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Appropriate use of mussel spat ropes to facilitate passage for stream organisms

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Executive summary

Rivers are presently subject to increasing levels of stress created by human activities. The cumulative impact of these activities has resulted in regional, national and international declines in aquatic biodiversity. Disruption of riverine connectivity resulting from the installation of structures is one such activity that has contributed to these declines. Relative to many other rehabilitation projects, remediation of structures deemed to be impairing movement of aquatic biota can be an effective and worthwhile activity since aquatic taxa tend to respond relatively rapidly to re-connection. Effective remediation can be expensive however, particularly for large structures. Over the last five years the Waikato Regional Council has pioneered the development and use of mussel spat ropes as a low cost alternative for improving passage of aquatic biota past small structures, particularly small perched and non-perched culverts. Culvert pipes, which are used to convey stream flows under roads, tracks and embankments, are commonly used for this purpose throughout the world and frequently result in artificial disconnection of the river network as a result of poor sizing and or installation processes. In this document we describe the potential use of ropes for improving passage by showcasing a number of lab and field studies and describe situations where ropes may or may not be an appropriate tool. To some degree the drive behind the development of this document has been to reduce inappropriate use of ropes and to establish a sound process for effective selection of this method and ideally pre and post installation assessment. The following summary briefly describes when ropes may or may not be a useful tool.

Mussel spat ropes <u>can be</u> used to enhance fish passage where:

- Culverts are perched and only climbing fish species are present
- Culverts are not perched but are < 1m diameter, and or >3m long and or >1^{O} slope.

Mussels spat ropes <u>should not be</u> used to enhance fish passage when:

- Passage for non-climbing species is required past perched culverts
- Culverts are > 1m in diameter unless other existing options are not suitable

1 Introduction

Over one third of New Zealand's native fish species need to migrate to and from the ocean to complete their lifecycle (McDowall 1990). This life-cycle strategy is known as diadromy and consequently these species rely on unimpaired river connectivity in both directions for maintaining healthy, functioning populations and abundant stocks of whitebait and eels. Any anthropogenic barrier that precludes fish passage is considered to have an adverse environmental effect and therefore requires a resource consent, unless expressly allowed for in a regional plan. In reality unauthorised or poor installation of some structures is not uncommon (Jones 2008) and this has resulted in many parts of the river network becoming inaccessible or partly accessible for some fish species.

Remediation of structures can be a costly exercise and for many long, difficult to access culverts there are few options available for improving passage potential. In this document we describe the development and testing of an option that can easily and relatively cheaply be retrofitted to some culverts and possibly other structures to improve fish passage. This report briefly describes some of the issues around culverts specifically and how use of mussel spat ropes may overcome some of the problems for particular species in particular situations. The type of rope to use and how it may be installed is also described. It is important to recognise that ropes are only suitable for use in specific situations and should not be used simply to save costs or avoid consenting requirements by using them in inappropriate locations. Therefore, the limitations of using this tool is also discussed. A list of current publications is provided at the end of this document demonstrating the potential and use of spat ropes based on both laboratory and field based investigations conducted thus far.

2 The issue

Instream structures such as culverts, weirs, dams and fords can be barriers to upstream and downstream native fish migration if not installed or maintained correctly. With respect to fish passage through culverts, there are generally two main issues to be aware of: culvert **perching** and/or **flow barriers** within the pipe itself. It can generally be implied that for upstream migrating fish the greater the **perch height**, **length** and **gradient** (and therefore water velocity within the barrel) of a culvert the harder it is for fish and other aquatic taxa to pass.

3 Culvert perching

Culverts that are too small or not installed correctly often tend to scour out over time at their downstream end. This creates a perched or hanging culvert where the culvert outlet is above the stream bed level (see Figure 1 A,B). Often culverts allow for passage when installed but over time perching can restrict or in severe cases eliminate access completely. Regular periodic inspections of culverts following installation (e.g. as part of an annual maintenance programme) is recommended to identify culverts that may be non compliant with legislation.

Figure 1: A,B. Poorly installed culverts on a tributary of the Mangakotukutuku stream in urban Hamilton. In the lower example a perch height in excess of 1m combined with a 12m pipe length and pipe gradient in excess of 10 makes this a formidable barrier to even the most aggressive upstream climbing species.

Over time the distance between the pipe outlet and the streambed below can increase creating a free flowing chute of water from the culvert lip to the stream below. Even if a fish is able to leap the vertical distance necessary to reach the pipe outlet, the fish then needs to negotiate the pipe itself where pipe length, gradient and laminar flows will dictate passage success. These particular aspects are described in more detail in the 'culvert hydrology' section.

4 Culvert hydrology

Even if a pipe is not perched, it can still present a barrier to fish. The key parameters dictating passage through the pipe are length, gradient and velocity. For a given culvert, length and gradient are fixed parameters that typically don't change (unless there is slumping which may increase culvert gradient) whereas flow may vary over time (e.g. following rainfall). So it is often important to consider the range of environmental conditions experienced by the culvert and the window(s) of opportunity that may or may not exist for passage of aquatic biota at various times and at critical life stages.

A further important consideration is the physiological capability of the different fish (and different life stages of fish) that may be expected to be found above the barrier. High flows within culverts and instream structures can generate velocities higher than a fishes' maximum burst speed capability, therefore creating an unsurpassable velocity barrier (e.g. Stevenson and Baker 2009).

To watch a laboratory video demonstrating the culvert hydrology problem for inanga (*Galaxias maculatus*) click here: http://www.youtube.com/watch?v=GBzssWr67og

To watch a laboratory video demonstrating the culvert hydrology problem for brown trout (*Salmo trutta*) click here: http://www.youtube.com/watch?v=kN4Am0J2o6o

In addition, steep culverts are likely to have high velocities within the barrel and therefore be barriers for the above reasons also. Long culverts can also become barriers if the length exceeds the fish's ability for burst swimming as there are usually no low velocity areas to rest within the barrel. Many juveniles migrating upstream can make use of shallow slow flowing wetted margins but these are generally absent in smooth culverts (Speirs and Ryan 2006) so need to be created. There are numerous ways to do this, for instance by installing baffles (blocks, bricks etc) into culvert barrels (see Stevenson et al. 2008) but in this document we will only discuss the use of ropes for this purpose, with a particular focus on narrow culverts where physical access for retrofitting is problematic.

5 What are mussel spat ropes and what do they look like?

Mussel spat ropes are typically used in marine mussel farm aquaculture to provide a settlement substrate for mussel larvae which then metamorphose into mussels and continue to grow attached to the rope. The ropes are made of woven polypropylene which makes them very strong to support the weight of growing mussels and most are treated to be resistant to Ultra-Violet light for increased longevity. There are a range of different types of rope for different applications in mussel farming. In this document we describe the use of two readily available commercial types - "Russet Loop" and "Super Xmas Tree" (Figures 2, 3) for use in improving fish passage through perched and non perched culverts.

Figure 2: Example of Russet loop (left) and Super Xmas tree (right) mussel spat rope.

These mussel spat ropes are manufactured by Donaghys Industries; http://www.donaghys.com/aquaculture.html and can be sourced directly or through distributor suppliers such as Wellington Povedoring; http://www.wellingtonprovedoring.co.nz/productslist.aspx?CategoryID=50&selection=22&page=2

Russet loop type rope is not advised for use within the culvert barrel as the loops may be prone to trap sticks and debris and hence influence culvert capacity. For use within the barrel we suggest use of non-looped ropes such as the Super Xmas tree.

Second hand ropes may be available from mussel farms around the country although the effectiveness and durability of these ropes or other types of ropes once installed have not been tested. To understand when it is and is not appropriate to use ropes for improving passage in freshwater environments, it is important to have some understanding of the locomotory ability of different aquatic biota as briefly described in the following section.

6 New Zealand fish species and life-stages: 'swimmers' and 'climbers'

In New Zealand a number of native fish have evolved the ability to 'climb' past obstacles such as waterfalls, especially when migrating upstream as small juveniles. Different species have different climbing abilities (shown in Table 1). Banded kokopu (*Galaxias fasciatus*) juveniles in particular are good climbers but for a more detailed list of locomotory abilities and climbing ability see Boubee et al. (2000) http://docs.niwa.co.nz/library/public/ARCTP131.pdf

Other fish species with similar climbing abilities and styles include upstream migrating juvenile koaro (*Galaxias brevipinnis)* and shortjaw kokopu (*Galaxias postvectis*). Juvenile longfin and shortfin eels (*Anguilla dieffenbachii and A. australis* respectively) also have excellent climbing ability.

To see a video showing elver climbing style click here:
http://www.youtube.com/watch?v=TO-SgCPOUqU

Although redfin bullies are considered to have some climbing ability, this species tends to 'hop' or 'row' over and through obstacles rather than climb. On the other hand, non-climbing fish such as inanga (*Galaxias maculatus)*, smelt (*Retropinna retropinna*), mullet (*Aldrichetta forsteri* and *Mugil cephalus*), torrentfish (*Cheimarrichthys fosteri*), trout and most bully species (excluding possibly juvenile redfin bullies) will **not** be able to use ropes to surpass culverts perched in excess of 0.2m. In some cases predictive models can be used to assess what species should be present in a given stream reach. If these fish species are expected to occur in the stream above the structure but are not present because of the structure being present, a different solution should be investigated (e.g. fish ladder/ramp).

Table 1: Table of expected abilities of some New Zealand fish species to negotiate perched barriers using spat ropes (adapted from Boubee et al. 2000). 'C' = species with 'climbing' ability.

Species	Life stage	Perch height		
		<0.2	>0.2 - <1m	>1m
Shortfin and longfin eels	Juveniles <100mm (c)	Likely	Likely	Likely
	Adults (c)	Likely	Unlikely	Unlikely
Banded/shortjaw kokopu, koaro	Juveniles <50mm (c)	Yes	Yes	Yes
	Adults	Likely	Unlikely	No
Giant kokopu	Juveniles <50mm (c)	Likely	Likely	Likely
	Adults	Likely	Unlikely	No
Redfin bully	Juveniles <20mm	Likely	Unlikely	No
	Adults	Likely	Unlikely	No
Inanga (not dwarf) and smelt	Juveniles <40mm	Likely	Unlikely	No
	Adults	Likely	Unlikely	No
Torrentfish	Juveniles <40mm	Unknown	Unlikely	No
	Adults	Unknown	Unlikely	No
Mullet spp. and other bullies	Juveniles <50mm	Unknown	Unlikely	No
	Adults	Unknown	Unlikely	No
Rainbow and brown trout	Juveniles <80mm	Yes	Likely	No
	Adults	Yes	Likely	Unlikely

7 When to use ropes

Many of New Zealand's climbing native fish species can negotiate seemingly insurmountable obstacles. For instance all of the climbing species noted above (excluding redfin bullies) have been found above natural, near-vertical features such as waterfalls exceeding 15-20 m high. Although passable, such structures probably reduce the quantity of fish upstream and so it is important to differentiate between natural features that naturally restrict fish access and artificial structures that restrict access but should not. A further consideration is to determine whether passage for all sizes of fish (not just climbing juveniles) should be provided. For instance the climbing ability of eels, koaro and kokopu is greatly reduced as they grow larger and more rotund. Adults of these species do still move throughout river networks at different stages in their life for various reasons (e.g. reproduction or feeding during floods). Limited research on tagged and telemetered native fish in New Zealand also indicates that some species and individuals have good spatial awareness within river networks and may move many kilometres and return back to specific localities. In other words, the ideal situation is to provide passage for all species and life-stages that would be expected to occur at all times. At times, particular flow conditions over or around structures may provide limited opportunities for some fish species to negotiate a structure that may not be passable at normal flows (see e.g. Appendix 1). While this may occur, the situation is not ideal and the intent around remediation of any structure should be to provide unimpeded natural access at all times if possible.

7.1 Improving passage past perched culverts

Despite their incredible climbing capabilities, even small features with **overhanging** or **perched** configurations (whether natural or artificial) can severely impede passage.
It is in these types of situations involving artificial structures (e.g. small diameter perched culverts, dam outlets) that ropes would be a beneficial tool to improve access for species with climbing capabilities.

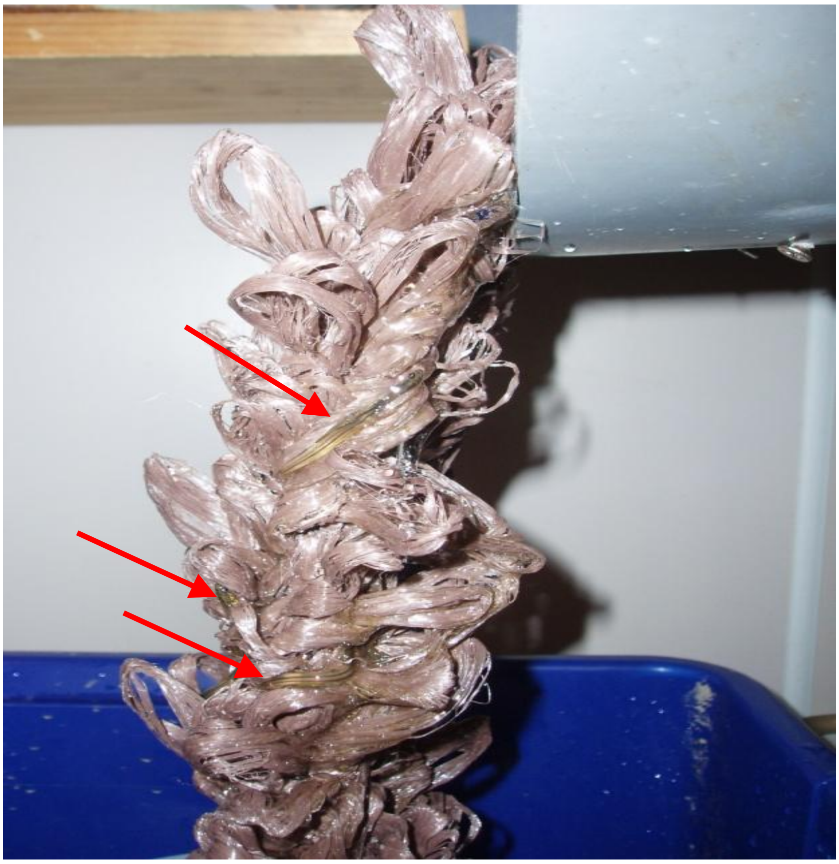


Figure 3: Banded kokopu (arrows) ascending 'Russet loop' (top) and 'Super Xmas tree' (bottom) mussel rope strands during laboratory trials

Both laboratory and field trials have demonstrated that banded kokopu can climb vertical ropes up to 2.4m but that species with lesser climbing ability such as redfin bullies (*Gobiomorphus huttoni*) cannot (David et al. 2009, David & Hamer 2012 or to see a laboratory video showing this behaviour for banded kokopu click here http://www.youtube.com/watch?v=a-HxTLPqi6w&feature=youtu.be and here: http://www.youtube.com/watch?v=rdbr3GTUiU8&feature=youtu.be

Although not specifically tested it is likely that upstream migrating juvenile koaro (*Galaxias brevipinnis)* and shortjaw kokopu (*Galaxias postvectis*) would exhibit similar passage success to banded kokopu for a given situation. This is primarily because these species have very similar climbing style and ability. Eels (*Anguilla sp*) particularly as juveniles (elvers) can also climb although they have a different style to that exhibited by juvenile kokopu. It is likely that eels would also be able to ascend vertical ropes and although this ability has not been specifically tested yet, anecdotally eels have been seen ascending ropes recently installed to a perched culvert in a stream near Wellington (Kelly Hughes, ATS environmental pers. obs).

If using ropes, it is important to use them for the appropriate species and in the appropriate context. For instance, the addition of ropes to small water supply dams that have vertical smooth, stepped or textured artificial surfaces would not improve fish passage unless the feature contained perched or undercut features preventing upstream movement**.** Additionally use of ropes to enable passage of say banded kokopu past a 1m perched culvert would be appropriate for juvenile fish, but not for adults. **In effect it is important that ropes are used in the correct context and not as a "tick the box exercise" for consenting requirements in situations where their addition will not improve overall passage**. Anecdotal observations indicate that in some instances running lines of rope along ramp edges or walls may be useful for providing much needed cover that fish will use as they ascend structures. In this context their use may be beneficial for reducing mortality of juvenile fish through direct predation rather than altering hydraulics or providing a climbing medium to improve passage efficacy.

Non-climbing migratory fish generally live in the mid to lower gradient reaches of catchments. Therefore ropes for addressing culvert perching should only be used in steep gradient and or upper reaches of catchments where inanga and other non-climbing species would not naturally occur. One exception to this would be to install ropes in non-perched culverts where the flows in the pipe and its length and or gradient are too severe to enable swimming fish to get past (see section 7.2 below for this application).

7.2 Improving passage through culvert barrels

Two recent laboratory studies have been conducted to look at the effectiveness of ropes for addressing the laminar hydraulic barrier often presented in culverts (Tonkin et al. 2012, David et al. 2013). The first pilot study (Tonkin et al. 2012) assessed passage by redfin bullies through pipes 3m and 6m long with and without ropes at a 10 degree slope. Despite some confounding methodological issues and the re-use of some fish, this pilot study nevertheless clearly showed that redfin bullies were only able to pass the 6m pipes at 10 degree slopes if ropes were present. Surprisingly, even at these slopes, fish were able to use the ropes to lay motionless and rest within the pipe on their way upstream. To observe this behaviour click here:

http://www.youtube.com/watch?v=9oltYP2gsD8&feature=youtube_gdata_player

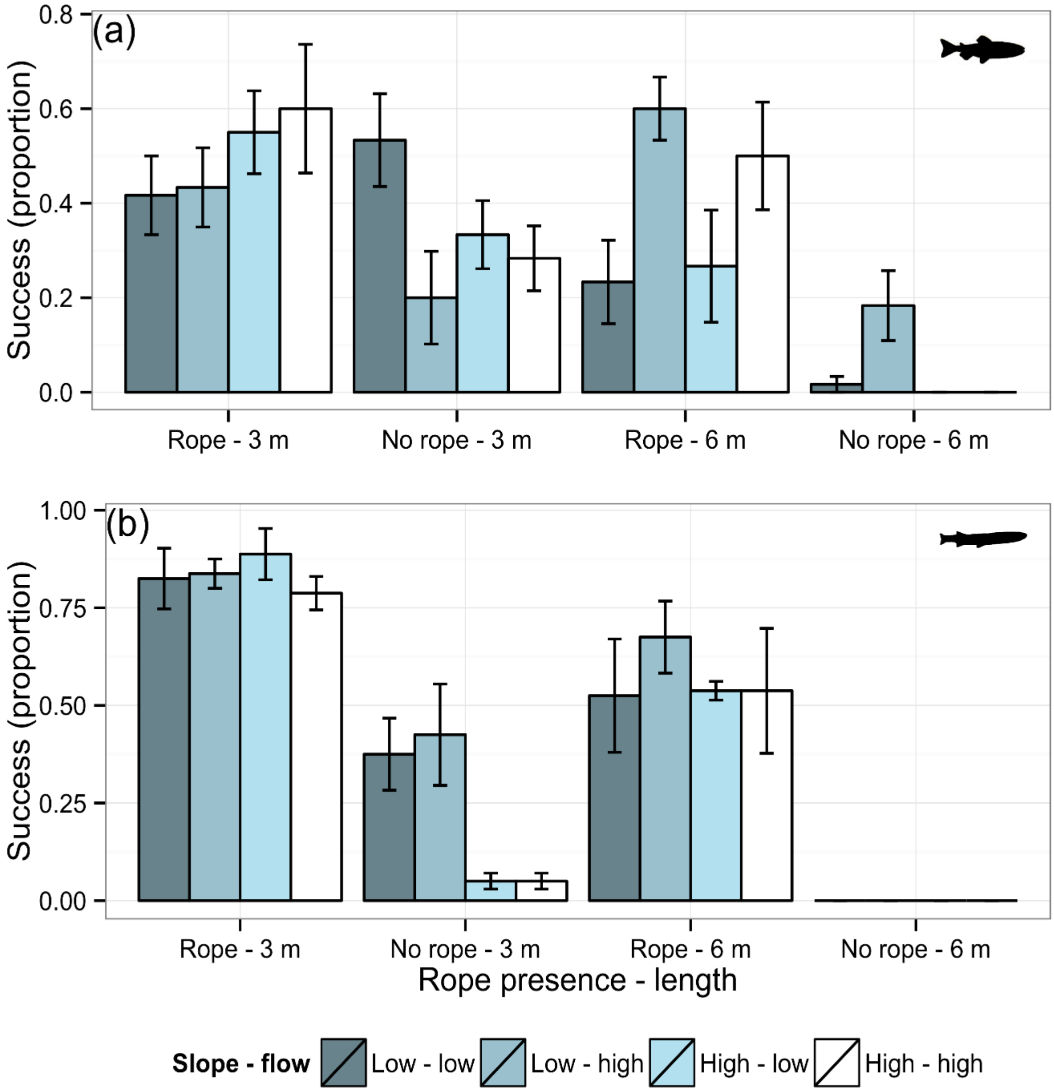
The second study (David et al. 2013) assessed passage performance for two fish (inanga and brown trout) and one crustacean (the freshwater shrimp *Paratya curvirostris*) species. The influence of flow, gradient and pipe length on passage success through the culverts by each of these species was investigated.

Figure 4: Paired experimental set-up for testing passage success of fish and shrimp through 3m and 6m culvert pipes with and without ropes and at varying gradients and flows.

Passage success for all three species was significantly improved through pipes with the addition of ropes. In particular, at extreme culvert settings (6m pipes at high flow and high slope), passage was only achieved for all three species if rope was present with no demonstrated success when ropes were absent. (see Figures 5 a - trout, b – inanga, c - paratya below and for more details see David et al. 2013).

To see a video of paratya using ropes filmed through a perspex pipe click here: http://www.youtube.com/watch?v=nbhuqur5GBc

To see a video of inanga using ropes to negotiate a 6 m pipe click here: http://www.youtube.com/watch?v=i6oNI7tPGBk
To see a video of brown trout using ropes to negotiate a 3 m pipe click here: http://www.youtube.com/watch?v=31TnXZoO8wU



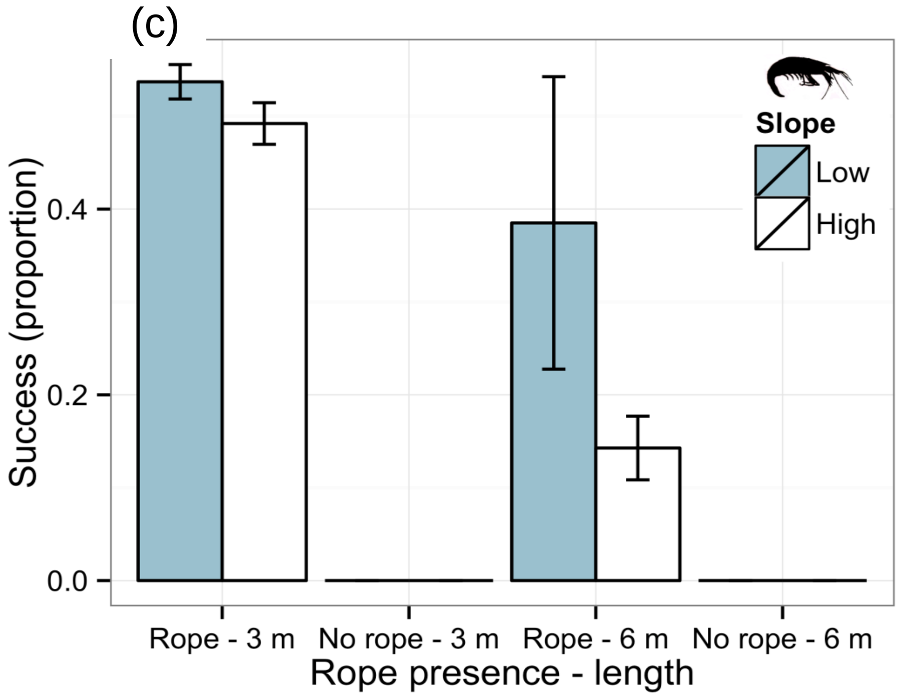
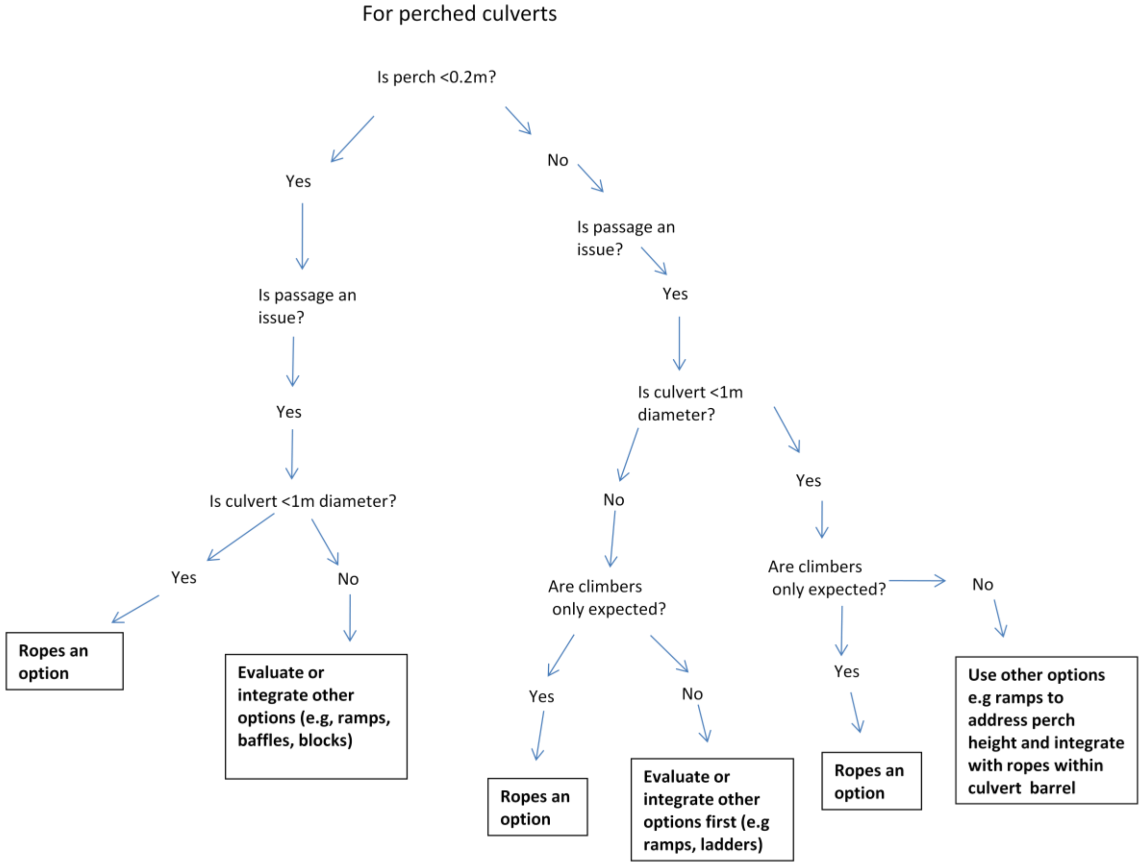


Figure 5: Successful passage of culverts of varying length with and without ropes for a - trout, b – inanga, c – paratya, Sourced from David et al. 2013.

7.3 Is a retrofit required ?

It is highly recommended to undertake a robust fish survey above and below the barrier prior to installing ropes to determine whether retrofitting is necessary and to establish target species of interest (see section 7.4). We consider that some form of monitoring is necessary for any given situation to select an appropriate retrofit method, to justify the resources required and to monitor outcomes. Assuming that some monitoring has been undertaken to establish target species for passage, two simple decision trees have been provided for evaluating when ropes would be an appropriate retrofit tool to improve passage past culverts. Tree A helps guide the reader through retrofits to perched culverts while Tree B is for non perched situations. In developing these trees we consider that in most cases culverts < 1m diameter would be too narrow to safely enter and retrofit features such as baffles throughout the culvert barrel and we have assumed that perch heights >0.2m would in many cases restrict (to varying degrees) upstream migrating swimming species.

A)



For perched culverts
Is perch <0.2m?
Yes
No
Is passage an issue?
Yes
Is culvert <1m diameter?
Yes
No
Ropes an option
Evaluate or integrate other options (e.g, ramps, baffles, blocks)
Is passage an issue?
Yes
Is culvert <1m diameter?
No
Yes
Are climbers only expected?
Yes
No
Ropes an option
Evaluate or integrate other options first (e.g ramps, ladders)
Are climbers only expected?
Yes
No
Ropes an option
Use other options e.g ramps to address perch height and integrate with ropes within culvert barrel

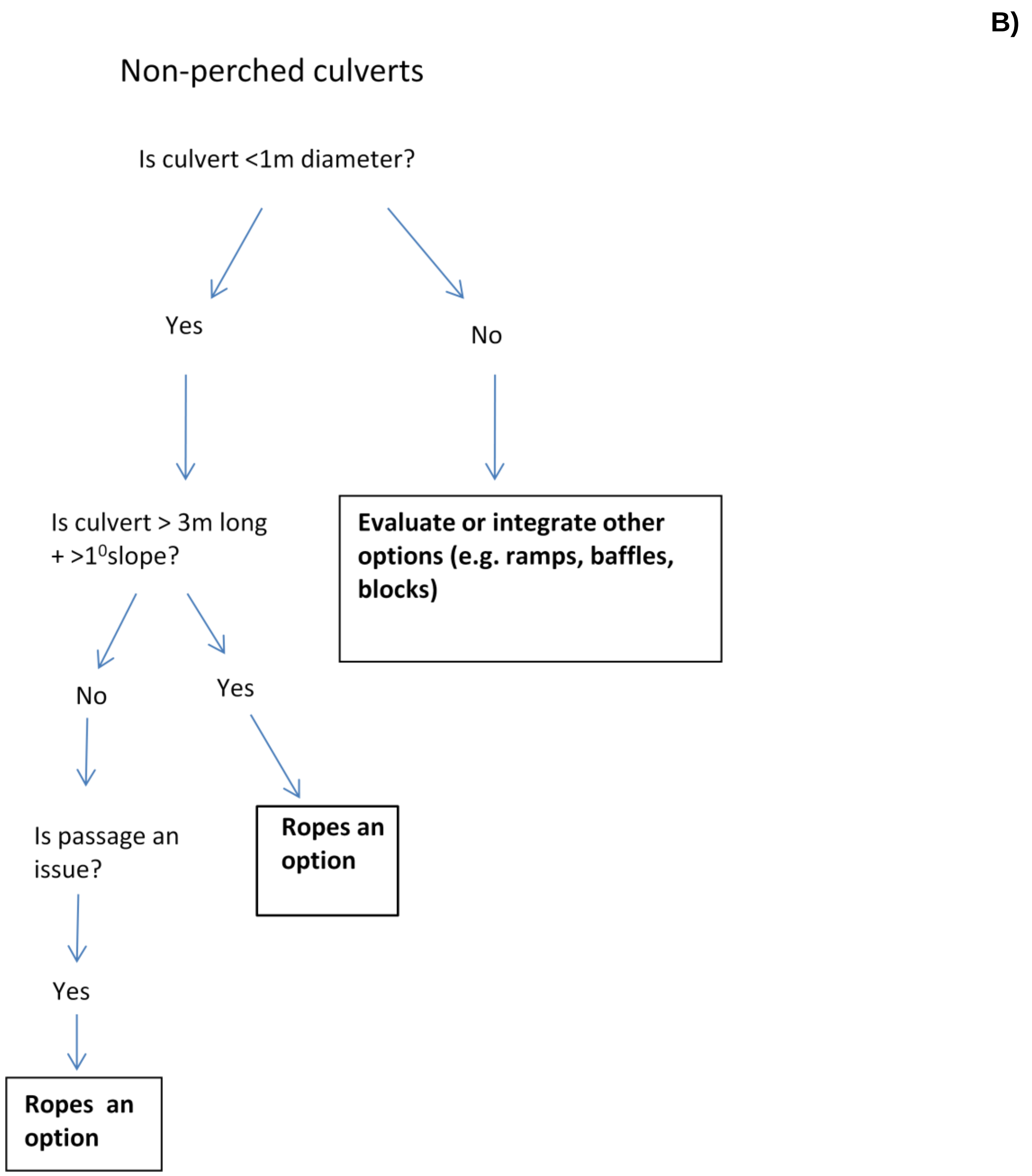


Figure 6: Are ropes an appropriate tool: simple decision tree for A) <u>perched</u> and B) <u>non perched</u> culverts.

7.4 Evaluating retrofit effectiveness through monitoring

It is highly recommended to undertake a fish survey above and below the barrier prior to installing ropes to determine whether retrofitting is necessary and to establish target species of interest. It is also advisable to sample a similar nearby 'control' stream without impediments to passage to assess retrofitting success on the 'treatment' stream.

It is important to note that successful passage of a fish through a culvert (or any other artificial structure that impeded passage prior to remediation) does not necessarily mean that <u>sufficient</u> numbers of that fish or other target species are passing the structure to support the upstream fish community expected to be there. In part this is why it is recommended that any new retrofit also includes a monitoring component of the upstream fish community to determine whether sufficient recruitment into upstream populations is occurring. Often other factors (e.g. predation, natural mortality) may reduce recruitment potential so a greater number of fish may need to successfully pass to fill available upstream habitat. Similarly, for diadromous species (species with a marine component to their life-history) if an obstruction is a long way inland, passage success past the structure may need to be higher than at locations closer to the coast simply because fewer recruits may arrive at the structure and attempt to surpass it. Additionally the time taken to reach inland streams may mean that arriving individuals may be slightly larger than those close to the coast and for climbing species in particular being bigger and heavier may reduce their climbing efficiency and ultimately their ability to scale obstacles.

At times there may be other confounding or human derived factors that may limit the potential to assess passage efficiency past a retrofitted structure. That is, the retrofit may not result in the predicted response, not because the retrofit was not appropriate but because other factors (e.g. upstream point source discharges or mining legacies) may have influenced the response. Thus having a good knowledge of the system and the climbing/swimming ability of the species of interest is important for evaluating retrofit success.

A before and after- control- treatment monitoring design is one of the most powerful to establish retrofit effectiveness. Ideally monitoring of both the control and treatment streams on at least three occasions before and after would be required to obtain reasonably robust information from a statistical point of view to evaluate success. If the stream is 'wadeable', consistent repeatable methods like those outlined in The New Zealand Freshwater fish sampling protocols for wadeable streams (Joy et al. 2013) could be used for conducting this type of work. These unbiased methods have been used previously to demonstrate passage efficacy of retrofitted structures (e.g. see David & Hamer 2012) and highlight the importance of methodological consistency when monitoring (e.g. at the same time of year, using the same effort etc) to minimise variability and maximise detection of an effect if there is one. These methods were specifically developed for effectively evaluating fish species diversity and to obtain a repeatable estimate of relative abundance at a reach scale. Thus multiple reaches monitored throughout a catchment may be required if catchment scale improvements (rather than reach scale improvements) are an objective of the fish passage work.

7.5 How to install ropes

If ropes are deemed to be a useful option (see decision trees Figure. 6), the first step is to measure the culvert length and if perched, the perch height to ascertain how much rope will be required. A little extra should be allowed for attachment above and below the culvert. There are numerous ways that ropes can be attached. The method we have most commonly used is to attach multiple lengths of rope upstream of the culvert to a metal stake hammered into the streambed (see Appendix 2) or other such structure installed in such a way to avoid debris build up. We then feed ropes downstream through the culvert and if there is a perch, tie them vertically to the streambed below. If there is no perch they can be fixed in the same way as they are upstream (i.e. by hammering metal stakes deep into the bed and ensuring a smooth transition. It is recommended that the ropes are as tight as possible and to minimise any rubbing and wear at either end of the culvert barrel and in perched situations, tight ropes give the fish a stable substrate to climb on. Multiple ropes side by side will allow greater surface area for climbing and possibly improved predator avoidance. We recommend a minimum of two rope lines through a 500 mm diameter culvert with more lines for bigger culverts.

Before the ropes are attached at the downstream end, knots (half hitches) can be tied along the section of rope located within the culvert barrel to break up the velocity in the culvert and potentially create additional rest areas for the fish. In perched situations we leave the vertical section from the culvert lip to the water below un-knotted as this could make the climbing section for aquatic taxa more difficult. If the culvert is perched we use either a gabion basket or metal stake at the downstream end and attach ropes to these (See installation photos Appendix 2).

7.6 Issues with using ropes

1. Not all fish will be able to use the ropes to surpass obstacles. Only climbing species will be able to use the ropes to navigate perched structures and usually only as juveniles (see table 1 and in the Summary section below). Some fish species and life stages (e.g. large deep bodied adult fish) may also struggle to use ropes to navigate through culvert barrels where there is insufficient water depth or flow refugia.

2. If adult fish are displaced downstream past a vertical or perched structure in flood events, it is unlikely they will be able to use ropes to get back upstream.

3. The durability of polypropylene ropes in flowing freshwater environments is unknown. A 10-15yr life-span is indicated for marine environment applications where they are exposed to full sunlight and wave action. When used in culvert applications ropes would be exposed to abrasion from sediment during high flows but be largely protected from sunlight within culvert barrels. At the time of writing our longest deployed example has been in place for five years and has not required any maintenance to date.

4. There is potential for the ropes to trap debris. While this has not occurred at sites where we have installed ropes, care should be taken when installing ropes to ensure that large debris will pass over and not collect on ropes. If sufficient culvert capacity exists small amounts of debris are fine and may even be beneficial for breaking up flow. Nevertheless keeping ropes tight and using non-looped types is advised. Limiting debris build-up may be particularly relevant in streams with high organic loads (e.g. forestry catchments where at times considerable amounts of slash may be present). Debris accumulation can lead to increased scour and ultimately culvert washouts. A regular structure inspection programme should be implemented to identify any issues that arise before they cause significant issues.

5. Ropes inside a culvert barrel take up some of the culverts capacity to convey water. We have noted that stream substrates may also settle in the culvert curve below ropes providing a semi natural stream bed which may be colonised by aquatic taxa. While some substrates are probably washed out during flood events, some also seem to remain or be replaced. Although settled material in the culvert curve is probably good for fish passage, it can lower culvert capacity so it is important to ensure that sufficient capacity does exist to accommodate this material in undersized or inadequate culverts. As a general guide, the increased roughness generated by ropes is likely to be comparable to that created by a corrugated culvert and typically less than many other roughness elements (e.g. baffles) used to improve passage efficacy.

8 Rules / laws around barriers to fish passage

In the Waikato region installing culverts in catchments under 100ha is a permitted activity in the regional plan (http://www.waikatoregion.govt.nz/Council/Policy-and-plans/Rules-and-regulation/Regional-Plan/) provided they meet a number of conditions including that “the structure shall provide for safe passage of fish both upstream and downstream” (Jones 2008) and that excessive suspended sediment and erosion should not be caused. For catchments greater than 100ha, a resource consent is required to install a culvert and it is likely that a condition of consent will be to provide for fish passage. Fish passage is also a requirement under the Freshwater fisheries regulations (1983).

Culverts should be designed and installed correctly at the time of installation (see Speirs and Ryan 2006 for guidelines). However, overtime scouring can occur downstream of culverts leaving them perched. **It is the landowners responsibility to ensure that culverts continue to allow for fish passage** even if a consent was originally issued for the site or if it was considered a permitted activity at the time of installation. If a culvert becomes perched and does not allow for fish passage it no longer meets the permitted activity criteria and is therefore unlawful and requires remediation.

9 Summary

Polypropylene mussel spat ropes are a cost effective solution for addressing fish passage issues for some climbing species past perched culverts and for some swimming and climbing species through long difficult to access culverts that present a hydraulic barrier.

For culverts perched higher than 0.2m assume that ropes are only appropriate for improving passage for the following species: Longfin and shortfin eels, koaro, banded and shortjaw and to a lesser extent giant kokopu.

Use ropes to disrupt uniform flows in narrow difficult to access culverts longer than 3m with slopes greater than 1-1.5 degrees. Laboratory tests indicate improved passage for inanga, redfin bullies, trout and paratya shrimp.

Successful passage in roped culverts up to 6m long with 10 degree slopes have also been recorded for redfin bullies and inanga in a limited number of uncontrolled laboratory trials.

There are no data currently available for evaluating passage success with ropes for any fish or crustacean species in culverts longer than 6m and or steeper than 10 degrees. Recent work on ramps suggests ramp slope has a greater influence on passage success than ramp distance (Baker 2014).

Ropes are likely to be more appropriate for difficult to access (long narrow diameter) culverts (e.g. narrow diameters <1m) and or older culverts (pre 1984) where culvert capacity issues and pre-legislative requirements may prevent installation of other suitable options (e.g. baffles).

New culverts should be installed and sized appropriately to avoid passage issues in the future (e.g. perching). As a general rule, culvert diameter should approximate the average stream width immediately above and below the proposed culvert location to prevent the concentration of stream energy that leads to downstream scour.

Culvert size/capacity should be 10-20% greater than required for purely hydraulic purposes to allow for the installation of ropes and potential settling of substrates within the culvert base to improve passage (e.g. baffles and/or cobbles/ropes) and to offset lost stream productivity from pipe installation.

In some limited cases mussel spat rope may be a useful tool to remediate perched culverts in locations where only climbing fish species are expected.

Mussel spat ropes <u>can be</u> used to enhance fish passage where: -Culverts are perched and only climbing fish species are present -Culverts are not perched but are < 1m diameter, and or >3m long and or >1^{O} slope. **Mussels spat ropes <u>should not be</u> used to enhance fish passage when**: -Passage for non-climbing species is required past perched culverts -Culverts are > 1m in diameter unless other existing options are not suitable

Further Information

Other useful resources/publications:

Best practice guidelines for waterway crossings
http://www.waikatoregion.govt.nz/PageFiles/4998/TR0625R.pdf.

Fish passage for the Auckland region, a synthesis of current research which can be found at the following link:
http://www.arc.govt.nz/albany/fms/main/Documents/Plans/Technical%20publications/Technical%20reports/2009%2051-100/TR2009084%20Fish%20Passage%20in%20the%20Auckland%20Region.pdf

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Appendix 1. Example of intermittent fish passage.

While this culvert appears to be a barrier, monitoring above this structure indicates that a full size range of banded kokopu, shortfin, longfin eels and redfin bullies are present upstream. Other species that may be expected such as inanga, torrentfish and smelt were not detected. During periods intense rainfall water can flow over the road above the culverts and at times be seen seeping through below the structure. These situations may provide short term opportunities for fish to negotiate the structure in different ways and ultimately populate upstream areas. While freedom of passage for all species at all flows would be the ideal situation, limited passage opportunities may be sufficient for maintaining some fish species in some instances.

Appendix 2. Installation photos.

Upstream end. Install with metal stakes and thread rope through galvanised 'D' shackles that fit through top hole (left photo). Once threaded through hammer into bed and cover over (right photo)

Completed retrofit looking downstream (left photo) and upstream from within culvert (right photo). Note 'swimming lanes' formed by ropes.

View from below the culvert during installation (left photo) and completed retrofit (right photo)

Lake Harihari culvert before (left photo) and after (right photo). Installed for improved eel passage in 2009 following a netting survey which suggested poor recruitment of elvers to this lake. Assessment of the effectiveness of this retrofit is planned to occur in 2015.