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Research article

Improved river continuity facilitates fishes' abilities to track future environmental changes

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ABSTRACT

Barriers represent one of the largest anthropogenic impacts on the ecological status of rivers, and they also potentially restrict fishes' ability to respond to future environmental changes. Thus, river management aims to restore the longitudinal connectivity of rivers to allow continuous migration and movement of water, sediments and biota. However, it is often unclear whether the targeted barriers are also those most relevant for fish species, particularly to track future habitat shifts caused by environmental change.

In this study, we applied species distribution models and the GIS-based fish dispersal model FIDIMO to evaluate the impacts of barriers (e.g. weirs and dams) on the dispersal of 17 native fish species in the European River Elbe with a particular focus on climate- and land use-induced habitat shifts. Specifically, we compared three scenarios of longitudinal connectivity: (i) current longitudinal connectivity, (ii) connectivity improvements as planned by river managers for 2021 and (iii) a reference with full longitudinal connectivity.

The models indicated that barriers restricted the movement of two modeled fish species on average, thus impeding fishes' abilities to track future habitat shifts. Moreover, the number of species affected by barriers increased downstream. For the River Elbe, our results suggest that river management has most likely identified the most relevant barriers in respect to the modeled species and future environmental change. We emphasize that river management and barrier prioritization must thoroughly consider species-specific movement and dispersal abilities, as well as the specific spatial arrangement of barriers in the river system in relation to the spatial distribution of species' populations and suitable habitats.

1. Introduction

Barriers represent one of the largest anthropogenic impacts on river ecosystems, affecting species' habitats and habitat connectivity on multiple spatial and temporal scales (Fuller et al., 2015). These impacts include (i) hydrological modifications and changes to the flow and sediment regime with associated changes to riverine habitats (e.g. Graf, 2006; Ligon et al., 1995; Petts and Gurnell, 2005), (ii) the general loss of connectivity of river habitats (e.g. Cote et al., 2009), (iii) in particular the impediment of ontogenetic migrations (e.g. spawning runs) and ordinary habitat movements of river fish (e.g. Marschall et al., 2011; Radinger and Wolter, 2015), and (iv) associated genetic fragmentation of populations (e.g. Gouskov et al., 2016). Thus, to improve the ecological status of river ecosystems, river management commonly aims to restore and improve longitudinal connectivity to allow continuous migration and movement of water, sediments and biota. Correspondingly, the continuity of rivers constitutes an indispensable element for the assessment of river water bodies according to the European water framework directive (EU-WFD) (Reyjol et al., 2014). In fact, to be classified as high status, the continuity of rivers must not be "*disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport*" (European Parliament and Council of the European Union, 2000).

At a global scale, climate and land use change constitute anthropogenic pressures on freshwater ecosystems (Meyer et al., 1999; Woodward et al., 2010), and these are superimposed on

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the local and regional impacts of habitat degradation and barriers to movement (Kail et al., 2015). These large-scale environmental pressures and their interacting effects will change the diversity and composition of river fish communities in entire catchments via modification to their habitats (e.g. Radinger et al., 2016). In particular, climate and land use changes cause species' habitats to move in space associated with spatially distributed losses and gains of suitable habitats. If and how species can track future habitat shifts largely depends on the extent of these shifts, the species-specific dispersal ability and on barriers to movement that impede species from reaching newly available habitats (Radinger et al., 2017). Hence, barriers and the associated loss of river continuity constitute not only an impact for the current ecological status of river systems, but might also restrict fishes' ability to respond to future climate and land use changes (Gibson-Reinemer et al., 2017).

The increasing awareness of the ecological impacts of barriers has led to the development of management tools to prioritize dams and identify those mostly affecting network connectivity (Brevé et al., 2014; Kemp and O'Hanley, 2010; O'Hanley et al., 2013; Segurado et al., 2013). Recent studies emphasized that the location of a barrier within a river system and especially its location relative to suitable habitats and species occurrences determines its impact on fish (Kuemmerlen et al., 2016; Musil et al., 2012; Radinger and Wolter, 2015). As a consequence, current attempts in river management at the catchment scale typically aim for an overall improvement of river continuity by installing fish migration facilities for specific barriers or by removing barriers completely. However, it is often unclear whether these targeted barriers are also those most relevant for fish species, particularly to track future habitat shifts as caused by environmental change.

Generally, weirs and dams are the two major types of barriers in the River Elbe (Fig. 1). Weirs are barriers creating impoundments upstream, are typically of smaller size and lower height compared to dams and are often characterized by overflowing water e.g. via a spillway. Numerous weirs in the River Elbe have been built for hydropower use or as small-scale watermills. In contrast, dams are barriers typically creating large reservoirs holding back significant amounts of water and which commonly serve multiple purposes

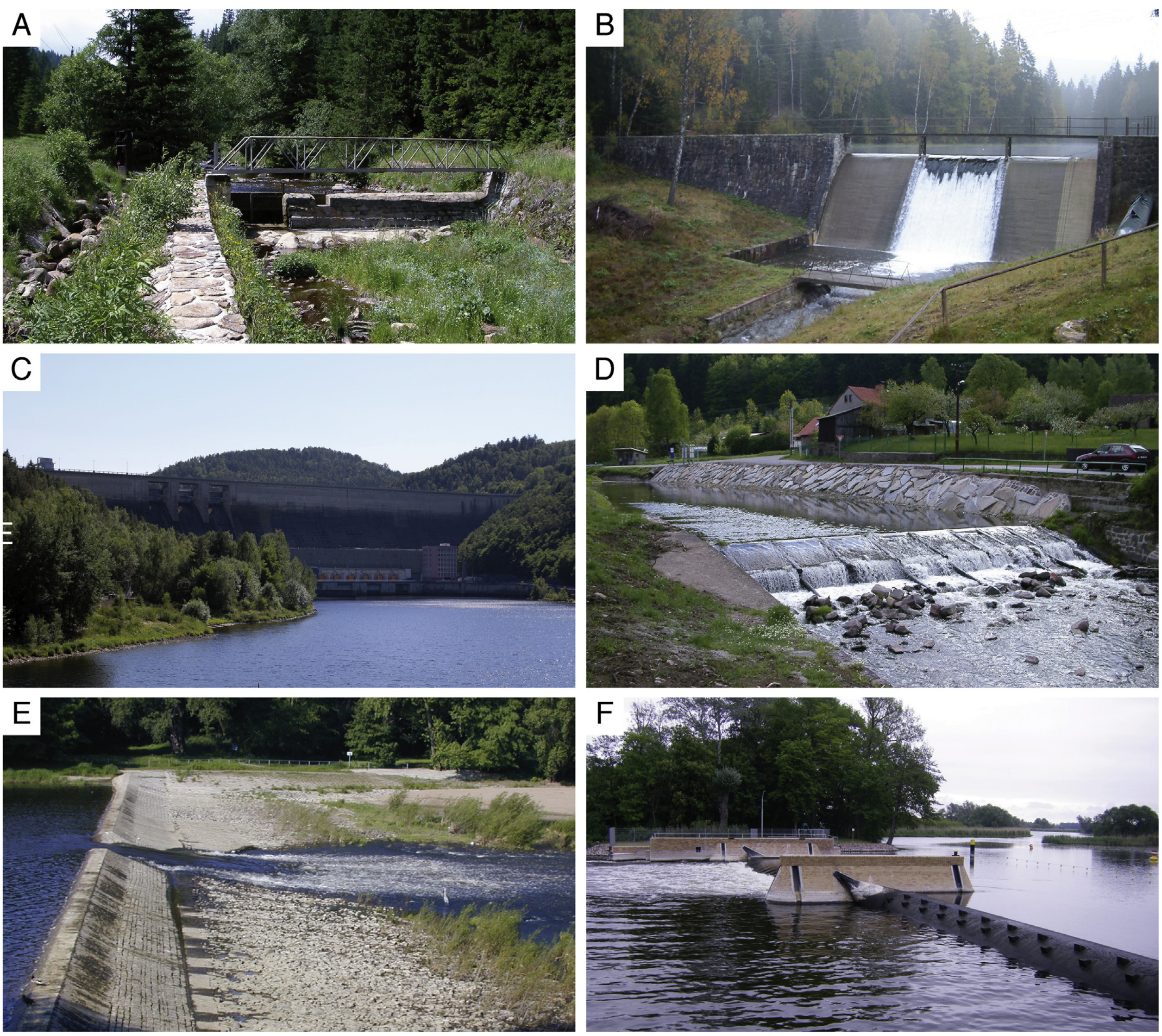

Fig. 1. Examples of different types of barriers in the River Elbe network: (A) small weir Františkov in the upper River Vltava, equipped with a non-functional fish pass. (B) small dam Černé jezero in the River Úhlava, no fish pass. (C) large Orlík dam in the River Vltava, highest dam (91 m) in the Czech Republic, no fish pass. (D) weir Čenkov in the River Litavka, no fish pass. (E) weir in the river branch Alte Elbe at Magdeburg. (F) weir in the River Havel at Bahnitz, equipped with a fish pass.