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Discussion

Adaptive management in the context of barriers in European freshwater ecosystems

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ABSTRACT

Many natural habitats have been modified to accommodate for the presence of humans and their needs. Infrastructures – such as hydroelectric dams, weirs, culverts and bridges – are now a common occurrence in streams and rivers across the world. As a result, freshwater ecosystems have been altered extensively, affecting both biological and geomorphological components of the habitats. Many fish species rely on these freshwater ecosystems to complete their lifecycles, and the presence of barriers has been shown to reduce their ability to migrate and sustain healthy populations. In the long run, barriers may have severe repercussions on population densities and dynamics of aquatic animal species. There is currently an urgent need to address these issues with adequate conservation approaches. Adaptive management provides a relevant approach to managing barriers in freshwater ecosystems as it addresses the uncertainties of dealing with natural systems, and accommodates for future unexpected events, though this approach may not be suitable in all instances. A literature search on this subject yielded virtually no output. Hence, we propose a step-by-step guide for implementing adaptive management, which could be used to manage freshwater barriers.

1. Context: barriers in European freshwater ecosystems

In comparison to their terrestrial counterparts, freshwater taxa are on average more imperiled (Dudgeon et al., 2006; Strayer and Dudgeon, 2010; Carrizo et al., 2013). Freshwater fish species represent approximately 25% of all living vertebrates, many of which are threatened (IUCN, 2016). Given the linear nature of freshwater systems, connectivity may be heavily affected as a result of the presence of in-river barriers (Stanford et al., 1996). Historically, rivers and their surroundings have been used for anthropogenic purposes more than any other habitat, which over centuries, has led to the loss of the original integrity of water courses (Jungwirth, 1998; Jager et al., 2001). Today, the majority of large rivers have been modified in one way or another – for the purposes of hydroelectric power plants (Welcomme, 1995) or other artificial barriers like dams, weirs, or road crossings (Jungwirth et al., 2000; Nilsson et al., 2005), posing increasing threats to freshwater ecosystems and the mobile biota, particularly fish, that live within them (Arthington et al., 2016).

In Europe, all major rivers, except for the Pechora River in Russia (Studenov et al., 2008), are now fragmented by artificial dams and weirs (Tockner et al., 2009). The high (and increasing) density of river barriers is contributing to the poor habitat quality and loss of biodiversity of freshwater systems in contravention of the European Union's Water Framework Directive (Acreman and Ferguson, 2010; Reyjol et al., 2014). Increasingly, barrier removal is viewed as a necessary management measure to reinstate natural connectivity within and amongst ecosystems (Garcia de Leaniz, 2008; Tonra et al., 2015), though we still have little knowledge to make predictions about the biological and geomorphological trajectory of a river system once a barrier has been removed (Pizzuto, 2002). Whilst removal projects for large barriers have revealed quick recovery of key biological components (Tonra et al., 2015), the same cannot be said of barriers in small streams as evidence is currently lacking (Tummers et al., 2016a). The presence of small-to-medium sized impoundments (i.e., height below 10m) is extensive in European streams and rivers, providing us with every reason to investigate their effects in order to enhance and focus management efforts.

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2. Management of barriers

Many barriers in European rivers originated in the 10th to 19th centuries to operate mills (Downward and Skinner, 2005; Nützmann et al., 2011) and a high proportion, often rebuilt or modified multiple times, are now redundant (Downward and Skinner, 2005). However, some mill weirs are of historical significance or are being converted for operation as low-head hydroelectric power facilities (Watkin et al., 2012). Since the 1950s, the approach to implement dams for achieving water storage has been to design and operate reservoirs so that they fill with sediments slowly (Palmieri et al., 2001) but some are approaching the end of their operational lives. Currently, there are challenging issues regarding the proper management of barriers, which may be addressed by an adaptive management (AM) approach.

AM stems from the idea that ecosystem management and conservation practice is a dynamic process, and thus should be modified as we gain further knowledge to achieve management objectives (Holling, 1978; Lindenmayer and Burgman, 2005; Westgate et al., 2013). Such an approach is especially appropriate when dealing with ecological resources, which are dynamic in nature, and hence would provide an appropriate method to manage barriers (for example management of flow characteristics - see Baumgartner et al., 2014; Summers et al., 2015). This dynamic conservation approach has grown greatly since the seminal work of Walters and Hilborn (1976) and Holling (1978), and is now considered fundamental to sustainable practices (Westgate et al., 2013; Williams and Brown, 2014). An adaptive approach requires extensive planning, along with an active and systematic effort to gather and document information, as well as the early involvement of stakeholders in the decision-making process (Lindenmayer and Burgman, 2005). There are four fundamental elements to AM, as identified by Davis and Shaw (2001): (1) acknowledging the uncertainties associated with management policies, (2) formulating management policies as testable hypotheses, (3) searching, using and assessing information in order to test hypotheses, and (4) adapting management policies periodically as new information is acquired.

While AM is widely supported in theory (Fabricius and Cundill, 2014), few real-world examples have been reported in practice (Keith et al., 2011; Westgate et al., 2013). Most applications test a single management option at a time, and change their approach only when it fails (Duncan and Wintle, 2008; Keith et al., 2011). Our initial objective was to use a systematic approach to review the current state of research in adaptive barrier management of freshwater ecosystems. However, an all-time initial search on Web of Science using "(adaptiv*)AND(manage*)AND(freshwater)AND(-barrier*)" as the word string yielded only 17 results, 13 of which were eliminated at the title level, and the remaining 4 were eliminated at the abstract level, suggesting that this area of research is highly understudied. We therefore opted to include a broader spectrum of literature, and gather relevant information on AM, in an attempt to apply it directly to barrier management in freshwater ecosystems. While we hoped to provide specific examples to demonstrate how AM has been successfully used in barrier management, the literature on the topic is scarce, although this is partly because some relevant projects that have adopted an AM ethos have not used this term explicitly (Box 1). Instead, we propose a step-by-step guide for how AM could be implemented in the management of freshwater barriers (Fig. 1), along with the potential benefits and challenges that come with using such an approach.

2.1. Potential benefits

One of the main advantages of AM is its regular reviews of the

Box 1
Adaptive management of river barriers in action - a case study

The Yorkshire Derwent, northeast England, is a tributary of the Humber, the UK's largest drainage. The Derwent catchment is mostly rural and has good water quality, suitable for potable supply after treatment. The catchment runs off the North Yorkshire Moors but the last 75 km of river falls only 20 m (mostly at six river barriers), creating a large managed floodplain. The downstream-most 35km of this comprises herb-rich damp meadows. From km 68 to the confluence with the Humber, the river was designated a national Site of Special Scientific Interest (SSSI) in 1975 and an EU Special Area of Conservation (SAC) in 2005. Adjacent wetlands form an EU Special Protection Area (SPA) for wetland birds and a RAMSAR wetland site. *Ranunculion fluitantis/Callitrichio-Batrachion* habitat and river lamprey *Lampetra fluviatilis* were primary reasons for selection of the lower Derwent as an SAC. However, since 2003, Natural England (NE) determined the Derwent SAC to be in unfavourable condition for these features. Key pressures were identified as siltation, and in-river barriers to fish movement. Additional management issues relating to River Derwent barriers are flood risk management (towns along the lower Derwent have flooded multiple times in recent decades); potable water supply (the lower two barriers stabilise water levels upstream for abstraction to 5 million people); new low-head hydroelectricity (the Environment Agency [EA] is required to support renewable power development alongside its environmental protection duties); flow-gauging (EA gauges river flow from several weirs) and navigation (on the lower 35 km of river, including to and from the Humber, via Barmby tidal barrage, the downstream-most barrier, managed by EA). In 2003 the EA and NE sought to develop a long-term ecological restoration plan for the river (River Derwent Restoration Project, RDRP), in an adaptive framework and consulted with a wide range of stakeholders, identifying objectives and information needs.

To provide information for the RDRP and more widely, lamprey research on the Derwent has included determining their abundance and distribution (Jang and Lucas, 2005; Nunn et al., 2008; Lucas et al., 2009); the distribution and use of lamprey habitats (Jang and Lucas, 2005); the effect of habitat fragmentation on lamprey population genetics (Bracken et al., 2015); migration and passability of different barriers and the utility of various fishway designs (Lucas et al., 2009; Foulds and Lucas, 2013; Tummers et al., 2016b; Silva et al., 2017); and hydroelectricity impacts on lampreys (Bracken and Lucas, 2013). The River Derwent Restoration Plan (Royal Haskoning, 2010) evaluated multiple options for solving in-river barrier impacts, site by site, including full barrier removal, barrier height reduction and provision of fishways. These options were appraised in concert with opportunities for reducing flood risk, managing key infrastructure (e.g. water abstraction), supporting hydroelectricity development, and the economic costs and benefits. This continues to be an ongoing adaptive process. For example, in 2010 EA decided not to remove its redundant flow-gauging weir at rkm 40, but to allow commercial hydroelectric development there and build a Larinier superactive baffle fishway, in the expectation that this would be usable by river lamprey. Research has since