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EVALUATION OF THE EFFECTIVENESS OF RENATURALIZATION TOOLS OF RENATURALIZED SECTIONS OF LITHUANIAN RIVERS

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Abstract. More than 40% of natural riverbeds of Lithuanian rivers have been affected by straightening, in the installation of melioration systems. The solution of gentle renaturalization was chosen and mild renaturalization measures were installed in straightened sections of riverbeds. A detailed assessment of the ecological condition of the renaturalized river sections was carried out according to the physico-chemical, ecological condition, biological (fish index, river macroinverte-brates, river macrophyte indexes) quality elements at 2019–2022. The results of complex studies show the renaturalization measures implemented have the greatest positive effect on the studied parameters in the river with the strongest turbulent flow formed.

Keywords: river renaturalization, biogens, ecological condition, fish index, river macroinvertebrates index, river macrophyte index.

Introduction

It is estimated that more than 40% of natural riverbeds of Lithuanian rivers have been affected by straightening, in the installation of melioration systems, since the middle of the last century. This action damaged the morphological and ecological balance of the rivers, which is worsened by intensive agricultural activities in the country. Straight beds are characterized by poor biodiversity due to monotonously uniform habitats. There are several methods of returning rivers to a state close to their natural state, collectively known as renaturalization. The most extreme is the return of the river to its old riverbed, the mildest is the creation of a variety of river flow in a straightened section without changing the existing riverbed. The solution of gentle renaturalization was chosen and mild renaturalization measures were installed in straightened sections of riverbeds by installing stone barriers and thresholds, placing stumps, reeds, logs and other natural materials in 2016, that would create obstacles and force ecological conditions close to the natural environment to be restored in the straightened riverbed. A detailed assessment of the ecological condition of the renaturalized river sections was carried out according to the physico-chemical, ecological condition, biological (fish index, river macroinvertebrates, river macrophyte indexes) quality elements at 2019–2022.

The aim of the project is to carry out the necessary research in the relevant river sections where renaturalization measures were installed and to determine the effectiveness of renaturalization measures.

Materials and methods

Vašuoka, Viešinta and Vyžuona – rivers of the Central hydrological region of Lithuania (Figure 1). This area is dominated by shallow incised furrows, mainly soils of heavy mechanical composition (Kilkus & Stonevičius, 2014). The Lielupe basin area, which includes the considered rivers, has an extremely dense network of rivers, and its surface is mainly covered by impermeable soil – bottom moraine loam, which shows that there are favorable conditions for the formation of surface runoff (Jablonskis et al., 2007). In the straightened sections in 2016 gentle renaturalization measures have been installed, which create the diversity of the river flow, forming ecological conditions close to the natural natural environment. All around are cultivated fields. The length of the renaturalized section

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is 1 km. Above the renaturalized sections are natural flow sections from which, as planned, natural flora and fauna were to spread into the renaturalized sections. In order to evaluate the effectiveness of the restoration of the renaturalized section, a representative regularized section of the same river was selected nearby, where no renaturalization measures were applied, and the surrounding fields are cultivated. In the years 2019–2022, the following studies were carried out in the renaturalized and representative sections of the three rivers:

- once a year, during the vegetation period, biological parameters are determined: Fish Index (*FI*), River Macroinvertebrate Index (*RMinvI*), River Macrophyte Index (*RMphI*);
- 4 times a year (in different seasons of the year), general physico-chemical parameters were determined;
- At the beginning and at the end of the research period, an assessment of the ecological condition according to hydro morphological quality elements was carried out.

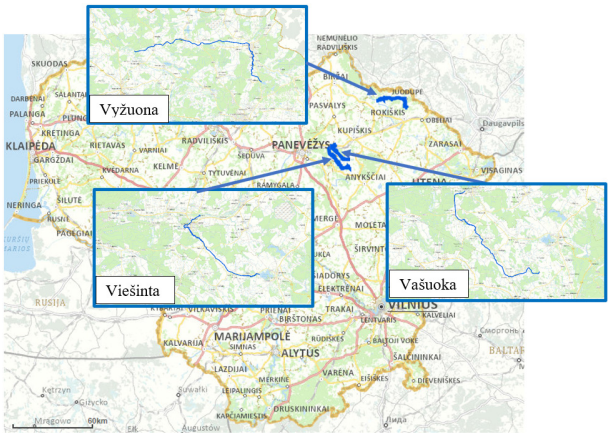

Figure 1. Location of the rivers Vašuoka, Viešinta and Vyžuona in Lithuania

Determination of physico-chemical quality elements

Water samples were taken 4 times a year, in different seasons of the year, at the beginnings and ends of the representative and renaturalized sections of the rivers. Elements studied: biochemical oxygen consumption in 7 days (BOD_7), dissolved oxygen (O_2) content in water (mg/l), total nitrogen (N_t) concentration (mg/l), ammonium nitrogen (NH_4-N) concentration (mg/l), nitrate nitrogen (NO3-N) concentration (mg/l), phosphate phosphorus (PO_4-P) concentration (mg/l) and total phosphorus (P_t) concentration (mg/l). Tests for substances dissolved in water were carried out in an accredited water testing laboratory. The results were evaluated according to the change in the ecological condition of the rivers for the investigated physico-chemical quality elements.

Hydro morphological quality elements

The hydro morphological index of rivers includes 4 indicators: 1) size and nature of runoff, 2) nature of the riverbed, 3) state of coastal vegetation; 4) soil composition. Investigations according to hydro morphological quality elements (Lietuvos Respublikos aplinkos ministerija, 2007; Rinaldi et al., 2013) were carried out in 2019 and 2022.

Evaluation of the Fish Index (FI)

At the study sites, a section of the bed was fished using a pulse current electrofishing device, before it was fenced off with drift nets. River sections from 70 to 150 m long were chosen for the study, where fishing was done 1–3 times in a row, every 45 minutes throughout the section (Bohlin & Sundstrom, 1977). All caught fish were sorted by species, lengths of all individuals were measured and weights were determined (LAND 85-2007, 2011; Virbickas, 2006; Virbickas & Gudas, 2007).

Later, according to the methodology of Zippin (1958), fish density N (units/100 m^2) and biomass B (kg/100 m^2) were determined at the research point. Depending on the abundance of fish, two or three fisheries were conducted at each point.

The two-fishing method was applied when less than 50% of one species of fish was caught in the second catch than in the first catch. This method was applied in small streams less than 10 meters wide, where the catch p was high enough to obtain 95% confidence, i.e. p>60% (Bohlin & Sundstrom, 1977). In other cases, when the catch rate was not high (p<50%) and/or the width of the river was more than 10 meters, the method of three deceptions was used. After analysis, viable fish were released back into the same body of water. The results are summarized using the values of the Lithuanian fish index (Lietuvos Respublikos aplinkos ministerija, 2016, 2007).

Evaluation of the River Macroinvertebrate Index (RMinvI)

Macrozoobenthos samples were taken with a D-shaped net. Since the studied rivers are shallow (depth up to 1 m) and with flowing water, samples were taken by the kick method, deceiving an area of the river bed with a width of 25 cm and a length of 40 cm. In each studied section of the river, 5 samples (semi-quantitative sample) were taken from different biotopes of the river and 1 sample (qualitative sample) was collected by collecting invertebrates from different parts of the river by catching around macrophyte meadows and large boulders and submerged tree branches. The results are summarized using the values of the River Macroinvertebrate Index (Lietuvos Respublikos aplinkos ministerija, 2007).

River Macrophyte Index (RMphI)

The studies were conducted in 2020 and 2022 at the end of July, in 2021 – at the beginning of August, during the period of intense vegetation, in the renaturalized sections of the Vašuoka, Viešinta and Vyžuonas rivers and in the neighbouring representative regulated sections of

the same rivers. The surveys were made by zigzagging across the river bed upstream for about 100 m. At that time, all plant species growing in the river bed and on the coast were recorded. The abundance of plant species is assessed on a 5-point scale: 1 – very rare, 2 – rare, 3 – not rare, 4 – common, 5 – very common/dominant (Meilinger et al., 2005).

Only underwater and floating macrophytes are included in the calculations. The dominance of helophytes in the river bed or banks was used as an additional criterion. The inventoried submersed macrophyte species were assigned to three different species groups: A. species abundant in reference condition sites (undisturbed or minimally affected by human activities) and rarely found in other conditions; C. species are rarely found under reference conditions and usually grow where there are very few or no group A species; B. species that show no attachment to reference or other conditions. Additional criteria are used to adjust the reference index of macrophytes calculated according to the formula: minimum number of species; aquatic *Ranunculus spp.* dominance of helophytes (*Glyceria maxima, Phalaroides arundinacea, Phragmites australis, Sagittaria sagittifolia, Sparganium erectum, Sparganium emersum, Typha spp.*). The results are summarized using the values of the River Macrophyte Index (Lietuvos Respublikos aplinkos ministerija, 2007).

Results and discussion

Research was carried out in sections of rivers where the riverbeds are straightened and regulated, with cultivated fields or meadows on both sides. The topography and substrate of the rivers are monotonous during the three years of the study in renaturalized sections (Table 1).

In the representative research sections of Viešinta and Vašuoka, the sludge fraction was washed out of the river bed after the heavy rainfall that fell in the region in the summer of 2022, but it is likely that the river bed will be covered again in the course of the year with organic and sludge carriers. Vegetation of the banks with trees, the shade of which casts a shadow on the riverbed for at least part of the day, does not even make up 10 in any section of the river. The sections of renaturalized rivers are morphologically slightly different from the representative ones: a specific riverbed relief has been formed, influencing the creation of habitat diversity (Del Tánago et al., 2021).

Table 1. Relevant morphometric parameters of the studied sections

Section	av. width, m	depth, m	flow velocity, m/s	ground composition, %
Vašuoka representative	3.0–4.5	0.2–1.1	0.8–1.0	G10/S10/ D70/C10
Vašuoka renaturalized	3.5–5.0	0.2–1.3	1.5–2.3*	B2/G60/S10/ D10/C18
Viešinta representative	3.5–4.3	0.4–1.2	0.2–0.6	G20/S25/ D10/C45
Viešinta renaturalized	4.3–4.8	0.4–1.2	0.4–0.9*	B1/G35/S54/ C10
Vyžuona representative	10.0–11.5	0.6–1.4	0.2–0.5	B1/G9/ S30D60
Vyžuona renaturalized	8.5–10.0	0.8–1.5	0.3–0.6*	B2/G5/S25/ D67/C1

Note: B – boulders, G – gravel, S – sand, D – sludge, C – clay. * – flow velocity at renaturalization facilities, average at a distance of 3 meters.

Summarizing the renaturalized and representative river sections of all three studied rivers over a three-year period, it can be resumed that the greatest positive effect of renaturalization in terms of hydrochemistry is observed in the smallest Vašuoka river, where the greatest turbulence is formed. When evaluating the nitrate concentrations of the Vašuoka River, it was noticed that in the renaturalized section, the change in water quality in terms of improvement is more efficient and reaches as much as 11%, while in the representative section it is only 7.8%.

Although an increase in the concentration of total nitrogen has been determined in the Vašuoka River, it reaches only 3.78% in the renaturalized section, while the same process takes place even by 17% in the representative section of the river (Figure 2).

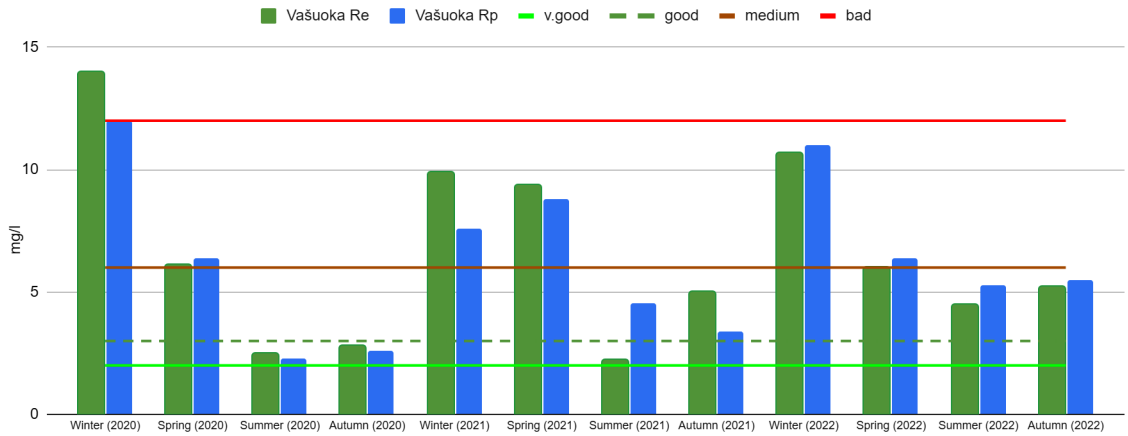

Figure 2. Results of changes of concentration of total nitrogen, Vašuoka river

Biochemical oxygen consumption is an indicator of pollution by organic substances, so it is important to evaluate its changes, which showed that in the renaturalized section, comparing the first and third years, the average annual concentration decreased by as much as 78.5 percent (from 9.84 mg/l to 2.11 mg/l). Comparing the first and third years of the Viešinta river, the average annual nitrate concentration in both river sections decreased from 13.8 to 43.7 percent. After evaluating the results of the water quality of the Vyžuona River, it can be said that in the third year, in the spring, summer and autumn seasons, nitrate concentrations kept decreasing and correspond to a very good value of ecological potential, in the renaturalized river section, comparing the first and third years, the average nitrate concentrations improved by 32 percent, i.e. from 1.44 mg/l to 0.97 mg/l, while the representative section shows an improvement of only 11 percent, from 1.69 mg/l to 1.50 mg/l. Total nitrogen also decreased during the three years of the study and from spring to autumn met the criterion of good and very good ecological potential (Figure 3).

BOD7 concentrations tend to decrease and have even reached a very good ecological potential. Comparing the average BOD7 concentrations in 2020 and 2022 in the renaturalized section, they varied from 9.27 mg/l to 2.26 mg/l, and in the representative section – from 9.56 mg/l to 2.10 mg/l. Analyzing the data for phosphate phosphorus and, respectively, total phosphorus, it was found that the condition is very good in all rivers. This indicates that the river basins in question do not have domestic sewage or the system is managed in such a way that there are no illegal discharges. The concentrations of ammonium nitrogen in all three rivers did not exceed the value of 0.02 mg/l.

Comparing the values determined by the 2020–2022 *FI* indices and their change, it is observed that in most river sections the changes are not significant, and the ecological condition according to the values of the *FI* indicator changed the most in the renaturalized section of Vyžuonas, when in 2020 a very good condition was determined, and in 2021 and 2022 year, the condition was rated only as good. The situation is opposite in the representative section of Vyžuonas, when in 2020 and 2021 the ecological condition according to *FI* was assessed as good, in 2022 it was assessed as very good. Such a change was mainly caused by the change in the relative abundance of one fish species, the *Alburnus alburnus*, in the river sections during the study period. In the representative section of Vašuoka since 2020, when a bad ecological condition was determined according to *FI* indicators, the overall values of the indicators have risen in the last two years, and the condition in 2022 is assessed as average, but due to the above-mentioned extremely low abundance of fish, it is likely that the condition may change drastically in the future.

Summarizing the research of the last three years, it can be said that according to the values of the *FI* indicator, no significant differences and changes are observed between renaturalized and representative river sections. The changes in *FI* values in the studied period of 2020–2022 in the river sections themselves (re-naturalized and representative) are not significant and were usually more influenced by changes in fish abundance than by changes in the ichthyofauna community itself. However, it is worth noting that in the renaturalized sections (with the exception of Vyžuona), greater species diversity is observed and fish species that are more sensitive to water quality and are considered indicators of good ecological condition are found more often, although individuals of these species are usually single. It can be assumed that the renaturalization works carried out in the smaller rivers (Vašuoka and Viešinta) had a positive impact on fish communities, creating a greater diversity of biotopes. Restoring the river, in all or most aspects of the past, is impossible due to the changed environment, river processes in the past context, about which there is a lack of knowledge, to be able to restore the complex ecosystem that determined the river's trajectories (Dufour & Piégay, 2009). A less successful than expected river restoration project is not a rare phenomenon, and in many cases the public will favor cosmetic river reconstructions rather than reconstructions with the aim of restoring less noticeable

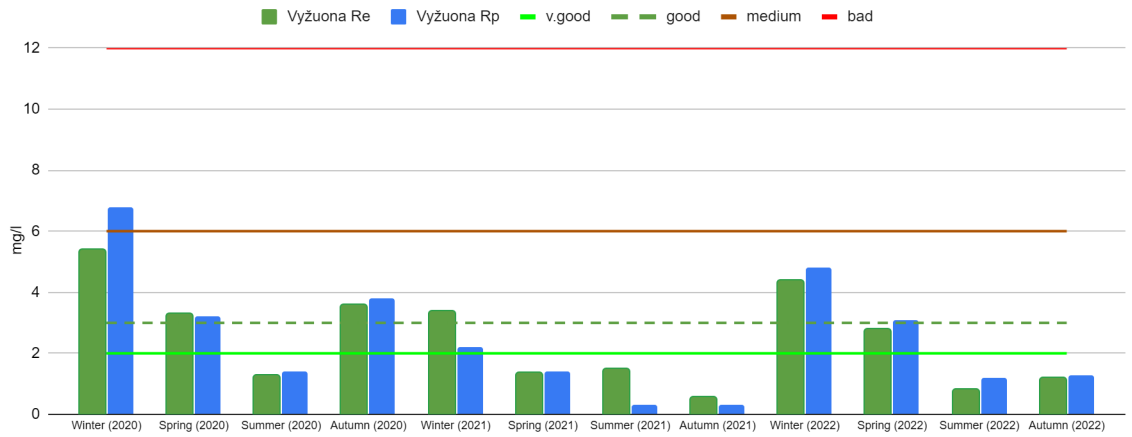

Figure 3. Results of changes of concentration of total nitrogen, Vyžuona river

but ecologically and hydrologically more important functions for two main reasons (Wohl et al., 2015): 1) the effort and volume of river restoration is significantly lower than the effort invested in replacing the natural river, usually and most of its basin; 2) The difference between societal expectations (which are often focused on the aesthetic or economic benefits of the river) and scientific understanding of the river's natural dynamics (which often require major changes just to restore ecosystem functions that are often not directly observable).

In the future, when similar renaturalization works are carried out, their scale should be larger, both in terms of the restoration of the river's meandering and the length of the section or even the entire river basin in a broader perspective.

River Macroinvertebrate Index. Comparing the data of all three studied years shows that *RMinvI* in 2022 was higher in all studied river sections than in 2020 and 2021. In general, the value of *RMinvI* increased in all river sections from 2020. However, when examining each section of the river separately and comparing renaturalized with representative ones, there are no significant differences, except for the Vašuoka River in 2022, in whose renaturalized section a greater difference in *RMinvI* values is visible than in the representative section of this river (in the re-naturalized section of the river, the value of the *RMinvI* index was 0.78, and in the representative one – 0.69). The sections of all studied rivers are similar (coasts without woody vegetation, flowing near cultivated fields) and renaturalization led to more hydrological differences in river sections. If macroinvertebrate species sensitive to organic pollution lived in them before the renaturalization of the riverbeds, even after changing the environmental conditions and during the relatively short research period, a significant increase in invertebrates cannot be expected (Figure 4).

River Macrophyte Index. It was found that in the 2020 and 2021 research years, the *RMphI* did not change in all studied renaturalized river sections. According to the *RMphI*, the renaturalized sections of the Vašuoka and Viešinta rivers can be assigned to the category of average ecological condition (*RMphI* value 0.4, respectively), while the renaturalized section of the Vyžuonas river belongs to the category of bad ecological condition (*RMphI* value 0.1). After conducting the research in the last year of 2022, a higher *RMphI* was determined in the representative sections of the Vashuoka and Vyžuona rivers. In the Vašuoka river, the condition of a representative section has risen to good, while in the Vyžuonas river to average. The condition of the representative section of the river remained unchanged – average (Figure 5).

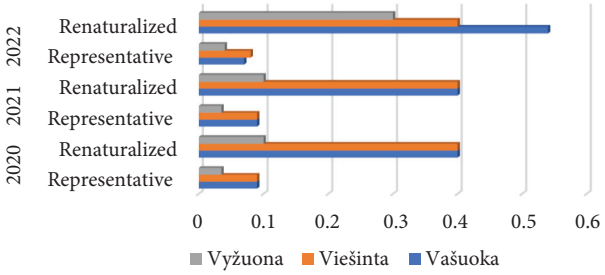

Figure 5. Results of changes of River Macrophyte Index

According to the *RMphI*, the representative sections of all studied rivers can be assigned to the category of very bad ecological status (*RMphI* values fall within the limits of 0.09–0.00).

The results of this study suggest that water plant communities are influenced by changes caused by renaturalization of river channel. Not only the composition of aquatic plants is changing, but also riparian vegetation. The obtainet results confirmed the studies in other countries (Helfield et al., 2012; Ecke et al., 2016). The studies demonstrated that restoring natural flow regimes can be an effective means of enhancing the diversity of aquatic plant communities along small streams (Helfield et al., 2007; Ecke et al., 2016), but less is known about the effects of restoration on larger rivers with multiple channels. The studies have demonstrated that restoring natural patterns of fluvial disturbance can induce relatively quick (3–10 years) responses in plant communities (Helfield et al., 2007). Consequently, the longer we carry out the study, the more changes in the composition of plants will be noticeable.

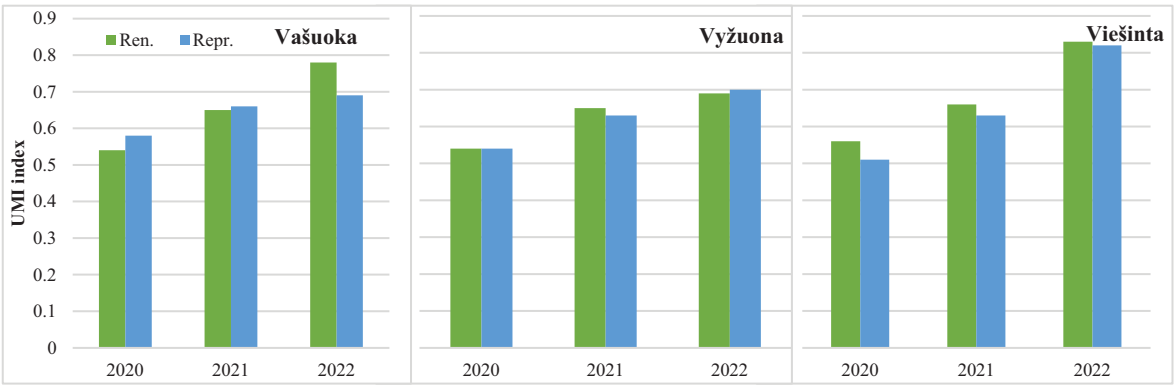

Figure 4. Results of changes of River Macroinvertebrate Index

It should be mentioned that the recovery and change of plant communities is highly dependent on the water level and the prevailing soil (Ecke et al., 2016). In the absence of fine soils suitable for colonization, establishment of riparian plant communities may take decades. Frequent water level fluctuations also negatively affect the change of water and coastal vegetation.

Although the renaturalization of a river channel can change the species composition of water and riparian plants, these changes are not always positive. The diversity of plant species is not always positively correlated with renaturalization of river chanel (Mackey & Currie, 2001; Li et al., 2004). For example, in areas where invasive plants are prevalent, increases in fluvial disturbance frequency might create open patches facilitating colonization by invasive species (Hood & Naiman, 2000; Tabacchi et al., 2005), resulting in potentially lasting reductions in diversity. Alternatively, in areas where flow regimes favour invasive species (Howell & Benson, 2000; Aguiar et al., 2001; Taylor & Ganf, 2005), restoring natural flow regimes can be an effective means of controlling invasive species (Stromberg et al., 2007).

So, renaturalization of river channel outcomes can vary according to physical and ecological factors as well as the type of river chanel.

The obtained results allow us to assume that, according to the used *RMphI*, river renaturalization measures affect the ecological condition of rivers, but it takes time to assess the effectiveness of renaturalization specifically for aquatic plant communities (Helfield et al., 2007), therefore, both during the summer season of 2020 and 2021, studies showed the same results and only in 2022 changes became visible. Changes in plant communities due to environmental conditions are relatively slow and require attention (Helfield et al., 2012). In particular, it is not known what can be expected when the water level fluctuates in the face of climate change, especially when natural heat waves or rains occur.

It should be noted that during the research during the 2022 season, it was noticed that the water level in all studied river sections was lower compared to the 2021 season. Fluctuations in the water level had an impact on the formation of vegetation during this growing season, so less vegetation of riverbeds with helophytes and tall coastal grasses was observed. This trend corrected the *RMphI* values in Vašuoka and Vyžuona rivers.

The total abundance of helophytes in renaturalized river sections was lower in 2022 than in 2021. The more open sections of the renaturalized rivers led to changes: faster current and better penetration of light into the deeper water layers, so more abundant growth of submerged macrophytes (Potamogeton sp.) was observed. An increase in the abundance of elodeids was also observed during the implementation of re-naturalization projects in nine other European countries (Ecke et al., 2016). Adapted species capable of faster currents from Potamogeton sp., Ranunculus sp. The genera began to multiply, while the abundance of nymphaeids decreased, as the latter settle in areas of slower currents (Ecke et al., 2016). During our research, the faster current at the renaturation measures showed trends that the width of the gap left to direct the water flow is very important when installing the renaturation measures in the riverbed.

It should also be noted that when the water level rose (situation in 2021), the renaturalization measures ended up under water, were covered with sedimentary materials and further encouraged the growth of helophytes, which slowed down the current. It is likely that such revegetation of renaturalization measures could be useful if the riverbanks are managed (mowed) so that the place where the current is diverted is open. Otherwise, a zone of stagnant water is formed behind the place of installation of the measures, and sediments accumulate in front of it. The same trends were observed in a study conducted in Sweden (Helfield et al., 2012). Therefore, it is very important to assess not only the possible changes in the water level, but also the prevailing soil, because the results of the renaturalization of the river bed may differ depending on the physical and ecological factors and the type of the river itself.

Conclusions

The results of complex studies show the renaturalization measures implemented have the greatest positive effect on the studied parameters in the Vašuoka River, compared to other rivers. Achieving better results was hindered by small flow velocities, in the case of the Vyžuona, barely exceeding the silting speed near the installed renaturalization measures.

During the investigated three-year period, according to the values of the *Fish Index* indicators, the ecological condition of the Vyžuona River in both sections varied from very good to good in the renaturalized section and from good to very good in the representative section. In both sections of the publicized river and in the renaturalized section of Vašuoka, the condition remained stable and during the entire studied period the condition was assessed as average. In the representative section of Vašuoka, the condition in 2020 was assessed as bad, but in 2021–2022 the condition was assessed as average.

In the renaturalized sections of Vašuoka and Viešinta, greater species diversity is observed and fish species that are more sensitive to water quality and are considered indicators of good ecological condition are found more often, although individuals of these species are usually single. It is likely that the renaturalization works carried out in the smaller rivers had a positive effect on the fish community, creating a greater diversity of biotopes. Monitoring of these sections should be continued, with ichthyological studies not being carried out annually, but every three to five years.

Comparing the data of three years of research in the renaturalized sections of the three rivers, the *River Macroinvertebrate Index* in the direction of improvement was the strongest in the Viešinta river, and the weakest in the Vyžuonas river.

In order to improve the living conditions of aquatic macroinvertebrates, it would be necessary for the straightened sections of the river to meander more and, as a result, river sections with riparian zones would form. The current renaturalization does not include changes in the direction of the riverbed, but only modifies the river's flow rate. It would also be necessary to at least minimally plant trees along the edges of rivers with woody vegetation. This would further improve the ecological condition of the river by darkening the riverbed and absorbing biogenic materials coming from cultivated fields.

Summarizing the data of all three research years, it could be said that the situation in renaturalized river sections is changing. The direction of change is greatly influenced each year by the prevailing environmental conditions in that season. Very important is the water level, which depends on the ratio and abundance of helophytes/macrophytes in the riverbed and on the banks. Therefore, the installation of renaturalization measures should be based on recommendations based on long-term generalized research.

Before installing the renaturalization measures, an assessment of possible water level fluctuations should be performed when selecting the height of the renaturalization measures, so that the measures are not carried away by sediments for at least 10 years after the installation. The height and width of the renaturalization measures should be evaluated depending on the width of the riverbed, so that the remaining open area for channeling the current is not too large;

It is needed: (1) to manage the banks of renaturalized river sections for at least 10 years after the installation of renaturalization measures, namely the mowing of tall grasses on the riverbanks (IMPORTANT!!! for real efficiency) during the period of intense vegetation, so that the latter species of plants do not fall on the river bed; (2) removal of helophytes (coastal and shallow plants, the greater part of which is raised above the water and the lower part is submerged) from the coastal zones and the riverbed, especially in those parts where the current is diverted; (3) leaving (not removing) helophytes and tall grass stands on the renaturalization measures, so that only the area left to direct the current remains open.

On the installing a renaturalization measures, it is necessary to strive to create appropriate speeds that create an intense turbulent flow through the measures, not only to adjust the direction of the stream flow or the variety of flow speeds. According to the results of the study, the determined flow velocities at the devices were 1.5–2.3 m/s at a flow depth of 0.2–0.5 m and 1.1–1.5 m/s at a flow depth of 0.9–1.0 of depth.

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Contribution

dr. Andrius Litvinaitis – conception and design of the work, acquisition, analysis and interpretation of ecological condition according to hydro morphological quality elements, acquisition of general physico-chemical parameters; dr. Lina Bagdžiūnaitė-Litvinaitienė – acquisition, analysis and interpretation of general physico-chemical parameters; dr. Jurgita Butkuvienė – acquisition, analysis and interpretation of River Macrophyte Index; Antanas Kontautas, Andrius Skersonas, Edgaras Ivanauskas – acquisition, analysis and interpretation of Fish Index; dr. Tomas Ruginis – acquisition, analysis and interpretation of River Macroinvertebrate Index.

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