Examining whether flexible baffles can create fish passage for whitebait (juvenile *Galaxias* spp.) through a culvert with a steep gradient.

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Abstract

This study examines the effectiveness of flexible baffles as a means of improving fish passage. The aim was to test the ability of whitebait (juvenile *Galaxias spp*.) to swim through a 9.6m long, 1600mm diameter culvert, with a gradient ranging from 9.3% to 4.4% (5.3° to 2.5°), retrofitted with 450mm wide by 100mm high flexible polymer baffles. A stop net was placed at the outlet of the culvert and a fish trap was placed at the inlet and 271 whitebait, identified as likely all inanga (*Galaxias maculatus*), were released into the culvert at the outlet. After a 64 hour period 20% of the whitebait successfully swam through the culvert into the inlet trap, 47% were recovered from within the culvert, 30% failed to enter the culvert or returned back down into the outlet net and 3% could not be found at the end of the trial. This result suggests that flexible baffles fitted to a culvert with a steep gradient can improve fish passage for poor swimming species of fish such as inanga.

Keywords

Connectivity, fish passage, baffles, migration, remediation

Introduction

In New Zealand, there are around 35 species of indigenous freshwater fish, of which 18 are recognized as diadromous and undergo migrations between fresh and saltwater during their life cycle (McDowall 1990). These movements are often hindered or stopped by the presence of structures such as culverts and dams (Silva 2018; Franklin and Gee 2019). Often, these structures can be modified or retrofitted to provide fish passage when complete removal is not an option. Culverts are a common barrier to fish movement. They are found universally throughout New Zealand, often associated with smaller waterways. Culverts are a cheap and simple option to form a stream crossing. When perched or overhanging, a culvert outlet can be fitted with ramps or climbing surfaces to aid fish passage into the culvert (Baker and Boubee 2006; Hicks et al. 2008; Doehring et al. 2011; David et al. 2013). However, high velocities of water flowing through the barrel of a culvert can present a barrier to fish movement, especially when a culvert is steep or when poor swimming species of fish such as inanga (*Galaxias maculatus*) are present (Boubee et al. 1999; Doehring et al. 2011). To address high water velocities through culverts, fish baffles can be fixed to the culvert base to break up linear flow, reduce water velocities, increase water depths and create rest areas for fish (Ead et al. 2002).

There are a number of fish baffle types currently being used in New Zealand, but their relative effectiveness is not well documented. From a hydraulic perspective, weir type baffle systems are the most effective means of reducing water velocities and increasing water depth within culverts (Rajaratnam et al. 1988; Ead et al. 2002; Stevenson et al. 2008; Feurich et al. 2011). While weir type baffle systems offer hydraulic advantages, little is known about how fish respond to the different hydrodynamic conditions created by the baffles. Variations within the weir type baffle system have been tested by Newbold (2014) who found corner and sloped corner baffles improve passage efficiency for European eel (*Anguilla anguilla*) in round culverts. Amtstaetter (2017) saw improved passage for young-of-year *Galaxias* spp. when offset weir baffles were used, however other factors including the installation of a downstream weir likely influenced the results.

Stevenson et al. (2008) undertook field trials using inanga at a culvert situated at Thompson Road drop structure on Cardinia Creek, Melbourne, Australia. Several baffle types were considered and modelled to improve fish passage at the site including spoiler baffles (rectangular), spoiler baffles (wedge), horizontal slot weir, vertical slot weir, and ring baffles. The ring and weir baffle types were found to be more effective at increasing water depth and providing a continuous low velocity zone on the culvert floor. Despite these hydrological advantages, the ring and weir baffles were overlooked as a fish passage solution due to concerns of high water velocities over the baffle crests and lips. Spoiler baffles were therefore placed in the Thompson Road Culvert and trapping at the culvert inlet, and a limited catch and release experiment was made to assess the effectiveness of the modifications. 71 of the 172 inanga released (41%) were captured upstream of the low gradient culvert within four hours.

Feurich et al. (2012) conducted preliminary laboratory trials observing juvenile inanga passage through a series of baffle designs including weir, slotted weir, and spoiler baffles. Based on visual and video recordings, spoiler baffles were chosen for further investigation due to observations of fish quickly progressing upstream through the entire length of open steel pipe with little effort or stress. Like the Stevenson et al (2008) work, weir and slotted weir baffles lost favor because it was theorized that fish were confused by the arrangements and would not pass easily over the weirs. However, relative fish passage efficiency was not evaluated, and no numerical data was presented to support this. The conclusions from Feurich et al. (2012) have been cited in several subsequent fish passage papers (Newbold et al. 2014; Franklin et al. 2018; Volwes et al. 2019; Magaju 2021) as evidence for weir type baffles performing poorly, and driven research towards the spoiler type baffle approach in New Zealand.

Other laboratory and field tests using spoiler baffle arrays in Australia (Macdonald et al. 2007), New Zealand (Franklin et al. 2012) and England (Vowles et al. 2019), examining a limited range of conditions and species, have had mixed outcomes. Results from these tests demonstrated fish passage successes of 80%, 6% and 0%, respectively, and all noted delays in fish movement. To date no studies have examined spoiler baffle fish passage efficiency in steep gradients similar to those often found in culverts i.e., >2%.

Kapitze (2010) evaluated offset baffles and corner "Quad" baffles in round culverts and offset baffles and corner EL baffles in box culverts. Biological monitoring including visual observations and various fish trapping and netting techniques suggested that all baffles were facilitating fish passage however the offset and corner quad baffles effectiveness was not yet as good as could be achieved or would be desired. Several other baffle types have been modelled in box culverts to better understand the hydrodynamic conditions being created (Chanson et al 2016, Sailema 2020).

Flexible baffles have been proposed as a cost-effective solution to facilitate fish passage through a range of different culvert types, sizes, and gradients without unduly affecting culvert capacity. A study undertaken by Olley (2018) showed improved fish passage through a long, steep, urban culvert following the installation of flexible baffles (Department of Conservation Te Papa Atawhai 2018). When added to the barrel of a culvert, flexible baffles appear to create complex flow dynamics, breaking up fast linear shallow flow into areas of slack, cascading, deep or reversed flow, more in keeping with the dynamics of a natural stream. It is assumed that by breaking up the linear flow in such a way, flexible baffles create fish passage by providing resting areas for fish to move between as they swim upstream through a culvert. From a hydraulic perspective flexible baffles perform like traditional weir type baffles by reducing water velocities and increasing water depth. However, unlike traditional designs, flexible baffles offer pathways for fish around individual baffles as they are cut on a forty-five-degree angle at each end (Figure 1). Flexible baffles are also designed to flex during high flows, thus potentially reducing the amount of capacity a culvert loses during periods of high flow. The flexibility of the baffles may also help debris pass through culverts reducing the chance of blockages. This may prove advantageous when compared to rigid baffle types (e.g., spoiler baffles), where, due to their shape and resistance to flow, the likelihood of debris build-up and clogging may lead to increased maintenance costs (Baker and Votapka 1990; Stevenson et al. 2008: Watson et al. 2018; Magaju 2021).

This study examines the effectiveness of flexible baffles as a fish passage solution by testing the ability of whitebait (juvenile Galaxias spp.) to swim through a steep culvert retrofitted with flexible baffles.

Site description

Todd Valley Stream is a low order coastal stream North East of Nelson, New Zealand. There are a number of man-made barriers within the catchment including a road culvert approximately 1.2km from the coast.

The culvert is 9.6m in length, has a diameter of 1600mm, and a gradient that ranges from 9.3% (5.3°) at the downstream end to 4.4% (2.5°) at the upstream end (Figure 3). As part of a region wide program to fix fish passage barriers, Nelson City Council commissioned work to fit the culvert with flexible baffles based on the assumption that due to its physical properties, it was likely a barrier to some species of fish.

Seventeen 450mm wide baffles were used throughout the culvert (Figure 1) spaced at 0.5m intervals to create a series of pools (Figure 1; Photo 1). This work was completed in May 2018.

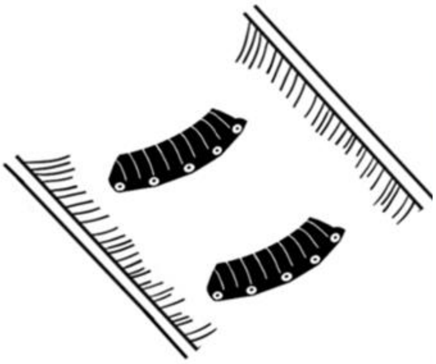 

Figure 1: Flexible baffles placed on the invert of a curved culvert (left), 450mm wide flexible baffles within the 9.3% grade section of the Todd Valley Stream Culvert (right).

Methodology

The culvert was first fished with hand nets and an electric fishing machine to ensure no fish were present within the barrel, inlet or outlet of the culvert. During this process no fish were found. A net was then secured at the culvert outlet sealed so as to exclude fish movement into or out of the culvert. This net was placed to also create a resting area of low velocity immediately below the culvert outlet (Figure 2, Figure 3). At the inlet of the culvert a fish trap was placed to capture any fish leaving the culvert (Figure 2, Figure 3).

 

Figure 2. The photo on the left shows the outlet net. The photo on the right shows the inlet trap.

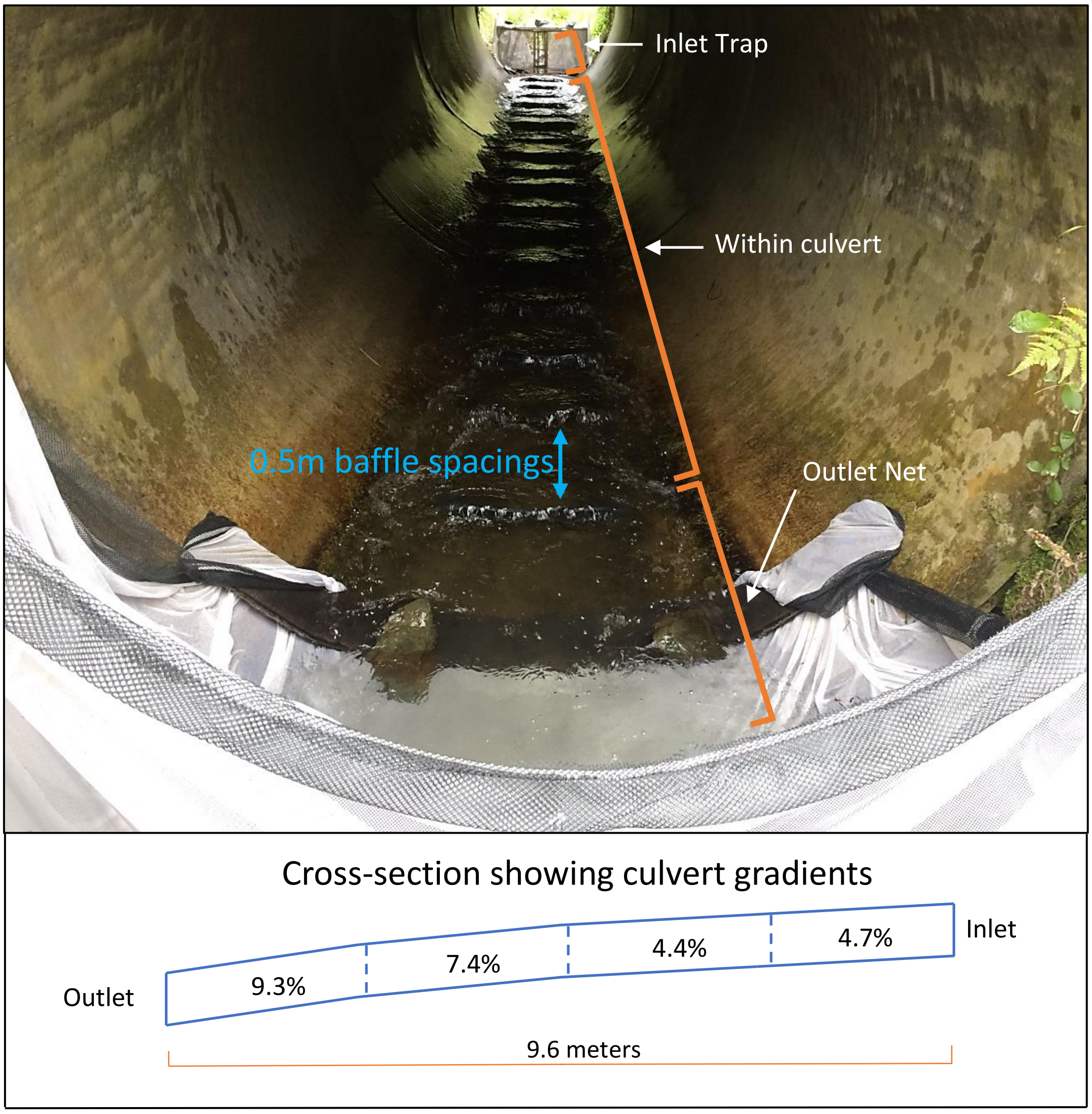

Figure 3. The orange bars show the three portions of culvert (outlet net, within culvert, top trap) used to assess how far inanga travelled through the culvert. The blue arrow indicates the distance in meters between baffles. The below cross-section shows how the sections of culvert, each measuring 2.4m in length, change in gradient from outlet to inlet.

Because at the time of the study very few whitebait were observed moving into Todd Valley Stream, whitebait were collected using scoop nets from several nearby coastal streams. The captured whitebait (n=271) were placed into the low velocity pool created by the net at the outlet of the culvert on 21st of September 2018 and then left undisturbed for 64 hours.

At the conclusion of the treatment period a hand held weighted stop net was placed within the barrel of the culvert upstream of the lowermost baffle. This was done to isolate the outlet net from the culvert. The section of culvert directly downstream of the first baffle was considered part of the outlet net as the net itself slowed the flow within this part of the culvert.

The whitebait within the inlet trap were then removed, followed by those from the outlet net. The fish from within the culvert were then captured by driving them towards the stop net at the outlet of the culvert from the inlet down using hand nets.

Finally, the entire culvert, outlet net and inlet trap were searched with hand nets three more times in order to capture any fish missed. These fish were considered to have most likely come from somewhere within the culvert as all fish found initially within the outlet net and inlet trap could be reliably recovered.

A subset of 20 fish each from within the outlet net, the culvert, and inlet trap were euthanized in 2-phenoxyethonol, weighed, had their lengths measured, and preserved in ethanol for species identification.

Stream flow was recorded downstream of the culvert using a Flow Tracker Acoustic Doppler Velocimeter.

No attempt was made to assess flow or velocity within the culvert due to the complex flow dynamics that the flexible baffles create. Any attempt to measure these variables was likely to only represent a simplified version of the true flow dynamics encountered by the fish.

Results

At the end of the 64 hour period, 80 of the 271 whitebait released were recovered from the outlet net, 27 of which were dead. 61 whitebait were recovered from within the culvert, two of which were dead. 54 whitebait were recovered from the inlet trap, one of which was dead. A further 67 were recovered after repeated sweeps through the culvert, resulting in a total of 128 from within the culvert and 9 un-recovered (Table 1; Figure 4).

All fish from each subset from each capture location were identified as inanga, an unsurprising result given the dominance of this species within the waterways from which they were captured. The subset of fish recovered from the outlet net were on average slightly smaller than those from the inlet trap (ANOVA weight f=8.0569 p=0.0072, length f=7.3362 p=0.0101). There was no significant difference in size between those fish recovered from the outlet net and those from the culvert, or between those fish recovered from the culvert and those from the inlet trap (Table 1).

Table 1: The number of fish recovered from each location within this trial. Mean weight and lengths of a subset of 20 fish from each location is also shown.

	Un recovered	Outlet net	Within culvert	Inlet trap
Living	9	53	126	53
Dead		27	2	1
Total fish numbers	9	80	128	54
Mean weight (g)	NA	0.47	0.52	0.62
Min weight (g)	NA	0.33	0.36	0.38
Max weight (g)	NA	0.68	0.94	1.15
Mean length (mm)	NA	50.95	52.40	53.60
Min length (mm)	NA	47	47	49
Max length (mm)	NA	55	60	64

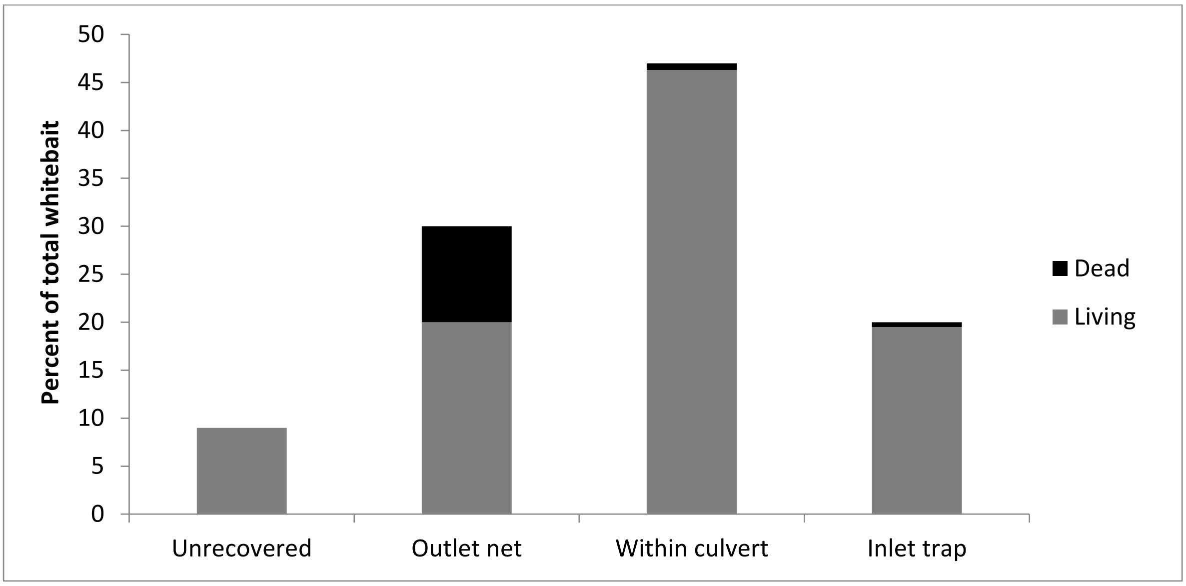

Figure 4: The percentage of whitebait from each location within this trail.

The flow downstream of the culvert was recorded as 6.7L/sec. This flow is considered a good representation of base flow for the particular reach of Todd Valley Stream containing the test culvert.

Discussion

This result suggests that flexible baffles can be fitted to a culvert with a steep gradient to provide fish passage for poor swimming species of fish such as inanga. After 64 hours of this trial, 54 (20%) whitebait (likely all inanga), successfully swam through the culvert into the inlet trap. 47% (128) were recovered from within the culvert. 30% (80) failed to enter the culvert or returned down into the outlet net, and 3% (9) were unrecovered.

14% (30) whitebait died during the trials. Mortality at this level is not unusual for an experiment of this type involving the stress of capture and relocation. It is likely that the 3% unrecovered fish can be accounted for due to the difficulty of recapturing fish from the inside of a culvert with complex flow and refugia created by flexible baffles. It is assumed the unrecovered fish most likely remained within the culvert.

It is possible that given more time, more whitebait would have passed through the culvert. A large portion of whitebait (47%) were recovered from within the culvert. The design of flexible baffles is such that resting areas of low or reversed water velocity is created within a culvert. This may provide the opportunity for a fish to rest and perhaps feed. Under such conditions there may not be a physical requirement or desire for a fish to continue moving upstream. If a fish can comfortably rest behind a baffle for an indeterminate length of time, movement through a culvert fitted with flexible baffles may take longer than might be expected.

Franklin et al. (2018) suggested that test fish that have been transferred into a new waterway display reduced upstream movement, and need a period of time to acclimatize before they begin to move upstream. This study did not acclimatize the whitebait before introducing them into the culvert, rather the low velocity area of the outlet net allowed fish to acclimatize during the treatment period. If a fish requires a period of at least 24 hours (Franklin et al. 2018) to acclimatize to its new water before it becomes motivated to move upstream then this may have effectively reduced the period of treatment in this study to 40 hours.

This study did not have the required design to assess the speed of individual fish movement. Generally, there is little information explaining how New Zealand fish respond to different hydraulic conditions created by baffles (Franklin et al 2018). Flexible baffles appear to create a range of complex flow types within the barrel of a culvert. More investigation into exactly how fish use and respond to the differing hydrological conditions flexible baffles create would be useful.

The slightly larger size of inanga from the subset recovered from the inlet trap suggest that larger fish may find it easier to negotiate a culvert fitted with flexible baffles. Although, the presence of small individuals within this subset also suggests that passage is still possible for small fish, but less of them might make it through, or it may take them longer. In most situations, providing that adequate habitat is available downstream of the fish passage barrier for fish to attain size and or condition, it is unlikely to be detrimental to a catchment population if individual fish must grow a little before being able to ascend a structure such as this.

The culvert tested in this study represents the upper limit of gradient in what is commonly observed in coastal situations; it is generally rare to see a culvert exceeding a gradient of 10%. In most cases fresh run inanga will only ever encounter culverts set at a much lower gradient until they are higher in the catchment. It seems reasonable to expect that the addition of flexible baffles to lower grade culverts (e.g. less than 5%) would likely create fish passage for inanga at an equal or greater success rate than demonstrated in this study.

It is also likely that flexible baffles fitted to steep upper catchment culverts would provide passage for at least a proportion inanga moving upstream given they are likely to be of a larger size. The addition of flexible baffles to culverts up to a 10% grade is also likely to allow passage for other fish species with stronger swimming abilities.

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