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Analysis of Benthic Macroinvertebrate Communities from the Lower Sections of Large River in Relation to Different Environmental Factors

Research Article

Tomasz Krepski*, Małgorzata Pilecka-Rapacz, Robert Czerniawski, Józef Domagała

Department of General Zoology
University of Szczecin
71-412 Poland

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Abstract: The aim of this study was to make a comparative analysis of macrozoobenthos composition at different sites at selected sections of lower the Odra River with relation to different physicochemical factors. The observations were made on the lower section of Odra River at five study sites: two of them were localized in the main channel, one in the left branch of river, another one in the channel carrying post-cooling water from Dolna Odra power plant, and the last one was in the channel connecting both branches of Odra River. At all sites, 26 taxa were found representing by: Bivalvia, Gastropoda, Oligochaeta, Hirudinea, Malacostraca and Insecta. The greatest biodiversity and the highest abundance of zoobenthos organisms were noted in the channel joining the two branches of the river, site 5, characterised by the lowest water flow rates and the densest coverage of the macrophytes at the bottom. Temperature was the sole parameter to be studied that affected the composition of benthic invertebrates. A clearly negative impact of temperature on the diversity of invertebrates was observed only in the channel with post-cooling water discharged from the power plant.

Keywords: *Benthic macroinvertebrates • Large river • Biodiversity • Post-cooling water*

1. Introduction

The environment of the lower sections of large lowland rivers is characterised by quiet current, high availability of detritus on which benthic invertebrates feed [1,2]. Water of large lowland rivers usually carry much pollution; such rivers are rather deep and have silt bottom [3]. It is interesting to establish which of the above factors are important for spatial distribution of macrozoobenthos communities in environment of such rivers.

Rivers are rich habitats of benthic macroinvertebrates, whose qualitative and quantitative composition depends on many environmental factors. The main factor affecting the composition of riverine macroinvertebrates is water current; *i.e.*, determining the presence or absence of limnetic or lotic taxa [4-7]. The velocity of the current indirectly affects water retention time, which is one of the most important factors shaping the physicochemical conditions and qualitative and quantitative structure of all aquatic organisms [1]. In lakes, where water retention time is longer than in rivers the influence of inorganic nutrients on macrozoobenthos communities is greater [1,3]. Thus, it can be suggested that in the lower section of large river, characterized by longer retention time in comparison to their upper section, the influence of inorganic nutrients could be a significant factor. Other important variables shaping the macrozoobenthos distribution in rivers is the presence of macrophytes. The higher the surface of the bottom covered by macrophytes, the higher density and taxa in the number of macrozoobenthos [8,9]. Moreover, Gonzáles and Graça [10] have shown that the type of bottom is a key factor in determining the bottom fauna composition. River beds with

* *E-mail: tomasz.krepski@univ.szczecin.pl*

high volumes of detritus are characterized by lower amounts of macrozoobenthos taxa, a phenomenon that is observed very often in lower sections of large rivers. [2,10]. This possibly is the most important environmental condition determining the occurrence or absence of many taxa of macrozoobenthos and thus it affects their biodiversity [11]. However, many studies concerning the impact of environmental variables on macroinvertebrates communities have been performed in small rivers and streams [4,7,10]. According to the studies cited, it can be concluded that in small and relatively shallow rivers, the impact of hydrological variables on macrozoonbethos communities is higher than in lower sections of rivers. In lower sections, those characterized by longer retention time, the impact of physicochemical variables on those communities can be more pronounced than in small rivers or streams. One of the most important physical variables affecting macrozoobenthos composition is water temperature [4]. Generally, higher temperatures reduce the taxa number of most bottom fauna. This relationship is shown in post-cooling waters [12]. Many authors who studied the effect of post-cooling water on lakes emphasize the negative effect of water temperature on qualitative structure of macrozoobenthos [*e.g.* 12]. However, the literature concerning the effects of such conditions on larger river macroinvertebrates, is lacking.

The lower Odra River in north-western Poland is an excellent system to study the dynamics of changes in macrozoobenthos. The river divides into two branches, and the presence of so many different environmentally-determining channels joining these branches, has produced many habitats differing in the type of bottoms as well as the water retention time. Thus, it has been possible to choose sites of study where the dynamics of changes in the qualitative and quantitative composition of benthic invertebrates would be pronounced. Moreover, the right branch of the Odra River receives post-cooling waters from Dolna Odra power plant. The influence of post-cooling water on the chemistry of the Odra River has been studied [13-15], but the effect of post-cooling water on macrozoobenthos in this area has not been determined.

The aim of this study was to make a comparative analysis of macrozoobenthos structures at different sites at the inter-connected sections of lower Odra River. It can be concluded that this inter-connected sections have significant differences in macrozoobenthos communities, despite their relatively close distances from one another. This pattern may be determined by different environmental conditions of these sections. The questions posed in the study were, (1) what are the spatial changes in the qualitative and quantitative composition of macrozoobenthos in the lower Odra River; (2) what physicochemical factors have significant effect on the macrozoobenthos structures in large, lowland river; (3) what is the effect of post-cooling water on macrozoobenthos in the channel carrying the heated water to the right branch of the Odra River?

2. Experimental Procedures

2.1 Study area

The observations were made on the lower section of the Odra River (N 53° 13’ 50”, E 14° 27’ 22”) at five study sites (Figure 1). Site 1 was established in the Odra River above its division into two branches, where the width of the river bed is 200 meters, the current is rapid and the river was regulated by the straightening of the bed. Site 2 was located in the left branch of Odra River, at 14 km below site 1, where the width of the river bed is 100 meters, the current is rapid, and the river bed is also straightened. Site 3 was located in the channel, immediately below the artificial basin where post-cooling water is discharged from the power plant. The width of this channel is close to 35 meters and the current is rapid. Site 4 was located in the right branch of Odra River, 10 kilometers below site 3, where the river bed width is close to 170 m, current is fast and the bed is straightening. At all this sites the bottom of the river is composed mainly of sand. Site 5 was in the Odyniec Channel joining two branches of the Odra river, at 6 km below site 4, where the channel width is 150 m, the channel bottom is muddy, overgrown with macrophytes and the flow rate is very slow.

2.2 Sample collection

Samples were collected in four months April, July, August and October in the years 2009, 2010 and 2011. A Van Veen grab was used to cut out three fragments of the bottom at each site, the area of fragment each cut out 0.062 m^2. The material collected was filtered through the mesh size of 0.5mm and preserved in a 4% solution of formalin. The sample was analysed under a stereoscopic microscope. The results were converted to and expressed in the number of individuals per 1m^2. The water temperature, pH, conductivity and saturation with oxygen were measured by a multifunctional instrument CX-401, made by Elmetron. The contents of nitrates, nitrites, ammonia, nitrogen, and the total amounts of nitrogen and phosphorus were measured by the photometer, Hach Lange DR-850. The mean values and standard deviations of the environmental variables are given in Table 1.

	Temp	pH	O_2	Cond	N-NH3	$N-NO_3$	$N-NO_2$	$P-PO_4$	NTOT	PTOT
	(ºC)		(mg l^{-1})	(µS)	(mg l^{-1})	(mg l^{-1})	(mg l^{-1})	(mg l^{-1})	(mg l^{-1})	(mg l^{-1})
Site 1	17.7	8.39	7.86	641.3	0.13	0.7	0.012	0.20	1.8	0.43
Site 2	18.1	8.15	7.05	681.8	0.20	0.8	0.015	0.20	1.9	0.41
Site 3	24.2	8.29	7.17	763.2	0.16	0.8	0.013	0.23	2.1	0.44
Site 4	18.5	8.29	7.23	673.9	0.16	0.7	0.012	0.19	1.8	0.37
Site 5	18.4	8.5	8.8	669.3	0.18	0.7	0.020	0.18	1.7	0.41

Table 1. Mean values of physico-chemical factors in sites examined of lower Odra River. Temp – temperature, Cond – conductivity, NTOT – total nitrogen, PTOT – total phosphor.

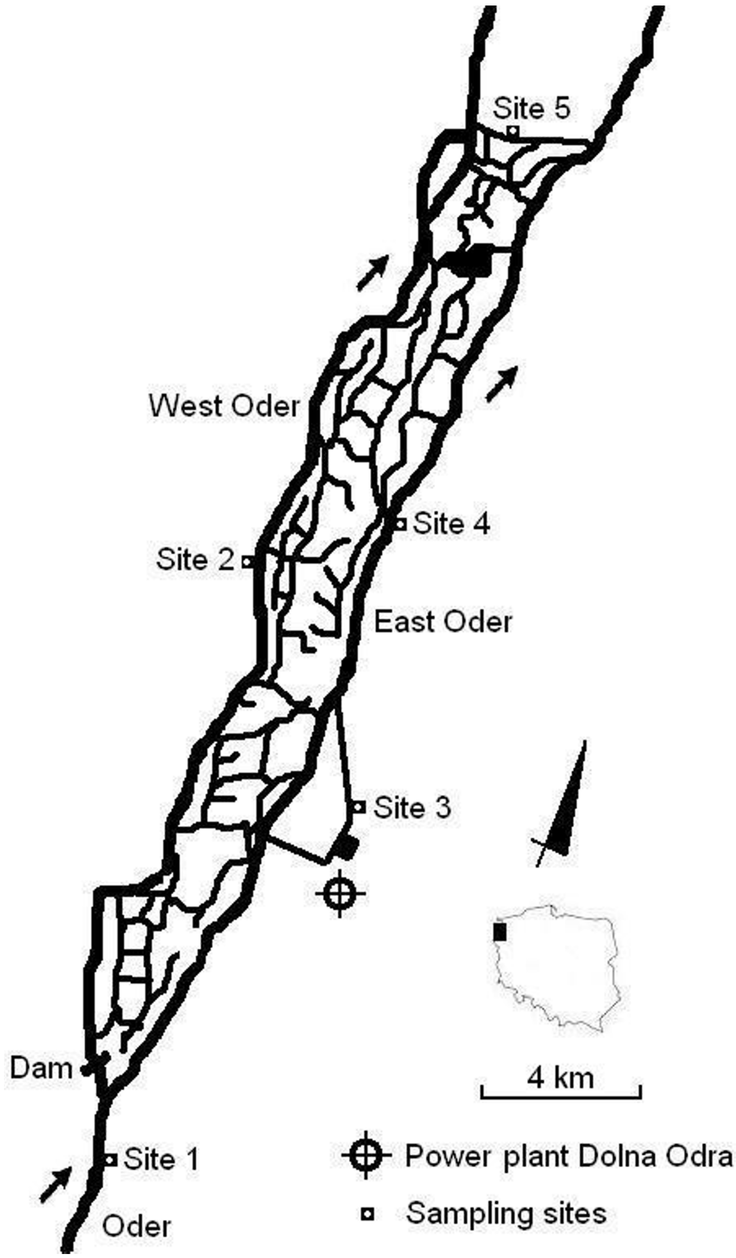

Figure 1. Study area.

2.3 Statistical methods

The taxonomic similarity between the sites was determined according to the Jaccard index: $C_J = J (a + b – J)^{-1}$. where a is the number of elements in set A, b is the number of elements in set B and J is the number of common elements of sets A and B [16]. The diversity index was calculated from the Margalef formula: d = s-1/ logN, where d is the index of diversity, s is the number of families represented at a given site, and N is the mean density of fauna at the site expressed per m^2 [16].

In order to perform statistical analyses, the taxons represented by the lowest number of individuals (smaller than 300 individuals per m^{-2}) were included in one group called "others", (Acroloxidae, Planorbidae, Hydrobiidae, Cambaridae, Libellulidae, Corixidae, Notonectidae, Ecnomidae, Limoniidae, Tabanidae). The statistical significance for the differences in the abundance of macroinvertebrata among sites were tested using the non parametric Mann Whitney U test ($P < 0.05$). The relationship between the environmental variables and the abundance of macroinvertebrata was checked by the Pearson's correlation. To find the best predictors for the abundance of macroinvertebrata, a multiple stepwise regression was employed. The percentage of variation explained by the pattern, was based on R^2. In order to determine the influence of environmental variables on the abundance of macroinvertebrata, the Canonical Correspondence Analysis (CCA) [17] was used.

3. Results

Analysis of the physicochemical data has revealed a great deal of similarity for the majority of data at the sites studied, with the exception of significant higher elevated water temperatures in the channel carrying the post-cooling water (site 3) than in other sites ($P < 0.05$). Differences in the other parameters, mainly hydrological ones, follow from the different morphology of the river sections examined.

Throughout the entire period of study at all sites, the presence of 26 taxa were established, represented by Bivalvia, Gastropoda, Oligochaeta, Hirudinea, Malacostraca and Insecta (Table 2). The highest number of taxa were noted in the channel joining both branches of the river (site 5), while the smallest was in the channel carrying the post-cooling waters (site 3) (Figure 2). The taxa represented by the highest mean number of individuals throughout the whole period of study were Dreissenidae, Sphaeriidae, Oligochaeta and Chironomidae (Table 2).

The taxonomic similarity among the sites was rather low, from 32 to 63%, the lowest between sites 3 and 5, the highest between 1 and 2 (Table 3). The highest macrozoobenthos diversity index was found at site 1 (above the river branching), and site 5, (the channel joining the two branches). The lowest diversity index was discovered at the channel where the water was discharged from the

	Site 1	Site 2	Site 3	Site 4	Site 5
Dreissenidae	338±437	778±631	-	114±204	1716±1880
Sphaeriidae	195±128	187±132	157±110	111±137	130±118
Unionidae	12±16	15±19	6±10	11±12	12±19
Bithyniidae	20±53	11±37	15±42	9±23	67±134
Valvatidae	95±130	28±52	-	20±56	3±6
Lymnaeidae	-	1±5	12±42	4±12	27±58
Viviparidae	152±167	78±80	31±107	79±88	51±90
Oligochaeta	128±72	174±134	103±54	86±66	119±124
Erpobdellidae	34±42	120±149	-	17±56	81±96
Glossiphoniidae	97±109	52±61	-	63±126	37±35
Corophiidae	41±63	233±541	-	228±755	-
Gammaridae	99±106	210±263	26±56	1579±5069	303±219
Asellidae	1±5	1±4	-	-	60±89
Caenidae	16±19	4±9	-	5±19	20±70
Ceratopogonidae	5±14	1±5	3±9	3±9	27±62
Chironomidae	479±333	506±389	196±152	1320±3586	348±260
Other	6±11	11±16	20±30	10±19	32±41
Total	1425±1087	2076±1535	461±195	3587±9781	2869±1867

Table 2. Mean ± SD abundance of macrozoobenthos in examined sites of lower Odra River in 2009-2011.

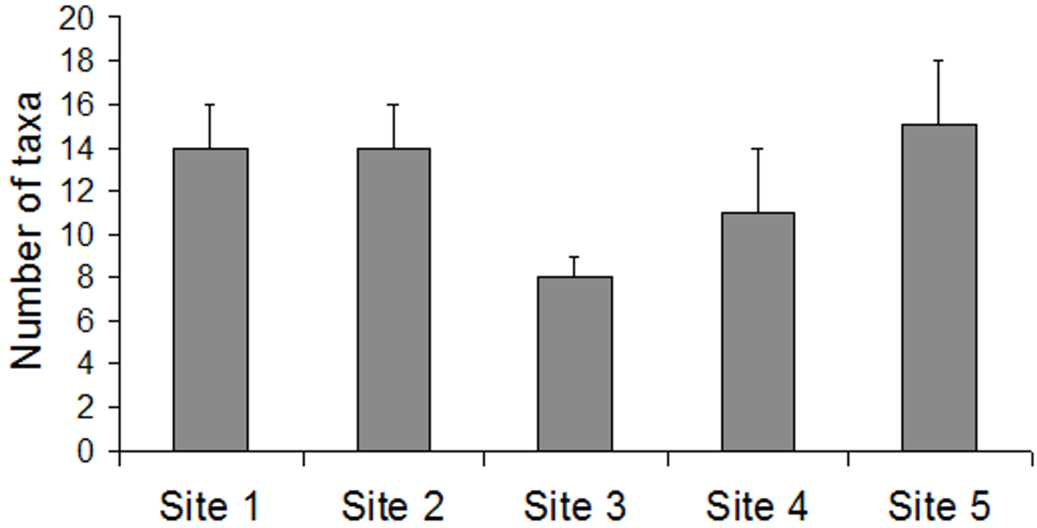

Figure 2. Mean + SD taxa number of macrozoobenthos at sites examined of lower Odra River.

power plant (Table 4), and its value was significantly lower than at all other sites (Table 5) (P<0,05).

Throughout the entire period of study, benthos macroinvertebrates were the most abundant at site 4 (the right branch of Odra River), while the least abundant in the channel was at site 3. Statistically significant differences in abundance were found among the sites in the following families, Dreissenidae, Viviparidae, Gammaridae, Asellidae and Chironomidae (Table 5) (P<0.05). Dreissenidae revealed more abundance in the channel carrying post-cooling water (site 3), than above the river branching (site 1) and at the right branch (site 4); the values obtained were statistically significant. Dreissenidae was also more abundant at site 2 (left branch) than at site 4 (right branch of the river). The abundance of Viviparidae was greater in the channel carrying post-cooling water (site 3), than at sites 1, 2 and 4, and again the values obtained were statistically significant. At site 5, at the channel connecting both branches, Gammaridae was more abundant than at site 1, above the river branching and at site 3, in the channel carrying post-cooling water. They were also more abundant at site 1 than at site 3. These values were statistically significant. The abundance of Asellidae was significantly greater in the channel connecting both branches (site 5), than at site 1 (above the branching) and site 2 (left branch). The abundance of Chironomidae was significantly smaller in the channel carrying post-cooling water (site 3), than above the branching (site 1) and at the right branch at site 2.

The relationship between temperature and dependent variables was found to have the closer relationship among all relationships studied (Table 6). Temperature was found to have a negative (or least) correlation with the density of macrozoobenthos and their biodiversity. Another variable, pH, showed the greatest correlation with the density of macrozoobenthos. Inorganic nutrients (NH_3, NO_2, PO_4, PTOT) correlated positively with nine families. Multivariate regression analysis revealed that the conditions at the sites studied accounts for from 18 to 35% of the differences in the abundance of benthic macroinvertebrates taxa. According to this analysis, the abundance of Dreissenidae was most affected by NO_2, Sphaeriidae by NH_3, Unionidae by temperature and pH, Planorbidae by the total amount of phosphorus, Bithyniidae by NH_3, Hydrobiidae by O_2, Viviparidae by temperature and the total amount of phosphorus, Oligochaeta by NH_3, Erpobdellidae by temperature and NO_2, Glossiphoniidae by O_2, Asellidae by NO_2, and Cambaridae by conductivity. It was also shown that elevated water temperature at the sites examined proved to be the most important factor determining the differences in macrozoobenthos biodiversity (Table 7).

The CCA of the samples and some of the values for the abundance of taxa, revealed that temperature, conductivity, pH, NTOT, and the concentration of oxygen correlated best with the first axis (Figure 3).

	Site 1	Site 2	Site 3	Site 4
Site 2	0.63			
Site 3	0.36	0.41		
Site 4	0.56	0.52	0.50	
Site 5	0.47	0.46	0.32	0.49

Table 3. Jaccard similarity of macrozoobenthos between examined sites of lower Odra River in 2009 – 2011.

	Site 1	Site 2	Site 3	Site 4	Site 5
Biodiversity	2.83	2.68	1.80	2.56	2.93

Table 4. Biodiversity of macrozoobenthos in examined sites of lower Odra River in 2009-2011.

	Site 1	Site 2	Site 3	Site 4
Site 3	V*, G*, C*, B**	V**, C*, B*		
Site 4		D*	V*, B*	
Site 5	D**, G**, A*	A**	G***, B**	D***

Table 5. Significant differences in number of macrozoobenthos taxa between examined sites. Significance: *P < 0.05, **P < 0.01, ***P < 0.001. D - Dreissenidae, V - Viviparidae, G - Gammaridae, A - Asellidae, C - Chironomidae, B - Biodiversity.

	Temp	pH	O_2	Cond	NH_3	NO_2	PO_4	PTOT
Dreissenidae	-0.270*					0.467***		
Sphaeriidae					0.398**			
Unionidae	-0.372**	-0.299*			-0.276*			0.259*
Planorbidae								0.343**
Bithyniidae		0.425**	0.373**		0.402**			
Hydrobiidae			0.445***					
Viviparidae				-0.304*				
Erpobdellidae	-0.338**							
Corophiidae		-0.289*						
Asellidae						0.474***		
Libellulidae						0.263*		
Notonectidae				0.271*			0.317*	
Ecnomidae	-0.280*	-0.258*						0.283*
Ceratopogonidae		0.336**	0.283*					
Biodiversity	-0.463***							

Table 6. Significant Pearson's correlations between environmental variables and abundance of macrozoobenthos taxa and biodiversity of macrozoobenthos. Significance: *P < 0.05, **P < 0.01, ***P < 0.001. Temp – temperature, O_2 – dissolved oxygen, Cond – conductivity, NH3 – ammonium nitrogen, NO2 – nitrites, PO4 – orthophosphates, PTOT – total phosphorus.

Predictor variable	Response variable												
	Dreissenidae	Sphaeriidae	Unionidae	Planorbidae	Bithyniidae	Hydrobidae	Viviparidae	Oligochaeta	Erpobdellidae	Glossiphoniidae	Asellidae	Cambaridae	Biodiversity
Temp	.	.	*	.	.	.	*	.	*	.	.	.	***
pH	.	.	*	.	.	.	.	.	.	.	.	.	.
O_2	.	.	.	.	.	*	.	.	.	*	.	.	.
Cond	.	.	.	.	.	.	.	.	.	.	.	*	.
NH_3	.	*	.	.	*	.	.	**	.	.	.	.	.
NO_2	***	.	.	.	.	.	.	.	*	.	***	.	.
PTOT	.	.	.	*	.	.	**	.	.	.	.	.	.
R^2	0.35	0.18	0.32	0.19	0.34	0.26	0.26	0.28	0.27	0.16	0.32	0.22	0.34

Table 7. Significances of the effects of environmental variables on the abundances of macrozoobenthos taxa and biodiversity of macrozoobenthos based on multiple regression (stepwise procedure). Significance: *P < 0.05, **P < 0.01, ***P < 0.001. Temp – temperature, O_2 – dissolved oxygen, Cond – conductivity, NH3 – ammonium nitrogen, NO2 – nitrites, PTOT – total phosphorus.

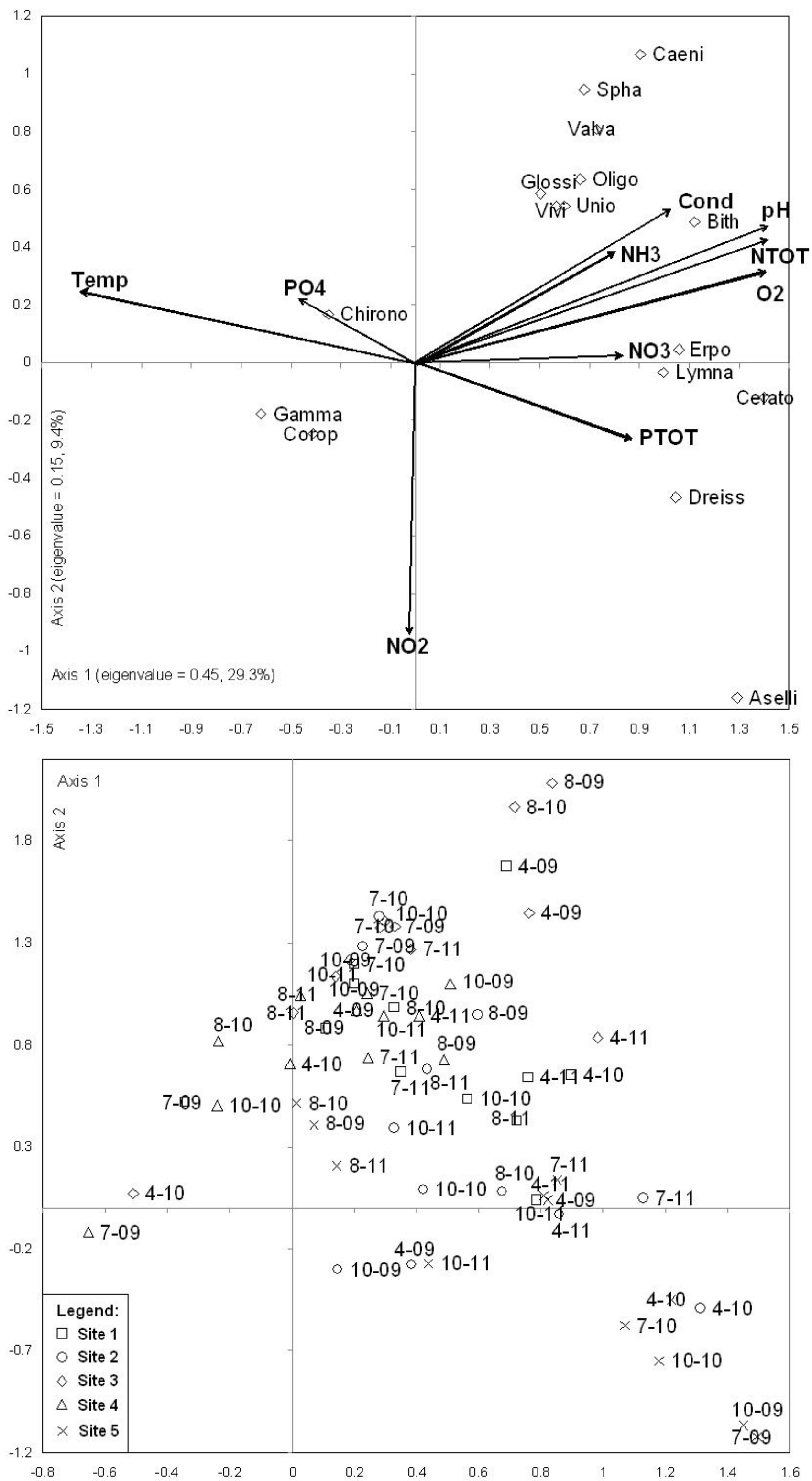

Figure 3. CCA constrained ordination of the taxa and the samples in the lower Odra River. Environmental variables: Cond – conductivity, Temp – temperature, pH, O2 – dissolved oxygen, NTOT – total nitrogen, NH3 – ammonium nitrogen, NO2 – nitrites, NO3 nitrates, PO4 – orthophosphates, PTOT – total phosphorus. Taxa: Dreiss - Dreissenidae, Spha - Sphaeriidae, Unio - Unionidae, Bith - Bithyniidae, Valva - Valvatidae, Lymna - Lymnaeidae, Vivi - Viviparidae, Oligo - Oligochaeta, Erpo - Erpobdellidae, Glossi - Glossiphoniidae, Corop - Corophidae, Gamma - Gammaridae, Aselli - Asellidae, Caeni - Caenidae, Cerato - Ceratopogonidae, Chirono – Chironomidae. First number means the month and second one means the year of the samples.

The concentration of nitrites had the best correlation with the second axis. The two axes accounts for 38.7% of the variability in the abundance of macrozoobenthos. The majority of the taxa were showed a statistically significant negative correlation with temperature, and positively correlation with NTOT, pH, oxygen, conductivity, N-NH3, N-NO3 and PTOT, with the exception of Chironomidae, Gammaridae and Corophiidae, (the randomization test value was 0.05). The CCA ordination did not show clearly the difference among seasonal samples at some sites. However, most of significant correlations were observed mainly in the spring and summer months, mostly at site 3 (the channel with post-cooling water).

4. Discussion

4.1. Spatial changes

At the sites of study in the lower Odra river, the number of taxons found were much smaller than those reported from other large, lowland rivers [18-20]. Although, as has been shown by a several authors, the lower sections of rivers are in general characterised by a smaller number of taxa than the upper sections [21,22]. The highest number of taxons and the greatest biodiversity, were found in the channel joining the two Odra River branches, which was dense growth of macrophytes (site 5). Pinto *et al*. [9] reported a strong positive correlation between the presence of macrophytes and invertebrates in the lower sections of rivers, pointing to the importance of macrophytes as refuges for invertebrates from predation, which account for the above observation. A similar conclusion has been drawn by Simon & Travis [23], who studied the invertebrates in the main river and its channel, reporting greater biodiversity in the channel, which had an abundance of macrophytes, than in the main river.

The lower index in taxonomic similarity between site 1 (above the branching) and site 5 (the channel connecting both branches) can be explained, assuming, after Langcheinrich *et al*. [24], that in the channel joining the two Odra River branches both lotic and limnic conditions exist allows the presence of rheophilic and limnic taxons. The highest taxonomic similarity was found between site 1 (above the river branching) and site 2 (left branch of the river). The close distance between the sites and similar hydrological conditions can explain this observation. The taxonomic similarity between site 4 (right branch of the river) and the other sites, varied from 50 to 56% and was the highest with site 1 (above the branching), because both sites are located in the same river bed.

The highest mean abundance at all sites was where the filtrating taxons were located (Dreissenidae and Sphaeriidae), as well as those feeding on organic matter, (Oligochaeta and Chironomidae), which according to the theory of "river continuum," [2] accumulate in lower sections of rivers. Moreover, these are ubiquistic taxons living in many types of habitats, both in stagnant water and in currents of water flow [25-28].

Significant differences in the abundance of Dreissenidae followed mainly from the hydrological conditions on the bottom of the river bed and the current strength of the river flow. The greatest abundance of representatives in this family at site 5 (in the channel connecting both branches) and at site 2 (left branch of the river), can be explained by the fact that the pelagic larvae of these bivalves are not disturbed by strong water currents at these sites. The greater abundance of Gammaridae at site 5 (the channel connecting both branches) than at site 1 (above the branching), is explained by its smaller depth, slower current and the greater abundance of macrophytes at site 5, such conditions favourable for this family [29]. The greater abundance of Asellidae at site 5 than at sites 1 (above the branching) and at site 2 (left branch), results, in part, from the limnetic character of the environment. *Asellus aquaticus* has been generally found more often in lower sections of rivers than in the upper ones [28].

4.2. Physicochemical factors

Statistical analysis has revealed significant direct correlations; *e.g.*, correlation in the number of bivalves and the content of nitrogen compounds in water. Such a relationship is often observed especially in Dreissenidae, as in the abundance of zebra mussel found to be proportional to the increasing amounts of nitrogen compounds dissolved in water [30]. Significant correlation was also found between the number of snails and the increased trophic quality of the environment, also reported by other authors [31]. Another interesting correlation was that between the abundance in the family Asselidae and the content of nitrites, which indicates their tolerance to biogenic compounds and their preferences of habitats with increased trophic properties [29]. For the other taxons, no strong correlations were noted among the particular environmental preferences. Statistical analysis revealed many significant correlations between the environmental variables and macrozoobenthos taxons, but these correlations were not great. These results imply that apart from temperature, there is no parameter that would significantly influence the structure of benthos organisms. Perhaps the effect of other factors should be considered, such as time of water retention, rate of flow, composition and the structure of bottom sediments or the concentration of heavy metals (whose considerable influence on macrozoobenthos composition has been cited by *e.g*. Korte [5], Bis *et al*. [18], Dukowska *et al*. [32].

4.3. Post-cooling water

It has been shown by numerous authors that water with elevated temperature, including post-cooling water, has negative effect on the abundance and biodiversity of bottom invertebrates [12,33,34]. According to the results of our study, in the channel with post-cooling water from the power plant, the lowest abundance of taxons and statistically significantly lower biodiversity, was observed among all the sites studied. However, at site 3, in the channel carrying post-cooling water, the abundance of snails from the family Viviparidae was much greater than at site 1 (above the branching), site 2 (left branch) and site 4 (right branch). This could be explained by fact that the increased water temperature has a positive influence on increasing abundance of Gastropoda [34,35]. Ciemiński and Zdanowski [12] have reported a positive effect of elevated temperature on the number of Chironomidae larvae. However, their observations are in contrast to our results. At the site with the warm channel, the number of Chironomidae larvae was significantly smaller than at site 1 and site 2. It can most probably be attributed to the fact that in the warm channel, the rate flow is high and the bottom is hard. At the site in the warm channel we also observed a significantly smaller number of Gammaridae than at site 1 (above the branching) and at site 5 (in channel joining both branches). Živi´c *et al*. [34] and Bat *et al*. [36] have also reported a negative effect of elevated water temperature on the abundance of Gammaridae. The negative effect of elevated water temperature can be observed only in the warm channel and perhaps in a short section of the right branch of the Odra river, immediately below the warm channel mouth. It was not noted at site 4, in the right branch, 10 km below the warm channel mouth.

5. Concluding remarks

Temperature was the only parameter of those being considered that affected the composition of benthos invertebrates. A clearly negative influence of temperature on the diversity of invertebrates was observed only in the channel with post-cooling water discharged from the power plant. Although the distances between the sites were rather small, differences in the number of taxons and the abundance of zoobenthos organisms related to the different morphology of the sites and these differences were notable. The morphological conditions determined the hydrological and biological conditions; consequently development of different ecosystems which were not influenced by the post-cooling waters. The greatest biodiversity and the highest abundance of zoobenthos organisms was noted in the channel joining the two branches of the river, site 5, characterised by the lowest water flow rates and densest growth of the macrophytes at the bottom.

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