Ecological Engineering 94 (2016) 214–224

Contents lists available at ScienceDirect

Ecological Engineering

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

Not just for adults! Evaluating the performance of multiple fish passage designs at low-head barriers for the upstream movement of juvenile and adult trout *Salmo trutta*

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ARTICLE INFO

Article history:
Received 20 August 2015
Received in revised form 22 March 2016
Accepted 22 May 2016
Available online 10 June 2016

Keywords:
Salmo trutta
Body size
Fish passage
PIT telemetry
Low-cost baffle
Pool-weir
Rock ramp
Culvert
Low-head barrier
Delay

ABSTRACT

Longitudinal connectivity in salmonid streams is vital for juvenile as well as adult fish, yet most upstream passage studies consider only larger adults. Upstream passage of juvenile and adult brown trout *Salmo trutta* at low-head (<3 m) structures on two River Ribble tributaries (NW England) was investigated using Passive Integrated Transponder (PIT) telemetry during summer-autumn 2013 and 2014. The efficiency of a Servais low-cost baffle (LCB) fish pass was evaluated for the first time, along with two pool-weir (PW) passes, an embedded rock ramp (ERR) and an open culvert (C), the latter a man-made structure within predicted swim speed, acting as an experimental control. We used a combination of naturally migrating trout and displacement experiments. Resident fish were displaced from above to below structures, utilising their homing instinct to instigate their ascent of the structure, with up to 91% of displaced trout attempting to pass. Approximately 30% of parr morphotype trout released at their capture locations attempted to pass upstream of structures in both streams. Passage efficiencies of up to 82% for the LCB pass design were similar to the PW (up to 79%) and better than the ERR (71%), but below that for C (96%–100%). Significant differences occurred between fish passes in time to passage, and number of attempts to pass, with all but PW1 having significantly longer time to passage than the control culvert. Median time to passage at PW2 decreased almost fifty fold between 2013 and 2014, following modification to equalise step heights at the structure. Logistic regression demonstrated a strong body-length effect on passage success at passes, with 50% probability of successful passage (82–132 mm) varying, but not significantly, between passes. We conclude that small trout, including juveniles, can and do exhibit functionally significant upstream movement and that greater consideration should be given of their passage needs as well as for large, adult trout.

1. Introduction

Connectivity is a fundamental element of landscape structure and ecological processes and the longitudinal connectivity dimension is especially important in rivers (Fausch et al., 2002; Taylor et al., 1993). The ecological impacts of impoundment by in-stream structures such as dams, weirs and culverts on river systems can be extensive, especially upon fish populations, altering habitat and creating upstream and downstream obstacles to migration and dispersal (Aarestrup and Koed, 2003; Larinier, 2001; Lucas and Baras, 2001). Loss of free passage due to artificial barriers can lead to habitat fragmentation and limit fish distribution in water courses by reducing access to key habitats such as spawning grounds (Fausch et al., 2002; Lucas et al., 2009). River systems are particularly susceptible to fragmentation (Nilsson et al., 2005; Calles and Greenberg, 2009) as one barrier has the potential to isolate large sections of river from one another (Jager et al., 2001). Where a structure acts as a total barrier to upstream fish passage it can result in stark changes in community structure due to isolation (Pringle et al., 2000; Thorncraft and Harris, 2000). For fish which rely on migration to reach different habitat patches for life-cycle completion, especially diadromous fishes which may need to traverse large numbers of structures on their migration between the sea and freshwater, fragmentation can lead to extinctions upstream of structures (Lucas and Baras, 2001; McDowall, 1992). Loss of longitudinal connectivity can also decrease abundance more widely in the catchment when recruitment is reduced by lack of access to

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http://dx.doi.org/10.1016/j.ecoleng.2016.05.048
0925-8574/

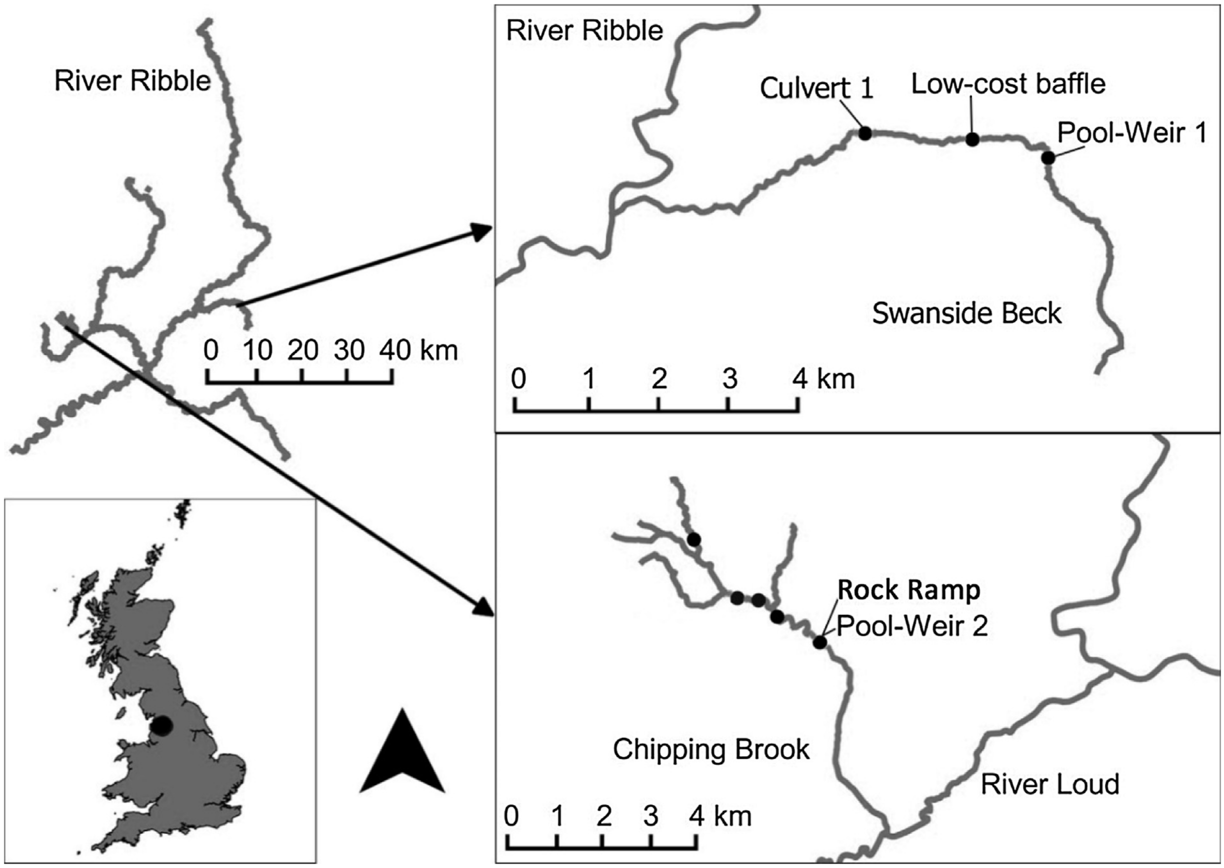

Fig. 1. Map of study area with in-stream structures shown as black circles (top and bottom right).

spawning/rearing grounds or due to reduced downstream migration success (Levin and Tolimieri, 2001; McDowall, 1992).

In contrast to high-head dams (>15 m; Poff and Hart, 2002), the effects of small structures such as low-head dams, weirs and culverts are less well studied (Alexandre and Almeida, 2010; Lucas and Frear, 1997; McLaughlin et al., 2006; Ovidio and Philippart, 2002). While small structures are often considered to be passable by strong swimmers and jumpers like salmonids (McLaughlin et al., 2006) they can still bring about migration delays while they are being negotiated (Svendson et al., 2004), reducing the condition of spawning fish and increasing exposure to predators. Kiffney et al. (2009) showed that access to small streams was particularly important in the rearing of juvenile salmonids, providing important habitat benefits for growth and survival. The presence of these structures, such as culverts, has been reported to have negative effects on the dispersal (Gibson et al., 2005; Park et al., 2008; Warren and Pardew, 1998) and distribution (Pépino et al., 2012) of fish populations with impacts on genetic diversity similar to those of natural waterfalls (Torterotot et al., 2014).

In order to mitigate the negative effects of obstacles on upstream migration, fish passage technologies have been developed, such that there is now a wide variety of designs, categorised as either technical (e.g. vertical slot, pool and weir, baffle-type) or nature-like (e.g. by-pass channels and rock ramps) (Clay, 1995; Katopodis and Williams, 2012). Evaluation of the performance of fish passage structures has indicated that the degree of success achieved can be very variable and site specific (Kemp, 2012). Even if a high proportion of fish manage to pass using a fishway, negative impacts are often still incurred, including migration delay, with fish attempting to pass structures on multiple occasions (Foulds and Lucas, 2013; Gowans et al., 1999; Haro and Kynard, 1997; Hasler et al., 2011; Laine, 1995; Keefer et al., 2004). The ability to understand the effects of migration delay have been limited by our ability to quantify it (Castro-Santos and Haro, 2003). With 25,000 known man-made barriers on UK rivers alone, and an increased ambition to provide free fish passage, it is important to determine the functionality of fish passage designs (Gough et al., 2012). This is especially true within tributaries where the impacts of barriers are less well investigated than in main stems of rivers where fish passage facilities have mainly been constructed (Clay, 1995; Marmulla and Ingendahl, 1996; Ovidio and Philippart, 2002).

Although fish passes have a long history (e.g. Denil, 1909) there remains a paucity of good quality empirical information about the true effectiveness of differing types of pass for different species of migratory fish (Bunt et al., 2012). Many fish pass designs originated to accommodate adult salmonids with strong swimming capacities and a persistent desire to pass upstream (Stuart, 1962, 1964). However, there is a range in swimming ability present not only across species, but different life stages also, for which passage structures are not always designed to accommodate. Free passage is not only important for adult fishes but can also be vital for juveniles where it is required for them to recover from disturbance events such as displacement by high flows (Ottaway and Clarke, 1981) or pollution incidents (Baras and Lucas, 2001), for the seeking of resources and seasonal shifts in distribution (Baras and Lucas, 2001), or where juvenile morphotypes mature (e.g. male precocious salmonid parr) and contribute towards population survival through alternative spawning strategies (Garcia-Vazquez et al., 2001).

In order to achieve effective fish passage solutions that allow free migration and assist in lifecycle completion, better quality information is required as to the performance of fish pass designs. This study used passive integrated transponder (PIT) technology