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Fish Passage Appraisal

Lumb Mill Weir, Eastburn Beck

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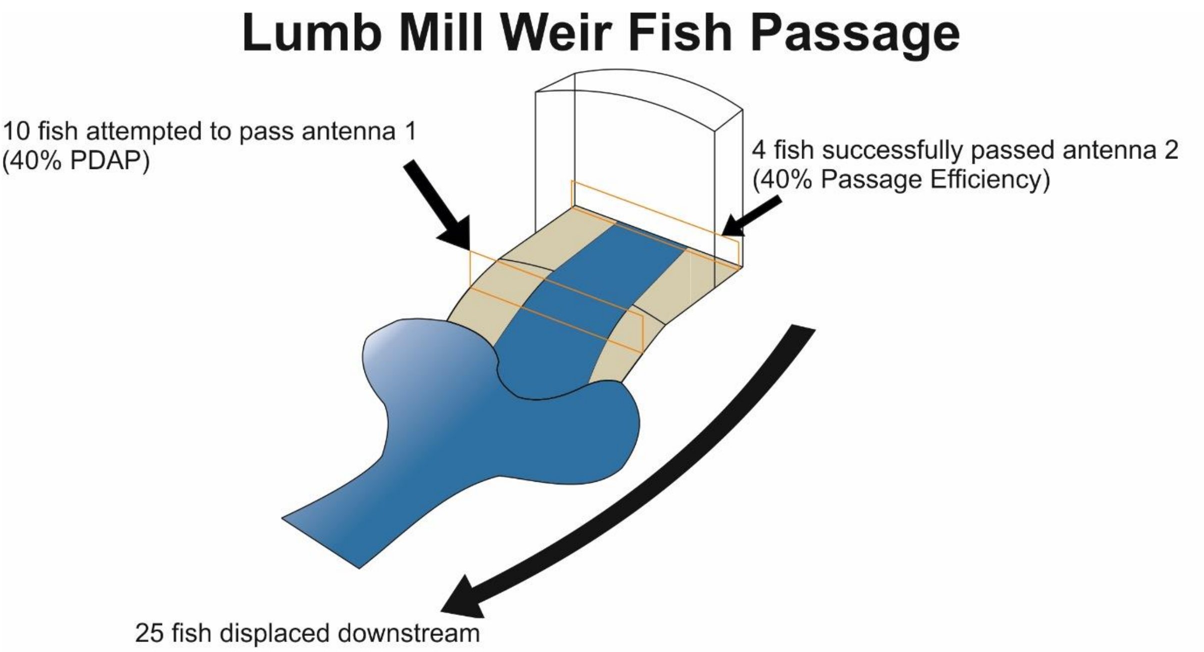
Executive Summary

The Wild Trout Trust (WTT) approached the Ribble Rivers Consultancy (RRCL) to undertake an investigation as to the barrier impact of Lumb Mill weir (Eastburn Beck, Upper Aire catchment) on the upstream passage of brown trout (*Salmo trutta*). The purpose of the investigation would be to inform upon future management decisions, deeming if it would be best to allocate the resources of the WTT on improving fish passage at this structure. The structure consists of a low-head weir with an 8-10 m concrete apron upstream passing the stream under a road bridge.

It was deemed a short-term evaluation using PIT telemetry would be the most accurate method while being less impacting upon the trout population. Trout were captured upstream of the weir, tagged, and then displaced downstream to instigate a homing response that would make them attempt to pass the structure.



The weir was found to have a 40% passage efficiency, with 40% of displaced trout attempting to pass upstream. Successful fish were observed to take up to 19 minutes to swim across the apron, during which time they would have a high exposure to predation in the shallow water. Equipment was washed out for 2 days following an extreme spate event before being reinstalled. The values for passage efficiency and proportion of displaced fish attempting passage (PDAP) may be taken as conservative due to the equipment downtime and the lower number of attempts that may have been observed due to the need to place the downstream antenna at the crest of the weir instead of the bottom.

The evaluation highlighted that Lumb Mill weir is a substantial barrier to upstream fish passage and that it is certainly a candidate as a site for investing in fish passage facilities. An outline-option to completely address fish passage issues at the structure is proposed, along with a lower-cost method for improving passage success over the shallow water apron.

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1.0 Introduction

The Wild Trout Trust (WTT) approached the Ribble Rivers Consultancy (RRCL) to undertake an investigation as to the barrier impact of a structure on the upstream passage of brown trout (*Salmo trutta*). The purpose of the investigation would be to inform upon future management decisions, deeming where it would be best to allocate the resources of the WTT. The management question being to determine whether the structure is a significant barrier to upstream migration (i.e. fish passage facilities are required) or whether fish were able to move past the structure and resources should be directed elsewhere.

Discussions were held between RRCL and WTT, including an ethical evaluation of the value of the project aims and the different methodologies available to answer the management question. These resulted in a short-term telemetry evaluation being deemed the most effective way to address the management question accurately while reducing the level of impact on the fish population in the Beck.

1.1 Barriers to fish migration

Many fish species present in freshwater systems in the UK require free passage, both upstream and downstream, in rivers for spawning, rearing and growth, with free movement between the sea and freshwater being vital for some species survival. A man-mad barrier to fish passage can take many forms such as weirs, culverts, or dams, where the physical presence of the structure or its impacts on stream flow mean that some or all fish are unable to pass. There are 25,000 man-made barriers to fish migration on UK rivers (Gough et al., 2012), highlighting a need for large scale remediation efforts to reconnect this disjointed habitat. Some structures are often discounted as being problematic, being considered passable by strong swimming/leaping fish like adult salmonids, however, they often incur an energetic cost to fish while they are negotiated. This cost comes from delays experienced by individuals repeatedly attempting to pass upstream over a prolonged period (Svendsen et al., 2004; Foulds & Lucas, 2013), with fish spending time migrating instead of resting/replenishing energy reserves. Ergo in-stream barriers can not only reduce the number, type and age-class of fish that can pass between habitat patches, but also the condition of those that do.

Recent years have seen an increased desire to improve fish passage within rivers, largely driven by the European Union Water Framework Directive (WFD; Directive 2000/60/EC), legislation requiring all surface water bodies to meet *Good* status by 2027. A common reason a water body to not be achieving *Good* status is due to an absence or low densities of migratory fish species whose populations have been impacted by multiple barriers to migration. As such it has been important for migration barriers to be identified, evaluated, and addressed via one of many available fish passage solutions.

2.0 Methodology

2.1 Site Description and location

Lumb Mill weir is located at SD 98796 44462, just west of Glusburn, North Yorkshire (Figure 1). The structure is located underneath a road bridge with its purpose being to protect the footings of the bridge from erosion. It is a two-part structure consisting of a low-head weir (Figure 2) with an 8-10 m concrete apron (Figure 3) upstream that passes the stream under the bridge. The weir pool downstream is *ca*. 1-1.5 m deep, giving some fish species a chance of leaping on to the apron. Due to the width and profile of the apron, water depths over it at base flows are shallow (< 0.2 m) with depth varying slightly where channels have been eroded by the stream. The head of the weir is ~0.75 m with the weir and apron combined being ~1-1.25 m.

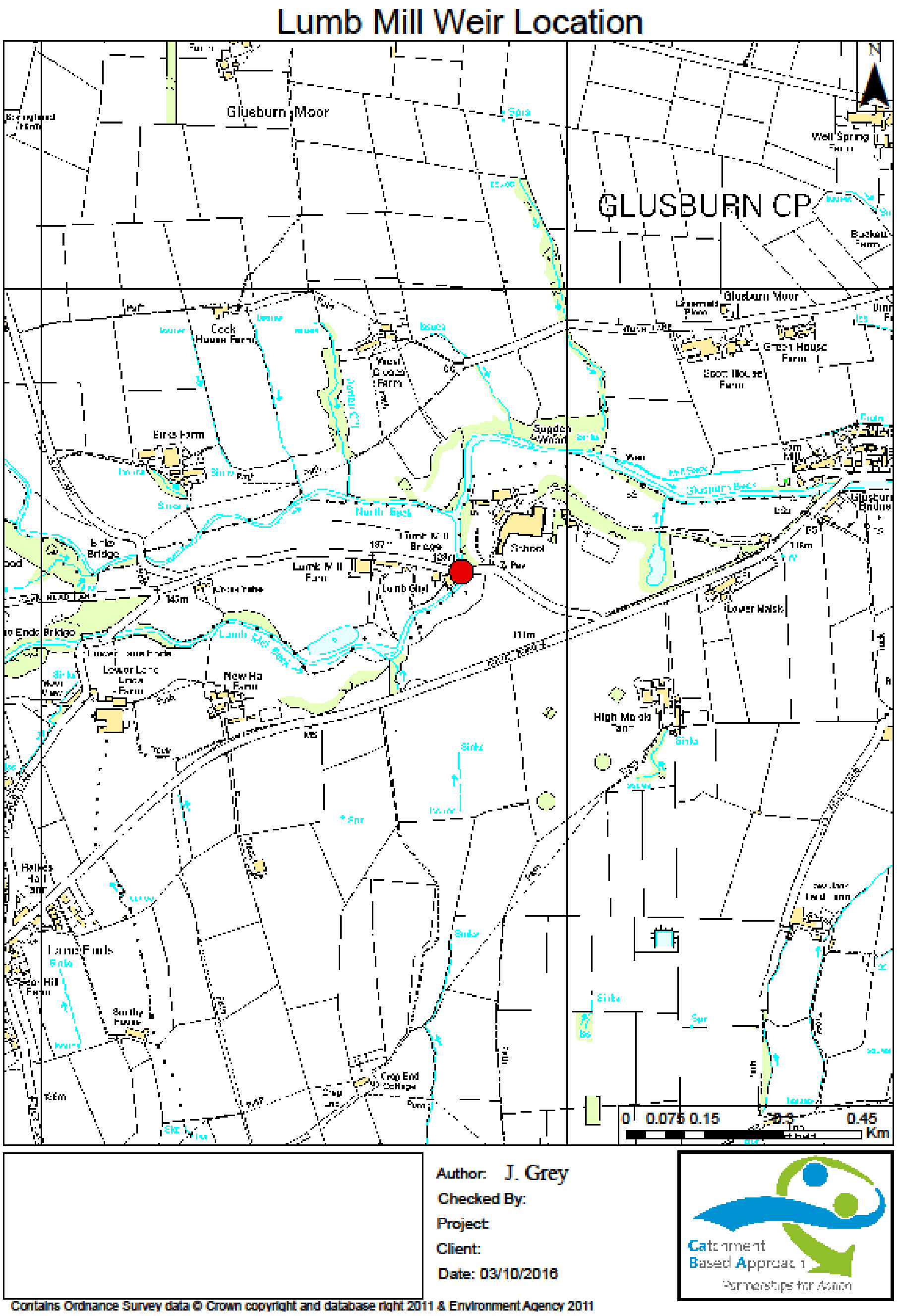

Figure 1. Map showing location of Lumb Mill Weir (red dot).

Figure 2. Lumb Mill weir as viewed from the top LHB of the weir.

The weir itself is located within the Humber River Basin District under WFD, specifically in the "Glusburn beck from source to Lothersdale beck" water body. The stream on which the weir is located will be referred to as Eastburn Beck hereon, though it is also known by Glusburn Beck and Lumb Mill Beck. The beck runs off Stott Hill and Ickornshaw moors, running through Cowling before joining with Lothersdale Beck 100 m downstream of Lumb Mill weir. The water body is not classified as artificial or as being heavily modified hydromorphologically and covers 17.27 km^2. The Overall Water Body classification is *Moderate* with fish being rated as *Moderate* or *Poor* since 2009. Additionally, pH has been a continuing issue since 2014 being rated as *Moderate* and classed as currently being under investigation by the Environment Agency. The beck has fish populations including resident brown trout and other less economically valuable species such as European Bullhead (*Cottus gobio*). The *Salmo trutta* phenotype Sea trout are not present in the stream at this point with multiple barriers to migration being the likely cause for their absence.

Figure 3. Upstream apron of Lumb Mill weir with PIT antennae in-situ below the blue water pipe.

2.2 Passive Integrated Transponder (PIT) telemetry

PIT telemetry was selected to determine whether brown trout could pass Lumb Mill Weir, as the small tag size involved (< 2% tag:body-weight ratio) would allow for very detailed information on passage to be collected, whilst minimally impacting for fish. The technique is widely used to evaluate barriers to migration and the efficacy of fish passage solutions (e.g. Bunt et al., 2012, Tummers et al., 2016). PIT telemetry involved placing antennae loops across the full width of the stream (6 mm multi-stranded, high quality copper speaker cable, 777 x 0.1 mm strands) at the extents of a structure. As fish swim/leap within range of the antennae, the unique tag number is sent to the logging device that records the tag, the date/time, and at which antenna the fish was detected. Placing one antenna at the downstream extent (A1), and one at the upstream (A2), it can be identified which direction a fish is swimming, how many fish are attempting to move upstream, how many fish are successful, the time it takes for their passage and the amount of delay incurred while doing so.

Each antenna was tuned via a tuning unit (RFID Tuner, Oregon RFID, USA) connected to a half-duplex multiple antennae reader and data logger (Oregon RFID, USA), connected by shielded twin-axial cable. The system interrogated each loop 6 times per second, where one interrogation composes of transmitting and listening for/receiving a signal from a tag. The loops were tuned to a maximum detection range and efficiency by adjusting the tuning while drawing a 23 mm PIT tag (23 x 2.12 mm, 0.1 g; Figure 4) through the loop at small intervals to determine range and identify holes in the field. Upon installation there were no holes in the fields and detection range from the loop was 25-50 cm from the antennae, detecting tags even at burst swimming speeds (up to $3 ms^{-1}$). The system was powered using two 12 V, 110 Ah deep-cycle leisure batteries run in parallel which were changed every 5-7 days to ensure power supply was not interrupted. Loops were retested at each battery change to ensure they were functioning correctly.

Figure 4. 12 mm, 23 mm and 32 mm PIT tags (not to scale). Source: Oregon RFID.

PIT stations ran continuously between 13:05 06/09/2016 and 13:00 23/09/2016 with the exception of one period when both antennae loops were snapped on the night of 13-14/09/2016 when extremely intensive rain led to a flashy peak of the stream. Loops were re-installed on 16/09/2016, once levels had dropped, and then ran continuously from 15:00 till the 23rd September.

2.3 Capturing and tagging procedure

Fish used in the investigation were captured by single pass electric fishing (pulsed DC backpack unit, Electracatch, UK) between the weir and 1 km upstream. The preference for using fish captured upstream of the structure is that displacing these fish downstream of a structure has been observed to instigate a homing response that stimulates these fish to attempt to move back upstream of an obstacle shortly after displacement. Forty et al. (2016) found that between 37 % and 88% of displaced trout attempted to move upstream within 15 days after displacement. However, it is not guaranteed that individuals will move back upstream following displacement, particularly when there is suitable/higher quality habitat downstream.

Following capture, fish were reserved with both circulation and aeration provided by a 12 V submersible aerator pump (1732 L hr^{-1}). The tagging procedure began by preparing a sterile tagging surface where fish would be supported during the procedure. Once preparations were complete, fish were individually immersed in an anaesthetic bath of 2-phenoxyethanol (250 µL L^{-1}) until stage III anaesthesia was achieved (McFarland, 1959). Fish were then measured (fork-length) and a PIT tag inserted in to the peritoneal cavity via a 3-5 mm incision on the ventral surface anterior to the pelvic girdle. The incision was left un-sutured as studies have shown that this is not necessary for small incisions (Larsen et al., 2013). Fish were then placed in to another aerated reservoir for recovery, during which they were observed, ensuring that they were able to maintain equilibrium, responsive to external stimuli, and exhibiting normal swimming behaviour before release.

2.4 Data analysis

Upstream fish passage at Lumb Mill Weir was evaluated by calculating the passage efficiency (PE), Proportion of Displaced fish Attempting Passage (PDAP, %), passage duration (minutes) and the minimum delay before passage (hours; as defined in Table 1). Water levels were not monitored directly during the evaluation but rainfall accumulation and temperature data were obtained from a local MET Office site at Riddlesden, 9.3 km from Lumb Mill Weir (MET Office,2016). Both data are reported at 30 minute intervals and rainfall accumulation is used as a proxy for indicating periods of increased stream flow that may influence attempts to pass upstream.

Table 1. Definitions of metrics used to evaluate upstream fish passage of brown trout.

Metric	Definition
Passage Efficiency (PE, %)	The proportion of fish successfully passing both antennae compared to the number detected at A1
Proportion of Displaced fish Attempting Passage (PDAP, %)	The proportion of fish attempting passage of those that were displaced
Passage duration	The time taken between for a fish to pass through the structure i.e. time between a fish's last detection at A1 and the first detection at A2
Minimum delay before passage	The amount of time between fish being displaced and their successful ascent

3.0 Results

Electric fishing upstream of the weir resulted in 25 brown trout being captured, all of which were in the parr or adult age classes (Table 2). The young of the year (fry) age group was found to be absent from the entire reach electric fished despite there being large areas of juvenile habitat present. Additionally, good numbers of healthy bullhead were found during electric fishing and non-native invasive American signal crayfish were observed both upstream and downstream of Lumb Mill weir during monitoring.

Table 2. Summary information of brown trout displaced downstream, attempting to pass the weir and those successfully passing the weir.

Group	n	Fork-length [mean SD (range), mm]
Displaced downstream	25	206 ± 37 (150 – 277)
Attempting to pass the weir	10	190 ± 32 (161 – 250)
Successfully passing the weir	4	178 ± 8 (169 – 186)

Of the 25 fish displaced downstream, 10 were detected attempting to pass through A1 (40% PDAP; Table 2., Figure 5). Of those 10 detected at A1, 4 fish were detected successfully passing upstream through A2 (40% Passage Efficiency). For those fish that did successfully pass upstream, passage durations were all under 20 minutes (mean ± SD (range) = 10.8 ± 5.4 (6.8 – 18.8) minutes).

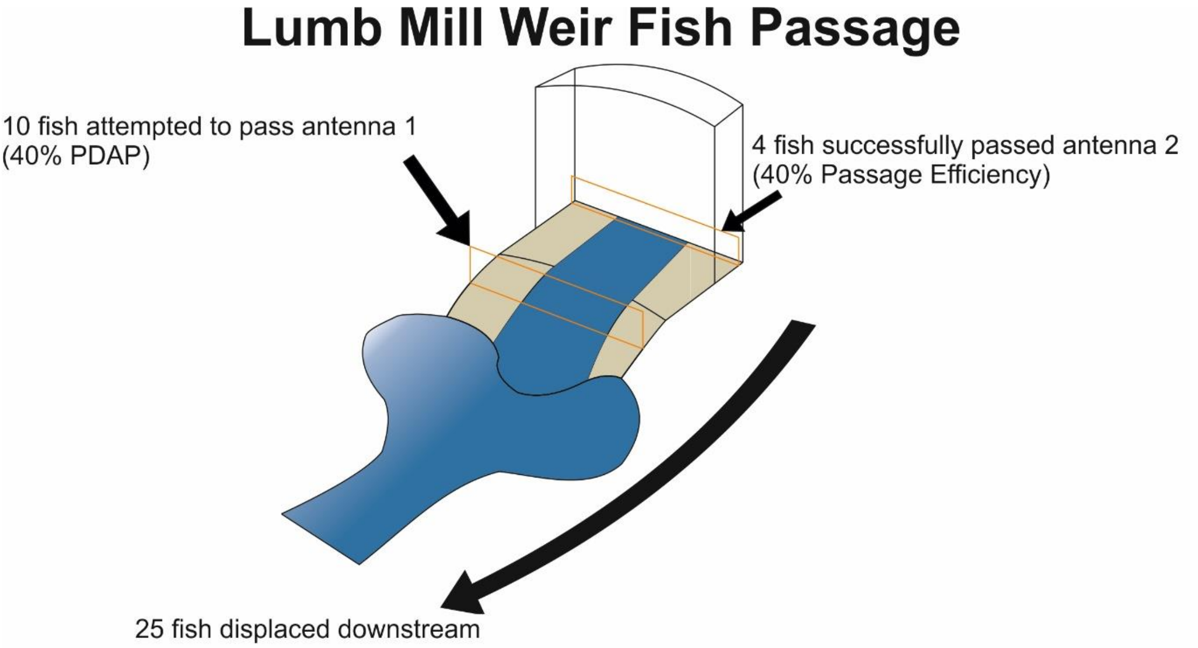

Figure 5. Diagrammatic representation of fish passage evaluation at Lumb Mill weir displaying number of fish displaced downstream, Proportion of Displaced fish Attempting Passage (PDAP) and passage efficiency.

Data for rainfall accumulation (Figure 6) and number of attempts/successful ascents per day (Figure 7) show the initial response of trout to home upstream, when motivation is expected to be highest (Forty et al., 2016). Of the four fish that attempted during the first 2 days after displacement, 100% were successful, compared to the attempts observed in the 15 days after this when 0% were successful. The occurrence of attempts generally coincided with rainfall events after the first 2 days, despite the lack of detections during the extreme rainfall event on 13/09 when equipment failure was experienced (Figure 6, Figure 7).

The minimum delay before passage was under 2 days (mean ± SD (range) = 15.3 ± 21.6 (3.1 – 47.6) hours), though the delay fish that didn't pass upstream during monitoring cannot be determined, it can be suggested it may have been at least as long as the monitoring duration (17 days).

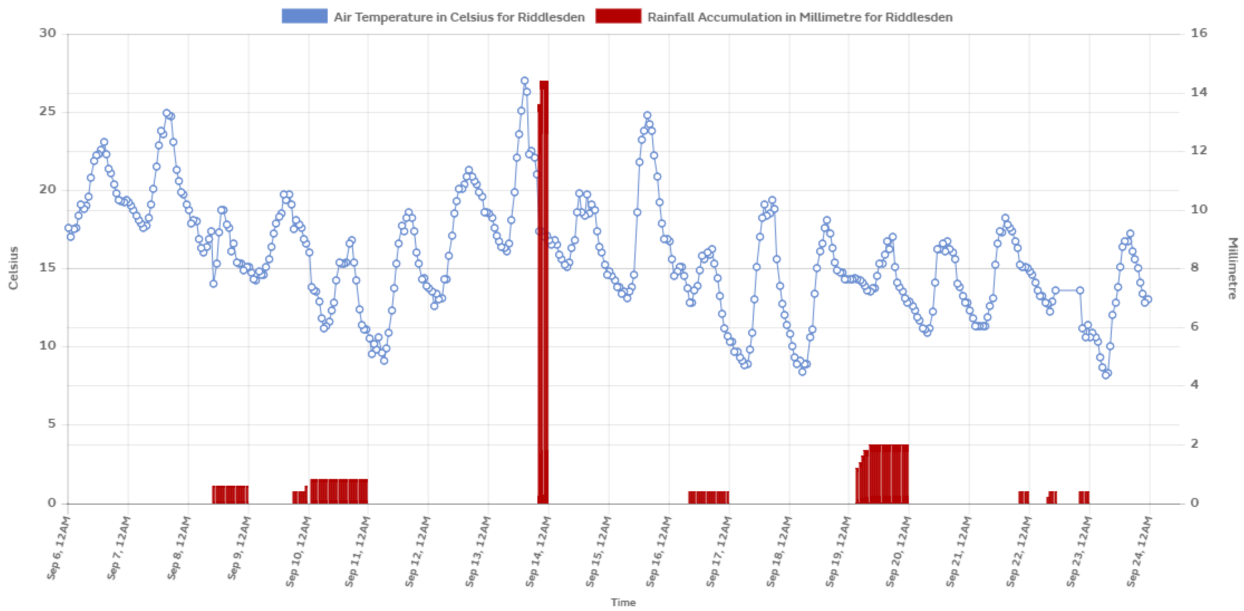

Figure 6. Air temperature (°C) and rainfall accumulation (mm) at Riddlesden. Source: MET Office.

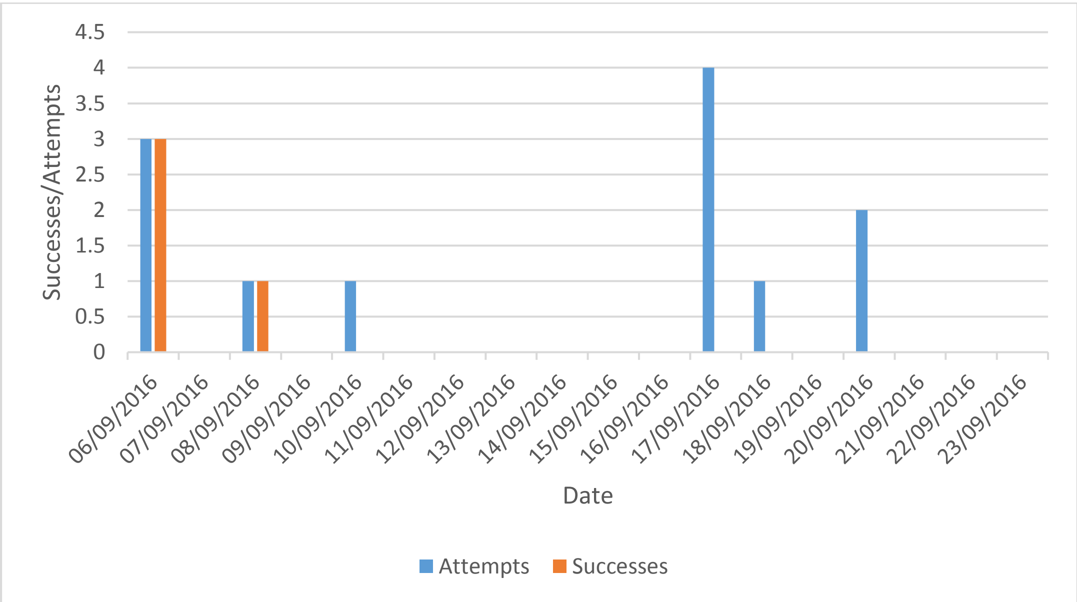

Figure 7. Number of attempts per day by fish to ascend Lumb Mill Weir.

4.0 Discussion, conclusions and recommendations

This evaluation gives supporting evidence that Lumb Mill Weir is acting as a barrier to upstream fish passage of brown trout. With a long term management objective of allowing diadromous sea trout populations to develop in this stream, a passage efficiency of 40% reduces the likelihood of this occurring, given the observed PE is far lower than the 90% recommended by Lucas & Baras (2001) for the sustaining and improvement of diadromous populations. The low PE will also affect the productivity of resident trout populations as it limits access to potential spawning grounds upstream. This will be particularly the case with barriers to migration further downstream that will be reducing the numbers of large adult trout that can reach these important spawning/rearing habitats.

The unfortunate equipment failure experienced when PIT loops were snapped meant that values for passage efficiency, PDAP and minimum delay may be taken as conservative as it is not known whether any fish attempted to pass during the period of downtime or whether they were successful. It is also likely that fish may have been attempting to pass upstream during this period while the levels were elevated (as with attempts coinciding with rainfall events) as the increased flow over the weir/apron would have afforded more favourable passage conditions with increased flow depth making swimming over the structure easier. The wide width at the downstream extent of the structure and the lack of surfaces to affix the antenna to meant that A1 needed to be placed at the top of the weir crest, rather than its ideal location at the bottom that would pick up fish leaping at the weir. This means that the number detected attempting to move upstream may be lower than the actual number as fish leaping at the weir face, but not reaching the crest will not have been detected at A1, further suggesting passage efficiency and PDAP may be conservative values. Low densities of brown trout upstream of this structure meant that the sample size of brown trout displaced was relatively small, limiting the range of sizes that could be tested and the ability to test for length effects. However, this was out of our control and the results found are still considered to be informative in that they suggest that the structure is proving to be a considerable barrier to upstream passage.

The mean fork-length of fish displaced was quite long, with 2-3-year-old parr dominating the group. Bearing in mind that swimming/leaping ability of brown trout has been shown to be a factor of body length (Beamish, 1978; Videler, 1984), the low passage efficiency observed in this study highlights that smaller salmonid parr and weaker swimming species will likely suffer a larger barrier effect from this structure. The two-part barrier of the structure also creates multiple issues for fish passage; firstly, that fish require the ability to leap over the weir on to the apron, an attribute that will be limited to larger salmonids; and secondly, the shallow depth of water over the apron during base/low flows favours smaller fish and makes passage difficult for larger fish, leaving parts of their body unsubmerged with a high exposure to predation. This may explain why some of the larger displaced fish were unable to pass the structure. The exposure to predation of fish in this study would have been up to 19 minutes, giving predators such as heron or otters a wide window to take advantage of fish being in shallow water.

4.1 Guidance on improving fish passage

The findings of this evaluation certainly make Lumb Mill weir a candidate for investing in passage facilities, as allowing greater passage at this site will likely provide greater benefit to brown trout populations in the stream than investing in habitat restoration/enhancement given the area of habitat that will be made more accessible upstream. The problem has been highlighted as 2-fold for fish passage at the structure, with the requirement to leap and then an up to 19-minute swim of a 10 m shallow apron.

Options for improving fish passage generally begin with “can the structure be removed”. In this case, the answer is no as it is providing a vital role in stabilising the footings of a road bridge and as such other options must be appraised. In order to address the problem of the weir part of the structure, the head difference needs to be overcome which can be achieved by a range of means. The most suitable here may be to install a rock-ramp which joins the bed downstream of the weir pool to the top of the weir crest at a shallow gradient, or one matching the downstream river bed. While this may be constructed as a loose-fill type, it may be more prudent to make it an embedded ramp using a concrete slab to stabilise the rocks and ensure it stays in place. This solution has the benefit of being the most aesthetic and highly efficient as it mimics a natural stream bed and creates passage for all species. Concerns may be raised that it would also allow passage of non-native invasive American signal crayfish, but considering they are present both up- and downstream this is not an issue. This solution may also be continued on to the apron, with a grano mix/mortar used to affix boulders to the concrete surface to create a deeper, more natural stream bed with heterogeneous flow and resting/refuge areas for fish, reducing risk to predation and the size selectivity and flow dependence currently affecting passage.

Constructing a rock ramp does require significant resources, especially when going down the embedded route, and as such may be difficult to achieve if resources are limited. However, without significant resources, complete fish passage will not be attainable at this site. There is still the potential to improve passage utilising a low-cost baffle type approach that will address passage concerns at the apron, if not at the weir. Placing wooden or recycled plastic baffles at intervals on the apron, alternating from LHB to RHB, a sinuous and deeper stream channel can be created through this section that will improve passage on the apron. The baffles will very slightly increase flood risk upstream by holding up the water to create a deeper channel, however the increased depth will allow larger fish that can successfully leap the weir to pass across the apron.

5.0 Acknowledgements

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