UNIVERSITY OF PÉCS
Biological and Sportbiological Doctoral School

Impact of hydrological regime changes on the structural and functional composition of aquatic macroinvertebrate communities

PhD Thesis

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1. Introduction

One of the major issues of our time is the changing hydrological regimes of surface waters that were previously considered to have a constant water level, which can lead to extremely complex and widespread societal problems (Brauman et al., 2007). Water scarcity directly impacts the economy, agriculture and industry, while also contributing to the decline in social well-being and indirectly, increasing the burden on healthcare systems (Rieb et al., 2017).

Watercourses and wetlands are among the most diverse environment in the world, due to the diversity of their appearance (Dudgeon et el., 2005). The physical and chemical properties of water play a crucial role in shaping the environmental conditions for the organisms that inhabit these ecosystems.

Changes in the hydrological regime of flowing waters can affect the essential conditions for these organisms, which can lead to changes in community structures (Poff et al., 1997). Aquatic macroinvertebrates, as key members of aquatic communities, serve as excellent indicators of the ecological status of water bodies because they respond rapidly to environmental changes. Aquatic macroinvertebrates are relatively easy to study, have limited mobility and have a life cycle long enough to reflect changes in their environment (Plafkin et al., 1989; Voshell et al., 1997). The structure of communities made up of groups with different ecological demands, follows and thus reflects changes in the environment, making them suitable for ecological assessment (Boda et al., 2014; Böhmer et al., 2004).

There are two primary drivers of changes in hydrological regimes. The first is natural fluctuations due to climate change (Arnell and Gosling, 2013; Schneider et al., 2013), and the second is due to human interference (Mittal et al., 2016). In my PhD thesis, we investigated the effects of both climate change-induced and human-induced changes in hydrological regime changes on the organisation of aquatic macroinvertebrate communities, which are presented in two separate chapters.

2.1. The impact of climate change-induced hydrological changes on the structural and functional composition of macroinvertebrate communities

2.1.1. Introduction

The spatial and temporal extent of climate-induced droughts is increasing, with more and more surface waters that were previously considered constant now becoming intermittent (Carey et al., 2021; Lucas-Picher et al., 2021; Zipper et al., 2021). This change has a significant impact on the functioning of communities and ecosystems (Aspin et al., 2018; Crabot et al., 2021a; 2021b).

Rising average temperatures and altered precipitation patterns due to climate change have led to an inconsistent water supply in streams throughout the year. This inconsistency can cause streams to dry up, a process that unfolds in multiple stages. Initially, the lack of recharge slows the flow of water, eventually leading to a complete cessation. As water levels drop, the connection with the riparian region is lost, followed by the disruption of longitudinal continuity, resulting in the formation of isolated pools. If the lack of recharge persists, surface water may disappear completely and the streambed may dry up (Chadd et al., 2017; Datry et al., 2014).

During different phases of drying, the habitat mosaics within streams undergo continuous changes, which are accompanied by shifts in the composition of aquatic macroinvertebrate communities (Boulton, 2003). Environmental filtering, driven by the changing conditions of these habitats, affects the traits possessed by individuals. Consequently, research is increasingly focusing on the trait-based functional composition of communities. Functional traits, which include morphological, biochemical, physiological, phenological, and behavioral characteristics of organisms can be used to describe species (McGill et al., 2006).

Individuals can respond to environmental changes through the full range of the possessed trait states. To survive drying events, they must possess traits that enable them to employ survival strategies successfully. Resistance and resilience are the most crucial strategies, that allowing aquatic organisms to endure drying events (Aspin et al., 2018; Bogan et al., 2015). Resistance refers to the ability of species to survive the dry phase by remaining within the habitat. In contrast, resilience refers to the capacity to recolonize following the return of water, primarily through strong dispersal abilities.

The impact of the transition from perennial to intermittent stream types, particularly the initial onset of drought, on the structural and functional composition of aquatic macroinvertebrate communities has been relatively understudied (Crabot et al., 2021a; 2021b; Pařil et al., 2019).

2.1.2. Aims

We aimed to compare the structural and functional composition of aquatic macroinvertebrate communities in perennial and intermittent stream sections, with a particular focus on their responses to the onset of intermittence, examined through the lens of resilience and resistance survival strategies. We hypothesize that in intermittent stream sections, traits that are crucial for resilience and resistance survival strategies play a significant role in the organization of aquatic macroinvertebrate communities.

2.1.3. Material and methods

We investigated the effects of climate change-induced hydrological regime changes within the catchment area of the Bükkösdi-víz, located on the southern side of the Mecsek Mountains, over two years between 2018 and 2021. Since September 2018, certain sections of streams within the catchment have transitioned from perennial to intermittent. We collected quantitative samples of aquatic macroinvertebrates from a total of 40 sampling sections – 18 perennial and 22 intermittent – following the sampling protocol outlined in the River Basin Management Plan of Hungary (Boda et al., 2023). During each biological sampling event, and at two additional time points, we recorded the current hydrological parameters of all stream sections, based on which we classified them into perennial and intermittent stream types.

To analyze the spatial autocorrelation of aquatic macroinvertebrate communities across the sampling sections, we performed a Mantel test using Pearson's Product-Moment correlation with 999 permutations. To compare the structural composition of aquatic macroinvertebrate communities in perennial and intermittent stream sections, we examined four structural metrics: taxon richness, abundance, Shannon diversity, and evenness. We applied a linear mixed model (LMM) using the restricted maximum likelihood (REML) estimation method with the ‘lmer’ function in the lme4 R package (Bates et al., 2014). Additionally, to explore differences in the structural composition of aquatic macroinvertebrate communities between the two stream types, we used non-metric multidimensional scaling (NMDS) and permutational multivariate analysis of variance (PERMANOVA) with Bray-Curtis distance measures.

We compiled the functional trait data of the species from the freshwaterecology.info website (Schmidt-Kloiber & Hering, 2015) and the DISPERSE database (Sarremejane et al., 2020). We analyzed 62 trait states across 12 traits associated with intermittency. The trait states were categorized into resistant (RT), resilient (RL), non-resistant (non-RT), and non-resilient (non-RL) state groups, based on their relevance to resistance and resilience survival strategies. From the trait state data and relative abundance data, we generated community-weighted mean (CWM) values and used t-tests to examine differences between the two stream types. Additionally, we assessed the range of CWM value changes by comparing the CWM values of each intermittent section to the average CWM values of the perennial sections. To explore the relationship between trait states and perennial or intermittent sections, we conducted an indicator species analysis (Laini et al., 2022). We also quantitatively defined the functional trait space occupied by aquatic macroinvertebrates in both intermittent and perennial sections (Podani et al., 2021; Cornwell et al., 2006)

2.1.4. Results and Discussion

We found that the taxon richness and abundance of aquatic macroinvertebrate communities were significantly lower in intermittent sections compared to perennial ones, while Shannon diversity and evenness did not differ between the two categories.

Aquatic macroinvertebrates can possess trait states linked to resistance and resilience survival strategies. By analyzing the quantitative ratios of these trait states, we can infer the strategies that individuals use to survive the onset of drying in intermittent waters. To calculate these ratios, we used the average CWM values of the perennial sections as a baseline and compared them to i) the average CWM value calculated from all intermittent sections and ii) the CWM value calculated for each intermittent section individually. In the first case, we observed that most resistance-related trait states had higher proportions (average CWM value) in intermittent sections. In contrast, resilience-related trait states appeared in either lower or higher proportions in the communities of intermittent sections compared to perennial ones. In the second case, we found that the range of change (the variance in CWM values) for RL, non-RL, and non-RT trait states varied widely, while the range of change for RT trait states was smaller and more consistent within the state group.

Overall, taxa in intermittent sections occupied a smaller functional space, indicating that these communities have lower functional redundancy and are, therefore, more sensitive to environmental changes.

Our results suggest that species following a resistance strategy were more prevalent in the community than those following a resilience strategy. This indicates that after the initial onset of drying, the organization of aquatic macroinvertebrate communities in newly intermittent sections is more strongly influenced by resistance traits than by resilience traits. However, not all resilience and resistance trait states exhibited the same degree of quantitative shift, indicating that the response of aquatic macroinvertebrate communities to a new, previously unexperienced environmental stress is not uniform. The time elapsed since the first occurrence of drying may significantly influence responses to drying, implying that the duration since the onset of drying should be considered in the ecological assessment of communities.

2.2. The impact of human-induced hydrological changes on the structural and functional composition of macroinvertebrate communities

2.2.1. Introduction

The modification of river systems serves multiple purposes. In some cases, the primary objective is rapid water drainage, primarily for flood and inland water protection (Ecsedi et al., 2020). In other instances, damming streams for irrigation storage and energy production is the most common management practice (Margeta, 2014). Conservation interventions can also alter the hydrological regimes of rivers and streams (Boros et al., 2013). These conservation interventions can also lead to significant changes in water flow.

In Hungary, most conservation-related habitat restoration efforts affecting wetlands are associated with soda pans, flooded grasslands, and salt marshes (Boros et al., 2013).

Successful restoration projects involving soda pans require three main interventions: 1. Water supply for a soda pan is typically provided by a surface stream that collects precipitation from the surrounding areas and flows through or near the lakebed. To maintain the necessary water level for appropriate flooding duration, water in this stream must be retained using a structure, and water management techniques must be employed to release the correct amount of water to the saline area as needed. 2. The efficient release of water should be facilitated by modifying the channel of the surface stream (e.g., altering the channel profile by reducing the slope gradient to create a shallow stream bank) to ensure that the retained water can reach the desired flooding area. 3. Simultaneously, the area of the soda pans and the surrounding land must be managed through extensive, sustainable grazing practices. Grazing helps restore soil salinity, which is beneficial for maintaining saline habitats, and creates a mosaic vegetation pattern that provides shelter and safe nesting sites for shorebirds (Adler et al., 2001; Skovlin, 1985).

The impact of water retention on the surface stream extends over a longer stretch, while channel modification and grazing only affect a shorter section. Consequently, the aquatic macroinvertebrate communities in these streams may experience single (water retention) or complex (water retention along with grazing and channel modification) pressures during restoration interventions.

2.2.2. Aims

The aim of this study was to investigate the impact of changes in water flow resulting from a conservation intervention on the structural, phylogenetic, and functional composition of aquatic macroinvertebrate communities in the supply stream of a soda pan. In addition to the effects of altered water flow as single stressor, the intervention also introduced complex stressor, such as channel modification and grazing on a section of the stream. Thus, our study also extends to examining the effects of a complex stressor. We hypothesize that changes in water flow alone cause only minor changes in the composition of aquatic macroinvertebrate communities, which may not be apparent in the phylogenetic and functional composition. However, under complex stress conditions, the structural changes in the community are expected to be reflected in both the phylogenetic and functional composition.

2.2.3. Material and Methods

The examined soda pan is located in the centre of Hajdú-Bihar County, near the town of Balmazújváros. The hydrology of the soda pan is regulated by the Magdolna-ér, which flows through the soda pan. The section of the Magdolna-ér that passes through the soda pan was dredged, resulting in a flattened channel profile, and sluices were constructed to facilitate controlled flooding. Additionally, ecologically sustainable and intensive grazing practices were initiated in the area. The effects of water retention are also noticeable upstream of the soda pan. Consequently, the habitat restoration led to the emergence of both single and complex stressors along the Magdolna-ér.

Aquatic macroinvertebrate samples were collected before the intervention in 2011 and in the two years following the intervention, 2013 and 2014, at the section affected by water retention (single stressor, V section) and complex stressor (K section). In both sections, three sampling sites were designated. To account for temporal repetitions and to represent the natural seasonal variation of the aquatic macroinvertebrate community, sampling was conducted three times each year (in spring, summer, and autumn) on both sections of the stream using the AQEM multihabitat sampling method.

To investigate temporal changes in the structural composition of the aquatic macroinvertebrate communities, we used non-metric multidimensional scaling (NMDS, Bray-Curtis distance, abundance data) and permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001). To compare the diversity values of aquatic macroinvertebrate communities between sampling sites and years, we used Rényi entropy (Borics et al., 2021; Kindt et al., 2006). For comparisons of the structural and functional composition of aquatic macroinvertebrate communities across sites and years, we conducted a two-way analysis of variance (ANOVA) with post-hoc Tukey tests. Functional diversity was assessed at both species and genus levels, using a total of 30 species-level and 24 genus-level functional traits for the analyses. From the functional trait data and the relative abundance of aquatic macroinvertebrates, we calculated the community-weighted mean (CWM) for each trait state. Using the CWM values, we calculated functional diversity using Shannon diversity. Changes in the functional diversity of aquatic macroinvertebrate communities were examined at both species and genus levels. We characterized changes in the phylogenetic composition of the aquatic macroinvertebrate community using taxonomic distances. The impact of restoration work on the ecological status of the stream was assessed using the Hungarian Multimetric Macrozoobenton Index (HMMI; Boda et al., 2023).

2.2.4. Results and Discussion

We have emphasized that various simple and complex stressor from different interventions influence the structural and functional composition of the aquatic macroinvertebrate community to varying extent. The alteration and dredging of the channel, water retention, livestock management, and grazing, along with their interactions, influence the hydrological and hydromorphological state of the stream. As a result, the stream no longer provides a suitable habitat for the pre-existing aquatic macroinvertebrate community, leading to changes in structural composition, with some species disappearing and a new community composition rebuilding. Water retention did not affect community diversity; however, the complex stressor resulted in changes in species composition and a decrease in community diversity.

Functional diversity also changed over the years due to both stressors. The combined effects of channel modification, grazing, and water retention led to greater changes in the functional diversity of aquatic macroinvertebrate communities than water retention alone. However, only 20% of the functional traits showed irreversible changes, meaning that the traits had not returned to their initial state even by the second year following the intervention. Changes in functional diversity were more detectable at the genus level than at the species level. However, the functional trait database assigns different levels of data to the genus and species levels, which can significantly influence the differences in functional diversity analysis.

The changes in the structural and functional composition of aquatic macroinvertebrate communities are reflected in the ecological status of the stream. Structural and functional changes led to alterations in the ecological quality ratio (EQR) values; however, these changes did not affect the ecological quality class (EQC), which remained unchanged due to water retention. In contrast, the complex stressor led to a deterioration of the watercourse's ecological quality by one quality class, shifting it from "good" to "moderate".

The altered water regime resulting from the conservation intervention caused only minor changes in the aquatic macroinvertebrate community. In contrast, the combined effects of channel modification, grazing, and water retention caused significant, long-term changes in the community.

3. Summary

During my doctoral research, we investigated the impact of hydrological regime changes on the structural and functional composition of aquatic macroinvertebrate communities. Regardless of their causes, these hydrological changes lead to changes in the structural composition of macroinvertebrate communities, although these shifts are not always reflected in their functional composition. Intermittency affect both the structural and functional composition of the communities, with the organization of macroinvertebrate communities being primarily determined by resistance survival strategies. In contrast, water retention mainly influence the structural composition. When water retention is combined with other stressors, such as channel modification or grazing, the complex stressor impacts the functional composition of the community; however, these changes are reversible. The practical application of our findings can contribute to the development of water management plans, water protection measures, and conservation strategies that help maintain the good ecological status of surface waters and improve the ecological condition of already degraded habitats.

4. References

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List of Publications

Scientific Papers Underpinning the Doctoral Dissertation

Bozóki, T., Várbíró, G., Csabai, Z., Schmera, D., Boda, P. (2024). Resistance not resilience traits structure macroinvertebrate communities in newly drying stream sections. Hydrobiologia, 1–14. https://doi.org/10.1007/s10750-024-05518-1 (IF = 2,2; SJR = Q1)

Boda, P., **Bozóki, T.**, Krasznai-K, E. Á., Várbíró, G., Móra, A., Csabai, Z. (2021). Restoration-mediated alteration induces substantial structural changes, but negligible shifts in functional and phylogenetic diversity of a non-target community: a case study from a soda pan. Hydrobiologia, 848, 857–871. https://doi.org/10.1007/s10750-020-04494-6 (IF = 2.822; SJR = Q1)

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Oral presentations and posters related to the Doctoral dissertation

Oral Presentations

Bozóki, T., Várbíró, G., Csabai, Z., Schmera, D., Boda, P. (2024). Resistance, not resilience traits, structure macroinvertebrate communities in newly drying stream sections. 4th Central European Symposium for Aquatic Macroinvertebrate Research. Stará Lesná. 2024.

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