

Win, win, win: Low cost baffle fish pass provides improved passage efficiency, reduced passage time and broadened passage flows over a low-head weir

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ABSTRACT

The number of low-head barriers to fish migration far outweighs the number of large magnitude barriers and thus the cumulative negative impact on fish communities could also be far greater. Removal of man-made obstructions to fish migration is the most beneficial mitigation measure for reconnecting fragmented rivers but is not always possible and thus fish passes must be constructed. Given the large number of low-head barriers, cheap but effective fish passes must be identified. This study measured passage of brown trout (*Salmo trutta* L.) at a low-head gauging weir on Eshton Beck, England, before and after low cost baffle (LCB) fish pass construction using passive integrated transponder (PIT) telemetry. The LCB fish pass significantly improved overall passage efficiency from a maximum of 64% to 91%. There was a significant decrease in delay at the obstruction after the LCB fish pass was constructed and fish passed on a greater range of flows ($0.08\text{--}5.39\text{ m}^3\text{ s}^{-1}$) in comparison to before ($0.56\text{--}1.92\text{ m}^3\text{ s}^{-1}$). Fish ascended the fish pass through the low velocity channel (gaps in the baffles) as well as over the baffles, though a higher proportion were detected ascending over baffles at higher flows. It was therefore concluded that similar low-head structures should incorporate this style of fish pass to improve longitudinal connectivity for brown trout and other species with similar passage capabilities.

1. Introduction

Anthropogenic alterations to rivers such as construction of barrages, dams and weirs have caused fragmentation of river systems globally (Katopodis and Aadland, 2006; Lucas et al., 2009). This break-up of longitudinal connectivity has reduced the bidirectional migration and dispersal of fish species resulting in restricted access to key life stage habitats to complete their life cycles which can cause declines in fish populations (Petts, 1984; Harris and Mallen-Cooper, 1994; Cowx and Welcomme, 1998; Lucas et al., 1999; Lucas and Baras, 2001; Radinger and Wolter, 2014). Barriers can also indirectly affect organisms such as unionoid bivalve molluscs that require movements of host fish for dispersal of their larvae (Watters, 1996). Small low-head obstructions may not present an absolute barrier to migration and dispersal but they outnumber large dams by a magnitude of two to four orders globally and thus the cumulative negative impact on fish communities could be greater (Lucas et al., 2009) while also altering flow and sediment regimes (Nilsson et al., 2005; Poff et al., 2007; Xu and Milliman, 2009). Removal of man-made obstructions to fish migration is the most beneficial mitigating measure for reconnecting fragmented rivers (Kurby

et al., 2005) but is not always possible and thus fish passes must be constructed.

Gauging weirs constantly monitor river flow (hydrometry) for societal demands such as preparation for flood events in both Europe (White et al., 2006) and worldwide (Wessels and Rooseboom, 2009). Indeed, there are over 1500 gauging stations in England and Wales (Turnpenny et al., 2002; Peirson et al., 2013). Such structures are known to have a negative impact on upstream fish migration (White et al., 2006; Russon et al., 2011). This can be during both periods of low river level when shallow depth on the weir apron can impede fish movement and elevated river level when flow over the weir can exceed the swimming capability of fish (Fraser et al., 2015; KLTAP, 2015). Additionally the reduction in velocity at the base of the obstruction can cause a hydraulic jump and increase turbulence that can potentially disorientate fish and act as an additional barrier (Beach, 1984; Boiten, 2002). The requirement to monitor river flow for societal purposes dictates such weirs cannot be removed and thus a cheap but effective fish pass must be identified to adequately conserve aquatic ecosystems.

Servais (2006) identified that the introduction of baffles to the apron of small low-head sloping weirs to retard water velocities and

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retain depth may be a relatively cheap method for improving fish passage. In theory, low cost baffles (LCB) provide passage at low flow when fish swim upstream through gaps between baffles and during high flow when fish can traverse the baffles. Forty et al. (2016) found LCB fish pass efficiency was 68% and 82% in 2013 and 2014, respectively, for brown trout (*Salmo trutta* L.) on Swanside Beck, England. However, Forty et al. (2016) did not report the passability of the weir prior to LCB construction and route choice over the obstacle was not established. Therefore, it remains unknown whether LCB fish passes increase the rate of upstream passage at both low and high flow and whether fish use the gaps in the baffles or traverse the baffles during such flows.

Efforts to address reductions in longitudinal connectivity of aquatic ecosystems has largely focused on anadromous salmonid fishes (Noonan et al., 2012). There is a general paucity of information on the efficiency of fish passes for potamodromous and river-resident species, despite free passage of fishes throughout river systems globally being a key legislative requirement, e.g. the European Union Water Framework Directive (WFD) (EC; 2000/60/EEC). Therefore, passage efficiency assessments are urgently required to determine if they are operationally effective, overcome WFD failures and help conserve river-resident species and ecotypes. River-resident brown trout were studied because they undertake migrations over many kilometres and are often the dominant fish species in upland rivers – where low-head barriers are most prevalent – in many regions, either in their native range or where introduced (Budy et al., 2013).

This study aimed to evaluate the passage of brown trout at a low-head gauging weir before and after low cost baffle (LCB) fish pass construction. In order to achieve this aim the following objectives of this investigation were to measure the passage efficiency and passage time before and after LCB construction and determine the effect of flow and fish size on passage. Passage metrics were determined by the use of passive integrated transponder (PIT) telemetry at the weir, before and after modification.

2. Materials and methods

2.1. Study site

The study was conducted between March 2014 and January 2017 at Eshton Beck gauging weir (53.988886, –2.0890425; hereafter referred to as Eshton Weir) on Eshton Beck, a tributary to the River Aire (53.981699, –2.0880099), which is regulated by Winterburn Reservoir (54.039685, –2.0852512) (Fig. 1). The weir allows for abstraction of water to maintain water level in Leeds and Liverpool Canal for navigation (53.984599, –2.0856656). The thin plate weir was 14.00-m wide, with a 0.59-m head and a 7.13-m flat concrete apron downstream of the crest, divided into two sections, with the upper section (3.08-m) having a slope of 1:9 while the downstream section (4.05-m) has a slope of 1:51 (Fig. 1). An iron girder at the crest of the weir aided water retention by the weir (Fig. 1). A LCB fish pass consisting of 17 recycled plastic baffles (0.2-m high and 0.1-m thick) that lay horizontally across the weir apron 90° to the flow was constructed in September 2015. Each of the baffles had a 0.3-m gap and these were progressively offset across the weir apron, resulting in an oblique corridor of notches, located from the right hand bank at the downstream end of the weir, to the centre of the river at the upstream end of the weir. Due to construction issues the most downstream baffle was not drowned sufficiently to create a constant streaming flow over the bottom baffle, as per best practice (Armstrong et al., 2010).

2.2. Sampling and tagging procedure

Fish were obtained from one site downstream (0.5-km) and two sites upstream (1.6 and 3.1-km) of Eshton Weir in March 2014 and July 2016 (Table 1). Fish were caught whilst wading with a single anode using pulsed DC (200 V, 50 Hz, ~1.5 A) electrofishing equipment,

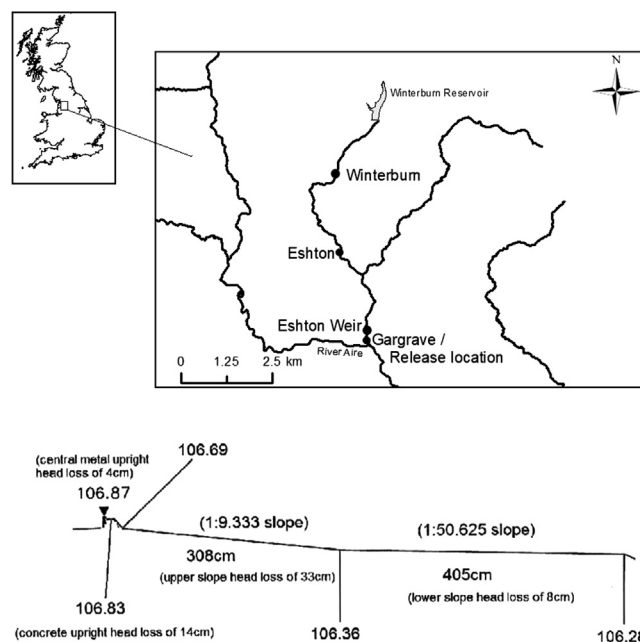


Fig. 1. Location of Eshton Weir, capture locations and tagged fish release location (black circles) (top), and cross-section through the weir (bottom).

powered by a 2 kVA generator. Fish caught from Winterburn and Eshton (upstream sites) were initially monitored for any signs of injury during capture (e.g. not regaining normal buoyancy or posture, physical injuries or electric fishing marks). All captured fish that were considered to be fit for tagging were transported downstream of Eshton Weir. On arrival fish were moved into an aerated holding tank containing fresh river water for a period of one hour, during which time they were again monitored for any signs of stress before undergoing surgery.

All brown trout > 120-mm were tagged with 23-mm (half-duplex, 23.0-mm long × 3.4-mm diameter, 0.6-g weight in air) PIT tags. Larsen et al. (2013) reported a 100% survival and tag retention rate for > 90-mm Atlantic salmon (*Salmo salar* L.) tagged with 23.0-mm PIT tags. Prior to tagging in the field, fish were anaesthetised using buffered tricaine methanesulphonate (MS-222). Once anaesthetised the fork length was measured (mm) and recorded. During surgery fish were placed ventral side up in a clean V-shaped foam support. The skin of the fish was disinfected with a dilute iodophore wipe. Tags were tested with a hand held detector, disinfected with alcohol and rinsed with distilled water before being inserted into the body cavity through a 5-mm long ventro-lateral incision made with a scalpel, anterior to the muscle bed of the pelvic fins. After the surgery, fish were continuously monitored in a well aerated tank of fresh river water. Once fish had regained balance and were actively swimming they were released into the river approximately 0.5-km downstream of Eshton Weir (53.984411, –2.0889916; Fig. 1). All fish were treated in compliance with the UK Animals (Scientific Procedures) Act 1986 Home Office licence number PPL 60/4400.

2.3. Monitoring

Four flat-bed half-duplex PIT antennas were installed during the study. Two antennas were installed before LCB construction (A1 and A4) in March 2014 with a further two antennas (A2 and A3) installed after LCB construction in March 2016 (Fig. 2). Specifically, A1 and A4 were ~0.5-m wide, constructed from 6-mm diameter copper cable and spanned the 13-m wide river 10-m downstream and 0.5-m upstream of Eshton Weir, respectively. A2 and A3 were constructed from multiple turns of single core 3-mm diameter copper cable, were 0.3-m by 0.1-m

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