

## **Impact of the incised stream restoration on habitats, aquatic fauna and ecological stream quality**

Impact de la restauration de rivières encaissées sur les habitats, la faune aquatique et la qualité écologique du cours d'eau

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### **RÉSUMÉ**

Les changements dans l'écosystème du ruisseau Krzczonówka (Carpatates, Pologne), profondément incisé, résultant de l'abaissement d'un haut barrage de retenue et de l'installation de plusieurs rampes de blocage dans la partie aval ont été examinés sur une période de 5 ans du projet de restauration. Les mesures ont augmenté l'élévation du lit, la largeur du canal et la vitesse près du lit et ont réduit la profondeur du canal. La richesse taxonomique des invertébrés benthiques a augmenté de manière significative et l'augmentation était inversement proportionnelle à la modification de la profondeur du lit du cours d'eau. La richesse des espèces de poissons et l'abondance des individus subadultes et adultes n'ont pas augmenté, mais la structure des communautés de poissons a évolué vers une structure plus naturelle. Les évaluations des effets de la restauration sur la qualité écologique des cours d'eau réalisées avec l'indice BMWP-PL basé sur les invertébrés et l'indice EFI+ basé sur les poissons ont donné des résultats différents, le premier indiquant une amélioration significative et le second une absence de changement de qualité. Une combinaison des mesures appliquées s'est avérée utile pour restaurer l'écosystème d'un ruisseau de montagne encaissé, mais avec des effets divers sur les différents groupes de la faune aquatique.

### **ABSTRACT**

Changes in the ecosystem of deeply incised Krzczonówka Stream, Polish Carpathians, resulting from lowering of a high check dam and installation of several block ramps in the downstream reach were examined over 5 years of the restoration project. The measures increased bed elevation, bankfull channel width and near-bed velocity and reduced bankfull channel depth. Taxonomic richness of benthic invertebrates significantly increased and the increase was inversely related to a change in bankfull channel depth of the stream. Fish species richness and the abundance of subadult and adult fish individuals did not increase, but the structure of fish communities changed towards more natural one. Assessments of restoration effects on ecological stream quality performed with the invertebrate-based BMWP-PL index and the fish-based EFI+ Index yielded different results, with the former indicating a significant improvement and the latter a lack of quality change. A combination of the applied measures appeared useful in restoring the ecosystem of incised mountain stream, though with diverse effects on different groups of aquatic fauna.

### **KEYWORDS**

aquatic fauna; ecological quality; mountain stream; physical habitat conditions; stream restoration

## 1 INTRODUCTION

Construction of 3.7-m-high check dam on Krzczonówka Stream, Polish Carpathians, in the mid-20th century resulted in a number of detrimental changes to the downstream reach. Moreover, channelization works conducted in this reach since the late 1950s caused up to a threefold narrowing of the active channel (Lenar-Matyas et al., 2015). The channelization-induced increase in transport capacity of the stream combined with sediment starvation resulting from the stream partitioning by the check dam have induced intense bed degradation. Until the early 2010s, up to 2 m of channel incision occurred and the alluvial channel bed was transformed into a bedrock–alluvial or bedrock bed. A restoration project realised between 2012 and 2016 aimed at lowering of the check dam and making it passable for fish and installation of several block ramps in the deeply incised downstream reach to trap the sediment released from the reservoir of the lowered check dam (Wyżga et al., 2021a). In May 2014 a moderate flood occurred on the stream, flushing out a substantial amount of gravelly material from the dam reservoir and depositing it in the downstream reach (Wyżga et al., 2021b). This study aims to assess the influence of the restoration measures on the stream ecosystem downstream from the lowered check dam, including changes in physical habitat parameters, fish and benthic macroinvertebrate communities and ecological stream quality.

## 2 STUDY METHODS

Ten stream cross-sections were examined each summer between 2012 and 2016 in terms of channel morphology, hydraulic conditions at base flow and bed-material grain size. Each year between 2012 and 2016 sampling of benthic macroinvertebrates in the cross-sections was carried out during spring, summer and autumn. Species composition and abundance of fish community were investigated twice a year: in July and September. Scores of the BMWP-PL index were calculated on the basis of individual samplings of benthic macroinvertebrates and ecological stream quality of each cross-section was determined on the basis of the index scores derived from spring, summer and autumn surveys of each year. Scores of the European Fish Index (EFI+) were determined on the basis of individual electrofishings and averages of the scores for summer and autumn electrofishings were used to allocate given cross-sections to relevant classes of fish-based ecological quality.

## 3 RESULTS

Flushing out of the sediment from the dam reservoir and its efficient entrapment by block ramps during a moderate flood in 2014 resulted in significant increases in bed elevation, bankfull channel width and near-bed flow velocity as well as a reduction of bankfull channel depth. Bed aggradation in the years 2012–2016 was larger close to the check dam, with the average change in bed elevation in cross-sections 1–5 amounting to 0.68 m and that in cross-sections 6–10 to 0.34 m. During 15 surveys performed over five years of the restoration project, a total of 50 benthic macroinvertebrate taxa were found in 10 study cross-sections of Krzczonówka Stream. The highest yearly average was recorded in 2016; it was more than twice greater than in 2014 and exceeded by two-thirds the value recorded in 2012, before the onset of restoration activities, with the difference being statistically significant (Fischer's LSD test,  $p = 0.004$ ) (Fig. 1A). Ten electrofishings performed over five years of the project indicated a permanent occurrence of five fish species in the study cross-sections of the stream. However, no significant differences in the average abundance of subadult and adult fish individuals occurred between five years of the restoration project (Fig. 1B), although the structure of fish community changed towards more natural one after the implementation of restoration measures.

Comparison of average scores of the invertebrate-based BMPW-PL index for each year showed significant differences between the five years of the restoration project. Between 2012 and 2015 individual cross-sections represented moderate to good ecological status. However, in 2016 at the end of the restoration project, the BMWP-PL index showed a very good ecological condition of the stream and this result differed significantly from the previous years. The European Fish Index calculated for each year of the project showed a different pattern of changes in the ecological condition of the stream. The average index score for the analyzed cross-sections did not differ significantly between individual years, consistently indicating a very good ecological state of the stream. A redundancy analysis performed to determine changes in physical habitat parameters explaining changes in the taxonomic richness of benthic invertebrates and in ecological status of the stream determined on the basis of the BMWP-PL index indicated a relative change in bankfull channel depth as the only significant variable explaining the change in the biotic parameters. This indicates a significant reduction in hydraulic forces acting during floods on the streambed and the organisms inhabiting it as a principal factor driving changes of the benthic invertebrate community.

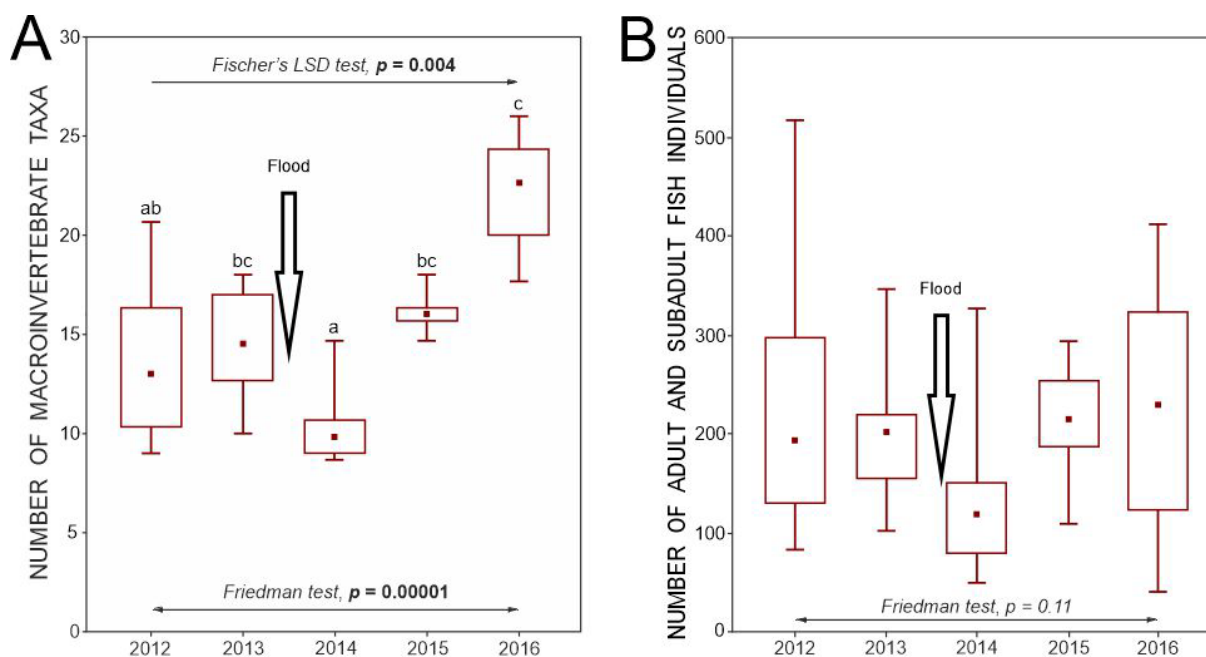


Figure 1. Changes in the number of benthic macroinvertebrate taxa (A) and in the number of subadult and adult fish individuals (B) in the surveyed cross-sections of Krzczonówka Stream in the years 2012–2016. Boxplots present median (square), the first and the third quartiles (bottom and top of boxes), and minimum and maximum values (whiskers). Statistical significance of the differences between all study years is indicated by a Friedman test. Different letters signify statistically different samples indicated by a Fischer's LSD *post hoc* test and the significance of the difference between 2012 and 2016 indicated by this test is shown. Statistically significant differences are indicated in bold. The vertical arrow points to the occurrence of a flood preceding the surveys in 2014.

#### 4 CONCLUSIONS

Lowering of a high check dam and installation of block ramps in the downstream reach enabled significant increases in bed elevation, bankfull channel width and near-bed flow velocity as well as a reduction of bankfull channel depth. After the deposition of dam-released sediments, the average taxonomic richness of benthic macroinvertebrates progressively increased and was significantly higher in the last year of the restoration project than before the onset of restoration activities. This change was reflected in a significant improvement of ecological stream quality indicated by the invertebrate-based BMWP-PL index. In contrast, the restoration did not increase species richness of fish and the average abundance of subadult and adult fish individuals, which was reflected in a lack of change in ecological stream quality indicated by the fish-based EFI+ index. Despite the diverse effects on different groups of aquatic fauna, the combination of the applied measures appeared useful in restoring the overall quality of the ecosystem of an incised mountain stream.

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