Science of the Total Environment 569–570 (2016) 850–860

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Evaluating the effectiveness of restoring longitudinal connectivity for stream fish communities: towards a more holistic approach

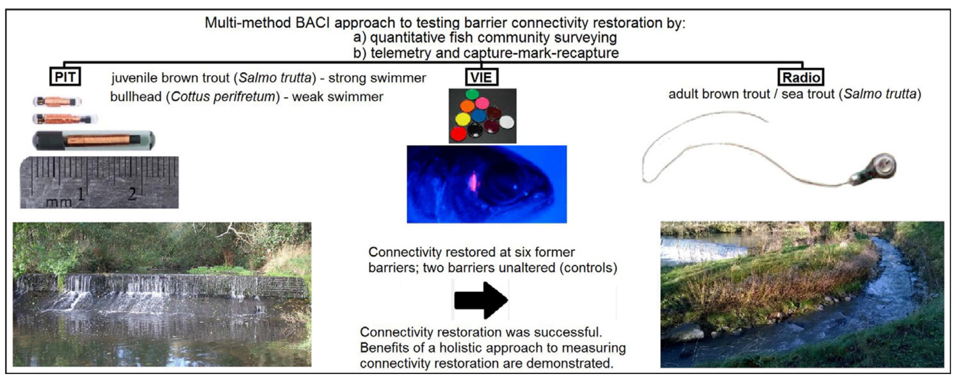
Jeroen S. Tummers [a,*], Steve Hudson [b], Martyn C. Lucas [a]

[a] School of Biological and Biomedical Sciences, Durham University, South Road, Durham DH1 3LE, UK
[b] Wear Rivers Trust, Low Barns Nature Reserve, Witton-le-Wear, County Durham DL14 0AG, UK

HIGHLIGHTS

- A more holistic approach to evaluating connectivity restoration for stream fish communities is tested.
- Connectivity restoration used methods suited to entire stream fish communities.
- Dispersal and migration studies of species with weak and strong swimming capacities demonstrated restoration success.
- Upstream recolonization occurred after removing perched culvert outflows, but not at a control site.
- Stream fish community restoration must aim to support dispersal of all native species and life stages.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 April 2016
Received in revised form 24 June 2016
Accepted 26 June 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Habitat fragmentation
Fish assemblages
Passage efficiency
Telemetry
PIT
VIE

ABSTRACT

A more holistic approach towards testing longitudinal connectivity restoration is needed in order to establish that intended ecological functions of such restoration are achieved. We illustrate the use of a multi-method scheme to evaluate the effectiveness of 'nature-like' connectivity restoration for stream fish communities in the River Deerness, NE England. Electric-fishing, capture-mark-recapture, PIT telemetry and radio-telemetry were used to measure fish community composition, dispersal, fishway efficiency and upstream migration respectively. For measuring passage and dispersal, our rationale was to evaluate a wide size range of strong swimmers (exemplified by brown trout *Salmo trutta*) and weak swimmers (exemplified by bullhead *Cottus perifretum*) *in situ* in the stream ecosystem. Radio-tracking of adult trout during the spawning migration showed that passage efficiency at each of five connectivity-restored sites was 81.3–100%. Unaltered (experimental control) structures on the migration route had a bottle-neck effect on upstream migration, especially during low flows. However, even during low flows, displaced PIT tagged juvenile trout (total $n = 153$) exhibited a passage efficiency of 70.1–93.1% at two nature-like passes. In mark-recapture experiments juvenile brown trout and bullhead tagged (total $n = 5303$) succeeded in dispersing upstream more often at most structures following obstacle modification, but not at the two control sites, based on a Laplace kernel modelling approach of observed dispersal distance and barrier traverses. Medium-term post-restoration data (2–3 years) showed that the fish assemblage remained similar at five of six connectivity-restored sites and two control sites, but at one connectivity-restored headwater site previously inhabited by trout only, three native non-salmonid species colonized. We conclude that stream habitat reconnection should support free movement of a wide range of species and life stages, wherever retention of

* Corresponding author.
E-mail addresses: j.s.tummers@durham.ac.uk, jtummers1@hotmail.com (J.S. Tummers).

http://dx.doi.org/10.1016/j.scitotenv.2016.06.207

such obstacles is not needed to manage non-native invasive species. Evaluation of the effectiveness of fish community restoration in degraded streams benefits from a similarly holistic approach.

1. Introduction

Due to resource exploitation by humans, river habitats have become increasingly fragmented (Poff et al., 1997; Nilsson et al., 2005), threatening aquatic species' abundance, distribution and diversity (e.g. Dunham et al., 1997; Vaughn and Taylor, 1999; Khan and Colbo, 2008) and wider ecosystem integrity (Fahrig, 2003; Pringle, 2003). Loss of connectivity between river habitats is often a result of construction of physical obstacles to migration and dispersal, such as dams, weirs and culverts (e.g. Morita and Yamamoto, 2001; Gehrke et al., 2002; Park et al., 2008; Doehring et al., 2011; Hall et al., 2011). Much attention has been paid to the partial or complete blocking effects of obstructions on the migration success and population persistence of diadromous fishes, migrating between freshwater and marine environments (McDowall, 1992; Baras and Lucas, 2001). Obstacles may also be strongly detrimental to species migrating or dispersing entirely in freshwater (Lucas and Batley, 1996; Porto et al., 1999; Branco et al., 2012; Gough et al., 2012; Benitez et al., 2015). Dispersal is crucial for population persistence and is intrinsic to ecological, behavioural and evolutionary processes (McMahon and Matter, 2006; Urban et al., 2009). Longitudinal reconnection is increasingly a major goal of river restoration (Fullerton et al., 2010; Kemp and O'Hanley, 2010).

Rehabilitation of stream ecosystem function and biodiversity often requires reversal of the impacts of multiple stressors (Palmer et al., 2005; Bernhardt and Palmer, 2007; Fullerton et al., 2010; Wohl et al., 2015). For example, improvements in water quality and physical habitat diversity, and reinstatement of more natural hydraulic connectivity may be needed to support a more abundant and diverse fish assemblage (Van Dijk et al., 1995; Bernhardt and Palmer, 2007). Degraded aquatic communities can recover from past environmental insults only if recolonization opportunities are provided (Langford et al., 2009). Where past pollution incidents, for example, have eliminated populations in river reaches, recolonization requires dispersal from adjacent population sources. Downstream fish dispersal is usually relatively easy, including by passive means, but under certain conditions, for example in reservoirs located upstream of hydroelectric dams, downstream-dispersing fish may encounter migration delay, injury or even mortality when traversing the structure (Lucas and Baras, 2001). In depopulated low-stream-order channels, recolonization is much more likely to entail upstream movement. Strongly-swimming species such as adult salmonids may pass small obstacles in order to access such habitat for spawning and resultant nursery habitat (Ovidio and Phillipart, 2002), while in other cases deliberate restocking has been used to aid recolonization (Cowx, 1994). However, most species in fish assemblages are not of economic importance and many are small, with a limited ability to pass upstream of physical obstacles (Utzinger et al., 1998; Warren and Pardew, 1998; Helfrich et al., 1999; Bolland et al., 2009). Nevertheless, they can contribute markedly to diversity and ecosystem function. If stream and river rehabilitation practices are to be effective in restoring diverse habitats and natural communities then they need to facilitate bidirectional dispersal of native fishes and other animals, not just enable concerted migrations of a few economically important species (Calles and Greenberg, 2007, 2009; Gough et al., 2012). Such an approach is needed to address the hydromorphological modifications that, in many cases, are inhibiting restoration towards the reference assemblage conditions ('good ecological status') required by the European Water Framework Directive (WFD) (Kemp and O'Hanley, 2010).

The preferred method of reinstituting effective longitudinal connectivity is physical removal of obstructions where possible (Poff and Hart, 2002; Garcia de Leaniz, 2008). Obstruction removal is sometimes not feasible due to budgetary constraints, flood risks or cultural history reasons. To improve migration and dispersal connectivity, passes for various biota (mostly fish) have been developed and evaluated (Clay, 1995; Larinier and Travade, 2002; Roscoe and Hinch, 2010; Bunt et al., 2012; Noonan et al., 2012). However, an adequate understanding of the ecological response to barrier removal or mitigation (provision of passes for biota) is required in order to prioritize restoration efforts and maximize returns on an often limited budget.

To be valuable in river restoration, fish passes should operate effectively for a wide range of species yet often they are of limited efficacy for target species (e.g. salmonids) (Aarestrup et al., 2003; Caudill et al., 2007) or the wider fish community (Mallen-Cooper and Brand, 2007; Bunt et al., 2012; Foulds and Lucas, 2013). In recent decades more effort has been made to improve longitudinal connectivity for a greater proportion of native fish species, including by barrier removal, use of low-gradient technical passes and nature-like passage solutions (Jungwirth, 1996; Calles and Greenberg, 2007; Gough et al., 2012). The effectiveness of particular fishway designs for fish taxa has been compared in several reviews (Roscoe and Hinch, 2010; Bunt et al., 2012; Noonan et al., 2012). Increased emphasis has also been placed upon predicting the most effective methods of reducing fragmentation at a catchment scale (Kemp and O'Hanley, 2010; Bourne et al., 2011). However, few empirical studies have examined the effects of connectivity restoration both at individual sites and on a wider spatial scale for fish communities. Ideally such studies should employ methods to describe changes in community composition and species abundance, combined with those measuring colonization and migration processes (Lucas and Baras, 2001). Where possible they should also incorporate a before-after-treatment-control (BACI) design (Pretty et al., 2003). The most commonly available data by which river managers can attempt to evaluate the outcomes of stream connectivity restoration on fishes are quantitative or semi-quantitative fish surveys, including those required for the European WFD (Jepsen and Pont, 2007). However, the degree to which fish community data, combined with environmental and GIS analyses can reflect connectivity processes in rivers with barrier networks (Branco et al., 2012) is debatable.

This study aimed to measure the effectiveness of reconnection in a tributary stream on the fish assemblage structure and in terms of movements of key species and life stages. A combination of quantitative community sampling, capture-mark-recapture and telemetry methods were employed in a BACI approach, within the constraints of limited control over the timing of restorative activities at different sites. The utility of this multi-method, more holistic, approach to better understand how stream fishes with strong or weak dispersal potential respond to barrier removal is discussed.

2. Methods

2.1. Study site

The River Deerness (source: lat. 54.747910, long. −1.8004704; 275 m above sea level), NE England, flows eastwards for 14.6 rkm through mixed agricultural land and woodland cover, with the riparian zone mostly consisting of semi-natural woodland and shrubs, before it joins the River Browney, a tributary of the lower River Wear. The Deerness (mean annual discharge in lower reaches *ca.* 0.5 $m^3\ s^{-1}$) and Browney respond rapidly to rainfall and the subcatchments are characterised mostly by pool-riffle-run habitats, dominated by cobble and gravel substrate. Annual maximum and minimum temperature in the Deerness, calculated from 15 min interval measurements, was