Linking Flow Intensity and River Morphology with Refugia Availability

Relier l'intensité du flux et la morphologie des rivières à la disponibilité de refuges

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RÉSUMÉ

Les rivières abritent une énorme biodiversité et comptent parmi les écosystèmes les plus menacés du monde. Beaucoup de rivières ont été rectifiées, ce qui a entraîné une réduction de la biodiversité et de l'hétérogénéité de l'habitat. Les refuges sont des habitats persistants ou temporaires qui atténuent les effets des perturbations sur les organismes. Malgré leur fonction importante pour la résilience des écosystèmes fluviaux, les refuges ont été peu étudiés et souvent négligés dans la gestion pratique. En comparant des tronçons quasi naturels, canalisés et restaurés de onze cours d'eau du nord de la Suisse, cette étude examine comment l'intensité du débit et la morphologie du cours d'eau influencent l'hétérogénéité de l'habitat et la disponibilité de refuges pour les organismes fluviaux. Les données d'observation recueillies seront combinées en une modélisation hydraulique pour simuler différentes intensités de débit. Les résultats fournissent des orientations fondées pour identifier, maintenir et restaurer les refuges, qui deviendront encore plus pertinents face au changement climatique.

ABSTRACT

Rivers host an enormous biodiversity and are among the most threatened ecosystems in the world. Many rivers have been channelised, leading to reduced biodiversity and habitat heterogeneity. Refugia are persistent or temporary habitats that mitigate disturbance effects on organisms. Despite their important function for river ecosystem resilience, refugia have been poorly investigated and often neglected in practical management. By comparing near-natural, channelised and restored reaches of eleven rivers in Northern Switzerland, this study investigates how flow intensity and river morphology influence habitat heterogeneity and refugia availability for riverine organisms. The gained observational data will be combined with hydraulic modelling to simulate different flow intensities. The results will provide evidence-based guidance for identification, maintenance and restoration of refugia, which will become even more relevant in the face of climate change.

KEYWORDS

floods, habitats, morphology, refugia, restoration

refuges, habitats, inondations, morphologie, restauration

1 REFUGIA ARE KEY FOR RESILIENT RIVERS

Natural rivers are highly dynamic and their structure, function and organism communities strongly shaped by flow patterns (Poff et al. 1997), resulting in spatio-temporal habitat heterogeneity (Poff and Ward 1990) and exceptional biodiversity (Dudgeon et al. 2006). According to the habitat heterogeneity hypothesis, physically diverse habitats offer a greater range of niches and various ways of resource exploitation – which enhances population persistence, species composition and richness (Bejar et al. 2020). Habitat heterogeneity has been substantially reduced in many rivers due to channelisation (Brooker 1985) for flood control and wetland drainage (Hupp 1992), with considerable ecological consequences for aquatic and terrestrial organisms (Brooker 1985).

Riverine organisms must cope with hydrogeomorphological variability and disturbances such as floods (Van Looy et al. 2019). Disturbances can have detrimental effects on organisms (mortality, reduction of resources), but also initiate key ecological processes (Marino et al. 2024). Over evolutionary time, aquatic organisms have developed a variety of adaptations to disturbances (Lytle and Poff 2004), affecting their resistance and resilience (Mathers et al. 2022). Three key mechanisms of ecological resilience include resource partitioning, recruitment and use of refugia (Van Looy et al. 2019).

Disturbance (e.g. flood) effects differ between habitats (Figure 1; Resh et al. 1988, Swanson et al. 1998). Refugia are persistent or temporary habitats that mitigate disturbance effects on organisms by offering sites to retreat, persist in and possibly expand from in the face of extreme events such as floods (Keppel et al. 2012). Both heterogeneity and continuity in habitat conditions thereby enhance species survival (Van Looy et al. 2019), with reaches closer to their natural state offering more refugia and heterogeneous habitats under various flows (Pearsons et al. 1992).

River restoration offers a possibility to re-establish habitat heterogeneity (Friberg et al. 2016) and to provide flood refugia (Rachelly et al. 2021). However, refugia and the effects of habitat structure on ecological diversity remain understudied – despite their crucial role in ecosystem functioning (Mathers et al. 2022). A fundamental understanding of what constitutes proof of the existence of refugia is still lacking (Selwood and Zimmer 2020) and connectivity between refugia and other habitat types requires greater consideration in the future (Rachelly et al. 2023). Providing a sound scientific basis to identify, protect, enhance or restore refugia (Selwood and Zimmer 2020) is therefore key for future conservation, management and restoration strategies (McLaughlin et al. 2017).

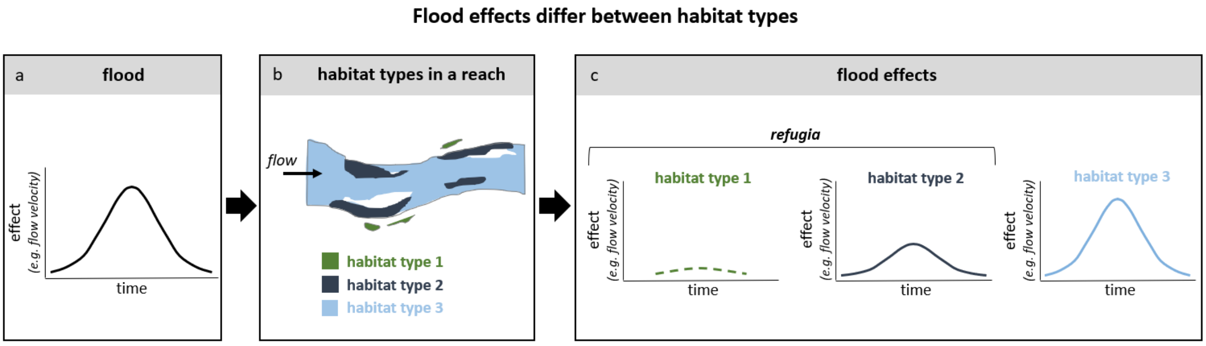

Figure 1: Flood effects vary between different habitat types within a reach. A flood is a pulse disturbance, occurring abruptly and within a short time (Lake 2000; a). Reaches consist of distinct habitat types (b), which show differences in resulting flood effects (c). Habitats buffering these flood effects can serve as temporal (habitat type 1) or permanent (habitat type 2) refugia (adapted from Weber et al. 2013).

2 CONSIDERING FLOOD REFUGIA IN RIVER RESTORATION

This study investigates how flow intensity and river morphology influence habitat heterogeneity and refugia availability for riverine organisms at reach scale. For this purpose, we compared in eleven rivers of Northern Switzerland three 100-meter-long reach types with different morphology (Figure 2): a near-natural, a channelised and a restored reach. At 51 points in each of these 33 reaches, we measured water depth and flow velocity and determined the 3D point coordinates using a differential GPS. The 51 selected measurement points were representative for the corresponding reach and included 21 Thalweg, 10 kink and 20 stratified-random points. We conducted the field measurements in winter and spring 2024 and combined them with drone images to create hydraulic models of all reaches, allowing simulations of spatio-temporal habitat and refugia availability at different flow (i.e. flood) intensities. The three organism groups considered (macroinvertebrates, macrophytes and terrestrial plants) cover gradients in habitats (aquatic, terrestrial), mobility (mobile, immobile) and relation to refugia (use, provision).

We expect flow intensity to have a major effect on habitat heterogeneity and refugia availability as, for example, the proportion of low bed shear stress areas (i.e. refugia) was shown to decrease with increasing flow (Rachelly et al. 2021). Disturbances are also known to induce changes in patchiness (Lake 2000), pronounced temporal variation and habitat heterogeneity in streams (McCluney et al. 2014). Habitat heterogeneity is expected to be reduced during floods (Lake 2000). Structurally complex habitats in near-natural and restored reaches remain more persistent than structurally poor ones (in channelised reaches; Schlosser 1987) and could offer valuable refugia (e.g. deep pools containing permanent structures; Pearsons et al. 1992).

Morphological alteration is expected to influence habitat heterogeneity and refugia availability as well. The underlying assumption is that reaches closer to their natural state offer more heterogeneous habitats and refugia under various flows (Pearsons et al. 1992). For example, Kemp et al. (1999) compared semi-natural and physically degraded rivers and revealed that reaches with shallow and deep areas showed higher habitat diversity than reaches of uniform water depth. Morphological degradation is also known to be negatively correlated with the provision of low bed shear stress areas (i.e. refugia) during high flows (e.g. Pearsons et al. 1992, Lancaster and Hildrew 1993). These areas are preserved under high flow intensity in near-natural and restored reaches, but are inexistent under high flows in channelised reaches (e.g. Pearsons et al. 1992, Lancaster and Hildrew 1993).

The results of our study are relevant for managing rivers towards resilience: First, they improve our understanding of how various flows affect aquatic habitat heterogeneity, refugia availability and the composition of blue-green communities. Second, our findings provide evidence-based guidance to identify and conserve existing refugia as well as to re-create refugia from floods in the framework of river restoration measures. Knowledge on the complex interplay between biodiversity and disturbances (i.e. floods) is likely to become even more important in the future (Mathers et al. 2022), as extreme events are expected to increase in frequency and intensity in the face of climate change (Lake 2000).

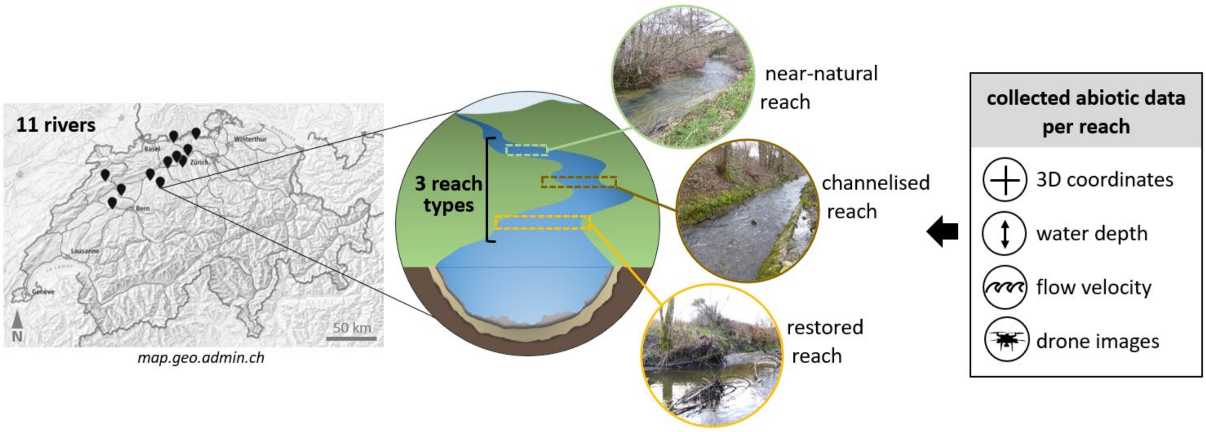

Figure 2: Study design. In eleven rivers across Northern Switzerland, three 100-meter-long reach types with different morphology (near-natural, channelised, restored) were compared. At 51 points in each reach, we determined the 3D coordinates and measured water depth as well as flow velocity. Each reach was further investigated by drone surveys.

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