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AN EFFECT OF REGULATORY WORKS RANGE ON ECOLOGICAL CHANGES IN WATERCOURSE BED

Elżbieta Bondar-Nowakowska, Justyna Hachoł
Wroclaw University of Environmental and Life Sciences

Abstract

This paper attempts to assess an effect of the range of regulatory works in watercourse beds on the aquatic plant communities. The results of field studies carried out on sections transformed as a result of regulatory works and the non-altered sections were compared for this purpose. The field studies were conducted in growing seasons in years 2008-2014 on 11 small and medium-sized lowland watercourses in Lower Silesia. They included identification of aquatic plant species and estimation of the degree of bottom coverage with them. The assessment was based on analysis of changes in the values of five biological indicators such as: the number of aquatic plant species, Jaccard similarity coefficient, ecological status, Shannon-Wiener biodiversity index and Pielou`s evenness index. Comparative analyzes enabled to determine the qualitative and quantitative changes in the aquatic plant communities. However, they did not show any correlation between the analyzed biological indicators and the range of regulatory works in watercourse beds.

Key words: species similarity, regulation, aquatic plants, species biodiversity, rivers

INTRODUCTION

The prerequisite for sustainable development is a comprehensive harmonization of economic processes with the state and capacity of natural environment. This requires solutions and actions that on the one hand may limit the pressure on the environment, on the other hand serve economic development. Reference of these principles to watercourses where the execution of regulatory works is planned requires a good recognition of accepted technical solutions, elements of watercourse ecosystem and their interactions.

The following research hypothesis was accepted in the study: "there is a strong correlation between the level of technical complexity of regulatory works and ecological effects of works performed". Field research and statistical analysis were performed in order to verify this hypothesis.

MATERIAL AND METHODS

An evaluation of regulatory works effect on watercourse ecosystem was based on the analysis of changes in the value of five biological indicators, i.e., species richness, measured by the number of vascular aquatic plants species, Jaccard similarity coefficient, ecological status of watercourse beds, Shannon-Wiener biodiversity index and Pielou's evenness index.

The basis for these indicators determination were field studies conducted during growing seasons in the years 2008 – 2014, on eleven small and medium-sized lowland watercourses in an area of Lower Silesia. Forty one study sections were selected on these watercourses. The length of each section was 100 m. They were located in areas used for agricultural purposes characterized by similar physiographic conditions. These streams were characterised by low average flow velocities and low hydrological variability. Watercourses were not contaminated with sewage during the field studies. Additionally, in order to exclude the study sites with strong trophic pollution, which could have a considerable impact on the qualitative and quantitative composition of aquatic plants communities, water quality analyzes were performed. They included six parameters: pH, dissolved oxygen, ammonia, nitrites, nitrates and phosphates. The values of these parameters were similar on the all study sections.

Watercourses sections selected for the study were characterized by varying degrees of anthropogenic transformation. Eleven sections, one for each watercourse, were characterized by the state close to natural. No evidences of technological interferences were noted in them. They were used as reference sections in the analysis conducted. In turn, regulatory works were performed over the last ten years in other sections, located in the immediate vicinity of the reference ones or at a small distance from them. These works included: changes in the parameters of watercourse cross-section, longitudinal slope, water level shading and manner of embankments reinforcement. The changes in cross-section dimensions related to the width of bottom, depth of watercourse and embankments slope. The changes in embankments reinforcement involved the naturally shaped shore replacing with biotechnical or technical reinforcement. The range of works on study sections in each watercourse is presented in table 1.

Table 1. The range of works on the study sections

No.	Water-course name	Estuary	Water-course length [km]	Range of works	Number of study sections	
					R*	U**
1.	Czarna Woda	Bystrzyca	43.8	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1:1,5 to 1: 2 slope, bank base strenghtening with fascine;	5	1
2.	Dobra	Widawa	36.1	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine,	1	1
				• mowing flora from the litoral zone and banks, • watercourse deepening, • creation of cross section with banks of 1: 2 slope, banks strengthening with stone coating,	1	
				• mowing flora from the litoral zone and banks, • watercourse deepening, • creation of the cross secion with vertical banks, banks strengthening with gabions;	1	
3.	Oleszna	Ślęza	19.7	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine;	2	1
4.	Oleśnica	Widawa	46.6	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine;	1	1
5.	Orla	Barycz	95.1	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine, • embankments;	1	1
6.	Potok Sulistro-wicki	Czarna Woda	14.7	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine, • embankments;	2	1

No.	Water-course name	Estuary	Water-course length [km]	Range of works	Number of study sections	
					R*	U**
8.	Smorta-wa	Odra	39.0	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1:1,5 to 1: 2 slope, bank strenghtening with fascine or turf;	3	1
9.	Ślęza	Odra	78.6	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1: 2 slope, bank base strenghtening with fascine,	1	1
				• mowing flora from the litoral zone and banks, • watercourse deepening, • creation of cross section with banks of 1: 2 slope, banks strengthening with stone coating,	1	
				• mowing flora from the litoral zone and banks, • watercourse deepening, • creation of the cross secion with vertical banks, banks strengthening with retaining wall,	1	
10.	Żalina	Żurawka	10.9	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1:1,5 to 1: 2 slope, bank base strenghtening with fascine;	2	1
11.	Żurawka	Ślęza	28.5	• mowing flora from the litoral zone and banks, • bottom desludging with water plants removing, • creation of cross section with banks of 1:1,5 to 1: 2 slope, • bank base strenghtening with fascine;	3	1
				• mowing flora from the litoral zone and banks, • watercourse deepening, • creation of the cross secion with vertical banks, banks strengthening with retaining wall.	1	

*R – regulated, **U – unmodified
Source: own elaboration

The study sections were characterized by similar dimensions of the bed over their entire length. The measurement of that value was carried out in the transverse profiles, spaced each 10 m. The mean value for the entire section was calculated on the basis of these measurements. The evaluation of shading was carried out optically according to the 5-point scale. Zero meant no shading, 1 – small shading, 2 – average, 3 – large, 4 – complete (Schaumburg et al. 2006).

The same way of embankments reinforcement was observed on a specified study section.

In order to determine the values of biological indicators adopted for the study, vascular plant species were identified, and the degree of bottom coverage by them was determined on each study section. The study included all vascular plants, rooted in water for at least 90% of the growing season, as well as higher plants, floating freely on the water surface or under it. Aquatic plant species were determined directly on the study site. A 9-point scale was used to determine the degree of bottom coverage (Szoszkiewicz et al. 2010).

The similarity of vascular aquatic plants communities on the compared sections was determined based on Jaccard coefficient. The higher value of this indicator proves a greater species similarity of the compared communities. This coefficient was calculated according to the following formula (Piernik 2008):

$$P = \frac{A}{A + B + C} \tag{1}$$

where:
P –Jaccard similarity coefficient
A – number of species common on the compared study sections,
B – number of species on the study section subject to technical interference,
C – number of species on the reference study section.

Ecological state of the watercourse is the degree of observed state deviation of the reference state, characteristic for non-altered bed (Directive 2000/60/EC). This index was determined on the basis of Macrophyte River Index, calculated according to the following formula (Szoszkiewicz et al. 2010):

$$MRI = \frac{\sum\left(L_i \cdot W_i \cdot P_i\right)}{\sum\left(W_i \cdot P\right)} \cdot 10 \tag{2}$$

where:
MRI – Macrophyte River Index;
L_i – index value for species *i*;
W_i – weighting factor for species *i*;
P_i – coverage index for species *i*.

The calculated values were referred to the MRI range for the ecological states and classes of water quality of lowland rivers with sandy bottom. Such a type of rivers corresponded to the watercourses with the study sections. On this basis, each section was classified into one of five classes of ecological status.

Shannon-Wiener biodiversity index was determined according to the following formula (Schaumburg et al. 2006):

$$H = -\sum_{i=l}^{s}(N_i \times \ln N_i) \tag{3}$$

where:
H – biodiversity index,
s – number of aquatic plant species on the study section,
N_i – index calculated according to the formula:

$$N_i = \frac{Q_i}{Q} \tag{4}$$

where:
Q_i – cube of the value of bottom coverage by plants of the *i*-th species,
Q – cube of the value of bottom coverage by plants of all species.

Pielou's evenness index determines the share of each species in the community. It takes a value from 0 to 1. A value close to unity means total equivalence of the species (Sienkiewicz 2010). This index was calculated according to the following formula (Pielou 1974):

$$J = \frac{H}{H_{\max}} \tag{5}$$

where:
J – species evenness index,
H – Shannon-Wiener index,
H_{max} – index of maximum possible species biodiversity calculated according to the following formula (Sienkiewicz 2010):

$$H_{\max} = \ln S \tag{6}$$

where:
S – number of species.

Spearman's rank correlation coefficient was used in order to evaluate the strength of correlation between the scope of works performed in the bed of the watercourse and ecological changes expressed by the presented indicators. Calculations were performed using Statistica V.12.5 software of StatSoft Poland Sp. z o.o.

RESULTS AND DISCUSSION

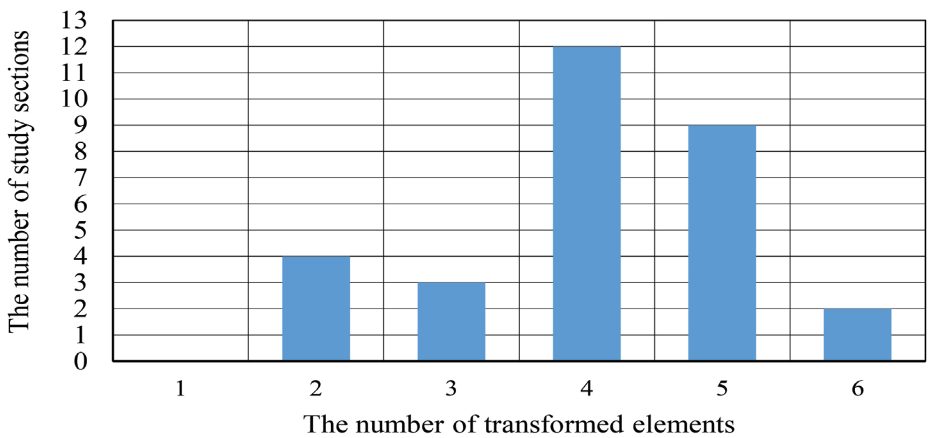
The structure of technical changes made within the regulatory works on the study sections is presented in Table 2.

It can be concluded from Table 1 that embankments reinforcement was made on all sections of regulated watercourse beds. Naturally formed slope were in 5 cases reinforced with turf, in 18 cases with fascine, and net-stone baskets, stone blankets and concrete-stone walls were used in other sections. The changes made on particular sections concerned from two to six elements considered, which is presented in detail in Figure 1.

Table 2. Changes in components of watercourses beds on the study sections

Bottom width	Bed depth	Longitudinal slope	Embankments slope	Embankments reinforcement	Bed shading
Number of sections with changed parameter					
increase	Increase	attenuation	attenuation	elimination of an existing	elimination or attenuation
9	10	9	9	0	10
decrease	Decrease	increase	decrease	reinforcement made	increase
11	9	9	10	30	6
Number of sections without parameter changes					
9	11	12	11	0	14

Source: own study



Source: own study

Figure 1. The number of components of watercourses bed transformed as a result of the regulatory works

Figure 1 shows that the changes in the case of the analyzed watercourses mainly concerned 4 – 5 elements of the watercourse bed. Direct field observations demonstrated that these were different elements on particular sections. Therefore, it was assumed in the study that the specific environmental effects of regulatory works are the result of all components of watercourse bed transformed on the specified section. The range of these interactions is presented on the Box-Whisker plots representing the differences by the values of analysed indicators depending on the number of elements of watercourse bed that were changed during the regulatory works (fig. 2-6). The squares denotes the average, the whiskers denote minimum and maximum values. The range of interactions can be summarized as follows:

- **species richness – number of vascular aquatic plants species**

From 2 to 8 species were noted on the study sections used as reference sections. The number of species increased on the eight sections, it did not change on four sections, and decreased in eighteen cases after the regulatory works. Figure 2 presents these changes in relation to the number of transformed elements of the watercourses bed.

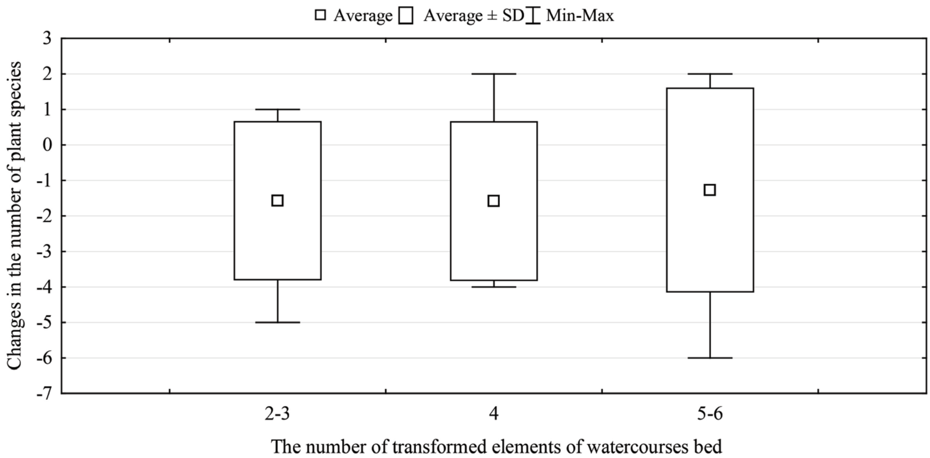


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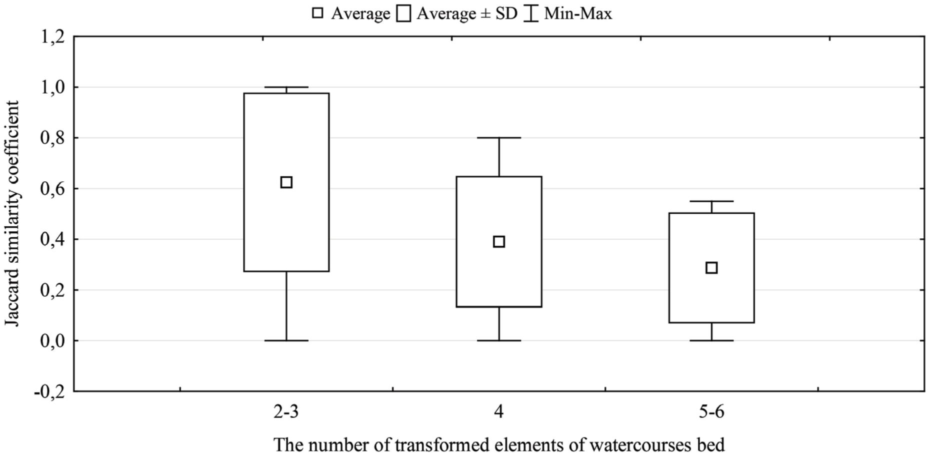
Figure 2. Changes in the number of aquatic plant species in the regulated sections of watercourses beds depending on the number of elements of watercourses bed that were changed during the regulatory works

Figure 2 shows that both an increase and a decrease in the number of species on regulated sections was independent of the range of changes made in the bed.

- **Jaccard similarity coefficient**

The similarity of aquatic plants communities observed on the reference sections and these transformed as a result of regulatory works ranged from 0 to 1.

Zero in this case means that the effect of regulatory works was a total change in aquatic plant species composition, while 1 means the absence of these changes. The detailed scope of changes is presented in Figure 3.



Source: own study

Figure 3. Similarity of aquatic plant communities in the regulated and non-transformed sections of watercourses beds depending on the number of elements of watercourses bed that were changed during the regulatory works

It should be concluded based on Figure 3, that with an increase in the number of watercourse beds transformed elements, the similarity of communities, in terms of vascular aquatic plants species composition, to the communities on non-transformed sections, is getting lower.

- **change in watercourse bed ecological status**

Ecological status of the river is classified according to the 5-point scale, where I – is a very good condition, II – good, III – moderate, IV – weak, V – bad. The results of field studies indicate that the ecological status of watercourse beds in the study sections not subjected to technical interference was on the level from II to V. In the sections where the regulatory works were performed, it was higher in 7 cases, in 6 cases no changes were noted, and in 17 sections it was one to three classes worse. The range of these changes depending on the scope of works performed in the bed is presented in Figure 4. It shows that the ecological status of the bed tends to deterioration when the majority of watercourse bed parameters is transformed. However, this relationship is very poor.

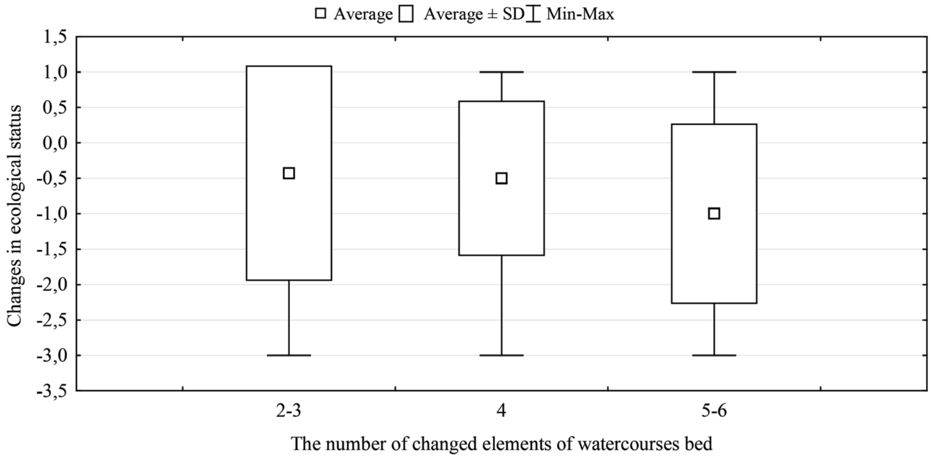


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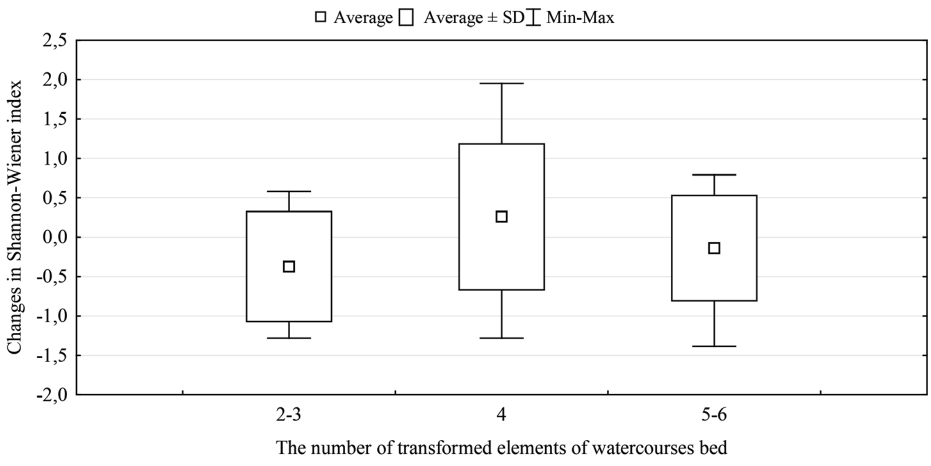
Figure 4. Range of changes in ecological status in the regulated sections of watercourses beds depending on the number of elements of watercourses bed that were changed during the regulatory works



Source: own study

Figure 5. Range of changes in Shannon-Wiener index in the regulated sections of watercourses beds depending on the number of elements of watercourses bed that were changed during the regulatory works

- **Shannon-Wiener biodiversity index change**

Performed studies and analyzes demonstrated that the considered indicator values were from 0 to 1.90 on the natural sections of watercourse beds. Technical interference resulted in its increase in 12 cases, and its decrease in 18 cases. The extent of these changes is shown in Figure 5.

Based on the graphs presented in Fig. 5 it cannot be demonstrated that there is a linear relationship between the scope of regulatory works in the water-course bed and biodiversity expressed by Shannon-Wiener index.

- **Pielou's evenness index change**

The evenness index was higher on 11 sections where the regulatory works were carried out than in the corresponding reference sections. A decrease in its value was noted on 19 sections. An effect of the range of bed regulation on that index changes is presented in Figure 6.

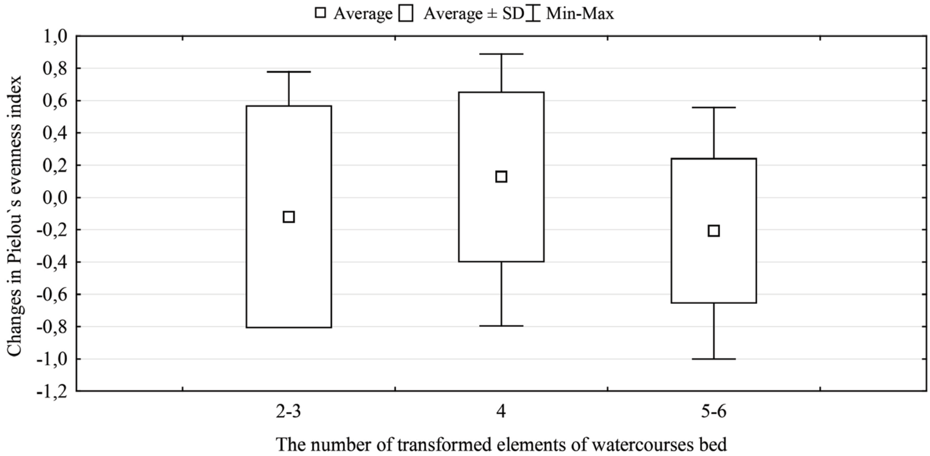


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Figure 6. Range of changes in Pielou`s evenness index in the regulated sections of watercourses beds depending on the number of elements of watercourses bed that were changed during the regulatory works

It may be concluded from Figure 6 that there are large fluctuations in the value of Pielou's index. However, it cannot be demonstrated that they are related to the scope of the works performed in the bed.

The results presented in Fig. 2-6 indicate that the regulatory works in a different manner affected bed's status described by another biological indicators. Their changes, considered in relation to aquatic ecosystem protection, were both favorable and unfavorable (Madsen et al. 2001, Herb et al. 2003, Grinberga 2010). Due to the differentiation in particular indicators value, an examination of the strength of the relationship between the range of regulatory works and the range of indicator changes was performed in order to determine which one best describes regulatory works effect on watercourse bed ecosystem. This analysis involved Spearman's rank correlation coefficient (Lipiec-Zajchowska 2003). The results of the calculations are presented in Figure 7.

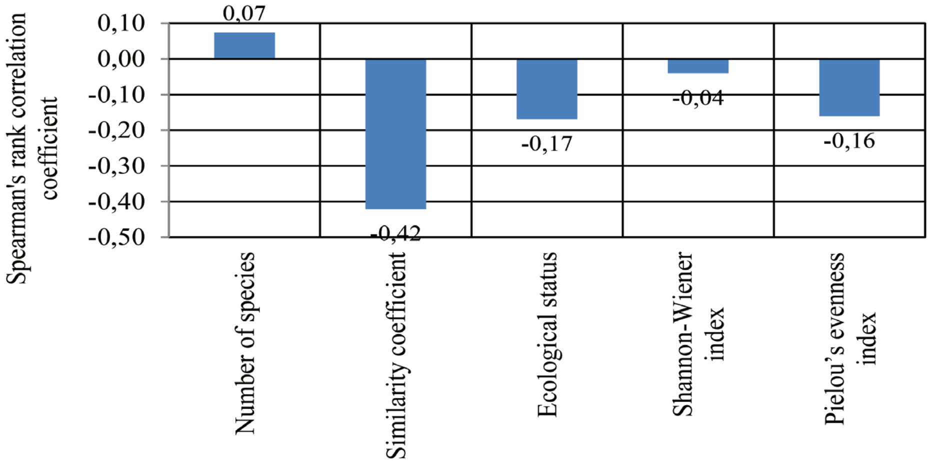

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Figure 7. The strength of the correlation between the range of regulatory works and ecological changes in the watercourses bed

It may be concluded from the Figure 7 that no relationship can be demonstrated between the range of regulatory works and changes in natural elements of the beds described by the considered indicators. Only in the case Jaccard similarity index it can be concluded that there is a weak relationship on the extent of the works performed. This confirms the results of numerous studies, according to which factors influencing water plant communities act synergetically and single correlations among environmental elements, anthropogenic interactions and water plants are rather rare (Demars, Harper 1998; Caffrey et al. 2006). This state hinders the planning and design of regulatory works, both in terms of flood protection and environmental protection. Concurrently, it indicates the need for further examination of that problem.

SUMMARY

Adopted in the study research hypothesis that "there is a strong correlation between the level of technical complexity of regulatory works and ecological effects of works performed" has not been verified positively. The study demonstrated that at the current stage of research it is not possible to determine a biological indicator, which value shows the relationship with the range of technical interference in the watercourse bed.

A wide range of results and the lack of examined relationship indicate that further analysis should also involve other elements of watercourse bed ecosystem. Therefore, this problem should be the subject of further research and detailed analysis. The results of such studies will be the basis for the principles of sustainable development in water management.

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Justyna Hachoł, Elżbieta Bondar-Nowakowska
Institute of Environmental Protection and Development
Wroclaw University of Environmental and Life Sciences
Plac Grunwaldzki 24
50-363 Wrocław
justyna.hachol@up.wroc.pl
elzbieta.bondar-nowakowska@up.wroc.pl

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