SHORT COMMUNICATION
https://doi.org/10.1071/MF23207

MARINE & FRESHWATER RESEARCH

Rubber ramp and spat rope did not facilitate upstream passage of a galaxiid through a perched culvert

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Handling Editor:
Max Finlayson

Received: 19 October 2023
Accepted: 6 January 2024
Published: 31 January 2024

Cite this:
Baker CF et al. (2024)
Marine and Freshwater Research **75**, MF23207.
doi:10.1071/MF23207

ABSTRACT

Poorly installed or undersized culverts at road crossings are one of the most frequently encountered barriers to fish movements, especially for small-bodied fish species. Although replacement with more 'fish friendly' culvert designs is the preferred solution, at many sites remediation will be required in the short to medium term. Consequently, there is a need for effective evidence-based fish passage solutions that can be deployed at scale. This study examined the passage efficiency of juvenile īnanga (*Galaxias maculatus*) past a perched culvert fitted with spat ropes and a flexible rubber ramp. Only four fish (0.79%) successfully passed the ramp, and no fish successfully passed the whole culvert by the conclusion of the trial. Deployment of flexible rubber ramps to remediate fish passage at perched culverts has recently become common practice in several regions of New Zealand, despite the absence of any evidence base to support their use. This study provides a strong preliminary indication that flexible rubber ramps are an ineffective fish passage solution for remediating perched culverts for non-climbing fishes. To overcome low head-migration barriers, there are alternative evidence-based fish ramp designs, which practitioners can have considerably greater confidence in for achieving restoration goals.

Keywords: barriers, common galaxias, evidence-based practice, fish migration, fish passage, *Galaxias maculatus*, īnanga, passage efficiency, puyen, remediation, success.

Introduction

Rivers worldwide are fragmented by large numbers of instream structures that impede or prevent movements of aquatic species (Jones *et al.* 2019; Belletti *et al.* 2020; Franklin *et al.* 2022). Restoring river connectivity is recognised as a critical action for the recovery of freshwater biodiversity (Tickner *et al.* 2020; Thieme *et al.* 2023). Evidence-based practice is essential for achieving goals to effectively reconnect waterways and translate action into outcomes (Sutherland 2022). However, globally, efforts to remediate fish passage have often been undertaken with little effort to assess their efficacy and, where monitoring has been carried out, it has often demonstrated that the performance of implemented solutions is low (Roscoe and Hinch 2010; Bunt *et al.* 2012; Noonan *et al.* 2012; Januchowski-Hartley *et al.* 2020; Hershey 2021).

In a recent meta-analysis of fish passage efficiency, Hershey (2021) excluded studies of culverts. However, small structures such as river crossings are one of the most frequently encountered barriers to fish movements, especially for small-bodied species (Januchowski-Hartley *et al.* 2013; Franklin and Gee 2019; Frankiewicz *et al.* 2021). Culverts are one of the most common types of structures used at road crossings, yet they often impede or block movements of fishes and other aquatic organisms due to high water velocities within the culvert barrel and because of vertical drops that develop at the culvert outlet (Franklin and Bartels 2012). Owing to their prevalence in the landscape, the cumulative effect of road crossings on riverscape connectivity can be ecologically significant (Januchowski-Hartley *et al.* 2013). Consequently, if fish movements are to be restored there is a need for low cost but effective fish passage solutions that can be deployed at scale.

Complete removal of culverts is often not an option for restoring fish passage due to the presence of essential infrastructure (e.g. roads) that must be retained. Although replacement with a bridge is the ideal solution, more often 'fish friendly' culvert designs, for example 'stream simulation' culverts (Cenderelli *et al.* 2011), are the preferred solution. However, at many sites in the short to medium term culvert replacement will be logistically and cost prohibitive. In response, efforts have increased to find interim solutions for remediating culverts to improve the passage of fish (Franklin *et al.* 2018).

The installation of culvert baffles is one method to overcome the challenge of water velocities in the culvert barrel that exceed the swimming capabilities of fishes. A wide range of baffle designs have been proposed including weir baffles, offset baffles, vertical baffles, corner baffles and spoiler baffles (e.g. Rajaratnam *et al.* 1988, 1991; Rajaratnam and Katopodis 1990; Sailema *et al.* 2020). Much of the published literature has focused on characterising the hydraulics of different baffle types (e.g. Ead *et al.* 2002; Feurich *et al.* 2011; Duguay and Lacey 2015; Zhang and Chanson 2018; Magaju *et al.* 2021). However, there are an increasing number of laboratory and field studies evaluating fish behaviour and passage efficiency associated with different baffle types and configurations (e.g. Macdonald and Davies 2007; Franklin and Bartels 2012; Amtstaetter *et al.* 2017; Enders *et al.* 2017; Goerig *et al.* 2017). Evidence from these studies demonstrates that the effectiveness of different baffles for enhancing fish passage cannot be determined based on hydraulic assessment alone, as the solutions that typically generate the lowest average water velocities often also create hydrodynamic conditions (e.g. large recirculating zones) not conducive to unimpeded upstream movement of fish.

Vertical drops below culverts often develop because of scouring and erosion at the outlet. Although some species (e.g. salmonids) are competent jumpers and can sometimes make their way past (albeit at lower success rates; Frankiewicz *et al.* 2021), for some small-bodied fishes (<60 mm) it has been demonstrated that vertical drops as little as 0.1 m can effectively prevent upstream passage (Baker 2003). Efforts to overcome these drops, where structure replacement is not an option, have focused on reducing the head drop by raising the downstream water level using rock ramp fishways (Franklin and Bartels 2012; Muraoka *et al.* 2017) or creating artificial ramps that connect to the culvert outlet (Baker 2014; Jellyman *et al.* 2017; Watz *et al.* 2019; Franklin *et al.* 2021).

One novel, low-cost solution that has been proposed for facilitating passage past smaller culverts where typical baffle designs may impair culvert capacity, is the deployment of mussel spat ropes (David and Hamer 2012; Tonkin *et al.* 2012; David *et al.* 2014*a*). David *et al.* (2014*a*) demonstrated experimentally that small-diameter culverts installed with lines of mussel spat ropes significantly increased the passage success of several small-bodied fishes and a freshwater shrimp compared to a control without ropes. It has also been shown that climbing fishes such as elvers (*Anguilla* spp.) and some species of climbing galaxiids (banded kokopu, *Galaxias fasciatus*) can use the ropes to overcome vertical drops at culvert outlets (David and Hamer 2012). Testing of mussel spat ropes in the laboratory and field indicate that fish species unable to climb with their bodies out of water (e.g. īnanga, smelt, *Retropinna retropinna*, and many bully species) will not be able to use ropes to surpass culverts perched in excess of 0.2 m (David *et al.* 2014*b*).

Owing to the prevalence of small culverts and low cost of deployment, spat ropes have been seen as an 'easy fix' for remediating fish passage in New Zealand (see Olley *et al.* 2022). Recently, a practice has emerged in New Zealand that includes the placement of a flexible rubber ramp in combination with spat ropes to improve fish passage at perched culverts (i.e. those with a vertical drop at the outlet). It has been claimed that the ramps placed behind the spat ropes enable non-climbing fish passage alongside those capable of climbing (Olley *et al.* 2022), yet no assessments of passage efficiency have shown īnanga or other non-climbing fish could effectively pass the rubber ramp and spat rope remediation at perched culverts.

In this study, post-remediation passage efficiency was evaluated at a culvert fitted with spat ropes and a flexible rubber ramp using mark–recapture methods. The trials were completed using the juvenile upstream migrant life stage of īnanga (*Galaxias maculatus*), a small-bodied amphidromous species distributed widely in the temperate Southern Hemisphere (McDowall 1990). *G. maculatus* are a non-climbing species and have commonly been used as a benchmark species for evaluating passage success (Baker 2003; Baker and Boubée 2006; Doehring *et al.* 2011, 2012).

Materials and methods

Site description

A culvert situated on an unnamed tributary stream of Oldham Creek, Nelson, New Zealand (−41.237889°S, 173.325191°E) had previously been remediated by Nelson City Council to facilitate the movement of fish, in particular weak swimming fish such as *G. maculatus*. The culvert is situated ~0.9 km inland from the coast and at an elevation of <20 m above sea level. The 0.9-m-wide, 7.5-m-long perched pipe culvert (drop height at the culvert outlet was ~180 mm) was retrofitted with a 440-mm-wide rubber ramp and two strands of mussel spat rope ('Super Xmas Tree'; Donaghys Industries, New Zealand) that ran along the length of the culvert and over the ramp (Fig. 1). The spat ropes were attached at the upstream end of the culvert inlet but were not attached at the downstream end and floated freely upon reaching the water surface downstream of the culvert outlet (Fig. 1). The rubber ramp was also not attached to the stream substrate so may have changed gradient with different stream discharges, but at the time of testing it was >45°. The flexible rubber ramp had a smooth surface with water depths of between 1 and 2 cm in regions outside of the spat ropes.

Fig. 1. Rubber ramp and spat rope installed at the outlet of the perched culvert in an unnamed tributary of Oldham Creek, Nelson, New Zealand. Barrier net retaining fish within the test arena is visible to the left of the picture.

Velocity measurements

Before releasing marked fish, the average water velocity through the culvert was calculated by recording the time a float (mandarin) took to travel the 7.5-m length of the culvert. As the spat rope was situated within the centre of the channel, the float was released on the outside edges of the spat rope, which would represent higher water velocities than between the ropes. Three replicate measurements were taken resulting in a mean water velocity through the culvert at the time of the trial of 0.55 m s^{-1} (range 0.54–0.57 m s^{-1}). This is approximately double the mean critical swimming speed of *G. maculatus* (0.28 m s^{-1}), but less than the median maximum allowable velocity (0.61 m s^{-1}) for a 7.5-m culvert (R. Crawford, unpubl. data). Spot measurements of water velocity were also taken at the top, middle and bottom of the rubber ramp, both outside and between the spat ropes, using a Marsh McBirney electromagnetic Flo-mate water velocity meter. Water velocities on the rubber ramp averaged 0.89 m s^{-1} (range 0.52–1.34 m s^{-1}) outside of the spat ropes and 0.57 m s^{-1} (range 0.19–0.82 m s^{-1}) between the spat ropes.

Mark–recapture methods

Sea run juvenile īnanga (commonly referred to as whitebait) were captured by fishers in the Richmond area of Nelson on 10 and 11 September 2018 and used in trials carried out between 11 and 14 September 2018. Īnanga were marked by immersion in a solution of either Rhodamine B (0.2 g L^{-1}; Sigma–Aldrich) (n = 190) or Bismarck Brown (0.05 g L^{-1}; Sigma–Aldrich) (n = 245). To increase survival and stain retention, aquarium salts were added to the solutions to produce a salinity of ~15 PSU (Franklin *et al.* 2024). During staining, the solution was aerated and ice was added as necessary to maintain the solutions at the same temperature as the creek. After 2 h, the fish were removed from the stain using a dip net and held in live bins within the unnamed tributary stream of Oldham Creek for 24 h before release. A batch of unmarked īnanga (n = 266) were retained in a separate live bin as a third replicate and to control for the effect of the marking procedure. Live bins are 56-L fish bins with 2-mm mesh installed on all four sides to retain fish but enable water flow through the bin. Polystyrene placed within conduit pipes was added along each top edge of the bin to ensure adequate floatation.

To retain fish at the site and prevent wild fish moving into the test area, two barricades were set 1 m apart at the downstream end of the pool immediately below the perched culvert. These consisted of 2-mm mesh nets weighted at the base and buried into the substrate and attached to metal Y poles that were dug into each stream bank (Fig. 1). To capture fish successfully passing the culvert, an aluminium A-frame whitebait trap was installed at the culvert inlet (Fig. 2). Rocks and 2-mm mesh nets were used to secure the base and edges of the trap at the inlet. The trap was weighted down to prevent movement with any change in flow (Fig. 2).

There was no significant difference in the size and weight of īnanga used between the three replicates (Table 1). All three sets of fish (pink, orange and clear) were released at 07:30 hours on 12 September 2018 and given 48 h to pass the culvert. The trap was also checked after 24 h on the morning of 13 September. At the conclusion of the trial, the culvert was checked for fish that had passed the rubber ramp but failed to pass the culvert barrel. As the culvert was too small for physical entry, the first 1.5 m of the culvert at the inlet and outlet (3-m total) was visually checked for fish and then the spat ropes were lifted and shaken several times to wash fish down and out of the culvert with one person standing at the outlet with a net to capture fish. Fish that

Fig. 2. Whitebait trap installed at the culvert inlet to capture fish successfully passing the structure.

Table 1. Summary of *G. maculatus* numbers and sizes used in the mark–recapture study.

Fish colour	*n*	Mean total length (mm)	Total length range (mm)	Mean weight (g)	Weight range (g)
Pink	138	50.8	44–55	0.38	0.23–0.45
Orange	175	50.4	42–53	0.38	0.26–0.46
Clear	193	50.3	48–55	0.37	0.30–0.46

Note that lengths and weights were only measured for a subset of individuals (pink, $n = 18$; brown, $n = 22$; clear, $n = 15$).

remained in the pool below the culvert outlet were captured using a Kainga EFM300 electric fishing machine (NIWA, Christchurch, New Zealand).

Results

After 48 h, all fish were successfully recovered from either the test arena between the culvert outlet and the downstream barrier net (Fig. 1), or within the culvert barrel. No fish had successfully passed the culvert and only four fish (0.79%) had successfully passed the ramp and were located within the culvert at the conclusion of the trial (Fig. 3). Insufficient fish passed the ramp to determine whether there was any statistically significant effect of fish size on success, but the four fish that passed the ramp had a mean length (51.3 mm) and weight (0.39 g) greater than the mean of all fish (Table 1).

Discussion

Removal or effective remediation of barriers to fish migration can achieve rapid gains for aquatic biodiversity (Thieme *et al.* 2023). However, failure to follow evidence-based practice can result in practitioners making decisions that do not achieve desired outcomes and waste scarce resources on ineffective solutions (Cook *et al.* 2013; Cooke *et al.* 2017; Sutherland 2022). Deployment of flexible rubber ramps to remediate fish passage at perched culverts has recently become common

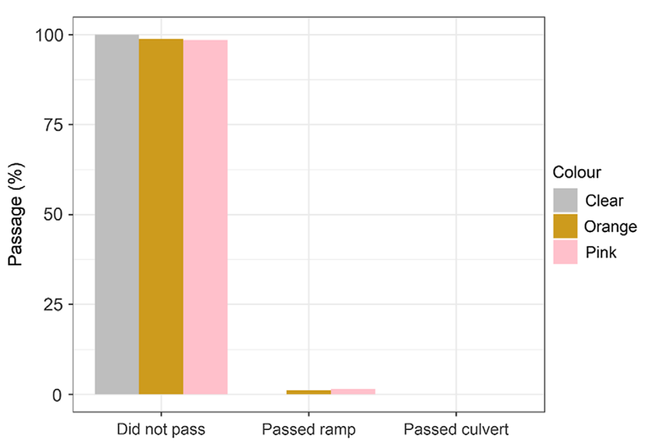

Fig. 3. Percentage of individuals that did not pass, passed the ramp and passed the culvert at the completion of the trial (48 h).

practice in several regions of New Zealand, despite the absence of any evidence base to support their use. Here, we have demonstrated that a typical deployment of a flexible rubber ramp in combination with mussel spat ropes at a small culvert failed to provide effective passage for a widely distributed amphidromous fish species that is common across lowland streams in New Zealand.

At this site, <1% of marked fish successfully passed the rubber ramp over a 48-h trial period. In comparison, Franklin and Bartels (2012) recorded a mean of 27% passage efficiency for *G. maculatus* over a 9-h trial period at a 15-m-long rock ramp, whereas Doehring *et al.* (2011) measured passage efficiencies for *G. maculatus* of 21–66% over 3-m artificial ramps (artificial grass substrate) at a range of gradients (4-h trial period). Likewise, Baker (2014), Baker and Boubée (2006) and Franklin *et al.* (2021) all recorded 3-h passage efficiencies for *G. maculatus* ranging from 20 to >90% over experimental fish ramps up to 3 m long with gradients of 15–30°.

A loss of motivation due to the marking procedure is unlikely to be the cause for low passage success as unmarked control fish (clear) also failed to pass the flexible rubber ramp and culvert. In addition, Franklin *et al.* (2024) demonstrated that both critical swimming speeds and passage efficiency for īnanga through a 73.8-m remediated pipe culvert were similar between control fish and those batch marked in Rhodamine B. In comparison, īnanga marked with visual implant elastomer tags exhibited significantly lower critical swimming speeds and passage efficiency compared to control fish.

Based on our observations at this site and the results of previous studies on fish ramps, we hypothesise that there are several potential factors contributing to the poor passage efficiency measured at this site. Previous studies have consistently shown that fish ramps with smooth surfaces achieve significantly poorer passage efficiency than ramps with roughened surfaces for climbing and non-climbing species (Baker and Boubée 2006; Jellyman *et al.* 2017; Lagarde *et al.* 2021). The flexible rubber ramps have a smooth surface and we observed high water velocities across much of the ramp surface. It has also been demonstrated that increasing ramp slope has a significant negative effect on passage efficiency (Baker and Boubée 2006; Doehring *et al.* 2012; Jellyman *et al.* 2017; Lagarde *et al.* 2021). The slope of a flexible rubber ramp can be highly variable across the length of the ramp and at times can be near vertical. Depending on how the ramp is installed, the slope of the flexible ramp also has the potential to vary over time, likely contributing to inconsistent fish passage. Another recommendation for fish ramp design that has arisen from previous studies is the benefit of a V-shaped cross-sectional profile to the ramp (Baker 2014; Franklin *et al.* 2018; Piper *et al.* 2023). This concentrates the main flow of water, helping to reduce the potential for insufficient water depth to become an impediment to movement, but also creates a lower velocity wetted marginal area that is beneficial for improving the passage efficiency of climbing species. Achieving the recommended V-shaped cross-sectional profile is extremely challenging with a flexible rubber ramp.

We acknowledge that this study represents only a single site under a limited range of hydrological conditions. In addition, the rubber ramp and spat rope were tested as a package rather than individual components. However, installation of this fix at small, perched culverts is always carried out as a package consisting of a flexible rubber ramp in combination with spat ropes. Overall, when compared to equivalent studies using different ramp designs, this study represents a strong indication that flexible rubber ramps are likely an ineffective fish passage solution for remediating perched culverts for non-climbing fishes relative to other ramp designs. Studies to determine the applicability of flexible rubber ramps as a passage solution for other swimming fish species (e.g. common bullies, *Gobiomorphus cotidianus*) with different behaviours and swimming abilities (Baker 2003) are urgently needed. The principles of evidence-based practice would suggest that the deployment of flexible rubber ramps at low-gradient sites, close to the coast where non-climbing species are the target fish for passage should cease until further independent and credible evidence has been collected to evaluate passage performance. Current best available information suggests that there are alternative fish ramp designs that practitioners can have considerably greater confidence in for achieving restoration goals.

Conclusion

Januchowski-Hartley *et al.* (2020) found few studies that evaluate the impact of culverts on ecological outcomes, despite their prevalence across riverscapes. This case study contributes to the growing literature on the efficacy and performance, or lack thereof, of different fish passage solutions at culverts. National freshwater policy in New Zealand dictates that best available information must be used for decision-making in freshwater management (Ministry for the Environment 2020), yet in this case it appears that decisions to install flexible rubber ramps to restore passage for swimming and climbing fishes are based largely upon myth-based inertia (*sensu* Sutherland *et al.* 2004) rather than substantive evidence. There is an urgent need to build the evidence base regarding the performance of different fish passage solutions for culverts so that practitioners can make rational and well-informed decisions about how best to invest limited resources, while still achieving desired environmental outcomes. This must include reporting negative results such as those detailed here so that lessons can be learned from successes and failures.

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Data availability. Data are available on reasonable request from the authors.

Conflicts of interest. The authors declare that they have no conflicts of interest.

Declaration of funding. NIWA was funded by the New Zealand Ministry for Business, Innovation and Employment Envirolink Medium Advice Grant, contract number C01X1806.

Acknowledgements. We thank Tim Olley (Olleycology) for assistance with field trials.

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