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Supporting decision-making for improving longitudinal connectivity for diadromous and potamodromous fishes in complex catchments

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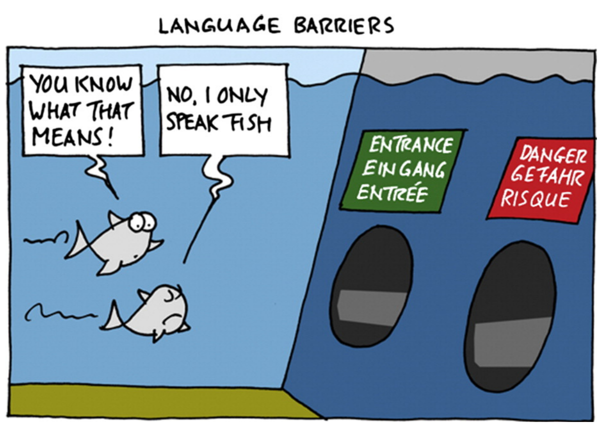
HIGHLIGHTS

- A prioritization method to help restore longitudinal connectivity is developed.
- 18 fish species are grouped into five guilds (diadromous and potamodromous).
- The essential water types for all native migratory fish species are identified.
- A national prioritization of 2924 barriers in all WFD water bodies is achieved.
- Application beyond regional or national borders is recommended.

GRAPHICAL ABSTRACT



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ABSTRACT

Preservation and restoration of Europe's endangered migratory fish species and habitats are high on the international river basin policy agenda. Improvement through restoration of longitudinal connectivity is seen as an important measure, but although prioritization of in-stream barriers has been addressed at local and regional levels the process still lacks adequate priority on the international level. This paper introduces a well-tested method, designed to help decision makers achieve the rehabilitation of targeted ichthyofauna more successfully. This method assesses artificial barriers within waters designated under the Water Framework Directive (WFD), Europe's main legislative driver for ecological improvement of river basins. The method aggregates migratory fish communities (both diadromous and potamodromous) into functional biological units (ecological fish guilds) and defines their most pressing habitat requirements. Using GIS mapping and spatial analysis of the potential ranges (fish zonation) we pin-point the most important barriers, per guild. This method was developed and deployed over a 12 year period as a practical case study, fitting data derived from the 36 regional water management organisations in the Netherlands. We delivered national advice on the prioritization of a total of 2924 barriers located within WFD water bodies, facilitating migration for all 18 indigenous migratory fish species.

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Scaling up to larger geographical areas can be achieved using datasets from other countries to link water body typologies to distribution ranges of migratory fish species.

1. Introduction

1.1. Restoration of Europe's ichthyofauna and longitudinal connectivity

In many European rivers rheophilous populations have declined and diadromous fish have become scarce or extinct during industrialization of the 19th and 20th centuries (European Inland Fisheries Advisory Commission, 1998). Today however, there is much greater appreciation for their societal value and the need to restore fish faunas and habitats is acknowledged. This is being implemented e.g. under the International Union for the Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), as required by the EU Habitats Directive (Directive No 92/43/EC) within the Natura 2000 sites, the Benelux Order on Fish Migration (M(2009)1), the Eel Regulation (Council Regulation No 1100/2007/EC), and the EU Water Framework Directive, WFD (Directive No 2000/60/EC). The WFD notably puts the restoration of fish faunas high on the international agenda of river basin policy, seeking to achieve "good ecological status" for all freshwater and coastal waters by set deadlines (2015 and 2027). All EU Member States share the need to establish goals and assessments of surface waters in a comparable manner within combined water management plans based on river basins. Fish are an important biological quality element within the WFD, and in the Netherlands, fish community composition has been specified for each water body type (natural water bodies: van der Molen, 2012; artificial water bodies: Evers et al., 2013).

The restoration of Europe's ichthyofauna is a major challenge as many factors have to be addressed. There is usually no single factor responsible for deterioration, but a combination of multiple stressors (Parrish et al., 1998). These include commercial exploitation (intensive fisheries), habitat degradation (water quality, water temperature, and riverbed deterioration), habitat losses (extraction of gravels and sands) and fragmentation of habitats due to infrastructural works (impounding, damming, embanking, etc.) in rivers, deltas and coastal areas for flood risk reduction, transport, energy production and freshwater supply. In particular the disruption of longitudinal connectivity is known to severely impact migratory fish (Aarts et al., 2004; Baras and Lucas, 2001; Fagan, 2002; Kroes et al., 2006; Roni et al., 2002, 2008; Vannote et al., 1980). Restoring fish migration can have a substantial positive effect on fish distribution, productivity and abundance (Fullerton et al., 2010; Roni et al., 2002, 2008; Slawski et al., 2008). This is recognized within the scope of the WFD: barriers that significantly hamper migration must be mitigated or removed before the end of 2027. Clearly, removal of all barriers would be the preferred solution seen through the eye of a fish. However, to keep the artefact functioning, many technical and semi-natural bypass systems are available. Fishways have to be customized since the solution depends on several variables: the target fish species, the type and dimensions of the water body, the type of barrier and the trade-off with the demands of socio-economic function the barrier supports. Multiple reference books to choose and design proper fishways are available. For the lowland conditions such as in the Netherlands Kroes and Monden (2005) and Kroes et al. (2006) are particularly relevant. The challenge, however, is immense since it is not only the type of fishway to choose, but the modern landscape in Europe is fragmented and characterised by hundreds of thousands of barriers hampering fish migration (e.g. European Inland Fisheries Advisory Commission, 1998). Currently it is neither feasible nor affordable nor does it seem necessary to resolve (removal or bypass) all barriers. Instead there is an urgent need to develop a procedure to prioritize which barriers are most critical.

Until recently tackling barriers has mostly been addressed at the regional level, but this approach lacks strategy and consistency at the national and international levels (Kemp and O'Hanley, 2010). For example in 2007 we screened the policy, criteria, level of detail and existing documentation of all 36 individual water management entities in the Netherlands (Kroes et al., 2008). At that time only one-third of the water authorities had a policy document for fish migration. There was no common understanding and relevant criteria and strategies to prioritize barriers varied considerably and were insular with jurisdictional boundaries, insufficiently tuned to neighbouring water authorities, and failing to address national borders. Furthermore, the actual migration requirements of fish species were too often not taken into account. This clarified the need for a higher level of integration, and a broader prioritization strategy. Much progress has been made in recent years as the river basin approach, as initiated by the WFD, has increasingly been implemented.

The sustainable management of man-made river infrastructure today requires planning of maintenance, replacement and renewal with ecological requirements firmly in mind. Existing migration barriers are therefore increasingly being opportunistically resolved during renovation or maintenance, and when any new constructions are planned (e.g. Kemp and O'Hanley, 2010). There is however a need to address the connectivity problem more strategically (Williams et al., 2012) and the following two examples demonstrate how cost-effective improvements can be delivered to address the rehabilitation of multiple species (fish guilds).

1.2. Migratory fish guilds

1.2.1. Example 1, from sea to source, long-distance migration of diadromous species

Many EU LIFE funded projects aim to rehabilitate populations of endangered anadromous species, e.g. the German "Rhine Salmon 2020" (*Salmo salar*) project (Bölscher et al., 2013; Molls and Nemitz, 2008) and the Allis shad (*Alosa alosa*) project (LIFE06 NAT/D/00005, LIFE09 NAT/DE/000008); in Denmark the houting (*Coregonus oxyrinchus*) project (LIFE05 NAT/DK/000153); in France the Loire salmon project (LIFE00 NAT/F/007252) and the European sturgeon (*Acipenser sturio*) projects in the Rivers Gironde–Garonne–Dordogne (B-3200/98/460 for 1998–2002 and B4-3200/94/754 for 1994–1997). These projects all include habitat restoration and focus on ex-situ aquaculture projects in fish farms for development of brood stocks. Despite substantial investment, the results in terms of rehabilitation and natural recruitment of populations remain fragile with only low level populations established (e.g. De Groot, 2002; MacCrimmon and Gots, 2011; Rochard and Lambert, 2011). This suggests the necessity of developing adaptive action on several levels other than re-stocking, focussing on ecosystem solutions that serve multiple migratory species, but also stocks of other non-migratory fish species.

Long-distance anadromous species share a life-style that makes them particularly sensitive as a group to specific degradations of longitudinal connectivity (De Groot, 2002). Rehabilitation solutions need to focus upon optimization of migration routes (Raat, 2001) and for anadromous species the concept 'from sea to source' is the right order in which to prioritize barriers. For the Rhine such an overview has been prepared for Atlantic salmon and eel by the International Commission for Protection of the Rhine (ICPR, 2009; www.iksr.org). This is a good strategic overview focussing on the long-distance migratory fish species travelling through various Rhine-bordering countries. It, however, addresses solely the Rhine and its major tributaries and as such covers