

Short-Term Effects of Stream Restoration and Management on Macroinvertebrate Communities in Lowland Streams

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Abstract:- As a result of hydrotechnical treatments, a 2.5 km long reach of the lowland Kwacza River was elongated to 3.5 km. Restoration triggered off short-term changes in the river ecosystem, which were studied through habitat and invertebrate analysis. Sampling was conducted at 10 sections before and after restoration. Invertebrates quickly colonized various habitats and thus improved biological diversity of the Kwacza River. The only taxon that increased its ecological importance was Gammaridae. In turn, Ephemerellidae concentrated at places with better oxygen conditions. The neural network model revealed that variables directly connected with restoration were not as important as primarily hypothesised.

Keywords:- biological engineering, monitoring, invertebrates, Poland

I. INTRODUCTION

Streams and rivers form a dense net of lotic waters, which constitute an interfacial system with the surrounding landscape. When humans influence the system, the stable ecological equilibrium is upset [1]. Anthropogenic pressure considerably affects biodiversity. It mainly causes the disappearance of stenotopic species [2]. That influence can be observed particularly in small watercourses flowing through urban settlements. Such systems allow a thorough analysis of the human impact on a river valley as well as the ecological structure of a watercourse and its vicinity. In order to counteract the morphological degradation of streams and rivers it is advisable to restore their former physical features (e.g. [3, 4]). This has been applied in the USA and Western Europe on various scales and with different approaches [1, 5, 6]. Restoration is usually defined as “a complete structural and functional return to a pre-disturbance state”. Most of river restoration projects located in lowlands are applied to re-create morphological features and, thus, increase the diversity of habitats. Since lowland streams are mainly located in agricultural areas or urban settlements, it is rarely feasible to achieve complete restoration [7, 8, 9].

The Słupia River with its tributaries is one of the main rivers in the Pomerania region. That system is valuable for salmonid fish habitats and spawning grounds. However, it is highly anthropogenically transformed, particularly in the central course of the river, which disturbance destabilizes functioning of the ecosystem. The Kwacza River (one of the largest tributaries of Słupia) was channelized at the beginning of 20th century. Its riverbed was straightened and fenced with weirs, which limited the migration of hydrobionts and thus deteriorated the ecological state of the watercourse [10, 11]. In order to improve ecological quality a set of hydrotechnical treatments were applied in 2007. They aimed at the restoration of the outlet fragment of the Kwacza River [12]. The effects of re-meandering have been the subject of an interdisciplinary research effort that included invertebrate analyses. That ecological formation, due to low mobility and considerable susceptibility to environmental changes, is an ideal object for surveying short-term changes [10, 13, 14]. The primary re-colonization source is downstream drift to new habitats [6, 15]. Restoration of invertebrate communities can be based on the diversification of habitats as well as the removal of obstacles blocking ecological channels. Large rivers are characterized by considerable resilience. They quickly recover after disturbance. Even the medium-sized rivers, like Słupia, can develop high resilience and their colonization is a rapid process [10, 14]. In contrast, the lack of upstream refuge areas in small headwater streams as well as the establishment of macroinvertebrate communities rely on the immigration from other stream systems [16]. Recovery from disturbances depends on the availability of stable substrata, which form refuge areas. Another important factor is the presence of macrophytes, which may be used as shelters and the source of food for invertebrates.

Water quality of the majority of Polish streams has significantly improved over the recent two decades (e.g. [8]). However, this improvement has not followed by an overall improvement in the quality of stream ecosystems. This situation is probably caused by poor physical conditions of many lowland streams (e.g. [12]). The deterioration of streams and riparian areas in Poland is mainly connected to the change in land use from forested land to intensively cultivated land. Almost 60% of Poland is presently arable farmland and 23% forest. Cultivation of farmland has been followed by the extensive straightening and culverting of streams and the drainage of riparian wetlands.

The main aim of the present study is to investigate the short-term effects of the restoration of the Kwacza River (tributary of the Słupia River) on invertebrate habitats and community structure. In order to investigate those relationships, the sampling the Kwacza River prior to the restoration in 2007 and again after the completion of restoration in 2008 were performed. We hypothesized that variables directly connected with restoration would be the most important parameters influencing macroinvertebrates.

II. CHARACTERISTIC OF THE STUDIED AREA

The Kwacza River is a tributary of the middle Słupia River and drains the area of 85 km². According to the physico-geographical division of Poland [17], Kwacza is located in the mesoregion Równina Słupska (313.43) being a part of macroregion Pobrzeże Koszalińskie (313.4). The Kwacza river basin borders on the Wieprza drainage area to the west and the middle Słupia subbasin to the east.

The hydrological regime of Kwacza is characterized by ground, rain and snow supply. Mean water flow is 0.97 m³s⁻¹. Unitary outflow from the drainage area is rather high compared to other rivers of the region and amounts to 13 ls⁻¹km². Water supply of the Kwacza River measured as annual outflow is equal to 34.89 mln m³ with more than half (54%) occurring in winter [8].

The applied restoration works included the formation of cataracts, semi-palisades, groins and artificial islands as well the removal of alder clusters which shadowed the riverbed. Altogether 67 deregulation solutions were applied in the outlet section of the Kwacza River [12].

III. MATERIAL AND METHODS

Sampling

Invertebrate communities were investigated every three months throughout four seasons before the restoration (2007) and also after re-meandering (2008). 30 sampling sites in the Kwacza riverbed were selected. Consecutive sites formed 10 sections and each of them ranged from one side, through the centre of the watercourse, to the other side of the river (Fig. 1).

Samples were taken from the surface with a 95 cm² scraper and then sieved through a 300 μm mesh size benthic sieve. The collected material was placed in glass containers and fixed in situ with 4% formaldehyde solution. Then, in a laboratory, organic matter and fine detritus were separated from benthic organisms. Invertebrates were identified to species or genus except for Oligochaeta, which due to the difficulties with identification were determined to class. Density of invertebrates was expressed as number m⁻². For Oligochaeta only the individuals with retained. In preliminary analysis the following factors were calculated: frequency (Fr, %), density dominance index (D_i, %), ecological importance index (Q, %), and Shannon diversity index (H'). The frequency of the identified taxa was calculated according to the following formula:

$$Fr = N_a/n \cdot 100\%$$

where: N_a – number of samples with a given species

n – total number of samples

The index of constancy of occurrence is mostly used as the parameter which indicates the level of connection between a taxon and the environment. According to Tichler the index is classified as follows: euconstants (75.1 – 100%), constants (50.1 – 75.0%), accesoric species (25.1 – 50.0%), accidental species (<25.0%).

The domination index in terms of density is defined by the formula:

$$D_i = A/A_{av} \cdot 100\%$$

where: A – average density of a given species

A_{av} – total average density for the whole reservoir

The ecological importance index Q was calculated according to the formula

$$Q = \sqrt{Fr \cdot D_i}$$

where: D_i – domination index (in terms of density)

Fr – frequency.

The following classification was applied in this study: very high >30.00%, high 15.01-30.00%, moderate 10.01-15.00%, low 5.01-10.00%, very low <5.00%.

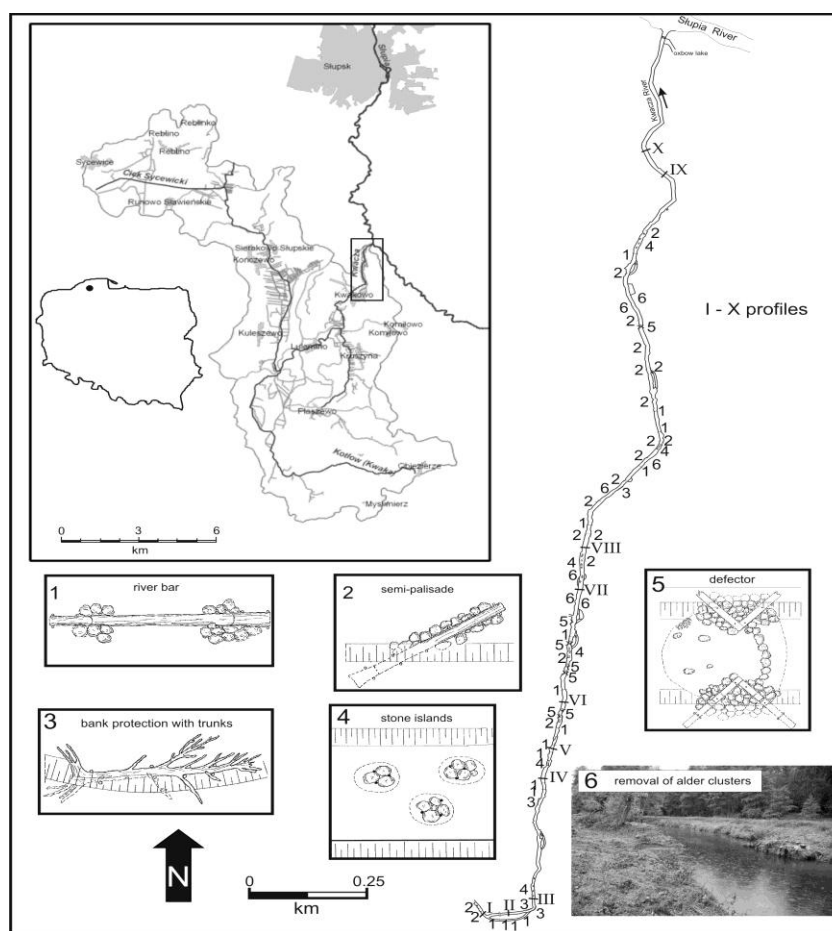


Figure 1 Distribution of consecutive hydrotechnical works (1-5) and sampling sections (I-X) in the restored part of the Kwacza River.

Environment quality was assessed using invertebrates according to the Polish biotic system BMWP-PL [18]. That index is calculated by summing up points attributed to the identified benthic organisms. Additionally the ASPT (Average Score Per Taxon) index was determined, which shows the average sensitivity of consecutive taxa:

$$\text{ASPT} = \text{index BMWP} / \text{no. of taxa}$$

The obtained values of both parameters after ascribing ranks X and Y were used in the general assessment of water quality OQR (Overall Quality Rating):

$$\text{OQR} = X + Y/2$$

Temperature, redox potential, conductivity, resistivity, dissolved oxygen (DO), oxygen saturation, nitrite, nitrate, ammonia nitrogen concentrations, total dissolved solids (TDS) and pH were measured *in situ* with the use of a calibrated portable multiparametric probe YSI 6600 (YSI Environmental, USA). 2.0 liter water samples were collected at an approximate depth of 20 cm into polycarbonate bottles rinsed with acid. In the course of 24 h, samples were filtered with the use of Whatman® glass fiber filters and GF/F glass fiber filters (incubation at 450°C for 4 h) to determine the quantity of dissolved particles. The samples were analyzed by ion chromatography DR2800 (Hach-Lange, USA) to identify the concentrations of total phosphorus concentrations, orthophosphates, chlorides, chlorophyll.

Each sampling site was described by its number ('sampling site'), the type of applied restoration treatment ('technical solutions'), its localization in the riverbed ('localization': left side, right site, centre) and the studied river section in km ('distance'). Additional variables used in data analyses were 'season' and 'restoration' (before/after).

Data analysis

First, data were analyzed with the help of ANOVA in order to indicate the influence of different seasons, trophic levels and thermal conditions. The post-hoc Tukey's test was used to reveal significant differences. The assumptions of ANOVA – normality and homogeneity of variances – were checked using the tests of normality (Kolmogorov-Smirnow, chi-square) and the Levene's test. When the assumptions were violated, additionally the non-parametric tests were applied (Kruskal-Wallis and Dunn's tests). Due to

multivariaty and non-normality of the obtained data set, the used modelling technique was ANN (Artificial Neural Networks) [19]. Multi layer perceptrons (MLP) were applied. They estimate a stochastic approximation of multivariate functions. The consecutive neural networks were formed and trained using back propagation and conjugate gradient algorithms by Automatic Problem Solver. Cases were divided using a bootstrap method into 3 subsets:

- training (Tr) - used for the training of a neural network;
- verification (Ve) - used for verifying the performance of a network during training;
- testing (Te) - used for assessing the predictability and accuracy of a neural model on data not presented during training and validation (cases remained after creating a training subset during bootstrap).

The following criteria for choosing the best neural network were applied: value of SD Ratio (ratio between error standard deviation and standard deviation of experimental data) and correlation (Pearson's correlation coefficient between experimental and calculated data). Then, the sensitivity analysis was performed. As a result, a ranking of input variables was created. It was based on calculations of the error, when a given input variable is removed from the model. The ratio of the error for the complete model to the one with ignored variable was used to order variables according to their importance.

The analyses were performed using Statistica 9.0 software [20] except for the Dunn's test, which was calculated with AZB software.

IV. RESULTS AND INTERPRETATION

Environmental conditions

Physico-chemical characteristics of the Kwacza River presented in Table I. Among the analyzed parameters nitrate nitrogen and phosphorus compounds deteriorated water quality of Kwacza and reached values exceeding the accepted norms for clear waters in Poland (first class).

Table I: Water quality of the Kwacza river before and after restoration (in the column mean value and standard deviation value in parentheses are presented) (Note: n- number of cases; TDS – Total Dissolved Solids; NTU - Nephelometric Turbidity Units).

Parameters	before restoration (n=90)			after restoration (n=90)		
	Spring	Summer	Autumn	Spring	Summer	Autumn
	2	3	4	5	6	7
Depth (cm)	10.5 (0.1)	10.5 (0.1)	10.5 (0.1)	16.8 (6.4)	12.3 (7.0)	10.6 (0.1)
Temperature (°C)	13.7 (0.4)	16.4 (0.1)	8.8 (0.1)	12.9 (3.5)	12.6 (4.2)	8.7 (0.1)
Reaction (pH)	7.57 (0.14)	7.68 (0.11)	7.35 (0.12)	7.54 (2.02)	6.79 (2.26)	7.74 (0.03)
Conductivity (mS cm ⁻¹)	0.372 (0.012)	0.369 (0.001)	0.374 (0.012)	0.350 (0.099)	0.332 (0.110)	0.389 (0.001)
Resistivity*(mS cm)	3247 (2) ^{5,6,7}	3246 (3) ^{5,6}	3247 (3) ^{5,6}	4874 (2) ^{2,3,4}	4857 (6) ^{2,3,4}	4839 (126) ²
TSD (mg L ⁻¹)*	2.4 (0.1) ⁵	2.4 (0.0) ^{2,4}	2.4 (0.1) ^{3,5}	2.3 (0.6) ^{4,3,7}	2.2 (0.7) ⁷	2.5 (0.0) ^{4,5,6}
N-NO ₃ (mg L ⁻¹)*	0.45 (0.17) ^{4,6,7}	0.35 (0.01) ^{4,6,7}	0.71 (0.04) ^{2,3,5,6}	0.56 (0.21) ^{2,3,7}	0.14 (0.05) ^{4,7}	0.16 (0.05) ^{2,3,4,5,6}
P-PO ₄ (mg L ⁻¹)*	0.296 (0.056) ^{3,6}	0.373 (0.065) ^{2,4,7}	0.254 (0.045) ^{3,6,7}	0.211 (0.059) ^{2,3,6}	0.328 (0.117) ^{4,5}	0.312 (0.058) ⁴
T-P (mg L ⁻¹)	0.834 (0.125) ^{3,5}	1.542 (0.207) ^{2,6,7}	0.832 (0.114) ⁵	1.163 (0.277) ^{2,4,6}	0.793 (0.278) ^{3,5}	0.799 (0.061) ³
Chlorides (mg L ⁻¹)	22.6 (2.4)	20.8 (3.6)	22.5 (2.6)	36.7 (10.6)	15.7 (5.4)	10.6 (2.5)
Chlorophyll (µg L ⁻¹)	13.2 (2.4)	14.1 (2.2)	8.5 (2.1)	8.2 (6.8)	5.7 (3.6)	9.2 (1.9)
Dissolved oxygen (mg L ⁻¹)*	8.03 (2.73) ^{3,4,7}	10.90 (9.51) ^{2,4,6,7}	3.46 (0.29) ^{2,3,5,6}	9.9 (3.5) ^{4,7}	7.81 (2.64) ^{3,4,7}	3.48 (0.30) ^{2,3,5}
Oxygen saturation (%)*	30.5 (3.5) ^{3,5,6}	111.9 (0.9) ^{2,4,6,7}	29.8 (2.5) ^{3,5,6}	95.21 (33.67) ^{2,4,7}	75.8 (25.6) ^{2,3,4,7}	29.9 (2.5) ^{2,3,5,6}
N-NH ₄ (mg L ⁻¹)*	0.28 (0.04) ^{5,6,7}	0.30 (0.02) ^{4,5,6,7}	0.23 (0.02) ^{3,5,6,7}	0.02 (0.01) ^{2,3,4,6}	0.01 (0.01) ^{2,3,4,5}	0.01 (0.01) ^{2,3,4}
Redox potential (mV)	150 (17)	137 (7)	154 (12)	105 (35)	176 (59)	206 (5)
Salinity (mg L ⁻¹)	0.18 (0.01)	0.18 (0.00)	0.18 (0.01)	0.17 (0.05)	0.16 (0.05)	0.19 (0.00)
Turbidity (NTU)	2.9 (0.9)	2.8 (0.9)	3.4 (1.4)	10.9 (16.3)	8.4 (21.6)	2.8 (1.6)

* = significant differences (nonparametric Kruskal-Wallis, $p \leq 0.05$) between research periods

1-7 = significant differences (nonparametric Dunns tests, $p \leq 0.05$) between consecutive research periods

Comparative analysis for average values of physiochemical parameters before and after Kwacza restoration revealed the decrease in total dissolved solids, nitrate nitrogen and orthophosphate contents. The remaining factors did not significantly changed their levels (Kruskal-Wallis and Dunns tests, $p > 0.05$) both between profiles as well as within a profile (centre, left and right sides). The biggest differences were found in the cut-off section with profile K2 where most of the parameters changed statistically significantly, i.e. conductivity and TDS concentration of PO_4 and Cl as well as oxygen saturation (ANOVA, $p = 0.00$ in all the cases).

Chemical parameters of water differed statistically significantly between seasons both before and after restoration. This situation was observed mainly for nutrients: NO_3 ($p < 0.02$), PO_4 ($p < 0.02$), T-P ($p = 0.00$) and NH_4 ($p = 0.00$), as well as for oxygen conditions ($p = 0.00$).

No statistically significant differences were obtained for the studied parameters between sites of different localization in the riverbed (centre, left and right riverbanks) both before and after restoration. Our study indicated considerable influence of land use in the Kwacza drainage area on the concentration of total phosphorus and orthophosphates (Obolewski *et al.* 2008). Both before and after restoration the contents of total phosphorus were within the range typical of the lowest quality waters (class V). Orthophosphate concentration in Kwacza was higher comparing to oligo- and β -mezosaprobic rivers [21]. The analyses of nitrogen mineral forms suggested their accumulation (biosorption) in the Kwacza river basin.

Patterns of macroinvertebrate abundance

The investigation of invertebrate communities inhabiting the Kwacza River was conducted every 3 months. Altogether 60 macrozoobenthos taxa both in the Kwacza were identified. Among them, both in 2007 and 2008 and in all the studied sections of Kwacza riverbed, the highest densities were found for Ephemeroptera and Diptera larvae (Table II).

Table II: Invertebrate composition in the Kwacza. Data are mean (s.d.) densities (indiv. m^{-2}) from seasonal samples after and before restoration of the Kwacza River (Note: R= right bank, C = central zone, L = left bank; n= number of cases; IR = Invertebrate richness; N = Total invertebrate abundance; H' = Invertebrate Shannon diversity index; J = Invertebrate evenness)

	before restoration (n=90)			after restoration (n=90)		
	R	C	L	R	C	L
	2	3	4	5	6	7
IR	20	14	21	24	14	20
N*	192 ⁵ (139)	42 (55)	102 (103)	350 ² (255)	35 (36)	127 (127)
H	0.93	0.74	0.83	0.91	0.83	0.84
J	0.93	0.77	0.85	0.91	0.84	0.84
Oligochaeta	2.1 ⁵ (2.6)	0.0	2.8 (2.1)	4.0 ² (2.7)	0.0	3.0 (2.4)
Hirudinea	0.0	1.1 (0.0)	1.0 (0.0)	0.0	0.0	1.3 (0.1)
Crustacea*	2.3 (1.8)	1.6 ⁶ (1.1)	6.0 (5.8)	2.9 (2.3)	4.1 ³ (1.3)	7.1 (10.3)
Ephemeroptera*	11.6 ⁵ (10.0)	8.2 ⁶ (8.4)	24.1 ⁷ (20.7)	6.3 ² (7.1)	1.8 ³ (1.0)	9.2 ³ (11.5)
Trichoptera*	3.5 (0.0)	1.8 (0.1)	1.3 ⁷ (0.6)	4.2 (5.1)	2.6 (2.2)	3.8 ⁴ (3.2)
Odonata	0.0	0.8 (1.2)	1.1 (1.6)	0.7 (0.0)	0.0	1.1 (0.0)
Plecoptera	0.0	3.5 ⁶ (2.7)	0.0	0.0	0.0 ³	0.0
Diptera*	4.4 ⁵ (4.9)	7.1 (10.4)	4.4 (4.9)	8.4 ² (11.0)	9.3 (14.7)	5.8 (7.8)
Lepidoptera	0.9 (0.0)	0.0	1.2 (0.6)	0.0	0.0	0.0
Coleoptera	3.9 ⁵ (0.9)	0.0	0.0	0.5 ² (0.0)	0.0	0.0
Gastropoda	0.0	0.0	0.4 (0.0)	0.0	0.0	0.0
Bivalvia*	9.2 (9.3)	0.8 ⁶ (1.1)	9.3 ⁷ (10.6)	12.0 (8.6)	4.5 ³ (4.8)	23.6 ⁴ (13.7)
BMWP-PL	131			146		
ASPT	2.98			3.17		
OQR	7 (excellent quality)			7.5 (excellent quality)		

* = significant differences (nonparametric Kruskal-Wallis, $p \leq 0.05$) between research periods

1 - 7 = significant differences (nonparametric Dunns tests, $p \leq 0.05$) the consecutive localizations

Total macroinvertebrate density increased significantly after restoration works at sites on the right side of the river, where new hydrotechnical solutions were concentrated [8]. Among the identified taxa, restoration significantly changes the density of Crustacea (ANOVA, $p = 0.01$) and Trichoptera ($p = 0.02$). We also observed statistically significant differences for Hirudinea ($p = 0.043$) and Gastropoda ($p = 0.013$). The changes partly resulted from seasonal dynamics of consecutive taxonomic groups: Oligochaeta ($p < 0.05$), Coleoptera ($p < 0.002$), Diptera larvae ($p < 0.02$), Lepidoptera ($p < 0.02$).

In case of Hirudinea, there were statistically significant ($p=0.00$) differences between profile K5 (deflectors) and K8 (stone islands) and between K5 and K10 ($p=0.03$). Even bigger differences were obtained for Plecoptera larvae at profile K5 comparing to K2 (cut-off section, $p=0.00$), K3 (riverbank reinforcement, $p=0.04$), K7 (removed alder clusters, $p=0.00$), K8 ($p=0.03$) and K10 ($p=0.04$).

Abundance of some taxa depends on the localization in riverbed [12]. Bivalvia density differed significantly between the centre and left riverbank ($p=0.00$), right riverbank ($p=0.00$) as well as between the banks ($p=0.02$). In case of Crustacea, significant differences occurred between the centre and the banks: left ($p=0.02$) and right ($p=0.00$). Similar situation was observed for Ephemeroptera larvae: centre – left riverbank ($p=0.00$), centre – right riverbank ($p=0.00$).

The applied restoration works significantly (nonparametric Kruskal-Wallis and Dunns tests, $p \leq 0.05$) influenced the abundance of pre-restoration dominant taxa and caused their reduction in favour of Crustacea (*Gammarus fossarum* Koch.) and Trichoptera (e.g. Hydropsychidae, *Limnephilus* sp.) (Table II).

The Ephemeroptera representatives after restoration decreased their contribution to the overall macrofauna density in the Kwacza River at all sampling locations. Among the other taxonomic groups we found significant increase in Diptera, Oligochaeta and Coleoptera densities on the right side of the river while Crustacea abundance was higher in the central zone and Trichoptera on the left side of the river. Bivalvia representatives occurred more abundantly after restoration in the central zone and near the left bank (Table II). The increase of Oligochaeta (Tubificidae), Bivalvia (*Pisidium* sp.) and Crustacea (*G. fossarum*, *Asellus aquaticus* L.) densities following restoration suggests upstream migration from the Słupia River (e.g. [10, 11]). Moreover, higher abundance of Hirudinea, Plecoptera, Lepidoptera and Gastropoda in Słupia indicates the possibility of further colonization of the Kwacza River over time (Table II).

Before restoration, macrozoobenthos representatives were abundant at the sites located 1000 m (section VIII, shallow zone), 1400 m (section V) and 2200 m (section II, near the water gate) from the outlet (Fig. 1). The water gate broke the continuity of river as an ecological channel and therefore higher number of invertebrate taxa was observed in this section [7, 22]. The number of taxa pre-restoration decreased downstream (Fig. 2)

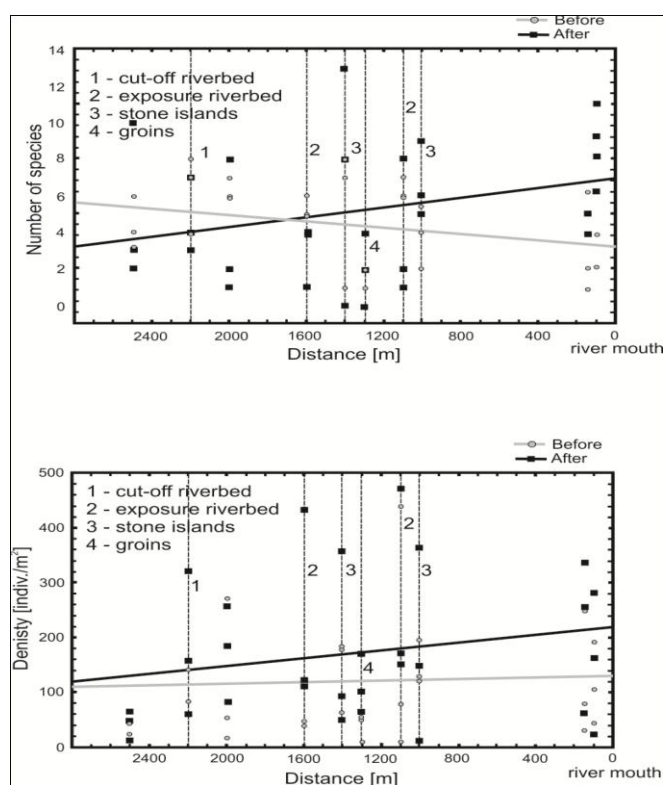


Figure 2 Trends of changes in invertebrate density at researched sections before and after restoration of the Kwacza River.

After restoration, in the places where various elements changing hydrological system were concentrated, an increase in the number of benthic taxa was observed [23, 24]. It was particularly distinct at sites with improved exposure and cataracts (Fig. 1). The most probable reason of such situation was the appearance of food supply (aquatic plants) and additional, diverse microhabitats [11, 25]. The BMWP-PL index, both before and after restoration, indicated very good water quality (Table II).

The analysis of benthofauna density at the selected profiles showed the increase in their abundance after restoration comparing to the period before re-meandering treatments (Table II). Particularly intensive

development was observed at sites located 1.6-1.3 km from the outlet (sections IV-VI), where many hydrotechnical solutions were applied (Fig. 2). Already in 2007, before restoration, invertebrate density increased with the shorter distance to the Kwacza outlet, but after restoration it was even more significant (Fig. 2). That indicates the colonization of new habitats by invertebrates which came mainly from the Słupia River (e.g. [10, 11, 24]).

Invertebrate community structure also depended on the localization of a sampling site. Much better habitat conditions are near the riverside, while the central part of a water course with higher current velocity is preferred by specialized taxa, i.e. *Ephemera vulgata* L., *G. fossarum* or *Cloëon* sp. Sites near the left riverbank before the restoration were characterized by considerable benthofauna diversity (H') at the level of 0.25-0.85. After deregulation works statistically insignificant decrease in biological diversity (Kruskal-Wallis and Dunns tests, $p > 0.05$) has been observed. The other reason could be the migration of organisms and recolonization of new habitats [7, 24, 26]. As for the central part of the river, the increase in diversity was observed at sections with deflectors and stone islands (IV-VI, Fig. 1). Diversification of riverbed morphology favors the colonization of habitats which used to be 'benthic deserts' (e.g. [26, 27]). As for sampling sites located near the right riverside, the invertebrate diversity before and after restoration differed the most at the first two sections. The by-pass of the old culvert (digging up a new river bed) caused the most changes near the right riverside, where stagnating water and the development of coastal plants triggered off the increase in macrozoobenthos diversity. Rapid re-colonization resembled the results from other studies concerning river restoration (e.g. [4, 7, 22, 26, 27]).

The obtained Q index of ecological importance revealed that mayflies of *E. vulgata* (euconstant species) played an important role in the Kwacza River before restoration (Q=24% - high) while after restoration it was substituted by crustaceans of *G. fossarum* (Q=21%), (Table III).

Table III: Frequency (Fr, %), domination index (Di, %) and ecological index (Q, %) of occurrence of the most abundant macroinvertebrate taxa in the Kwacza River before and after restoration.

Taxa	before restoration			after restoration		
	Fr	Di	Q	Fr	Di	Q
<i>E. vulgata</i> *	60.0	10.0	24.26	65.0	5.6	19.10
<i>Pisidium</i> sp.	45.0	6.5	17.10	55.0	3.9	14.43
Chironomidae n.d.*	45.0	3.8	13.03	33.3	2.7	9.01
<i>G. fossarum</i> *	40.0	2.0	8.86	60.0	7.5	20.75
<i>Dicranota</i> sp.	26.7	1.5	6.29	20.0	0.6	3.60
<i>Tabanus</i> sp.*	20.0	0.8	4.01	20.0	0.4	2.68
<i>Limnephilus</i> sp.*	21.7	0.7	3.91	8.3	0.1	0.70
<i>C. macrura</i> *	15.0	0.8	3.57	1.7	0.1	0.22
<i>Simulium</i> sp.	10.0	1.1	3.26	15.0	1.7	4.83
Oligochaeta	15.0	0.5	2.69	10.0	0.2	1.45

* = significant differences (nonparametric Kruskal-Wallis test, $p \leq 0.05$) between research periods

Freshwater shrimps gained their ecological importance (Q) after restoration (nonparametric Kruskal-Wallis test, $p \leq 0.05$) and additionally they became a constant species (Fr=60%) while before restoration works gammarids were only accessoric species. Mayflies and freshwater shrimps being attractive food for fish are valuable representatives of benthic fauna. Kwacza is a river intensively penetrated by *Salmo salar* L. and *Salmo trutta* L., for which crustaceans and insects are the basic food. Among the other identified invertebrate taxa the following decreased their ecological importance: flies and midges of Chironomidae (before restoration Q=13 and after restoration 9%, accessoric taxa) and Limoniidae genus (*Dicranota* sp.) (Q=6 and 4%), *Tabanus* sp. (Q=4 and 2%), *Limnephilus* (Q=4 and >1%) as well as *Caenis macrura* Stephens (Q=3.5 and >0.5%) (Table III). The last taxon as the only one decreased significantly both in frequency and domination index and its ecological importance in the restored section of the Kwacza River was lower.

Short-term effects of restoration on macroinvertebrates

After collecting the biological data and their preliminary verification, five taxa with the highest ecological importance (Q) were chosen. Then the neural model was constructed, which enabled us to indicate variables the most influencing changes in macrozoobenthos abundance and composition. The obtained network MLP 23:40-17-5:5 (Fig. 3) consisted of three neuronal layers.

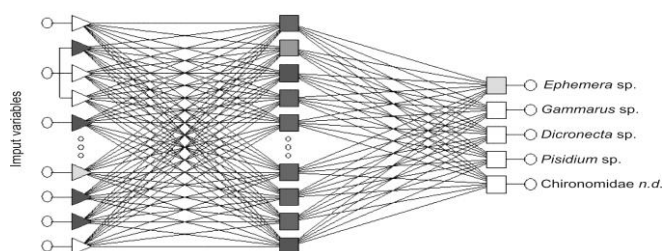


Figure 3 Structure of the obtained neural model MLP 23:40-17-5:5.

At the first layer environmental variables were introduced, i.e. ‘restoration’ (before/after), ‘season’ (summer, autumn, winter), ‘sampling site’ (section number), ‘localization’ (right, left, centre), ‘technical solutions’ (none, deflectors, by-passes, exposure of riverbed, stone islands), ‘distance’, water temperature, resistivity, TDS, ammonium nitrogen, chlorides, chlorophyll, depth, oxygen saturation, nitrate nitrogen, redox potential, pH, salinity and turbidity. The last layer of neurons in the model predicted the density of dominant taxa: *G. fossarum*, Chironomidae larvae, *Pisidium* sp., *E. vulgata* and *Dicranota* sp. The second layer was formed by so-called hidden neurons. The Pearson’s correlation coefficient between the experimental and calculated data was above 0.9 while SD Ratio oscillated around 0.2-0.3 (Table IV). Those results as well as graphical comparison of empirical and predicted values (Fig. 4) indicated high performance of the obtained model.

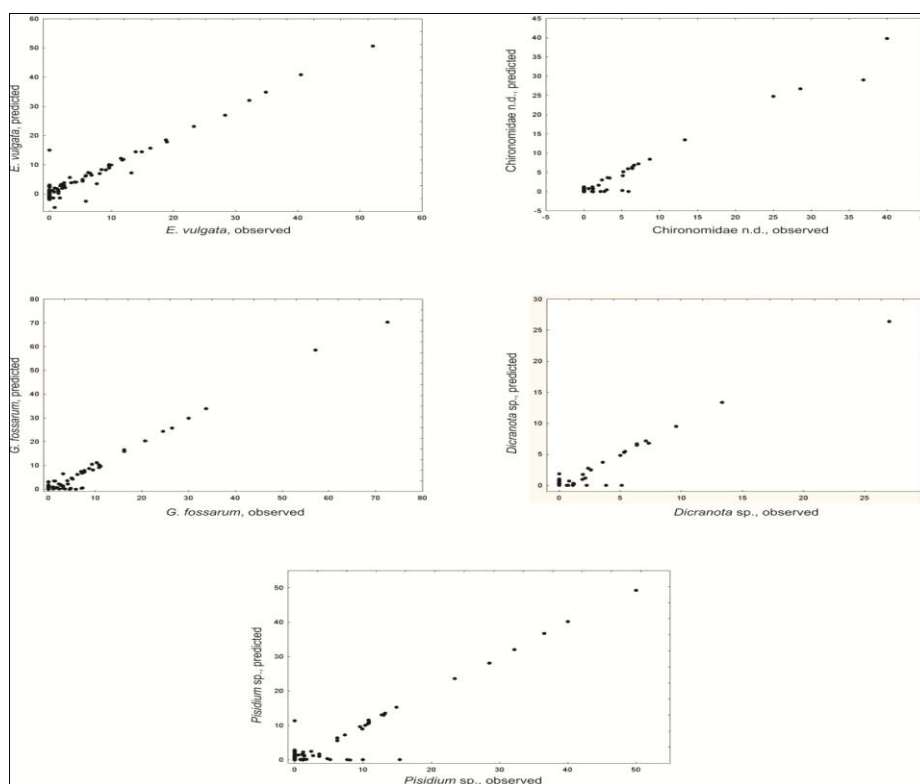


Figure 4 Comparison of experimental data and those calculated from neuronal model MLP 23:40-17-5:5.

Table IV: Statistical assessment of the obtained neural model MLP 23:40-17-5:5 of short-term effects of restoration on macroinvertebrates.

	Subsets														
	Training					Verification					Testing				
	<i>E. vulgata</i>	<i>Dicranota</i> sp.	<i>Pisidium</i> sp.	<i>G. fossarum</i>	Chironomidae n.d.	<i>E. vulgata</i>	<i>Dicranota</i> sp.	<i>Pisidium</i> sp.	<i>G. fossarum</i>	Chironomidae n.d.	<i>E. vulgate</i>	<i>Dicranota</i> sp.	<i>Pisidium</i> sp.	<i>G. fossarum</i>	Chironomidae n.d.
Average	5.20	1.54	4.94	5.75	2.36	5.80	1.24	5.38	4.35	2.30	6.21	1.30	4.10	6.33	2.35

Standard deviation	8.98	3.29	9.22	11.5	6.34	9.85	3.68	10.41	9.36	7.62	9.76	4.04	8.00	13.0	7.25
SD Ratio	0.13	0.27	0.23	0.14	0.12	0.28	0.24	0.31	0.19	0.22	0.29	0.13	0.37	0.15	0.18
Correlation	0.99	0.96	0.97	0.99	0.99	0.96	0.97	0.95	0.98	0.98	0.96	0.99	0.93	0.99	0.98

The performed sensitivity analysis showed that all the input variables were important (Ratio>1). The highest ranks reached the following parameters: ‘localization’, ‘sampling site’, ‘season’, ‘technical solutions’, ‘restoration’ and then chemical physico-chemical factors (Table V).

Table V: Results of sensitivity analysis for neural model MLP 23:40-17-5:5.

	Restoration	Season	Sampling site	Localization	Technical	Distance	Temperature	Conductivity	Resistivity	TDS	N-NH ₄	Chlorides	Chlorophyll	Depth	Oxygen	N-NO ₃	Redox potential	pH	Salinity	Turbidity
Ratio	2.1	2.9	3.0	4.4	2.6	1.3	1.6	1.4	1.1	1.1	1.2	1.0	1.5	1.1	1.3	1.2	1.3	1.1	1.0	1.0
Rank	5	3	2	1	4	9	6	8	14	15	13	18	7	17	11	12	10	16	20	19

The applied restoration works were not the most important variables influencing benthofauna in a short time after hydrotechnical treatments as we had primarily hypothesised. Durable effects of restoration are supposed to appear after 10 years [14, 28].

The highest rank in the model fell to localization of a sampling site in the riverbed. Freshwater shrimps and mayflies prefer habitats with considerable current velocity, where water mixing favors its oxygenation. In turn Chironomidae larvae and pea cockles inhabit places with slow current and muddy substrate. Season also significantly influenced invertebrates, since many taxa show seasonal changes in density. The measured physico-chemical parameters of water did not have a strong impact on qualitative and quantitative structure of benthofauna. Probably it resulted from small, short-term changes in water chemistry after restoration [12, 29].

V. CONCLUSIONS

The performed restoration of the Kwacza River increased habitat diversity and resulted in unblocking of the studied watercourse as an ecological channel compared to the channelized river divided by culverts. Significant changes in water chemistry were not observed in general. Most probably biological methods better reflect the ecological state of watercourses than chemical analysis. However, the appearance of new, diverse habitats gave the opportunity to recolonize the Kwacza River by invertebrates along the watercourse as well as crosswise. That concerned mainly crustaceans of Gammaridae family, characterized by considerable mobility. The qualitative and quantitative composition of benthic organisms after restoration changed and reflected the increase in habitat diversity. The short-term monitoring of the restoration effects indicated favorable trend in the overall biodiversity of the restored river.

Data analyses revealed that the most important factors influencing invertebrate abundance were the localization of a sampling site in the riverbed and the distance from the outlet of Kwacza to the Stupia River. The research hypothesis has already been partly verified. First effects of restoration works have appeared and probably they will be more intensive in the following years. Further research on relationships between restoration parameters and invertebrates in the Kwacza River are planned in order to investigate the dependences in a longer period of time.

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