Fish Passage in the Forestry Environment

A study of instream structures within Tairua Forest

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Acknowledgments

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Executive Summary

Fish passage at stream crossings is an issue that is front of mind to many forestry professionals. With an estimated 25,000 km of forest roads in New Zealand and 1500 km more constructed every year, stream crossings are inevitably part of daily forestry activities. Freshwater fish passage in the New Zealand forestry context has great importance to the many endangered freshwater species. While forestry practitioners realise that fish passage needs to be considered when designing and maintaining instream structures, the importance of effective fish passage may not be as well-known.

This report is an investigation of the issues around fish passage as well as the performance of current stream crossing infrastructure, using Tairua Forest as a case study area. The following questions were proposed to guide this research:

- What native freshwater fish species are present within Tairua Forest and what are their fish passage requirements?
- How does the current state of crossing infrastructure meet these requirements within Tairua Forest?
- To what extent do instream structures affect interconnection of fish habitat?
- How can fish passage remediation be prioritised?

To identify the fish passage requirements of structures, the swimming ability of the species presented was investigated. The swimming ability of fish falls into four categories listed from least to most sensitive to structures as an obstacle to fish passage: anguilliforms (Eels), jumpers (trout), climbers (bullies), and swimmers (Inanga). Where swimmers are present, structures must not have any vertical drop (perch), require the velocity of water through the structure to be less than the burst swimming speed of the species and provide rest pools. Climbing species can use the wetted edge of the structure to pass greater velocity within structures. However, climbers cannot pass the laminar flow of perched structures, especially if they are undercut as well. As jumping species are predominantly non-native and predate on native fish they are not accounted for when considering fish passage requirements. Anguilliforms can absorb air through their skin allowing them to travel over land if their skin and the land remains wet. Hence these species are often not obstructed by instream structures.

Tairua Forest is 12,600 ha and contains 29 piped structures, one drift deck, and four ford crossings. Using the New Zealand Freshwater Fish Database (NZFFD) and eDNA, nine fish species were identified within the forest. Of these species, seven migrate upstream during the lifecycle and five carry the conservation status “At Risk Declining”. Only one species was non-native.

When surveying existing stream crossings for fish passage, limited resources provide an opportunity for developing a priority system based on the understanding of what effect the lack of fish passage has on a waterway and a catchment. Within Tairua Forest, it was identified that there are nine catchments containing structures. The length of potential habitat in each catchment was measured using the River Environment Classification New Zealand (RECNZ) map from NIWA and found to be 580 km. The largest catchment was Tairua River with 330 km of potential habitat and the smallest was Gumdigger Gully with 5 km of potential habitat. The length of potential habitat above each structure was also measured showing the potential habitat loss that can occur due to a lack of fish passage. The total potential habitat upstream of all structures in Tairua Forest is 117 km, this is 20% of the potential habitat across all nine

catchments. In a survey of the crossings, of the 35 stream crossing structures 16 were perched and the total potential habitat upstream of perched structures is 13.7 km.

Using the length of potential upstream habitat and the network position of the structures with the attributes of the fish species present, structures can be given a level of relative importance. A list of the top six priority structures was created. Interestingly, none of these structures were culverts; all four fords, a battery culvert, and a drift deck. These structures are often overshadowed by culverts when considering fish passage, but as seen in this research they are the most important for migratory fish as they are the gateway to the greatest amount of habitat. Fords are more often barriers to fish passage due to the often-low water depth across them. They also lack complex flows for swimming species to use when passing them. While none of these fords were identified as having perch, they are likely restricting fish passage for some species.

Knowing the location and extent of these issues is a good starting point, but there is an opportunity to implement proven remediation methods. Fish passage remediation is part science and part art; it requires a level of creativity accompanied by understanding the physics of fish swimming capabilities. Reviewing other fish passage remediation attempts and learning from them is recommended. Learnings can be made about features that worked and what did not.

While nearly every crossing structure is going to have different requirements, the main goal is to make the water through a crossing structure simulate the natural waterway as much as possible. Within the scope of this project a priority system tool, based on the potential upstream length and network position matrices, was used for improving the fish passage performance of instream structures. This allows modifications to be made which best meet fish passage requirements based on where it is within the catchment and within the current structure network. Finally, surveying fish species presence and understanding the abilities of the species found is one of the most important methods in ensuring effective fish passage.

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1 Introduction

Fish passage is an issue that is front of mind to many forestry professionals. With an estimated 25,000 km of forest roads in New Zealand and 1500 km more constructed every year (NZFOA, 2020b). Stream crossings are inevitably part of daily forestry activities. Freshwater fish passage in the New Zealand forestry context has great importance to the many endangered freshwater species. Many forestry practitioners realise that fish passage needs to be considered when designing and maintaining instream structures. However, the importance of effective fish passage and the effects of a lack of fish passage may not be as well-known. As such this research project is an in-depth investigation of the issues around fish passage as well as the performance of the current stream crossing infrastructure. This report covers Tairua Forest, a 12,600 ha plantation forest in the Coromandel District, Waikato.

1.1 Aim of Research

This research project aims to gain insight to fish passage requirements both from a legislative and practical perspective. The research should also broadly identify fish species present in New Zealand and specifically in Tairua Forest including their habitat, conservation status, numbers, and swimming ability. The stream crossing infrastructure Tairua Forest should also be summarised with regard to fish passage. A successful research project will answer the following questions:

- What native freshwater fish species are present within Tairua Forest and what are their fish passage requirements?
- How does the current state of crossing infrastructure meet these requirements within Tairua Forest?
- To what extent do instream structures affect the interconnection of fish habitat?
- How can fish passage remediation be prioritised?

2 Review of Literature

This section looks at current regulations and best management practices for fish passage in New Zealand and explores the current understanding of the types of native fish in New Zealand waterways. The habitat of these fish and their swimming capabilities are also researched. A large part of understanding native fish is sampling, sample methods are also covered in this section.

2.1 Overview

There are currently 74 species of freshwater fish in New Zealand of which 51 are native. 67% of native species are considered threatened or at risk (Allibone et al., 2010). It is clear that protecting these rare native fish is vital. Creating barriers for New Zealand native fish is problematic as many rely on migration to complete their lifecycle. This can be moving between fresh water and the ocean to spawn or between habitats within the freshwater system (DoC, 2021*-b). Native fish populations are already rare, and their population continues to decline. Many factors contribute to the declining populations of native fish. A large contributor is the loss of habitat such as the clearing of bush that fish require for shelter and food. 90% of New Zealand's wetlands have been drained which is an important habitat for many native species. Non-natural structures acting as barriers to fish passage also add to declining populations (SLU, 2017). Pollution, fishing, and exotic fish species have and continue to harm native fish populations.

Fish passage requires connectivity within a waterway that allows fish to reach critical habitats. Man-made structures act as barriers to fish passage by reducing connectivity (NIWA, 2016). U.S. Fish and Wildlife Service provide a definition of a 'barrier' to fish passage. "A barrier is anything that prevents or reduces the ability of aquatic species to move where needed to survive and complete their life cycle. This includes physical barriers, such as dams, culverts, and levees, and environmental barriers such as excess sediment, poor water quality, and temperature or flow variations" (USFWS, 2021*). Man-made structures impede fish passage in different ways. The main issue is excessive water velocity and drops, structures can also alter the flow patterns of streams (NIWA, 2016).

Within streams, there are many natural challenges such as waterfalls. Some native fish species spend their entire lives protected by these natural barriers such as non-migratory galaxiids and mudfish (Franklin et al., 2018). In some cases, man-made structures can create unnatural fish passage which allows exotic species to move and threatens these native fish. Species such as Salmon, Trout and Koi carp predate on native fish and removing passage for these species can help to protect native populations (Franklin et al., 2018).

A study of fish passage was conducted by Georgie Holdaway (2018). She surveyed culverts within the One Forty One Estate (formerly Nelson Forests Ltd.) in the Tasman district with the aim of finding the state of fish passage in plantation forestry. The study looked at 75 culverts with the estate and it was found that 53% of the culverts were a barrier to fish passage within the rules of the NES-PF. Of the culverts presenting barriers to fish passage, 93% were due to perch. Holdaway concluded that to mitigate fish passage loss, the recommended embedment depth of a culvert should be increased from 20% to 25-50% in the NES-PF (Holdaway, 2018).

2.2 New Zealand Freshwater Fish

To understand what limits fish passage, the swimming ability, migratory patterns, and habitat of fishes must be known. The most well-known native freshwater fish species in New Zealand are eels and galaxiids. Five species of galaxiids are known as whitebait, and have been part of commercial and cultural fisheries for many years (NIWA, 2021*-b). A large proportion of New Zealand's freshwater fish species are diadromous, meaning they have a marine phase in their lifecycle. Hence maintaining fish passage is vital for these species to migrate both and up and downstream throughout their lifecycle. Many native species are also small, cryptic and nocturnal so their presence is often not known by observation (NIWA, 2021*-b). Larger galaxiid species often live in small streams under the cover of bush canopy which lends itself to the plantation forestry environment (NIWA, 2021*-b). There is an overall lack of knowledge about the location, number and swimming ability of New Zealand native fish as identified in the New Zealand Fish passage Guidelines (Franklin et al., 2018).

The swimming ability of native fish is often characterised by their speed and ability to climb. Some species are particularly good climbers such as eels. Speeds of fish are usually determined by their burst speed. Fish can move relatively quickly for short distances and need static pools to rest before travelling further.

2.3 Current Regulations

There are currently three legal documents that regulate and protect native freshwater fish in New Zealand. The Resource Management Act 1991, the Freshwater Fisheries Regulations 1983, and the National Environmental Standard for Plantation Forestry (NES-PF). By law forestry activities must comply with these documents however, the NES-PF is the main guiding document for forestry activities.

2.3.1 National Environmental Standard for Plantation Forestry

The governing document for environmental performance in forestry including fish passage is the National Environmental Standard for Plantation Forestry (NES-PF). The NES-PF is regulations made under the Resource Management Act 1991 (RMA). The NES-PF includes technical standards, methods or requirements for matters relating to the RMA. The aim of the NES-PF is to provide consistent rules across New Zealand for plantation forestry activities. The NES-PF is the prevailing set of regulations for plantation forestry activities unless a district or regional council plan requires more stringent practices. Figure 2.1 is an extract from the NES-PF and shows the specific regulations relating to fish passage as a permitted activity.

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.

Figure 2.1 Extracted from NES-PF (New Zealand Government, 2017).

2.3.2 Freshwater Fisheries Regulations 1983

The Freshwater Fisheries Regulations 1983 (FFR83) guides the regulations within the NES-PF. As such Figure 2.2 shows the relevant section of the FFR83. The FFR83 came into effect in 1984 which means all instream structures must comply with the regulations built after that date (Gee et al., 2018).

The regulations for fish passage in New Zealand are clear. Unless given written confirmation from a fisheries manager that fish passage would have adverse effects, all stream crossings must be constructed to have fish passage. They must also be maintained in a manner that crossings do not become an obstacle to fish passage.

42 Culverts and fords

(1) Notwithstanding regulation 41(2)(d), no person shall construct any culvert or ford in any natural river, stream, or water in such a way that the passage of fish would be impeded, without the written approval of the Director-General incorporating such conditions as the Director-General thinks appropriate.

(2) The occupier of any land shall maintain any culvert or ford in any natural river, stream, or water (including the bed of any such natural river, stream, or water in the vicinity of the culvert or ford) in such a way as to allow the free passage of fish:

provided that this requirement shall cease if the culvert or ford is completely removed or a written exemption has been given by the Director-General.

Figure 2.2 Extracted from the FFR (New Zealand Government, 1983).

2.4 Best Practice Guides

There are several best practice guides used within the New Zealand forestry industry that relate to the passage of fish. These include:

- New Zealand Fish Passage Guidelines for structures up to 4 meters (Gee et al., 2018)
- Forest Practice Guides (NZFOA, 2020a)
- New Zealand Forest Road Engineering Manual 2020 (NZFOA, 2020b)
- New Zealand Environmental Code of Practice for Plantation Forestry (NZFOA, 2007)

Best practice guides are not legal documents and are not enforced. However after an incident, proving that they have been followed shows that design and construction was done to an adequate standard.

2.4.1 New Zealand Fish Passage Guide

The “New Zealand Fish Passage Guide for structure up to 4 m” (NZFPG) is the most comprehensive of the guides around fish passage. It is intended as guidance for instream structures to improve fish passage management in New Zealand. This guide aims to help designers create crossings that meet legislative requirements and improve existing structures that do not meet these requirements (Gee et al., 2018). This guide is relatively new (published 2018) and does not seem to be widely used by forestry professionals, but it is referenced within the ‘Crossings’ section of the FPG. The guide is not meant as regulations but is being used more often in that way by regulating authorities such as regional councils (Boxall, 2021). The guide contains recommendations for new structures, remediation of existing structures and aims to provide prescriptive solutions to fish passage. The guide also addresses the issue of artificial barriers created to protect native fish from predation by exotic species, as well as monitoring success of fish passage, which is a large part of the FFR83 and NES-PF. The NZFPG recognises that fish passage requirements are unique to a site and design solutions should be considered on a site-by-site basis. The NZFPG states that the guide should not be taken as a “cookbook” in the sense that there is no one solution that will work for all sites (Gee et al., 2018).

The main focus of the NZFPG is stream simulation, this means that structure should mimic the natural stream conditions. This should include natural channel width, depth, and slope. The NZFPG presents an order of preference for instream crossing structures as seen in Figure 2.3. In forestry situations, infrastructure budget restrictions often eliminate the economic feasibility of bridge construction. Next on the preference list, stream simulation, is not seen often due to the lack of knowledge on how to construct effectively. It should be noted that the culvert with no bed material (as often seen in forestry infrastructure) is not on the list at all. Baffles inserted into culverts are a form of artificial bed material, hence contradicting the NES-PF requirement of natural riverbed material. Words such as 'minimise' and 'avoid' throughout the guide show the nature of the document as a guide and not a rule book but do allow for a wider interpretation of the guide which could be a downfall. The NZFPG provides a minimum design standard for hydraulic culvert design which is common in New Zealand forestry infrastructure, this can be seen in Figure 2.4.

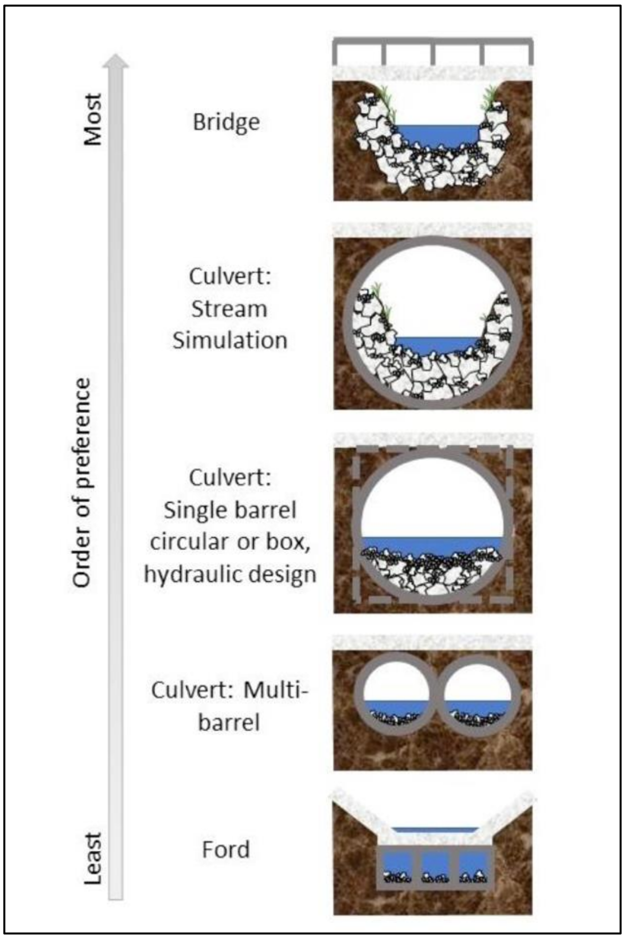


Figure 2.3 Extracted from NZFPG, order of preference for instream crossing structures. (Gee et al., 2018).

Minimum culvert design standards

- Low (Q_L) and high (Q_H) fish passage design flows should be defined. As a rule of thumb, $Q_L \leq 95\%$ exceedance flow and $Q_H \geq 20\%$ exceedance flow.
- Alteration of natural stream channel alignment should be avoided or minimised.
- Alteration of natural stream channel gradient should be avoided or minimised.
- Culvert span will be:
  - 1.3 x bankfull width for streams with a bankfull width ≤3 m.
  - 1.2 x bankfull width + 0.6 m for streams with a bankfull width >3 m.
- Open bottom culverts will be used or the culvert invert will be embedded by 25-50% of culvert height.
- Mean cross-sectional water velocity in the culvert over the fish passage design flow range will be equal to or less than the greater of:
  - mean cross-sectional water velocity in adjacent stream reaches, or
  - the maximum allowable water velocity calculated from fish swimming speeds of agreed target fish species and/or life stages.
- Minimum water depth in the culvert at the low fish passage design flow will be the lesser of:
  - 150 mm for native fish passage, or 250 mm where adult salmonid passage is also required, or
  - mean cross-sectional depth in adjacent stream reaches.
- Well graded substrate will be present throughout the full length of the culvert bed.
- Substrate within the culvert will be stable at the high fish passage design flow.
- Any ancillary structures must not create an impediment to fish passage.
- Vertical drops through the structure will be avoided.

Figure 2.4 Extracted from the NZFPG showing minimum design standard for hydraulic design culverts (Gee et al., 2018).

2.4.2 Forest Practice Guides

The Forest Practice Guides is a non-regulatory document aimed at forest operations practitioners and professionals. The intent of the guide is to assist in meeting legislative requirements of the RMA91 and NES-PF. They "provide options and information on a range of practices and methods to manage the effects of the operation on the environment" (FFNZ, 2020). The guide does state that structures should be designed with fish passage but does not have technical specifications on how to achieve this. For example in Section 3.4, design statement 8 of the FPG states "Design for upstream and downstream passage of fish" (NZFOA, 2020a). The guide does reference the NZFPG for further design criteria on fish passage (Figure 2.5).

e. Seek specialist assistance and view online resources.

Refer also to the Department of Conservation **Fish Passage Guidelines:** https://www.doc.govt.nz/nature/habitats/freshwater/fish-passage-management/nz-fish-passage-guidelines/

National Environmental Standards for Plantation Forestry

Particular relevant provisions for crossings are Regulations 38 – 49.

Figure 2.5 Extracted from FPG referring users to the NZFPG (NZFOA, 2020a).

2.4.3 New Zealand Forest Road Engineering Manual

The New Zealand Forest Road Engineering Manual is aimed at forestry professionals and covers all aspects of planning, designing, construction and maintenance of unsealed forest roads (NZFOA, 2020b). The NZFRM contains a plethora of information about fish passage for instream crossing structures most of which comes directly from the NZFPG for example, the extract seen in Figure 2.6. There is a specific section (8.1) within the NZFREM that talks explicitly about fish passage.

The following are principles of good fish passage design, while also taking into account other design factors including cost and hydraulic flow requirements:

- Maintain continuity of in-river habitat within the culvert. The NES-PF requires that the invert be embedded by 20% of the culvert height
- Minimise alterations to river alignment
- Minimise alterations to river gradient
- Maintain water velocities and depths within a range equivalent to adjacent river reaches
- Minimise constraints on bankfull channel capacity resulting from the structure
- Avoid vertical drops
- Provide an uninterrupted pathway along the bed of the structure.

Figure 2.6 Extracted from the NZFREM pg. 145 (NZFOA, 2020b).

2.4.4 Environmental Code of Practice

The New Zealand Environmental Code of Practice for Plantation Forestry (ECoP) was published in 2007 and is targeted at all parties involved in plantation forestry activities. It is designed to be a reference tool for prioritising environmental values as well as giving best environmental practices around many forestry activities (FFNZ, 2020). The aims of the ECoP are summarised in Figure 2.7. The ECoP contains regulatory rules that must be met during forestry operations as well as guidelines which should be followed where it is safe and practical to do so (NZFOA, 2007). There is a rule in the ECoP relating to fish passage “Fish passage must not be impeded by structures”. This is referring to waterway crossings. Other than this rule there are no other guidelines on fish passage.

Aims of the code
To plan, manage, and carry out commercial forest operations in a way that avoids, remedies, or mitigates adverse effects on the environment.
The code is a practical means of helping forest planners, contractors and operators to consistently accomplish required levels of environmental performance consistent with good health and safety and financial performance and the community and regulatory expectations that they face.

Figure 2.7 Aims of ECoP extracted from the ECoP (NZFOA, 2007).

2.5 Freshwater fish surveying

A key to understanding fish passage is knowing which species of fish are present. With a sound knowledge of which species are present in a given waterway, the fish passage design of instream structures can be optimised. There are many methods of surveying waterways for native fish. The method used by the researcher will be decided based on many factors including, cost, time, accuracy, habitat, and species looking for.

New Zealand freshwater fish are generally functionally grouped into categories which represent common ecologies, behaviours and other features which influence the survey method (Grainger et al., 2013). The groups are as follows:

- Large galaxiids (Kōkopu and Kōaro)
- Non-migratory galaxiids
- Mudfish
- Inanga and Smelt
- Bullies and Torrent fish

- Eels
- Lamprey
- Invasive fish (Gambusia)
- Invasive fish (Rudd, Koi carp and Catfish)
- Sports fish

Habitat types are also grouped for determining the survey method to use (Grainger et al., 2013). These groups are:

- Wadable streams/river (<1 m deep)
- Non-wadable streams/rivers (>1 m deep)
- Riparian
- Lakes
- Wetlands
- Estuaries

Within the scope of this research project survey methods for wadable streams will be focused on as the stream crossing infrastructure being studied are in this habitat type. A publication from The Ecology Group – Institution of Natural Resources in 2013 attempted to create New Zealand's first standardised approach to freshwater fish sampling focusing on wadable streams (<1 m) (Joy et al., 2013). This guide used three methods for sampling freshwater fish including, backpack electrofishing, spotlighting, and trapping. It was identified that using one of these methods is the minimum standard, ideally multiple methods should be used to increase the probability of catching all species present. The guide presents a table for choosing the appropriate sampling method for a site (Figure 2.8) as well as the relative advantages and disadvantages for each method (Figure 2.9).

Site name Wharerоa DS — Method decision table — Method

Trap = Fyke nets and Gee minnow traps combined, Spot = Spotlight, EFM = backpack electrofishing machine(see protocols for details)

Parameter	Condition				Trap	Spot	EFM
Water velocity	Low →			High			
	Still Trap 3, Spot 3, EFM 1	Slow Trap 3, Spot 3, EFM 2	Medium Trap 2, Spot 3, EFM 3	High Trap 1, Spot 1, EFM 3	3	3	2
Conductivity	Low →			High			
	< 30 µS/cm Trap 3, Spot 3, EFM 0	30-300 µS/cm Trap 1, Spot 1, EFM 3	300-450 µS/cm Trap 3, Spot 3, EFM 2	>450 µS/cm Trap 3, Spot 3, EFM 0	3	3	0
Turbidity	Clear →			Turbid			
	Clear (bed visible* > 80% of reach) Trap 1, Spot 3, EFM 3	Slightly discoloured (bed visible* 50 -80% of reach) Trap 2, Spot 2, EFM 3	Moderate turbidity soft bottom (bed visible* 20 - 50% of reach) Trap 3, Spot 1, EFM 1	Very turbid soft bottom (bed visible* <20% of reach) Trap 3, Spot 0, EFM 1	3	1	1
Vegetation or anything that obscures vision of bed	High visibility →			Low visibility			
	80 - 100% bed visible Trap 3, Spot 3, EFM 3	Bed visible over 50 - 80% of reach Trap 3, Spot 2, EFM 3	Bed visible over 20 - 50% of reach Trap 3, Spot 1, EFM 2	Bed visible over <20% of reach Trap 3, Spot 1, EFM 0	3	1	0
Depth	Shallow →			Deep			
	100% of reach < 0.4m Trap 1, Spot 3, EFM 3	>75% of reach < 0.4m Trap 2, Spot 3, EFM 2	75 - 25% of reach < 0.4m Trap 3, Spot 2, EFM 2	< 25% of reach < 0.4m Trap 3, Spot 2, EFM 0	3	2	0
				TOTAL	15	10	3

*when not obscured by other structures (eg. macrophytes, large woody debris)

Figure 2.8 Example of sample selection table from New Zealand Freshwater Fish Sampling Protocols (Joy et al., 2013).

TABLE 1. Relative advantages and disadvantages of protocol methods; if the Method Decision Table gives an equivocal result (method scores are within 0–3 points) then this table can be used to help make a final decision.

Parameter	Spotlighting	Electrofishing	Trapping
Time taken to sample	Fast	Moderate	Moderate
Return trip required	No	No	Yes
Amount of equipment	Low	High	High
Expense of equipment	Low	High	Moderate
Impaired by broken water	Yes	No	No
Sampling done during normal working hours	No	Yes	Yes
Ease of identification of fish	Low	High	High
Potential harm to fish	Low	Moderate	High
Reliability of relative abundance estimates	High	High	Low
Effectiveness for collecting size class data	Low	High	High

Figure 2.9 Extract from New Zealand Freshwater Fish Sampling Protocols showing relative disadvantages of fish sampling methods (Joy et al., 2013).

2.5.1 Electro-fishing

Electro-fishing is a simple and efficient of determining which species of fish are present within a waterway. The method involves applying an electric field to the water which temporarily incapacitates a fish, making it float to the surface and therefore easier to catch. There is the risk of harming the fish but with the correct application this risk can be mitigated (Game & Wildlife Conservation Trust, 2021*).

2.5.2 Environmental DNA

A relatively new technique for fish surveying in New Zealand is environmental DNA (eDNA) Currently, Wilderlab (founded 2019) is the only specialised environmental DNA testing laboratory (Wilderlab, 2021*). All living organisms shed DNA during their life which is left in the non-living environment (Díaz-Ferguson & Moyer, 2014). eDNA is collected by taking a water sample then filtering particles that contain the DNA (EPA, 2021*). Using the DNA found in the samples, researchers can create signatures that allow organisms present to be identified (Schallenberg et al., 2020). Some organisms are particularly hard to identify using traditional methods, hence eDNA is an effective way to gain insight into a stream's ecosystem.

eDNA samples are faster to collect and can often be processed faster than traditional methods making them a more cost-effective way to collect data (Schallenberg et al., 2020). However, there are downfalls to eDNA. An article, 'What can DNA in the environment tell us about an ecosystem?' (Schallenberg et al., 2020) identified three drawbacks to eDNA sampling. The first is during the DNA sequencing phase, where mistakes can be made in reading and copying the sequence leading to species being misidentified or missed altogether. Another downfall is that traditional sampling methods involve counting the number of individual species present and eDNA does not allow this to happen. Hence, understanding populations of species and the change in their population over time is not possible. Finally, species can be misidentified based on the DNA signature. To identify species, their DNA signature is compared against a large database of known organisms and matches are done off similarity. If the species is not in the database, their signature will be assigned to the closest match which could be a very different species. There is also the issue of cross-contamination, for example if a bird eats a fish species from one stream, then defecates the DNA into a different stream that does not contain the species the eDNA could show a false presence (Boxall, 2021).

An Australian study compared traditional fish sampling methods including electro-fishing, gill nets, and fyke nets to eDNA. The study compared single detection for both rare and abundant freshwater fish. It was found that eDNA surveying for single detection is more efficient and sensitive than traditional methods but did tend to show more false positives than traditional methods. Also, traditional methods did not detect rare freshwater fish in some sites. The study also augmented the results from traditional methods and eDNA and found that there was no improvement in single detection but stated that it could help "improve confidence and provide confirmatory evidence" of species presences. Another positive of eDNA that the study found was that supplementary data such as spatial and temporal is not required for identifying species present with eDNA however, is required for traditional methods (Piggott et al., 2021).

2.5.3 MPI Fish Spawning Tool

The MPI fish spawning tool is available for determining fish presence in streams throughout New Zealand. The tool is designed for managing activates in and around waterways as some species are particularly sensitive to disturbance during spawning. Figure 2.10 shows an example output from the tool. There are activities within the NES-PF that are only permitted if the specific species are not present or the activity is outside the spawning period (New Zealand Government, 2017). The MPI fish spawning tool gets information from three sources:

- Non-migratory species habitat range data provided by the Department of Conservation
- Habitat range of freshwater species from NIWA's NZ Freshwater Fish Database
- Modelled fish habitat ranges to fill in the gaps, also provided by NIWA

(Te Uru Rakau, 2021*)

The limitation is that the data is based on models so it is not guaranteed that fish are present in that waterway.

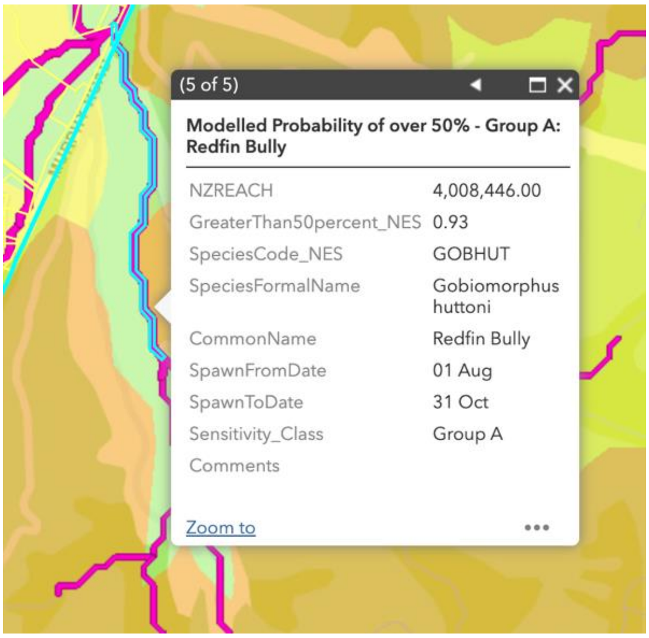


Figure 2.10 Showing example output from MPI fish spawning tool for a stream within the RMF estate (MPI, 2020).

2.5.4 NZ Freshwater Fish Database

The NZ freshwater fish database (NZFFD) is a public access tool provided by NIWA of over 34,000 freshwater fish observations. It includes data on locations of sample sites, species present and numbers. The NZFFD relies on voluntary contribution from many organisations so it is not guaranteed that the waterways required are included in the database or that the sources of the sample are accurate (NIWA, 2021*-a). However, if the waterway required for this research is included in the database then it would be a good way to identify species present.

2.6 Limitations

There seems to be no standard practice for assessing instream structures in a forestry context. Understandably assessments could be made for a variety of purposes and assessments would be designed to meet these requirements.

Between nations, there is some consistency in fish passage requirements, especially North America where there are a variety of resources available on the topic. But as the New Zealand freshwater species are native and often predated on by North American species, this literature review has not included guidelines from outside of New Zealand.

Throughout this literature review, it has been identified that there is a lack of 'black and white' guidelines for fish passage in the forestry context. This is expected as every instream structure site poses different conditions for the fish passage issue. There are many conditions that affect what individual species require for fish passage and which design criteria need to be implemented. It was found there are two main regulatory documents relating to fish passage, namely the NES-PF and FFR83. These documents both say that instream structures must not impede fish passage. The NES-PF also states that bed material must be in structures that are in place of the natural stream bed. The FFR83 states that instream structures must be maintained by the landowner so that fish passage is not lost. It should be noted that nowhere in regulatory documents fish passage is defined, as the actual requirements vary for different species. This is a knowledge gap that should be explored and hopes to be understood within this research project.

A common misconception about is fish passage that it is related to perch or vertical drops at the downstream end of structures. While many best practice guidelines recommend avoiding vertical drops in structures, not all perched structures impede fish passage. Many native fish species are capable climbers and can navigate large vertical features in a waterway such as eels. Culverts inevitably become perched through erosion, particularly culverts not embedded. So, perch potentially does not always cause loss of fish passage. The are many naturally vertical structures in streams such as rapids and small waterfalls which are not barriers to fish passage. Hence it is important to find out what exactly would cause a barrier to fish passage to create a definition that can be used for analysis.

There are a number of methods for collecting data on fish presence. eDNA is a relatively new method and is promising for achieving sufficient sensitivity. eDNA can be independently collected at relatively low cost compared to its efficacy. The NZFFD is another method that can be used for fish presence but relies on the accuracy of input from contributors. Overall, this study could contribute knowledge on the fish passage requirements of different species and provide a link to the performance of infrastructure.

3 Methodology

3.1 Data Collection

The inventory assessment was conducted for Rayonier Matariki Forests during the 2020-21 summer for the primary purpose of updating their 2010 inventory and finding maintenance issues. Due to this, some of the measurements taken were not relevant to this report and hence not included. Also, some measurements were not relevant to RMF and therefore are only included in this report, not the RMF inventory.

The scope of this infrastructure assessment covers the 12,600 ha of Tairua Forest. There are around 500 km of roads within the forest, meaning that locating all crossings was difficult. For the purpose of this study, the crossing survey lower bounds were set as, all perennial streams and ephemeral streams where there was more than one pipe or one pipe with a diameter larger than 900 mm. As the inventory was to be conducted during the peak of summer, with low rainfalls, it was assumed that if the steam had no water running at the time of survey it was ephemeral.

3.1.1 Structures

To comment on the fish passage performance of instream structures within the Tairua Forest a comprehensive inventory of infrastructure is required. For the study to be worthwhile is it important that sufficient quality data is gathered. The limiting factors for fish passage as identified in the literature review are vertical drops, water speed, slope, and length without rest. Hence, these features need to be captured during data collection. Other important features to be captured are, location, so stream crossings can be linked to specific streams and fish presence data, and type of crossing, including size and material. Table 3.1 shows the list of measured variables, the unit, and the measurement method for surveying piped crossings. This table is specifically for pipes and measurements were added/removed for fords, bridges, drift decks, and battery culverts. This includes further dimensions of the structure.

Table 3.1 Showing variables measured, units and measurement method for culverts in the infrastructure inventory.

Variable	Unit	Measurement method
Location	NZTM	iPad GPS, dropping pin on AVENZA maps application*
Diameter (for pipes)	mm	Tape measure of inner diameter
Length	m	Tape measure or lazar range finder
Perch**	mm	Tape measure and seen in Figure 3.1
Material		Description and photographed
Inlet condition (stream and pipe)		Description and photographed
Outlet condition (stream and pipe)		Description and photographed
*all photos for variables were added to the pinned location on AVENZA to keep track of them **the distance from the bottom inside edge of pipe to outlet water level.		

During the data collection period, all the roads with crossings were driven in Tairua Forest. Data was collected at each crossing as per the above measurements. Locations and photos were inputted to Avenvza, titled with a crossing ID, measurements and descriptions were added to a table also referenced by the crossing ID. The crossing ID numbers were used to collate the data collected in the field to a raw data inventory spreadsheet and the GIS layer.

Figure 3.1 Demonstrating how perch is measured.

3.1.2 Fish Data

There is no fieldwork involved with data collection for this part. There are two parts to collecting data on native fish. Initially, the species of native fish present within the RMF estate need to be found, then the details about those species that influence their ability to pass through instream structures will be researched.

The preferred method of data collection is eDNA. This data has been taken from the Wilderlab database. The NZFFD (NIWA, 2021*-a) is a valid way of collecting and/or verifying data from eDNA. The MPI fish spawning tool can also be used to determine fish presence. However, this tool only gives a probability of the presence of fish and only includes fish that are susceptible to disturbance during spawning so this tool will be given the least priority.

After the database of fish presence has been established, a further literature review will be conducted to determine the abilities of these fish to pass instream structures. The information required on individual species will include, their migratory patterns, swimming ability. It should also be considered if any species would benefit from non-natural barriers to protect them from predation from exotic species. Physical testing of fish species swimming ability is possible but not within the scope of this research project, so previous studies will be used to gain this information.

3.2 Data Collation and Analysis

3.2.1 Structures

The first step of data collation was taking the raw field data and presenting it in a way that could be analysed in a spreadsheet and GIS. This involved creating fields to quantify each variable in consistent units and options. Within GIS, structures are specified as follows in Table 3.2.

Table 3.2 Showing descriptions of GIS headings for structures.

RMFID	X NZTM	Y NZTM	Forest	Structure Type	Material	Size mm	Perch mm	Inspection date	Info
Unique identifier for each structure	Latitude in NZTM200 (meters)	Longitude in NZTM200 (meters)	Forest within BoP estate	One of the categories in Table 3.3	Main material of structure	Diameter of pipes in mm	Vertical drop from base of structure to water level	Date of inspection	Extra information about structure

In spreadsheet form, the data was separated into further groups. These groups are shown in

Table 3.3. These categories are aimed to align with commonly used structure type names in the NZFREM (2020). Also, in spreadsheet analysis, the length of piped structures is included.

Table 3.3 Showing category and definition for crossings.

Category	Definition	Photo Example
Culverts	Single pipe under fill. Note: photo showing inlet.	
Poly culverts	Multiple pipes under fill. Note: photo showing inlet.	

Category	Definition	Photo Example
Bridges	Elevated structure.	
Fords	Concrete pad submerged.	
Battery culverts	Multiple pipes with concrete pad. Note: photo showing outlet.	
Drift decks	Concrete box culverts. Note: photo showing outlet.	

3.2.2 Fish Data

Data collection points from available eDNA sites and the NZFFD were mapped on top of the estate boundary for the Bay of Plenty. The relevant, close proximity, sites were used for analysis. All these data points fell within the estate boundary. Each data point will be related to its closest structure to show the species present at that structure. A list of species present within the estate will be created including attributes relating to their fish passage requirements.

3.2.2.1 Conservation Status

A distinction to make is the difference between native and endemic species. Many species of New Zealand freshwater fish are migratory and spend some part of their life cycle in the ocean. This means that is possible that they may end up in different countries. So, a fish found naturally in New Zealand and other countries such as the shortfin eel, is native. An endemic species is only found in New Zealand. On the other hand, some species are introduced, primarily for sport in the case of freshwater fish, for example Trout and Salmon.

Many of New Zealand's freshwater fish species are endangered to some level. With waterways in forestry making up large parts of native species habitats it is important that species are protected. All fish species are given a conservation status based on the New Zealand Threat Classification System. By understanding this system, species that are more endangered can be identified and their habitat protection can be prioritised. There are levels to the New Zealand Threat Classification System, these are shown in Figure 3.2. The majority of species identified within this research are either 'At risk declining' or 'Not threatened'. Figure 3.3 breaks down how the species are classified.

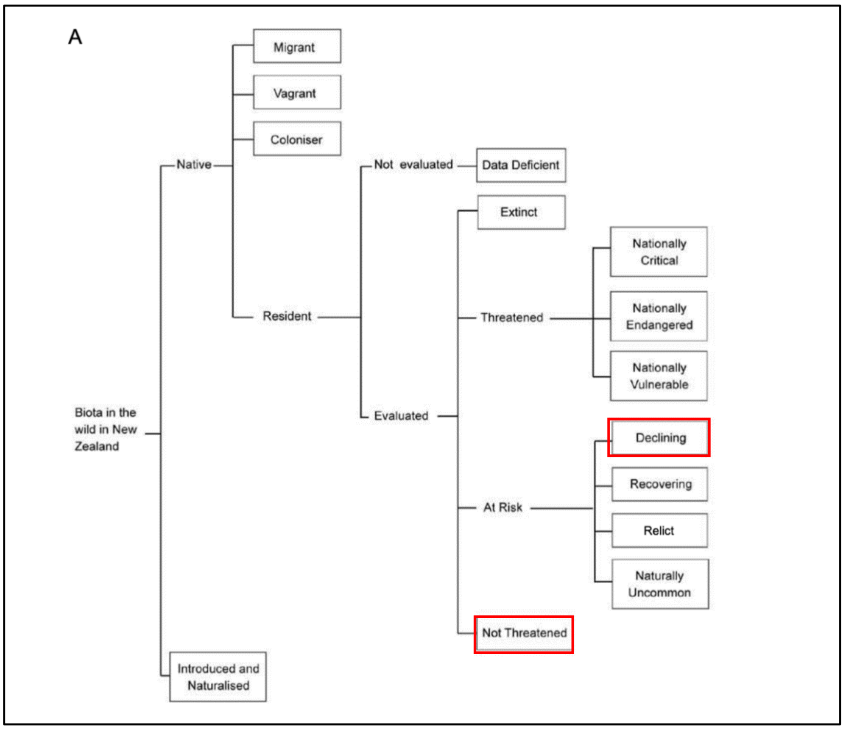


Figure 3.2 Chain of conservation status for New Zealand biota from (Dunn et al., 2018). Red boxes showing path to most common status seen in analysis.

TABLE 2. PRIMARY CRITERIA FOR 'THREATENED', 'AT RISK' AND 'NOT THREATENED' TAXA.

Note that population changes are calculated over 10 years or three generations, whichever is longer. See Table 3 for secondary criteria (based on sub-population number and size, or area of occupancy). Abbreviations: Dec = Declining, NC = Nationally Critical, NE = Nationally Endangered, NT = Not Threatened, NU = Naturally Uncommon, NV = Nationally Vulnerable, Rec = Recovering, Rel = Relict, RR = Range Restricted.

TOTAL POPULATION TREND*	TOTAL NUMBER OF MATURE INDIVIDUALS < 250	250–1000	1000–5000	5000–20 000	20 000–100 000	> 100 000
> 10% increase	NC	NV/NU	NU/Rec	NU/Rec	NT/NU$_{RR}$/Rel	NT/NU$_{RR}$/Rel
Stable (± 10%)	NC	NE/NU	NV/NU	NU/Rel	NT/NU$_{RR}$/Rel	NT/NU$_{RR}$/Rel
10–30% decline	NC	NE	NV	Dec	Dec	Dec
30–50% decline	NC	NE	NV	NV	Dec	Dec
50–70% decline	NC	NC	NE	NV	NV	Dec
> 70% decline	NC	NC	NC	NC	NC	NC

* Predicted and ongoing due to existing threats.

Figure 3.3 Criteria for conservation status from (Dunn et al., 2018).

3.2.2.2 Swimming Modes

Fish passage is inherently hard to define as every species and probably individual within a species has different swimming capabilities. There can never be one set of criteria that will work for all species.

There are four main swimming modes for fish. Swimmers, anguilliforms, climbers, and jumpers (Mitchell & Boubee, 1989). Swimmers have the least ability to pass obstacles, specifically crossing structures, as they rely on low-velocity areas within a stream to swim around obstructions. Swimmers also can 'burst', which is swimming at a higher speed which they can maintain for a short period. But burst swimming consumes a lot of energy and fish need areas to rest. Burst swimming often only lasts for around 30 seconds (Franklin et al., 2018). To pass a structure, this burst speed must be able to overcome the water velocity within the structure and maintain that speed for long enough to reach the other end of the structure. Many larger species of fish such as giant Kokopu and Kouraro are swimmers. Inanga, Smelt, and common bullies are also swimmers.

Anguilliforms include eels. They can travel out of water across land if their skin is kept wet. Longfin eels can absorb 50% of their oxygen need through their skin. They can also worm their way through tight spaces. While they cannot climb a perched culvert, they would be able to make their way around it other ways.

Climbers use surface tension and friction to climb faster-flowing water or through the wetted edge of a waterway. This allows them to navigate very shallow water, waterfalls, rapids, and spillways. Banded Kopuku are a climbing species that have been observed above a 20 m tall vertical waterfall (SLU, 2017). Redfin Bullies, juvenile Kokopu, and Torrent Fish are also examples of climbing species.

Jumpers can leap waves within rapids and waterfalls to save energy. Trout and salmon are examples of jumping species. To a lesser extent, adult Inanga can jump around 100 mm.

There could be a set of criteria which would allow the weakest of swimmers to pass through structures. But this would most of the time be unnecessary as this would only be required if these species are present. Designing a structure to cater for the weakest swimmers would often be unfeasible in an environmental, physical, and economic sense. However, perch is one condition that seems to be an obstacle to fish passage which is common to all swimming abilities. Perch is a vertical drop from the downstream end of the structure to the waterway below. For low levels of perch, some species could still pass the structure, including very strong swimmers and jumpers. Climbers and Anguilliforms could also pass the structure if there are sufficient wetted edge for the climbers to use or the Anguilliform can maintain a wet body. To prioritise perched structures, it is logical to order them from largest to smallest vertical drop at the outfall.

3.2.2.3 Migration and Migration

Migration behaviour is a key piece of information relating to a species fish passage requirement. Understanding at what point in the species lifecycle they migrate in which direction can help to decide if a structure caters for this movement. Some species are nonmigratory and maintain a small range. Others migrate when they are juveniles and have climbing abilities which are lost when they become adults. Hence, knowing this behaviour is important.

Habitat is the final step in understanding which fish are present. This attribute can be particularly useful when fish survey data or eDNA data is not in close proximity to the structure of interest. It can be used to decide if a surveyed species would actually be present at the structure, or if there is a possibility that a surveyed species is actually present.

3.2.3 Structure Network Position

Another way to prioritise the upgrade/repair of instream structures would be to base it on their network position. Where the structures within a catchment are assigned nodes on the stream network. A single structure with no further structures upstream was given a network position of 1. Whereas structures lower down the catchment with multiple structures upstream were given the network position n+1 where n is the number of structures upstream. This is demonstrated by Figure 3.4. This can be an effective way to prioritise instream structure repair as a high order structure that lacks fish passage also cuts off all the structures upstream of it. Hence there is no point in fixing a low order structure until the high order structures that are barriers to fish are fixed. It is also important to know which structures make up a high order structure. Hence a matrix system was created to show how the network interacts.

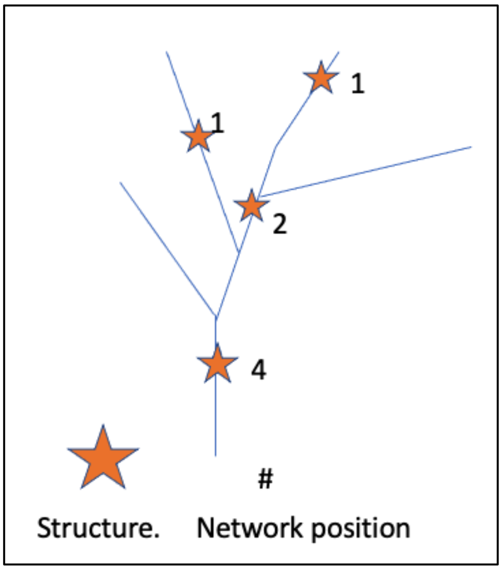


Figure 3.4 Theoretical example of structure network position concept.

A perched culvert can potentially restrict fish from kilometres of habitat. The further downstream the structure, the more potential habitat loss. Using the RECNZ stream map, the upstream distance from each structure was measured. To do this the stream map was converted to a geometric network within GIS. Then the upstream accumulation was measured for each structure on the network. This information can also be used to prioritise the remediation of fish passage issues.

3.2.4 Priority System

The next step was to make a priority system for structure importance. This can be used for deciding the order for structures requiring remediation of fish passage. Also, when designing new structures their interaction within the system can be seen. This can help justify the extra cost of creating fish passage. Conversely, if they are low order with minimal potential upstream habitat, it can be justified to have minimal design. The following key attributes are important as found within the literature review:

- Structure
    - Physical dimensions
    - In-situ conditions
        - Perch
        - Bed material within the structure
        - Structure damage
        - Water velocity through structure
    - Upstream habitat
    - Network position
- Fish Presence
    - Species
    - Conservation Status
    - Mode of swimming

For new structures, if the species present at the structure are known, the structure should be designed to fit these species regardless of the network position or potential upstream habitat of the structure. For existing structures with a lack of fish passage, their remediation should be prioritised based on where they sit in the catchment. High network position structures and structures with the greatest length of potential upstream habitat should be first on the list. When comparing catchments, the catchment with the most important fish species present should be prioritised. The most important fish species, requiring the most care in design/remediation, are high conservation value migratory species moving from the weakest swimmers to strongest climbers.

4 Results

4.1 Tairua Forest Structures Overview

Tairua Forest lies within the Waikato region, with Pauanui township at the northern, Whangamata at the southern end and State Highway 25 running through it. A map of Tairua Forest is shown in Figure 4.2. Tairua Forest contains 495 km of road infrastructure and over 150km of waterways (measured with RECNZ map) in nine catchments. Also shown in Figure 4.2 is the location of stream crossing infrastructure and fish survey points. There are 35 structures that make up the crossing infrastructure in Tairua forest, Figure 4.1 shows a breakdown of these structures by type. There are several fish observations within Tairua Forest, with the majority being from the NZFWFD. Some of these are in direct proximity to structures. There are a number of structures on the same waterway as the samples, as seen in Figure 4.2.

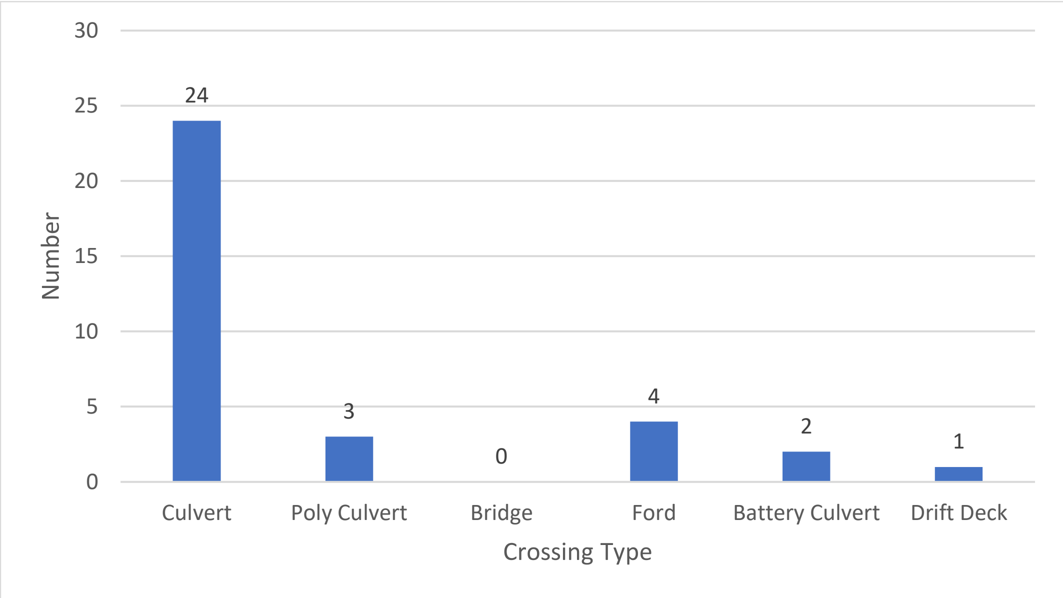


Figure 4.1 Showing a breakdown of structure types within the Tairua Forest part of the RMF Estate.

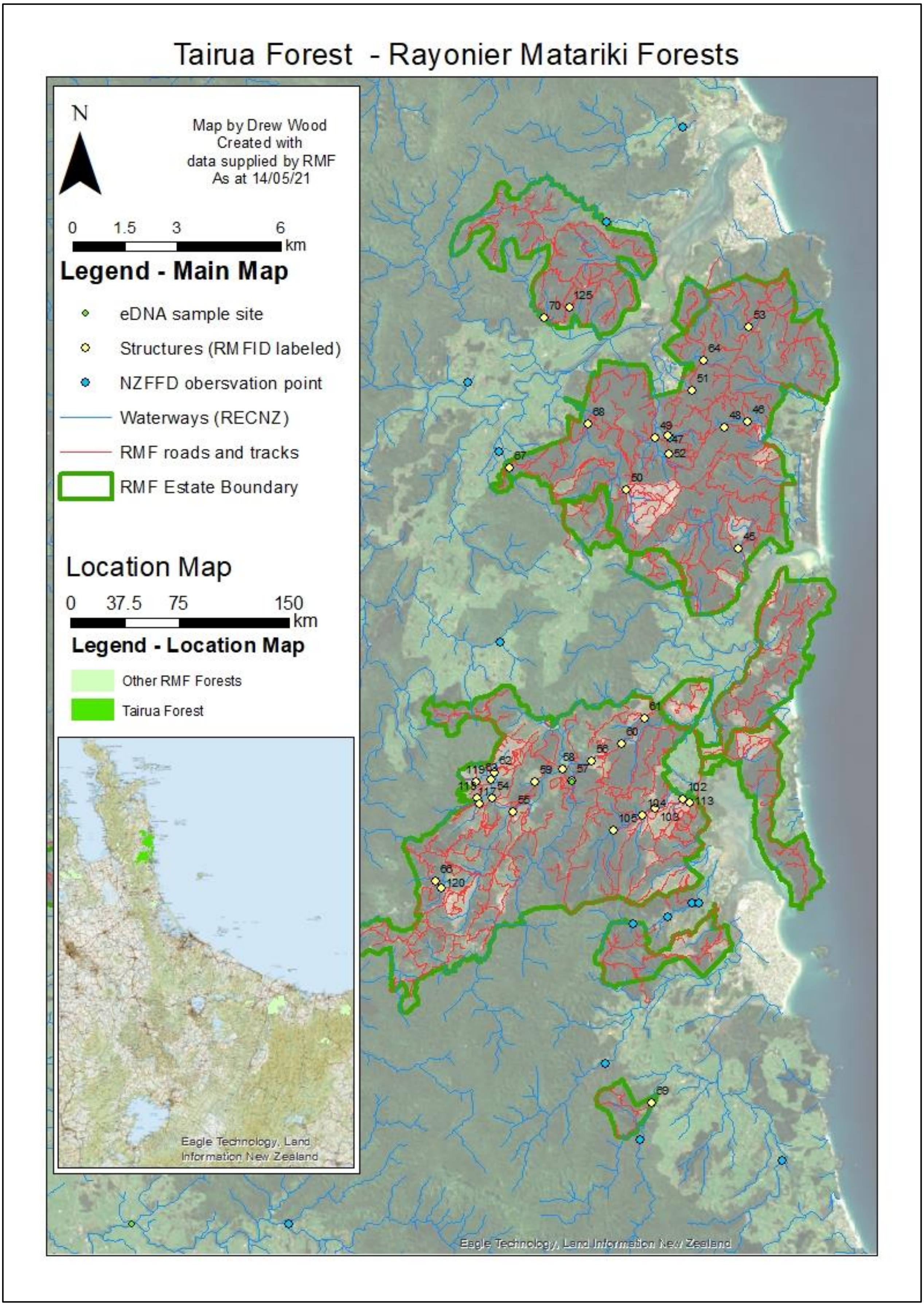
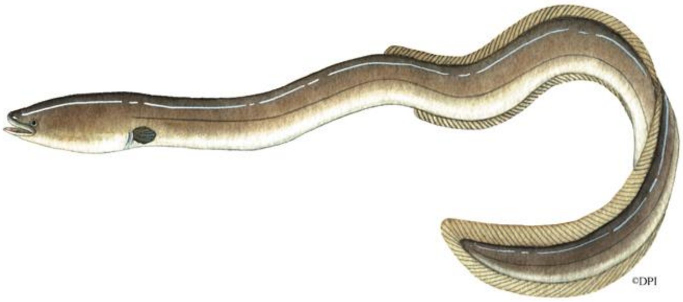


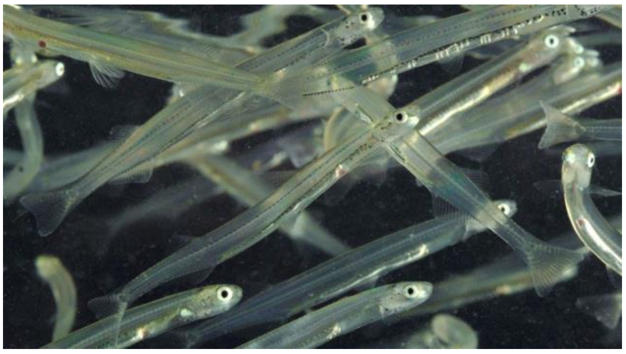
Figure 4.2 Map showing Tairua Forest and locations of structures and fish observations points.

4.2 Fish Species Present

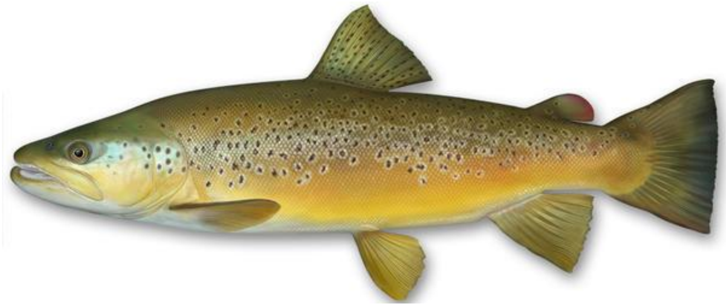
Nine unique fish species were observed in Tairua Forest. Species were identified from NZFFD and eDNA as seen in Table 4.1.

Table 4.1 Species present in Tairua Forest and information about each species.

Common Name, *Species Name*, and photo	About
Shortfin/Australian Eel, *Anguilla australis*  	**Origin[1]:** Native **Conservation Status[2]:** Not threatened **Migratory Behaviour[3]:** Migratory as juvenile **Swimming Mode[4]:** Anguilliform **Habitat*:** lake, river *(DoC, 2021*-a)
New Zealand longfin Eel, *Anguilla dieffenbachia* 	**Origin[1]:** Endemic **Conservation Status[2]:** At Risk Declining **Migratory Behaviour[3]:** Migratory **Swimming mode[4]:** Anguilliform **Habitat[5]:** All types of water
Banded Kokopu, *Galaxias fasciatus* 	**Origin Status[1]:** Endemic **Conservation Status[2]:** Not threatened **Migratory Status[3]:** Migratory **Swimming Mode[4]:** climber as juvenile swimmer as adult **Habitat[5]:** small tributaries

Common Name, *Species Name*, and photo	About
Giant Kokopu, *Galaxias argenteus* 	**Origin[1]:** Endemic **Conservation Status[2]:** At Risk Declining **Migratory Behaviour[3]:** Migratory **Swimming Mode[4]:** Swimmer **Habitat[5]:** Small to medium streams with gentle flow
Inanga/Common Galaxias, *Galaxias maculatus* 	**Origin[1]:** Native **Conservation Status[2]:** At Risk Declining **Migratory Behaviour[3]:** Migratory **Swimming Mode[4]:** Swimmer as juvenile, adults can jump small obstacles. **Habitat[5]:** lowland waterways
New Zealand Smelt, *Retropinna retropinna* 	**Origin[1]:** Endemic **Conservation Status[2]:** Not Threatened **Migratory Behaviour[3]:** Migratory **Swimming Mode[4]:** Swimmer **Habitat[5]:** Warm waters, estuaries, freshwater as adults in the summer

Common Name, *Species Name*, and photo	About
Redfin bully, *Gobiomorphus huttoni* 	**Origin[1]:** Endemic **Conservation Status[2]:** At Risk Declining **Migratory Behaviour[3]:** Migratory **Swimming Mode[4]:** Climber **Habitat[5]:** Fast moving water, no landlocked populations
Common bully, *Gobiomorphus cotidianus* 	**Origin[1]:** Endemic **Conservation Status[2]:** Not Threatened **Migratory Behaviour[3]:** Semi-migratory **Swimming Mode[4]:** swimmer **Habitat[5]:** Slow-moving streams and lakes
Torrent Fish, *Cheimarrichthys fosteri* 	**Origin[1]:** Endemic **Conservation Status[2]:** At Risk Declining **Migratory Behaviour[3]:** Migratory **Swimming Mode[4]:** Climber **Habitat[5]:** Fast flowing, shallow riffles and rapids, unstable substrates

Common Name, *Species Name*, and photo	About
Brown Trout, *Salmo trutta* 	**Origin[1]:** Introduced **Conservation Status[2]:** Introduced sports fish **Migratory Behaviour*:** Non-migratory **Swimming Mode[4]:** Jumper **Habitat*:** Mostly rivers but can be found in estuaries. Predate on native fish especially bullies * (Walrond, 2008)
[1] From (Dunn et al., 2018) [2] From (Dunn et al., 2018) [3] From (Smith, 2015) [4] From (Mitchell & Boubee, 1989) [5] From (SLU, 2017)	

Of these fish species identified, five species carry the conservation status of "At Risk Declining". The Giant Kokopu and Inanga are highly sensitive to perch in structures as they are both swimmers. They also are "At Risk Declining" so have the highest importance.

4.3 Network Position and Upstream Habitat of Structures

There are nine catchments with Tairua Forest which contain structures, shown in Figure 4.3. Table 4.2 shows the total length of potential habitat available in the catchment measured from the RECNZ map.

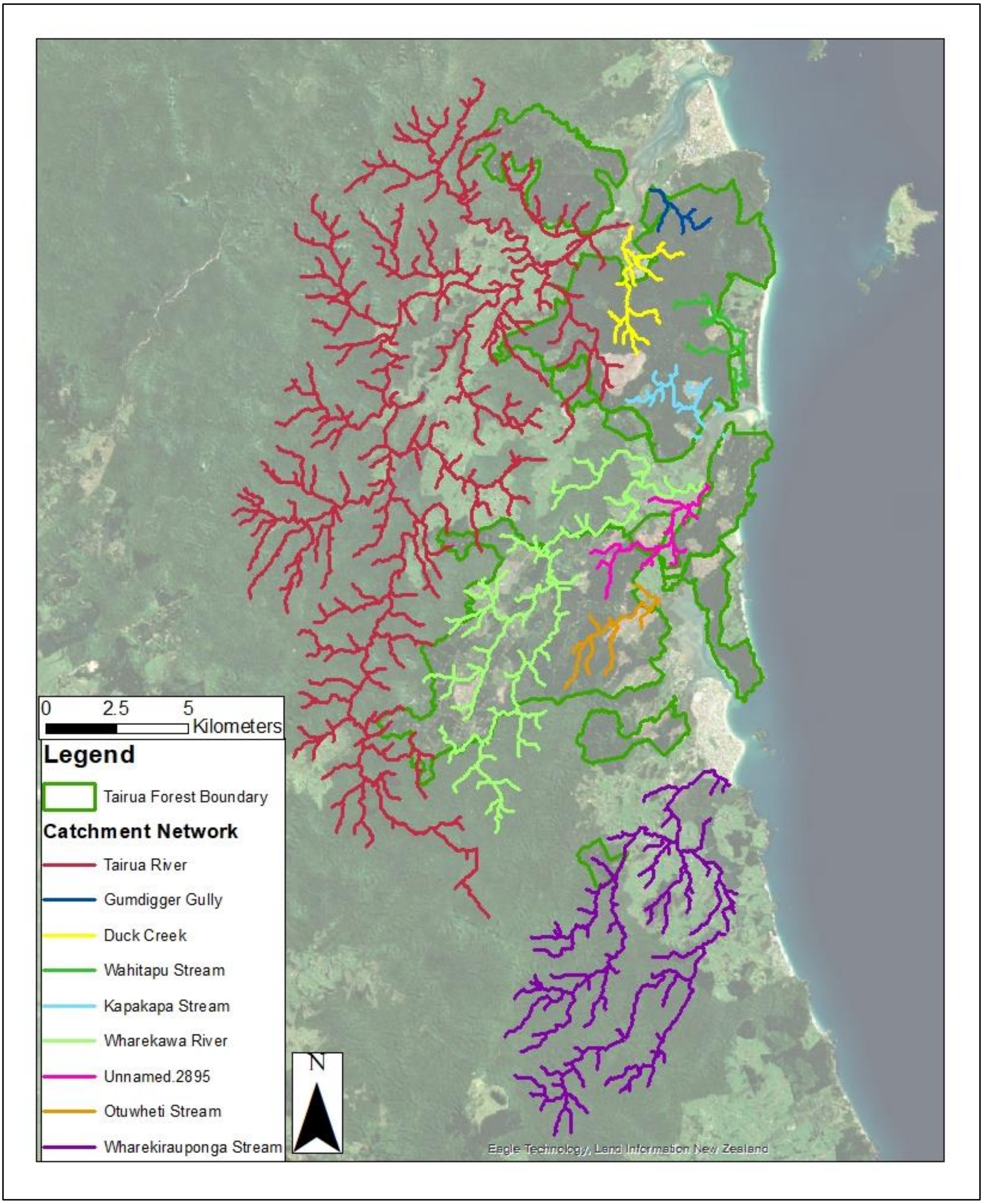


Figure 4.3 Map showing the catchments networks containing structures within Tairua Forest.

Table 4.2 Showing total length of potential fish habitat in each catchment of Tairua Forest and the assigned catchment ID.

Catchment ID	Catchment Name	Total habitat Length (km)
1	Tairua River	326.7
2	Duck Creek	15.5
3	Gumdigger Gully	5.2
4	Wahitapu Stream	10.5
5	Kapakapa Stream	9.7
6	Wharekawa River	79.4
7	Otuwheti Stream	12.6
8	Unnamed 2895	15.1
9	Wharekirauponga Stream	103.5
	Total	578.2

Table 4.3 below shows the network position and upstream habitat of each structure within the Tairua Forest. The extent of perch is also noted. The network position of a structure is the number of structures upstream from itself. A network position 1 structure has no structures upstream. These three measures can help prioritise structures. Structures displaying “N/A” for potential upstream habitat do not fall on the RECNZ river map so their length could not be measured.

Table 4.3 Showing attributes related to the fish passage priority.

RMFID	Catchment	Perched (mm)	Network position	Potential Habitat Length Upstream (km)	Crossing Type
45	5	0	1	2.1	Culvert
46	4	0	2	1.3	Culvert
47	2	0	1	1.3	Culvert
48	4	600	1	N/A	Culvert
49	2	0	2	4.8	Culvert
50	1	100	1	2.6	Culvert
51	2	200	1	0.2	Culvert
52	2	1500	1	N/A	Culvert
53	3	1500	1	0.5	Culvert
54	6	0	6	8.1	Ford
55	6	0	9	8.6	Ford
56	6	600	1	0.3	Culvert
57	6	0	1	27.4	Ford
58	6	0	11	22.2	Ford
59	6	0	1	0.5	Culvert
60	8	0	1	0.1	Culvert
61	8	320	1	1.1	Culvert
62	6	0	1	0.8	Culvert
63	6	60	2	2.0	Poly Culvert
64	2	0	1	0.7	Culvert

RMFID	Catchment	Perched (mm)	Network position	Potential Habitat Length Upstream (km)	Crossing Type
66	6	0	1	1.0	Culvert
67	1	100	1	2.4	Battery Culvert
68	1	0	2	13.8	Drift Deck
69	0	0	1	34.5	Battery Culvert
70	1	300	1	0.9	Culvert
102	7	200	1	0.9	Culvert
103	7	700	1	N/A	Culvert
104	7	0	1	2.1	Poly Culvert
105	8	200	1	1.5	Poly Culvert
113	7	0	1	N/A	Culvert
117	6	0	1	1.2	Culvert
118	6	0	1	2.2	Culvert
119	6	100	1	0.6	Culvert
120	6	300	1	0.7	Culvert
125	1	1300	1	N/A	Culvert

While knowing the network position of a structure is important. It is useful to know which structures contribute to the total network position of the structure. The following nine tables are a matrix system for individual catchments (Table 4.5 to Table 4.13). Structures in different catchments are independent of each other. However, structures in the same catchment can be in series. The matrices are set out to be read vertically with the key information at the base. Using this matrix system for catchments, the structures contributing to the total network position of each structure can be identified. The matrices are ordered from left to right by lowest network position first, then potential upstream habitat from smallest to largest. The matrices have acronym titles which are outlined in Table 4. 4.

Table 4. 4 Key for acronyms in network position matrices.

Key	Description
RMFID	Structure identification number
N.P	Network position – Number of upstream structures plus one. A ‘1’ has no structures upstream. Figure 3.4 demonstrates this.
P.U.H (km)	Potential upstream habitat – length in km of potential habitat upstream from structure measured from the RECNZ map.
P.U.H (%)	Potential upstream habitat – length of habitat upstream from a structure as a percentage of total potential habitat in the catchment.
Shaded Cell	Perched structure – only measured for piped structures.

Table 4.5 Network position matrix and potential habitat length for catchment 1 – Tairua River.

	RMFID	125	70	67	50	68
	125	1				
	70		1			
	68			1		
	50				1	1
	67					1
N.P		1	1	1	1	2
P.U.H (km)		0	0.9	2.4	2.6	13.8
P.U.H %		0	0%	1%	1%	4%

Table 4.6 Network position matrix and potential habitat length for catchment 2 – Duck Creek.

	RMFID	52	51	64	47	49
	52	1				1
	51		1			
	64			1		
	47				1	
	49					1
N.P		1	1	1	1	2
P.U.H (km)		0	0.3	0.7	1.3	4.8
P.U.H %		0	2%	5%	8%	31%

Table 4.7 Network position matrix and potential habitat length for catchment 3 – Gumdigger Gully.

	RMFID	53
	53	1
N.P		1
P.U.H (km)		0.5
P.U.H %		9%

Table 4.8 Network position matrix and potential habitat length for catchment 4 – Wahitapu Stream.

	RMFID	46	48
	46	1	1
	48		1
N.P		1	2
P.U.H (km)		N/A	13.0
P.U.H %		N/A	12%

Table 4.9 Network position matrix and potential habitat length for catchment 5 – Kapakapa Stream.

	RMFID	45
	45	1
N.P		1
P.U.H (km)		2.1
P.U.H %		22%

Table 4.10 Network position matrix and potential habitat length for catchment 6 – Wharekawa River.

	RMFID	56	59	119	120	62	66	117	118	57	63	54	55	58
	56	1											1	
	59		1											1
	119			1							1	1	1	1
	120				1								1	1
	62					1						1	1	1
	66						1						1	1
	117							1				1	1	1
	118								1			1	1	1
	57									1				
	63										1	1	1	1
	54											1		1
	55												1	1
	58													1
N.P		1	1	1	1	1	1	1	1	1	2	6	9	11
P.U.H (km)		0.3	0.5	0.7	0.7	0.8	0.9	1.2	2.2	27.4	2	8.1	8.6	22.2
P.U.H %		0%	1%	1%	1%	1%	1%	2%	3%	34%	2%	10%	11%	28%

Table 4.11 Network position matrix and potential habitat length for catchment 7 – Otuwheti Stream.

	RMFID	113	103	102	104
	113	1			
	103		1		
	102			1	
	104				1
N.P		1	1	1	1
P.U.H (km)		N/A	N/A	0.9	2.1
P.U.H %		N/A	N/A	7%	17%

Table 4.12 Network position matrix and potential habitat length for catchment 8 – Unnamed 2895.

	RMFID	60	61	105
	60	1		
	61		1	
	105			1
N.P		1	1	1
P.U.H (km)		0.1	1.1	1.5
P.U.H %		7%	1%	10%

Table 4.13 Network position matrix and potential habitat length for catchment 9 – Wharekirauponga Stream.

	RMFID	69
	69	1
N.P		1
P.U.H (km)		34.5
P.U.H %		9%

4.4 Analysis of Structures with Fish Presence

Structures can be analysed using fish survey points near them. Due to the lack of samples points in close proximity to structures within the forest, not all structures can be analysed. However, three structures have useable data which is presented in Table 4.14.

In section 4.3, one of the following three structures, RMFID57, is listed as a high priority structure based on the length of upstream potential habitat (27.4 km). The other two structures are not high priority based on this metric. RMFID67 is listed as a perched structure that could inhibit upstream fish passage.

Table 4.14 Showing structure analysis detail for fish species present.

Structure Info	Waterway Info	Fish Species Present
RMFID: 47 **Type:** Culvert (concrete) **Dimensions:** d – 1200 mm l – 12 m **Perch:** None **Other:** Pipe fully submerged in still water (Figure 4.4)	**Catchment:** Duck Creek (1) **Network Position:** 1 **Potential Upstream Habitat:** 1.3 km	**Anguilliforms:** Shortfin Eel Longfin Eel* **Swimmers:** Banded Kokopu (a) **Climbers:** Banded Kokopu (j) **Jumpers:** None Source: (NZFFD downstream of structure)
RMFID: 57 **Type:** Ford **Dimensions:** w – 4.5 m l – 30 m **Perch:** Varies across width up to 300 mm **Other:** (Figure 4.5)	**Catchment:** Wharekawa River (6) **Network Position:** 1 **Potential Upstream Habitat:** 27.4 km	**Anguilliforms:** Shortfin Eel Longfin Eel* **Swimmers:** Inanga* Banded Kokopu (a) **Climbers:** Banded Kokopu (j) Redfin bully* Torrent Fish* **Jumpers:** Brown Trout Source: (eDNA downstream of structure)
RMFID: 67 **Type:** Battery Culvert (3 pipes under concrete) **Dimensions:** d – 400 mm w – 4.5 m l – 10 m **Perch:** 100 mm **Other:** One pipe flowing with an undercut on the downstream side. (Figure 4.6)	**Catchment:** Duck Creek (1) **Network Position:** 1 **Potential Upstream Habitat:** 2.4 km	**Anguilliforms:** Shortfin Eel Longfin Eel* **Swimmers:** Inanga* **Climbers:** Redfin bully* **Jumpers:** None Source: (NZFFD downstream of structure)
Key		
d – diameter w – width l – length	(#) Catchment ID	* At Risk Declining

Figure 4.4 showing RMFID 47, a single culvert. The left image is zoomed in on the submerged pipe and the right image is from the road looking down the pipe. Both images are on the downstream end of the culvert.

Figure 4.5 Showing RMFID 57, a ford crossing. Both images taken from the true right of the waterway.

Figure 4.6 Showing RMFID67 a battery culvert crossing with upstream on the left and downstream on the right.

All three structures above have species with a conservation status listed as "At Risk Declining". Any structure with high-value conservation species should be prioritised in a fish passage sense. But extra focus should be given to these species that have the swimming mode "swimmer". These species have the least probability of passing a perched structure and for the case of the ford, low depth high-velocity water across the structure. Both RMFID57 and RMFID67 have "At Risk Declining" swimmer species. For these structures, it could be assumed that the chances of these species passing the structure are low and remediation would be necessary.

4.5 Prioritising Structures for Fish Passage

Tairua Forest has 16 structures that present some level of perch. Perch can be used as one identifier of fish passage restriction. Table 4.15 shows the perched structures ordered from greatest to least potential upstream habitat. By summing the potential upstream habitat of each of these structures, the total habitat lost due to obstruction of fish passage is 13.7 km. There is the potential for lengths to double-counted if more than one perched structure is in sequence in a catchment. In Tairua Forest, there are two, network position two, perched structures but, in both cases, the upstream structure does not present perch so are not double counted.

Table 4.15 Perched structures in Tairua Forest ordered from greatest to least potential upstream habitat.

RMFID	Catchment	Perched (mm)	Network position	Potential Upstream Habitat Length (km)	Pipe Diameter (mm)
50	5	100	1	2.6	1200
67	4	100	1	2.4	900
63	2	60	2	2.0	900
105	4	200	1	1.5	900
61	2	320	1	1.1	450 (x2 pipes)
102	1	200	1	0.9	1200
70	2	300	1	0.8	1000
120	2	300	1	0.7	1800
119	3	100	1	0.6	700, 1150 (x2 pipes)
53	6	1500	1	0.4	1500 (x2 pipes)
56	6	600	1	0.3	400 (x3 pipes)
51	6	200	1	0.2	700
52	6	1500	1	N/A	600
125	6	1300	1	N/A	900
103	6	700	1	N/A	900
48	8	600	1	N/A	900

These structures currently present an obstruction to fish passage based on perch. But many are of relatively low importance based on potential upstream habitat and network position. There are some extreme examples of perch seen in this list, but the loss of potential upstream habitat is not significant. Also in Table 4.15, it can be seen that perch used alone as fish passage priority can underrepresent high importance structures based on upstream habitat. The most important structures are shown in Table 4.16.

Table 4.16 High priority structures based on potential upstream habitat.

RMFID	Potential upstream habitat (km)	Network position	Catchment	Structure Type
69	34.4	1	Wharekirauponga Stream	Battery Culvert
57	27.3	1	Wharekawa River	Ford
58	22.1	11	Wharekawa River	Ford
68	13.8	2	Wharekawa River	Drift Deck
55	8.5	9	Wharekawa River	Ford
54	8.1	6	Wharekawa River	Ford

None of these structures are perched, mostly due to the nature of their structure type. Perch is difficult to quantify on non-piped structures as some areas across their width have no drop and others can have more significant vertical drop. Hence, it is difficult to comment on their fish passage ability. It is an interesting observation that while 24 of the 35 structures in Tairua Forest are culverts, none of the six most important structures for fish passage are culverts. Supporting this idea, Figure 4.7 shows the network position vs potential upstream habitat by structure type. Interestingly, no single culverts have a network position greater than two or more than 5 km of potential upstream habitat. The high network position or high potential upstream habitat are fords, a battery culvert (ford like structure), and a drift deck. The same structures as in Table 4.16.

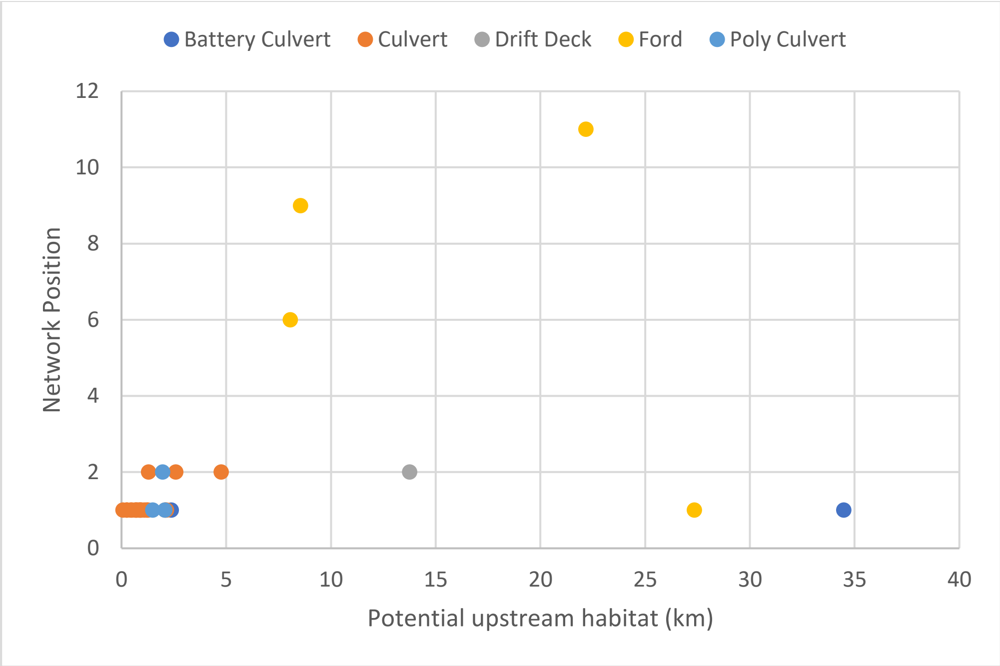


Figure 4.7 Showing potential upstream habitat length verses network position for different structure types.

5 Discussion

5.1 Results Summary

The following subsection discusses the results found in Section 4 broken down into the relevant subparts. Key findings are stated with suggestions on improvements and sources of uncertainty.

5.1.1 Crossing Infrastructure

Across Tairua Forest, all stream crossings were surveyed excluding single culverts smaller than 900 mm unless they were perennial. It was determined that was negligible aquatic habitat in these ephemeral flow paths. Many physical attributes of the crossing structures were measured and with photographs, some environmental features could be inferred. In retrospect, a more accurate and comprehensive picture of the stream habitat and environment would be useful to show what is required for fish passage through an instream structure. It is however satisfying to have structures mapped with attributes across 12,600 ha Tairua Forest. One missing attribute which could provide some insight to structure patterns would be the instalment year. It would be interesting to analyse the trends of material and construction method to the age of the structures. Also, the level of damage based on age, especially perch.

One of the difficulties in surveying is photographing the structures. This can provide some useful information about the structure, especially temporally. This information is often difficult to record in words or numbers, as it can be inconsistent. Many structures are hard to access as they are down steep slopes or covered by vegetation. To get good photos some vegetation was removed to see more of the structure but many photos are only useful to jog the memory of the surveyor about the location and condition of the structure. In future, it would be recommended to spend more time ensuring that the photos taken are useful. A good way to achieve this would be to set a list of attributes that photos should be able to show.

Overall, a basic survey of structures can be completed with a relatively low time investment and still provide useful insights about the forest's crossing infrastructure. Just knowing the locations of crossing structures can allow them to be mapped. Then key structures can be identified, by large upstream habitat and/or high network position.

5.1.2 Fish Surveys

Using publicly available fish survey data for Tairua Forest, nine native fish species were found. The data available was limited to eight sample points within Tairua forest. With the majority of these being downstream of structures. This is not enough to accurately predict which species are present at each structure. The main issue regarding the lack of data within the forest boundary is private ownership of the land. The majority of fish sampling data is on public or government-owned land. So from these data points, it is impossible to tell if these fish species can pass the structures in their current state or compare sample data after a fish passage remediation. However, knowing the species present in the forest is useful to predict what the fish passage requirements are for the specific species.

It should be noted that data from eDNA and NZFFD have their respective pros and cons. On one hand, NZFFD data is useful as there is a large database of professionally gathered fish surveys. These surveys have also been taken over time, so it is possible to see temporal changes in the data collected. NZFFD shows the actual numbers of fish seen which is one of the key downfalls of eDNA. Many different methods are used to survey fish for the NZFFD, so it is important to understand which methods are used in the data you are looking at. Some methods are very effective for finding certain species but can underrepresent the presence of others. On the other hand, eDNA can seem expensive at around $160 a sample but could be much cheaper than contracting a freshwater ecologist to survey a waterway. eDNA can be very accurate in picking up all species in a waterway. But as already mentioned it is very difficult to identify to populations of fish species present. There is also the risk of cross-contamination where species can be picked up that are not expected. These can be introduced from birds for example.

These two methods can be used effectively in conjunction with each other depending on the data available and the importance of the structure in an economic sense. If there is NZFFD data available for your site this can be a good starting point in identifying species present. If there is no data available, then eDNA can be used to get an idea of which species need to be catered for in the design of a crossing structure. In high-value projects, crossings that have high potential upstream habitat, or high network position in a catchment, it could be worth getting a freshwater ecologist to professionally survey the stream for fish after an eDNA sample has been taken. This could be especially useful if unexpected endangered species are found, and special consideration can be given in design.

To truly know if a structure accommodates the passage of fish, samples need to be taken both up and downstream of the structure. eDNA would be an effective method to do this. The preferred method of fish sampling was eDNA. However, less of this was available than previously expected. RMF did have a few eDNA samples, but they weren't taken for the purpose of this research. They were taken to identify species present in a wetland. One of these wetlands had a crossing in it but was a bridge so fish passage is not an issue. It should be noted the importance of bridging this significant wetland.

There are some studies on native freshwater fish swimming abilities however this knowledge is limited. Inanga have some research on their burst and sustained speeds. This research is mainly in very controlled lab environments (Franklin et al., 2018). There is very limited, if any, research on the real-world abilities of these fish. So, it is very difficult to draw a conclusion on what really determines fish passage. One way to do this would be to do fish surveys both above and below structures to see what species are able to pass structures of different types and conditions. Over time this could help to build up a picture of what factors are influencing the ability of a fish to pass a structure. Understanding the environment of freshwater fish species is important too. There is a fair amount of research into where these species occur generally. But when it comes to a specific waterway or catchment it is very difficult to know at what point species stop travelling up or downstream.

5.1.3 Structure Network Priority System

Throughout this report, the importance and priority of structures refers to fish passage. In an engineering/operation sense, this might not always align. A high use arterial road with a stream crossing that is first order with not much potential upstream habitat is of great importance in an engineering sense as the failure of the structure is high consequence. But for fish passage, a high order structure with lots of potential upstream habitat is of higher importance, even if the road is not used.

A system was created to rank structures for their relative importance to fish passage. This order can be used to prioritise the remediation of fish passage loss. The two main factors used are the length of potential fish habitat upstream of the structure and the network position of the structure within its catchment. These two factors often go hand in hand as high order structures also have a greater length of potential upstream habitat. Within catchments that contain many structures, the network position is useful to know as the interaction of structures in sequence can be seen. When comparing catchments with fewer structures or even a single structure, the potential upstream habitat is the more useful measure. Also, when comparing catchments, it would be good to know if the species present differs particularly if there is a change in the swimming modes of the species present.

An interesting observation within this study is high order structures and structures with the greatest length of potential upstream habitat are often fords or battery culverts. These structures are of greatest importance to fish passage, but the structure type is least recommended by the FPG. The reason these structures are chosen is most likely due to the size of the waterway being too large for a piped crossing to be feasible. However, if the importance of fish passage at these crossings was given a higher priority, perhaps the type of crossing chosen would have been different.

5.1.4 Stream Mapping

The main inconstancy when measuring the potential upstream habitat was the quality of the stream map used. While the relative difference between potential habitat lengths of different structures can guide prioritisation, the actual lengths vary considerably between different streams maps and to ground truths. In this study, the New Zealand River Environment Classification (RECNZ) map was used (Snelder et al., 2010). This map turned out to be too coarse for the application as some structures did not fall onto a stream line on the map causing no length of potential upstream habitat to be measured. There are finer scale maps that could have been used to improve the length measurements such as the topo blueline 1:50 000 scale map or a LiDAR feature extraction stream network. These options also have their own set of limitations.

RECNZ maps were useful as they came with attribute data that could be used for other areas of analysis. Although they were at a coarse scale, they could still be used for identifying the catchment structure network. Due to the coarseness of this map the stream network was less complex, hence making the geometric network within GIS was easier. This was a good proof of concept making a structure network with catchments. Comparing the RECNZ map to aerial imagery visually the coarseness can be seen easily in Figure 5.3. For streams that are mapped with RECNZ, the length would be underestimated due to the distance between nodes of the lines. Some streams are not on the RECNZ map, and some lines end too soon, adding to the underestimation of stream lengths.

Another data source available was provided by RMF and is streams mapped using 30cm LiDAR imagery. The system for mapping streams using LiDAR is called GeoNet and is geomorphic feature extraction from high-resolution terrain data (Wu et al., 2019). RMF paid to get this process completed for them. This data was a lot finer resolution but still had some issues. In many cases, this map followed streams accurately when compared visually to an aerial image. But as demonstrated by Figure 5.1, sometimes this method mapped streams too far up a catchment, or where there is no stream present at all. The LiDAR stream model picks up depressions in a terrain model to map streams. This means that ephemeral flow paths will be mapped with good accuracy, which is good for NES-PF compliance but is not necessarily fish habitat so overestimated habitat length. It could be hypothesised that in lower slope areas the difference in length between the two data sources be less than the higher slope areas with more ephemeral flow paths.

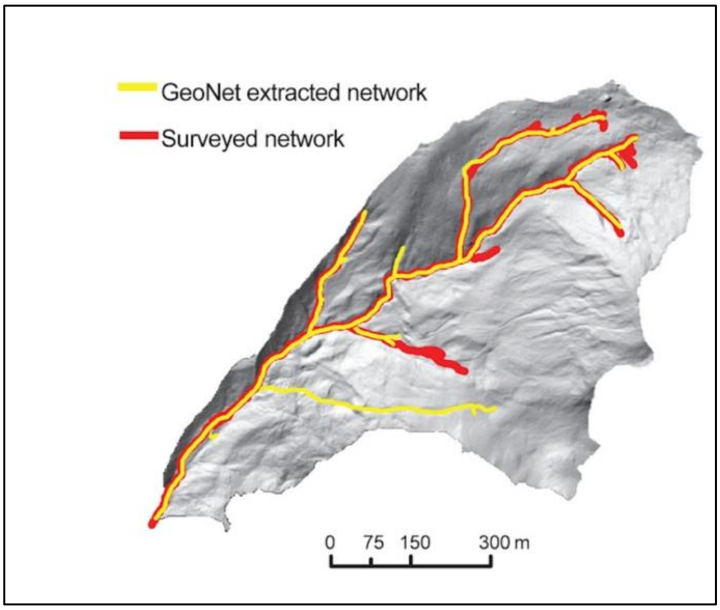


Figure 5.1 Showing how LiDAR derived waterways can differ from the surveyed waterway (Wu et al., 2019).

The difference between stream length measured by RECNZ and GeoNet LiDAR derived waterways were investigated to see if the above hypothesis is true. To do this roughly 10 ha sample areas were created throughout Tairua Forest with the average slope calculated for each. GeoNet stream length and RECNZ stream length were measured in GIS. The difference between each of these lengths was plotted against the average slope of the sample area in Figure 5.2.

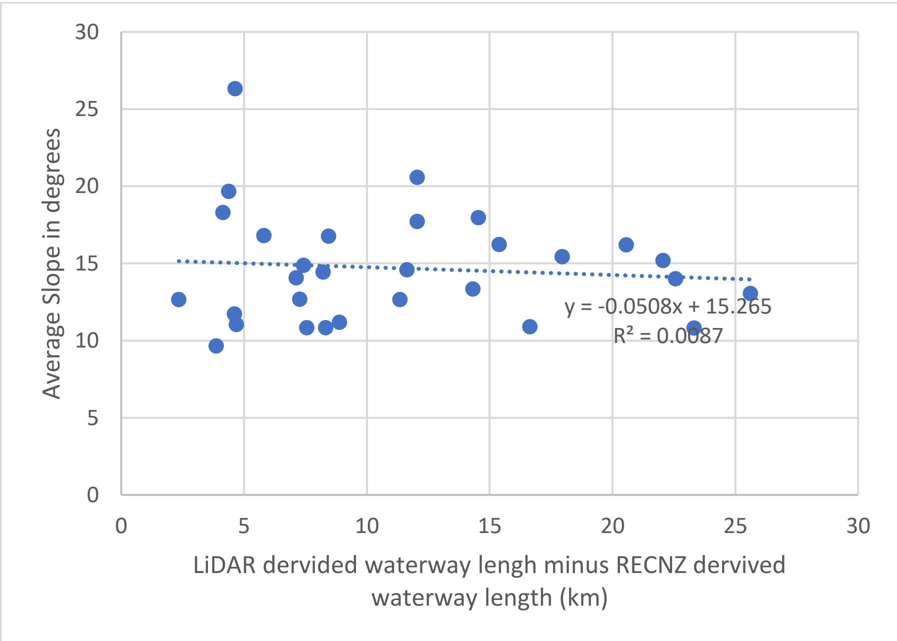


Figure 5.2 Comparing the difference between LiDAR derived waterways and the RECNZ map to average slope.

As can be seen from the R^2 value of 0.009 there is no correlation between average slope and difference in length between LiDAR and RECNZ. The fitted trend, although showing a very low correlation, also shows the hypothesis is wrong. Within 10 ha sample areas, the average difference between the two lines was found to be around 11 km. But there is no statistical indication that this difference increases with average slope. The large difference can be expected though due to the much finer scale of the LiDAR data. Another major disadvantage to this data is that it is only available within the forest boundary. This means that measuring waterways throughout the catchment would be inconsistent. This is because the stream map within the forest would be at a much finer scale than the data available outside the forest. It would only be recommended to use the LiDAR data for catchment that has been entirely covered. Even then, comparing catchments would be impossible if they are measured off maps with different scales. This data cannot be used as a geometric network within GIS due to irregularities caused by the fine scale and how the whole catchment is not covered.

The topo blueline is mapped at a finer scale than the RECNZ map (1:50 000). However, this map is not without its own limitations. The scale is still not as fine as LiDAR so lengths will still be underestimated. This map also has some of the issues that the LiDAR map has, with ephemeral flow paths occurring on the map and some perianal streams not occurring on the map. Figure 5.3 demonstrates the difference between different sources of stream data.

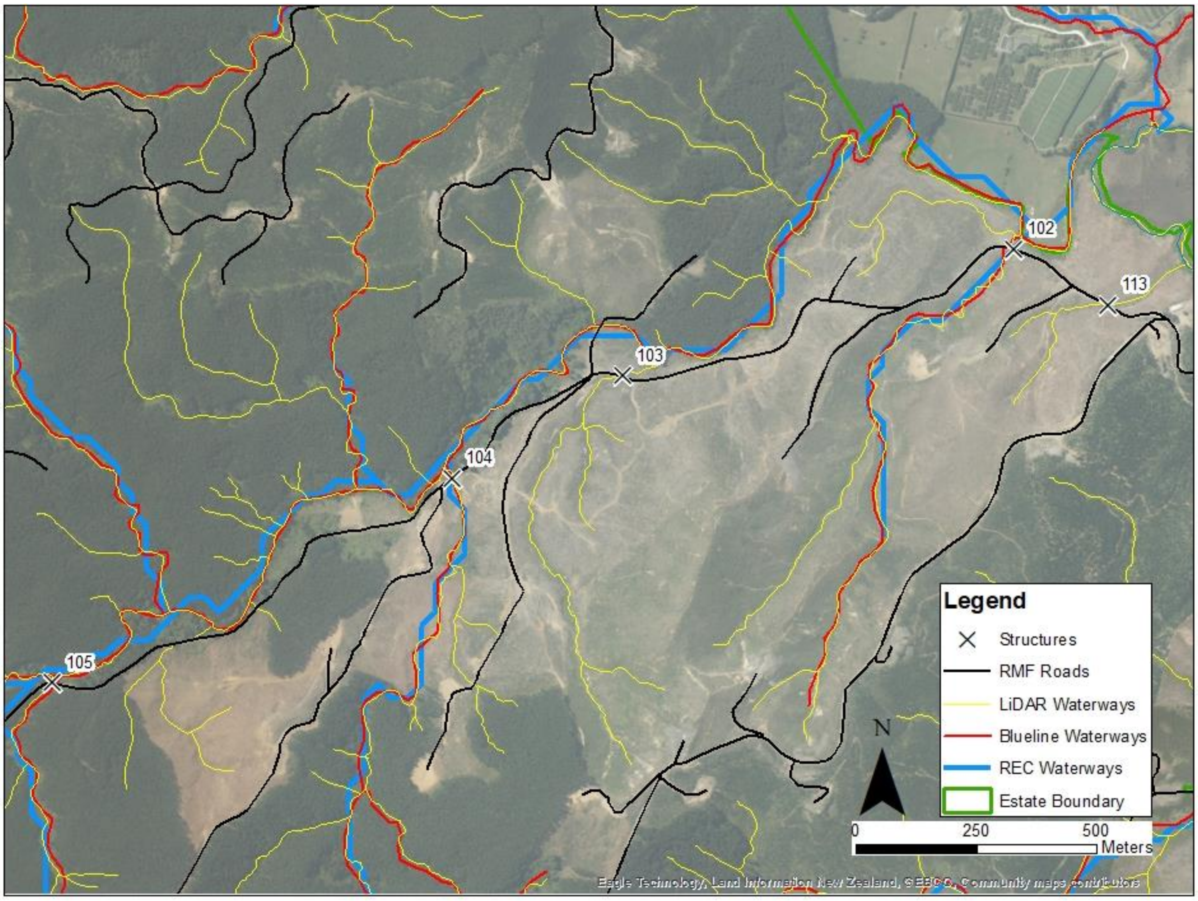


Figure 5.3 Map extract demonstrating the difference in stream lines from different map sources.

Overall, it is best to choose a stream map that covers all the area of interest. Also using different maps within the same analysis should be avoided so that fair comparisons can be made. However, it is important to understand the limitations of the map that is being used.

5.2 Recommendations to Practitioners

Based on the findings of this research the following key recommendations are made for the design, maintenance and monitoring of stream crossings structures.

Surveying crossing infrastructure accurately can be very useful especially for monitoring changes. Creating a network of structures within each catchment can help understand how structures interact with each other. eDNA sampling is simple to collect and can provide good information about which species are present within the waterway. While regulations may remain broad and somewhat ambiguous, by having solid data and design backing upstream crossings, regulators can understand why decisions are made. Also, it can be proved that the structure provides sufficient fish passage for the species present.

The best type of crossing for fish passage is a bridge. While this is often the most expensive crossing type, if the crossing is of great importance to fish passage the cost could be justified where it would not have been based on timber volume going across it. I think that if practitioners can show they are willing to shoulder the extra cost to protect sensitive fish species, regulators will be more open to a lower design standard for less important crossings. However, this does require an understanding of the waterways in your forest, including what species are present and the interaction structures have with each other and the potential habitat in the catchment. It would be good to look at other options rather than the classic culvert. There are many open-bottomed crossing options now which are not too expensive or difficult to install.

It is inevitable and recognised widely that some structures within any forest or any stream crossing anywhere for that matter will have fish passage issues. So, while knowing the location and extent of these issues is a good starting point some proven remediation methods are needed. Within the FPG, some methods of remediation are discussed, including baffles, ramps, and mussel spat ropes. While these methods can offer a novel solution to a lack of fish passage, some careful consideration should be taken when choosing a method. It is tempting to choose the option that is the cheapest or easiest to install, but this will not always fix the issue.

To remediate fish passage, the species that cannot pass the structure and the reason they cannot pass the structure need to be known. For example, a perched culvert has high water velocity through the pipe that is stopping the passage of Inanga, a relatively weak swimming species. Mussel spat ropes would be a cheap and easy installation that would look like fish passage remediation has taken place. However, as Inanga are a swimming species, they will still not be able to climb the ropes to pass the structure. So, the cheap spat ropes become an expensive and time-wasting non-solution. The culvert could be reinstalled deeper, or a weir could be created to backwater the culvert, ensuring the weir does not become a new obstacle to fish passage.

Fish passage remediation is part science part art, it requires a level of creativity accompanied by understanding the physics of fish swimming capabilities. It is recommended to look at other fish passage remediation attempts and learn from them, what worked and what did not. Also, experimenting with out of the box ideas is good, there is no one right way to remediate a lack of fish passage and nearly every crossing structure is going to have different requirements. The main goal is to make the water through a crossing structure simulate the natural waterway as much as possible.

Regular monitoring of structures can have many benefits. Structure performance or damage after weather events can be identified. Settlements of fill over buried structures causing the displacement or crushing of structures can also be found. But from a fish passage perspective, the performance of the structure can be monitored. In a physical sense, perch can be seen and mitigated before it starts becoming too much of an obstacle to fish passage. It is also helpful to see how the structure operates at different flow levels and if low flow becomes an obstacle to fish passage. This can be especially useful if the structure was constructed in higher than usual flows.

Continually surveying fish species both above and below the structure is also useful. Changes in species present outside of normal above the structure could indicate that the structure has lost fish passage for some species if species decrease. Or that a remediation effort has been successful if species increase. Understandably this is an expensive and time-consuming exercise so the priority system could be used to identify which structures are more important to monitor often.

5.3 Limitations of Research

While every effort has been made to ensure this research is comprehensive and accurate. There are some areas that limit the analysis quality of the report. Many of these points have been covered in previous sections of the discussion. Fish presence data is the main area of concern for this report.

The lack of survey data has meant that a detailed analysis of structures based on which species are present cannot be carried out. The species present within the forest can be shown with reasonable confidence. But it is impossible to know which species are present at an individual crossing without having surveys done at these locations.

The other area of concern is how representative the potential upstream habitat lengths are to real life. This has been discussed in detail in Section 5.1.4. While it is known that these lengths are significantly underestimated, the relative difference between them can be used with confidence.

5.4 Future Research Direction

Further research can be undertaken to improve knowledge on fish passage through instream structures. With regard to this study, in future the stream network and potential upstream habitat length could be automated within a map to show more visually the interaction and relative importance of structures. When new structure surveys are done, the change in condition could be seen in terms of structure interaction.

Using what has been learnt about structure importance, a survey system could be created where key information about the structure is scored and given weights. This would allow structures to be given an overall score which would show structure priority. This would be useful as is it often difficult to definitively say if a structure provides fish passage.

6 Conclusion

This research project aimed to gain insight to fish passage requirements and instream structure performance within Tairua Forest The following questions were proposed to guide this research:

- What native freshwater fish species are present within Tairua Forest and what are their fish passage requirements?
- How does the current state of crossing infrastructure meet these requirements within Tairua Forest?
- To what extent does instream structures affect the interconnection fish habitat?
- How can fish passage remediation be prioritised?

Tairua Forest is 12,600 ha and has 35 crossing structures. This is made up of 29 piped structures, one drift deck, and four ford crossings. Using the New Zealand Freshwater Fish Database (NZFFD) and eDNA, nine fish species were identified within the forest. Of these seven migrate upstream during the lifecycle and five carry the conservation status "At Risk Declining". Only one species was non-native.

To identify the fish passage requirements of structures, the swimming ability of the species presented was investigated. The swimming ability of fish falls into four categories listed from least to most sensitive to structures as an obstacle to fish passage: anguilliforms (Eels), jumpers (trout), climbers (bullies), and swimmers (Inanga). Where swimmers are present, structures must not have any vertical drop (perch) and require the velocity of water through the structure to be less than the burst swimming speed of the species. Areas of lower velocity must be provided for these species to rest. Climbing species can use the wetted edge of the structure to pass greater velocity within structures. However, climbers cannot pass the laminar flow of perched structures. As jumping species are predominantly non-native and predate on native fish they are not accounted for when considering fish passage requirements. Anguilliforms can absorb air through their skin allowing them to travel over land if their skin remains wet. Hence these species are often not obstructed by instream structures.

It is difficult to definitively say if a structure provides fish passage or not based on physical appearance alone. In saying this, perched structures present a high chance of obstructing fish passage to swimming and climbing species. Within Tairua Forest, 16 structures have some level of perch. This is nearly half of the structures. There are other factors that could restrict fish passage as mentioned above. So, there are potentially more structures that could restrict fish passage. With such a large proportion of structures that require fish passage remediation, it raised the question of how can these structures be prioritised?

The first step in prioritising structures for fish is understanding what effect the lack of fish passage has on a waterway and a catchment. Within Tairua Forest, it was identified that there are nine catchments containing structures. The length of potential habitat in each catchment was measured using the River Environment Classification New Zealand (RECNZ) map from NIWA. The total length of potential habitat across all nine catchments was found to be 580 km. The largest catchment was Tairua River with 330 km of potential habitat and the smallest was Gumdigger Gully with 5 km of potential habitat. The length of potential habitat above each structure was also measured showing the potential habitat loss that can occur due to a lack of fish passage. The total potential habitat upstream of all structures in Tairua Forest is 117 km, this is 20% of the potential habitat across all nine catchments. The total potential habitat upstream of perched structures is 13.7 km. This is that amount of habitat that is currently inaccessible to species that cannot pass perched structures.

When considering the remediation of fish passage in structures, it is important to understand the interaction of structures within each catchment. Structures in a catchment occur in a network. A fish travelling upstream must pass the lowest structure first before moving further upstream. This means that fish passage must be prioritised to downstream structures. Some structures have no further structures upstream, and others have many in sequence. Using a matrix, the interaction between structures within a catchment was found. Structures with no further structures upstream were given network position one and structures at the start of a sequence of other structures were given a network position as the number of upstream structures. The matrix was able to show which other structures made up the network position. This is useful for prioritising remediation, as there is no point fixing an upstream structure until all down steam structures have fish passage.

Using the length of potential upstream habitat and the network position of the structures with the attributes of the fish species present, structures can be given a level of relative importance. A list of the top six priority structures was created. These structures have the highest length of potential upstream habitat and the highest network position. Interestingly, none of these structures were culverts. The list includes: all four fords, a battery culvert, and a drift deck. These structures are often overshadowed by culverts when considering fish passage. But as seen in this research they are the most important for migratory fish as they are the gateway to the greatest amount of habitat. Fords are more often barriers to fish passage due to the often-low water depth across them. They also lack complex flows for swimming species to use when passing them. While none of these fords were identified as having perch, it is likely that they are restricting fish passage for some species.

Overall, the priority system tools, specifically the potential upstream length and network position matrices can be used for a number of applications in improving the fish passage performance of instream structures. The main use is prioritising the remediation of structures lacking fish passage. When designing new structures these tools can also be useful. This is so the importance of structures can be seen before they are built. This allows designs to be made which best meet fish passage requirements based on where it is within the catchment and within the current structure network. Finally, surveying fish species present and understanding the abilities of the species found is one of the most important methods in ensuring effective fish passage.

7 References

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