Environment Protection Engineering

Vol. 36 2010 No. 2

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ECOLOGICAL IMPACT OF A DAM ON BENTHIC MACROINVERTEBRATES IN MONTANE RIVERS OF LOWER SILESIA

The ecological impact of dams on benthic macroinvertebrates found in three small montane rivers in south-western Poland was assessed. The macroinvertebrates lived in upstream and downstream zones as well as in the river free of any anthropogenic impact. We sampled 14 543 macroinvertebrate individuals in order to show how they respond to an impounding reservoir. We employed biotic indices (BMWP-PL, ASPT) to prove their usefulness as the indicators of anthropogenic perturbation. The diversity of macroinvertebrate species above dams and in the "natural" river was significantly higher than below dams. The chironomids and dipterans dominated downstream. However, the density of Ephemeroptera, Trichoptera and Crustacea was significantly reduced downstream. The analysis of Simpson's diversity index also proved the above results.

1. INTRODUCTION

The structure and functioning of ecosystem can vary considerably across environmental gradients [1]. As is commonly known, a river continuity is rapidly broken when dams impound the river flow. The impoundment of river by building barriers to keep backwater and raise its level leads to the formation of reservoirs [2]. Such transformations bring about structural, physical and chemical changes which affect the biota [2].

The search for improved methods of monitoring water quality has led to the development of techniques for rapid bioassessment of river and evaluation of water quality using benthic macroinvertebrates [3]. The purpose of biological assessment is to characterize the status of the water condition associated with anthropogenic perturbations [4].

Although the problems associated with the impoundment have been mentioned in a variety of scientific articles, for example [2], [5], the ecological impact of river impoundment on macroinvertebrates in Poland has rarely been studied [6], [7]. In our country, BMWP-PL system, a modified version of the method used by the British

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Monitoring Working Party (BMWP), is recommended but rarely used for assessing water quality. This method has never been employed to study the impact of impoundments on biodiversity in Poland.

The purpose of this paper is to present a general assessment of benthic macroinvertebrate species composition and the diversity of upstream and downstream zones of the reservoir and to compare them with those of not transformed river, applying BMWP-PL and its modification, i.e. ASPT (Average Score Per Taxon), in order to prove the usefulness of the latter in the detection of anthropogenic perturbances.

2. MATERIALS AND METHODS

All rivers chosen for our studies are within the basin of the Odra river, being either its direct tributaries (the Bóbr) or the tributaries of the rivers which supply the Odra river (the Kwisa, the Bóbr tributary) and the Biała Lądecka (the Nysa Kłodzka tributary). The studies were carried out downstream and upstream the Leśniawski reservoir on the Kwisa river (sites 1 and 2), downstream the Bóbr river (the Wrzeszczyński and Bukówka reservoirs) and upstream this river (the Pilchowicka dam) (sites 3, 4 and 5) and finally within the Biała Lądecka river still free of big dams (site 7). All rivers occur in the mountainous region of Lower Silesia, south-western Poland. **Seven river sites were chosen in such a way as to represent as many microhabitats as possible, thus their distance from the dam constructions might be various** (figure 1). Main features of the sampling sites are described below:

Site 1, the Kwisa river, is located about 2 km downstream the Złotnicki reservoir. The marginal vegetation comprises mainly grasses, shrubs and trees. The substratum is composed of mud (55%), sand (40%), gravel (5%) and small stones. Water very cloudy. The dominant macrophytes are *Saggitaria sagittifolia*, *Ranunculus* sp., and *Callitriche* sp.

Site 2, the Kwisa river, is located about 2 km upstream the Leśniawski reservoir. It is the forest part of the river. The marginal vegetation comprises mainly grasses (*Poaceae*). The substratum is composed of gravel (40%), stones (40%), and sand (10%). Water is slightly cloudy without any water vegetation.

Site 3, the Bóbr river, is located about 1.5 km downstream the Wrzeszczyński reservoir. Forest part of the river. The marginal vegetation comprises mainly grasses (*Poaceae*), shrubs and trees. The substratum is composed of mud (90%) and sand (10%). Water is slightly cloudy. The dominant macrophytes are *Saggitaria sagittifolia*, *Callitriche* sp. and *Nymphaea alba*. The dominant plants along the bank are *Phragmintes australis* and *Acorus calamus*.

Site 4, the Bóbr river, is located about 200 m upstream the Pilchowicki reservoir. It is a forest-meadow part of the river. The marginal vegetation comprises mainly grasses (*Poaceae*) and shrubs and trees. The substratum is composed of stones (50%), gravel (40%) and sand (10%). The dominant macrophytes are *Callitriche* sp., *Potamogeton natans*, and *Ranunculus* sp. Along the bank *Phragmintes australis* and *Acorus calamus* predominate.

Site 5, the Bóbr river, is located about 100 m downstream the Bukówka reservoir. Meadow part of the river. The marginal vegetation comprises mainly willows, *Salix alba* predominates, few grasses and a plant *Alisma plantago-aquatica*. Lack of submerse vegetation is observed. The substratum is exclusively composed of mud and loam.

Site 6, the Bóbr river, is located about 200 m upstream the Bukówka reservoir. Concrete canal. The marginal vegetation comprises mainly grasses and willows, mainly *Salix alba*. The water is clear. The substratum is composed of stones and gravel (95%) and sand (5%). The substratum is rich in submerse vegetation, mainly *Ranunculus* sp.

Site 7, the Biała Lądecka river, is free of dams. The marginal vegetation is very rich, comprises mainly grasses, shrubs and trees. The water is clear. The substratum is composed of stones and gravel (95%) and sand (5%). The submerse vegetation is poorly developed, *Ranunculus* sp. predominates.

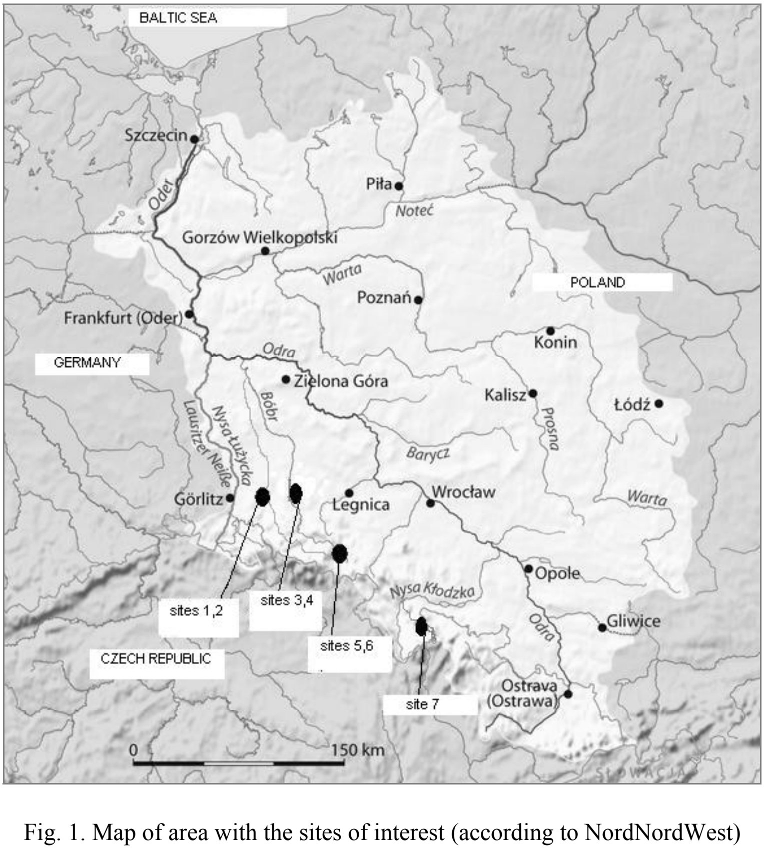

Fig. 1. Map of area with the sites of interest (according to NordNordWest)

The samples of benthic fauna were collected within the seven study sites at fortnightly intervals from the beginning of June to the end of July 2005, 2006. Althogether, 8 samplings were done at each site (the number of the samples collected at each site were at least 10). All sampling and data processing were done according to the stipulations of BMWP-PL (http://www.eu-star.at/pdf/PolishMacroinvertebrateSamplingProtocol.pdf z dnia 24.03.2009 [8]. At each site, macroinvertebrates samples were collected using kick sampling technique [9]. A handnet (160 μm mesh size) and Birge-Ekman Box Corer were also used for the studies in deeper water. We sampled 0.25 m^2 of the substratum at 7 sampling points to form one composite site. The samples collected were preserved in 96% ethanol, and all specimens identified to family or higher taxon in the case of non-insects according to BMWP-PL. The percentages of macroinvertebrate taxa were calculated for each site for the total sampling period. The Average Score per Taxon (ASPT) was also determined, by dividing the macroinvertebrate score (obtained from BMWP-PL calculations) by the number of taxa at each site [10], [11]. At each site the minimum physical properties of the water were examined using the multi-probe method for pH, temperature and conductivity measurements.

The temperature, conductivity, pH, BMWP-PL scores, ASPT and the number of individuals from all the sites were subjected to ANOVA single-factor analysis. Taxon diversity was calculated using Simpson's diversity index (Ds). Regression analysis was carried out for the number of taxa, temperature, conductivity, and pH.

3. RESULTS AND DISCUSSION

A total of 14 543 invertebrate individuals were sampled (table 1). The differences upstream (sites 2, 4, 6) versus downstream the dam (sites 1, 3, 5) and in the Biała Lądecka river (site 7) in an abundance of macroinvertebrates (Ephemeroptera, Diptera, Trichoptera and Crustacea) were highly significant. The differences in an abundance of Hirudinea, Odonata, Coleoptera and Gastropoda were not significant (table 2).

Table 1

Percentage of species participation in all the samples collected

Taxon	Participation (%)
Diptera	58.9%
Trichoptera	16.8%
Ephemeroptera	14.6%
Crustacea	3.5%
Hirudinea	2.4%
Odonata	2.7%
Coleoptera	0.8%
Gastropoda	0.16%

Table 2

Differences in abundance of taxa upstream dam and in not transformed river versus those downstream dam

Taxon	Mean abundance per sampling site upstream dam	Mean abundance per sampling site downstream dam	Mean abundance in site No. 7 (no dam)	Significant difference (*P*)
Ephemeroptera	920.9	410.74	790.77	<0.01
Baetidae	550.8	410.74	560.45	0.34
Ephemerellidae	370.1	0	230.32	0.20
Trichoptera	749.07	354.08	1345.3	0.04
Glossosamatidae	230.41	0	440.67	0.07
Leptoceridae	90.71	270.65	50.45	0.23
Hydropsychidae	241.45	0	141,32	0.06
Lepidostomatidae	43.22	0	0	0.13
Polycentropodidae	0	83.43	0	0.98
Ryacophilidae	143.28	0	689.41	<0.01
Sericostomatidae	0	0	23.45	0.87
Diptera	24.91	8519.67	24.45	<0.01
Muscidae	24.91	0	0	0.4
Chironomidae	0	7750.66	0	<0.01
Culcidae	0	769.01	0	0.78
Limoniidae	0	0	25.45	0.98
Hirudinea	27.56	322.98	0	0.02
Erpobdellidae	27.56	322.98	0	0.02
Odonata	0	396.18	0	0.07
Lestidae	0	197.2	0	0.2
Colapterygidae	0	198.98	0	0.3
Coleoptera	0	123.45	0	0.05
Gyrynidae	0	123.45	0	0.05
Crustacea	509.76	0	0	<0.01
Gammaridae	176.87	0	0	<0.01
Asellidae	332.89	0	0	<0.01
Gastropoda	0	0	24.08	0.4
Physidae	0	0	24.08	0.4

There were significant differences in BMWP-PL score and ASPT upstream the dam (sites 2, 4, 6) and within the Biała Lądecka (site 7) versus downstream the dam (sites 1, 3, 5) (table 3). Downstream the dam (sites 1, 3, 5) variances were also lower than upstream the dam (sites 2, 4, 6) and in the Biała Lądecka (site 7), suggesting a reduced macroinvertebrate diversity as a result of impoundment (figure 2). This was also the case with abiotic variables (water temperature and conductivity, but not with pH values, which differed significantly; table 4). The Ephemeroptera, mainly Beatidae, predominated. They preferred upstream and not transformed sites, but could also be found in less numbers downstream (table 2). The second family, Ephemerellidae, occurred only upstream the dam and in the Biała Lądecka river. Of Trichoptera the species

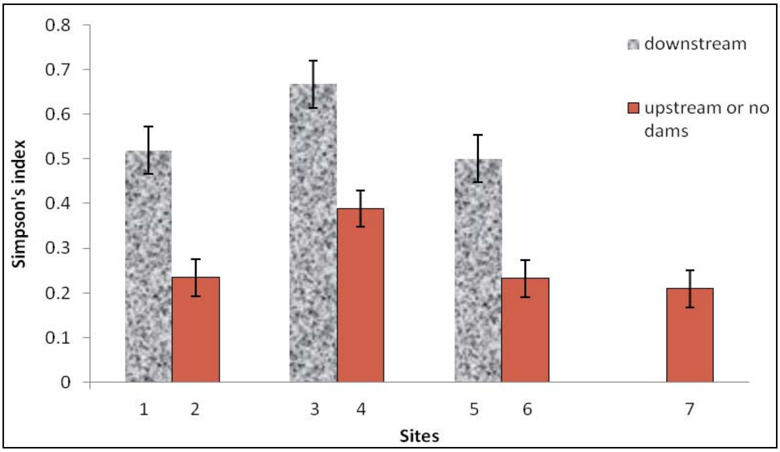

Fig. 2. Differences in macroinvertebrate diversity among sites (sites 2, 4, 6 upstream dams, sites 1, 3, 5 downstream dams, site 7, the Biała Lądecka river – not transformed)

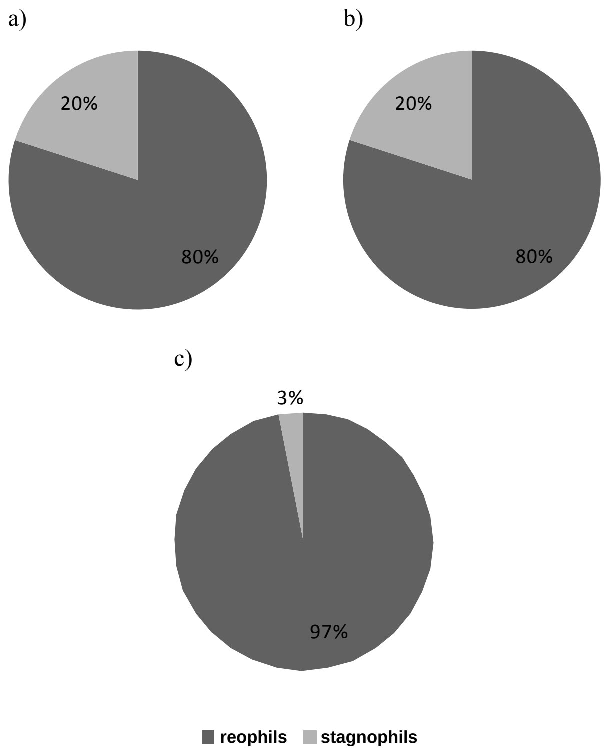

Fig. 3. The structure of domination: reophil (grey) and stagnophil (white) macroinvertebrates in the Bóbr river and the Kwisa river. Sites 2, 4, 6 upstream dam (a), sites 1, 3, 5 downstream dam (b), site 7, the Biała Lądecka – not transformed river (c)

belonging to such families as Glossosomatidae and Hydropsychidae were abundant upstream the dam and in the Biała Lądecka river as the organisms preferring running water, the family Leptoceride which prefers stagnant water was found in all the sites, and finally the families like Ryacophilidae were abundant accidentally (upstream the dam and in the Biała Lądecka). An absolutely reophil family Sericostomatidae which prefers mountainous streams occurred only in the Biała Lądecka, and Lepidostomatidae was always found in clean running water (upstream the dam and in the Biała Lądecka), Chrinomidae downstream the dam was found in great abundance, and some Culcidae representatives were also observed only downstream. The adult Coleoptera and also the Odonota larvae (Lestidae and Colapterygidae) were caught only downstream the dam and vice versa – Crustacea were present only upstream. Impoundment changes the species structure from that dominated by reophil species to that of stagnophil species which was proven by our study (figure 3). To sum up, the biodiversity of macrozoobenthos is strongly affected by dam constructions.

Table 3

Differences in macroinvertebrate scores (BMWP-PL, ASPT) for all taxa combined upstream dams and in not transformed river versus those downstream dams

Method	Mean score per sampling unit upstream dam	Mean score per sampling unit downstream dam	Mean score per sampling, the Biała Lądecka (no dams)	Significant difference (*P*)
BMWP-PL	41.89	34.44	59.16	<0.01
ASPT	6.56	5.83	7.83	<0.01

Water quality, substratum, peryphitone type and food availability are the most important factors influencing the abundance and distribution of benthos [2]. The granulation of substratum is also of a great importance, because in the case where the substratum particles are big enough they can be the hiding places for the animals described in our study (species diversity decreased significantly downstream the dam (sites 1, 3, 5), the greatest species diversity was observed at not transformed site 7). Dams change a lotic habitat of a river into a lentic one [12], since they reduce the amount of running water and make the transport of organic deposits and inorganic substratum impossible. This phenomenon is responsible for the formation of a homogeneous substratum on the river bottom. Such a substratum is known to favour both colonization of the place by Oligochaeta, Chironomidae and Mollusca and their quick development [6], [7]. Macroinvertebrates also respond to the rise in water temperature [13] which subsequently decreases the water flow and oxygen availability. Such a situation was observed in our study (table 3).

Table 4

Differences in abiotic variables for all taxa combined upstream dams
and in not transformed river versus those downstream dams

Abiotic variable	Mean value per sampling unit upstream dam	Mean value per sampling unit downstream dam	Mean value per sampling, the Biała Lądecka (no dams)	Significant difference (*P*)
Water temperature (C°)	14.0	21.3	17.1	<0.01
Conductivity (mSm^{-1})	0.53	0.32	1.36	<0.01
pH	6.0–7.0	7.0	7.0	0.12

Usually, pH of water in unpolluted streams ranges between 6.0 and 9.0 [14], which is confirmed by our study. The similarity of the pH values in different stations irrespective of the nature of anthropogenic perturbations is a typical feature of stream [15].

In this study, Trichoptera and Ephemeroptera predominated in the upstream zone (sites 2, 4, 6), and Diptera in the downstream one (sites 1, 3, 5) which has also been proved by other studies on the influence of impoundment on the macrozoobenthos communities [6], [7]. Epheromtera and Trichoptera die as soon as dams are built and are replaced by Diptera occurring in abundant amounts [16].

The values of macroinvertebrate scores BMWP-PL and ASPT were considerably lower upstream the dam, which confirms their usefulness as a biomonitoring tool (rapid assessment protocols for water quality monitoring).

4. CONCLUSIONS

- The changes in the number and diversity of macroinvertebrate communities were observed at the sites located upstream and downstream the dam and in the river with no anthropogenic transformations.
- High chironomid domination, observed downstream the dam, showed their flexibility and resistance to habitat transformations.
- The ecological structure of benthos communities changed from the dominance of reophil species which inhabited shallow water with strong currents to the dominance of stagnophil species preferring stagnant, slowly moving water.
- The scores calculated from biotic methods for assessing the water quality (BMWP-PL and ASPT) also showed the impoundment impact on biodiversity.

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