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# Comparing modified biological monitoring working party score system and several biological indices based on macroinvertebrates for water-quality assessment

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## Abstract

Macroinvertebrate communities from the lower Nysa Kłodzka River catchment, southern Poland, were analyzed seasonally, in order to assess changes in their composition and structure, in relation to water quality. Two major groups of sites, differing in both morphological structure and taxonomical composition by cluster analysis, were identified within the catchment area. Wider and deeper sites, located along the Nysa Kłodzka River, were associated with the dominance of Chironomidae. Sites assigned along tributaries were characterized by a diversified structure of dominant taxa, including Oligochaeta, Hirudinea, Crustacea, Trichoptera, Ephemeroptera and Diptera. The performance of the modified procedure, named BMWP(PL) index, in accurately classifying 26 sites has been assessed through comparison with saprobic, diversity and biotic indices as well as chemical data. Due to diversified taxa richness and the presence or absence of specific indicator groups, values of the BMWP(PL) index varied from 27 to 93, and were correlated with the other biological indices and chemical variables. It has been stated that there is strong potential for application of the BMWP(PL) system in Poland, although some further testing is recommended.


***Keywords:*** Macroinvertebrates; Biological indices; Water quality; Nysa Kłodzka river

## Introduction

Looking through the history of running water-quality assessment based on biological indicators one observes that at least 100 indices have been developed over the past tens of years, of which about 60% are biotic ones based on macroinvertebrate analysis (De Pauw & Hawkes, 1993). Biotic indices are numerical expressions combining a quantitative measure of species diversity with qualitative information on the ecological sensitivity of individual taxa, among others. They are based on two principles: (1) macroinvertebrates Plecoptera, Ephemeroptera, Trichoptera, *Gammarus, Asellus,* red midges Chironomidae and Tubificidae disappear in the order mentioned as the organic pollution level rises, (2) the number of taxonomic groups is reduced as pollution increases (Hellawell, 1986). Of course, the sequence of disappearing macroinvertebrates reflects only a general trend of their increasing tolerance against organic pollution. Indices developed for a particular geographical region, like the Belgian Biotic Index (BBI) (De Pauw & Vanhooren, 1983) or the Biological Monitoring Working Party (BMWP) score system for river pollution surveys in the UK (Armitage, Moss, Wright, & Furse (1983) have been successfully applied in other countries, including Spain (Zamora-Munoz & Alba-Tercedor,

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1996), Argentina (Capitulo, Tangorra, & Ocon, 2001), Canada (Barton & Metcalfe-Smith, 1992) and Thailand (Mustow, 2002), among others. However, the application of biological indices for environmental conditions or pollution types other than the ones they were developed for requires their previous adaptation.

Recent water-quality monitoring programmes in Poland were mainly based on the determination of physical and chemical parameters. Sporadically applied biological methods used the saprobic index based on the analysis of microorganisms belonging to the plankton community. With the reference to running waters, there are many limitations concerning the application of this method in the biological water-quality assessment. The main objections are as follows: specific list of species and saprobic values, which attributed to species may not be appropriate over a wide geographical area; difficulties in the taxonomic identification of microorganisms; and the lack of possibilities of the presentation of local conditions, due to the analyses of the community drifted by water current, often of allochthonous origin. Therefore, interest has been shown in the application of biological water-quality monitoring techniques using macroinvertebrates, which tend to be advantageous, cost-effective and simple in use. Since 1999, an attempt has been made towards the elaboration of a biological method, in relation with European Union requirements, for assessing the biological quality of running water. Results from the investigation, which was carried out all over Poland, has led to the adaptation of the BMWP score system.

Kownacki, Soszka, Kudelska, and Fleituch (2004) have reported on the modification of the BMWP system, which is based on a score derived from points attributed to different invertebrate families, according to their degree of intolerance against organic pollution. The biotic system has been modified as follows: (1) several families were given new scores, e.g. dipterans Chironomidae (original score 2 – new score 3), mayflies Leptophlebiidae (10–7) and snails Ancylidae (6–3), (2) several families were included in the Polish system that are not used in the original BMWP score, e.g. dragonflies Calopterigidae, dipterans Blephariceridae and mayflies Ameletidae. These are families that do not exist in the UK due to zoographical isolation, although in Polish conditions constitute good indicators of water quality.

The purpose of this study is to present (1) an overall picture of the macroinvertebrate communities along the streams in the lower Nysa Kłodzka River system, (2) the biological water quality of the investigated rivers based on benthic communities, (3) the modified BMWP score system, called BMWP(PL), by accurately classifying the investigated sites through comparison with other biological indices. These comprised: the most commonly used nonparametric community structure indices of Margalef (D) and Shannon (H) (Washington, 1984), the saprobic index in Friedrich's modification, SI (Friedrich, 1990), the BBI (De Pauw & Vanhooren, 1983) and the BMWP score system (Armitage et al., 1983). Apart from diversity indices, four other biological methods applied for water-quality assessment were developed in Europe.

## Materials and methods

### Study area

Field studies were conducted within the catchment area of the lower Nysa Kłodzka River (catchment area: 729 $km^2$), downstream two retention reservoirs in Otmuchów and Nysa (southern Poland). Twenty-six sampling sites were established along the Nysa Kłodzka river (sites N1-6) and its six tributaries, being 1st and 2nd order streams: Cielnica (C1-4), Korzkiew (KO1-3), Potok Skoroszycki (P1-2), Stara Srtuga (SS1-2), Kamienica (K1-2) and Ścinawa Niemodlińska (S1-7) (Fig. 1). Sites were selected: (1) to be easily accessible, (2) to permit a sampling of all representative habitats for each study site, (3) to have no or significantly modified stream channel.

Ranges for physical variables recorded at the sampling sites were as follows: mean width of streams

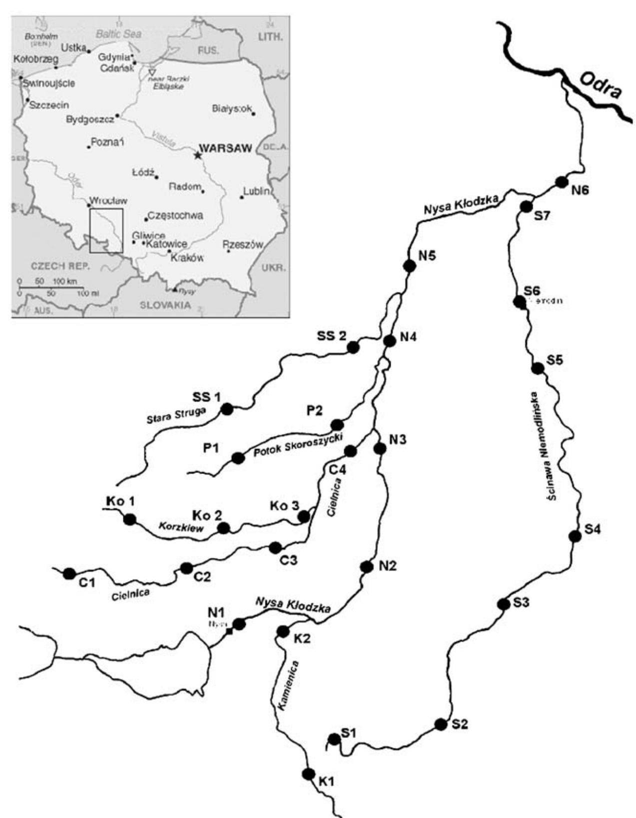


**Fig. 1.** Location of the study area and the sampling stations.

0.6–34 m, mean depth 0.15–25 m, mean flow velocity 20–110 cm $s^{-1}$ (Table 1).The slopes of the study sites ranged from 0.5‰ to 6‰. The substratum consisted mainly of sand and gravel, covered in part by fine particulate organic matter. Major land uses in the catchment basin include agriculture and urban development. Therefore, the main water hazard in the investigated area is caused by an excessive inflow of nutrient compounds. Results of physical and chemical analyses confirm the higher content of such pollutants as phosphorus, phosphates and nitrogen (data from Regional Inspectorate of Environmental Protection in Opole).

**Table 1.** Mean values of environmental and chemical parameters at the sampling sites of the lower Nysa Kłodzka River catchment

| Parameter/site | N1 | N2 | N3 | N4 | N5 | N6 | C1 | C2 | C3 | C4 | KO1 | KO2 | KO3 | P1 | P2 | SS1 | SS2 | K1 | K2 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Width (m) | 30 | 27 | 26 | 30 | 34 | 33 | 1 | 1.8 | 3.2 | 3.5 | 0.8 | 1.3 | 2.5 | 1.6 | 1.7 | 2.3 | 1.8 | 0.9 | 1.2 | 0.6 | 3.5 | 4.3 | 2.5 | 2.3 | 6.0 | 5.5 |
| Depth (m) | 1.8 | 2.2 | 2.5 | 2.3 | 1.9 | 2.5 | 0.3 | 0.4 | 0.5 | 0.4 | 0.4 | 0.6 | 0.5 | 0.3 | 0.8 | 0.15 | 0.3 | 0.2 | 0.8 | 0.3 | 0.4 | 0.7 | 0.9 | 1.0 | 0.7 | 1.7 |
| Flow velocity (cm $s^{-1}$) | 80 | 110 | 90 | 100 | 110 | 110 | 20 | 24 | 29 | 24 | 24 | 38 | 35 | 21 | 29 | 31 | 35 | 53 | 29 | 49 | 32 | 35 | 58 | 37 | 85 | 64 |
| DO (mg $dm^{-3}$) | 10.0 | — | — | 9.4 | 10.3 | 10.7 | — | 6.3 | 9.5 | 10.1 | — | 7.4 | 9.5 | 8.6 | 7.7 | 10.2 | 9.1 | 10.1 | 7.6 | 10.6 | 6.5 | 8.6 | — | 10.9 | 10.4 | 8.2 |
| $NO_2$-N (mg $dm^{-3}$) | 0.03 | — | — | 0.04 | 0.03 | 0.03 | — | 0.09 | 0.05 | 0.04 | — | 0.09 | 0.04 | 0.07 | 0.11 | 0.03 | 0.04 | 0.07 | 0.09 | 0.03 | 0.05 | 0.06 | — | 0.03 | 0.02 | 0.06 |
| $NH_4$-N (mg $dm^{-3}$) | 0.4 | — | — | 0.6 | 0.5 | 0.4 | — | 3.3 | 0.9 | 0.5 | — | 1.2 | 0.4 | 0.7 | 2.0 | 0.3 | 0.5 | 0.4 | 0.9 | 0.3 | 3.5 | 1.0 | — | 0.4 | 1.3 | 1.4 |
| $PO_4$-P (mg $dm^{-3}$) | 0.1 | — | — | 0.3 | 0.2 | 0.1 | — | 0.9 | 0.5 | 0.3 | — | 0.7 | 0.2 | 0.2 | 0.6 | 0.1 | 0.1 | 0.4 | 0.6 | 0.1 | 2.5 | 1.0 | — | 0.2 | 0.4 | 0.7 |
| P – total (mg $dm^{-3}$) | 0.2 | — | — | 0.7 | 0.2 | 0.2 | — | 0.6 | 0.6 | 0.2 | — | 0.4 | 0.2 | 0.3 | 0.8 | 0.2 | 0.1 | 0.2 | 0.3 | 0.1 | 0.9 | 0.3 | — | 0.1 | 0.3 | 0.6 |

## Sampling techniques

Altogether, 156 samples of macroinvertebrates were collected during spring, summer and autumn seasons in years 2001–2002. At each site, two or three samples were taken from various locations by means of the standard Surber Sampler. Qualitative samples were also taken in order to capture taxa richness more completely. Looking for the biggest spatial heterogenity within a distance of 2 m, a kick-sampling technique was applied using a handnet (0.5 mm mesh size). Then, the content of each sample was washed in the field by a sieve with a mesh size of 0.5 mm. The collected individuals were preserved in 70% ethanol. Identification was done to the lowest possible taxonomic level (Kołodziejczyk & Koperski, 2000; Piechocki, 1979).

## Data analysis

The degree of similarity between macroinvertebrate communities and classification of sites was defined on the basis of Ward's method and a hierarchical cluster analysis (Bis, Zdanowicz, & Zalewski, 2000). For each site, in addition to the measure of total number of taxa and abundance, the diversity (D, H), saprobic (SI) and biotic (BBI, BMWP, BMWP-PL) indices were calculated. Correlations between biological indices and chemical variables were computed using the nonparametric Spearman's rank coefficient of correlation. All statistical analyses were performed using the STATISTICA package (version 5.1 PL).

For the statistical analyses a $\ln(x+1)$ transformation was used for the values of biological and chemical parameters to reduce the effects of extreme values (Digby & Kempton, 1987).

## Results

Examination of all samples resulted in a total number of 44 families representing the orders Oligochaeta, Hirudinea, Crustacea, Gastropoda, Bivalvia, Ephemeroptera, Trichoptera, Odonata, Coleoptera, Heteroptera, Megaloptera and Diptera. The total number of identified families varied between eight and 22 among particular sites. During each sampling, the minimum number of families (<8) was found in the middle stretches of Cielnica (sites C2-3) and Korzkiew (KO2) streams and the upper stretch of Ścinawa Niemodlińska (S2) one. On the other hand, the maximum number of families (>16) was usually observed within areas without settlements, i.e. in the headwaters of Ścinawa Niemodlińska (S1) and Stara Struga (SS1) streams, as well as the lower stretches of Cielnica (C4) and Korzkiew (KO3) streams and the Nysa Kłodzka river (site N6). At these locations the greatest total taxa number and the presence of the more sensitive ones to anthropogenic disturbance were simultaneously recorded. Whereas, in polluted areas taxa representing caddisflies Trichoptera (Limnephilidae, Leptoceridae, Polycentropodidae, Hydropsychidae), mayflies Ephemeroptera (Heptageniidae, Ephemerellidae, Ephemeridae, Baetidae, Caenidae) and also dragonflies Odonata (Calopterygidae, Coenagrionidae, Platycnemididae) disappeared or their numbers were significantly reduced. The most evident changes were recorded along the Ścinawa Niemodlińska River. At sites S1 and S5, benthic macrofauna revealed the highest taxa richness considering caddiesflies (four and five families, respectively) and mayflies (four and two families). These insects were absent at site S2. At the remaining four sites, caddiesflies and mayflies were represented only by Hydropsychidae, Limnephilidae and Baetidea. Moreover, particular families did not exceed 50 larvae, contrary to site S1.

Fauna of the lower Nysa Kłodzka River system was dominated by chironomid larvae, but the dominance structure differed among particular sites. Chironomidae were the dominant taxa in the majority (14) of the investigated sites, constituting from 36.8% to 61.2% of the benthic community structure. While among the remaining 12 sites macroinvertebrates showed greater differentiation in the community structure and the most abundant taxa were caddies larvae of Hydropsychidae (34.2–62%) and Limnephilidae (54%), mayflies Baetidae (24.7–60.4%), dipterans Limonidae (21%) and Simulidae (38.8%), oligochaetes Tubificidae (42.6–79%), freshwater hoglouse *Asellus aquaticus* L. (24.3%) and a predatory leech *Erpobdella octoculata* L. (25–55.5%). All other organisms were found in lower numbers and the abundance of particular taxa did not exceed 10%.

Site classification based on the macroinvertebrate composition as a result of cluster analysis is presented in Fig. 2. The dendrogram separates all sampling sites into two major groups, namely those of the Nysa Kłodzka River (with the exception of N5) and its tributaries (without C4 and KO3). The first major group, comprising almost all sites located along the trunk river as well

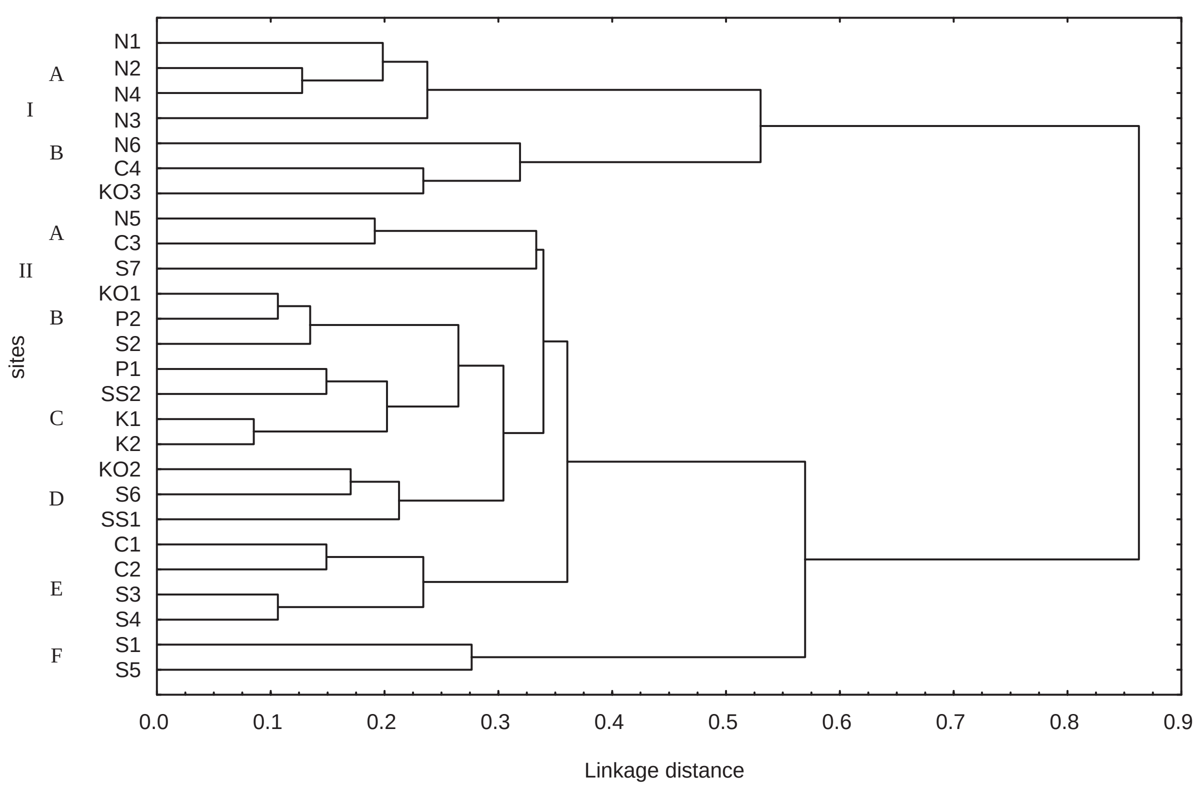


**Fig. 2.** Classification of sites based on similarities of macroinvertebrate communities. Ward's clustering method.

as in the mouths of two left-bank tributaries (the Cielnica and Korzkiew streams), was characterized by a number of taxa with habitats in slowly flowing water with sandy substrate abundant in the detritus, riparian vegetation and open canopy, e.g. common mollusc *Bithynia tentaculata* L., *Lymnaea* sp., and *Sphaerium* spp., and atmospheric breathing heteropterans *Sigara* sp. Further division resulted in two subgroups IA and IB, revealing moderate and low level of water pollution, respectively. This was caused by the higher taxa richness ($>20$ families) and the presence of taxa indicating low nutrient load conditions (Leptoceridae, Heptageniidae) in sites forming IB subgroup, in comparison with the IA one.

The second major group included almost all sites located along left- and right-bank tributaries, and also one site (N5) of the trunk river. This site, however, had a different character when compared to the other ones at the Nysa Kłodzka River, due to very shallow littoral zones. The results of the cluster analysis allowed for further separation of six subgroups of sites (IIA–IIF). They were characterized by a diversified structure of dominant taxa. The most abundant and representative families, apart from ubiquitous Chironomidae, were as follows: A – coleopterans Dytiscidae and oligochates resistant to organic pollution Tubificidae; B – leeches Erpobdellidae and Glossiphonidae; C – mayflies Baetidae and dipterans Limoniidae; D – caddisflies Hydropsychidae; E – dipterans Simuliidae; F – caddisflies Limnephilidae, Leptoceridae and Polycentropodidae.

Changes in the number of recorded taxa among particular sites as well as the presence/absence of organisms sensitive to pollution had a direct impact on the results obtained during the water-quality assessment. Values of the indices, calculated for each site, showed a similar pattern when compared with the taxonomic abundance (Table 2). Generally, the narrowest range of indices' values was usually obtained for sites situated along the streams of Kamienica (K1-2), Potok Skoroszycki (P1-2) and Stara Struga (SS1-2). These are small streams (1st order), flowing through agricultural areas and villages, where both sites are characterized by similar anthropogenic pressures and abiotic properties, e.g. width, depth and current velocity. On the other hand, the widest range was obtained for the streams of Cielnica, Korzkiew and Ścinawa Niemodlińska. All of them flow through villages and intensively cultivated areas as well as uninhabited areas, where meandering natural stream profiles have been preserved. Thus, sites assigned to the study varied considerably, from those with relatively low impact, a diverse macrofauna and, consequently, with high index scores (C4, KO3, S1, S5) to sites being significantly contaminated by organic pollutants, low index scores, resulting from less diverse fauna assemblages (C2-3, KO2, S2).

**Table 2.** Mean values of biotic, diversity and saprobic indices of 26 sites in the study area

| Index/site | N1 | N2 | N3 | N4 | N5 | N6 | C1 | C2 | C3 | C4 | KO1 | KO2 | KO3 | P1 | P2 | SS1 | SS2 | K1 | K2 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMWP(PL) | 51 | 52 | 68 | 50 | 36 | 78 | 46 | 27 | 28 | 89 | 46 | 28 | 87 | 40 | 30 | 69 | 59 | 65 | 63 | 88 | 29 | 51 | 49 | 93 | 57 | 46 |
| BMWP | 47 | 39 | 56 | 32 | 28 | 77 | 34 | 21 | 26 | 68 | 35 | 18 | 88 | 29 | 27 | 63 | 51 | 46 | 58 | 82 | 33 | 44 | 39 | 81 | 39 | 40 |
| BBI | 6 | 7 | 7 | 6 | 4 | 9 | 6 | 5 | 4 | 9 | 6 | 5 | 7 | 6 | 6 | 9 | 8 | 8 | 8 | 9 | 7 | 7 | 7 | 9 | 7 | 7 |
| Margalef (D) | 1.6 | 1.5 | 2.1 | 1.6 | 1.0 | 2.2 | 1.6 | 1.2 | 1.3 | 2.6 | 1.4 | 1.0 | 2.5 | 1.2 | 1.2 | 2.1 | 1.8 | 1.3 | 1.2 | 2.8 | 1.3 | 2.0 | 1.8 | 2.7 | 2.2 | 1.5 |
| Shannon (H) | 1.5 | 1.7 | 1.5 | 1.2 | 1.1 | 1.6 | 1.3 | 1.2 | 1.0 | 1.6 | 2.0 | 1.3 | 2.9 | 1.2 | 1.1 | 2.4 | 2.4 | 2.1 | 1.7 | 2.6 | 1.1 | 1.5 | 1.6 | 2.1 | 1.4 | 1.3 |
| Saprobic (SI) | 2.5 | 2.2 | 1.8 | 1.6 | 2.9 | 1.5 | 2.6 | 2.8 | 3.1 | 1.5 | 2.4 | 3.0 | 1.9 | 2.5 | 2.7 | 1.5 | 1.8 | 2.3 | 2.4 | 1.4 | 3.2 | 2.5 | 2.4 | 1.6 | 2.3 | 2.9 |

The BMWP(PL) index varied from 27 to 93 scores which, according to Polish classification, corresponded with the range of the classes IV–II of water quality, i.e. from heavily polluted to slightly polluted (Table 3). Altogether, the percentage distribution of the BMWP(PL) mean values revealed slightly polluted (23.1%), moderately polluted (61.5%) and heavily polluted (15.4%) sites.

As shown in Table 4, BMWP(PL) score system was well correlated with five common variables of chemical water quality (DO: 0.6814, $p<0.001$; nutrient compounds: from $-0.5017$, $p<0.05$ to $-0.7111$, $p<0.001$). Similar significant correlations, though slightly lower (except for phosphates), were obtained between chemical parameters and the saprobic index. The other biological indices were all correlated with DO, ammonium nitrogen and P-total.

## Discussion

Within the last decades, an increasing effort has been devoted to designing a more effective use of macroinvertebrates as monitoring and assessment tools for management of water resources (Buffagni, Crosa, Harper, & Kemp, 2000; Lorenz, Hering, Feld, & Rolauffs, 2004). The most effective use of such tools occurs when there is a clear understanding of the mechanisms, which lead to the presence or absence of species in the environment. The distribution of macroinvertebrates is known to be influenced by their response to various factors, such as food availability (Peeters, Gylstra, & Vos, 2004), hydraulic conditions (Voelz, Shien, & Ward, 2000), substrate composition (Sandin & Johnson, 2004) and increase in nutrient loads (Buss, Baptista, Silveira, Nessimian, & Dorville, 2002; Camargo, Alonso, & De la Puente, 2004). Moreover, the invertebrate fauna of different habitats is known to respond in different ways to water-quality variations (Parsons & Norris, 1996).

In the present study, the highest taxonomic richness of Trichoptera and Ephemeroptera was found at sites S1, SS1 (headwaters of streams), S5 and KO3 (stretches displaying suitable conditions for the self-purification of streams). However, the highest abundance for both orders occurred at sites K2, P1 and SS2, displaying an intermediate level of degradation. This was due to the high abundance of mayflies Baetidae and caddisflies Hydropsychidae. Both families are regarded as tolerant to organic pollution among mayflies and caddisflies, respectively, with species being segregated within different water-quality characteristics. Studies on caddiesflies from the Spanish Mediterranean coast (Bonada, Zamora-Munoz, Rieradevall, & Prat, 2004) revealed that at the family and species levels certain caddiesflies were sensitive to some variables but more tolerant to others, pointing at a high ecological diversification in rivers. *Hydropsyche dinarica*, for example, occurred sensitive to suspended solids and tolerant to phosphates. This may explain the presence of genera of *Hydropsyche* sp. and *Baetis* sp., though in low abundance, even in more nutrient contaminated river reaches of Cielnica and Korzkiew. However, insects belonging to mayflies and caddiesflies were not registered at sites S2 and C3, assigned along stream stretches with modified bank, limited abundance of macrophytes, and also subjected to uncontrolled domestic sewage discharge from unsewered villages. Sensitivity of these insects can be explained by their need for rather unpolluted water with high dissolved oxygen and low siltation (Lemny, 1982).

On the other hand, larvae of Chironomidae showed higher abundance with increasing organic pollution,

**Table 3.** Percentage distribution of water-quality classes, based on mean values of BMWP(PL), in particular streams and rivers

| River | Water-quality classes | | |
|---|---|---|---|
| | II (%) | III (%) | IV (%) |
| Nysa Kłodzka | 15 | 85 | — |
| Kamienica | — | 100 | — |
| Ścinawa Niemodlińska | 30 | 55 | 15 |
| Cielnica | 25 | 25 | 50 |
| Korzkiew | 33 | 34 | 33 |
| Potok Skoroszycki | — | 100 | — |
| Stara Struga | 50 | 50 | — |

**Table 4.** Values of correlation coefficients between the biological indices and the most relevant chemical variables

| Variables | DO | $NO_2$ | $NH_4$ | $PO_4$ | *P*-total |
|---|---|---|---|---|---|
| BMWP(PL) | 0.6814 | −0.5333* | −0.6318* | −0.5017** | −0.7110 |
| BMWP | 0.5827* | −0.5127** | −0.5431* | nc | −0.6443* |
| BBI | 0.6384* | nc | −0.6114 * | −0.5521* | −0.7228 |
| D | 0.6254* | −0.6419* | −0.4396 ** | nc | −0.5423* |
| H | 0.4482 ** | nc | −0.5190 ** | nc | −0.6743 |
| SI | −0.6632 | 0.5224* | 0.6228* | 0.6028* | 0.5955* |

$p<0.001$; $^*p<0.01$; $^{**}p<0.05$; nc – non correlated.

despite their dominance (>10%) or subdominance (9.9–1%) at most of the sites. Many authors (Grzybkowska, 1993; Dumnicka, 2002) have already demonstrated a significantly higher density and biomass of gathering collectors (Oligochaeta, Chironomidae) in river stretches affected by anthropogenic organic pollution. Chironomids appear to be least affected by environmental changes and may have more efficient recolonization mechanisms (Pires, Cowx, & Coelho, 2000).

As might be expected (Bis et al., 2000; Sandin & Johnson, 2004), the distribution of aquatic fauna within the study area is strongly determined by environmental variables, both chemical parameters of water and physical features of streams. Ward's method of cluster analysis segregated sites into several groups indicating similarities among macroinvertebrate communities. At present stage, the research focused on the investigation of the macroinvertebrate assemblages and the assessment of biological water quality of streams, where this information has not become available yet.

It is concluded that corresponding ranges of taxa richness/abundance and water-quality indices are determined by the same factors, and reflect the natural and anthropogenic disturbances in the Nysa Kłodzka River system. Mean values of the BMWP(PL) scores showed significant differences between relatively undisturbed (S1, S5, C4, KO3, SS1) and anthropogenically impacted (S2, C2-3, KO2) river stretches. They also showed a high correlation with several chemical variables. According to Armitage et al. (1983), the use of the average value of the family biotic indices seems to be preferable to the total value because average scores are less sensitive to sampling effort, seasonal changes and macroinvertebrate diversity. The other biological indices followed the same trend and indicated an overall increase in nutrient pollution, particularly along the middle reaches of Cielnica and Korzkiew streams as well as at S2 site of Ścinawa Niemodlińska. The saprobic index, however, seemed to be more restricted in water-quality classification in comparison with the BMWP(PL), as about 19% of the investigated sites obtained lower quality. Although saprobic and biotic indices are well correlated with organic pollution (Dahl, Johnson, & Sandin, 2004), saprobic indices proved to have a higher discriminatory power in undisturbed or poor water-quality conditions (Sandin & Hering, 2004). The degree of tolerance at the family level is related to the diversity of species and the tolerance range of individual species, therefore scores at the family level usually use intermediate values of species tolerance (Walley, Grbowitč, & Dzeroski, 2001). In this regard, indices at the family level may under- or overestimate water quality more than those based on species. Notwithstanding, indices at the family level may be adequate in terms of cost-efficiency and taxonomic experts available. Results obtained in this study are in agreement with the opinion and considerations of many authors (e.g. Graca & Coimbra, 1998) about the need and usefulness of the biotic index application in routine programmes of running water-quality monitoring.

In conclusion, the invertebrate fauna of the investigated streams and rivers are sensitive to the environmental conditions experienced and can, therefore, be used as a valuable monitoring tool in assessing freshwater ecosystems. The modified procedure, named the BMWP(PL) index, clearly distinguished impacted from relatively unpolluted sites and was correlated with the other existing biological indices and chemical variables. Although there is still a need for more intensive study and further testing of the effectiveness of the BMWP(PL) score, especially when incorporating the effects of abundance and biotop type, the index would be of use for the authorities responsible for water-quality monitoring and control.

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