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Research article

Efficiency of a nature-like bypass channel for restoring longitudinal connectivity for a river-resident population of brown trout

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ABSTRACT

Man-made, physical barriers have disrupted longitudinal connectivity for migratory fish in many river systems throughout the world for centuries. These barriers are considered to be a key reason for the decline of many fish species in river systems. To date, most research to ease movement of anadromous salmonids past such barriers to help dwindling populations has focused on the use of technical fishways. More recently emphasis has been placed on nature-like fishways to enable a wider range of fish species to bypass these barriers, but few studies have examined their efficacy. In this study, Passive Integrated Transponder (PIT) telemetry was used to assess the upstream-directed movements of 111 river-resident brown trout (length, 151–510-mm) into and through a 150-m long, nature-like bypass on the River Aire, England. Attraction (51%), entrance (86%), passage (78%) and exit (97%) efficiencies were high, and trout of a wide range of sizes entered and exited (197–510 mm) the pass across a wide range of flows (entrance = 3.55–67.44 m^3s^{-1} and exit = 3.89–35.5 m^3s^{-1}). There was evidence that two trout inhabited the pass during the day, entering at sunrise and exiting at sunset. This information is important to improve understanding of fish pass performance, thus informing future best practice guidance of fish passage designs.

1. Introduction

Uninterrupted longitudinal connectivity enables species and populations to move between suitable habitats, shaping aquatic communities (Hilty et al., 2006). For centuries man-made physical barriers such as weirs and dams have been constructed for the purposes of navigation, power generation and water abstraction (Katopodis and Aadland, 2006). For example, the Environment Agency in England and Wales have developed a database of almost 26, 000 obstructions within the waterways (Environment Agency, 2010). These barriers have impacted upon longitudinal connectivity and disrupted migration of fish in riverine ecosystems worldwide (Petts, 1984; Calles and Greenberg, 2009; Noonan et al., 2012; Williams et al., 2012). The disruption of longitudinal connectivity has caused declines in numerous fish species globally (Petts, 1984; Cowx and Welcomme, 1998; Lucas et al., 1999; Lucas and Baras, 2001). The loss of connectivity impacts on the ability of fish move between feeding and spawning grounds (Lucas and Baras, 2001; Amoros and Bornette, 2002) which can effect recruitment success and lead to a reduction in gene flow between populations (Pelicice et al., 2015). Considerable efforts are now focused on addressing these problems and ways to ameliorate the impacts through construction of fish passes and easement of fish migration (Larinier, 1998; Northcote, 1998; Branco et al., 2014).

Total removal of a barrier (Kanehl et al., 1997; Catalano et al., 2007; Burroughs et al., 2010) is the preferred option to remediate longitudinal connectivity, but this cannot always be achieved due to factors such as flood control (Kurby et al., 2005), abstraction and loss of other services for which the barrier was created. Therefore, to ameliorate the potential effects barriers have on interrupting fish migratory pathways and disconnecting habitats, numerous fish pass designs have been developed to ease fish passage and improve longitudinal connectivity (Clay, 1995; Lucas and Baras, 2001; Larinier et al., 2002; Roscoe and Hinch, 2010; Bunt et al., 2012). To date, most efforts to ease movement of anadromous salmonids has focused on the use of highly engineered technical fishways (i.e. pool and weir, pool and slot, and Denil), but Noonan et al. (2012) found they rarely achieve 100% fish passage efficiency, normally within the range of 22–71%. They found passage efficiency decreases with increased slope and that pool and weir designs achieved highest passage efficiency results. More recently, however,

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nature-like bypass channels have received attention (Jungwirth, 1996; Wang and Hartlieb, 2011; Williams et al., 2012) because morphology and water velocities are designed to be similar to those of a natural stream (Parasiewicz et al., 1998), and thus should, in theory, permit free passage of all fish (Eberstaller et al., 1998; Calles and Greenberg, 2005) and present benefits to the wider biodiversity, such as invertebrates and nematoda (Gustafsson et al., 2013).

There is, however, a dearth of investigations into the efficiency of fish passes, especially for nature-like fish pass solutions where the majority of studies relate to anadromous salmonid fishes (Roscoe and Hinch, 2010; Bunt et al., 2012; Noonan et al., 2012; O'Hanley et al., 2013), with a paucity of information on potamodromous and river-resident species through a nature like bypass. Where studies have been carried out, they suggest variable rates of passage efficiency with entrance and exit configuration, attraction flows and hydraulic conditions in the pass and fish size as the main factors affecting efficiency (Calles and Greenberg, 2007; Steffensen et al., 2013; Tummers et al., 2016). However, few studies attempt to investigate all these factors, across a wide range of flows and all seasons during the same investigation.

The free passage of migratory fishes throughout river systems is a key requirement of the European Union Water Framework Directive (WFD) (EC; 2000/60/EEC) because many water bodies throughout Europe are failing to meet environmental targets of Good Ecological Status (GES) or Potential (GEP) due to the presence of barriers. A large number of fish passes have been and are currently being constructed to overcome WFD failures but these are often not assessed for their efficacy or optimal design. There is thus an urgent need to assess the efficacy of all fishway designs to determine if they are operationally effective for all species and inform future designs. One such scheme is the nature-like bypass channel at Rodley Weir on the River Aire in Yorkshire, northern England. This study explores the performance of Rodley Weir nature-like bypass channel to allow free passage for a river-resident population of brown trout (*Salmo trutta* L.), using Passive Integrated Transponder (PIT) telemetry. More specifically, the objectives were to: 1) quantify attraction, entrance, passage and exit and efficiencies; 2) establish the influence of fish size on approaches and movements into and through the fish pass; and 3) evaluate the timing of movements in relation to time after release and environmental conditions (flow and temperature). Such information is critical for improving the design of such passes and inform management decisions on their suitability as a solution for various scenarios where such fish easements may be considered.

2. Materials and methods

2.1. Study site

The study was conducted between October 2013 and January 2015 on the River Aire, which runs from its source in North Yorkshire (53.843807, −002.812065), through major conurbations, including Bradford, Castleford and Leeds, to its confluence with the River Ouse at Airmyn (53.726818, −000.90824701). The River Aire is 114 km long with a catchment area of 1100 km^2, has 34 weirs situated along its length, of which 11 are regarded as key barriers to fish movements. Steps are now being taken to improve longitudinal connectivity of the river for fish, which for centuries has been fragmented by largely impassable man-made obstructions. One such example is the 50-m wide, 1.8-m high weir at Rodley (53.819763, −001.645892), which was largely impassable to upstream migrating fish.

A nature-like bypass channel was constructed at Rodley in the summer of 2013. It is 150-m long, average slope of 0.688° and located on the north bank of the River Aire at Rodley Nature Reserve, adjacent to the weir (Fig. 1). The downstream section of the fish pass (1.8-m wide x 15-m length) is constructed of vertical concrete-block banks, the middle section contains 12 low-head (100–150-mm) notched vertical steps, gentle sloping landscaped banks and an area of backwater habitat. The upstream section (2.5-m wide x 3-m length) was constructed from steel pilings.

2.2. Sampling and tagging procedure

Initially, an attempt was made to capture fish downstream of Rodley Weir in August 2013, but this was unsuccessful and was presumed to be the consequence of two pollution incidents in the preceding weeks. Consequently, brown trout were captured using electric fishing from four sites upstream of Rodley Weir (Appendix 1) on 10–11 October 2013 and translocated to 350-m downstream of the weir. In addition, brown trout were captured from the 400-m long reach downstream of Rodley Weir on 30 June 2014. Fish were caught either whilst wading or from a boat with a single anode using pulsed DC (200 V, 50 Hz, ~1.5 A) electric fishing equipment, powered by a 2 kVA generator.

Fish caught from each site were initially monitored for any signs of stress before being placed in a holding tank, which was transported over the short journey to Rodley Nature Reserve. 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 were >150-mm and were tagged with 23-mm (half-duplex, 23.0-mm long x 3.4-mm diameter, 0.6-g weight in air) PIT tags (Appendix 1). Larsen et al. (2013) reported a 100% survival and tag retention rate for >90-mm Atlantic salmon (*Salmo salar* L.) tagged with 23-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 iodiphore 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 back into the river approximately 350-m downstream of Rodley Weir. 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 fixed location, cross-channel, swim-through half-duplex PIT antennae were installed during the study; two antennae were installed at each of the upstream and downstream ends of the nature-like bypass channel, enabling direction of movement to be recorded (Fig. 1). All antennas interrogated full channel width and depth at all river levels during the study. Specifically, Antenna 1 (A1) was located at the downstream entrance, Antenna 2 (A2) was 10 m upstream of the first antenna, Antenna 3 (A3) was located 5-m downstream of the fish passage exit and Antenna 4 (A4) was ~1 m downstream of the steel pilings at the upstream exit to the fish pass. A4 could not be located any closer to the upstream exit as the steel pilings would interfere with the antenna's PIT tag read range. Antennae were constructed from 6-mm diameter copper cable, connected to manual tuning boards (Oregon RFID) attached to a multi-antenna data logger (Oregon RFID), synchronously interrogated 10 times per second and powered by two 110 Ah, deep-cycle,