Evaluation of Fish Passage Remediation Methods Used in Tasman District's Freshwater Improvement Fund Programme

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Executive Summary

This report details the evaluation of the efficacy of common fish passage remediation methods used in the ongoing Jobs for Nature (J4N) Fish Passage Project—administered by the Tasman District Council. The objective of these studies was to:

1. evaluate the efficacy of the typical package of cost-effective culvert remediation methods used in the Fish Passage Project to date and,

2. determine the range of culverts (fish passage barriers) where these methods are appropriate to install.

Fish passage improvement rates were monitored at three separate trial culvert remediation sites in small coastal streams, using a before-after comparison study design. In addition, a field-realistic experimental culvert was constructed to test the culvert slopes at which the installation of flexible internal baffles improved passage for īnanga.

The experimental culvert results suggest that īnanga are unable to negotiate un-remediated culverts with slopes >4%, flowing at 2.5L/sec. The internal flexible baffles were highly effective for enabling upstream passage for īnanga through the constructed culvert to gradients of up to 6%. At an 8% gradient, the flexible baffle remediation enabled īnanga passage rates of 65%.

The field evaluation trials suggest that the addition of flexible ramps to perched culverts with outlet fall heights of up to 0.7m, enhanced passage rates for common climbing fish species, such as longfin eels, banded kōkopu and kōaro. Across the three trials, passage rates for banded kōkopu improved from between 11% to the near complete restoration of passage, with the degree of passage enhancement depending on the initial site-specific features of the barrier structure.

These results suggest flexible rubber ramps installed to remediated perched culverts with outlet fall heights of >0.26m (at a flow rate of between 4.2-12.8L/sec) are not likely to ensure īnanga passage (which are not a climbing species). However, in one instance the flexible ramp was partially effective at a culvert 0.4m high for īnanga late in the upstream migration season, when they are presumably stronger swimmers. At one culvert a flexible ramp was compared with the plastic floating (textured) ramp method, neither of these methods enabled īnanga passage at this site.

The combined results of the field evaluation and experimental culvert trials give confidence that the remediation methods used in the Tasman District Council Fish Passage Restoration Project are effective at substantially improving native fish passage for a range of climbing fish species. At sites where restoration of īnanga passage is considered a high priority, additional (more substantial) fish passage remediation actions related to the outlet of perched culverts are likely to be required. However, this will come at significant additional cost, so careful prioritisation of īnanga remediation sites is needed. In the interim, installing the flexible rubber ramps and internal culvert flexible baffles is a practical cost-effective method for enhancing passage for a range of highly valued native fish species.

Introduction

Evaluation of the success of fish migration past in-stream structures was carried out as part of a Fish Passage Restoration Project managed by Tasman District Council. This five-year project began in July 2021 and was funded by Ministry for the Environment under the Jobs for Nature (J4N) initiative.

The aim of the project is to assess the characteristics of at least 4300 in-stream structures in the Nelson / Tasman region and restore fish passage at one third of these. This report documents four studies, undertaken during spring 2023, that evaluate the performance of the most common fish passage remediation methods used in the J4N project to date. Some of these remediation methods are currently not referred to in the NZ Fish Passage Guidelines (Franklin et al 2018), as it was considered at the time that there was insufficient evidence to support the use of these methods (Franklin, pers.com.).

There are two main objectives for the fish passage evaluation studies:

1. Evaluate the efficacy of the typical package of cost-effective fish passage remediation methods used in culverts as part of the J4N Fish Passage project. Typical remediation methods include flexible baffles, flexible rubber ramps with mussel-rope, and floating ramps.

2. Determine the range of fish passage barriers (e.g., as determined by culvert slope and degree of perching) where flexible baffles and flexible ramps are appropriate fish passage remediation methods.

The field evaluation studies described in this report compare fish capture rates (past culverts) over multiple days both before and after remediation in three small coastal streams:

- Williams Creek, Tasman
- Mulligans Creek, Onekaka
- Shambhala Creek, Onekaka

This was achieved by comparing the number of fish making it passed the culverts relative to those moving passed a fixed location downstream of the culverts before and after remediation.

At the Williams Creek site, fish capture rates were assessed on two separate occasions to determine passage remediation efficacy during different periods of the migration season. The evaluations, completed in 2023, complement earlier remediation efficacy trials undertaken at Williams Creek during 2021 (Olley & Olley, TDC Client Report 20220629).

In addition to the field remediation evaluations, an experimental culvert was constructed to test whether flexible fish baffles enabled passage for īnanga through a culvert set at different slopes. The slopes tested were representative of culvert slopes commonly observed in the field in Tasman and other regions.

Sunset Valley Experimental Culvert Trials

Objective

To determine the range of culvert slopes where flexible baffles can enable migratory fish passage.

Method

An 849mm internal diameter, six-meter-long culvert was suspended within an adjustable frame connected to two open topped 500L bins at either end (Figure 1). The outlet end of the culvert was able to be raised or lowered to determine the gradient within the barrel. Nets were sealed to the base of the culvert and the edges of each bin at either end of the culvert. The outlet net was fixed in place while the inlet net could be removed.

A hide was built around the inlet bin so that two people could work around it without unduly disturbing any fish within the inlet net (Figure 1).

Figure 1. Sunset Valley trial setup.

Water was pumped from a farm dam, located next to the experimental set up. Water entered the upstream end of the culvert at a constant rate of 2.5L/sec via a lay flat pipe through a hole cut into the bottom of the inlet bin. It then flowed through the culvert into the outlet bin and then out of a drainpipe cut into the top of the outlet bin, back down into the dam. Thus, while the trial was running, both bins were full of water submerging their respective nets. New water was continuously pumped through the experimental culvert for the duration of a trial. These trials were run throughout the month of November 2023.

Four culvert gradients were examined with the outlet bin backwatering the culvert by approximately 75cm, 2%, 4%, 6% and 8%. For each gradient, the trial was repeated without baffles and with baffles up to the point where no fish passed through the un-baffled treatment. This meant un-baffled and baffled treatments were run for the 2% and 4% gradients, while only baffled treatments were run for the 6% and 8% gradients.

The number and arrangement of the baffles was determined by the gradient (Table 1) matching the method used when remediating actual fish passage barriers in Tasman region, as referenced in the Fish Passage Remediation Training Aid 2022 (Olley et al 2022). All baffles used were 450mm long and 100mm high with 50mm slits and 45 degree cuts at both ends (Figure 2).

Table 1. Table shows the number and spacing of baffles used for each of the Sunset Valley trials.

Gradients (%)	Number of baffles	Baffle spacing (mm)
2	5	1250
4	7	833
6	9	625
8	11	500

Figure 2. Example of flexible baffles within the experimental culvert when positioned at a 6% gradient.

For each treatment approximately 50 īnanga were selected randomly from a small coastal stream (average fork length 48mm, range 44mm to 76mm). These fish were captured using large mesh nets and once counted were placed into a 10L bucket for transportation. Care was taken to minimise handling stress during this process.

Fish were released directly from the bucket into the outlet net (within the outlet bin). The trip from the source stream to the trial set up site was less than 15 minutes, so that the time between capture and release into the set up was around 30 minutes.

The treatment period began as soon as the fish were released. Every 30 minutes all fish within the inlet net were removed by lifting the net and scooping the fish out. This process took about 30 seconds, during which time on the unlikely chance that a fish would transition out of the culvert, it would end up in the inlet bin and so could be noted and captured at the termination of the treatment period.

Each treatment period ran for four hours. At the end of the treatment period all fish were removed from the outlet net and from the section of culvert that was backwatered in the un-baffled treatments or from the outlet net as far into the culvert as the first baffle in the baffled treatments. The pump was then turned off, and any fish within the culvert were removed. All fish were measured on removal from the trial.

Thus, at the completion of each treatment, fish were assigned to one of three locations: The inlet net, within the culvert or the outlet net.

Results

The tables and figures below show the proportion of fish making it upstream from the outlet net, into the culvert and through to the top net for various culvert gradients and for baffled and unbaffled treatments. The figures also show the time frames for achieving this movement.

Table 2: Proportion of fish, expressed as a percent of the total number of fish introduced to a net at the outlet of the experimental culvert, that either successfully passed through (top net), were recovered from the culvert barrel (within culvert), or failed to enter the culvert after a four hour time period (outlet net). The culvert was set at four different gradients, 2%, 4%, 6% and 8% and either had no flexible baffles fitted or had flexible baffles fitted. No fish were able to swim through the culvert at a 4% gradient without flexible baffles, so no non-flexible baffle treatments were undertaken at 6% or 8% gradients.

Trials		Portion of fish (%)		
Gradient	Remediation	Top Net	Within culvert	Outlet net
2%	Un-baffled (Figure 3) Baffled (Figure 4)	29.6 98.1	0 0	70.4 1.9
4%	Un-baffled (Figure 5) Baffled (Figure 6)	0 81.8	0 9.1	100 9.1
6%	Baffled (Figure 7)	84.8	15.2	0
8%	Baffled (Figure 8)	64.9	22.8	12.3

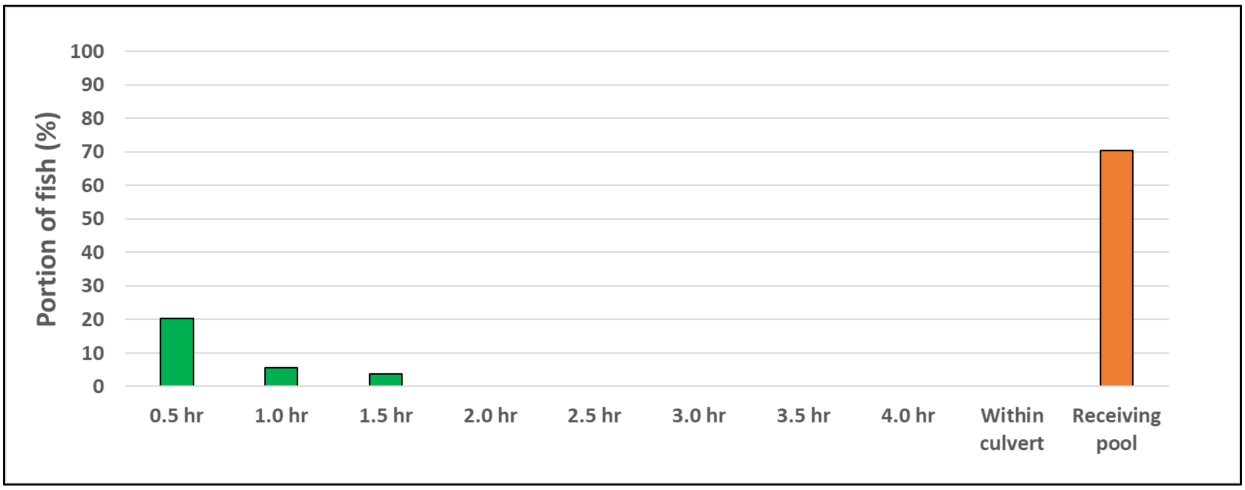

Figure 3. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at a 2% gradient **without any baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from within the culvert (blue bar), and the outlet net/ receiving pool (orange bar) after a four hour time period.

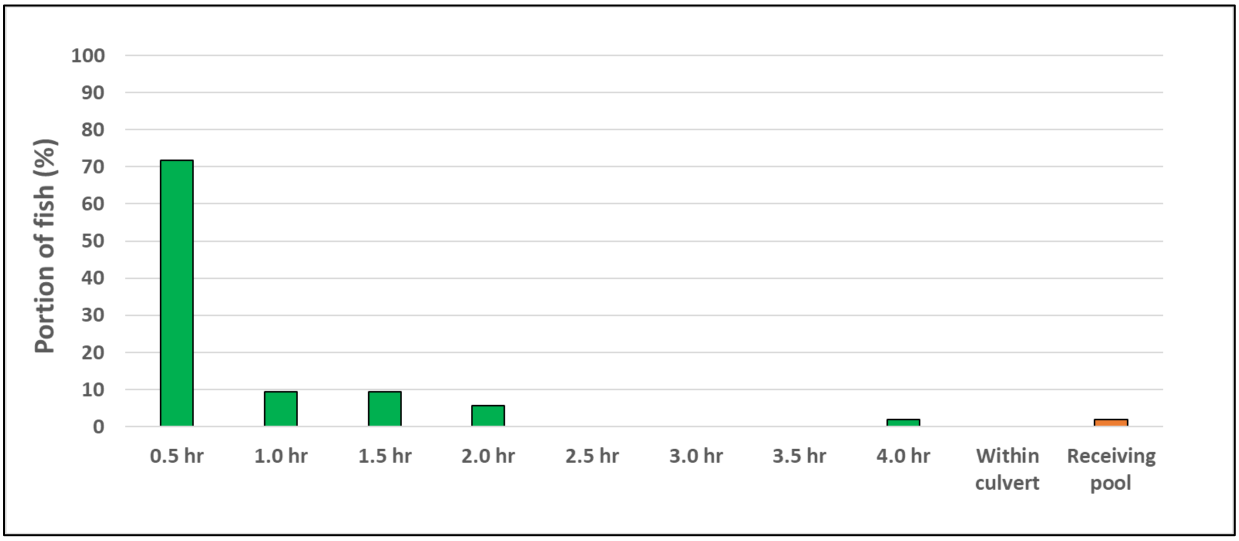

Figure 4. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at a 2% gradient **with flexible baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from within the culvert (blue bar), and the outlet net/receiving pool (orange bar) after a four-hour time period.

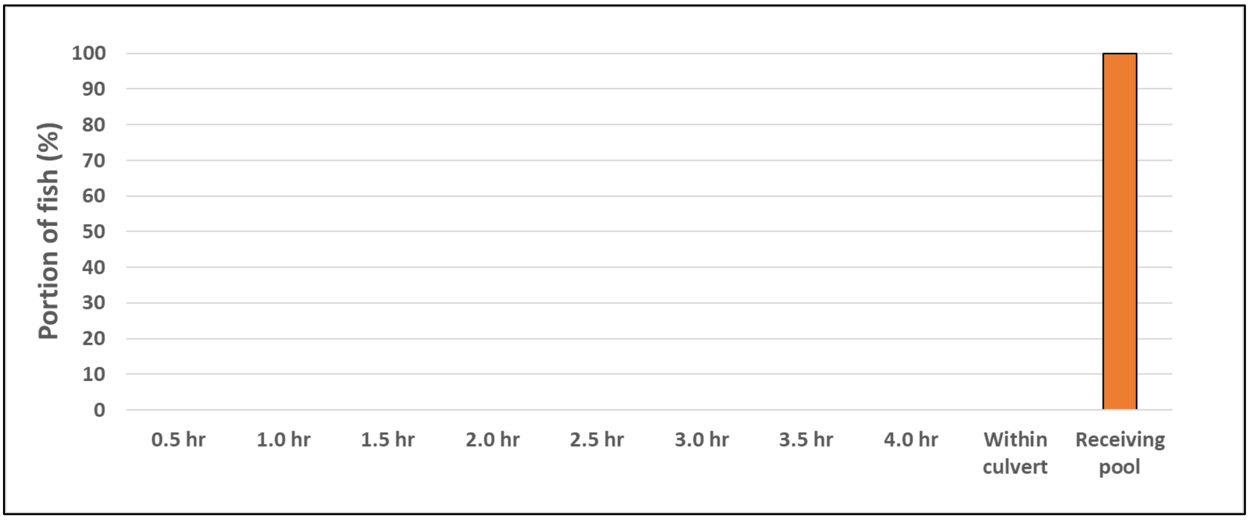

Figure 5. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at a 4% gradient **without any flexible baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from the outlet net/ receiving pool (orange bar) after a four hour time period.

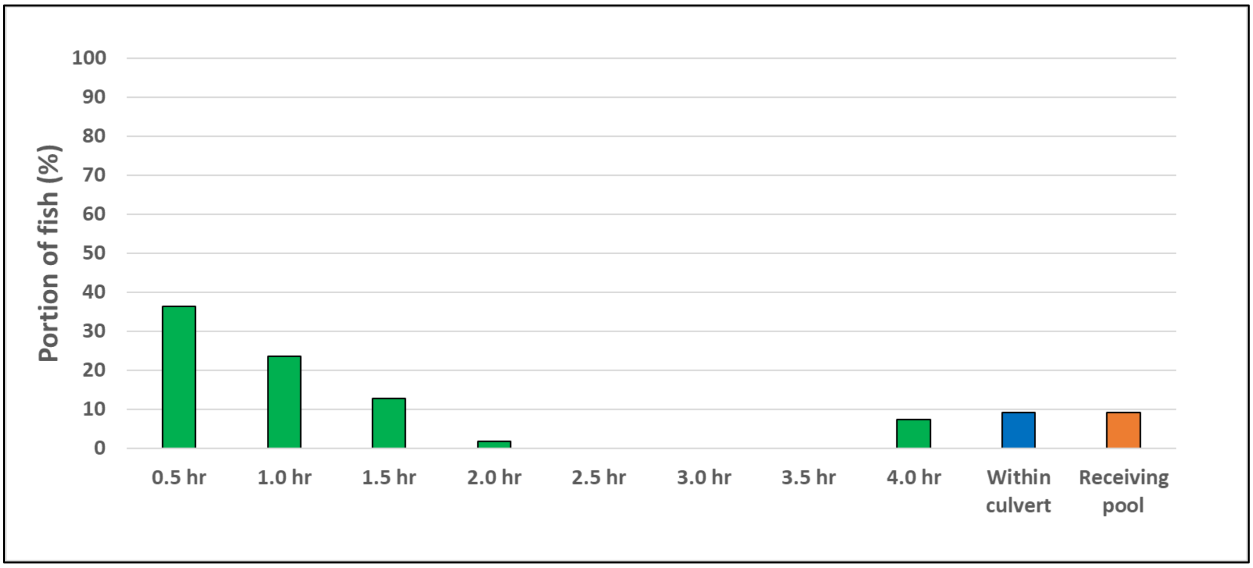

Figure 6. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at a 4% gradient **with flexible baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from within the culvert (blue bar), and the outlet net (orange bar) after a four hour time period.

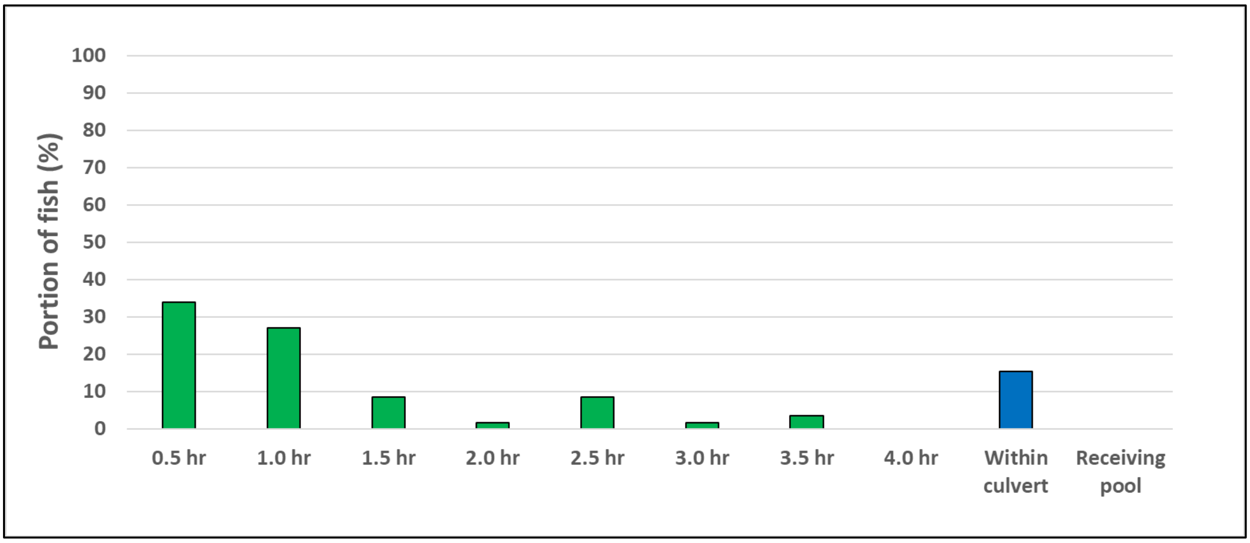

Figure 7. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at a 6% gradient **with flexible baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from within the culvert (blue bar), and the outlet net (orange bar) after a four hour time period.

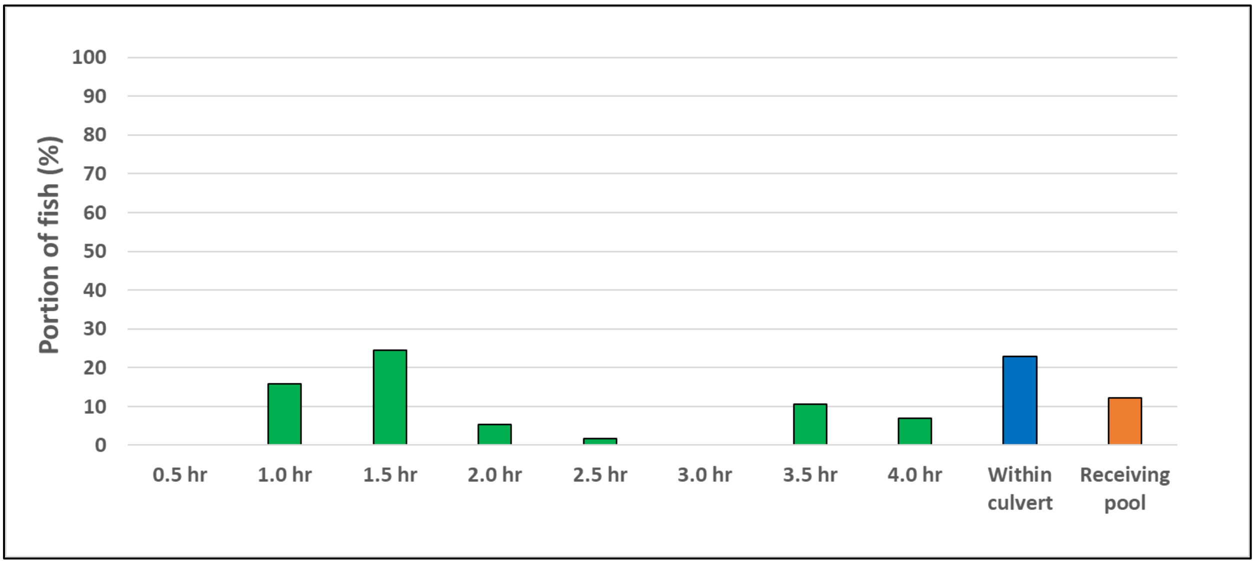

Figure 8. The percent of the total number of fish introduced to a net at the outlet that made it to the upstream end of the experimental culvert set at an 8% gradient **with flexible baffles fitted**. The percent of fish having moved through the culvert after each half hour time period is shown as green bars. Also shown is the percent of fish recovered from within the culvert (blue bar), and the outlet net (orange bar) after a four hour time period.

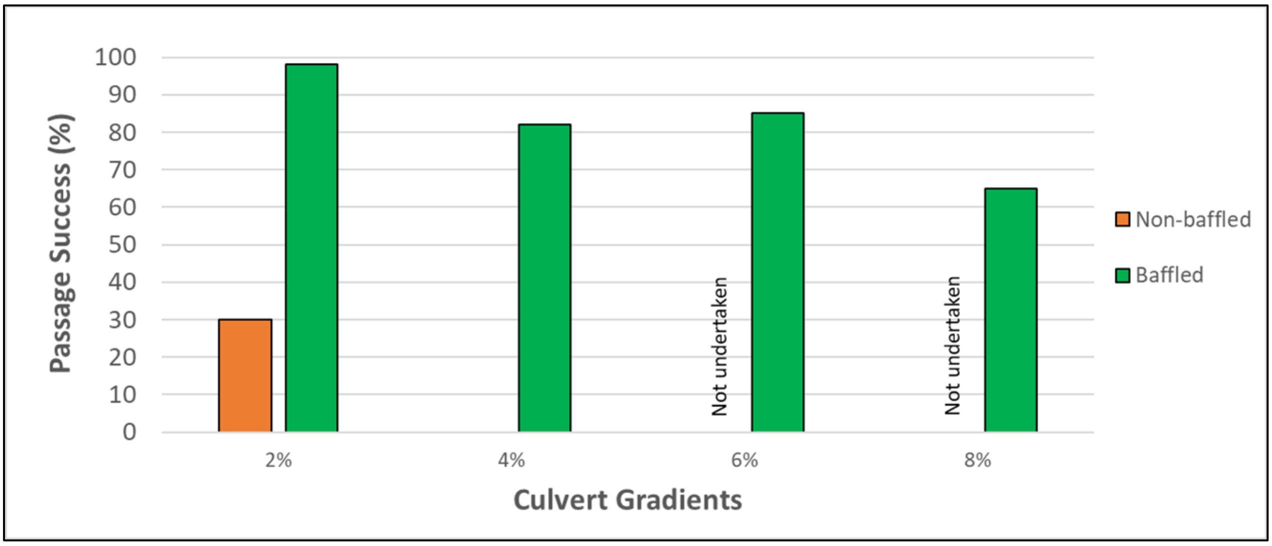

Figure 9. The proportion of fish, expressed as a percent of the total number of fish introduced to a net at the outlet of the experimental culvert, that successfully passed through to the top after a four hour time period. The culvert was set at four different gradients, 2%, 4%, 6% and 8% and either had no flexible baffles fitted (orange bars) or had flexile baffles fitted (green bars). No fish were able to swim through the culvert at a 4% gradient without flexible baffles, so no non-flexible baffle treatments were undertaken at 6% or 8% gradients.

Discussion

The experimental culvert design tested a range of culvert slopes representative of typical situations fish encounter in the field.

Īnanga were not able to negotiate the experimental culvert at slopes at or greater than 4% but the installation of flexible baffles enabled passage for the majority of fish at gradients of up to 8% within just four hours.

Fish passed through the culvert in a shorter time period in the lower gradient treatments (71.7% of fish made it to the top of the baffled culvert set at 2% grade within the first half hour), and passage rates through the culvert set at steeper gradients was slower (33.9% of fish made it to the top of the baffled culvert set at a 6% grade, and no fish made it to the top in the culvert set at 8% grade, within the first half hour). Given a longer trial period however, it seems likely that total passage success would increase at steeper gradients.

These results give confidence that the use of flexible baffles within the internal component of culverts is likely to adequately enable fish passage in most small stream field circumstances where it has been used. Passage success through similar culverts set at an 8% gradient or less when fitted with flexible baffles would likely be at least 65%.

The efficacy of flexible baffles was tested on īnanga. Of the common migratory galaxiid species, īnanga is considered the weakest swimmer and does not utilise climbing locomotion. Therefore, the result from the experimental culvert is a conservative demonstration of passage efficacy following flexible baffle installation regarding other whitebait species.

Williams Creek Field Trial

Two separate remediation evaluations were undertaken at the Williams Creek culvert over the course of the 2023 spring period. The first began in late September with the objective of examining fish capture rates early in the migration season. The second began in mid-November and aimed to examine capture rates later in the migration season when upstream migrating fish are larger and stronger.

Site description

Williams Creek is a small tributary of Tasman Valley Stream which flows into the Moutere Inlet in Tasman Bay. Diadromous fish species with a predicted presence greater than 10% include īnanga, banded kōkopu, giant kōkopu, long and shortfin eels, and common bully (Leathwick 2008). Approximately 20m upstream of its confluence with Tasman Valley Stream, Williams Creek is piped through two parallel concrete culverts where it crosses Aporo Road (Figure 10). This crossing is located about one kilometre inland from the Moutere Inlet and is the first barrier fish encounter when moving upstream from the coast. Both culverts are 1.2m in diameter, 18m long and have gradients of up to 2%.

At the start of the first fish passage remediation evaluation, on the 26th of September 2023, both culverts were undercut by 0.05m, with fall heights of 0.38 m on the true right culvert and 0.4m on the true left. Both culverts had a concrete headwall that extended below the invert into the streambed that was being constantly wetted from the “splash zone”. Under base flow conditions, the average water velocity within the culverts was 0.8m/s (true left pipe) and 0.7m/s (true right pipe). Flow rates were 4.2L/sec and 6.9L/sec through the true left and right pipes, respectively.

Figure 10. Perched culverts at Williams Creek in September 2023 (prior to any remediation for fish passage).

Remediation

Flexible ramps with mussel-rope and flexible baffles

With reference to the Fish Passage Remediation Training Aid 2022 (Olley et al 2022), culvert remediation involved installing a total of seven flexible baffles that were secured within each of the culvert pipes. All fourteen baffles used were 450 mm wide and 100 mm high. Baffles were spaced at 2.4m intervals where culvert gradients were 0-1%, and 1.2m intervals where gradients were between 1-2%. The most downstream baffle was a V-baffle.

A flexible fish ramp, made of reinforced PVC rubber, was installed at the outlet of both pipes (Figure 11). Both ramps were 900mm wide by 1500mm long. The ramp included a central bundle of four strands of looped mussel-rope fixed to the ramp invert.

In total, the remediation took approximately 90 minutes to complete.

Figure 11. The remediation at the Williams Creek culverts, showing two flexible rubber ramps with mussel-rope and V-baffles.

Williams Creek Evaluation 1

Method

Prior to the commencement of Evaluation 1 on the 26th of September 2023, both culvert barrels were searched to ensure that no fish were present within the structure. No fish were found.

A-frame fish traps were installed at the culvert inlets to determine numbers of fish that successfully negotiated the culvert. In addition, a trap was also set downstream of the culvert to provide an indication of the number of fish that were likely to attempt to pass through the culvert during each day of the trial. The downstream trap was set approximately 5m below the culvert outlet, immediately below the culvert plunge pool. The trap was secured to the bed and stream banks. The two upstream traps (one for each culvert barrel) were secured to the culvert walls and base using rubber flanges and wedge anchors so that no fish could pass through either culvert without entering a trap. All of the traps were designed with “non-return” zones to prevent fish from escaping and had fine mesh netting (0.5mm mesh size) attached to their front edges spanning out to funnel fish into the traps.

The fish traps were checked daily (each morning), fish caught in the downstream trap were released immediately upstream into the culvert plunge pool, fish caught in the upstream traps were released upstream of the culvert. All captured fish were identified to species level when possible and individual lengths (fork length) were recorded.

Prior to the study, a water level staff gauge was installed in a stable pool, and water level and water temperature were recorded at the same time each day.

Fish trapping was undertaken for 14 days prior to remediation. At the conclusion of this un-remediated period on the 9th of October 2023, both culvert barrels were searched to recover and record fish that were present within the culvert pipe. Sweeps of the culvert were made with a spotlight and hand nets until no fish could be seen. The fish passage remediation was then installed, and the fish trapping continued for a 14 day remediated period.

At the conclusion of the trial, on the 23rd of October 2023, a final search within both culvert barrels was done to recover and any record fish that were present.

Fish passage success was determined by comparing the numbers of fish caught in the upstream trap before and after the installation of the remediation. Fish caught in the downstream trap were used to indicate the numbers of fish attempting to negotiate the culverts on any given day during the un-remediated and remediated periods.

Results

In total seven species of fish were observed throughout the course of the evaluation period: banded kōkopu, īnanga, longfin eel, shortfin eel, giant kōkopu, kōaro and redfin bully, with banded kōkopu the most common species (Table 3; Figure 12).

Table 3. Total numbers, size range and species composition of fish caught upstream and downstream of the culvert both before and after remediation by the end of the study period (N/A = Not applicable).

Species	Number of fish in downstream trap	Fish fork length range (mm)	Number of fish in upstream traps	Fish fork length range (mm)	Number of fish in culverts at end of trial	Fish fork length range (mm)
Un-remediated						
Banded kōkopu	108	39-81	74	39-45	2	42-43
Īnanga	21	49-55	0	N/A	0	N/A
Shortfin eel	0	N/A	0	N/A	0	N/A
Giant kōkopu	0	N/A	0	N/A	0	N/A
Kōaro	1	53	0	N/A	2	47-52
Redfin bully	0	N/A	0	N/A	0	N/A
Remediated						
Banded kōkopu	72	39-150	58	39-150	29	39-96
Īnanga	8	46-53	0	N/A	0	N/A
Longfin eel	0	N/A	0	N/A	1	160
Shortfin eel	2	64-65	0	N/A	7	60-115
Giant kōkopu	1	46	1	46	0	N/A
Kōaro	4	43-54	2	42-49	1	54
Redfin bully	2	41-67	1	45	0	N/A

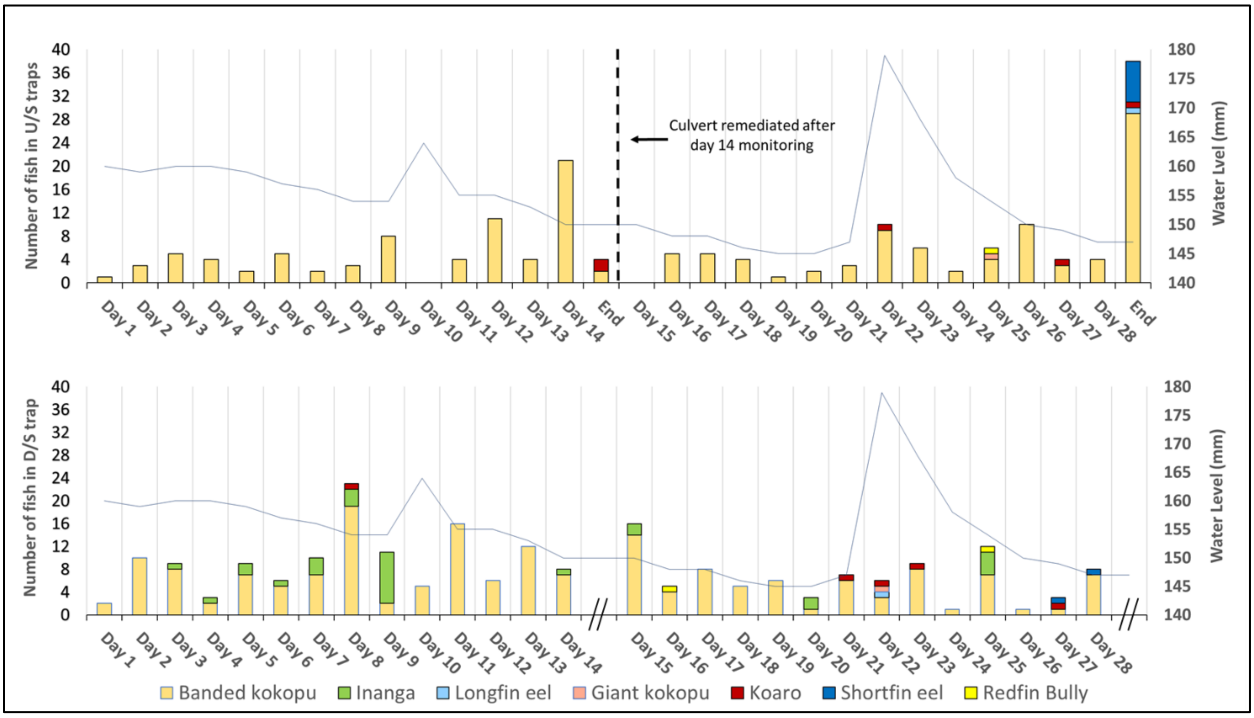

Figure 12. Results of fish trapping upstream (top) and downstream (bottom) of Williams Creek culvert. The top graph shows the combined numbers of fish caught in both the true right and true left traps set at the inlets of both culvert barrels before and after remediation. The data on the bar labelled 'End' (after day 28) refers to fish removed from the culvert barrels at the termination of both the un-remediated and remediated trial periods. Remediation of the structure occurred after day 14 and is indicated by a black dotted line. The bottom graph shows the number of fish caught in the trap set downstream of the structure over the same time period. Different species of fish are colour coded and displayed as a stacked total for each day. Water level throughout the entire trial period is shown as a blue line (D/S = Downstream U/S = Upstream).

The average daily capture rate of banded kōkopu through the downstream trap over the entire 28 day monitoring period was 6.3 fish, 7.7 fish during the un-remediated period, and 5.1 fish during the remediated period (Table 4; Figure 13).

The average daily capture rate of banded kōkopu through both upstream traps over the entire 28 day monitoring period was 4.7 fish, 5.3 fish during the un-remediated period, and 4.1 fish during the remediated period (Table 4; Figure 13).

Banded kōkopu comprised 75% of all fish caught (at both upstream and downstream traps combined). Given this dominance, some summary statistics are presented below for this species by comparing the difference in capture rates from before and after remediation. Comparing the average difference in daily captures rates between the upstream and downstream traps for the un-remediated and remediated periods provides an indication of the effect of the remediation. This was converted into a % daily capture rate by determining the difference in daily capture rates in from the downstream and upstream traps.

Table 4. Descriptive statistics for the daily capture rates of banded kōkopu (only) in the upstream and downstream culvert traps before and after remediation (D/S = Downstream U/S = Upstream).

Traps	Un-remediated			Remediated			Average difference from un-remediated to remediated
	Daily Average	Range	Standard error	Daily Average	Range	Standard error	
Downstream traps	7.7	2-19	1.4	5.1	1-14	1.0	-2.6
Upstream traps	5.3	0-21	1.4	4.1	0-10	0.7	-1.2
% average daily passage rate	69%			80%			

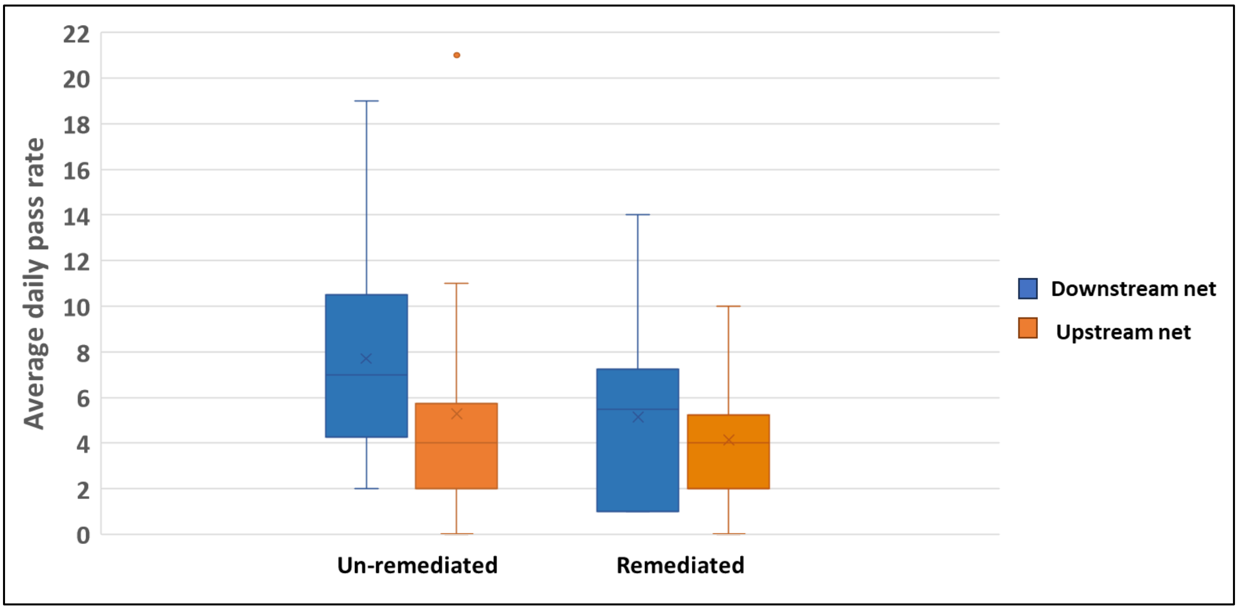

Figure 13. Box plots showing the average daily capture rates of banded kōkopu caught upstream and downstream of the culverts in an un-remediated and remediated state.

Discussion

Young of the year (YOY) banded kōkopu (size range 39 to 45mm) were by far the most common fish species both upstream and downstream of the culvert, comprising 75% of all fish captured during the trapping period. In total 74 and 58 negotiated the culvert before and after remediation, respectively. The numbers of banded kōkopu successfully negotiating the culvert were similar during the un-remediated and remediated periods. However, the numbers of banded kōkopu captured in the downstream trap were higher during the un-remediated period with 108 fish caught, compared to 72 fish caught during the remediated period. A higher percentage of banded kōkopu attempting to negotiate the structure were successful following the remediation. This is shown by the higher average daily capture rate percentage between the downstream trap and the upstream trap following remediation (69% in the un-remediated culverts compared to 80% in the remediated culverts) (Table 4).

The Sunset Valley trials suggest that baffles set within a culvert at a similar gradient to the Williams Creek culvert allow passage for close to 100% of īnanga (see Sunset Valley trials, page 5). It is reasonable to expect that those banded kōkopu recovered from within the culvert at the termination of the remediated trial period were capable of continuing upstream out of the culvert. When these fish are added to the total numbers of fish caught in the upstream traps, 76 and 87 were recovered before and after remediation, respectively, which is 32 less fish than were captured in the downstream trap during the un-remediated trial period, and 15 more during the remediated trial period. The above results combined suggest some improvement in passage for YOY banded kōkopu.

Six banded kōkopu greater than 45mm were caught in the downstream trap over the entire evaluation period (size range 68 to 150mm), however none of these larger fish were recorded in the upstream traps prior to remediation. During the remediated period, seven banded kōkopu greater than 45mm in length passed through the upstream traps (size range 77 to 150mm), suggesting the remediation allows passage for a wider range of banded kōkopu sizes and ages.

Twenty-nine īnanga (size range 46 to 55mm), were captured in the downstream trap over the full 28 day trial period, 21 and eight were captured during the un-remediated and remediated trial periods, respectively. No īnanga passed through the upstream traps over the full trial period. These data suggest that the culvert was a complete barrier to upstream migrating īnanga, both before and after remediation.

A single YOY giant kōkopu was captured in the downstream trap on day 22. A single YOY giant kōkopu was also captured in the upstream traps on day 25. On each occasion the fish measured 46mm, meaning it was almost certainly the same individual passing through the respective traps. This suggests that the remediated culvert enabled passage for YOY giant kōkopu.

Five YOY kōaro passed through the downstream trap over the 28 day trial period. Two were recovered from the culvert at the end of the un-remediated trial period, two were caught in the upstream traps after remediation, and one was recovered from the culvert at the end of the remediated trial period. These results suggest that the structure was not a complete barrier for this species with or without remediation in place.

Three eel elvers passed through the downstream trap over the 28 day trial period but none were recorded in the upstream traps over this time. However, seven were recovered from within the culvert at the termination of the remediated trial period, while none were recovered following the un-remediated trial period. It is likely that the extra eels recovered from the culvert were in between the downstream trap and the culvert outlet before the start of the study. This result suggests that the remediation may have improved passage for eel elvers, as if given more time, these eels would likely have continued upstream out of the culvert.

Two redfin bullies (41mm and 67mm) passed through the downstream trap over the 28 day trial period. One redfin bully (45mm) was recorded passing through the upstream trap during the remediated period. This suggests that this species can successfully pass through the remediated culvert.

Overall, these results from September suggest that the Williams Creek culvert was a complete barrier to īnanga in both its un-remediated and remediated state. YoY banded kōkopu, YoY kōaro and eel elvers were able to negotiate the Williams Creek culvert in its un-remediated state. This is may have been due to the presence of the wetted headwall feature at the outlet enabling passage over the perch for some climbing species. This situation differs from more completely perched and undercut culverts where often it is dry underneath the pipe which generally presents a total barrier to all native fish. Nevertheless, capture rates for YOY banded kōkopu appears to have improved moderately following remediation. Although the numbers of other fish species were too low to confidently determine if an improvement in passage occurred, eel elvers were only recorded upstream of the culvert outlet following remediation and kōaro, giant kōkopu and redfin bullies were caught in the upstream trap following remediation suggesting that they were able to pass through the remediated culvert.

Williams Creek Evaluation 2

Method

Evaluation 2 commenced on the 13th of November 2023 using a similar methodology as Williams Creek Evaluation 1 (see Willimas Creek Evaluation 1 method, pages 13 & 14). However, in this evaluation the fish passage remediation (at the outlets and within both culvert barrels) was left in place (following on from Evaluation 1) for a period of 11 days. The remediated structures were then removed and fish trapping with no remediation in place was then run for a further 11 days until the 4th of December.

Results

In total six species of fish were observed throughout the course of the evaluation period; banded kōkopu, īnanga, shortfin eel, giant kōkopu, kōaro and redfin bully, with īnanga the most common species (Table 5; Figure 14). During this monitoring period īnanga comprised 75% of all fish caught (at both upstream and downstream traps combined).

Table 5. Total numbers of fish caught upstream and downstream of the culverts both before and after remediation, including the size range of all fish in millimetres (N/A = Not applicable).

Species	Number of fish in downstream trap	Fish fork length range (mm)	Number of fish in upstream traps	Fish fork length range (mm)	Number of fish in culvert at end of trial	Fish fork length range (mm)
Un-remediated						
Banded kōkopu	9	35-41	3	35	0	N/A
Īnanga	53	48-57	0	N/A	0	N/A
Shortfin eel	5	63-75	2	63-66	0	N/A
Remediated						
Banded kōkopu	14	37-43	16	35-44	14	37-44
Īnanga	81	47-57	7	50-56	10	48-57
Shortfin eel	6	62-70	0	N/A	13	62-120
Giant kōkopu	0	N/A	0	N/A	1	46
Kōaro	0	N/A	0	N/A	1	49
Redfin bully	0	N/A	1	46	2	46-47

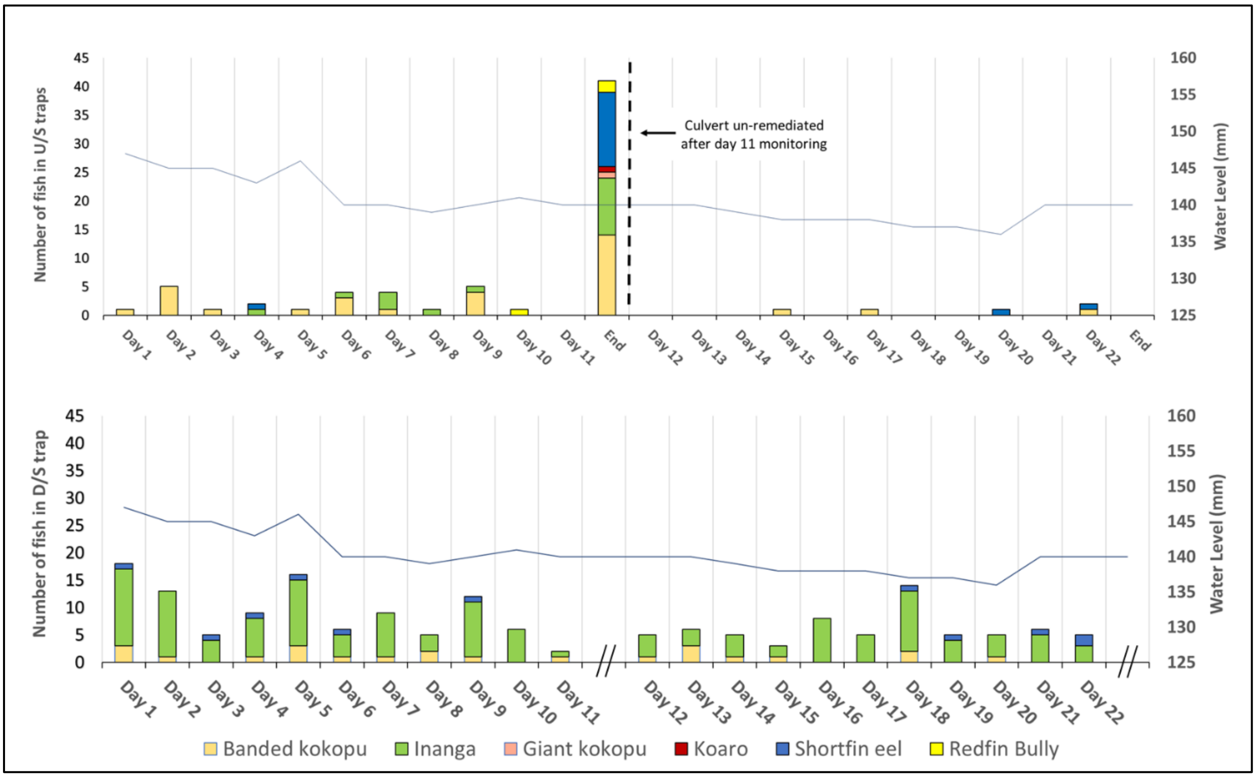

Figure 14. Results of fish trapping upstream and downstream of Williams Creek culvert. Top graph shows the combined numbers of fish caught in both the true right and true left traps set at the inlets of both culvert barrels before and after remediation. Bottom graph shows the number of fish caught in the trap set downstream of the structure over the same time period. Different species of fish are colour coded and displayed as a stacked total for each day. Data labelled ‘End’ refers to fish removed from the culvert barrels at the termination of both the un-remediated and remediated trial periods. The fish passage remediation measures were removed (“un-remediated”) from the structure after day 11, as is indicated by a black dotted line. Water level throughout the entire trial period is shows as a blue line (D/S = Downstream U/S = Upstream).

Given that īnanga were the dominant species captured during this trial period, below some summary statistics are presented for this species by comparing the difference in capture rates from before and after remediation. This was converted into a % daily capture rate by determining the difference in daily capture rates from the downstream and upstream traps. The average daily capture rate of īnanga through the downstream trap over the entire 22 day monitoring period was 6.1 fish, 4.8 fish during the un-remediated period, and 7.4 fish during the remediated period (Table 6; Figure 15).

The average daily capture rate of īnanga through both upstream traps was 0 fish during the un-remediated period, and 0.8 fish during the un-remediated period (Table 6; Figure 15).

The average daily capture rate for īnanga passing through both upstream traps over the remediated trial period and including those recovered from within the culverts at the termination of the remediated trial period was 1.6 fish (Table 6; Figure 15).

Table 6. Descriptive statistics for the daily capture rates of īnanga upstream and downstream of the culverts both before and after remediation (D/S = Downstream U/S = Upstream).

Traps	Un-remediated			Remediated			Average difference from un-remediated to remediated
	Daily Average	Range	Standard error	Daily Average	Range	Standard error	
Downstream Trap	4.8	2-11	0.8	7.4	1-14	1.3	2.6
Upstream traps	0	0	0	0.6	0-3	0.3	0.6
% average daily passage rate	0%			8%			

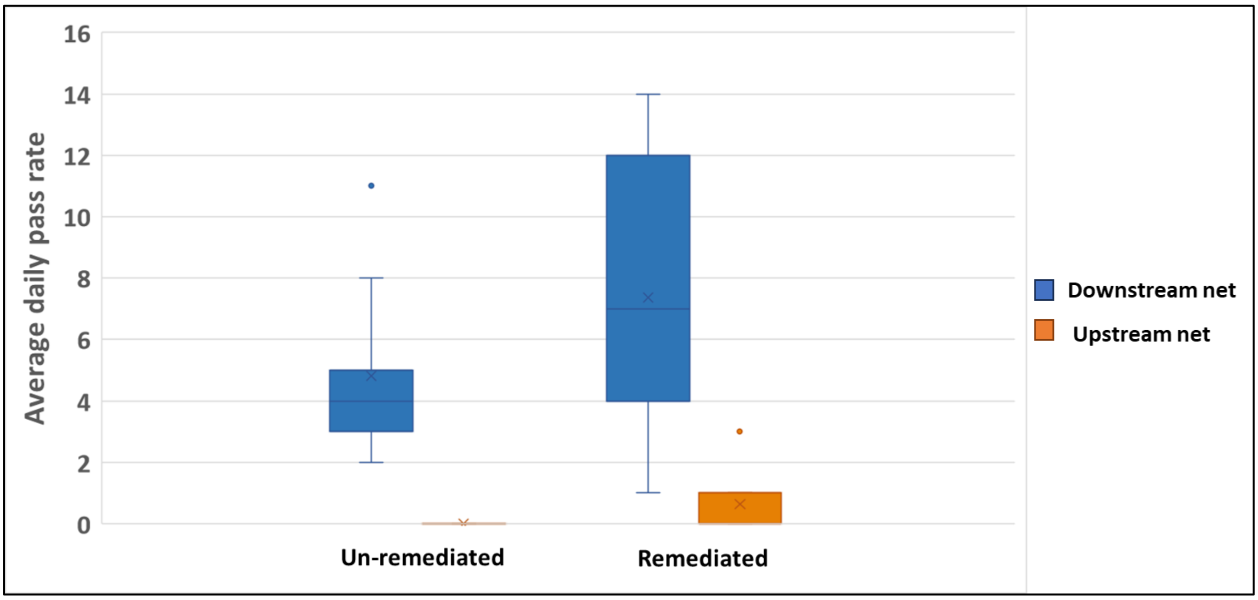

Figure 15. Box plots showing the average daily capture rates of īnanga caught upstream and downstream of the culverts in an un-remediated and remediated state.

Discussion

During the November evaluation period, īnanga were the most common fish species caught. In contrast to the September period banded kōkopu numbers were low, indicating that the migration period for this species was nearing an end.

134 īnanga passed through the downstream trap over the full 22 day trial period (size range 47 to 57mm), 53 and 81 were captured during the un-remediated and remediated trial periods respectively. Seven īnanga were captured in the upstream traps over the remediated period (size range 50 to 56mm), while none were captured during the un-remediated period.

10 īnanga were recovered from both culverts at the end of the remediated trial period (size range 48 to 57mm). No īnanga were recovered at the end of the un-remediated trial period.

The Sunset Valley experimental trials suggest that baffles set within a culvert at a similar gradient to the Williams Creek culvert allow passage for close to 100% of īnanga (see Sunset Valley trials, page 5). Therefore, it is reasonable to expect that those fish recovered from within the culvert at the termination of the remediated trial period were capable of continuing upstream out of the culvert.

When those īnanga that were recovered from both culverts at the end of the remediated trial period are included with those caught in the upstream trap, the remediation allowed passage for approximately 21% of what passed through the downstream trap over the remediated period.

These results suggest that the un-remediated structure is a complete barrier to īnanga and that the remediation has allowed passage for some fish during the later stages of the īnanga migration period.

There was no statistically significant difference in average size between those īnanga captured within the downstream trap during the September trial (51.1mm), and those īnanga captured in the upstream trap during the November trial (52.5mm) ($F=3.513$; $P=0.068$). The increase in capture rates for īnanga seen in November as compared to September may be a result of there being more fish migrating later in the season. If an increase in fish size results in better capture rates, then body mass (not measured) may have more relevance than body length.

Nine and 14 YOY banded kōkopu passed through the downstream trap during the un-remediated and remediated trial periods respectively, while three passed through the upstream trap during the un-remediated trial period and 16 passed through the upstream trap during the remediated trial period. A further 14 were recovered from the culvert at the termination of the remediated period. These results further confirm the conclusions from the September trial, indicating that while the Williams Creek culvert is not a complete barrier to YOY banded kōkopu, the remediation has likely improved passage for this species.

Eleven eel elvers passed through the downstream trap over the 22 day trial period, two were recorded in the upstream traps during the un-remediated period. Although none were recorded from the upstream trap during the remediated period, 13 were recovered from within the culvert at the termination of the remediated trial period. As with the September trial this result suggests that the remediation may have improved passage for eel elvers.

Two redfin bullies (size range 46 to 47mm) passed through the downstream trap over the 22 day trial period and one (46mm) was recorded from the upstream trap during the remediated period. Although like the September trial, such low numbers off fish affords little confidence when assessing passage success for this species, this result does show redfin bullies can successfully pass through the remediated culvert. A similar conclusion can be made for kōaro and giant kōkopu. One kōaro (46mm) and one giant kōkopu (46mm) were recovered from the culvert at the termination of the remediated trial period.

Overall, these results from November further confirm that the Williams Creek culvert was a complete barrier to īnanga in its un-remediated state and was a partial barrier to banded kōkopu. However unlike in September, in November the remediation appeared to improve capture rates for juvenile īnanga to a moderate extent, enabling passage for 8% of fish attempting to negotiate the structure. Potentially this is explained by better swimming abilities of īnanga as they develop through the season. Capture rates for banded kōkopu improved following remediation, and although the numbers of other fish species were too low to confidently determine if an improvement occurred, as was the case in the September trial, the numbers of eel elvers increased upstream of the culvert outlet following remediation and kōaro, giant kōkopu and redfin bullies were caught in the upstream trap following remediation suggesting that they were able to pass through the remediated culvert.

Mulligans Creek Field Trial

Site description

Mulligans Creek is a small tributary of the Otere River. Diadromous fish species with a predicted presence greater than 10% include īnanga, banded kōkopu, giant kōkopu, long and shortfin eels, common bully, redfin bully and giant bully (Leathwick 2008). Approximately 90m upstream of its confluence with the Otere River, Mulligans Creek is piped through dual culverts where it crosses a private driveway crossing (Figure 16). Both culverts are 1.2m diameter, 7.2m long. This crossing is located approximately one kilometre inland from the Onekaka estuary and it is the first barrier fish encounter when migrating up from the coast. The true right culvert receives most of the flow and was the focus for evaluating fish passage at the site. At the commencement of the evaluations at Mulligans Creek on the 4th of October 2023, the true right culvert was undercut approx. 0.42m, had a fall height of 0.26m, and internal gradients ranging from 1-3%. The average water velocity within the culvert was 1.8m/s, and the average flow rate was 12.8L/sec.

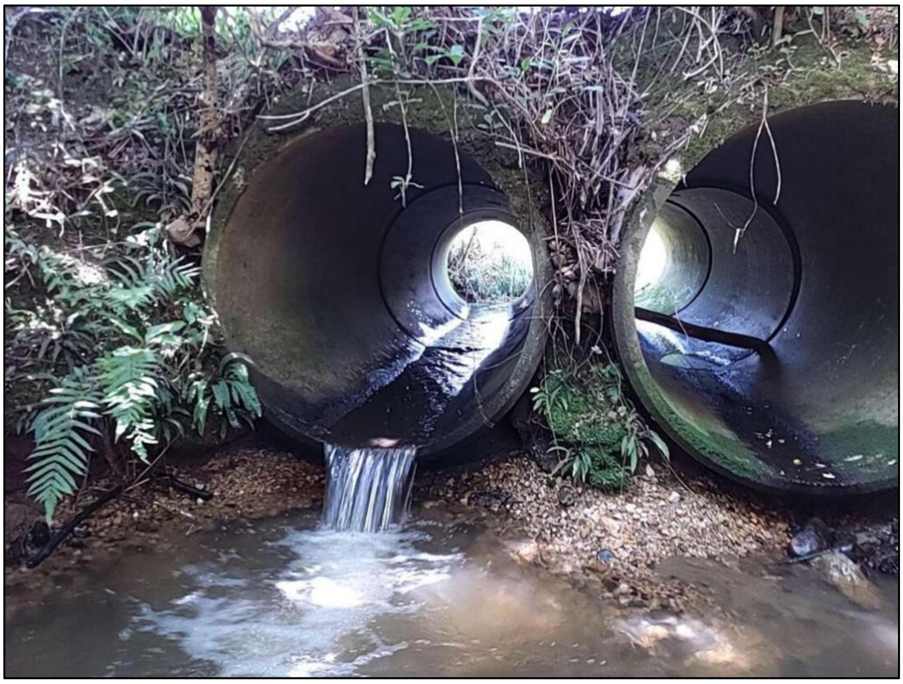

Figure 16. Perched culverts at Mulligans Creek (prior to any remediation for fish passage).

Remediation

Flexible ramp with mussel-rope and flexible baffles

With reference to the Fish Passage Remediation Training Aid 2022 (Olley et al 2022), a total of six flexible baffles were secured to the true right culvert pipe. All six baffles were 600 mm wide and 100 mm high. Baffles were spaced at 2.4m intervals where culvert gradients were 0-1%, 1.2m intervals where gradients were between 1-2%, and 0.8m intervals where gradients were between 2-4%. The most downstream baffle was a V-baffle.

A flexible fish ramp, made of second-hand conveyor belt rubber, was installed at the outlet of true right pipe (Figure 17). The ramp was 900mm wide by 1400mm long. The ramp included a bundle of looped mussel-rope fixed to the ramp invert consisting of four strands of rope.

In total, the remediation took approximately 45 minutes to complete.

Figure 17. The remediation at Mulligans Creek on the true right culvert, showing a flexible rubber ramp with mussel-rope and a V-baffle.

Method

Prior to the start of the Mulligans Creek Evaluation the entire upstream flow was diverted through the true right culvert barrel using a wooden board placed at the inlet of the true left culvert barrel. The true left culvert dried out in the process. The true right culvert then became the focus of this trial.

The trial period then commenced on the 16th of October 2023 using a similar methodology as Williams Creek Evaluation 1 (see Williams Creek Evaluation 1 method, page 13 & 14) with the un-remediated and remediated periods lasting 11 days each. The trial period ended on the 30th of October. Note also that during this evaluation the downstream trap was located approximately 15m downstream of the culvert outlet as the downstream plunge pool was larger than that at the Williams Creek culvert, and due to higher numbers of fish only the first 15 fish of each species recovered from each trap, each day were measured.

Results

In total five species of fish were observed throughout the course of the evaluation period: īnanga, banded kōkopu, kōaro, shortfin eel, and redfin bullies (Table 7; Figure 18).

Table 7. Total numbers of fish caught upstream and downstream of the culvert both before and after remediation, including the size range of all fish in millimetres (N/A = Not applicable).

Species	Number of fish in downstream trap	Fish fork length range (mm)	Number of fish in upstream trap	Fish fork length range (mm)	Number of fish in culvert at end of trial	Fish fork length range (mm)
Un-remediated						
Banded kōkopu	512	34-45	0	N/A	0	N/A
Īnanga	312	45-53	0	N/A	0	N/A
Redfin bully	2	40-43	0	N/A	0	N/A
Remediated						
Banded kōkopu	71	39-100	430	36-70	3	41-42
Īnanga	104	44-88	1	52	0	N/A
Shortfin eel	1	60	0	N/A	0	N/A
Kōaro	0	N/A	2	48-49	0	N/A
Redfin bully	5	30-58	0	N/A	0	N/A

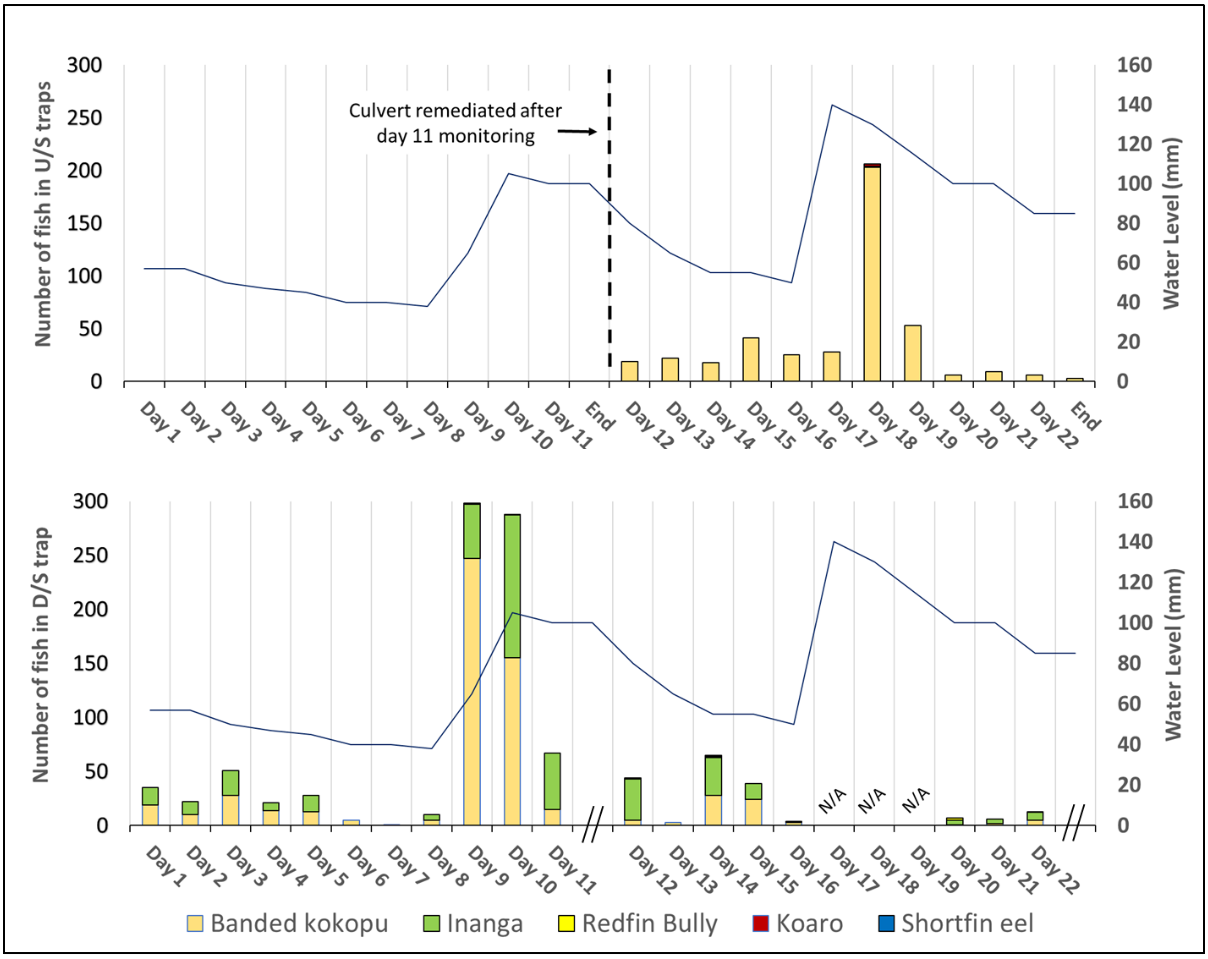

Figure 18. Results of fish trapping upstream and downstream of Mulligans culvert. Top graph shows the numbers of fish caught in the upstream trap set at the inlet of the culvert barrel before and after remediation. Remediation of the structure occurred after day 11 and is indicated by a black dotted line. Bottom graph shows the number of fish caught in the trap set downstream of the structure over the same time period. On days 17, 18 and 19 the downstream trap was lost to flooding so data from the downstream trap is not included for these days. Different species of fish are colour coded and displayed as a stacked total for each day. Water level throughout the entire trial period is shows as a blue line (D/S = Downstream U/S = Upstream).

No fish were captured in the upstream trap during the un-remediated period, or recovered from the culvert at the end of the un-remediated period (Table 7; Figure 18). Banded kōkopu (430), kōaro (2) and īnanga (1) were recovered from the upstream trap during the remediated period.

The average daily capture rate of banded kōkopu through the downstream trap over the entire 28 day monitoring period was 30.7 fish, 46.6 fish during the un-remediated period, and 8.9 fish during the remediated period (Table 8). Note that three days of data was lost (days 17, 18 and 19) when the downstream trap was flooded out and these data, including the upstream trap data for those days, have been excluded from the analysis in table 7.

No fish were recorded in the upstream trap during the entire un-remediated period. The average daily capture rate of YOY banded kōkopu through the upstream trap during the remediated period was 18.3 fish (Table 8).

Table 8. Descriptive statistics for the daily capture rates of banded kōkopu upstream and downstream of the culvert both before and after remediation (U/S = upstream D/S = Downstream). Note that three days of data was lost (days 17, 18 and 19) when the downstream trap was flooded out and these data, including the upstream trap data for those days, have been excluded from the analysis.

Trap	Un-remediated			Remediated			Average difference from un-remediated to remediated
	Daily Average	Range	Standard error	Daily Average	Range	Standard error	
Downstream Trap	46.6	1-247	23.9	8.9	1-28	3.2	-38.0
Upstream traps	0	0	0	18.3	6-41	17.0	39.0
% average daily passage rate	0%			206%			

Discussion

The culvert at Mulligans Creek appeared to be a complete barrier to all fish species prior to remediation. During the remediated period, the average daily capture rate for YOY banded kōkopu was 18.3 fish, this is 206% more fish than what was captured in the downstream trap over the same period. This result suggest that the remediation has successfully created passage for YOY banded kōkopu. The more than 100% passage result is likely a combination of some fish being present between the downstream net and the upstream net at the start of the study and that downstream trap was not operational for 3 days during the trial. Further to this, two larger banded kōkopu measuring 60mm and 70 mm in length were captured in the upstream trap during the remediated period. Like at Williams Creek, this would suggest that the remediation may be successful in providing passage for a range of banded kōkopu sizes.

Two YOY kōaro passed through the upstream trap over the remediated trial period. No kōaro were recorded in the downstream trap at any time, or in the upstream trap over the un-remediated trial period. It is likely that these two kōaro were in between the downstream trap and the culvert outlet before the start of the study, but these results still suggest that YOY kōaro can also successfully pass through the remediated culvert.

416 īnanga, seven redfin bullies and a shortfin eel elver passed through the downstream trap over the entire trial period. Only one īnanga passed through the upstream trap during the remediated trial period suggesting the culvert remains a barrier to this species following remediation. No redfin bullies or shortfin eel elvers passed through the upstream trap during the remediated trial period suggesting that the culvert may remain a barrier to these species although numbers of eel elvers and redfin bullies were too low to draw a reliable conclusion.

During the November Williams Creek (Evaluation 2), 17 juvenile īnanga migrated passed a flexible ramp with a perch height of around 0.4m. At Mulligans Creek only one īnanga passed a lower perch height of 0.26m. The higher flow rate through the Mulligans Creek culvert (13L/sec at the start of the trial period compared with 4.2-6.9L/sec at the start of the Williams Creek trial period) and consequent higher velocities may likely explain why the ramp remains a barrier for īnanga. Further research should focus on defining the flow, slope and fall height conditions where flexible ramps can provide passage for īnanga.

Shambhala Creek Field Trial

Site description

Shambhala Creek is a first order stream which flows into the Onekaka estuary. Diadromous fish species with a predicted presence greater than 10% include īnanga, banded kōkopu, giant kōkopu, long and shortfin eels, common bully and redfin bully (Leathwick 2008). Approximately 350m upstream of its confluence with the Onekaka estuary, Shambhala Creek is piped through dual concrete culverts where it crosses a private driveway (Figure 19). This structure is the first barrier fish encounter when migrating from the coast. Both culverts are 1.2 m diameter and 9.6 m long. The true left culvert has a concrete fish pass constructed at the outlet and receives most of the flow. The true right culvert was the focus for the fish passage evaluation.

At the commencement of the evaluations at Shambhala Creek on the 2nd of October 2023, the true right culvert was undercut approx. 2.2m, had a fall height of 0.7m, internal gradients ranging from 1-6%. The average water velocity through the culvert was 1.3m/s, and the average flow rate was 8.5L/sec.

Figure 19. Perched true right culvert at Shambhala Creek (prior to any remediation for fish passage).

Remediation

As well as remediating passage within the culvert with flexible baffles, two different culvert perch remediation methods were trialled sequentially. First a flexible rubber ramp with mussel-rope was installed. This was then removed and a floating ramp with a textured surface was installed (discussed in detail below).

Remediation 1 - Flexible rubber ramp with mussel-rope and flexible baffles

With reference to the Fish Passage Remediation Training Aid 2022 (Olley et al 2022), a total of seven flexible baffles were secured to the true right culvert pipe. All seven baffles were 600 mm wide and 100 mm high. Baffles were spaced at 2.4m where culvert gradients were 0-1%, 1.2m intervals where gradients were 1-2%, 0.8m intervals where gradients were between 2-

4%, and 0.6m intervals where gradients were between 4-6%. The most downstream baffle was a V-baffle.

A flexible fish ramp, made of second-hand conveyor belt rubber, was installed at the outlet of true right pipe (Figure 20). The ramp was 900mm wide by 1800mm long. The ramp included a bundle of looped mussel-rope fixed to the ramp invert consisting of four strands of rope.

In total, the remediation took approximately 60 minutes to complete.

Figure 20. The remediation at Shambhala Creek on the true right culvert, showing a flexible rubber ramp with mussel-rope and a V-baffle.

Remediation 2 - Floating ramp and flexible baffles

A plastic floating fish ramp was installed at the outlet of the true right-hand culvert (Figure 21). The ramp was 540mm wide, 2400mm long and lay at a 17 degree angle. The ramp had Miradrain® attached to its top surface. Note that the NZ Fish Passage Guidelines (Franklin et al 2018) suggests that these ramps are installed at 15 degrees or less, so the floating ramp installation at Shambhala Creek represents the upper limit for its recommended use as per the guidance.

All flexible baffles that were installed as part of Remediation 1 remained in place within the true right hand culvert barrel. The V-baffle at the outlet was replaced with a regular flexible baffle.

In total, the remediation took approximately 60 minutes to complete.

Figure 21. The remediation at Shambhala Creek on the true right culvert, including a floating fish ramp and flexible baffles.

Method

Prior to the start of the Shambhala Creek evaluation, a sealed, wooden board was placed at the inlet of the true left culvert barrel to direct the flow towards the true right culvert barrel. The true right culvert then became the focus of this trial.

The trial period then commenced on the 2nd of October 2023 using a similar methodology as Williams Creek Evaluation 1 (see Williams Creek Evaluation 1 method, page 13 & 14) with the exception that unlike the previse evaluations discussed, no downstream trap was used as very early in the evaluation period the downstream trap was stolen. The four days of downstream data that were gathered are discussed. The un-remediated period lasted 19 days and both subsequent remediation periods lasted 10 days each. The trial period ended on the 9th of November. Like the Mulligans Creek Evaluation, only the first 15 fish of each species recovered from each trap, each day were measured.

Results

Two species of fish were observed throughout the course of the evaluation period: banded kōkopu and shortfin eel elvers (Table 9; Figure 22).

Only one YOY banded kōkopu was captured in the upstream trap during the un-remediated period (Table 9; Figure 22).

During the first remediated trial period (flexible ramp and baffles), 24 banded kōkopu and four shortfin eel elvers were captured from the upstream trap, and during the second remediated trial period (floating ramp and baffles) 11 banded kōkopu were captured from the upstream trap (Table 9; Figure 22). Note that one day of data was lost (day 24) when the trap was flooded out.

Table 9. Total numbers of fish caught upstream of the culvert and within the culvert both before and after remediation, including the size range of all fish in millimetres (N/A = Not applicable).

Species	Number of fish in upstream trap	Fish fork length range (mm)	Number of fish in culvert at end of trial	Fish fork length range (mm)
Un-remediated				
Banded kōkopu	1	41	0	N/A
Remediated (Flexible rubber ramp)				
Banded kōkopu	24	38-43	1	42
Shortfin eel	4	60-65	0	N/A
Remediated (Floating ramp)				
Banded kōkopu	11	39-42	0	N/A

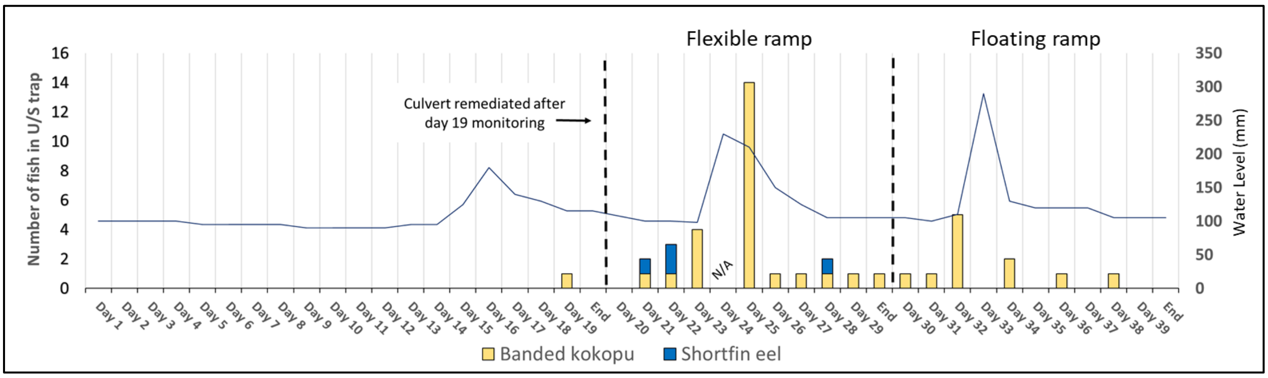

Figure 22. Results of fish trapping upstream of Shambhala culvert. Graph shows the numbers of fish caught in the upstream trap set at the inlet of the true right culvert barrel before and after remediation. Different species of fish are colour coded and displayed as a stacked total for each day. Remediation 1 (flexible ramp with mussel-rope and flexible baffles) occurred after day 19 and is indicated by the first black dotted line. Remediation 2 (floating ramp with flexible baffles) occurred after day 29 and is indicated by the second black dotted line. Water level throughout the entire trial period is showed as a blue line. On day 24 the trap was lost to flooding so data is not included for this day (U/S = Upstream).

Discussion

These results suggest that the culvert at Shambhala Creek was almost a complete barrier to YOY banded kōkopu prior to remediation, and a complete barrier to shortfin eel elvers.

The remediation with a flexible ramp and baffles created improved passage for YOY banded kōkopu and shortfin eel elvers and the remediation with a floating ramp and baffles created improved passage for banded kōkopu, but without a downstream trap in place during the evaluation period it is difficult to assess the degree of improvement, or whether the lack of shortfin eel elvers using the floating ramp remediation represents a failure of this method for this species.

Prior to the theft of the downstream trap, over the first four days of the un-remediated trial period 13 banded kōkopu (size range 40 to 44mm) and 50 īnanga (size range 46 to 52mm) were captured. This result would suggest that as well as banded kōkopu and eel elvers, īnanga were also present downstream of the culvert, however, during the full course of the trial period no īnanga were captured in the upstream trap. This suggests that not only was the culvert a barrier to this species prior to remediation, but that neither the flexible ramp nor the floating ramp improved passage for īnanga.

Conclusion

The combined results of the field evaluations and the experimental culvert give confidence that the remediation methods used in the Tasman District Council Fish Passage Restoration Project are effective at improving fish passage.

The experimental culvert results suggest flexible baffles are effective at creating passage for a weak swimming species of fish (īnanga) in culverts flowing at around 2.5L/sec set at a gradient of up to 8%. This is typical of types of culverts commonly encountered in the field.

Although testing a range of culvert sizes, water velocities and flow rates should be the focus of further work to continue testing the efficacy of flexible baffles, these experimental results combined with the field evaluation results suggest fitting flexible baffles provides a significant positive benefit to fish passage through a range of culvert conditions.

The field evaluations suggest that the addition of flexible ramps to remediate perched culverts up to 0.7m effectively enhances passage for most common climbing species however, they were only partially effective for īnanga over the range of perch heights tested. In one situation flexible ramps were tested alongside floating ramps with a textured surface (Miradrain). Both remediation methods were ineffective at improving fish passage for īnanga at this site.

Considering the results of the field trials and culvert experiment together, flexible ramps are effective at improving or restoring passage for climbing species (such as banded kōkopu) but are unlikely to be sufficient to remediate passage at sites where complete or near complete restoration of īnanga passage is a priority.

Determining the range of situations where flexible ramps can provide adequate passage for īnanga should be the focus of further evaluation trials and experiments.

These results show that flexible ramps are a useful method which greatly improve passage rates for a range of species, including īnanga in some situations. Given that they are low cost, robust and can be installed in a wide range of situations, when compared to other remediation methods, their continued use is recommended for improving passage for climbing native fish species.

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