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THE STRUCTURE OF MACROZOOBENTHOS ASSEMBLAGES IN THE AREA OF SEWAGE-TREATMENT PLANT IN JURATA - JASTARNIA (THE PUCK BAY COASTAL ZONE)

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Abstract: Single study on horizontal distribution of macrozoobenthos in the sandy bottom of Jastarnia and Jurata coastal zone was conducted in summer 2004. 15 sampling sites in Jurata were divided into 4 radii every 100 m and 4 sampling sites were located near the harbor in Jastarnia. 18 species and 3 groups represented benthic invertebrates in the studied area. They reached the density of $\overline{x}$ = 1840 indiv.$\cdot m^{-2}$ and wet mass of $\overline{x}$ = 121.8 $g_{ww}\cdot m^{-2}$ near Jurata and near Jastarnia $\overline{x}$ = 638 indiv.$\cdot m^{-2}$ and $\overline{x}$ = 376.6 $g_{ww}\cdot m^{-2}$, respectively. The most abundant species were *Hediste diversicolor*, *Cerastoderma glaucum* and *Hydrobia ulvae*. As for the biodiversity calculated with the Shannon index, it reached the highest values at sampling sites the most distant from the shore in Jurata. Species composition as well as qualitative and quantitative structure of benthic fauna in the studied area indicated unsatisfactory environmental conditions and low value of the area as a feeding ground for fish.

INTRODUCTION

The Puck Bay is a specific part of the Baltic Sea, which peculiarity results from its geographical location and hydrological conditions [16]. The Bay is divided by a sandy, submerged bank, ranging from the headland near village Rewa towards Kuźnica on the Hel Peninsula and is called Rybitwia Mielizna [9]. The western, separated fragment of the Puck Bay (120 km^2) is a shallow-water lagoon known as the internal Puck Bay [8] or the Puck Lagoon [4]. Its biological, physical and chemical conditions are influenced by the rivers (Reda, Gizdepka and Płutnica) rather than by marine waters [9, 10]. In turn, the eastern part of the Bay, called the external Puck Bay, is deeper and directly connected to the Gulf of Gdańsk [1]. As a result, a higher resistance to anthropogenic influence is observed in this part of the Puck Bay. Therefore, a sewage-treatment plant has been located on the Hel Peninsula, at the border between the internal and external Puck Bay. Its role is to collect sewage from the peninsula the amount of which is considerably high during summer. As a result, deterioration in water quality has particularly influenced benthic organisms – a widely studied fauna of the southern Baltic Sea – mostly due to their scare migration [3, 12, 13, 21, 25]. Structural changes of zoobenthos and decrease in the number of stenotopic species indicate the acceleration process of the Puck Bay eutrophication [22]. The most disturbing changes have taken place in the shallow zone around the Hel Peninsula (up to 10 m depth), where molluscs and polychaetes – resistant to contamination – have substituted crustaceans. One of the factors, resulting in an increase of water fertility, can be the post-treatment waters discharged from the sewage-treatment plant directly to the bay. Recently, in order to minimize negative effects, a 1630 m long pipeline has been built, which pipes the waters away to the deeper zones of the reservoir. However, the ecological changes caused by the former practice have not been thoroughly studied so far [19]. Long-term investigations of the sewage-treatment plant influence on benthos in Swarzewo (the Puck Lagoon) [6, 23] suggest, that in the case of the Hel Peninsula negative effects can also be considerable.

The aim of this study was to determine the qualitative and quantitative structure of macrozoobenthos in the shallow zone of the Puck Bay near the Jurata – Jastarnia sewage-treatment plant within the EU Water Framework directive, particularly its part concerning estuary research.

MATERIALS AND METHODS

The sampling material for this study was collected in summer 2004 in the coastal zone near Jurata (15 sampling sites) and near the water lane at the entrance to the harbor in Jastarnia (Fig. 1).

The sampling sites near the sewage-treatment plant were located in 4 radii every 100 m. Samples were taken using the Petersen scoop bottom sampling device (area of 0.225 m^2) 2–3 times at each site. The collected material was next sifted through a benthos sieve of 1 mm mesh size and then preserved in the 4% formalin solution. In each sample the following parameters were determined: species composition; abundance of the consecutive taxa; formalin mass (wet mass) after removal of water on a filter paper, measured on a laboratory scales (WPT 60) exact to 0.01 g. Molluscs were weighted jointly with shells. The results were related to the area of 1 m^2.

Biocenotic indexes of structural relations in benthic macrofauna (domination – D, frequency – Fr) were used in the successive analysis. Domination index was calculated both in case of density (D) and biomass (D_m). The most abundant of the species with the highest biomass in a given assemblage were divided according to the common classification [5]. In order to determine biodiversity, the Shannon index (H') was used.

Statistically the agglomeration analysis with Euclidian distances was performed using Statistica 5.1 G software [17]. In order to assess significance of the differences between average values, the Cochran and Cox test was used (for $\alpha = 0.05$), because of a small size of the data set and non-homogeneity of variances. The lack of differences between the compared objects ($C < C_\alpha$) indicated that the samples originated from the same general population and any differences observed were random.

The Cochran and Cox test: $C = \dfrac{\bar{x}_1 - \bar{x}_2}{\sqrt{E^2_{\bar{x}_1} + E^2_{\bar{x}_2}}}$ E = error of standard deviation

$$C_\alpha = \frac{E^2_{\bar{x}_1} \cdot t_{1_\alpha} + E^2_{\bar{x}_2} \cdot t_{2_\alpha}}{E^2_{\bar{x}_1} + E^2_{\bar{x}_2}}$$ $\alpha = 0.05$ (from t-student distribution)

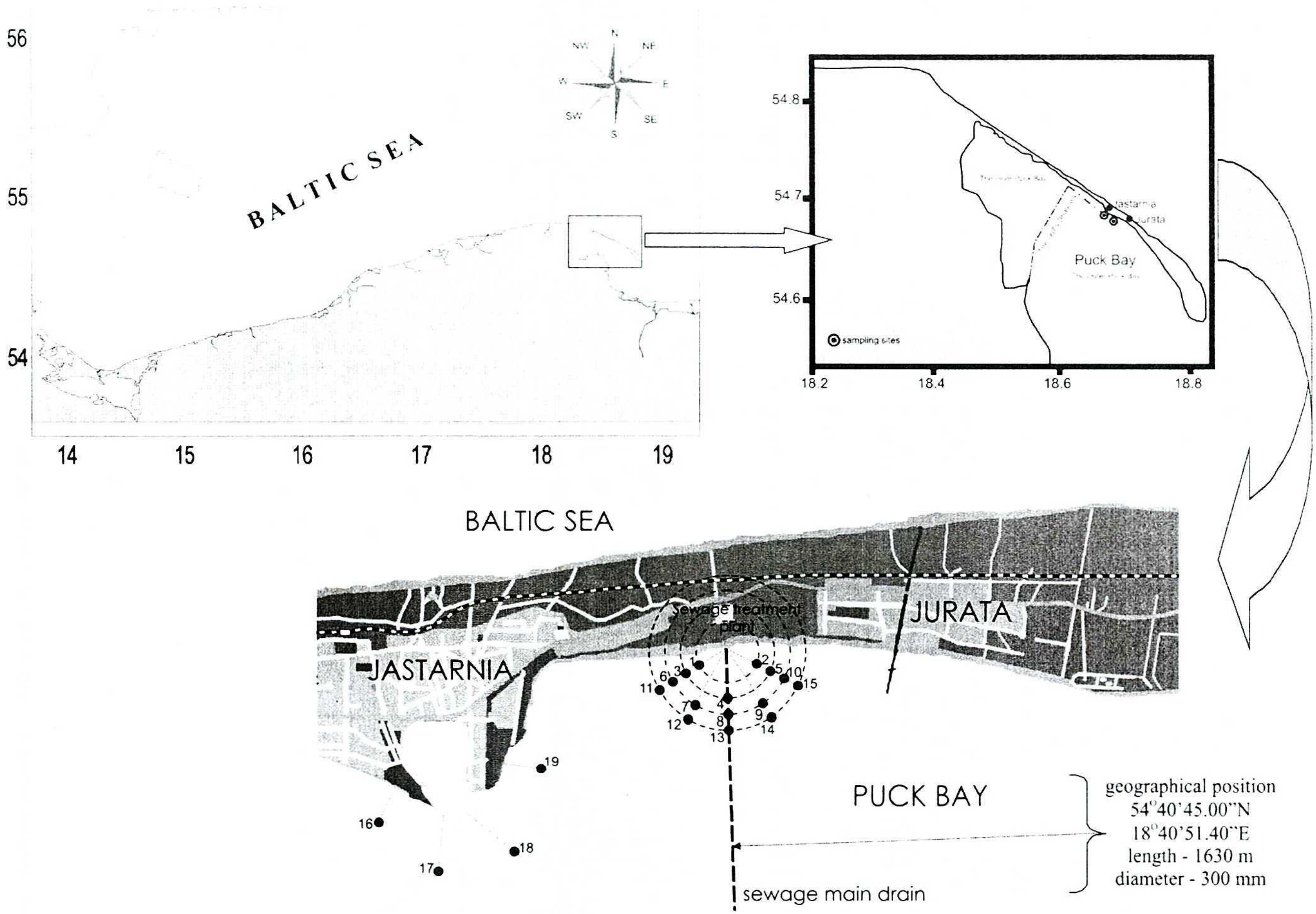

Fig. 1. Localization of sampling sites

RESULTS

Performed sampling revealed presence of 18 species and representatives of 4 groups, which were not divided into species (Tab. 1). Those groups included Prostoma, Jaera and also partly *Gammarus* representatives. Their species classification was found impossible due to their small size.

Table 1. Qualitative composition and domination structure of macrozoobenthos density (D) and biomass (D_m) in the studied area of the Puck Bay

Species	Jurata radius [m]								Jastarnia distance [m]			
	I 100		II 200		III 300		IV 400		100		300	
	D	D_m	D	D_m	D	D_m	D	D_m	D	D_m	D	D_m
NEMERTINEA												
Prostota sp.	--	--	--	--								
POLYCHAETA												
Hediste diversicolor (Müller)	++	+	++	-	+	--	-	--	-	--	--	--
Pygospio elegans Claparĕde											--	--
CRUSTACEA												
Cyathura carinata (Kröyer)					--	--	--	--				
Idotea chelipes (Pallas)					--	--					--	--
Idotea balthica (Pallas)			--	--								
Jaera sp.							--	--				
Gammarus tigrinus Reid					--	--					--	--
Gammarus salinus Spooner											--	--
Gammarus zaddachi Sexton											--	--
Gammarus sp.	--	--			+	--	--	--	+	--	+	--
Leptocheirus pilosus Zaddach											--	--
Corophium volutator (Pallas)					--	--					--	--
GASTROPODA												
Theodoxus fluviatilis (L.)					--	--						
Hydrobia ulvae Pendant			+	--	--	--	++	--				
Hydrobia ventrosa Montagu	--	--	--	--	--	--			+	--		
BIVALVIA												
Mytilus edulis trossulus Gould					--	--	--				--	--
Cerastoderma glaucum (Poiret)	--	+	--	++	--	++	--	++	-	++	--	+
Macoma balthica (L.)	--	-	--	--	--	--			--	+	--	++
Macoma calcarea Chemnitz			--	--								
Mya arenaria L.	--	-	--	--			--	+				

+++ – eudominant, ++ – dominant, + – subdominant, - – recedent, -- – subrecedent

At the sampling sites located close to Jurata (radius I) only 5–7 macrozoobenthos species were observed, with predominant *Hediste diversicolor* (Fr = 100%). The remaining species were recedent or subrecedent (Tab. 1). In turn, 5 taxa with predominant *Hy-*

drobia ventrosa (Fr = 75%) were distinguished in the vicinity of harbor in Jastarnia. The calculated biodiversity index ranged from 1.04 to 1.91 in Jurata while in Jastarnia it reached 2.04 (Tab. 2). An average macrozoobenthos density in the zone 100 m off the shore in the sewage-treatment plant was measured at 1328 indiv.$\cdot m^{-2}$, which was 2.3 times higher than near the harbor in Jastarnia (Tab. 3). The highest fraction in macrozoobenthos density structure fell to Polychaeta near the shore in Jurata and to Gastropoda in Jastarnia (Fig. 2). As for the wet mass, Bivalvia predominated at the sampling sites close to the sewage-treatment plant, reaching ¾ of the total macrozoobenthos mass in that zone (Fig. 3). Near the harbor in Jastarnia clearly prevailed Gastropoda (95% of the total benthofauna mass). On average, wet mass values in the first radius were measured at 80.26 $g_{ww} \cdot m^{-2}$ in Jurata, while in Jastarnia –58.50 $g_{ww} \cdot m^{-2}$ (Tab. 3). Higher density and wet mass values were observed at one sampling site, west of the sewage-treatment plant.

Table 2. Species and biocenotic biodiversity (Shannon index, H') in the studied area of the Puck Bay

Radius [m]	Jurata						Jastarnia	
	Mean no. of taxa	H'	West off the sewage-treatment plant		East off the sewage-treatment plant		Mean no. of taxa	H'
			No. of taxa	H'	Number of taxa	H'		
I – 100	6	1.48	7	1.91	5	1.04	5	2.04
II – 200	7	1.60	5	1.28	9	2.26	–	–
III – 300	7	2.06	6	1.54	8	2.30	7	2.00
IV – 400	5	1.30	4	1.05	5	1.68	–	–

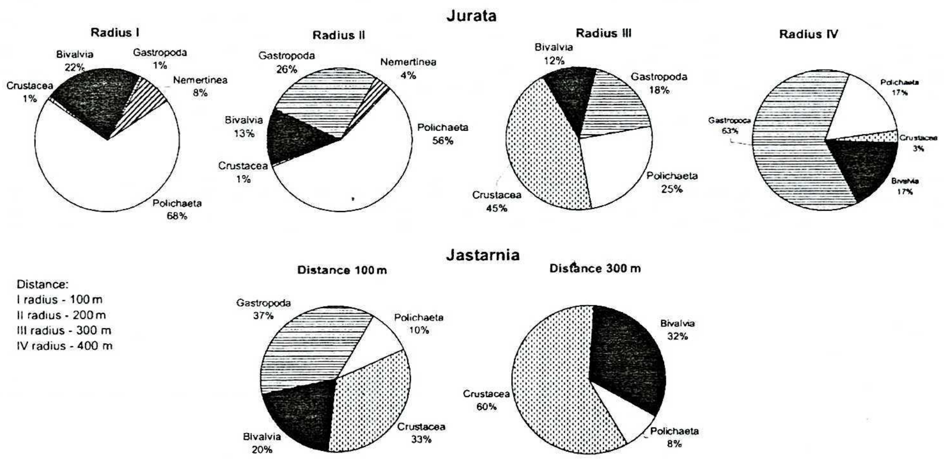

Fig. 2. Density (D) domination structure of macrozoobenthos near the sewage-treatment plant in Jurata and the harbor in Jastarnia

Table 3. Macrozoobenthos density (A – indiv.·m^{-2}) and biomass (B – g_{ww}·m^{-2}) in the studied area of the Puck Bay

	Jurata radius [m]								Jastarnia distance [m]			
	100		200		300		400		100		300	
	A	B	A	B	A	B	A	B	A	B	A	B
NEMERTINEA												
Prostota sp.	96	0.06	61	0.01								
POLYCHAETA												
Hediste diversicolor	911	19.25	1133	22.13	462	9.50	382	6.68	67	0.90	22	2.90
Pygospio elegans											45	0.01
CRUSTACEA												
Cyathura carinata					98	0.40	18	0.07				
Idotea chelipes					33	0.01					45	0.70
Idotea balthica			15	0.01								
Jaera sp.							4	+				
Gammarus tigrinus					13			0.02			22	0.04
Gammarus salinus											56	0.15
Gammarus zaddachi											11	0.10
Gammarus sp.	11	0.01			689.	1.48	40	0.10	222	0.3	289	0.15
Leptocheirus pilosus											34	0.01
Corophium volutator					4	+					11	0.02
GASTROPODA												
Theodoxus fluviatilis					44	1.18						
Hydrobia ulvae			430	1.42	125	0.90	1404	4.44				
Hydrobia ventrosa	11	0.04	96	0.40	169	0.42			122	1.1		
BIVALVIA												
Mytilus edulis trossulus					4	0.02	4				45	3.70
Cerastoderma glaucum	122	37.55	178	98.30	191	90.04	22	101.20	89	36.90	22	332.00
Macoma balthica	56	11.45	59	3.27	27	4.92			44	19.30	11	355.00
Macoma calcarea			7	2.37								
Mya arenaria	111	11.90	15	1.47			58	56.12				
Σ	1328	80.26	2014	129.38	1889	108.87	2291	168.63	564	58.5	653	694.78

+ abundance < 1 indiv.·m^{-2} and biomass < 0.01 g_{ww}·m^{-2}

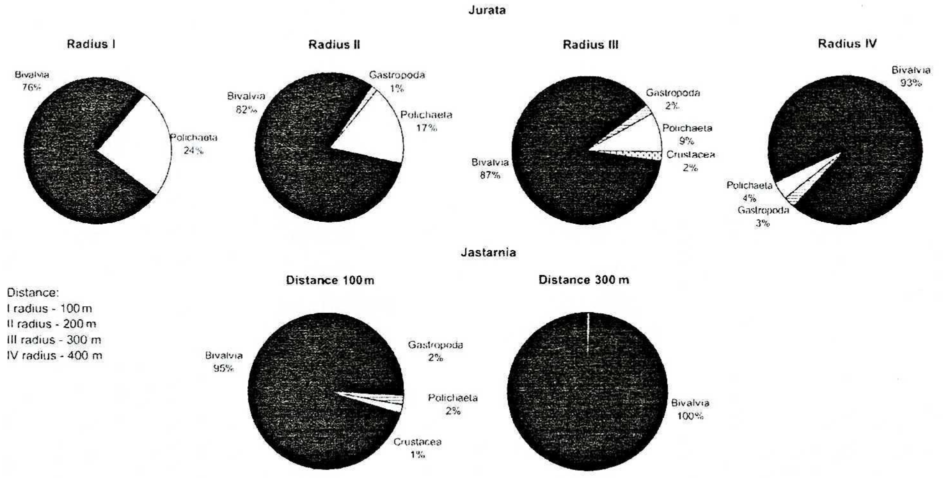

Fig. 3. Biomass (Dm) domination structure of macrozoobenthos near the sewage-treatment plant in Jurata and the harbor in Jastarnia

At the sampling sites in Jurata, 200 m off the sewage-treatment plant, the abundance of macrofauna ranged from 5 to 9. As regards density, Polychaeta (mainly *H. diversicolor*, Fr = 100%) was predominant while Gastropoda (mainly *Hydrobia ulvae*, Fr = 75%) subdominant (Tab. 1). The average biodiversity index (H') amounted to 1.603 and was slightly higher in comparison to the first radius.

Macrozoobenthos density at the sites 200 m off the Jurata shore varied between 22 and 1133 indiv.·m^{-2} ($\overline{x}$ = 2014 indiv.·m^{-2}) and was 4-fold higher west of the sewage-treatment plant (Tab. 3). In turn, biomass in the second radius reached 62.2–260.1 g_{ww}·m^{-2} (Tab. 4). The wet mass value was mostly influenced by bivalves (82% of the total biomass) and polychaetes (17%), (Fig. 3). The highest mass among Bivalves reached lagoon cockles while among Polychaeta – *H. diversicolor* (Tab. 1).

At the sampling sites of the third radius (300 m off the sewage-treatment plant) in Jurata, the collected benthofauna was represented by 5–9 taxa, the most in front of the sewage-treatment plant. Mean biodiversity index (H') was definitely the highest of the studied coastal zone near Jurata (Tab. 2). In turn, in Jastarnia macrozoobenthos was represented by 9–10 taxa, with the highest number observed at the harbour exit. The obtained mean H' values were similar to those in Jurata (Tab. 2). Macrozoobenthos density at the third radius in Jurata varied between 22 and 1911 indiv.·m^{-2}. Gammaridae (Fr = 80%) representative predominated but *H. diversicolor* (Fr = 60%) and *Cerastoderma glaucum* (Fr = 100%) also significantly contributed to the total density (Tab. 1). In Jastarnia, the observed benthofauna density ranged from 510 to 711 indiv.·m^{-2} and was 1.4-fold higher east of the sewage-treatment plant than at the western sampling sites (Tab. 4). Biomass of benthic invertebrates at the third radius near the sewage-treatment plant varied between 59.94 and 171.70 g_{ww}·m^{-2} while in Jastarnia it reached 50.90–1339.05 g_{ww}·m^{-2}. The species that mostly contributed to the total biomass where *C. glaucum* in Jurata ($\overline{x}$ = 90 g_{ww}·m^{-2}) and *Macoma balthica* ($\overline{x}$ = 355 g_{ww}·m^{-2}) in Jastarnia (Tab. 3).

The last radius (400 m off the sewage-treatment plant) was inhabited by a lower number of taxa than sampling sites closer to the coast. Biodiversity index varied between

0.70 and 2.47, with the highest values west of the sewage-treatment plant. Benthofauna density at the studied sites of the last radius ranged from 22 to 4667 indiv.$\cdot$m^{-2} (Tab. 4) with the highest contribution of common *Hydrobia ulvae* (Fr = 60%, $\bar{x}$ = 1404 indiv.$\cdot$m^{-2}) and then euconstants – *C. glaucum* and *H. diversicolor*. As for biomass, it varied in a wide range (32.10–467.83 $g_{ww}\cdot m^{-2}$). The observed wet mass was based on Bivalvia which constituted 90% of the total macrozoobenthos biomass (Fig. 3). Lagoon cockles were predominant (Tab. 1).

The agglomeration analysis of macrozoobenthos density indicated the tendency for group sampling sites of the same distance from the shore and located east and west (Fig. 4A). The most similar sites were the furthest ones off the coast (400 m) while one site to the west near Jurata was considerably different. As for biomass, agglomeration was formed by sampling sites near the shore of Jurata while the most different were the sites at the water lane to the harbor entrance in Jastarnia (Fig. 4B). It should be also noticed, that similarly as for macrozoobenthos density, biomass was grouped into western and eastern agglomerations.

The Cochran and Cox test (α = 0.05) revealed that there were no significant differences in mean densities between the consecutive radii near the sewage-treatment plant and the harbor in Jastarnia, except for the sampling sites 300 m off the shore in both of the studied zones (Tab. 4).

DISCUSSION

Macrozoobenthos in the shallow-water zone of the Polish Baltic coast is the main food for fry and also serves as a bioindicator of water quality. Therefore, its qualitative and quantitative structure has been widely studied [3, 6, 21]. Performed investigations have indicated negative influence of contamination on benthic macrofauna development and unfavorable changes in species composition. The analysis of benthofauna structure also allows for assessment of estuary ecological conditions according to the guidelines of EU Water Framework Directive.

Sewage-treatment plants in Swarzewo and Jurata were supposed to organize water-sewage management in the drainage basin of the Puck Bay and improve ecological conditions of that ecosystem [24]. However, sewage-treatment plants are also sources of contamination and the discharge point of waters rich with nutrients negatively influences biocenosis of that reservoir.

The data obtained from the Jurata – Jastarnia sewage-treatment plant reveal a high amount of sewage discharged in 2004 (Q_{24h} = 2344 $m^3\cdot d^{-1}$) but with reduced content of most of the pollutants (Tab. 5). However, concentration of phosphorus compounds in the bay waters is still considerable. In general, post-treatments waters are classified as II class of water quality and only the amount of suspended matter corresponds with class I. Piping post-treatment waters off with 1630 m long and 300 mm diameter pipe to the deeper zone (> 6 m) of the Bay seems to be rational. However, due to the currents, post-treatment waters may still influence hydrobionts in the Bay.

The density of benthic fauna near the sewage-treatment plant in Jurata was mostly contributed by *Hediste diversicolor* – species resistant to organic contamination. Its high abundance was typical for contaminated waters and indicated bad ecological conditions in the studied zone of the Puck Bay. The discussed species is an important food for ben-

Table 4. Comparison of density bentofaunal in the vicinity of sewage treatment plant in Jurata city and harbor in Jastarnia: range, arithmetic average ($\overline{x}$), standard deviation (SD), different of variability (CV) and biodiversity Shannon index and Cochran and Cox test for ring

<table>
<tr><td rowspan="2"></td><td colspan="6">Jurata</td><td colspan="2">Jastarnia</td></tr>
<tr><td>Radius I
100 m</td><td>Radius II
200 m</td><td>Radius III
300 m</td><td>Radius IV
400 m</td><td>West off
the sewage-
treatment plant</td><td>East off the
sewage-
treatment plant</td><td>Distance
100 m</td><td>Distance
300 m</td></tr>
<tr><td>Average no. of taxa</td><td>6</td><td>7</td><td>7</td><td>5</td><td>4–7</td><td>5–9</td><td>5</td><td>7</td></tr>
<tr><td>Density range
$[indiv.\cdot m^{-2}]$</td><td>0–911
n = 2</td><td>0–1133
n = 3</td><td>0–1911
n = 5</td><td>0–4667
n = 5</td><td>0–4667
n = 8</td><td>0–1911
n = 7</td><td>0–244
n = 2</td><td>0–578
n = 2</td></tr>
<tr><td>Density min.–max.
$[indiv.\cdot m^{-2}]$</td><td>22–911</td><td>22–1133</td><td>22–1911</td><td>22–4667</td><td>22–4667</td><td>22–1911</td><td>44–244</td><td>22–578</td></tr>
<tr><td>$\overline{x}$ – average density
$[indiv.\cdot m^{-2}]$</td><td>1321.0</td><td>2014.7</td><td>1840.0</td><td>2226.2</td><td>2433.3</td><td>1364.4</td><td>666.0</td><td>610.5</td></tr>
<tr><td>SD</td><td>198.4</td><td>257.7</td><td>175.8</td><td>311.9</td><td>1910.8</td><td>948.2</td><td>56.8</td><td>62.4</td></tr>
<tr><td>$\overline{x}$ – average biomass
$[g_{ww}\cdot m^{-2}]$</td><td>80.25</td><td>128.97</td><td>108.89</td><td>168.61</td><td>148.47</td><td>93.39</td><td>58.50</td><td>694.97</td></tr>
<tr><td>Median (Me)</td><td>155</td><td>244</td><td>489</td><td>355.5</td><td>1766.5</td><td>1199.0</td><td>133.2</td><td>55.5</td></tr>
<tr><td>CV [%]</td><td>175.3</td><td>163.3</td><td>139.7</td><td>172.0</td><td>78.5</td><td>69.5</td><td>69.7</td><td>55.7</td></tr>
<tr><td>Shannon index</td><td>1.48</td><td>1.60</td><td>2.06</td><td>1.30</td><td>1.44</td><td>1.82</td><td>2.04</td><td>2.00</td></tr>
<tr><td rowspan="6">Cochran & Cox test
(C)</td><td colspan="2">Radius I – Radius II
$C < C_{\alpha(0.05)} = 0.791 < 2.323$</td><td colspan="2">Radius III – Radius IV
$C < C_{\alpha(0.05)} = 0.7 < 2.341$</td><td colspan="2">Profiles West – East
$C < C_{\alpha(0.05)} = 1.438 < 2.376$</td><td colspan="2">Jastarnia – Jastarnia
$C < C_{\alpha(0.05)} = 1.711 < 2.748$</td></tr>
<tr><td rowspan="2"></td><td colspan="2">Radius II – Radius III
$C < C_{\alpha(0.05)} = 0.192 < 2.263$</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Radius II – Radius IV
$C < C_{\alpha(0.05)} = 0.784 < 2.352$</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Radius I – Radius IV
$C < C_{\alpha(0.05)} = 1.200 < 2.360$</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Radius I Jurata – Jastarnia 100 m
$C < C_{\alpha(0.05)} = 0.971 < 2.375$</td><td></td></tr>
<tr><td colspan="2"></td><td colspan="6">Radius III Jurata – Jastarnia 300 m
$C > C_{\alpha(0.05)} = 2.282 > 2.200$</td></tr>
</table>

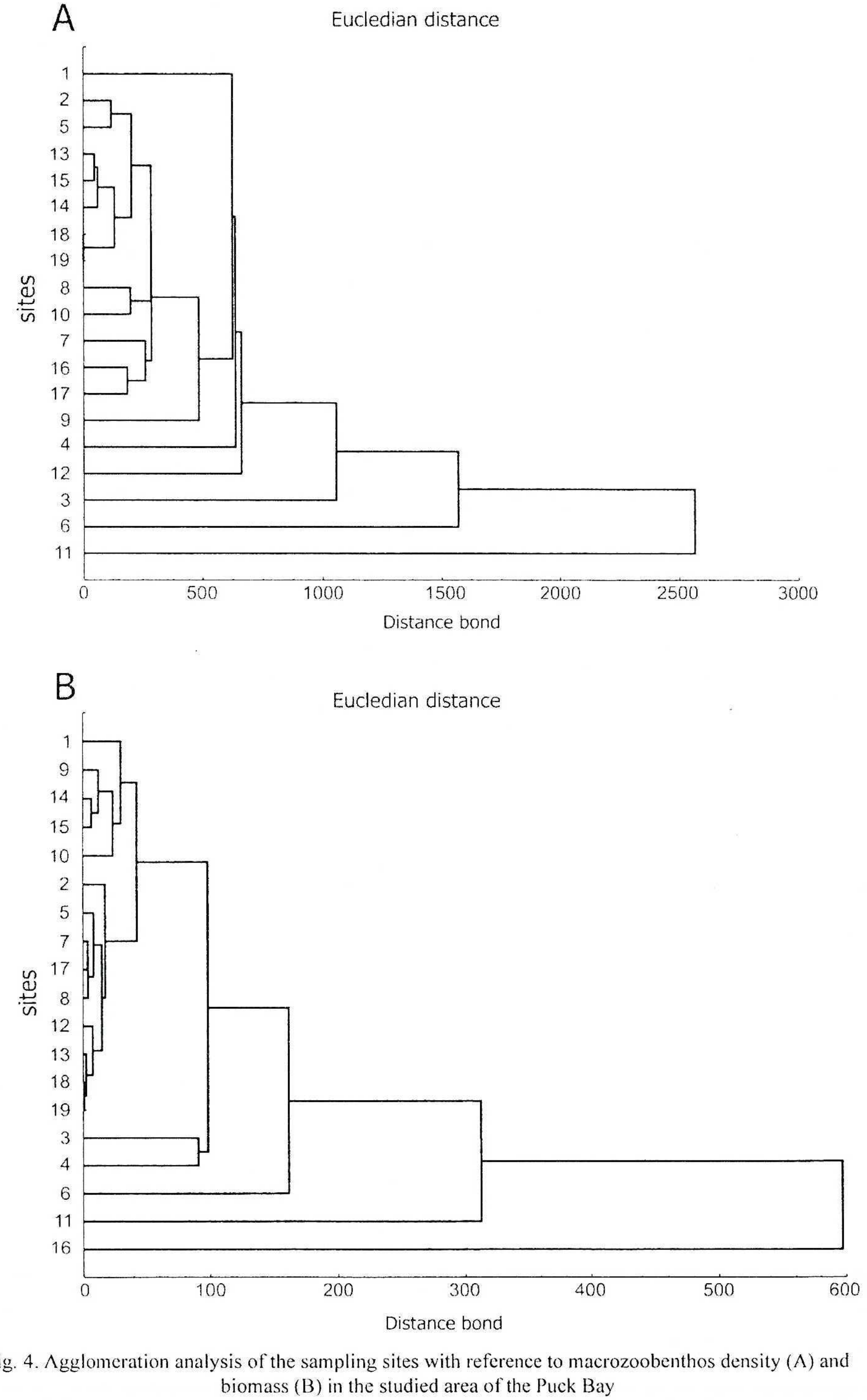

Fig. 4. Agglomeration analysis of the sampling sites with reference to macrozoobenthos density (A) and biomass (B) in the studied area of the Puck Bay

Table 5. Quality of post-treatment waters from the Jurata – Jastarnia sewage treatment plant piped off to the Puck Bay in summer 2004 (sewage treatment plant data)

Post-treatment waters discharged to the Puck Bay							Reduction of pollutants [%]			
COD [mg $O_2 \cdot dm^{-3}$]	BOD_5 [mg $O_2 \cdot dm^{-3}$]	Suspended matter [mg·dm^{-3}]	N_{total} [mg N·dm^{-3}]	$N\text{-}NH_4$ [mg N·dm^{-3}]	P_{total} [mg P·dm^{-3}]	$P\text{-}PO_4$ [mg P·dm^{-3}]	BOD_5	Suspended matter	N_{total}	P_{total}
29.1	1.7	9.4	6.5	0.18	0.60	0.32	96.5	99.6	97.1	96.2

thivorous fish, for example sand lances (*Ammodytes tobianus* L., *Hyperoplus lanceolatus* Sauvage), sticklebacks (*Gasterosteus aculeatus* L., *Pungitius pungitius* (L.), *Spinachia spinachia* L.) and gobies (*Gobius niger* L., *Phe omatoschistus minutus* (Pall.), *Pomatoschistus microps* (Kröyer), *Coryphopterus flavescens* (Fabricius), *Neogobius melanostomus* Pall.).

Water discharged from sewage-treatment plants is rich in nutrients and may induce phytoplankton blooms as well as increase in macrozoobenthos abundance, mostly bivalves. Particularly *Macoma balthica* is resistant to eutrophication [14], opposite to benthic crustaceans. In the investigated zone near Jurata, *Macoma* had the highest density at the sampling site the closest to the sewage-treatment plant, where the constant inflow of organic contaminants used to take place. *Macoma* was accompanied by *Mya arenaria*, which is commonly treated as an indicator of contaminated sediments [7, 13]. That species occurred at the closest and the furthest sites with relation to the sewage-treatment plant, where its direct influence and post-treatment water discharge were observed, respectively. *Mya arenaria* is often eaten by *Neogobius melanostomus*, which compete for food with viviparous blenny and flounder fry [15].

Among filter feeders, lagoon cockles predominated in the studied zone. That confirms the thesis that it is the most common bivalve in the Baltic Sea, highly resistant to anthropogenic pressure [11, 20]. Mean density of that species in the Polish costal zone amounts to 180 indiv.·m^{-2} and is similar to the density observed in Jurata and Jastarnia (191 indiv.·m^{-2}) [20]. However, frequency of lagoon cockles in the studied zone was higher (Fr = 100%) than given for the Polish coastal zone (Fr = 58%) while biomass was 12-fold higher. Due to considerable size and thick shells, fish reluctantly eat lagoon cockles.

The clear water indicator, *Pygospio elegans*, avoided the zone adjacent to the sewage-treatment plant in Jurata. It occurred at the entrance to the harbor in Jastarnia with low density. This contradicts the investigation performed 10 years before at the same place [19], which reported high abundance of *Pygospio elegans* and suggested the improvement in habitat conditions.

The littoral zone (0–2 m depth) of the southern Baltic coast is inhabited by the assemblage with predominant *Corophiumvolutator*, Hydrobiidae [20]. It is adapted to a sandy, moving bottom, which in the studied zone occurred only in the strip directly in contact with the land. That strip was narrow; therefore the observed density and biomass were low for Crustacea representatives.

The obtained bivalve biomass was mostly influenced by *Cerastoderma glaucum*. Its average wet mass for the Polish coast amounts to 9.25 $g_{ww} \cdot m^{-2}$, which is 9-fold higher than the wet mass obtained near Jurata and almost 25-fold higher in the case of Jastarnia region [11]. Considerable contribution to the benthic invertebrate biomass in Jurata was observed for *Hediste diversicolor*, which was accompanied by molluscs and to some extent by the *Mya arenaria – Macoma balthica* assemblage, typical for sandy bottom in the deeper zone of the Baltic Sea (10–25 m). Among the Crustacea representatives, Gammaridae reached the highest biomass. They avoided the closest and the furthest zones in relation to the shore and gained the highest biomass 300 m off the coast, at sampling sites with sandy, sludge bottom. In Jastarnia, the highest biomass was observed near the water lane, at the exit from the harbor, where crustaceans appeared. They were mainly represented by Gammaridea (*G. tigrinus*, *G. salinus*, *G. zaddachi*) and *Corophium volutator*. That made the discussed zone a valuable feeding ground for benthivorous fish. The only problem could be posed by the noise caused by ships near the harbor, petroleum contaminants and regular deepening of the water lane. High abundance of Crustacea in that zone must have been the result of sludge removement that had revealed sandy bottom, which is favored by crustaceans [25].

The structure of benthic fauna in the shallow-water zone of the Puck Bay may be formed not only by ichtyofauna but also by water fowls. Avifauna of the whole Puck Bay varies considerably and each year over 50 000 individuals are recorded [18]. They can reduce the molluscs population. Moreover, some species (for example *Clangule hymealis* L., *Samaterie mallissima*, *Fulica atra* L.) feed even on Gammaridae. In winter, common golden eye can reach a high number – on average 1144 indiv. This species feed only on crustaceans [2, 18]. As a result, all these factors influence macrozoobenthos density and biomass and also ecological conditions of the shallow-watered zone near Jurata and Jastarnia.

CONCLUSIONS

1. Macrozoobenthos near the sewage-treatment plant in Jurata was characterized by a low biodiversity, which is typical for simplified ecological systems.
2. As regards macrozoobenthos density, *Hediste diversicolor* predominated, as a species abundant in degraded aquatic ecosystems, while biomass was influenced by *Cerastoderma glaucum*.
3. Macrozoobenthos density and biomass were the highest at sites the most distant from contamination sources.
4. The performed analysis of benthic fauna structure in the studied area indicates bad ecological conditions according to the classification proposed in the EU Water Framework Directive.

REFERENCES

[1] Bolałek J.: *Krążenie materii między wodą naddenną a osadem na przykładzie Zatoki Puckiej*, Uniwersytet Gdański, Rozprawy i monografie, nr 186, Gdańsk 1993.

[2] Brodecki Z., L. Żmudziński: *Morskie obszary chronione w Polsce*, CBM PAN, Uniwersytet Gdański, nr 138, Gdańsk 1997.

[3] Demel K., Z. Mulicki: *Studia ilościowe nad wydajnością biologiczną dna południowego Bałtyku*, Prace Morsk. Inst. Ryb., 7, 75–126 (1954).

[4] Jackowski E.: *Stan tarlisk w Zatoce Puckiej*, Morsk. Inst. Ryb., Studia i Materiały, Seria B, nr 71, Gdynia 1998.

[5] Kasprzak K., W. Niedbała: *Wskaźniki biocenotyczne stosowane przy porządkowaniu i analizie danych w badaniach ilościowych*, [w:] Metody stosowane w zoologii gleb, M. Górny, L. Grüm (red.), PWN, Warszawa 1981, pp. 397–402.

[6] Kotwicki S., M. Miłosek, M. Szymelfenig, A. Witkowski, M. Wołowicz: *Struktura i dynamika zespołów bentosu w strefie brzegowej Zatoki Puckiej w rejonie oczyszczalni ścieków w Swarzewie*, Archiwum Ochrony Środowiska, **3-4**, 133–154 (1993).

[7] Kruk-Dowgiałło L.: *Przyrodnicza waloryzacja morskich części obszarów chronionych HELCOM BSPA województwa pomorskiego*, Nadmorski Park Krajobrazowy, Crangon 7 CMB PAN, Gdynia 2000[8] Majewski W.: *Morfometria i hydrografia*, [w:] Zatoka Gdańska, A. Majewski (red.), Wyd. Geolog., 1990, pp. 10–19.

[9] Nowacki J.: *Ogólna charakterystyka warunków termiczno-zasoleniowych w Zatoce Puckiej*, Zesz. Nauk. Wydz. BiNOZ UG, Oceanografia, **10**, 67–93 (1984).

[10] Obolewski K., M. Konkel: *Zagęszczenie makrofauny bezkręgowej w strefie płytkowodnej Zatoki Puckiej porośniętej trzciną*, Słup. Prace Biol., **4**, 79–92 (2007)

[11] Obolewski K., M. Konkel, A. Strzelczak, Z. Piesik: *Distribution and the role of Cerastoderma glaucum (Poiret, 1789) in the Polish Baltic Sea coast*, Balt. Coast. Zone, **11**, 13–24 (2007)

[12] Okołotowicz G.: *Biomasa makrozoobentosu polskiej strefy Bałtyku wskaźnikiem jej zanieczyszczenia*, Biul. Mor. Inst. Ryb., **5-6**, 27–39 (1985).

[13] Ostrowski J.: *Wpływ zanieczyszczenia na zoobentos Zatoki Gdańskiej ze szczególnym uwzględnieniem określenia gatunków wskaźnikowych*, Stud. i Mater. Morsk. Inst. Ryb., **26A**, 5–20 (1985).

[14] Piesik Z.: *Macrozoobenthos of the coastal zone in the region of Słowiński National Park*, Balt. Coast. Zone, **2**, 47–60 (1998).

[15] Skóra K.: *Ryby dla Zatoki, Założenia do koncepcji odtworzenia zasobów ryb Zatoki Puckiej*, Stacja Morska UG, Hel 1997.

[16] Słomianko P.: *Zatoka Pucka*, Oceanologia, PAN – KBN, **5-2**, 271 (1974).

[17] StatSoft Inc.: *STATISTICA for Windows* (Computer program manual), Tulsa, http://www.statsoft.com (1997).

[18] Stepniewicz L., W. Meissner: *Assessment of the zoobenthos biomass consumed yearly by diving ducks wintering in the Gulf of Gdańsk (southern Baltic Sea)*, Ornis Svecica, **9**, 143–154 (1999).

[19] Szcześniak E.: *Makrofauna denna przybrzeżnej okolicy oczyszczalni ścieków w Juracie w latach 1992–1993*, maszynopis, Uniwersytet Gdański 1994.

[20] Warzocha J.: *Classification and structure of macrofaunal communities in the southern Baltic*, Arch. Fish. Mar. Res., **42**, 3, 225–237 (1995).

[21] Wenne R., K. Wiktor: *Fauna denna wód przybrzeżnych. Biocenoza wód przybrzeżnych Zatoki Gdańskiej w warunkach wzrostu eutrofizacji*, Biologia Morza, (6), 39, KBM PAN, 137–172 (1982).

[22] Wiktor K.: *Makrozoobentos*, [w:] Zatoka Pucka, K. Korzeniewski (red.), Inst. Oceanogr. Uniw. Gdańskiego, 442–454 (1993).

[23] Wołowicz M.: *Zmiany biocenozy strefy płytkowodnej Zatoki Puckiej w rejonie ujścia oczyszczalni ścieków w Swarzewie*, [w:] Materiały Konferencji Ekologia rejonów lądowych, przybrzeżnych i morskich Bałtyku – ochrona i kształtowanie, Cz. 1 – Środowisko morskie, Sopot 1993, 97–114.

[24] Wołowicz M., S. Kotwicki, M. Geringer d'Odenberg: *Wieloletnie zmiany biocenoz Zatoki Puckiej w rejonie ujścia oczyszczalni ścieków w Swarzewie*, [w:] Zatoka Pucka, K. Korzeniewski (red.), Inst. Oceanogr. Uniw. Gdańskiego, 510–519 (1993).

[25] Żmudziński L.: *Zoobentos płytkowodnej strefy Bałtyku*, WSP, Słupsk 1982.

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STRUKTURA ZESPOŁU MAKROZOOBENTOSU W STREFIE BRZEGOWEJ ZATOKI PUCKIEJ W OKOLICACH OCZYSZCZALNI ŚCIEKÓW JURATA – JASTARNIA

Badania nad poziomym rozmieszczeniem makrozoobentosu piaszczystego dna w okolicach Jastarni i Juraty prowadzone były jednorazowo latem 2004 roku. Wyznaczono 15 stanowisk w okolicach Juraty dzieląc stanowiska na cztery promienie oddalone od siebie o 100 m oraz 4 stanowiska w pobliżu portu w Jastarni. Bezkręgowce denne na tym obszarze reprezentowane były przez 18 gatunków i 3 grupy ponadgatunkowe, które w pobliżu Juraty osiągały zagęszczenie $\overline{x}$ = 1840 osobn.·m^{-2} i masę mokrą $\overline{x}$ = 121,8 g_{mm}·m^{-2}, a w okolicach Jastarni $\overline{x}$ = 638 osobn.·m^{-2} i $\overline{x}$ = 376,6 g_{mm}·m^{-2}. Najczęściej spotykanymi gatunkami były *Hediste diversicolor*, *Cerastoderma glaucum* i *Hydrobia ulvae*. Większą bioróżnorodnością wyznaczoną wskaźnikiem Shannona-Wienera charakteryzowały się stanowiska najbardziej oddalone od brzegu w Juracie. Skład gatunkowy oraz struktura jakościowo-ilościowa fauny dennej w tej części Zatoki Puckiej świadczy o niezadowalającym stanie środowiska oraz niskiej wartości tych obszarów jako miejsca żerowania ryb.