Evaluating the impact of engineered in-stream structures to upstream fish passage of *Salmo trutta*

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Introduction

Figure 1 - Sea trout (*Salmo trutta* Linnaeus)

Throughout its natural range, brown trout (*Salmo trutta*) and its anadromous form, sea trout, are important ecological components of swiftly-flowing, cool freshwater, but are also of substantial socio-economic importance (Jonsson & Jonsson, 2011). The migratory nature of many fishes, including *S. trutta*, has meant that populations are susceptible to river modification through the construction of structures such as weirs and culverts. The impacts of an in-stream structure on fish passage can be complex; while small structures are often considered to be passable by salmonids, they can still bring about significant delays while they are being negotiated, reducing the condition of spawning fish (Svendsen *et al.*, 2004). This detrimental impact may be increased in situations where there are multiple structures along a migration route.

Although fish passage solutions have a history of many decades, 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). This is especially true of recently developed low-cost baffle fish passes whose performance has not been extensively assessed previously compared to the more traditional pool-weir fish passes. In order to achieve effective restoration solutions that allow free migration and assist lifecycle completion, better quality information is needed as to the biological impacts of obstructions, and the biological effectiveness of engineered fish pass designs.

Aim: This study investigates patterns of upstream migration of brown and sea trout in relation to barrier impacts of engineered in-stream structures using PIT telemetry to quantify the impact of individual structures as well as the efficiency of three fish passes.

Methodology

Study sites

This study was conducted on Swanside Beck and Chipping Brook, tributaries of the River Ribble and River Hodder respectively in the River Ribble catchment, North-West England between August and December 2013 (Figure 2).

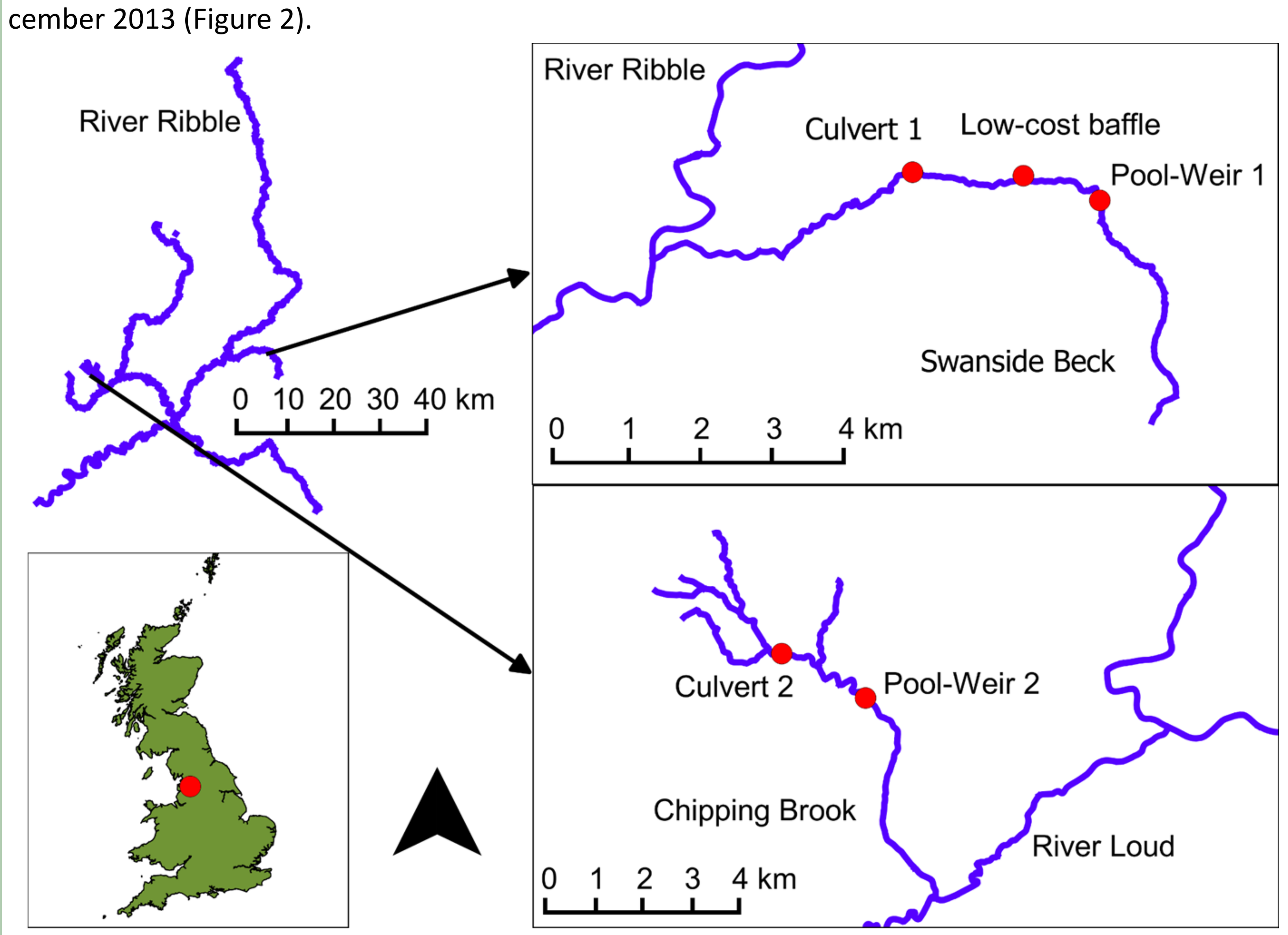

Figure 2 - Map showing location of study sites with River Ribble catchment (top left) and the two study streams, Swanside Beck (top right) and Chipping Brook (bottom right).

Fish passage was evaluated at five structures across the two rivers using Passive Integrated Transponder (PIT) telemetry. Each structure had monitoring equipment installed on it including a loop antennae at both the upstream and downstream extremities (so as to determine attempts, successes and direction of fish passage). Fish were captured using electric fishing upstream and downstream of each structure and had a PIT tag inserted in to the peritoneal cavity under general anaesthesia.

Figure 3 - A half-duplex PIT tag

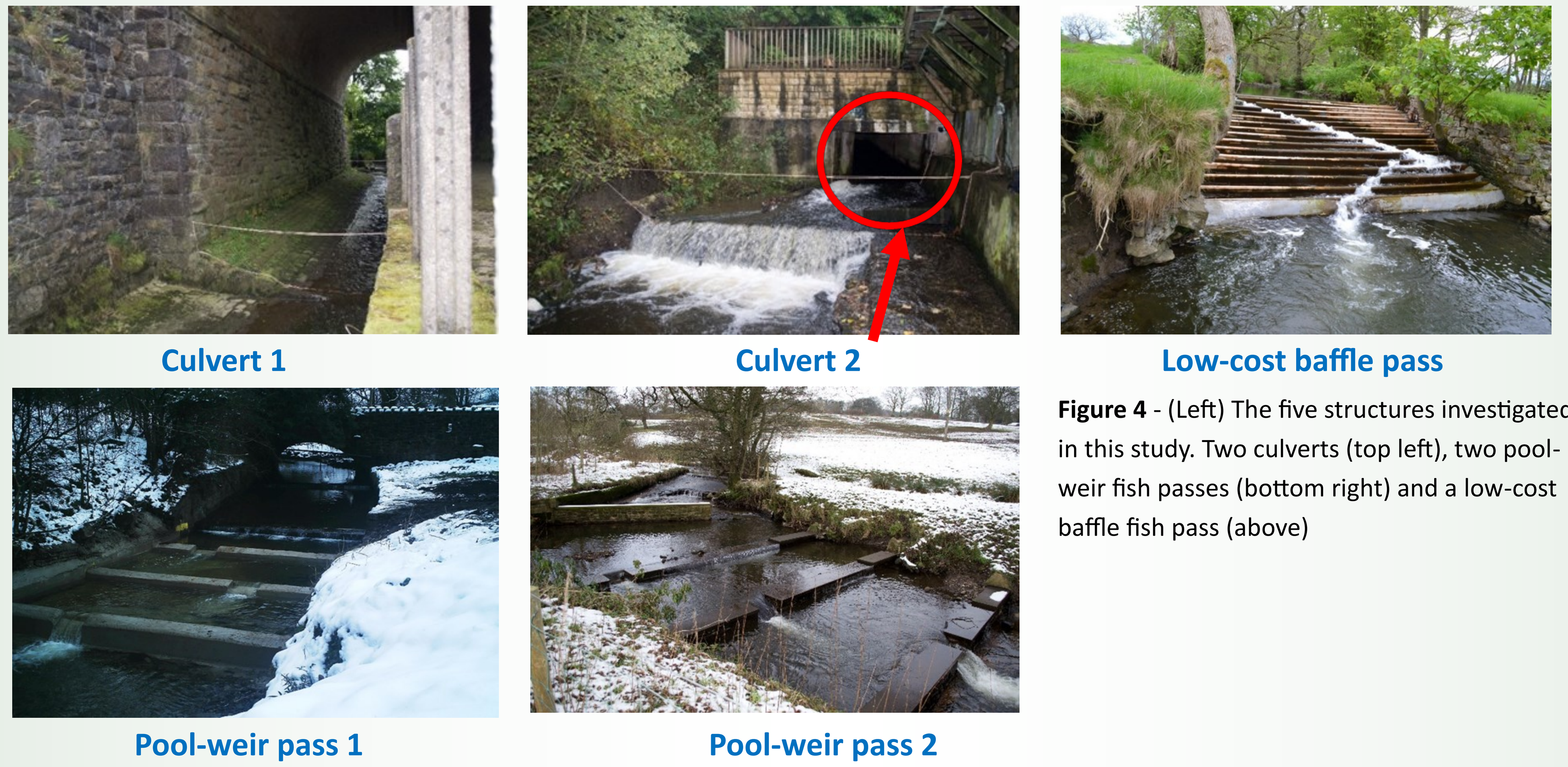

Figure 4 - (Left) The five structures investigated in this study. Two culverts (top left), two pool-weir fish passes (bottom right) and a low-cost baffle fish pass (above)

Results

Passage efficiency, delays and attempts

Culvert 1 (Figure 4) demonstrated a man-made structure which poses negligible impact on fish passage (Table 1, Figure 5) in terms of passage efficiency (100%), delay (mean = 1.19 h) and attempts (mean = 1.05). This porous quality was also identified at Pool-weir 1 (Table 1, Figure 4, Figure 5), which performed the best of the three fish passage structures, where delay was not significantly different from Culvert 1 (Mann-Whitney test; U = 774, P = 0.313). This is in contrast to Pool-weir 2 (Figure 4) which performed the least successfully of the three fish passes with both delays and attempts being not significantly different (U = 164, P = 0.775 & U = 1087, P = 0.397 respectively) from Culvert 2 which appears to severely impact fish passage (Table 1, Figure 4, Figure 5).

The low-cost baffle fish pass performance was comparable to the more efficient Pool-Weir 1 in terms of attempts per individual (U = 6403, P = 0.321; Table 1, Figure 4, Figure 5).

Cumulative passage efficiency

The three structures on Swanside Beck being in series meant we could investigate the cumulative impact they are having upon upstream fish passage. High success (100%) for fish ≥ 250 mm is contrasted with a greater cumulative impact for fish ≤ 250 mm where only 51% remain after passing these three structures over 2.5 Km.

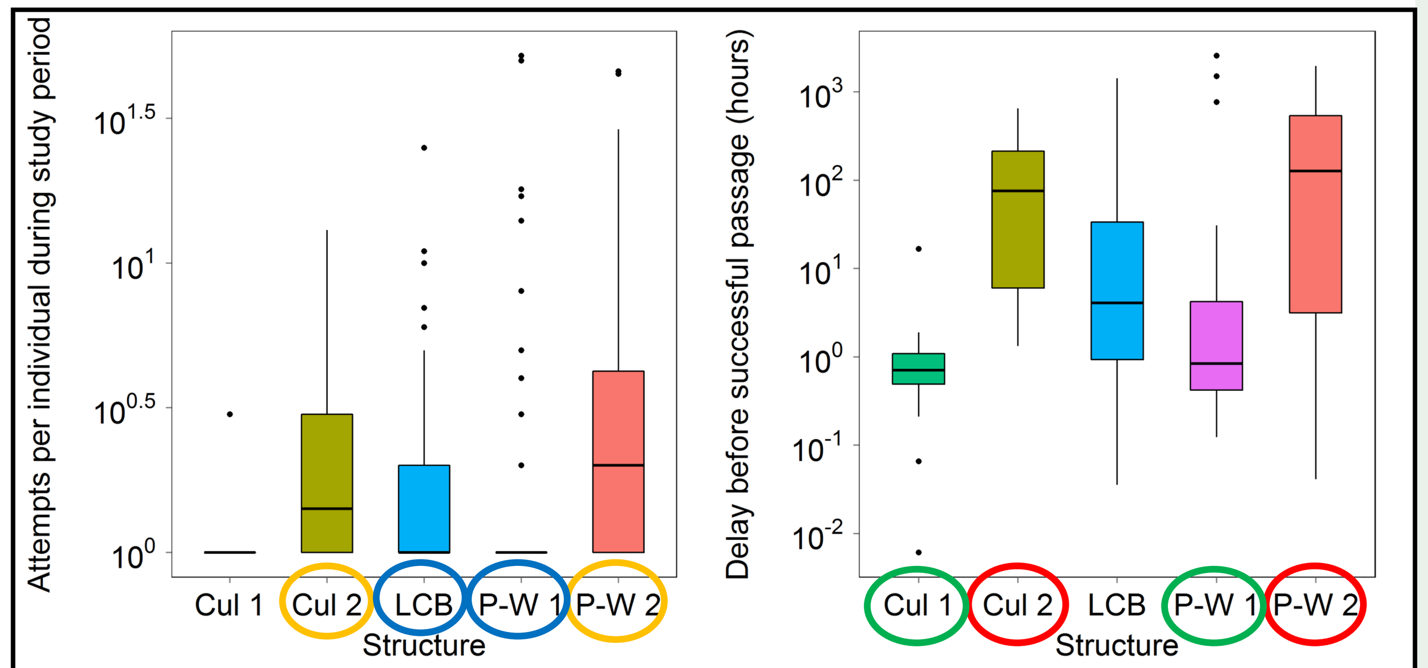

Figure 5 - Attempts per individual (left) and delay before successful passage (right) for *Salmo trutta* for each of the studied structures. ⬭ Indicates structures not significantly different for attempts/delays. P > 0.05, Mann-Whitney U test.

1 Attempt = a detection at downstream antenna ≥ 24 hour of previous detection

Delay = duration between first detection at downstream antenna and first detection at upstream antenna

Table 1 - Number of fish detected attempting each structure and their passage efficiencies

	Culvert 1	Culvert 2	Low-cost baffle	Pool-weir 1	Pool-weir 2
Attempted					
Brown trout	38	59	191	107	196
Sea trout	4	0	4	2	2
Total	42	59	195	109	198
Passage Efficiency	**100%**	**37%**	**68%**	**76%**	**65%**

Length and probability of passage

Logistic regression models identified that while all three fish passes performed well for longer lengths of *Salmo trutta* (> 250 mm, predicted probability of passage ≥ 0.92; Figure 6), there was much more variation for shorter individuals with 0.5 predicted probability of passage being associated with a longer length for Pool-weir 2 (128 mm) than for the low-cost baffle pass (113 mm) or Pool-weir 1 (90 mm), indicating Pool-weir 2 to be more difficult to pass for shorter *Salmo trutta*. No significant models were able to be constructed for Culvert 1 or Culvert 2.

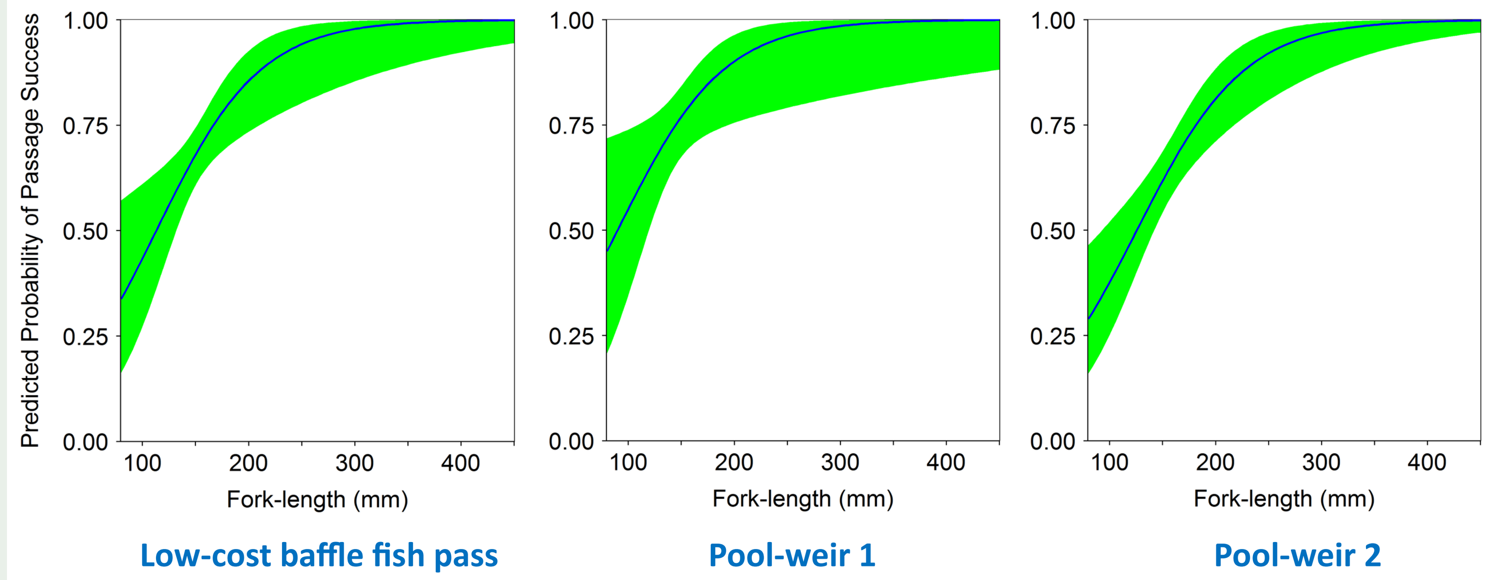

Figure 6 - Logistic regression models for predicted probability of passage of an individual based on ultimate passage success data collected during study. All models significant at P < 0.05.

Discussion and Conclusion

This study is helping to inform conservation efforts by providing valuable empirical measurements of impacts of engineered in-stream structures on upstream fish passage of *Salmo trutta*, including an empirical assessment of the recently developed low-cost baffle fish pass design which has not previously been extensively studied.

- Evidence from this study suggests the low-cost baffle fish pass design can be an effective passage solution where flat-faced weirs must remain in-situ with comparative numbers of attempts required to pass to a more efficient pool-weir fish pass.
- A marked difference in delay and attempts between pool-weir fish passes identifies that small variations in design/construction may have great impacts on condition of fish through greater effort expended in passing the structure.
- A large barrier impact of the 70 m long Culvert 2 (velocity ~3 ms^{-1}) compared to the 20 m long Culvert 1 (velocity ~ 0.7 ms^{-1}) highlighted in differences in passage efficiency, delays and attempts. This further identifies effort which may be required by individuals to pass man-made in-stream structures and the impact this can have upon numbers of fish successfully passing these structures as well as the condition of those which do.
- Cumulative impacts of in-stream structures can lead to reduced numbers of fish reaching upstream spawning grounds, particularly for shorter fish with lower swimming ability. Even ~70% efficiencies of fish passes observed in this study are unlikely to be sufficient for systems with multiple impacting barriers where suitable spawning grounds aren't available until further up the system after passing these structures.

Acknowledgements

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