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Editorial

Effects and persistence of river restoration measures: ecological, management and research implications

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1. Introduction

As a result of intense human pressures, most streams and rivers in densely populated areas have experienced negative impacts on the functioning and integrity of their aquatic and riparian ecosystems and on the ecosystem services they deliver, including the supply of drinking water, fisheries, flood regulation. Recognition of these detrimental effects of humans on watercourses has stimulated activities aimed at improving their degraded attributes. Together these activities are called *river restoration*, with improvement of ecological integrity being an essential but not the only objective (Wohl et al., 2015). In many countries, particularly the USA, a very large number of river restoration projects have been implemented over the last ca. 30 years. In the European Union, restoration activities have been strengthened by the Water Framework Directive requirement to re-establish good ecological status of surface waters. These widespread experiences of river restoration activities have also become an important subject for review in scientific papers (Palmer et al., 2007; Wohl et al., 2005, 2015), books (Roni and Beechie, 2012; Simon et al., 2011) and special issues of international journals (e.g. Friberg et al., 2017).

Despite knowledge based on extensive practical experience, restoration activities frequently fail to achieve their ecological goals (Palmer et al., 2010) or the long-term persistence of their hydraulic and geomorphic effects (e.g. Geerling et al., 2008; Kondolf et al., 2001). This probably reflects an emphasis on designing and creating channel forms that look more natural rather than re-establishing or working with hydrological and geomorphic processes that can induce and sustain changes in channel form and habitat structure. To make restoration activities successful and sustainable, the variety of stressors acting individually or in combination on a given river need to be taken into account when devising restoration measures both for different physiographic conditions and also for specific local contexts. At the same time, river restoration must take account of cultural constraints (LeLay et al., 2008) and must compromise between environmental and stakeholder needs (McDonald et al., 2004). Improving recognition of the most appropriate restoration measures in terms of their effects and persistence, as well as adoption of environmentally-friendly methods of river maintenance provided the foundations for the international conference *'Towards the best practice of river restoration and maintenance'*.

2. International conference on river restoration and maintenance

The conference was held in Kraków, Poland, on 20–23 September 2016 and was attended by over 140 participants from 18 countries. The conference aimed to bring together river scientists and practitioners to share and discuss recent scientific research on river functioning, river status evaluation and various aspects of river restoration, and to facilitate exchange of experiences on river restoration and environment-friendly river maintenance, especially with regard to flood risk management and nature protection. The event also aimed to encourage interest in science-based practices of river restoration in Poland by bringing together internationally renowned river restoration scientists and supporting communication with representatives of local water and environmental authorities, non-governmental organizations and private companies through provision of simultaneous translation.

Four plenary sessions were held, each followed by three parallel thematic sessions focusing on: functioning of mountain rivers; modelling of fluvial processes; management of flood hazard and risk in the context of environmental needs; evaluation of river status: technical interventions in river restoration and environmentally-oriented maintenance; European and regional perspectives on river restoration and management as well as legal and social aspects of river restoration. In total, 62 oral contributions and 26 posters were presented. In addition, two workshops on *National strategies for monitoring and success evaluation in river rehabilitation* were held and led by Swiss experts in river restoration—dr Christine Weber and dr Ulrika Åberg.

The conference was organized by a consortium including the Ab Ovo Association and several scientific institutions (universities and institutes of the Polish Academy of Sciences) from Kraków. The non-governmental organization Abo Ovo Association had carried out a river restoration project *'The Upper Raba River spawning Grounds'* during the four years prior to the conference. This project and the conference were supported by Swiss Contribution to the Enlarged European Union, and the outcomes and experiences from the restoration project were presented during a field excursion following the conference.

Papers collected in this virtual special issue represent a selection of the conference contributions. They provide insights into innovative study methods or important, emerging aspects of river restoration activities.

3. Summary of contributions to the special issue

3.1. Physical river forms, processes and impacts

Five papers included in this virtual special issue consider different physical aspects of rivers relevant to river management and restoration.

Fernandez et al. (2018) address the important problem of soil erosion in mountainous catchments. They propose a GIS-based methodology coupled with the Universal Soil Loss Equation to integrate morphological, soil, climate, vegetation cover and land use information to estimate soil erosion and map erosion fragility. They apply the methodology to the Darro river basin, Spain, identifying the central part of the basin, with unconsolidated rocks and low soil permeability and agricultural land use, as the area most threatened by soil erosion. These analyses have supported river managers in undertaking measures aimed at reducing soil and river erosion and supporting recovery of the environmental values of the basin.

Channel maintenance practices form a second theme that affects the majority of rivers. Improvement of such practices is of utmost importance for enhancing river ecological status. Bączyk et al. (2018) conduct a meta-analysis of papers concerning dredging, macrophyte removal, and the fish, macroinvertebrate and overall ecological status of maintained rivers to review the nature and ecological impacts of channel maintenance practices on lowland agricultural rivers. 96% of the analysed papers indicate negative responses of river ecosystems to maintenance measures, including changes in the abundance and composition of river communities. This review illustrates the pressing need to adjust channel maintenance practices along lowland agricultural rivers in order to minimize their impacts and maximize benefits for river ecosystems and local communities. Long-term monitoring is also needed to identify recovery trajectories and thus optimize the use of different management adjustments.

Increasing river water temperatures resulting from heat exchange with the atmosphere under a warming climate are investigated by Kędra and Wiejaczka (2018). They compare trends in air temperature with water temperature downstream of 3 reservoirs on Polish Carpathian rivers before and after dam construction. Through analysis of linear trends and wavelet analysis they identify weaker increases in water than air temperature and a five-fold increase in the phase difference between the two temperatures following reservoir construction, confirming a mitigating effect of the reservoirs on warming water temperatures. This suggests that reservoirs with hypolimnetic water releases can help to shape more favourable thermal conditions for native aquatic biota, especially coldwater fish species.

In rivers whose morphology has been simplified by engineering interventions, an increase in the diversity of physical habitats is a prerequisite for improvement of their ecological quality. While measures such as the placement of stones or fixed large wood have previously been described in the river restoration literature, Kałuża et al. (2018) evaluate the usefulness of baskets planted with willow cuttings for improving hydromorphological conditions and initiating ecological recovery in a small, lowland river in Poland. Over three years, the developing in-channel willow vegetation induced flow divergence and increased hydraulic diversity, and trapped sediment and plant debris upstream of the baskets, inducing morphological changes. Pre- and post-installation assessments revealed an increase in hydromorphological river quality by 1 quality class. This improvement, coupled with a low impact on high-flow water levels and low installation costs indicate that plant baskets are a useful restoration measure in lowland rivers with insufficient energy for spontaneous hydromorphological recovery.

A final paper concerned with the physical aspects of rivers considers ecosystem engineering undertaken by beavers. Gorczyca et al. (2018) analyse the contribution of beaver activities to improving hydromorphological conditions and initiating naturalization of a channelized river in the Polish Carpathians. Beavers, extinct in southern Poland for at least three centuries, have gradually recolonized mountain watercourses since the 1980s. In the study river, the largest number of beaver habitats was found in reaches heavily impacted by channelization and construction of flood embankments, where relatively flat channel gradients, small maximum bed-material grain sizes and high channel sinuosity were found to favour beaver presence. The principal forms of beaver activity differed between upper (beaver dams) and lower (slides and burrows) reaches of the river, but they consistently led to bank retreat and channel widening, initiating channel migration in previously laterally-stable reaches. These observations are summarised in conceptual models of beaver impact on channel development in mountain, intramontane-basin and foreland reaches.

3.2. Biological responses

A further five papers consider ecological aspects of rivers relevant to river management and restoration.

Assessment of the ecological status of rivers is a crucial element of the evaluation of the success of restoration projects and the attainment of the environmental goals of the EU Water Framework Directive. Hajdukiewicz et al. (2018) compare assessments of ecological status of channelized and unmanaged cross-sections of a Polish Carpathian river performed before and after an 80-year flood. Prior to the flood significant differences in some abiotic and biotic metrics of the ecological state of the river were recorded between its channelized and unmanaged cross-sections, but the flood eliminated these differences. However, invertebrate- and fish-based indices revealed different impacts of the flood, with the former pointing to a significant reduction of the quality in unmanaged cross-sections and the latter indicating no change. The authors conclude that final assessments should be based on repeated surveys of abiotic and biotic river elements to balance the effect of extreme hydrological events such as floods or droughts.

The effects of passive restoration of mountain rivers on aquatic biota are relatively well recognized, but much less is known about effects on the biota of exposed riverine sediments. Impacts of abandonment and ensuing recovery of a channelized river on ground beetles (terrestrial invertebrates characteristic of riparian habitats) are investigated on a mountain river in southern Poland by Bednarska et al. (2018).. Over less than a decade, channel width tripled, a multi-thread channel pattern was established, and a significant increase in abundance and species richness of beetle communities was observed in recovering reaches compared with adjacent channelized reaches. However, a lack of significant differences in biodiversity indices for ground beetle assemblages indicates that more time is needed to re-create a sufficiently high heterogeneity of riparian habitats within the recovering reaches to support more diverse beetle communities.

Reintroduction of species that were previously eliminated from rivers or their reaches is one of the goals of restoration activities. Zając et al. (2018) investigate reintroduction of the thick-shelled river mussel, *Unio crassus*, into a Polish Carpathian river in order to identify habitat features determining reintroduction success. Adult mussels were reintroduced into marginal, still water channel sectors with fine sediment on the bed, which were identified as a functional habitat suitable for this species. The longitudinal extent of reintroduction matched the historical range of the species, but successful reintroduction was limited to the downstream part of this range, with a rapid change in the rate of juvenile recruitment below a critical value of channel slope, most likely reflecting a change in hydraulic conditions caused by channelization of the river about a century ago. The analyses confirmed that fine-grained areas of channel bed are a suitable habitat for reintroduction of the species, but that mussel reintroduction needs to take account of longitudinal gradients of habitat parameters, particularly the key role of channel slope in regulating the long-term fate of any reintroduced population.

Hitherto, the assessments of biodiversity changes attained in river restoration projects have focused on taxonomic diversity. However, England and Wilkes (2018) suggest that restoration of functional diversity should also be considered. They illustrate this assertion with reference to the impact of two UK lowland river restoration schemes on macroinvertebrate communities. While both schemes increased complexity of physical processes and habitat composition, rehabilitation of the structure and function of macroinvertebrate communities was limited and inconsistent. They found that increases in taxonomic diversity could be attained with functional redundancy of different taxa, meaning that it may be more difficult to restore high functional diversity of river communities than taxonomic diversity. The authors thus recommend that evaluation of river restoration projects should encompass both functional and taxonomic indices.

A common assumption underlying river restoration projects is a progressive improvement of the condition of aquatic and riparian communities with time following hydromorphological restructuring of river sections. Lorenz et al. (2018) investigate whether the condition of the communities improves with time following restoration by analysing surveys of riverine and riparian biota performed twice at a five-year interval at restored sites. They found significant changes in richness and abundance metrics only for ground beetles coupled with significant improvement of indicator plant and beetle taxa for near-natural habitat conditions in the riparian zone, whereas no significant improvement was observed in the condition of fish, benthic macoinvertebrates or aquatic plants. This suggests strong stability of aquatic communities despite improvement of hydromorphological conditions and indicates a need for defining different timelines for the ecological recovery of riparian and aquatic communities after restoration. The results also suggest that successful recovery of aquatic communities may require not only the improvement of local habitat conditions but also targeting of stressors acting at a larger scale.

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