification was limited to higher taxonomic levels. Three months after collection, the formalin wet weight of the macrobenthos was established (Mills *et al.*, 1982). Mollusca were weighed with shells. Later on, the dry weight was calculated, using the formula presented by Rumohr *et al.* (1987). The dry weight (d.w.) was used as a measure of biomass in this study. Abundance and biomass of macrobenthos were calculated per 1 m^2.

The meiobenthos analysis was done in accordance with the method described by Elmgren and Radziejewska (1989). The identification was restricted to the major taxa. The volumetric method and conversion factors were used in order to determine the dry weight of the meiobenthos (Feller and Warwick, 1988). Its abundance and biomass was calculated per 10 cm^2.

Because of the low number of taxa encountered in the samples analysed, as well as their uneven rank, no diversity or community measures were introduced in the present study. A similar opinion was expressed by Giere (1993), who assumed that meiofauna patchiness dominated any possible 'community' pattern.

3. Study area

The sampling locality of Jurata was situated within the borders of the outer Puck Bay. It is sheltered by the Hel Peninsula from NW–NE winds and is surrounded by extensive shallow sand beds acting as wave breakers, so it is situated in the most stable locality. Although situated in the inner part of Puck Bay, Osłonino is exposed to frequent NW winds; it too has a relatively narrow sandy sediment zone, with rich phytal beds in the adjacent sublittoral. Hence, waves not only supply a considerable amount of detritus, as is clear from the changes in the amount of organic matter, but also frequently stir up and sort the sediment. Mikoszewo is situated on a relatively exposed coast, close to the large estuary of the river Vistula, where the salinity changes recorded suggest an unstable environment. The neighbouring shallow sublittoral is composed of barren sandy beds.

The highest and lowest water temperatures at individual localities were typical of this area (Fig. 3).

Over the year the salinity in the water column did not differ significantly at Osłonino or Jurata (6.1–7.5 and 5.7–7.3 PSU respectively), but at Mikoszewo it did vary considerably, ranging between 0.54–7.7 PSU (Fig. 3).

Five different types of sediment were recorded at the sampling localities, the predominant type being medium-grained sand (Fig. 4). At Jurata, throughout the year, the sediment was homogeneous and consisted exclusively of such sand. At Mikoszewo the situation was similar, except in February, when the sediment was made up of fine sand. At Osłonino the sediment exhibited a pronounced variability between layers as well as during

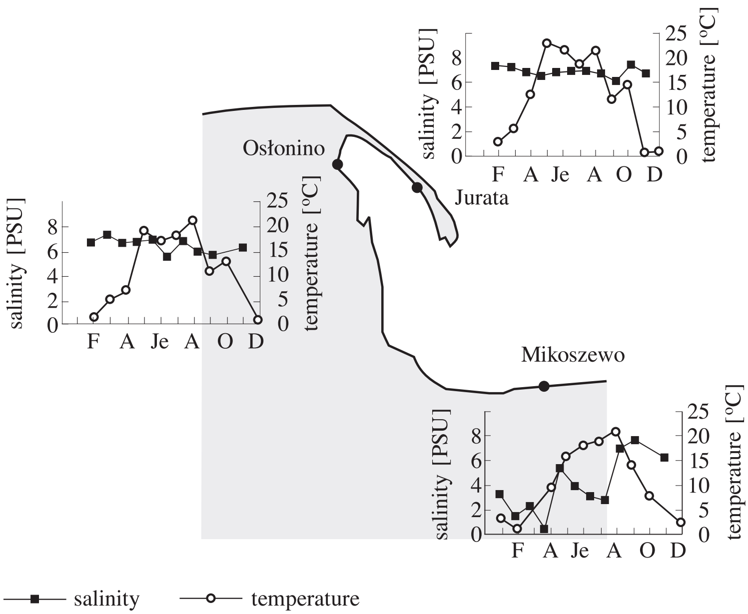

Fig. 3. Seasonal changes in water salinity and temperature

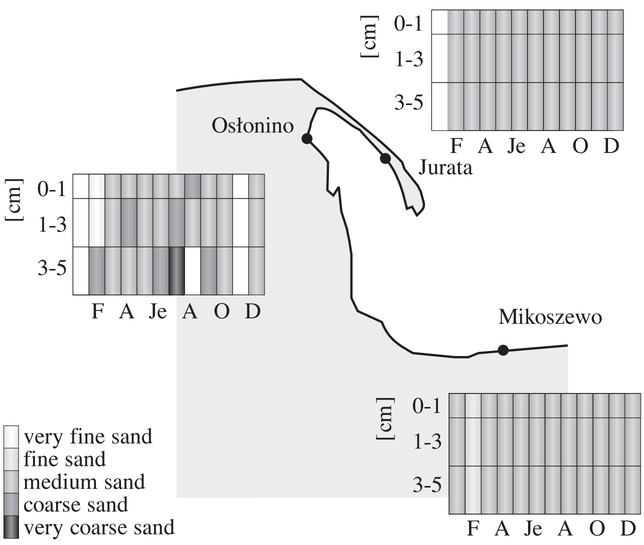

Fig. 4. Seasonal changes in sediment types at the stations

the course of the year. While the most common sediment type here was medium-grained sand, the whole range of grain sizes from very fine to very coarse was present (Fig. 4).

No significant variations in the sediment organic matter content were observed at Jurata or Mikoszewo. It varied there within the respective ranges of 0.11–0.57% and 0.14–0.43%. Over the first half of the year at Osłonino, the sediment organic matter content differed clearly between the layers, ranging from 0.22 to 2.8%. The superficial layer (0.0–1.0 cm) always had the lowest and the second layer (1.1–3.0 cm) the highest organic matter content. During the second half of the year at Osłonino, the organic matter content in the sediment hardly differed between the layers, but did vary between months, in the range 0.45–2.09% (Fig. 5).

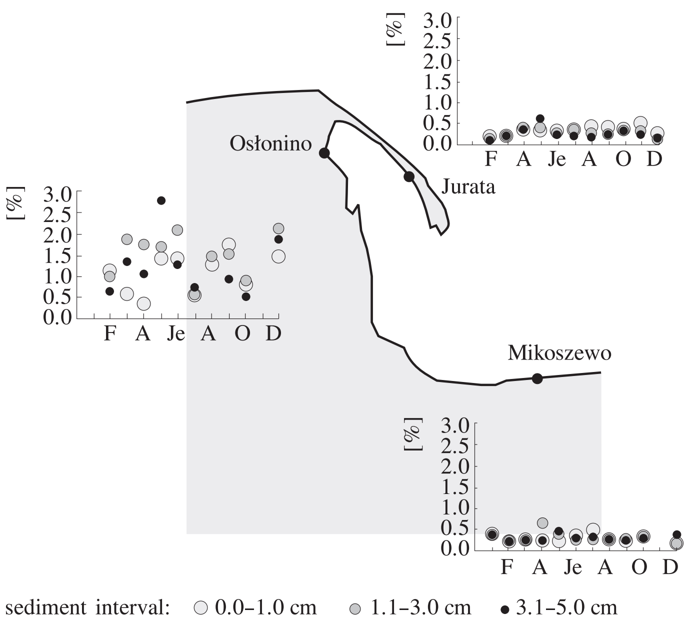

Fig. 5. Seasonal changes in the organic matter content in the sediment at the stations

4. Results

4.1. Taxonomic composition

A total of 22 macrobenthos taxa were recorded at the sampling stations during the year (Tab. 1). As regards the number of macrobenthos taxa at individual stations, the most diversified locality was Osłonino (16 taxa), followed by Jurata (15 taxa) and Mikoszewo (only 5 taxa). Only three taxa – *Nereis diversicolor*, Oligochaeta and Chironomidae larvae – were common to all stations. The first two taxa determined the overall biomass and abundance at Jurata and Osłonino (Fig. 6).

Table 1. Proportions of selected taxa in major macrobenthos groups at the stations

Class	Taxa	Jurata		Osłonino		Mikoszewo	
		A	B	A	B	A	B
Polychaeta	*Nereis diversicolor*	0.99	0.99	1.00	1.00	1.00	1.00
	Marenzelleria viridis	0.01	0.01				
Oligochaeta		1.00	1.00	1.00	1.00	1.00	1.00
Isopoda	*Idotea balthica*			0.01	0.11		
	Idotea chelipes			0.01	0.01		
	Cyathura carinata	0.50	0.63	0.24	0.25		
	Sphaeroma hookeri	0.50	0.37	0.74	0.63		
Gastropoda	*Hydrobia* spp.	1.00	1.00	0.99	0.98		
	Theodoxus fluviatilis			0.01	0.02		
Bivalvia	*Cerastoderma glaucum*			0.61	0.27		
	Mya arenaria	0.50	0.57	0.36	0.48		
	Macoma balthica	0.50	0.43	0.03	0.25		
Amphipoda	*Corophium volutator*	1.00	1.00	0.90	0.70		
	Gammarus duebeni					1.00	1.00
	Gammarus spp. juveniles			0.10	0.30		
Insecta	Chironomidae larvae	0.50	0.28	0.83	0.58	1.00	1.00
	Insecta adult	0.50	0.72	0.17	0.42		
Turbellaria		1.00	1.00				
Nematoda		1.00	1.00			1.00	1.00
Hirudinea		1.00	1.00				
Bryozoa				1.00	1.00		

A – abundance, B – biomass

Table 2. Proportions of Harpacticoida and Cyclopoida within Copepoda at the stations

Class		Jurata		Osłonino		Mikoszewo	
		A	B	A	B	A	B
Copepoda	Cyclopoida	0.46	0.60	0.44	0.53		
	Harpacticoida	0.54	0.40	0.56	0.47	1.00	1.00

A – abundance, B – biomass

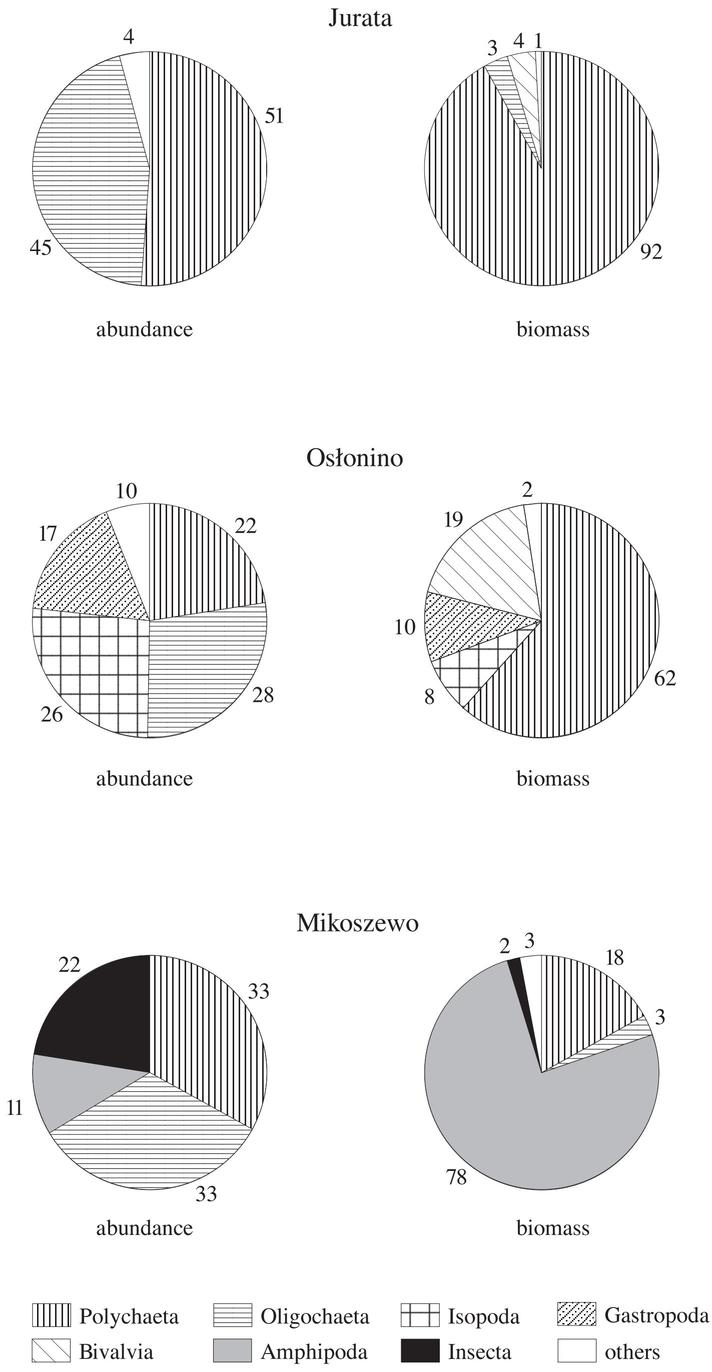

Fig. 6. Percentage of major taxa in the total macrobenthos abundance and biomass at the stations

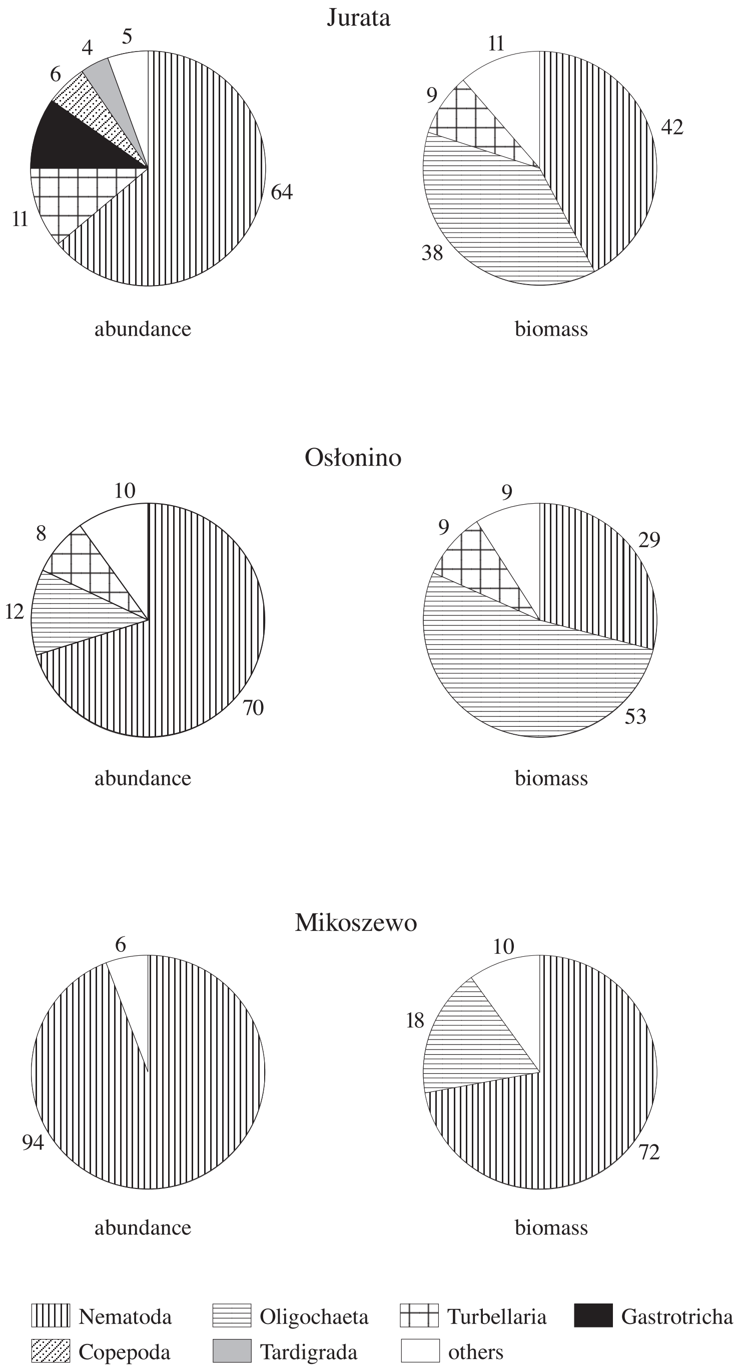

Fig. 7. Percentage of major taxa in the total meiobenthos abundance and biomass at the stations

The three stations had the following meiobenthos taxa in common: Nematoda, Oligochaeta, Turbellaria, Copepoda, Gastrotricha, Tardigrada and Ostracoda. Halacaridae and temporary meiobenthos (Chironomidae larvae and juveniles of Polychaeta, Gastropoda, Bivalvia, Amphipoda) were also found. The proportions of two Copepoda representatives, Harpacticoida and Cyclopoida, varied between stations (Tab. 2). At every station, the largest portion of the annual total meiofauna abundance was made up of Nematoda, but the bulk of the meiofauna biomass was due to Nematoda and Oligochaeta (Fig. 7).

4.2. Seasonal changes in the occurrence of taxa

In general, seasonal changes in the percentages of individual taxa in the total macrobenthos abundance and biomass at particular stations exhibited a pronounced variability during the course of the year (Fig. 8). At Jurata there were practically only two taxa dominating the abundance – Polychaeta (*N. diversicolor*) and Oligochaeta. At Osłonino, more taxa contributed significant proportions to the macrobenthos abundance, but no seasonal pattern was maintained as regards the abundance domination. In addition to Polychaeta, Bivalvia and Gastropoda, Isopoda contributed a significant fraction to the biomass, particularly in winter and autumn. At Mikoszewo, the macrobenthos was extremely sparse, so that reliable conclusions cannot be drawn (Tabs. 3 and 4).

The meiofauna abundance and biomass at Jurata was dominated by Nematoda for most of the year (Fig. 9). Oligochaeta dominated the total meiobenthos biomass at Jurata in winter and in summer. At Osłonino, the seasonal fluctuations in the meiofauna abundance reflected the fluctuations in the occurrence of Nematoda, which predominated during the entire sampling season. A pronounced pattern was recorded in the seasonal changes of the taxa dominating the biomass. In the warmer months, Oligochaeta were predominant in the meiofauna biomass, but in the colder months Nematoda took over the lead (Fig. 9). At Mikoszewo, Nematoda was the only taxon predominating with respect to both abundance and biomass throughout the year. At Jurata, in addition to Nematoda, Turbellaria, Gastrotricha and Copepoda also contributed in significant numbers to the meiofauna abundance and biomass. At Osłonino, apart from the absolute numerical dominant taxon (Nematoda), Oligochaeta, Turbellaria and Copepoda also made up discernible fractions of the total meiofauna, while Turbellaria were only of importance for the biomass (Tabs. 5 and 6).

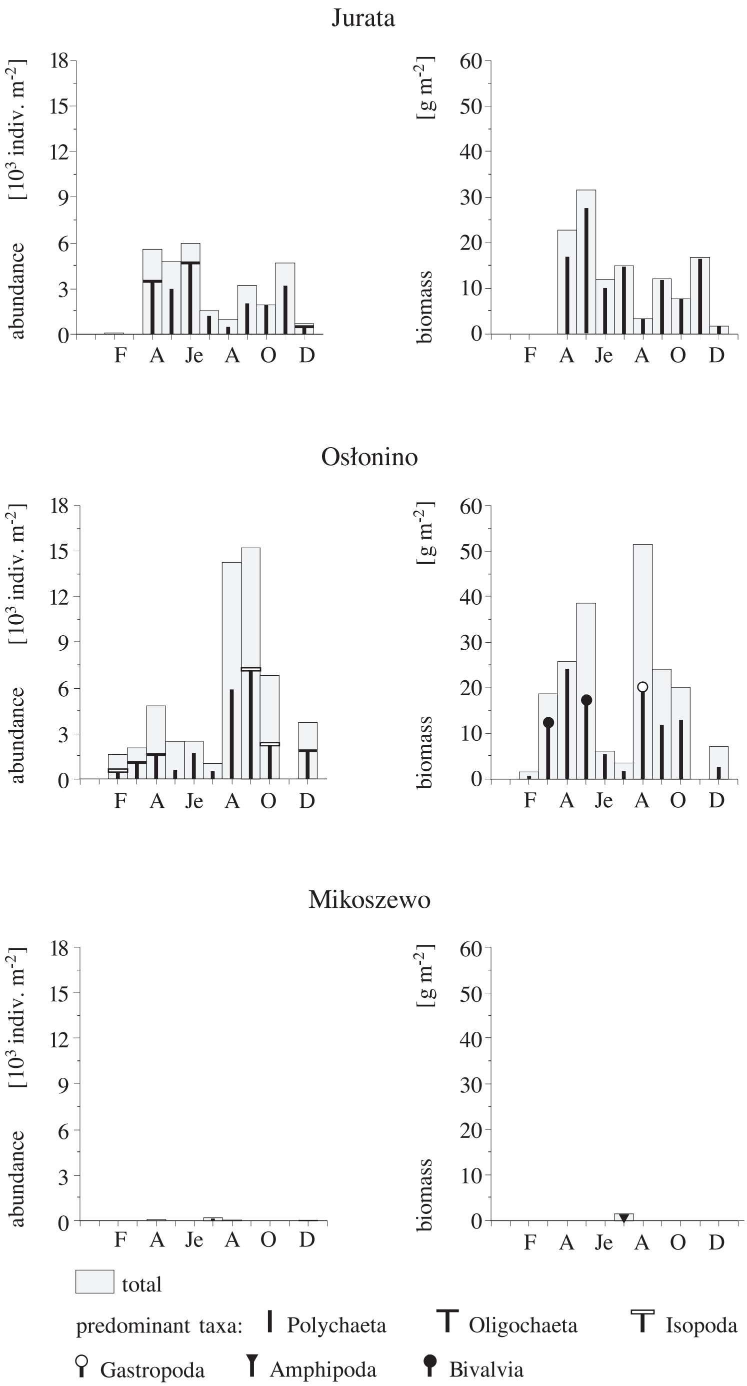

Fig. 8. Seasonal changes in the abundance and biomass of macrobenthos and predominant taxa at the stations

Table 3. Abundance [indiv. m^{-2}] of major macrobenthos taxa at the stations

Month	Total	Polychaeta	Oligochaeta	Isopoda	Gastropoda	Bivalvia	Amphipoda	Insecta	Others
				Jurata					
January									
February	42.5	0	0	0	42.5	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	5562.6	2080.7	3439.5	0	0	42.5	0	0	0
May	4755.8	2887.5	1613.6	0	0	42.5	0	84.9	127.4
June	5944.9	1189.0	4670.9	42.5	0	0	0	42.5	0
July	1528.7	1146.5	339.7	0	42.5	0	0	0	0
August	934.2	467.1	382.2	42.5	0	0	42.5	0	0
September	3184.7	1995.8	976.6	84.9	0	0	127.4	0	0
October	1910.8	1868.4	0	0	0	0	42.5	0	0
November	4670.9	3142.3	1146.5	84.9	42.5	0	0	42.5	212.3
December	679.4	212.3	467.1	0	0	0	0	0	0
Mean	2655.9	1362.7	1185.1	23.2	11.6	7.7	19.3	15.4	30.9
SD	2249.4	1121.6	1534.6	34.8	19.8	17.2	39.7	28.6	71.3
				Osłonino					
January									
February	1571.1	127.4	509.6	636.9	297.2	0	0	0	0
March	2038.2	382.2	1104.0	169.9	297.2	42.5	0	42.5	0
April	4798.3	1401.3	1613.6	806.8	891.7	0	84.9	0	0
May	2420.4	594.5	127.4	594.5	891.7	169.9	42.5	0	0
June	2462.8	1698.5	424.6	212.3	42.5	0	42.5	42.5	0
July	1019.1	594.5	169.9	0	127.4	42.5	0	84.9	0
August	14225.1	2165.6	5859.9	2208.1	3099.8	849.3	42.5	0	0
September	15159.2	2420.4	3312.1	7261.1	1656.1	169.9	254.8	84.9	0
October	6794.1	1783.4	0	2377.9	1528.7	0	1061.6	0	42.5
November									
December	3694.3	1061.6	1868.4	84.9	467.1	42.5	169.9	0	0
Mean	5418.3	1222.9	1498.9	1435.2	929.9	131.6	169.9	25.5	4.2
SD	5174.7	790.1	1845.1	2214.8	945.4	260.6	324.0	35.8	13.4
				Mikoszewo					
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	84.9	0	0	0	0	0	0	84.9	0
May	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0
July	212.3	127.4	42.5	0	0	0	42.5	0	0
August	42.5	0	42.5	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0
November									
December	42.5	0	42.5	0	0	0	0	0	0
Mean	38.2	12.7	12.7	0	0	0	4.2	8.5	0
SD	67.7	40.3	20.5				13.4	26.9	0

Table 4. Biomass [g m^{-2}] of major macrobenthos taxa at the stations

Month	Total	Polychaeta	Oligochaeta	Isopoda	Gastropoda	Bivalvia	Amphipoda	Insecta	Others
					Jurata				
January									
February	0.300	0	0	0	0.030	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	22.679	16.655	0.896	0	0	5.128	0	0	0
May	31.476	27.193	0.378	0	0	3.833	0	0.042	0.030
June	11.832	9.857	1.866	0.077	0	0	0	0.033	0
July	14.831	14.500	0.227	0	0.104	0	0	0	0
August	3.264	3.120	0.073	0.017	0	0	0.054	0	0
September	11.900	11.556	0.168	0.100	0	0	0.076	0	0
October	7.598	7.571	0	0	0	0	0.027	0	0
November	16.794	16.272	0.233	0.067	0.039	0	0	0.013	0.170
December	1.645	1.566	0.079	0	0	0	0	0	0
Mean	11.10	9.85	0.36	0.03	0.02	0.82	0.01	0.01	0.02
SD	10.03	8.52	0.56	0.04	0.03	1.84	0.03	0.02	0.05
					Osłonino				
January									
February	1.474	0.539	0.146	0.461	0.329	0	0	0	0
March	18.737	4.409	0.179	0.071	0.455	13.582	0	0.041	0
April	25.792	24.062	0.178	0.449	1.078	0	0.025	0	0
May	38.617	18.387	0.028	0.390	1.405	18.392	0.015	0	0
June	6.096	5.417	0.126	0.398	0.116	0	0.027	0.013	0
July	3.361	1.751	0.037	0	0.378	1.182	0	0.013	0
August	51.489	10.303	0.644	1.754	21.211	17.520	0.057	0	0
September	24.121	12.008	0.459	5.358	5.255	0.848	0.160	0.033	0
October	20.096	12.860	0	2.583	4.028	0	0.626	0	0
November									
December	7.078	2.616	0.316	0.059	1.482	2.329	0.275	0	0
Mean	19.69	9.24	0.21	1.15	3.57	5.39	0.12	0.01	0
SD	16.23	7.74	0.21	1.70	6.43	7.80	0.20	0.02	0
					Mikoszewo				
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	0.023	0	0	0	0	0	0	0.023	0
May	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0
July	1.367	0.231	0.009	0	0	0	1.127	0	0
August	0.019	0	0.019	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0
November									
December	0.009	0	0.009	0	0	0	0	0	0
Mean	0.13	0.02	0.003	0	0	0	0.10	0.002	0
SD	0.41	0.07	0.01				0.34	0.01	

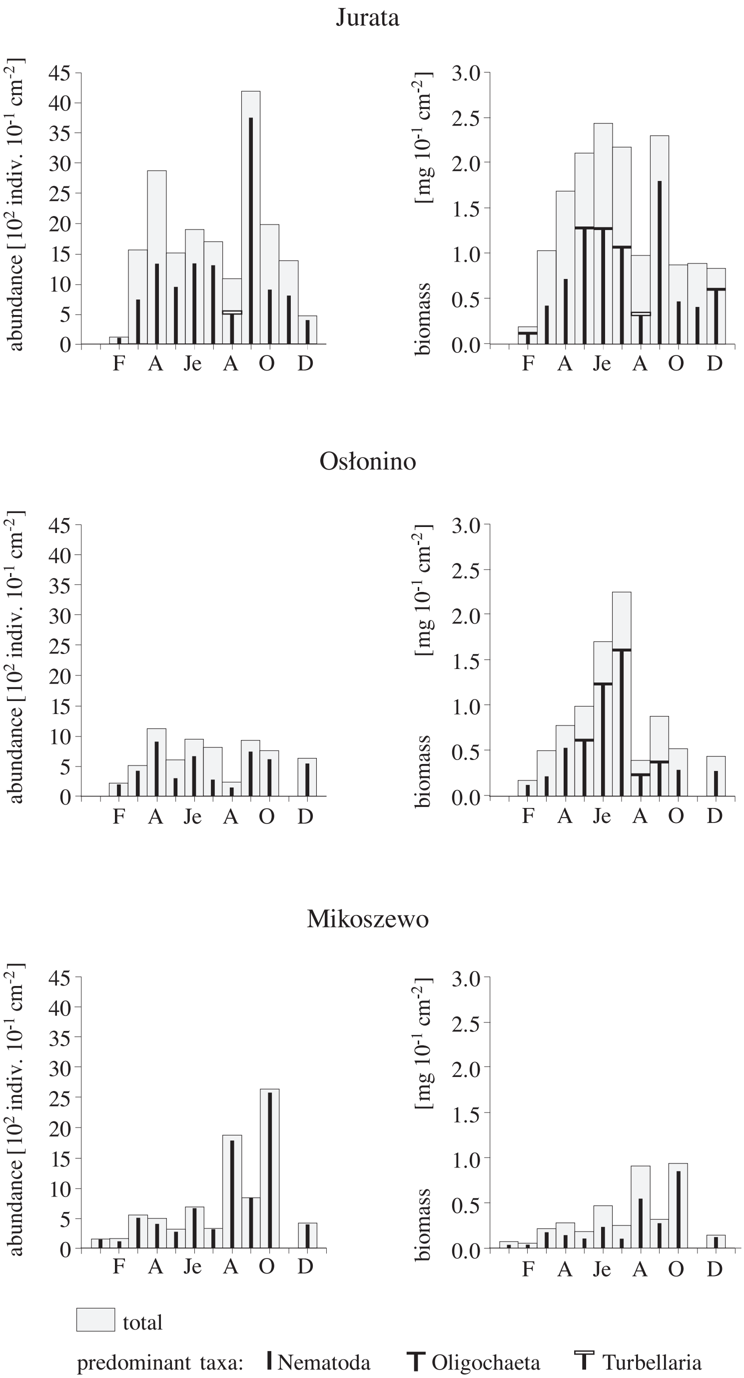

Fig. 9. Seasonal changes in the abundance and biomass of meiobenthos and predominant taxa at the stations

Table 5. Abundance [indiv. 10^{-1} cm^{-2}] of major meiobenthos taxa at the stations

Month	Total	Nematoda	Oligochaeta	Turbellaria	Gastrotricha	Copepoda	Tardigrada	Ostracoda	Bivalvia	Others
					Jurata					
January										
February	101.5	88.9	6.7	5.9	0	0	0	0	0	0
March	1560.1	723.9	18.5	462.2	346.4	5.0	0.8	3.4	0	0
April	2872.0	1321.1	17.6	393.4	728.9	76.3	30.2	296.1	0	8.4
May	1500.6	935.2	151.0	31.9	197.1	66.3	37.7	58.7	0	22.6
June	1890.6	1323.6	75.5	32.7	1.7	393.4	0	15.9	0	47.8
July	1681.8	1292.6	59.6	107.4	0	127.5	0	93.9	0	0.8
August	1077.8	482.3	17.6	540.2	0	28.5	0	5.0	0	4.2
September	4193.9	3751.9	26.8	192.9	114.9	58.7	26.8	5.9	0	15.9
October	1970.3	890.8	7.5	203.0	41.1	229.0	597.2	0.8	0	0.8
November	1373.9	785.1	16.8	60.4	400.9	71.3	36.9	1.7	0	0.8
December	458.0	383.3	37.7	15.1	0	1.7	19.3	0	0	0.8
Mean	1698.2	1089.0	39.6	185.9	166.5	96.2	68.1	43.8	0	9.3
SD	1111.5	969.3	42.8	193.9	236.9	118.9	176.2	89.0		14.8
					Osłonino					
January										
February	212.2	188.7	4.2	7.5	0	10.1	0	0	0	1.7
March	510.0	416.9	31.0	22.6	2.5	21.0	0.8	14.3	0	0.8
April	1116.4	906.7	14.3	57.9	94.8	23.5	0.8	16.8	0	1.7
May	598.9	324.6	125.0	46.1	0.8	31.9	2.5	43.6	0	24.3
June	942.8	668.5	224.8	6.7	0.8	27.7	0	10.9	0	4.2
July	809.4	179.5	270.9	213.9	0	110.7	0	14.3	2.5	17.6
August	227.3	138.4	37.7	43.6	0	1.7	0	4.2	0	1.7
September	924.3	740.7	60.4	59.6	2.5	33.6	0	11.7	0	15.9
October	751.6	613.2	8.4	65.4	7.5	36.1	0	8.4	0	12.6
November										
December	625.7	547.7	13.4	11.7	21.0	21.8	0	5.0	0	5.0
Mean	671.9	472.5	78.9	53.5	13.0	31.8	0.4	12.9	0.3	8.6
SD	298.6	264.0	96.3	60.6	29.4	29.7	0.8	12.0	0.8	8.4
					Mikoszewo					
January	151.8	144.3	0	5.9	0	0	0	0	0	1.7
February	159.4	107.4	0	1.7	0	12.6	0	0	0	37.7
March	548.6	497.4	0.8	0.8	0	49.5	0	0	0	0
April	490.7	396.7	4.2	48.6	0.8	3.4	0	36.9	0	0
May	317.9	267.6	3.4	7.5	0.8	0.8	0	37.7	0	0
June	681.9	655.1	24.3	0.8	0	1.7	0	0	0	0
July	328.0	307.8	15.9	1.7	0	0	0	0	1.7	0.8
August	1857.9	1774.9	37.7	4.2	0	32.7	0	0	6.7	1.7
September	833.8	826.2	4.2	0.8	0.8	0.8	0	0.8	0	0
October	2626.2	2569.2	3.4	52.8	0	0.8	0	0	0	0
November										
December	411.0	389.2	1.7	13.4	0	5.0	1.7	0	0	0
Mean	764.3	721.4	8.7	12.6	0.2	9.8	0.2	6.9	0.8	3.8
SD	777.9	767.6	12.2	19.3	0.4	16.3	0.5	15.1	2.0	11.3

Table 6. Biomass [mg 10^{-1} cm^{-2}] of major meiobenthos taxa at the stations

Month	Total	Nematoda	Oligochaeta	Turbellaria	Gastrotricha	Copepoda	Tardigrada	Ostracoda	Bivalvia	Others
					Jurata					
January										
February	0.191	0.049	0.123	0.020	0	0	0	0	0	0
March	1.035	0.425	0.245	0.268	0.090	0.002	0	0.005	0	0
April	1.696	0.720	0.215	0.277	0.189	0.031	0.003	0.260	0	0.001
May	2.117	0.615	1.286	0.053	0.047	0.044	0.004	0.066	0	0.002
June	2.445	0.806	1.279	0.026	0	0.307	0	0.021	0	0.005
July	2.186	0.812	1.075	0.088	0	0.101	0	0.108	0	0.002
August	0.985	0.270	0.322	0.351	0	0.018	0	0.006	0	0.018
September	2.309	1.801	0.357	0.077	0.030	0.028	0.003	0.007	0	0.006
October	0.878	0.473	0.076	0.142	0.011	0.110	0.067	0.001	0	0
November	0.891	0.411	0.281	0.063	0.097	0.029	0.004	0.001	0	0.004
December	0.840	0.213	0.608	0.012	0	0.001	0.002	0	0	0.004
Mean	1.42	0.60	0.53	0.13	0.04	0.06	0.01	0.04	0	0.004
SD	0.76	0.47	0.46	0.12	0.06	0.09	0.02	0.08		0.01
					Osłonino					
January										
February	0.167	0.121	0.027	0.012	0	0.006	0	0	0	0
March	0.499	0.219	0.193	0.039	0.001	0.015	0	0.025	0	0.009
April	0.776	0.529	0.085	0.083	0.027	0.014	0	0.026	0	0.011
May	0.990	0.185	0.620	0.057	0	0.026	0	0.063	0	0.040
June	1.701	0.408	1.237	0.012	0	0.024	0	0.020	0	0
July	2.250	0.094	1.609	0.322	0	0.094	0	0.022	0.029	0.079
August	0.389	0.071	0.2380	0.062	0	0.001	0	0.008	0	0.008
September	0.878	0.317	0.378	0.084	0.001	0.018	0	0.020	0	0.060
October	0.519	0.287	0.055	0.095	0.002	0.024	0	0.012	0	0.044
November										
December	0.434	0.277	0.087	0.013	0.006	0.016	0	0.009	0	0.025
Mean	0.86	0.25	0.45	0.08	0.004	0.02	0	0.02	0.003	0.03
SD	0.65	0.14	0.55	0.09	0.01	0.03		0.02	0.01	0.03
					Mikoszewo					
January	0.067	0.038	0	0.012	0	0	0	0	0	0.018
February	0.050	0.039	0	0.001	0	0.006	0	0	0	0.004
March	0.204	0.175	0.006	0.001	0	0.022	0	0	0	0
April	0.265	0.142	0.031	0.059	0	0.001	0	0.031	0	0
May	0.174	0.105	0.023	0.018	0	0	0	0.028	0	0
June	0.445	0.238	0.207	0	0	0.001	0	0	0	0
July	0.238	0.104	0.097	0.008	0	0	0	0	0.021	0.009
August	0.863	0.545	0.230	0.001	0	0.015	0	0	0.072	0
September	0.304	0.274	0.021	0.008	0	0	0	0.001	0	0
October	0.889	0.847	0.023	0.019	0	0	0	0	0	0
November										
December	0.136	0.121	0.008	0.005	0	0.002	0	0	0	0
Mean	0.33	0.24	0.06	0.01	0	0.004	0	0.01	0.01	0.003
SD	0.29	0.25	0.08	0.02	0	0.01		0.01	0.02	0.01

4.3. Seasonal changes in abundance and biomass

The annual mean total macrobenthos abundance and biomass differed between stations: 2656 indiv. m^{-2} and 11.09 g m^{-2} for Jurata, 5418 indiv. m^{-2} and 19.68 g m^{-2} for Osłonino and 38 indiv. m^{-2} and 0.13 g m^{-2} for Mikoszewo (Tabs. 3 and 4). Seasonal variations in the total macrobenthos abundance and biomass underwent similar changes at Jurata and Osłonino, whereas at Mikoszewo the macrobenthos was impoverished and no clear seasonal pattern could be established (Fig. 8). During spring (April–June) the macrofauna was more abundant at Jurata (5563 indiv. m^{-2}) than at Osłonino (4798 indiv. m^{-2}). In late summer (August–September) the situation changed and the macrofauna was much more abundant at Osłonino (15 159 indiv. m^{-2}) than at Jurata (3185 indiv. m^{-2}). At both sampling localities the macrofauna was less numerous during winter and in early summer. The biomass of the macrofauna at Jurata and Osłonino increased dramatically from winter values of 0.3 and 1.5 g m^{-2} to spring values of 31.5 and 38.6 g m^{-2} respectively. During early summer at both localities there was a very clear decrease in biomass. From this point on, the courses taken by the seasonal biomass changes at Jurata and Osłonino differed: at Jurata the macrofauna biomass increased steadily before peaking at 16.8 g m^{-2} in November. At Osłonino the biomass of the macrofauna reached its maximum of 51.5 g m^{-2} already in August, after which it fell into a steady decline (Fig. 8).

The respective annual mean total meiobenthos abundance and biomass at the stations differed very clearly: 1699 indiv. 10^{-1} cm^{-2} and 1.42 mg 10^{-1} cm^{-2} at Jurata, 672 indiv. 10^{-1} cm^{-2} and 0.86 mg 10^{-1} cm^{-2} at Osłonino and 764 indiv. 10^{-1} cm^{-2} and 0.33 mg 10^{-1} cm^{-2} at Mikoszewo (Tabs. 5 and 6). At Jurata and Osłonino the total abundance increased from a winter low to a spring peak, and fell before rising again in autumn. At Mikoszewo, the meiofauna abundance increased at a steady rate from low winter values of 152 indiv. 10^{-1} cm^{-2} to an autumn peak of 2626 indiv. 10^{-1} cm^{-2}. The seasonal biomass changes exhibited a slightly different pattern (Fig. 9).

5. Discussion

5.1. The taxonomic composition of zoobenthos in the sandy littoral

The basic meiofaunal composition is typical of most littoral communities and the dominance of Nematoda in the intertidal is well known (Weiser, 1959; Jansson, 1967; Kurian, 1974). The remainder of the meiofauna varies from one area to another but Harpacticoida are usually well represented, particularly on sandy beaches (McIntyre, 1969; Jansson, 1971). Turbellaria, Oligochaeta and Gastrotricha are found on most beaches but numerical relationships remain variable (Gray and Reiger, 1971; Feder and Paul, 1980; Orren *et al.*, 1981). The dominance of Nematoda in the meiofauna abundance in the present study is much the same as that reported earlier for the Gulf of Gdańsk (Miłosek, 1989; Szymelfenig, 1990; Drgas, 1993; Jankowska, 1996). The high number of Nematoda may also suggest a polluted environment, since the Nematoda:Copepoda ratio has been used with success as an indicator of environmental quality (Heip, 1980; Raffaelli and Mason, 1981). Non-polluted, coarse sandy shores as on the open Baltic coast (Haque *et al.*, 1996) and at Bjornoya (Szymelfenig *et al.*, 1995) are dominated by Oligochaeta and Turbellaria. Certain taxa are restricted to particular sediment types, like Gastrotricha and Tardigrada, which typically absent from muddy substrates (Brown and McLachlan, 1990). The taxonomic composition of the macrobenthos in the present study corresponds closely with the results obtained by other authors in the littoral of the Gulf of Gdańsk where Polychaeta (mainly *N. diversicolor*) followed by Oligochaeta dominated the abundance (Kotwicki, 1995). Species not found in the present study but reported by other authors in the shallow coastal zone of the same area were Polychaeta (*Pygospio elegans*, *Streblospio shrubsoli* and *Fabricia sabella*), Crustacea (*Asellus aquaticus*, *Bathyporeia pilosa*), Gastropoda (*Lymnaea peregra*, *Potamopyrgus jenkinsi*), Bivalvia (*Dreissena polymorpha*) (Tab. 7). On the other hand, some taxa noted in this study but unreported by other authors in the sandy littoral included crustaceans (*Gammarus duebeni*, *Balanus improvisus*), macroscopic Turbellaria, Nematoda, Hirudinea, and Bryozoa (Tab. 7). However, their occurrence is of low numerical importance. The presence or absence of these taxa is very probably related to salinity fluctuations (Żmudziński, 1990), sediment properties (Żmudziński and Ostrowski, 1990), season (Żmudziński, 1990), biological cycles (Wołowicz, 1977; Dye and Furstenberg, 1978) and perhaps eutrophication and a number of anthropogenic and climatic factors (Piesik and Świerczyński, 1996). The differences between the fauna found at these stations and that from the neighbouring open Baltic coast are striking: the relatively high number of macrobenthic taxa (22 in the Gulf versus 7 in open coast) and the absence from the Gulf of Gdańsk of the most typical inhabitants of the Baltic sands (*Talitrus saltator*, *Eurydice pulchra*, *Bathyporeia pilosa*) (Tab. 7). Their occurrence in the Gulf of Gdańsk was reported in early studies (review in Jażdżewski and Konopacka, 1995) but both the present work and a recent extensive study by Kotwicki (1995) have confirmed the absence of those species from the Gulf of Gdańsk littoral.

Table 7. Checklist of macrobenthos found on the Polish coast (sandy sediment, between depths 0 and 2 m)

Class	Coastal zone of the Gulf of Gdańsk	Polish open littoral coasts
	Taxa/species	
Polychaeta	*Pygospio elegans* [1,2,4]	*Pygospio elegans* [4]
	Streblospio shrubsoli [1,2]	*Nereis diversicolor* [4]
	Fabricia sabella [1]	
	Nereis diversicolor [1,2,4,*]	
	Marenzelleria viridis [2,4,*]	
Oligochaeta [1,2,4,*]	Oligochaeta [1,2,4,*]	
Crustacea	*Balanus improvisus* [1,*]	*Sphaeroma hookeri* [5]
	Heterotanais oerstedi [1]	*Eurydice pulchra* [1,5]
	Cyathura carinata [1,2,*]	*Bathyporeia pilosa* [1,5]
	Idotea chelipes [1,2,*]	*Talitrus saltator* [7]
	Idotea balthica [2,*]	*Crangon crangon* [1]
	Sphaeroma hookeri [1,2,3,*]	*Palaemon adspersus* [4]
	Jaera spp. [1]	
	Asellus aquaticus [2,6]	
	Eurydice pulchra [1]	
	Bathyporeia pilosa [1,2,3,4]	
	Leptocheirus pilosus [1]	
	Melita palmata [1]	
	Gammarus duebeni [*]	
	Gammarus salinus [1,2]	
	Talitrus saltator [7]	
	Talorchestia deshayesii [7]	
	Corophium volutator [1,2,4,*]	
	Corophium multisetosum [7,8,9]	
	Crangon crangon [7]	
Gastropoda	*Hydrobia* spp. [1,2,4,*]	*Hydrobia* spp. [4]
	Lymnaea peregra [1,2]	
	Theodoxus fluviatilis [1,2,4,*]	
	Potamopyrgus jenkinsi [2]	
Bivalvia	*Cerastoderma glaucum* [1,2,*]	*Mytilus trossulus* [4]
	Mytilus trossulus [1,2,*]	
	Macoma balthica [1,2,*]	
	Mya arenaria [2,*]	
	Dreissena polymorpha [2]	
Insecta	Chironomidae larvae [1,2]	
	Insecta adult [1,*]	
Turbellaria [1,4,*]	Turbellaria [1,4,*]	
Nematoda [*]	Nematoda [*]	
Hirudinea [1,2,*]	Hirudinea [1,2,*]	
Bryozoa [1,4,*]	Bryozoa [1,4,*]	

1 – Żmudziński (1996), 2 – Kotwicki (1995), 3 – Jażdżewski (1962), 4 – Żmudziński and Andrulewicz (1996), 5 – Haque *et al.* (1996), 6 – Jażdżewski (1965), 7 – Jażdżewski and Konopacka (1995), 8 – Janta (1995), 9 – Wenne and Wiktor (1982), * present study

A newcomer to Polish coastal waters – *Marenzelleria viridis* – recently reported from the Gulf of Gdańsk (Żmudziński *et al.*, 1996), was present in our material only in a single sample from Jurata.

5.2. Littoral zoobenthos abundance and biomass in the Baltic Sea

Studies detailing the abundance of the meiobenthos in different parts of the Baltic Sea yielded various results. Densities noted for the Baltic Sea

Table 8. Meiobenthos abundance and biomass in the Baltic Sea

References	Location	Abundance [indiv. 10^{-1} cm^{-2}]	Biomass
Szymelfenig (1990)	coastal zone of the Gulf of Gdańsk, 5–40 m	754–3500	
Miłosek (1989)	Inner Puck Bay, 2–4 m	419–3758	
Kotwicki *et al.* (1993)	Puck Bay, 0.5–1 m	43–3468	
Jankowska (1996)	littoral Puck Bay, 0.5–1 m	1524–10069	
Jończyk and Radziejewska (1984)	beach near Świnoujście, 0–0.75 m	330–2340	
Haque *et al.* (1996)	littoral of Polish Baltic coasts, 0–0.5 m	38–760	0.86–34.9*
Arlt (1973)	near-shore waters of the Greifswalder Bodden, 0.5 m	150–840	
Elmgren (1976)	shallow soft and sandy bottoms between depths, 0.1 and 0.7 m	2000	
Jansson (1968)	Swedish sandy beaches, 0.2 m	1500	
present study	littoral sediments of the Gulf of Gdańsk, 1 m	101–4193	0.05–2.45**

*[mg 10^{-1} cm^{-2} d.w.], **[mg 10^{-1} cm^{-2}]

littoral ranged from 38 to 10 000 indiv. 10^{-1} cm^{-2} (Tab. 8). The lowest numbers were observed in the sandy littoral of the open Polish Baltic coast (Haque *et al.*, 1996). The highest values were noted at eutrophic sites close to sewage and effluent outfalls (Jankowska, 1996). The sublittoral of the Gulf of Gdańsk displayed more average values, 754–3500 indiv. 10^{-1} cm^{-2} (Szymelfenig, 1990). The present study shows a high annual mean meiobenthos abundance (670 to 1698 indiv. 10^{-1} cm^{-2}), which fits in the upper range of values recorded on the Baltic sandy littoral (Tab. 8). Since the abundance but not the biomass of the meiofauna in our samples lay in the upper range of the values reported in the literature, it is likely that the meiofauna in the Gulf of Gdańsk littoral consists of smaller individuals than in the sublittoral. The littoral macrobenthos biomass is as variable as the density cited above, ranging from 0 to 370 g m^{-2} w.w. (Tab. 9). Showing a mean annual macrofauna density in the sandy littoral between 38 and 5418 indiv. m^{-2} and a biomass from 0.13 to 19.7 g m^{-2} d.w., the present results are within the top ranges reported for Baltic sandy substrata.

Table 9. Macrobenthos abundance and biomass in the Baltic Sea littoral

References	Location	Abundance [indiv. m^{-2}]	Biomass [g m^{-2} w.w.]
Żmudziński and Ostrowski (1982)	Baltic littoral sands, 0–2 m	4–3000	0.5–3.60
Kotwicki (1995)	littoral of the Gulf of Gdańsk, 0.5–1 m	85–16700	0.6–370
Haque *et al.* (1996)	Polish sandy shores, 0–0.5 m	0–987	0–3.19
present study	littoral sediments of the Gulf of Gdańsk, 1 m	0–15159	0–51.5*

*[g m^{-2} d.w.]

5.3. Seasonal changes in the zoobenthos of littoral sediments

It seems that the picture of seasonal variability in the zoobenthos of this study is typical of temperate zones (Arlt and Holtfreter, 1975; Coull and Vernberg, 1975; Coull, 1985; Widbom, 1988; Szymelfenig, 1990). Intertidal and shallow sublittoral meiofauna communities generally show a distinct seasonality, with maximum numbers in summer and early autumn and minima occurring in winter in temperate regions (Arlt, 1973; Arlt and Holtfreter, 1975). The present results confirm the occurrence of two seasonal peaks in meiofauna abundance (spring and autumn), unlike the reports from the deeper sublittoral of the Gulf of Gdańsk, where detailed studies showed no seasonality in the biomass of either meiofauna (Szymelfenig, 1990; Drgas, 1993) or macrofauna (Wenne and Wiktor, 1982). The seasonal changes occurring in the littoral meiofauna populations may be caused by a number of factors. Among them are the seasonal fluctuations in environmental parameters such as oxygen, temperature and salinity; these have been documented (Cooper *et al.*, 1970; Tietjen and Lee, 1972; Dye *et al.*, 1978). Physiological adaptations in response to environmental pressures, such as changes in growth rate and fecundity, are also responsible (Dye, 1978).

The Gulf of Gdańsk littoral is exposed to extreme seasonal variations in temperature, not comparable to the ranges reported for the neighbouring sublittoral (Witek, 1995). This is most probably one of the reasons behind the seasonality of the littoral benthos, but food availability should also be considered. Production of Baltic coastal algae usually peaks three times: in spring, summer and autumn. No information is available on microphytobenthos production from the Baltic sandy littoral, but its periodicity is probably the same as that of phytoplankton production. A study of a sewage-impacted locality in the Gulf of Gdańsk littoral supports this statement (Geringer d'Oedenberg and Wołowicz, 1996). Both the microphytobenthos (rich in the sandy littoral examined, prof. A. Witkowski, pers. comm.) and the supply of sedimented organic matter from the water column and sublittoral may stimulate the seasonality of littoral fauna growth. However, a detailed study on the Gironde mudflats has shown that the meiobenthos is not food-limited in temperate waters: it is salinity that is responsible for most of the seasonal variability there (Santos *et al.*, 1996).

5.4. Causes of littoral benthos variability

Littoral macro- and meiofaunal abundance shows substantial variabilities among different geographical regions and even within the same area. The lowest values are generally recorded on the beaches near the ends of the physical or chemical gradients (Brown and McLachlan, 1990) as well as in the deep sea (Coull, 1988). The highest values are known from intermediate beaches, where there is an optimum and reasonable balance between organic input and oxygenation. The distribution and diversity of both macro- and meiofauna of sandy beaches are largely determined by wave action, sediment grain-size and organic input (Brown and McLachlan, 1990). The differences between the stations examined are caused primarily by physical factors.

In the case of the localities analysed in the present work, interspecific competition and predation are unlikely to be of importance. Another important factor might be pollution, known to affect local zoobenthos in the Gulf of Gdańsk (Kotwicki *et al.*, 1993; Jankowska, 1996). A study of the littoral macrofauna from 10 stations in the Gulf of Gdańsk (Kotwicki, 1995) shows that the stations examined in the present work are typical of the Gulf in terms of macrofauna taxonomic composition, abundance and biomass.

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