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Original Research

Effect of Environmental Factors on Communities of Bottom Fauna in Littoral Zones of Ten Lakes in the Wel River Catchment

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Abstract

The results of a study of littoral macroinvertebrate communities of lakes in the Wel River catchment (central Poland) are presented. Semi-quantitative sampling was performed in April and October 2009. Redundancy analysis (RDA) was used to demonstrate relationships between macroinvertebrate assemblages and environmental variables. There were significant relationships between transparency (Secchi depth), P-PO_4 concentration, lake area, and taxa occurrence, which explained 22%, 19%, and 14% of the observed variability, respectively. The lakes were grouped according to littoral fauna communities in a pattern similar to that noted with regard to physicochemical variables and other communities inhabiting the lakes.

Keywords: benthic macroinvertebrates, littoral, environmental variables, RDA, lake, Wel River

Introduction

The EU Water Framework Directive (WFD) stipulates attaining good water quality [1]. The assessment of water quality status must be based on biological methods. The aim of the wide-ranging research campaign in 2009 in the lowland Wel River (central Poland) was to perform an integrated assessment of the ecological status of watercourses and lakes situated in this exemplar catchment area in accordance with WFD requirements [2]. The trophic state was assessed based on analyses of macrophytes, phytoplankton, and zoobenthos communities, and on the physicochemical and hydromorphological characteristics of the waters.

Benthic organisms are regarded as good bioindicators and have long been used to assess the trophic status of waters in rivers [3-6] and lakes [7].While many water quality assessment systems are based on profundal zone communities [8, 9], similar systems based on littoral communities are less numerous [10].This is because of difficulties in unequivocally interpreting the influence of various factors [11] such as the structural heterogeneity of littoral areas, animal distribution [12], and natural factors that are not connected directly with water quality but do significantly influence the biota in littoral zones (eg. wave action) [13, 14]. Littoral zones are very important parts of lakes, since they participate in the energy and matter flows between river catchments and water bodies [15].

Assessing the influence of environmental factors on invertebrate animals inhabiting littoral zones will provide a reference for observing the effects of water parameters on other groups of organisms inhabiting other lake zones.

The aim of the current study was to analyze the relationships between fauna composition and abiotic parameters in the littoral zones of lakes in one drainage basin. The second objective was to establish whether macroinvertebrate community composition differed among these lakes, and to determine how these differences were related to trophic state assessments based on different groups of bioindicators and water physicochemical parameters.

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Materials and Methods

Study Area

The investigation focused on the ten largest lakes located in the Wel River basin. The largest and deepest of these is Lake Dąbrowa Wielka with a surface area of 615 ha and a maximum depth of 34.7 m. Lake Rumian has the second largest surface area of 305.8 ha. The surface areas of lakes Dąbrowa Mała, Tarczyńskie, Grądy, and Lidzbarskie range from 100 to 200 ha, while the remaining lakes are smaller than 100 ha with the smallest, Lake Zwiniarz, at 50 ha. The investigated lakes are subject to anthropogenic pressure of varying intensities. Five of them are located in the protected area of the Welski Landscape Park, while Lake Lidzbarskie is in its buffer zone. Agricultural land use in the catchment area exerts a major influence on the water quality of the investigated lakes. Tourism and recreation are also developing dynamically in the catchment area, and all of the lakes investigated are also exploited by inland fisheries [16].

Sampling Methods

Water samples for physicochemical analyses were collected monthly from April to October 2009, and detailed descriptions of these and results are presented in Soszka and Ochocka [17] and Hutorowicz et al. [18].

Sampling sites were designated in the littoral zones of each of the ten lakes. Benthic macroinvertebrate specimens were captured at ten sites (one site per lake) in April and October 2009. Four (April) or three (October) quantitative bottom samples were collected with a 25 cm^2 Surber net (250 µm mesh) at all of the sampling sites. Sediment samples were collected within a 0.125 m^2 sampling area at depths not exceeding 1 m, and 30-second qualitative samples were collected with a Surber net in a variety of habitats proportionally to their occurrence at each site. In the laboratory, the macroinvertebrates were separated from the sampled sediment, and then identified either alive or after preservation in 70% ethanol. In addition to quantitative samples, qualitative samples were used to assess the taxa richness and to aid in taxonomic identification. The fauna collected was identified to the lowest possible taxonomic level.

Data Analysis

Analysis of similarity (UPGMA, Bray-Curtis distance metric) was used to compare the differences among the lakes with regard to macroinvertebrate communities. Cluster analysis dendrogram classification was produced using the MultiVariate Statistical Package 3.13 [19].

Zoobenthos taxa were expressed in relative abundances, and only those with a relative abundance of at least 1% in a given lake were retained for further ordination analysis. For these analysis the four (April) or three (October) samples representing each lake were pooled.

Detrended correspondence analysis (DCA) was used to examine the taxonomic data and to determine if RDA or Canonical correspondence analysis was appropriate for evaluating the association between lake water chemistry, physical properties, and biological data. The DCA ordination gradient was <3 standard deviations (0.299 SD), so the linear model associated with RDA was appropriate for this dataset [20]. RDA measured the dispersion of the macroinvertebrate abundance matrix in relation to the chemical and environmental matrices; associations between the two matrices were tested using Monte Carlo unrestricted 499 permutations [21].

Ordination analyses was done with CANOCO version 4.5 [22] on log (x + 1) transformed abundance data.

Results

A total of 18,769 individuals belonging to 126 macroinvertebrate taxa were identified in 90 samples. The highest fauna richness was recorded in Lake Kiełpińskie with 69 taxa, while the lowest was in Lake Zwiniarz with 44 taxa.

Distinctly higher littoral fauna abundance was observed in fall in all of the lakes except in Lake Dąbrowa Wielka (Fig. 1).

The taxa found in all of the lakes investigated were as follows: leeches *Erpobdella octoculata* and *Helobdella stagnalis*; isopod crustacean *Asellus aquaticus*; caddis flies *Molanna angustata* and the family Limnephilidae; mayfly *Caenis horaria*; non-biting midge group *Chironomus plumosus*; group A *Glyptotendipes* sp.; bivalves *Dreissena polymorpha* and *Unio tumidus*; gastropod *Bithynia tentaculata* and Hydracarina (Table 1).

The most abundant taxa were *Dreissena polymorpha*, group A *Glyptotendipes* sp., and *Pseudochironomus* sp. which comprised 30, 25, and 6% of the total number of macroinvertebrate individuals, respectively. The contributions of other taxa (82%) was less than 1%.

The similarity dendrogram indicated there are three groups of lakes, one of which included only Lake Dąbrowa Wielka (Fig. 2).

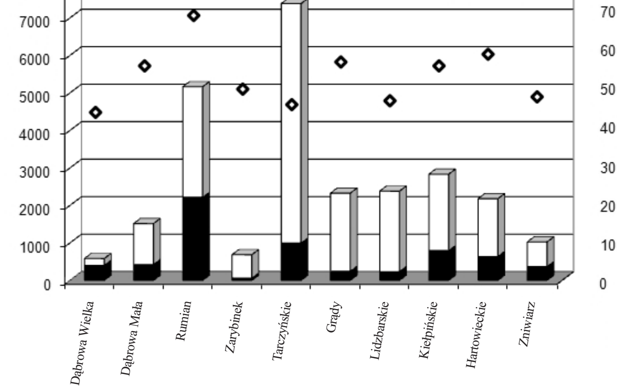

Fig. 1. Abundance and number of macroinvertebrate taxa found in the studied lakes.

Table 1. List of the macroinvertebrate taxa used in RDA analysis, including their abbreviations, number of occurrences, relative abundances (% total), and maximum relative abundances (% max).

Taxa	Abbrev.	Lakes present	% max	% total
Turbellaria	Tur	3	1	0
Oligochaeta				
Limnodrilus claparedeanus	*Lim cla*	2	1	0
Limnodrilus hoffmeisteri	*Lim hof*	8	1	0
Potamothrix hammoniensis	*Pot ham*	10	2	0
Potamothrix heuscheri	*Pot heu*	5	1	0
Psammoryctides albicola	*Psa alb*	9	10	3
Psammoryctides barbatus	*Psa bar*	9	3	1
Lumbriculus variegatus	*Lum var*	4	3	0
Hirudinea				
Erpobdella monostriata	*Erp mon*	3	1	0
Erpobdella nigricollis	*Erp nig*	7	1	0
Erpobdella octoculata	*Erp oct*	10	7	3
Helobdella stagnalis	*Hel sta*	10	3	1
Hemiclepsis marginata	*Hem mar*	9	1	0
Crustacea				
Asellus aquaticus	*Ase aqu*	10	17	3
Gammarus sp.	*Gam sp.*	3	1	0
Trichoptera				
Cyrnus trimaculatus	*Cyr tri*	5	1	0
Molanna angustata	*Mol ang*	10	1	0
Mystacides nigra	*Mys nig*	8	1	0
Tinodes waeneri	*Tin wae*	5	6	1
Limnephilidae	Lim	10	4	1
Ephemeroptera				
Baetis sp.	*Bae sp*	5	2	0
Caenis horaria	*Cae hor*	10	7	3
Zygoptera				
Ishnura elegans	*Ish ele*	9	4	1
Heteroptera				
Micronecta sp.	*Mic sp*	8	8	1
Megaloptera				
Sialis lutaria	*Sia lut*	8	3	1
Chironomidae				
Cricotopus sylvestris gr.	*Cri syl*	6	2	0
Chironomus plumosus gr.	*Chir plu*	10	14	2
Cladotanytarsus sp.	*Cla sp.*	8	1	0

Table 1. Continued.

Taxa	Abbrev.	Lakes present	% max	% total
Cryptochironomus sp.	*Cry sp.*	6	1	0
Dicrotendipes sp.	*Dic sp.*	7	6	1
Endochironomus sp.	*End sp*	9	2	0
Glyptotendipes sp gr A	*Gly sp.*	10	58	25
Microtendipes pedellus gr.	*Mic ped*	9	8	2
Paratanytarsus sp.	*Par sp*	8	2	0
Polypedilum sp.	*Pol sp.*	9	26	3
Polypedilum sp. (nubifer)	*Pol nub*	5	2	0
Pseudochironomus sp.	*Pse sp*	3	34	6
Stictochironomus sp.	*Sti sp.*	5	7	2
Tanytarsus sp.	*Tan sp.*	8	1	0
Ceratopogonidae	Cer	10	1	1
Hydracarina	Hyd	10	4	1
Bivalvia				
Anodonta anatina	*Ano ana*	5	1	0
Dreissena polymorpha	*Dre pol*	10	62	30
Pisidium henslowanum	*Pis hen*	5	1	0
Sphaerium corneum	*Sph cor*	3	1	0
Unio tumidus	*Uni tum*	10	1	0
Gastropoda				
Acroloxus lacustris	*Acr lac*	5	1	0
Anisus contortus	*Ani con*	2	2	0
Armiger crista	*Arm cri*	2	2	0
Bithynia tentaculata	*Bit ten*	10	7	1
Gyraulus albus	*Gyr alb*	2	7	0
Hippeutis complanatus	*Hip com*	1	3	0
Lymnaea auricularia	*Lym aur*	8	2	0
Potamopyrgus antipodarum	*Pot ant*	3	2	0
Valvata piscinalis	*Val pis*	6	1	0
Theodoxus fluviatilis	*The flu*	5	14	1

The highest similarity was between the littoral benthic fauna of lakes Hartowieckie and Zwiniarz (0.341 Bray-Curtis dissimilarity score) and lakes Lidzbarskie and Tarczyńskie (0.428) from the second group.

Redundancy analysis was performed for 56 taxa, the five environmental variables of water transparency (Secchi depth), pH, conductivity, P-PO_4, chlorophyll *a* and lake area (Fig. 3). The total organic carbon (TOC), and total nitrogen (Ntot) parameters were excluded from the analysis because their variance inflation factors exceeded 20.

Table 2. Summary of a RDA of the lakes in the Wel River catchment littoral data (pH, P-PO_4, conductivity, chlorophyll *a*, Secchi depth).

Axes	1	2	3	4	Total variance
Eigenvalues	0.247	0.187	0.152	0.094	1.000
Species-environment correlations	0.981	0.968	0.999	0.986	
Cumulative percentage variance of species data	24.7	43.3	58.5	67.9	
Cumulative percentage variance of species-environment relation	30.5	53.6	72.3	83.9	
Sum of all unconstrained eigenvalues					1.000
Sum of all canonical eigenvalues					0.809

Other variables (i.e., N-NH_4, N-NO_3, TP, lake volume, maximum and mean depths) were not included in the analysis at all since they were strongly correlated with the variables selected. Only transparency (Secchi depth) P-PO_4 and lake area were selected for stepwise analysis since they had significant relationships (p=0.002, p=0.012, and p=0.032, respectively) with macroinvertebrates, and they explained 22, 19, and 14 %, respectively, of the variability.

The ordination procedure produced four significant axes. The sum of all the canonical eigenvalues was 0.809 (Table 2). The first two components of RDA explained 53.6% of the taxonomic variation, while the first axis accounted for 30.5% of total variance. This represents a water transparency gradient that is correlated positively with Secchi disc visibility and negatively with chlorophyll *a* concentration. The second axis (23.1% of total variance) was correlated with the phosphorus gradient (P-PO_4). The third axis (18.7% of total variance) was correlated with surface area.

The lakes were separated well in terms of environmental variables (Fig. 4); their position relative to each other was similar to that derived from the fauna similarity diagram.

Discussion

Chironomidae larvae and Bivalvia were the dominant groups in the benthic fauna of the lakes investigated. In all the lakes except Dąbrowa Wielka they comprised over half of all the benthic invertebrates noted in the littoral zones. The separateness of the Lake Dąbrowa Wielka zoobenthos composition appears to be largely because of environmental factors, since it has the lowest total phosphorus concentration of all the lakes investigated, while its water transparency is one of the highest. These two factors provide a substantial explanation for the variability in taxa occurrence. Moreover, this lake had some of the lowest values of conductivity, total nitrogen concentration [17], and chlorophyll *a* [18] noted in the current study. Another factor that could influence the benthic fauna could be lake surface area, which is linked to wave action that favors groups such as Gastropoda and Bivalvia, but are clearly adverse for Chironomidae. Therefore, in Lake Dąbrowa Wielka the last group of invertebrates is less abundant than Mollusca, oligochaets, and *Asellus aquaticus*. Wave action can also be responsible for higher fauna abundance in spring than in fall; the situation in the other lakes investigated was exact-

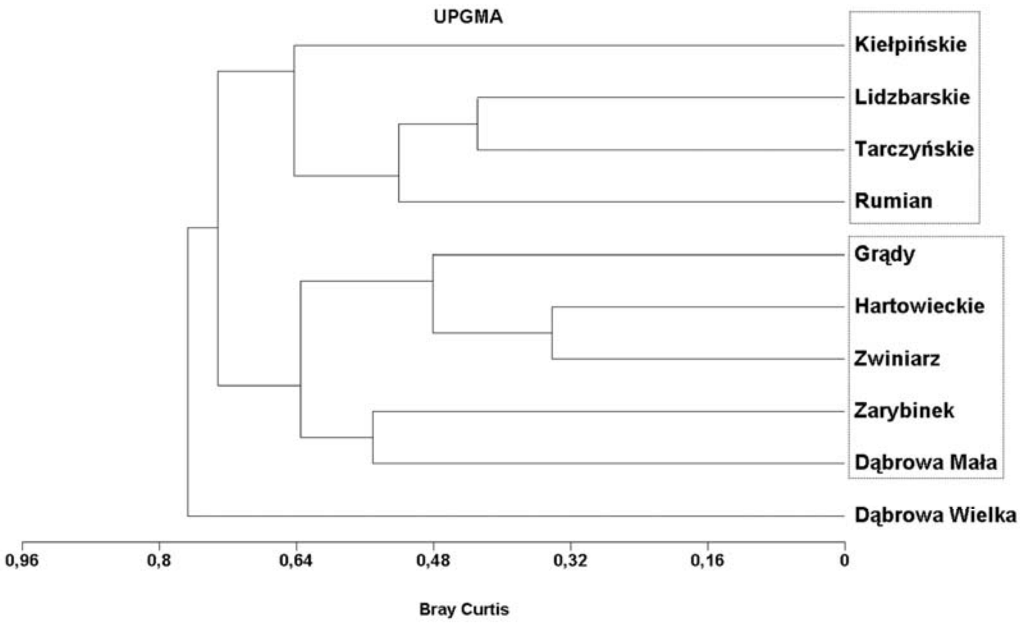

Fig. 2. Dendrogram based on Bray-Curtis dissimilarities of macroinvertebrate assemblages for studied lakes in Wel River catchment.

ly inverse. The ice cover that lasted until March protected the fauna from wave action that can transport invertebrates to deeper zones of lakes or strand them on shores from spring to fall. Scheifhacken et al. [23] reported that wind-induced shear stress in the upper eulittoral zone was responsible for reducing zoobenthos abundance and biomass in littoral zones. According to Tolonen et al. [13], shallow sandy or stony shores with mobile substrates that are disturbed by wave action are probably the most unfavorable habitats for macroinvertebrates.

Lake Dąbrowa Wielka was the only one of the lakes investigated to be classified as having a very good ecological status (ESMI index) based on macrophyte investigations [24]. The occurrence of representatives of the genus *Pseudochironomus* was noted only in three of the lakes investigated; however, it was abundant in Lake Kiełpińskie, which means it can be regarded along with *Glyptotendipes* sp., which is also of Chironomidae, and the zebra mussel (*Dreissena polymorpha*), as taxa with the highest benthos abundance. The catchment area of Lake Kiełpińskie is highly natural as it comprises forests that are not susceptible to high degrees of degradation [16]. Consequently, the investigations of chosen biological, physicochemical, and hydromorphological parameters indicated that only lakes Dąbrowa Wielka and Kiełpińskie met the criteria for the moderate ecological state [25].

RDA analysis indicated that the occurrence of taxa that tolerate high trophic states, including chironomids of the genera *Chironomus*, *Endochironomus*, *Glyptotendipes*, and *Polypedilum* of the Chironomini subfamily, and oligochaete species of the genus Limnodrilus, was linked to chlorophyll *a* concentrations in waters. Other taxa that occurred commonly in waters of a higher trophic state and in sediments rich in organic matter were linked to conductivity (i.e. Hirudinea, Ceratopogonidae, *Sialis* sp., the mayfly *Caenis* sp., and chironomids of the genera *Microtendipes* and *Tanytarsus*).

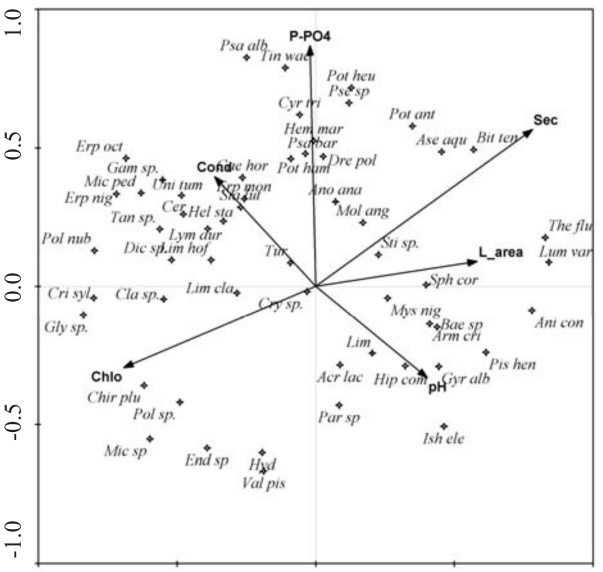

Fig. 3. RDA-ordination of macroinvertebrate taxa in relation to environmental variables. Abbreviations of variables as follows: phosphate (P-PO$_4$), electrical conductivity (cond), pH, chlorophyll *a* (Chlo), Secchi depth (Sec), lake area (L_area).

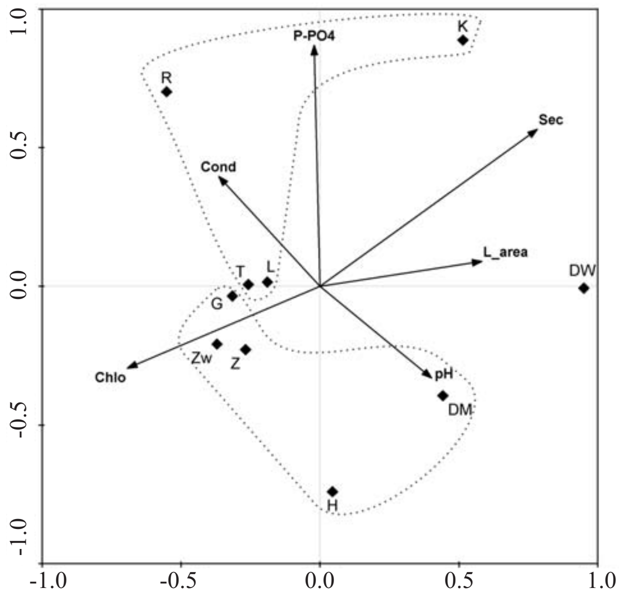

Fig. 4. Position of 10 lake data in the area of RDA cannonical axes characterized by 5 environmental variables – phosphate (P-PO4), electrical conductivity (cond), pH, chlorophyll *a* (Chlo), Secchi depth (Sec), lake area (L_area).
Abbreviations of lakes: DW – Dąbrowa Wielka, DM – Dąbrowa Mała, R – Rumian, Z – Zarybinek, T – Tarczyńskie, G – Grądy, L – Lidzbarskie, K – Kiełpińskie, H – Hartowieckie, Zw – Zwiniarz. Groups are circled.

Statistically significant factors such as Secchi disc visibility and P-PO$_4$, were linked to the oligochaetes of the genera *Potamothrix* and *Psammoryctides*, caddis flies, some snails, and bivalves.

It seems that water pH had the strongest influence on taxa of caddis flies, snails, and Sphaeridae bivalvia.

Obviously, the relationships noted were not necessarily caused by the effects of abiotic physicochemical factors; they could also have been modified by biotic factors [26]. Moreover, according to Heino [27], habitat structure has a stronger impact on the distribution of macroinvertebrate communities than does trophic status. An attempt was made to counterbalance this tendency in the present research by sampling from diverse habitats in the littoral zones of each of the ten lowland lakes.

Similarity in the grouping patterns of the lakes investigated based on environmental factors and taxonomic composition do support the hypothesis that macroinvertebrate inhabitants of littoral zones are potentially good indicators of lake ecological status. Such good convergence is comparable with trophic state assessments performed using other communities inhabiting lakes. If the Polish method for lake status assessment was augmented by the use of littoral zoobenthos, the results would provide for more precise comparisons of the numerical values of indexes that characterize trophic status using littoral organisms with those obtained with profundal fauna or other indicative groups used in investigations of lakes.

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