Case study of the state of Fish Passage in a Plantation Forest Estate and the Most Effective Ways to Fix it

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Executive Summary

The implementation of the NES-PF (National Environmental Standards for Plantation Forestry) in May 2018 requires that new stream crossings must allow for the passage of fish. To date the majority of research on this issue in New Zealand, has been in urban settings. This work doesn't account for the cost and time constraints that occur in providing and maintaining fish passage in a large production forest roading network. Therefore, it is important to understand the predominate causes of loss of fish passage in plantation estates.

The data for this case study was collected over the summer of 2016/17 and 2017/18. The study is supported by NFL (Nelson Forests Ltd) and the area is the entirety of the NFL estate in the Tasman district. Data collection includes, crossing type, size and materials, fish passage status and NES-PF Erosion Susceptibility Classification.

Comparison of the NES-PF culvert construction rules and new national fish passage guidelines found that the embedment depth should be increased from the regulated 20% to 25-50%. It also found that the rest of the NES-PF culvert design rules are fairly concurrent with best practice guidelines.

Analysis of remediation methods for forestry usage found that the most effective remediation types in a forest environment are currently ramp fishways, baffles and mussel spat ropes. These methods should also be used in conjunction with each other and information on the species present in the waterway should be used to determine remediation requirements. Further studies are required to find longevity and economic value of different remediation combinations.

Analysis of the field data found that loss of fish passage occurred at a rate of 53% across the estate and that 93% of this loss occurs due to a perch in the system. These rates could be representative of plantation estates across the country and indicate this will be a significant issue faced by plantation forest managers as crossing infrastructure is replaced and upgraded.

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Introduction

By law, a river crossing for forestry is defined as any structure that is required for the operation of a plantation forest and provides for vehicles or machinery to cross over a water body. It also includes the apron, other structures and materials required to complete a river crossing. A river crossing doesn't include drainage infrastructure such as a storm water culvert or a culvert under a forestry road or track. A culvert is defined as a pipe or box structure that conveys a storm water flow under a forestry road or forestry track; or the entire structure used to channel a water body under a forestry road or forestry track. Therefore a river crossing can be a culvert but not all culverts are river crossings (NES-PF, 2017).

In the forest we use a wide variety of crossing structure types both temporary and permanent. When designing a river crossing it is important to consider how fish will pass through the structure. Maintaining fish passage in river crossings is extremely important as of New Zealand's 35 indigenous fresh water fish species, 18 are diadromous, meaning they undergo migrations between fresh and salt water as part of their life cycle (Boubée et al.,1999).

This is a case study on the state of fish passage, in a plantation forest estate. Data for this study was collected through a summer work project for NFL (Nelson Forests Ltd). The data collection was prompted by the following new rule in the Tasman Resource Management Plan (TRMP):

28.1.2.1 Permitted activities

> *Any activity in, on or under the bed of a river ….. is permitted if:*
>
> *(q) the design, placement and maintenance of any structure does not impede the passage of fish, except that in the respect of culverts, fords and flood gates existing as at 27 February 2010, this condition does not have legal effect until 5 years from its operative date. (Tasman Resource Management Plan, 2013)*

This section of the TRMP became operative on 8 March 2014, therefore the rule requiring that all structures in the beds of rivers provide for fish passage, comes into effect on 8 March 2019. As of September 2018 all initial field assessments have been completed, and a list of sites that need to be remediated had been compiled along with suggestions of possible options for each site. This list is now being used start remediation works.

Sites that need to be assessed were identified using NFL's stream classification system, with all class 1, 2 and 3 crossings identified as needing to be assessed. From the classification guidelines, class 1 streams are trout spawning areas, wetlands or important habitat corridors. Class 2 streams are known or highly likely fish habitats. Class 3 streams have high potential water flows and a potential to house fish. A fourth classification level also exists for small gullies and headwaters.

In this assessment, other data was also collected such as crossing type, dimensions, site photos, Erosion Susceptibility Classification (ESC) and soil type at site. An objective of this report is to find if loss of fish passage is more common at a particular crossing type, size or soil type. It also looks to find the most common way fish passage is lost in a large plantation forest estate. If a relationship was found it could be used to establish control sites in areas with different degrees of that characteristic present. This would be a more efficient way to monitor loss of fish passage across large estates.

The erosion susceptibility classification system was established within the NES-PF (National Environmental Standards for Plantation Forestry) and is used to determine the risk of erosion on any site within New Zealand. It uses environmental characteristics such as rock type and slope, to classify sites into 4 categories, low (green), moderate (yellow), high (orange), and very high (red) (NES-PF,2017).

The NES-PF, which came into effect on the 1st of May 2018, also requires:

40 Permitted activity condition: passage of fish

1. *River crossings must provide for the upstream and downstream passage of fish in rivers, except where the relevant statutory fisheries manager advises the relevant regional council in writing that to provide for the passage of fish would have an adverse effect on the fish population upstream of the river crossing.*
2. *River crossings must provide for fish passage by maintaining river bed material in any structure that would be in place of the river bed (NES-PF, 2017).*

This does not apply to existing river crossings, as defined below. However, fish passage must be maintained in new or upgraded crossings which over time would come to encompass all crossings in the estate. This could then discourage the upgrading or replacement of waterway crossings where fish passage would be too costly to occur.

existing river crossing—

a. *means a river crossing that was operational and able to be used at the commencement of these regulations; and*
b. *includes a river crossing described in paragraph (a) that is used and maintained; but*
c. *does not include a river crossing—*
    I. *that is described in paragraph (a) that is upgraded, removed, or replaced in accordance with these regulations; or*
    II. *that is a ford or a temporary river crossing (NES-PF, 2017)*

River is the only term used to refer to waterway's in the NES-PF. This definition has been interpreted by NFL as all class 1, 2 and 3 streams. However the Resource Management Act (2018) defines a river as **"**a continually or intermittently flowing body of fresh water; and includes a stream and modified watercourse; but does not include any artificial watercourse (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal)". With class 4 for small gullies and headwaters, some sites from this class should also be included in NES-PF fish passage compliance monitoring to ensure compliance.

Regulation 40(2) of the NES-PF appears vague in places and this report aims to better define what are acceptable remediations under this regulation. Would allowing rocks to congregate in the bottom of a culvert in a rocky stream sufficiently maintain the river bed material? Or in the future, should all culverts be open bottomed, half or box culverts, or be bridged?

Literature review

Waterway crossings acting as barriers to fish passage is an issue experienced by all managers who look after infrastructure that interacts with waterways. Much research has been done on this issue, especially across North America where there is a strong environmental focus on fish and waterways. In New Zealand the majority of information is produced by regional and district councils, DOC (Department of Conservation) and other environmental authorities. This also means much of the focus of this work has been in urban settings. There is minimal research on how this issue can be managed in a large remote roading network such as a New Zealand production forest estate.

American studies are also at a large scale such as (Maitland et al., 2016) which looks at the prioritization of culvert removals in the Boreal Forests of North America, where instead of performing remediations the culvert is simply removed and/or replaced with a bridge or open bottomed culvert. This study compared variables such as budget, individual barrier remediation costs, barrier passability and biologically relevant information to create guidelines for prioritization.

Another North American study (Anderson et al., 2012) looked at the difference between results obtained through different fish passage assessment methods. This found that the differentiating factor in fish passage assessments is the size and climbing ability of the fish the assessment is designed for. Therefore, the most effective assessment method would be to establish what species should be present in that catchment and gear the assessment towards their climbing abilities. Another study (Januchowski-Hartley et.al., 2014) used a combination of perch height and water velocity to predict fish passage. This study also used information about the common fish species swimming abilities to justify its results.

In the NFL Tasman estate the following native fish are expected to be present: Long Finn Eels, Koaro and Torrentfish (TDC, 2009). Other species which are also present in the estate are Dwarf Galaxias, Upland Bully and Brown Trout (TDC, 2011) . To better assess what a passable barrier in the Tasman estate would be defined as, the climbing ability of each of the above species should be assessed. The NES-PF fish spawning guide is also a tool which can be used to establish what species are likely to be present in a waterway.

Fish climbing abilities can vary greatly and these abilities can be put into 4 categories. Anguilliforms are able to respire oxygen as long as they remain wet, this allows them to worm their way through vegetation on the banks of the river and makes them more mobile. Common Anguilliformes are Eels (Shortfinned and Longfinned), juvenile Kokopu and Koaro. Torrentfish could also be considered Anguilliformes, though they have to stay submerged (Boubée et al.,1999).

Climbers are able to climb up waterfalls and rapids. They can do this as they have "sucker like" fins and other adaptions which allow them to climb. Common climber species are Lamprey, Elvers, juvenile Kokopu, Koaro and Shrimp. Jumpers are able to leap over waves and rapids and use this function to save energy in high velocity flows. The two key jumping species are Trout and Salmon.

The final category of climbing abilities are Swimmers, who like to avoid obstacles and require low flow areas to rest. Species in this category are Inanga, Smelt, and Grey Mullet. Swimming species are the most susceptible to loss of fish passage and therefore, the way loss of fish passage is most likely to occur is through a too high water velocity through the culvert or a large drop off within or at the end of the culvert (perch).

The New Zealand Fish Passage Guidelines for structures under 4m (2018) provides a summary of all known fish swimming speeds in New Zealand along with their movement type (Swimmer, Climber, Anguilliformes and Jumpers). It also gives a summary of the migration periods of key species, both are provided in appendix 3 and 4. This document also provides a table for calculating the maximum allowable water velocity that Inanga can swim against depending on the fish size and culvert diameter. This is provided below in Table 1. Inanga is a common study fish as it is often the worst swimmer in a catchment, and therefore the most susceptible to fish passage loss.

Table 1- Maximum allowable water velocity (Uw; m s-1) for a range of fish (Lf) and culvert sizes (L) for inanga. Maximum allowable water velocity should be calculated as the mean cross-sectional water velocity in the culvert.

		Fish length (mm)								
		40	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Culvert Length (m)	**5**	0.16	0.20	0.24	0.28	0.32	0.36	0.39	0.43	0.47
	10	0.13	0.16	0.20	0.23	0.26	0.29	0.32	0.36	0.39
	15	0.12	0.15	0.18	0.20	0.23	0.26	0.29	0.32	0.34
	20	0.11	0.14	0.16	0.19	0.21	0.24	0.27	0.29	0.32
	50	0.08	0.10	0.12	0.15	0.17	0.19	0.21	0.23	0.25
	75		0.09	0.11	0.13	0.15	0.17	0.18	0.20	0.22
	100			0.10	0.12	0.14	0.15	0.17	0.19	0.20
	150							0.15	0.17	0.18
	200									

The range of swimming and movement abilities in appendix 4 shows that there cannot be a nationally acceptable maximum perch height or velocity, as they are so species dependent. Therefore, establishing if remediation works are required should always be done on a case by case basis.

It is possible that the high velocity can cause stream bed erosion which in turn causes a perch. This perch further increases the water velocity at the outlet, causing the outlet to erode further, creating a pool. Therefore these two issues are often linked. There is no hard limit available providing a maximum acceptable perch or velocity but this information is available for most individual species.

When major barriers, such as dams, are removed, there is a risk of negative effects to native populations such as spread of disease, spread of invasive species and large sediment flushes

(McLaughlin et al., 2013). Therefore, before removing barriers where a native population is known to live upstream, an environmental group such as Fish and Game should be consulted.

Review of Culvert construction and design guidelines

The NES-PF has significantly tightened culvert design and other crossing design rules. This section looks to compare these tightened rules with the recommendations in New Zealand Fish Passage Guidelines for structures up to 4 meters, which is a new set of guidelines for fish passage best practice released in 2018. It was compiled by the New Zealand Fish Passage Advisory Group, NIWA (New Zealand Institute for Water and Atmospheric Research) and DOC. This section also provides examples of good culvert design and installation practices.

From the NES-PF, the culvert invert must be located so that at least 20% of the culvert's diameter is below the river bed level. The Guidelines increase this invert/embedment to 25-50% of culvert height, unless the culvert is open bottomed. This increase makes sense as it increases the amount of natural stream bed materials that can congregate in the bottom of the culvert. Natural Stream bed materials aid fish passage by providing rocks and other rough surfaces the fish can grip and/or hide behind while they rest. It also slows the water velocity by roughening the surface it flows over. Figure 1 shows a correctly inverted culvert which has now filled in to provide a natural streambed. This filling process can also be aided by Mannualy setting large material in the pipe, which will help maintain the streambed materials. This is shown in Figure 2.

Figure 1- Correctly inverted culvert (Pacific Watershed, 2018)

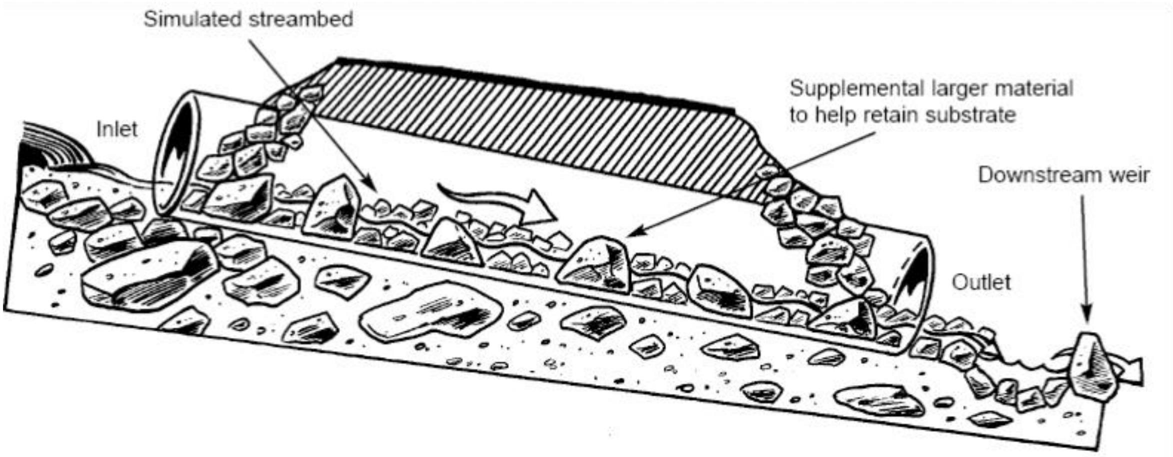

Figure 2- Illustration of how large rocks placed in a culvert can help stimulate streambed settlement in the pipe (British Columbia Ministry of Transport and Infrastructure, 2013)

In the NES-PF, for a single culvert the diameter must be at least 450mm, and where the bankfull channel width is 3m or more, the bed invert gradient must be no greater than 6%, measured 50m upstream and downstream of the river crossing. This is compared to the fish passage guidelines, which states alteration of the natural stream channel alignment and gradient should be avoided or minimised. This is less specific and should be simple to follow at most sites.

In more general terms culverts should be installed at a low angle to reduce velocity in the pipe. However, this gradient should be concurrent with the stream gradient either side of the crossing as shown in Figure 3. If this gradient is not kept consistent figure 3 shows it will quickly erode creating a perch.

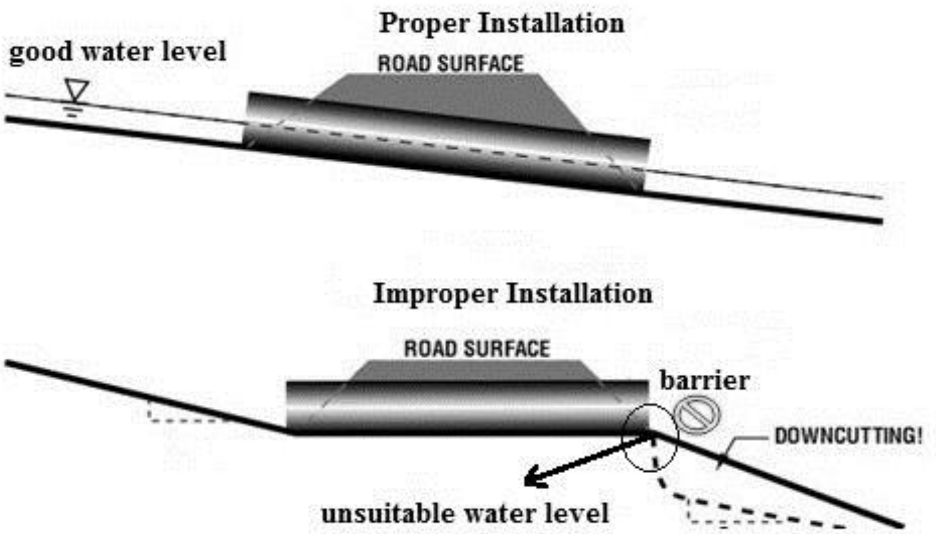

Figure 3- Example of prpper culvert installation when considering gradient (Nasiri et.al, 2012)

The broadest specification in the NES-PF for culverts is that the culvert inlet (entry point) and outlet (exit point) must be protected from erosion. A way this can be done is through the installation of a rock weir. These work by decreasing the stream gradient (and therefore velocity) and introducing a structure that fish can easily ascend. Figure 4 shows an example of how a rock weir can be designed. A rock weir also aids fish passage by slowing velocity in the pipe and providing resting places for the fish before they enter the culvert.

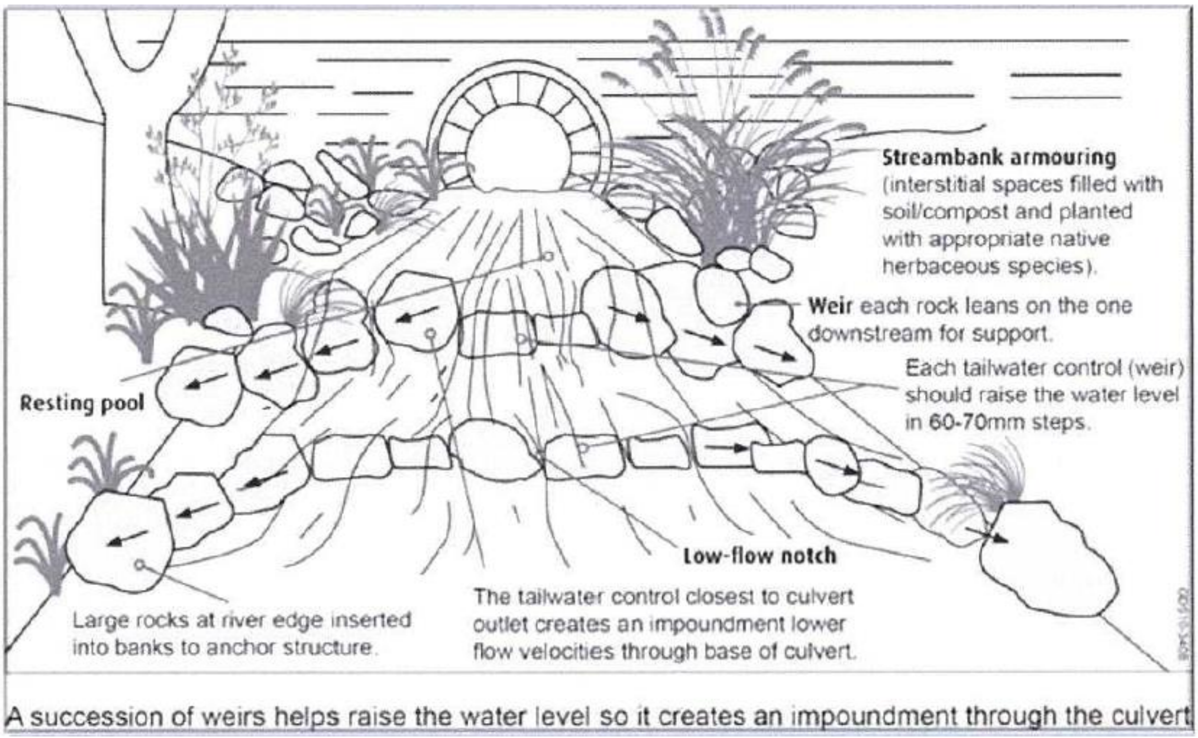

Figure 4- example of rock weir to reduce culvert outlet erosion (Culvert remediation - case studies, 2013)

Another way to mitigate fish passage disturbance in culvert installation is to try install outside of fish migration season so disturbances are occurring when fish are less likely to be around. These periods are broken down by species in Appendix 3.

When designing a waterway crossing where fish passage needs to be considered. Alteration of natural stream channel alignment and gradient should be avoided or minimised. The water depth in the pipe should be kept at least 150mm deep to maintain native fish passage. However, it is recognised that not all waterways have this much flow so it is also acceptable to maintain the mean cross-sectional depth of the adjacent stream reaches.

Other points included in the fish passage guidelines which are not included in the NES-PF rules are that bridges are always the preferred crossing type as they allow a large percentage of the streambed to remain undisturbed. The guidelines also emphasise consideration of minimum water depths, and velocities. Overall the NES-PF culvert design rules are fairly concurrent with best practice guidelines.

Remediation type comparisons for forestry uses

New Zealand takes a different approach to fixing passage barriers. Instead of removing the crossing or weir altogether it is recommended and acceptable to just remediate the barrier. There is a large amount of work by regional and national authorities that advises on how to manage and remediate fish passage. However, a majority of this is based on urban settings and not always appropriate to be applied over a large-scale forest estate. An example of this is that there are no provisions in most policy to differentiate between different size waterways, i.e. exclusion of intermittently flowing streams where fish presence is unlikely. Three National documents that provided recommendations of best practice for fish passage before the new national guidelines are: (David et al. 2014), (TDC, 2009), (Boubée et al.,1999). The preferred remediation method is removal but, in a forest environment this is rarely an option. Replacement with a bridge is an option in some cases. The New Zealand fish passage guidelines for structures up to 4 meters outlines the construction and acceptable uses of 4 different remediation and/or improvement methods. These are the installation of Ramp fishways, Mussel spat ropes, Baffles and Bypass structures. There is no set rules in the NES-PF regarding acceptable fish passage remediation methods.

The most common remediation method is the installation of a ramp fishway. They are predominantly used where a perch is present and there is a large vertical drop that fish cannot scale within the system. The guidelines consider a full width rock ramp the optimal design, however, for a forestry environment this solution requires a large amount or materials and labour. Therefore it should only be considered for sites where the perch is especially large. Figure 5 shows a full width rock ramp at low flows. Further design guidelines and recommendations can be found in the New Zealand fish passage guidelines for structures up to 4 meters.

Figure 5- concrete rock ramp (Franklin et al. 2018)

A more versatile and easier to install alternative to a concrete rock ramps are artificial substrate ramps (common forestry terminology calls them fish mats). These are typically made of rubber or another flexible material. Studies have found that effective substrate mats had an angle of 15° and only installed on drops up to 0.5m. Ramps should also be designed with a roughened surface to make it easier for fish to grip and a v-shaped cross section to provide a variety of water depths (Franklin et al. 2018).

An issue with artificial substrate mats is that they can break and be washed away in a flood. This is known to have occurred to one installed in the NFL estate 5 years ago. Therefore, sites with this remediation will still require a level of monitoring to ensure this hasn't occurred. Figure 6 shows a site in the NFL estate where TDC has installed an artificial substrate ramp (Fish Mat) on a perch of 3m. The left image was taken the summer of 2016/17 and the image on the right was taken summer 2017/18. As the rope which was holding the ramp out has snapped the ramp is now at an angle near vertical and will be ineffective. This crossing should never had this remediation type installed on it as its perch is greater than the 0.5m limit for this remediation type (Franklin et al. 2018).

Figure 6- Arial view of fish mat set up over a 3m perch

An area where there isn't a lot of information is the longevity of different fish passage remediations. An example of a remediation method which could be investigated, and a viable option if it has a long life span, is a cheaper version of the rock ramp, built with concrete or sandbags.

Baffles are commonly used at sites where there is a high water velocity that is restricting fish passage. They return fish passage by increasing boundary roughness, reducing water velocity, dissipating energy, developing flow patterns to guide fish, and to create low velocity resting zones for fish (Franklin et al. 2018) .

Like ramp fishways there are a multitude of designs available for baffles, depending on the objective. A baffle is a plate, block or still which is attached to the base of a culvert or other structure. Baffles are typically installed in a series throughout a pipe, and can encourage congregation of stream bed materials on the culvert floor. They are only recommended for use in pipes with a diameter greater than 1.2m. Baffles can also be used in conjunction with other remediation structures (especially fish rampways) (Franklin et al. 2018).

Figure 7 shows 4 baffle designs. Design (a) is a weir baffle and design (b) is an Alberta fish weir. Both these designs work by creating a series of mini weirs which will slow the water. However, weir style baffles are not currently recommended for use where the objective is to optimise fish passage success until further work is done to establish their performance relative to the preferred spoiler baffle designs(Franklin et al. 2018). Design(c) shows the preferred spoiler baffle which is more effective than a weir baffle as fish don't need to be able to climb, they can just weave between the barriers. The slotted weir baffle shown in design (d) slows the flow like a weir of Alberta fish weir baffle, but, leaves a gap for fish to swim through flush with the culvert bottom. This gives it easier fish passage for swimmers than designs (a) and (b).

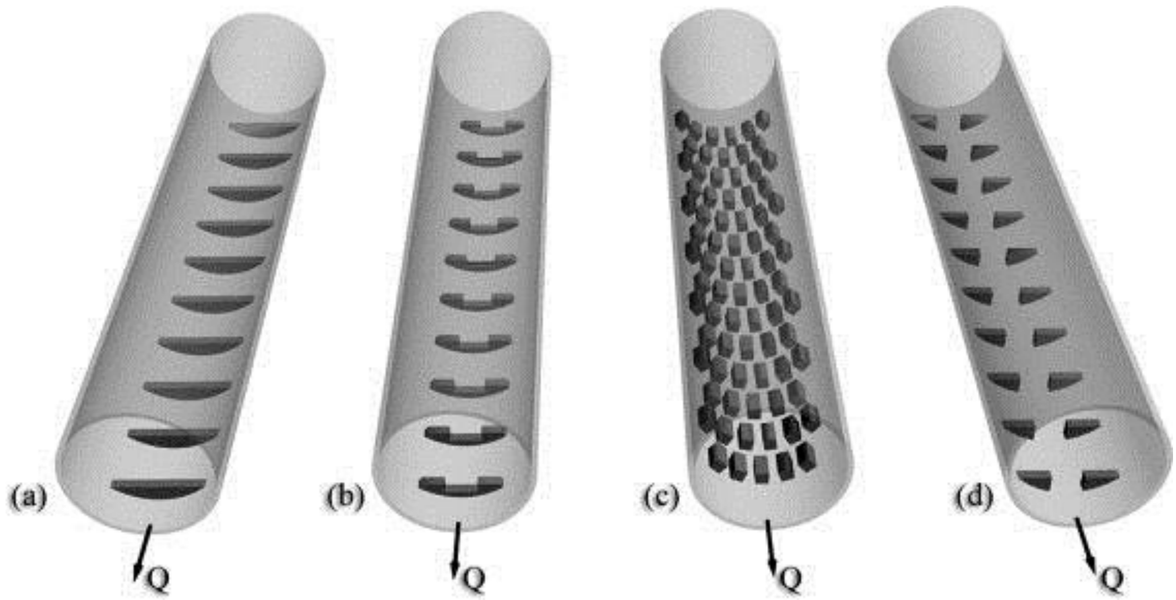

Figure 7- Diagram of different baffle designs(Franklin et al. 2018)

Mussel spat ropes are a good alternative to baffles where the pipe is less than 1.2m in diameter. They are also considered a low cost option, making them optimal for forestry usage. Mussel spat ropes (as the name suggests) are designed for mussels to spawn in and predominantly made of polypropylene with the fibres splayed out to create a bushy texture around the rope. When installed in a culvert fish can grip onto and hide in this rope, providing passage through the barrier.

A drawback of this remediation method is that its effectiveness is dependent on correct installation, and is only proven to be effective for small bodied fish. To install spat ropes correctly they should be installed at a ratio of 2 for every 0.5m of diameter, leaving a channel for fish to swim up between each rope. Knots can also be tied in the rope to break up the rope and create a rest area for fish. Like the artificial substrate mat there is a higher risk of damage and/or the ropes being washed away in storm events so sites with this remediation should be regularly monitored.

The final remediation type recommended in the fish passage guidelines is bypass structures. These are a last resort solution for when the fish passage barriers cannot be mitigated through any of the above methods. The two main types of bypass structures are Nature-like fishways, which mimic natural stream characteristics in an artificial bypass channel and Technical fishways. Technical fishways include vertical slot fishways, pool and weir fishways, and denil passes. Though these are widely used internationally, there are few examples of these in New Zealand. Most bypass structures require advanced engineering and come at a high cost. Therefore, in a forest location it would be more cost effective to just remove and/or replace the structure which is creating a barrier.

Method

Data for this study was collected via site visits to each site where field data was collected. This included culvert/crossing, diameter, length, type, existing fish passage problems and stream bed composition. The data collection sheet is shown in appendix 1 and was adapted from a form used for assessments by Tasman District Council. Photos were also taken at each site which show the crossing condition and surrounding vegetation.

The sites were identified by overlaying the fish stream and forest road layers in Arc GIS. This was the most efficient method to quickly identify each site. However, this method generated numerous unnecessary points which had to be removed either by site visits or colleague's existing site knowledge. These errors included stream or river access points, bridges and fords, as these are already compliant within this area of the estate.

The current study area is the NFL estate within the Tasman District, conditions in this area range from stable greywake geology to Moutere gravels and Separation Point Granites. Appendix 2 shows the location and assessment findings of all sites included in the study. It also shows a high concentration of sites in the central Golden Downs (Moutere Gravels). Figures 8 and 9 show 2 sites from the study area, and how they have now been fixed.

Figure 8- Large corrugated iron culvert with a medium perch, has had remediations which have washed away due to the high velocity of water.

Figure 9- 6 pipe concrete splash culvert, high velocity 0.3-0.5m perch and large sediment build-up upstream. Has now been replaced with bridge due to the large sediment build ups and regular flooding of this crossing

As sites were assessed and data was collected, key findings such as site location and ID, culvert diameter (if applicable) and fish passage status were combined in a spreadsheet to summarise the field work data to easily identify the sites with current fish passage blockages, Table 2 shows the spreadsheet categories and gives an acceptable data entry. The site locations and scans of assessment forms where then entered into FMIS (NFL's Forest Information Database) to make it easily accessible to all relevant parties across the company.

Table 2- Excerpt from data spreadsheet

Number	**Block**	**Stream name**	**Road name**	**Type**	**Diameter (mm)**
1	Kohatu		Neils Rd	single concrete culvert	1400
Fish Passage provided ? Y/N	**Issue**	**Minimum perch height**	**Reasoning?**	**date of assessment**	**Remediations done (date of check)**
n	Outlet Perched	500	Has high flow when in flood with high velocity	Nov-16	

The Data was then compared with any other data in the system. Standardisation of terminology and descriptions was necessary to allow countif functions to be used in excel and group data by text properties for analysis. This standardisation found that there are 6 different crossing categories with 14 configurations of these categories present in the estate. The 6 categories are concrete, plastic and corrugated iron pipes, concrete splash culverts, old railway tunnels and battery culverts (all concrete). Different configurations are the number of pipes of that type.

The GIS layer of site locations was then overlaid with NES Erosion susceptibility layer to find the erosion susceptibility rating of each site. These classes also dictate whether harvesting and other activities require resource consents.

Results

Initial data analysis found that 55% of the 75 crossings in the study area had a fish passage issue. This includes sites that have been remediated over the period of the study. Figure 10 shows the 7 different pipe and type combinations present in the estate and their prevalence.

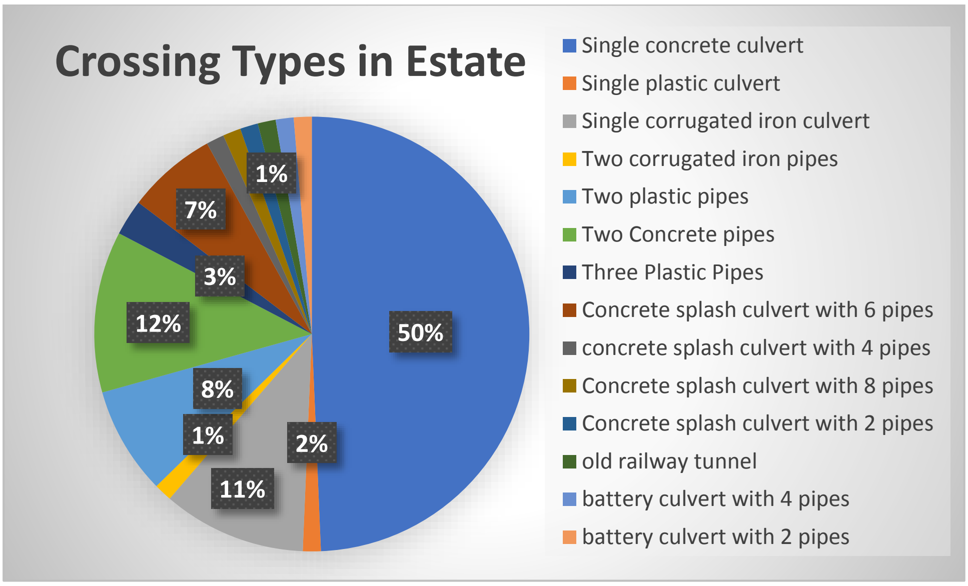

Figure 10- Pie Chart of crossing types in the estate

Table 3 shows what percentage of each crossing type has lost fish passage, with types occurring only once sorted to the other category. Single concrete culverts are by far the most common making up 49% of crossings. There are 4 other crossing types with a percentage share over 5%. These are a single corrugated iron culvert, two plastic culvert pipes, two concrete pipes and a concrete splash culvert with 6 pipes. All other culvert type and pipe combinations do not occur enough to draw conclusions from their fish passage status.

Table 3- Break down of crossing type and percentage with issues

crossing infrastructure breakdown	Count	Percentage	Percentage with Passage loss
Single concrete culvert	37	49%	70%
Single corrugated iron culvert	8	11%	38%
Two plastic pipes	6	8%	17%
Two Concrete pipes	9	12%	22%
Three Plastic Pipes	2	3%	50%
Concrete splash culvert with 6 pipes	5	7%	60%
Concrete splash culvert 2, 4 or 8 pipes	3	4%	67%
Other	5	7%	40%

The final column of table 3 show the percentage of crossings in each category that has lost fish passage. Compared with the estate average of 53%, single concrete culverts have a high rate of loss with 70% of crossings losing passage. This is not surprising as many of the crossings in this category are very old, at least 2 rotations (50 years). Figures 11 and 12 show two old single pipe concrete culverts and how they have developed perches of different heights over time.

Figure 11- Single 1200mm concrete culvert with a large perch which flows over a rock face. Primary remediation method is through spat ropes.

Figure 12- this medium size concrete culvert has a small perch and overhang. It was easily remediated trough the installation of a fish mat and Spat ropes.

A majority of new crossings were two concrete pipes or plastic pipes, which had a lower than average loss of fish passage of 22% and 17% respectively. For concrete splash culverts with 6 pipes, loss of fish passage is higher than average at 60%. The type with the lowest percentage loss is single corrugated iron culverts, which despite being older, tend to be larger and maintain a flush with the stream bed.

Table 4 examines whether crossings with more pipes, (typically wider and potentially better designed to fill the stream channel) more readily lose fish passage. It shows that single pipes have a higher occurrence of losing fish passage than any other pipe configuration.

Table 4- Crossing breakdown by number of pipes

Number of pipes	Count	Percentage with passage loss
1	47	62%
2	18	17%
3 or more	10	50%

This is likely as, as mentioned above, new culverts tended to be two concrete pipes, as shown in Figure 13. There is also a chance that only 1 pipe is a barrier at 2 pipe crossings.

Figure 13- Newly installed concrete 2 pipe crossing. Second pipe is lower to aid fish passage

Table 5 assesses the effect of material on fish passage. It finds that concrete crossings have the highest percentage of loss with 61%. This is likely caused by the large portion of single concrete pipes which have fish passage issues.

Table 5- Breakdown of passage issues by material

crossing infrastructure material	Count	Percentage of count
concrete splash culverts	8	50%
concrete	46	61%
corrugated iron	9	44%
plastic	9	33%

Comparing Erosion Susceptibility Classifications (ESC) in table 6, found that sites with a high ESC did have a much higher loss of fish passage with 85% of sites losing passage. Sites with a low ESC had a slightly higher occurrences of fish passage loss. However, many low sites sat in gullies with moderate classed hills surrounding them, making these ratings interchangeable in places.

Table 6- Breakdown of passage loss by Erosion Susceptibility classification

ESC	Count	Percentage with passage loss
Low	26	50%
Moderate	37	46%
High	12	83%

There were found to be 7 different causes of loss of fish passage with the most common one being an outlet perch. Table 7 shows that a perched apron was the most common cause for loss of fish passage in concrete splash or batter culverts and this makes up 13% of passage loss. The next most common cause of fish passage loss was both an inlet and outlet perch. This shows that the most common cause of loss of fish passage is a perch and remediations for this are the most important.

Table 7- Breakdown of passage restriction by cause

Passage restriction	count	Percentage
outlet perched	27	68%
perched apron	5	13%
blockage and high erosion	2	5%
inlet perched and outlet perched	3	8%
Other	3	8%
Total	40	

The issues at the sites in the other category were a perch at both the outlet and in the middle, the culvert was blocked, and the culvert being blocked and damaged. Figure 14 shows an example of how a concrete splash culverts apron becomes a barrier to fish passage.

Figure 14- 4 pipe concrete splash culvert, apron slows velocity, but, creates small perch which has been remediated through creating a rock ramp at one end

For the sites which were found to be perched, 28 have had their perch heights recorded. A key cause of missing data was lack of access. For perched sites the average perch height was found to be 300mm. However, there is a clear outlier data point, so excluding the outlier the average perch height was found to be 280mm. Figure 1 clearly shows the outlier point, it also shows there is no clear relationship between culvert diameter and perch height.

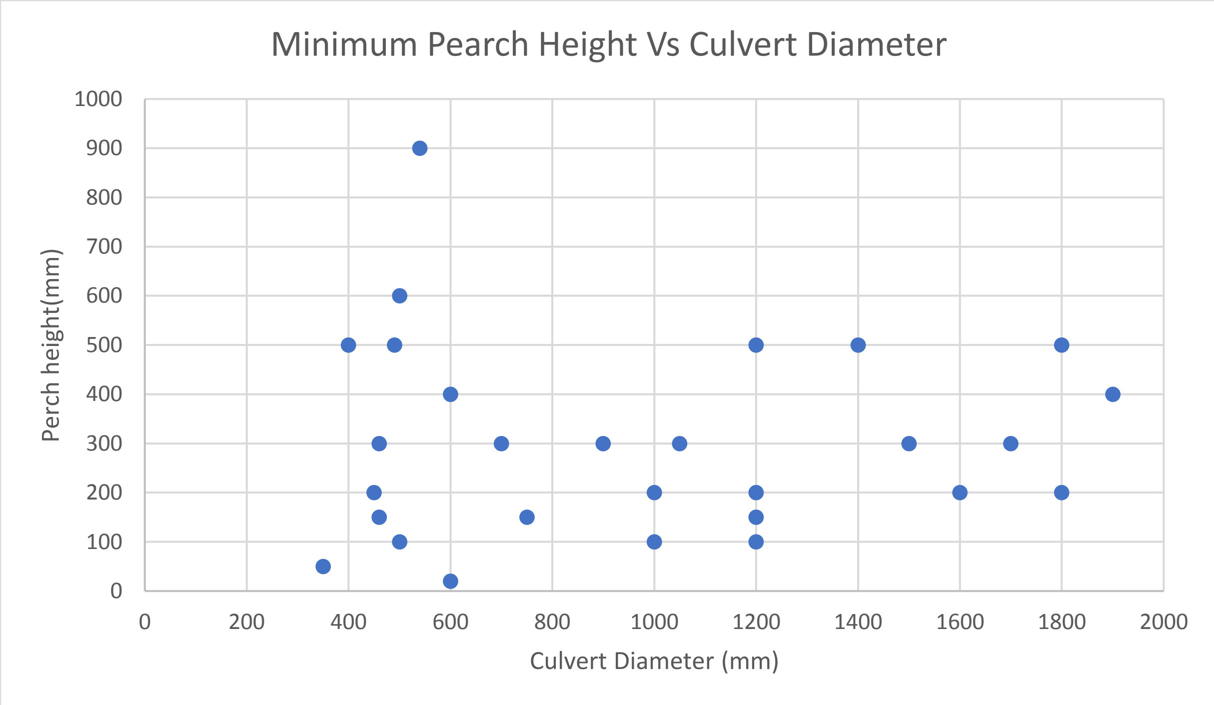

Figure 15- Graph of perch heights and culvert diameters

Discussion

The loss of fish passage across the estate rate of 53% indicates that many old New Zealand Forest estates could have similar rates of culverts without fish passage. The fact that 93% of crossings lost passage through a perch indicates that this is likely the case across the country and this is the area where further research into remediation cost, longevity and effectiveness is vital. This study area would be a good place to start this research as remediations (particularly fish mats) are currently being installed and they could be monitored over the next 5-10 years to see how they last.

From the breakdown of crossing assessment data, the only factor found to have a clear relationship with loss of fish passage was the ESC of the site. Therefore, there is likely other factors which were not considered in this study that are contributing to loss of fish passage. A factor which was considered but not include in this study was crossing infrastructure age. It was not included as for many sites it would have to be an estimate. Many crossings in the study area are at least 50 years old and there are no Forest Service records of when they were installed.

Another factor not considered is the flow velocity through the pipe. Even though there was a basic flow measure (low, normal or high) on the assessment sheet there were no measurements taken and to accurately measure the velocity measurements need to be taken at different flows. High Velocities, as well as causing loss of fish passage by themselves, can cause erosion and increase perch heights.

The breakdown of crossing types in the estate shows that traditional concrete culverts are still dominant, and as fish passage loss was most prevalent in this crossing type, there needs to be a greater focus on installing crossing infrastructure which is more inclined to maintain the stream bed material such as box culverts and drift decks.

Contrary to its objective, this case study shows that even once remediations have been completed, monitoring is a continual process which we can use to make the remediations we install more effective and last longer.

Conclusion

Comparison of the NES-PF culvert construction rules and new fish passage best practice guidelines found that to give a new culvert fish passage longevity, emphasis should be put on retaining the streams gradient and maximizing embedment percentage. The requires embedment depth is 20% but best practice is 25%.

There are three key remediation methods in a forest environment which are, ramp fishways, baffles and mussel spat ropes. These options should be considered in conjunction with each other and monitored after installation. A good area of future study would be to monitor the longevity of different remediation methods in a forestry environment and consider if more robust designs could be implemented to increase longevity and reliability.

Key findings from the field data are that 93% of sites lost fish passage through a perch somewhere within the system. The other key findings are that 53% of sites were found to have a loss of fish passage and the average perch height is 300mm. This indicates it is a significant issue and other estates in New Zealand could have similar rates of passage loss.

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Appendix 1

Fish Passage - Field Sheet

Stream Name: ______________ **Road name:** ______________

GPS Co-ordinates: **E** ______________ **N** ______________

Date: ______________ Recorded by: ______________

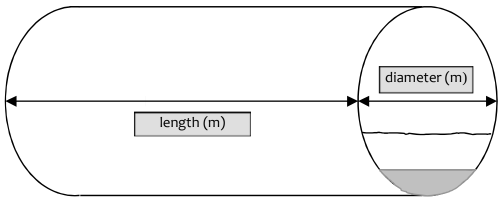
Crossing Type		**Material Type**		**Crossing Type**			
Bridge	◯	Concrete	◯	**Single culvert**	◯		
Culvert	◯	Corrugated Iron	◯	Multi-barrel	◯	No. of pipes	☐
Culvert & weir	◯	Steel	◯	Box culvert	◯		
Weir	◯	Plastic	◯	Ford/multi-barrel	◯	Apron?	☐

Culvert dimensions

Height (m): ______________

Length (m): ______________

Diameter (m): ______________



Site/stream crossing diagram

Culvert Inlet & Outlet details

Inlet		**Outlet**	
Flat	○	Flat	○
Perched	○	Perched	○
Pooled	○	Pooled	○

For perched culverts provide an estimate of water fall (for multiple culverts only note maximum):

Overhang height (m) ____________________ Undercut length (m) ____________________

Blockages

Inlet blocked	○	Blocked with	____________________	Blockage cleared	○
Outlet blocked	○	Blocked with	____________________	Blockage cleared	○
Inside blocked	○	Blocked with	____________________	Blockage cleared	○

Water flows

High Flow ○ Normal flow ○ Low flow ○ No flow ○

Fish passage restrictions

All flows ○ High flows ○ Low flows ○ Most flows ○ None ○

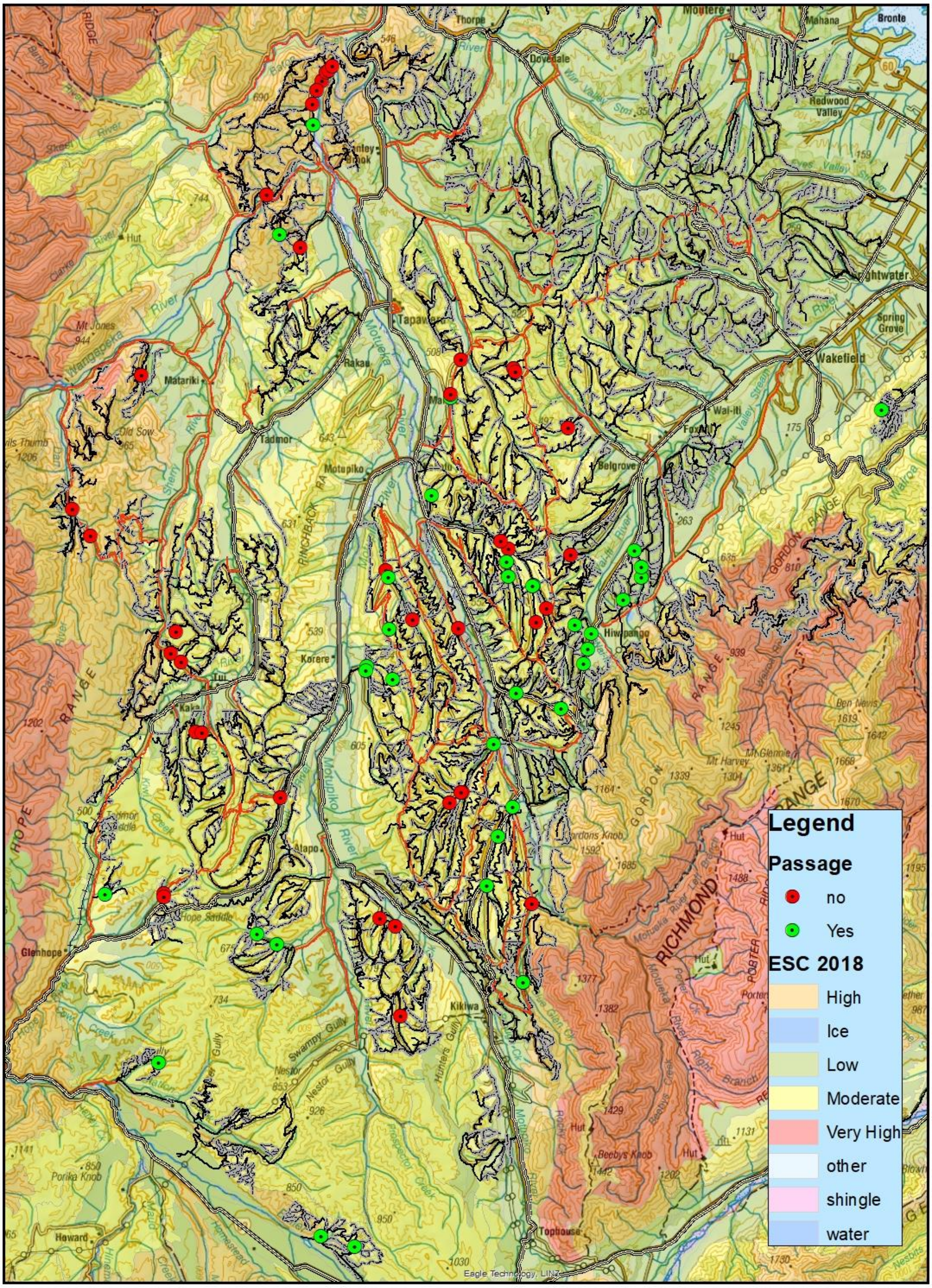
Stream bed material %

Silt/Mud ____ Sand ____ Gravels ____ Cobbles ____ Boulders ____ Bedrock ____

Comments

Appendix 2

Map of Erosion Suceptability Classifications and passage status across the estate



Appendix 3

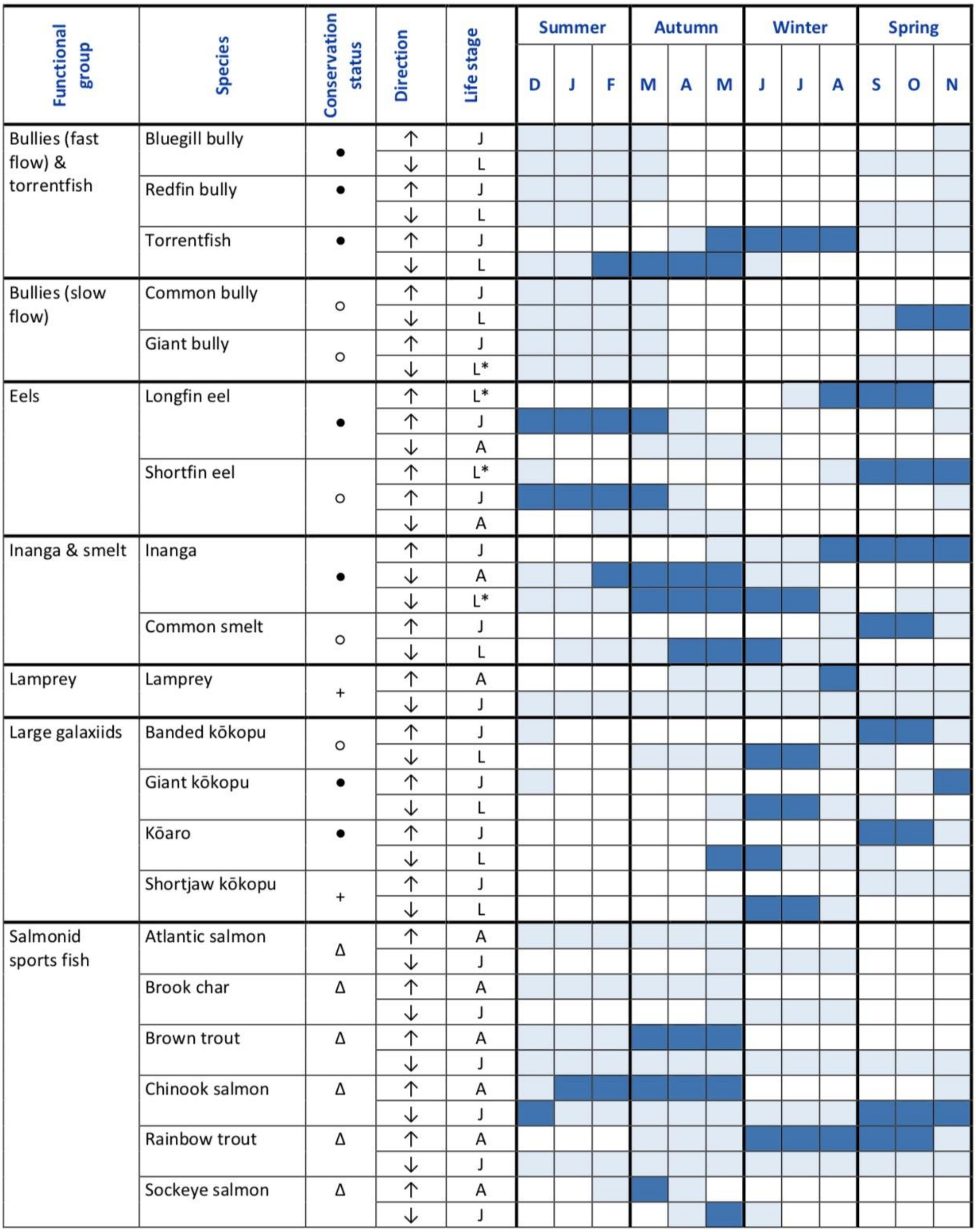


Figure D-3: Freshwater fish migration calendar for key New Zealand fish species. Showing migration range (light blue ▪) and peak periods (dark blue ■), migration direction and life stage at the time of migration. ○ Not threatened; ● At risk declining; + Threatened nationally vulnerable; Δ Introduced sports fish. Life stages: L = larval, J = juvenile, A = adult. * indicates the life-stages that are present only within the lower reaches of rivers and streams. Modified from Smith (2014).

Appendix 4

Table D-1: Summary of fish swimming data for NZ species. Where possible equations are given for fish swimming speed (U or U_{crit} for critical swimming speed) in terms of fish length (L for total length or L_f for fork length) and swimming time (t for swimming time or t_f for specifically time-to-fatigue). Comments are given on the mode of fish swimming, and the level of standardisation of the experimental methods. It is important to note that the values given in the table are relative to water velocity, and are not fish velocity over the ground. Design velocities must consider that a fish must first exceed the water velocity before it can make any headway upstream.

Species	Size (mm)	Swimming speed ($m\ s^{-1}$)	Comments	Source
Inanga	52-73	0.19	Non-standard method. "Sustained" swimming.	Mitchell (1989)
Inanga	52-73	0.36	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Inanga	52-73	0.47	Non-standard method. "Burst" swimming.	Mitchell (1989)
Inanga	50	1.09 @ 5s 0.60 @ 20s	$U=14.4L^{0.63}.t^{-0.43}$ Non-standard method. Burst swimming.	Boubée et al. (1999)
Inanga	72	1.37 @ 5s 0.76 @ 20s	$U=14.4L^{0.63}.t^{-0.43}$ Non-standard method. Burst swimming.	Boubée et al. (1999)
Inanga	48 ± 2.5 (SD)	0.62 @ 5s 0.46 @ 20s 0.36 @ 1min 0.25 @ 5min	$U=8.86L_F^{0.76}.t_f^{-0.22}$ for t_f 1 to 400 s. Fixed velocity tests. Burst to prolonged swimming. Temperatures 16-22°C.	Nikora et al. (2003)
Inanga	62 ± 6.5 (SD)	0.75 @ 5s 0.55 @ 20s 0.43 @ 1min 0.31 @ 5min	$U=8.86L_F^{0.76}.t_f^{-0.22}$ for t_f 1 to 400 s. Fixed velocity tests. Burst to prolonged swimming.	Nikora et al. (2003)
Inanga	92 ± 10.3 (SD)	1.01 @ 5s 0.75 @ 20s 0.59 @ 1min 0.41 @ 5min	$U=8.86L_F^{0.76}.t_f^{-0.22}$ for t_f 1 to 400 s. Fixed velocity tests. Burst to prolonged swimming.	Nikora et al. (2003)
Inanga	84 ± 8.5 (SD)	0.48 @ 37s (SD 40) 0.60 @ 21s (SD 13)	Time to fatigue fixed velocity test. Prolonged swimming mode.	Plew et al. (2007)
Inanga	47-50	0.25	Critical swimming speed. $U_{crit\ max}$ @ 17.7°C. 0.5 BL s^{-1} increments every 15 min. Decreased U_{crit} at higher and lower temperatures. Hypoxia reduced U_{crit} at temperatures > 15°C.	Bannon (2006)
Inanga	39-40	0.22	Critical swimming speed. $U_{crit\ max}$ @ 9.4°C Decreased U_{crit} at higher and lower temperatures.	Bannon (2006)
Inanga	55-68	0.25	Critical swimming speed. $U_{crit\ max}$ @ 18.3°C Decreased U_{crit} at higher and lower temperatures.	Bannon (2006)
Common bully	30-42	0.24	Non-standard method. "Sustained" swimming.	Mitchell (1989)
Common bully	30-42	0.28	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Common bully	30-42	0.60	Non-standard method. "Burst" swimming.	Mitchell (1989)
Banded kōkopu	44-55	0.19	Non-standard method. "Sustained" swimming.	Mitchell (1989)
Banded kōkopu	44-55	0.29	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Banded kōkopu	44-55	0.43	Non-standard method. "Burst" swimming.	Mitchell (1989)
Smelt	56-67	0.19	Non-standard method. "Sustained" swimming.	Mitchell (1989)
Smelt	56-67	0.27	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Smelt	56-67	0.50	Non-standard method. "Burst" swimming.	Mitchell (1989)
Smelt	70	1.35 @ 5s 0.74 @ 20s	Non-standard method. $U=14.4L^{0.63}.t^{-0.43}$ "Burst" swimming.	Boubée et al. (1999)
Shortfin eel	55-80	0.20	Non-standard method. "Sustained" swimming.	Mitchell (1989)

Species	Size (mm)	Swimming speed (m s^{-1})	Comments	Source
Shortfin eel	55-80	0.34	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Shortfin eel	55-80	0.57	Non-standard method. "Burst" swimming.	Mitchell (1989)
Shortfin eel	54	0.29	Max "sustained swimming" speed. 30 min.	Langdon and Collins (2000)
Shortfin eel	54	0.29-0.35	"Steady prolonged". 3 - 30 min.	Langdon and Collins (2000)
Shortfin eel	54	0.35-0.64	"Rapid prolonged". 24 - 180 s.	Langdon and Collins (2000)
Shortfin eel	54	0.64-0.79	"Burst swimming" speed. 3 – 2.4 s.	Langdon and Collins (2000)
Shortfin eel	746 ± 25 (SE)	0.74 ± 0.03 (SE)	Critical swimming speed. 0.1 m s^{-1} increments at 20 min intervals.	Tudorache et al. (2015)
Shortfin eel	746 ± 25 (SE)	0.51 ± 0.02 (SE)	Swimming speed with minimum energy consumption (U_{opt}).	Tudorache et al. (2015)
Koaro	50-100	0.40-0.64	"Critical swimming speed", non-standard method. 12hr fixed velocity tests. U_{crit} defined as water velocity with 60% mortality. 14°C.	Moffat and Davison (1986)
Grey mullet	25-45	0.12	Non-standard method. "Sustained" swimming.	Mitchell (1989)
Grey mullet	25-45	0.2	Non-standard method. "Prolonged" swimming.	Mitchell (1989)
Grey mullet	25-45	0.35	Non-standard method. "Burst" swimming.	Mitchell (1989)
Rainbow trout	70 ± 5 (SE)	0.41	$U_{crit\ max}$ @ 15.1C. U_{crit} declines with increasing or decreasing temperature & hypoxia at 20°C.	Bannon (2006)
Roundhead galaxias	5.5-7.5	0.037 ± 0.010 (SE)	Critical swimming speed. 0.02 m s^{-1} increments at 2 min intervals.	Jones and Closs (2016)
Taieri flathead galaxias	7-8	0.068 ± 0.013 (SE)	Critical swimming speed. 0.02 m s^{-1} increments at 2 min intervals.	Jones and Closs (2016)
Eldon's galaxias	8-10	0.057 ± 0.005 (SE)	Critical swimming speed. 0.02 m s^{-1} increments at 2 min intervals.	Jones and Closs (2016)
Dusky galaxias	8-11	0.068 ± 0.024 (SE)	Critical swimming speed. 0.02 m s^{-1} increments at 2 min intervals.	Jones and Closs (2016)

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Species	Size (mm)	Swimming speed (m s^{-1})	Comments	Source
Canterbury galaxias	64-77	1.08 ± 0.065 (SE)	Non-standard method. Burst swimming. n=4. t=5-20 s.	NIWA unpublished data
Canterbury galaxias	62-69	0.88 ± 0.034 (SE)	Non-standard method. Prolonged swimming. n=14. t=25-600 s.	NIWA unpublished data
Bluegill bully	53-63	0.78 ± 0.065 (SE)	Non-standard method. Burst swimming. n=4. t=10-15 s.	NIWA unpublished data
Bluegill bully	38-64	0.37 ± 0.040 (SE)	Non-standard method. Prolonged swimming. n=10. t=30-600 s.	NIWA unpublished data
Upland bully	55-60	0.32 ± 0.037 (SE)	Non-standard method. Prolonged swimming. n=4. t=40-165 s.	NIWA unpublished data
Common bully	51-67	0.64 ± 0.107 (SE)	Non-standard method. Burst swimming. n=5. t=10-20 s.	NIWA unpublished data
Common bully	51-66	0.43 ± 0.065 (SE)	Non-standard method. Prolonged swimming. n=5. t=29-508 s.	NIWA unpublished data

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Appendix 5- Fish passage site compendium

Figure 16- This medium size concrete culvert has a small perch and overhang. It was easily remediated trough the installation of a fish mat and Spat ropes.

Figure 17- This concrete splash culvert with 8 pipes regularly blocks in flood events. It also has a high velocity which is increased by the lack of friction in the concrete pipes. Could be fixed through replacement or slowing the velocity in one pipe to aid fish passage.

Figure 18- These three plastic pipes were a temporary culvert and have now been removed. Their passage issue is that they are perched with an overhang.

Figure 19- This crossing is a concrete splash with 2 pipes. It has been damaged and has a large overhang, perch and velocity in 1 pipe while the other is blocked by a silt build up. This needs to be pulled out and replaced with a culvert designed for greater capacity.

Figure 20- Single concrete culvert has large silt build up at inlet and large perch and overhang at outlet. Outlet is good for fish mat and spat ropes.

Figure 21- Inlet of these 2 plastic pipes are blocked with woody debris do not appear to sit in a defined stream channel. The road has been eroded away when this crossing floods. The outlets are also perched and have an overhang.

Figure 21- This large concrete crossing with 3 pipes has an apron with a small perch on the outlet this perch could be quickly built up with a rock ramp.

Figure 23- This double concrete culvert is perched and overhung. It has already been remediated with a fish mat.