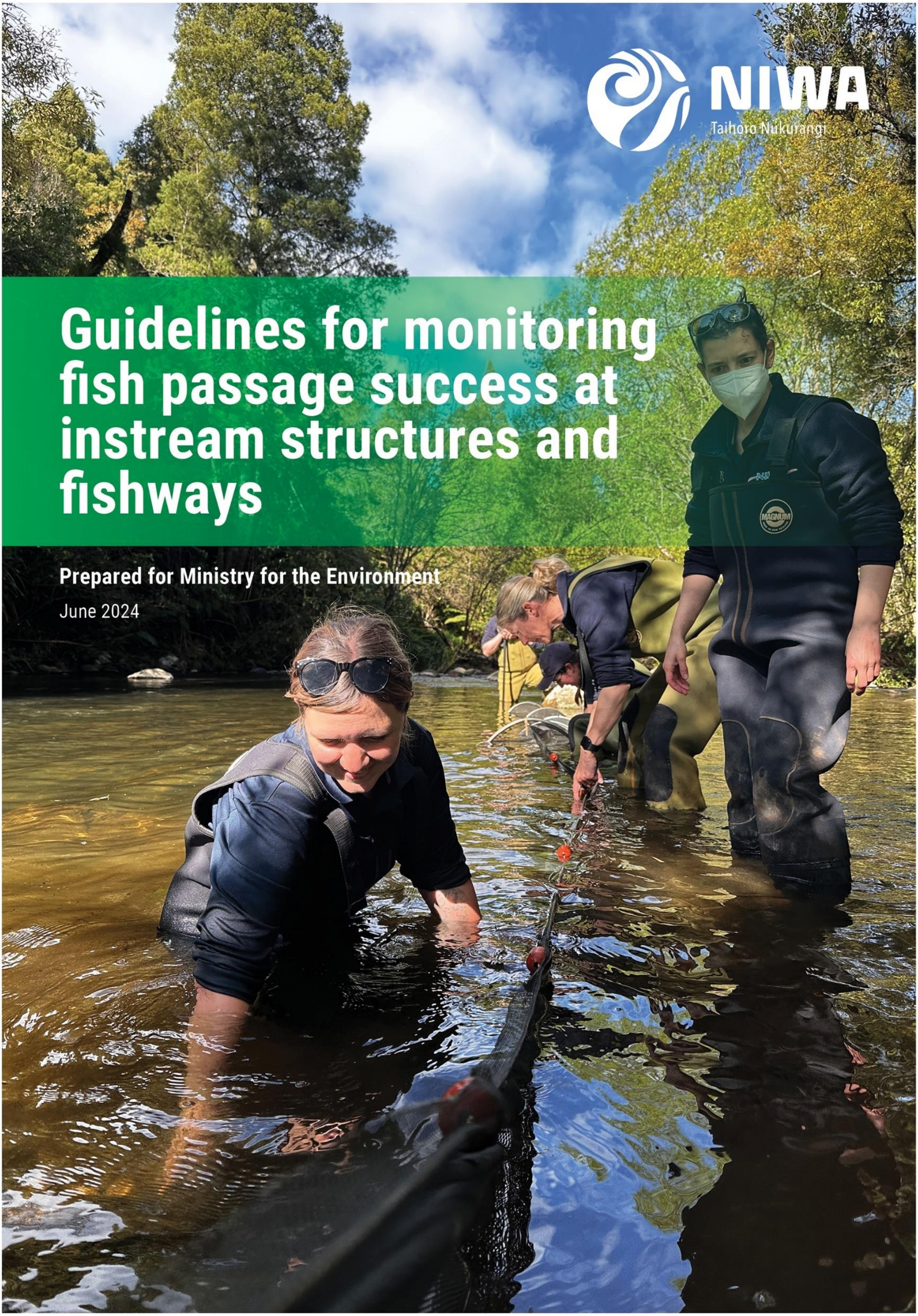

NIWA
Taihoro Nukurangi

Guidelines for monitoring fish passage success at instream structures and fishways

Prepared for Ministry for the Environment

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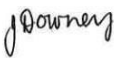	Formatting checked by:	Jo Downey
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Contents

Tables

Figures

Introduction

1 Introduction

Around a third of New Zealand's freshwater fish species undertake significant migrations as part of their lifecycle. For some species (e.g., eels and lamprey) these migrations are obligatory, and they require access to both marine and freshwater environments to successfully complete their lifecycle. Even species that can live solely in freshwaters carry out extensive movements to access the range of habitats necessary to support different life-stages, e.g., reproduction and rearing, and ecological functions, for example feeding or finding refuge.

One of the most significant causes of the decline in freshwater fish populations in New Zealand is the construction of structures such as dams, culverts and weirs that prevent or restrict fish from migrating or moving into suitable or critical life-stage habitats. Consequently, poorly installed and/or maintained instream infrastructure results in reduced distributions and abundances of some of New Zealand's most iconic and valued freshwater species.

The New Zealand Fish Passage Guidelines have been developed to assist infrastructure designers and managers, waterway managers, environmental officers, tangata whenua, and local communities with understanding and promoting better management of fish passage requirements in New Zealand (Franklin et al. 2024a). Based on current knowledge, the guidelines set out evidence-based approaches for providing fish passage at instream structures to help maintain the diversity and abundance of freshwater fish and other aquatic organisms in our streams and rivers.

Whether it is a new structure being installed, or remediation of an existing structure, planning and implementing an effective monitoring and maintenance programme *before* the works is undertaken is an essential part of the project. Even when best practice guidelines are followed for the design or remediation of an instream structure, a well-designed monitoring and maintenance programme is essential to ensure the structure remains fit-for-purpose and meets the means objectives and performance standards. However, relatively few fish passage solutions have had robust and independent monitoring programmes carried out to evaluate their success and ensure an effective use of capital resources. Well-designed monitoring programmes help to increase knowledge of the functionality of different fish passage solutions, allowing adaptive management, informing future improvements in design, and optimising evidence-based investment of limited resources. Furthermore, evaluating the performance of a structure or fish pass can inform the level of mitigation that might be required to overcome poor passage efficiency at a structure.

1.1 Objective

The objective of this manual is to describe evidence-based methods suitable for evaluating the effectiveness of fish passage solutions. These methods can be used to ensure that solutions are fit-for-purpose and fulfil objectives for improving upstream fish communities. This provides greater certainty for regional councils, tangata whenua and asset owners that their investments are optimised and are effective.

Monitoring is the only way to understand how well a structure is working. It is essential for ensuring that any reduction in fish passage caused by a structure is not adversely impacting upstream communities and that environmental outcomes are being achieved. It is particularly important to understand how well a structure is functioning in situations where:

- High value fish communities or ecosystems are present, or are expected to be present, upstream of the structure.

- Unproven designs are being used.
- Proven designs are being used in novel situations.
- Retrofit solutions form only one component of an instream structure.
- Multiple structures exist within a waterway causing cumulative effects.
- Selective barriers are being used to manage the movement of undesirable species.

The monitoring methods outlined in this manual will ensure that fish passage assessments are fit-for-purpose and consistent across New Zealand, enabling a comparison of efficacy, and consequently ensuring that investment leads to the best possible outcomes for fish passage, catchment connectivity, and threatened species restoration.

Objectives and monitoring approaches

2. Fish passage objective and performance standards
3. Monitoring fish passage success
4. Setting objectives

2 Fish passage objectives and performance standards

Having clear and specific objectives is essential for effective fish passage design and implementing appropriate outcome monitoring. Conroy and Peterson (2013) define objectives as "specific, quantifiable outcomes that reflect the values of decision makers and stakeholders and relate directly to the management decisions." They also distinguish between **fundamental objectives**, which are the things that a decision maker truly values and wants to achieve, and **means objectives**, which are a means of fulfilling or achieving the fundamental objectives.

Our experience is that *a priori* objectives are rarely explicitly defined for fish passage projects in New Zealand. This contributes to ill-informed fish passage design and the absence of performance measures against which to evaluate success. In fish passage projects where *a priori* objectives have been identified, they are often vague and fail to distinguish between fundamental and means objectives. This leads to confusion in the design process and in determining appropriate monitoring methods for measuring success.

2.1 NPS-FM fish passage provisions

The NPS-FM (2020)[1] (herein referred to as the NPS-FM) Section 3.26 sets out a range of policy provisions relating to the maintenance and improvement of fish passage. In particular, it directs councils to include a fish passage objective in its regional plan:

> "The passage of fish is maintained, or is improved, by instream structures, except where it is desirable to prevent the passage of some fish species in order to protect desired fish species, their life stages, or their habitats."

To support achievement of this objective, councils must also include policies in their plan(s) that:

- identify the desired fish species, and their relevant life stages, for which instream structures must provide passage,
- identify the undesirable fish species whose passage can or should be prevented,
- identify rivers and receiving environments where desired fish species have been identified, and
- identify rivers and receiving environments where fish passage for undesirable fish species is to be impeded in order to manage their adverse effects on fish populations upstream or downstream of any barrier.

Section 3.26(4) also sets out specific matters that must be taken into account when considering an application for consent relating to an instream structure. These include:

- the extent to which it provides, and will continue to provide for the foreseeable life of the structure, for the fish passage objective,
- the extent to which it does not cause a greater impediment to fish movements than occurs in adjoining river reaches and receiving environments,

[1] National Policy Statement for Freshwater Management (NPS-FM)

- the extent to which it provides efficient and safe passage for fish, other than undesirable fish species, at all their life stages,
- the extent to which it provides the physical and hydraulic conditions necessary for the passage of fish, and
- any proposed monitoring and maintenance plan for ensuring that the structure meets the fish passage objective now and in the future.

Fish Passage Action Plans (Section 3.26(6)) will set out a work programme for improving the extent to which existing structures achieve the overarching fish passage objective and set targets for remediation of existing structures. Importantly, the Fish Passage Action Plan work plan (Section 3.26(7)(f)) must specify how the ongoing performance of remediated structures will be monitored and evaluated, including the effects of the structure on the abundance and diversity of desired fish species. Consequently, **a robust, evidence-based monitoring programme is essential to meeting environmental outcomes relating to biodiversity under the NPS-FM fish passage provisions**.

2.2 Fish passage objectives

Objective setting should precede decisions regarding the design of new structures or remediation options for existing barriers. Effort should be taken to determine both fundamental and means objectives and understand how objectives link to, or conflict with, each other. Objectives may, amongst other things, reflect legal mandates (e.g., policy requirements under the NPS-FM and Freshwater Fisheries Regulations 1983—FFR83), community and stakeholder values, cultural needs (e.g., mahinga kai), economic values, and/or logistical considerations. We suggest that councils consider defining fish passage objectives in their Fish Passage Action Plans.

Figure 2-1 provides an example objectives network for a fish passage project. The example is focused on ecological objectives, but expanding this to consider and incorporate broader economic, social, cultural, and logistical objectives, for example, may be important for effectively evaluating trade-offs in the decision-making process (Gregory and Keeney, 2002). The process of identifying objectives should involve tangata whenua and stakeholders. This will increase the legitimacy of the objectives and subsequent decision-making regarding potential solutions and performance measures.

Setting clear fundamental objectives enable decision-makers to identify all options for fish passage solutions that will meet goals and guide defining performance measures. Status quo bias often leads decision-makers to short-cut the process of identifying and evaluating alternative solutions by defaulting to a known or easily accessible intervention (Conroy and Peterson, 2013). This can result in better alternatives being missed and/or solutions being poorly aligned with objectives, and should be avoided. It is important for decision-makers to recognise that multiple means objectives may have to be fulfilled to achieve the fundamental objectives. This is a common occurrence in fish passage management where providing passage for multiple species and life stages at the same site is a typical pre-requisite for achieving broader fundamental objectives relating to sustaining healthy upstream fish communities. Translating the means objectives into performance measures and standards (O'Connor et al. 2022) and aligning this with the development of design criteria and project monitoring and evaluation is an important step for helping to evaluate alternative solutions and ensuring accountability.

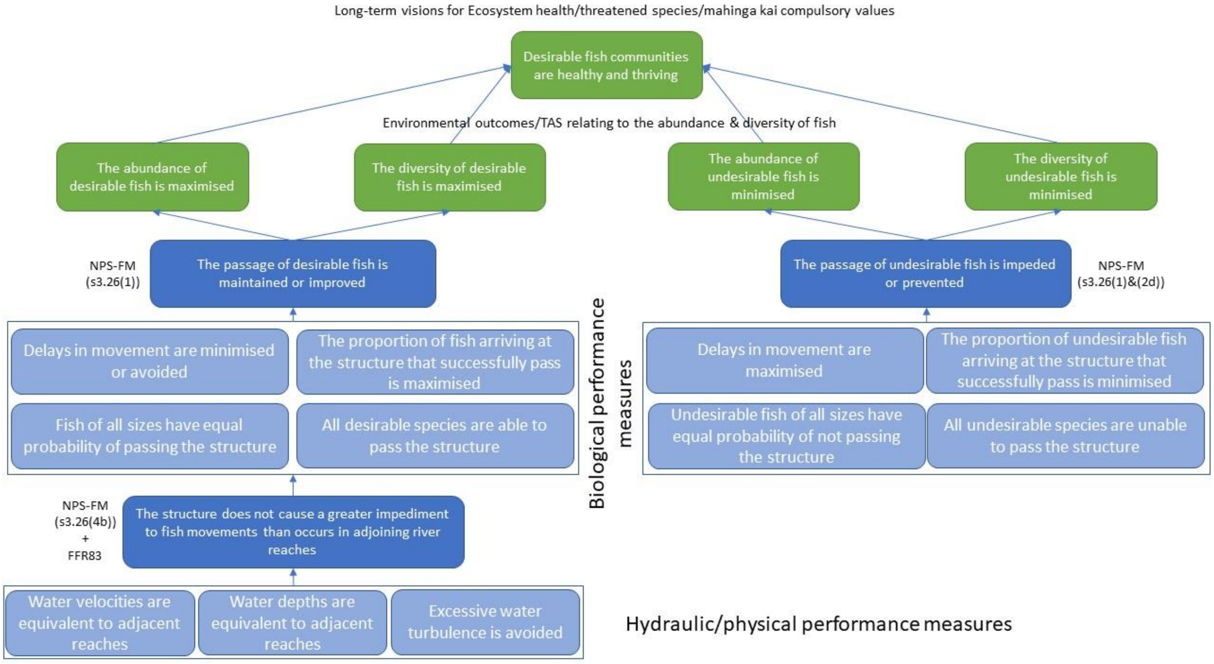


Figure 2-1: Illustration of a potential objectives network that links means objectives to achieving fundamental objectives. The green boxes are examples of fundamental objectives, and the blue boxes are examples of possible means objectives. This objectives network is not intended to be exhaustive and will vary depending on the specific context and values for the site. References to the NPS-FM and FFR83 show links with specific provisions within those policies/regulations. Abbreviations: TAS, target attribute state.

2.3 Performance measures and standards

Performance measures describe the metrics or variables used to measure the performance of a structure while **performance standards** describe the actual value of a metric that is needed to meet objectives (O'Connor et al. 2022). Performance measures and standards must, therefore, be aligned with and informed by the objectives and will inform monitoring requirements.

At the scale of an individual structure, performance measures will generally align with the means objectives. Typically, this will result in both *hydraulic/physical* and *biological* performance measures (Table 2-1). **Hydraulic/physical performance measures** describe the hydraulic or physical conditions (e.g., water velocity, water depth, turbulence) within/at the structure. The hydraulic or physical conditions within/at the structure will determine how easy it is for a given fish to pass the structure and so are an important aspect of the design criteria for a structure. **Hydraulic/physical performance standards** define the acceptable range or limits for different hydraulic or physical performance measures. The design criteria for the structure must ensure that the hydraulic or physical performance standards will be achieved. Hydraulic or physical performance standards should be informed by laboratory or field-based tests of fish behaviour and passage success under different (ideally controlled or experimentally manipulated) hydraulic or physical conditions.

Biological performance measures will be derived from the biological objectives and describe different measures of fish passage success (Table 2-1). Depending on the structure type there may be biological performance measures relating to the attraction efficiency, entrance efficiency, and/or passage efficiency at the structure (Wilkes et al. 2018). Attraction efficiency relates to the ease with which fish can find the entrance of a structure. Entrance efficiency describes the success of fish entering the structure. Passage efficiency describes the success of fish passing the structure after entering.

Biological performance measures are often framed around the proportion of a species (or multiple species) successfully passing and/or delays in fish movement resulting from the structure as these are two key metrics that are typically related to achievement of the fundamental objectives. Biological performance measures may be established for individual species or life stages, or for the overall fish community. This will be dictated by the values that have informed the objectives. In most cases, more than one biological performance measure will be relevant for achieving the overarching fundamental objectives and this should be accounted for in both the structure design and evaluation stages. **Biological performance standards** define the acceptable range or target for different biological performance measures. They should be set at a level to achieve the fundamental objectives and will typically be quantitative. Setting biological performance standards can be challenging, but as far as possible should be evidence-based and acknowledge uncertainty. They may be most effectively implemented within an adaptive management framework and tied to outcome monitoring of fundamental objectives.

Both hydraulic and biological performance measures and standards will be relevant to evaluating success and should be the basis of designing effective monitoring and evaluation frameworks. Sections 3 - 9 provide guidelines on designing and undertaking effective biological performance measures whilst Section 10 provides guidelines on hydraulic and physical performance measures.

Table 2-1: Examples of some possible biological, hydraulic, and physical performance measures that could be identified to inform structure design and evaluate success.

	Performance measure	Explanation
Biological	Percentage passage of target species	May be defined for individual species or overall fish communities. The lower the percentage passage rate, the greater the risk of adverse effects on fish communities.
	Length of delay	Delays increase the risk of predation and may prevent fish from reaching critical habitats.
	Number of fish species passing successfully	Different species have different requirements for sustaining successful passage. Ensuring multiple species can pass may be an important measure of success.
	Size range of fish passing successfully	Individuals of different sizes have different movement capabilities. We should generally be seeking to ensure that fish of all sizes are able to pass a structure.
	Undesirable species cannot pass	In some cases, we may wish to prevent undesirable species or life stages from reaching critical habitats of threatened species.

	Performance measure	Explanation
Hydraulic	Maximum water velocity	High water velocities may exceed the burst swimming capabilities of fish and prevent them from passing.
	Mean water velocity	If mean water velocities are high fish may become exhausted before they reach the end of the structure.
	Minimum water depth	If water is too shallow, fish cannot swim past.
	Maximum pool turbulence	Excessive turbulence can disorientate and tire fish.
	Maximum head loss	The head loss between pools in a fishway controls maximum water velocities and/or may exceed fish jumping capabilities.
Physical	Minimum fall height	If fall height is not great enough it may allow passage of undesirable species at an exclusion barrier.
	Minimum overhang distance	If the overhang distance is too short at an exclusion barrier, undesirable species may be able to jump or climb past.

3 Monitoring fish passage success

For either a new or existing structure, designing a robust monitoring programme is essential in providing credible evidence on the effectiveness (or otherwise) of different fish passage solutions. The methodologies employed will be contingent upon performance measures, target species and practical considerations. Figure 3-1 can assist in using this manual to design and implement an effective monitoring programme.

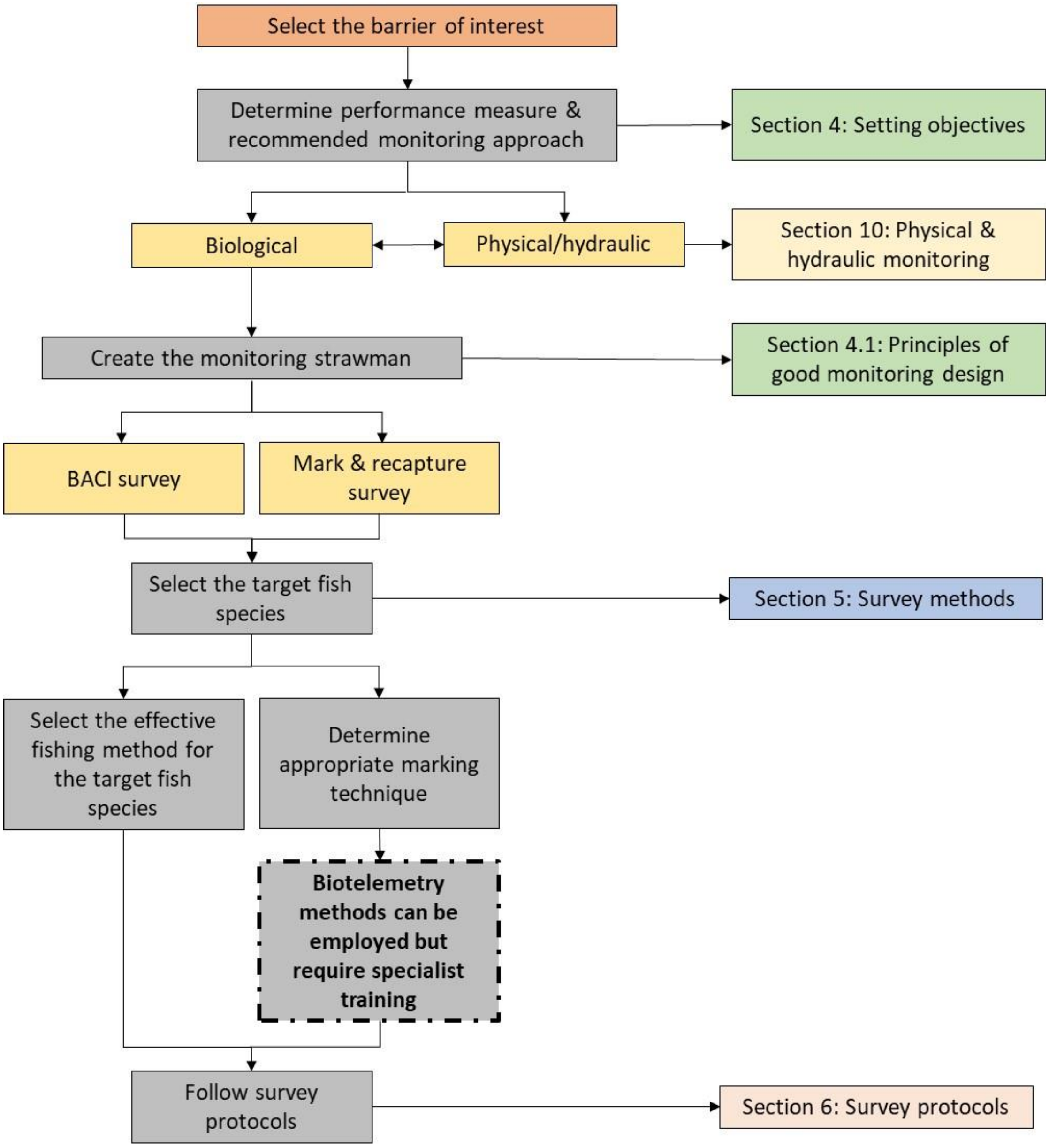


Figure 3-1: Flowchart to guide monitoring methods contingent upon fish passage objectives.

The appropriate type of monitoring approach for any situation will be contingent on the fundamental objective(s) and means objective(s). Physical and/or hydraulic objectives can often be utilised alongside biological monitoring of fish passage past instream structures. The following sections provide guidelines on biological monitoring approaches (Section 3.1 to 9) and physical and/or hydraulic monitoring approaches (Section 10) for fish passage projects.

3.1 Biological monitoring approaches covered in this manual

A range of monitoring approaches are available but based on the small body size of most of New Zealand's migratory fish, the two approaches recommended for evaluating upstream fish passage success are: a before-after-control-impact (BACI) survey, and/or an in-situ mark-and-recapture study. If adult fish (e.g., lamprey) or larger elvers (>120 mm) are the focal species then biotelemetry approaches such as Passive Integrated Transponders (PIT) tags, acoustic and radio tags can be successfully utilised. As such, this manual details methods for undertaking biotelemetry studies, BACI surveys and mark-and-recapture studies (see Sections 5 & 6), which have the widest applicability for monitoring upstream fish passage with New Zealand species. The main benefits and drawbacks of these approaches are outlined in Table 3.1.

Table 3.1: The main benefits and drawbacks of biotelemetry, before after control impact (BACI) and mark-and-recapture monitoring approaches.

Monitoring	Benefits	Drawbacks
Biotelemetry (e.g., PIT, acoustic and radio tagging)	Timing and location of fish movements and behaviour can be captured.	Tags too big for some species and/or life stages and may alter behaviour.
	Remote data capture possible.	Battery life of tags may not be sufficient.
	Passage efficiency can be estimated.	Tags and antennae can be relatively expensive.
BACI survey (e.g., electrofishing or netting surveys)	Documents changes to fish communities upstream of the remediated structure following intervention (e.g., structure removal or installation).	Can take several years to determine if the remediation is effective (e.g., recruitment of diadromous species can be variable between years).
	Minimises handling and stress to fish species.	If the retrofit is unsuccessful in promoting fish passage no information is provided on which component of the remediated structure is still problematic.
		Does not provide any indication of the proportion of fish successfully passing the structure
Mark & recapture study (e.g., stain and release)	Can be used to test different components of an instream structure independently and collectively.	Fish are subjected to handling and stress, which may affect passage success.
	Immediate results on the effectiveness of the solution.	Does not document changes in upstream fish communities.
	Provides an estimate of passage efficiency.	May require permits from MPI, DOC or Fish and Game for the transfer and release of fish.
		Lack of ability to capture test fish downstream can limit use.

3.2 Other biological monitoring approaches

Other automated methods can also be utilised for monitoring fish passage success, but they generally require a higher investment in resources and have severe limitations in monitoring small-bodied fish with a slim morphology (i.e., juvenile galaxiids). Simpler methods such as visual checks can also be used but can be subject to observer bias and a lack of reproducibility. A brief overview of the main automated approaches utilised globally and their applicability to fish passage monitoring in New Zealand is provided below with advantages and drawbacks outlined in Table 3.2.

Table 3.2: The main benefits and drawbacks of various automated or visual monitoring approaches.

Monitoring	Benefits	Drawbacks
Fish counters	Minimises handling of fish.	Does not document passage failure.
	Can be low cost.	Does not document changes in upstream communities.
		Does not accurately identify species.
Video and acoustic cameras (e.g., ARIS, DIDSON)	Avoids handling of fish.	Video processing can be laborious. AI technology currently unable to reliably automate fish counts, especially for small-bodied fishes.
	Can be relatively low cost.	Ineffective in water with poor visibility (video cameras).
	Can provide semi-automated monitoring of target species.	Generally restricted to enclosed areas and does not document changes in upstream communities.
		Does not accurately identify similar species, particularly when small, i.e., cannot discriminate between īnanga and climbing galaxiids as whitebait.
Visual checks	Quick and cost-effective means of identifying potential problems.	Ineffective at quantifying passage success rates.
		Does not document changes in upstream communities.
		Ineffective in water with poor visibility.
		Does not accurately identify similar species, particularly when small, i.e. cannot discriminate between īnanga and climbing galaxiids as whitebait.

3.2.1 Fish counters

A range of automated fish counters are available commercially that operate using either resistivity between the water and body of the fish or infrared beams. The VAKI Riverwatcher is one of the more widely used electronic fish counters that measures the size and shape of fish that pass through an infrared scanner (Jones and O'Connor, 2017).

Major disadvantages of fish counters are that they cannot discriminate between species other than by their size, and their accuracy is negatively affected by visibility, fish size, and speed of travel. For example, laboratory testing of the Riverwatcher found it underestimated counts of Silver perch (*Bidyanus bidyanus*; size range: 345–498 mm), a slow swimming species, by 56–84% at moderate migration rates (12 fish h^{-1}; Baumgartner et al. 2012). Based on current limitations, fish counters are not recommended for monitoring upstream migrating fish through fishways or past instream structures in New Zealand.

3.2.2 Acoustic technology

Acoustic technology or sonar can collect real-time data on fish moving past or through fishways using acoustic sampling from fixed transducers. The sonar systems commercially available have high resolution and fast frame rates. Currently, the Adaptive Resolution Imaging Sonar (ARIS) camera is the most technologically advanced acoustic camera commercially available. The ARIS can capture details as small as a few millimetres, and view targets at a range of up to 40 metres. Alternative acoustic technology includes the Dual-Frequency Identification Sonar (DIDSON) which uses sound to produce images of fish at ranges up to 15 m in high-frequency mode (1.8 MHz) and up to 40 m in low-frequency mode (1.2 MHz). However, image clarity for small fish (e.g., juvenile galaxiids) will be at a lower resolution relative to ARIS technology. In the past three decades, this technology has been extensively used at hydroelectric dams to study the approach and passage behaviour of both upstream and downstream migrating fish (Nielsen and Szabo-Meszaros, 2022). In New Zealand, the DIDSON has been used successfully to monitor rainbow trout (Oncorhynchus mykiss) and Chinook salmon (Oncorhynchus tshawytscha) movements at the Level Plain irrigation screen.[2] The disadvantages of acoustic technology are the intensive data processing due to the continuous surveillance, and the high capital investment. In addition, it is unlikely that sonar will accurately identify the five whitebait species and smelt within upstream moving shoals of juvenile fish. Their accuracy for enumerating small-bodied (<100 mm TL) fishes, particularly that shoal, also remains subject to relatively high error rates (Wei et al. 2022). For these reasons, acoustic technology is recommended for use primarily in monitoring fish passage at large head dams and/or for larger fish species/life stages.

3.2.3 Video surveillance

Video surveillance provides another tool to monitor fish passage success and Artificial Intelligence (AI) using deep-learning and machine-learning techniques is emerging that filters video recordings to automate species detection (e.g., Kandimalla et al. 2022; Magaju et al. 2023). In time, automated video surveillance could reliably be used to identify different species, collect abundance information, passage rates, and the size structure of each species successfully moving through a fishway or past an instream structure. Currently, this technology is not fully developed for any fish species and generally performs poorly for small bodied (<150 mm) species/life stages (Egg et al. 2018). Consequently, video surveillance is not yet recommended for use in accurately monitoring upstream fish passage success in New Zealand.

[2] Levels Plain irrigation fish screen trial 6-9 December 2010 (irrigationnz.co.nz)

4 Setting objectives

Setting performance measures for fish pass design or remediation (Section 2) provides clear metrics for monitoring the effectiveness of the fishway/structure. Without setting clear performance measures *a priori*, there is a higher risk of drawing false conclusions from the data generated from effectiveness monitoring (Bunt et al. 2012; Mahlum et al. 2018).

Figure 4-1 provides guidelines on identifying the desired performance measure for any structure and, subsequently, the most appropriate monitoring approach and survey method for evaluating those performance measures. Where other performance measures are identified, it is important to carefully match the monitoring approach and survey methods following a similar framework, and to provide a defensible and transparent justification for the approach taken.

Multiple performance measures may require that both monitoring approaches and/or multiple survey methods be utilised. Pairing BACI surveys with mark-and-recapture trials will provide the most robust assessment of passage efficacy for an instream structure. This would be the recommended approach for initially ensuring any new instream structure or remediation is fit-for-purpose and for determining their effective operating range. Once sufficient evidence is available to have confidence in the effectiveness of particular solutions, and the circumstances under which they are suitable, the need for comprehensive monitoring may be reduced.

4.1 Principles of good monitoring design

Based on the chosen performance measure, it is critical to ensure that data are collected in a consistent, standardised and reproducible way. Key principles to follow for either a BACI or mark-and-recapture survey are provided below.

BACI survey - for both the control and impact reaches, and before and after remediation:

- Sampling is carried out using the same method for each survey.
- The same sites are used for each survey with a minimum of one survey reach upstream and one survey reach downstream of the structure.
- Sampling effort is equivalent between reaches and surveys (i.e., the same area is fished with a similar amount of time (effort)).
- Sampling is carried out under similar conditions (e.g., similar flows) for the before and after surveys.
- Sampling equipment (nets & traps) are the same for every reach within and between surveys (i.e., the before, after, control and impact reaches)
- Sampling upstream and downstream of the structure is carried out on either the same day or subsequent days (depending on method) and the before and after surveys are carried out at the same time of year (i.e., within the same calendar month).

Mark-and-recapture survey – this method requires the stream to be barricaded at the top and bottom of the test reach. It is, therefore, difficult to carry out in large non-wadable rivers and streams, or streams with high discharges and water velocities. In such situations, a BACI survey using nets and traps would need to be implemented. For mark-and-recapture surveys:

- Sampling before (control) and after remediation (treatment) is essential.
- The control and treatment surveys are carried out at the same time of year under similar conditions (e.g., similar flows).
- The time fish are given to pass the structure is equivalent in control and treatment surveys.
- Sampling equipment (e.g., traps, nets and barricades) and their set locations are the same between surveys.

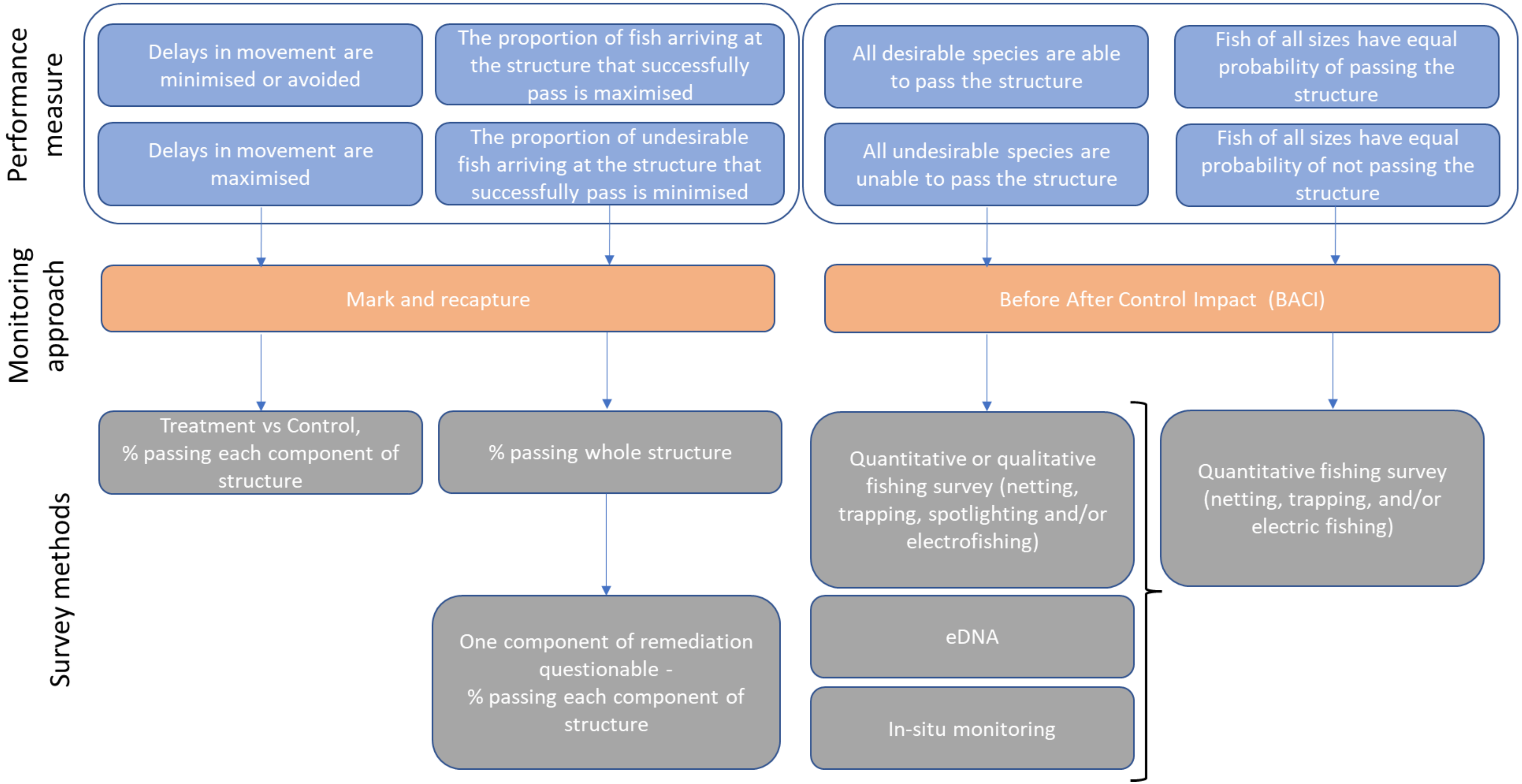


Figure 4-1: Identifying appropriate survey methods based on *a priori* performance measures.

Biological surveys

5 Survey methods

This section focuses on selecting appropriate methodologies for BACI surveys and mark-and-recapture studies (including biotelemetry techniques) at a given structure. For detailed descriptions of the protocols refer to Section 6.

5.1 BACI Methods

Where the performance measure relates to the effects of improved connectivity on upstream fish communities, species richness at a site, and ensuring all size classes are represented within populations, the recommended long-term approach is to utilise a before-after-control-impact (BACI) survey design. This is where fish surveys are undertaken downstream (control) and upstream (impact) of the structure (assuming the focus is on upstream migration), before and after remediation is carried out. Before and After sampling will determine how the installation of a structure or structure remediation changed the fish community through time relative to its previous condition. Control and Impact sampling can allow effects of the structure to be discerned from natural variability, stochastic events, and underlying trends in fish populations in the wider area. The BACI survey design is widely used for environmental impact assessments. The main survey methods recommended for carrying out BACI surveys are:

- A physical fishing survey (qualitative or quantitative).
- Environmental DNA (eDNA) sampling.
- In-situ monitoring.

Regardless of which method is utilised, a well-designed and balanced BACI survey remains one of the best methods for assessing environmental effects (Smokorowski and Randall, 2017). That is, adequate pre-data are collected to provide a robust baseline for measuring effects against, and the same method (and deployment time for in-situ monitoring) is used for the before, after, control and impact components of the monitoring. The following section outlines the three main BACI survey methods and helps identify the applicable target species for any given site. Once an appropriate method is selected, the recommended survey protocols for deploying the method are provided in Section 6.

Fishing Survey

A fishing survey is the recommended option for all BACI monitoring as it provides the most information about community structure upstream and downstream of the structure. Utilise Figure 5-1 to determine the target species and, subsequently, the appropriate fishing method for the site from Table 5-1. If a combination of electrofishing, fyke nets, and Gee minnow traps are required to effectively capture the target species, then using all recommended methods will maximise the information gained and provide the most robust data for measuring whether objectives have been met. For example, if īnanga (weak swimmer), common bullies (weak swimmer) and banded kōkopu (good climber) are the target species, then Gee minnow traps and fine mesh fyke nets would be the effective fishing methods. If redfin bullies (weak climber) were also targeted, then electrofishing would be necessary as fyke netting can underestimate their abundance.

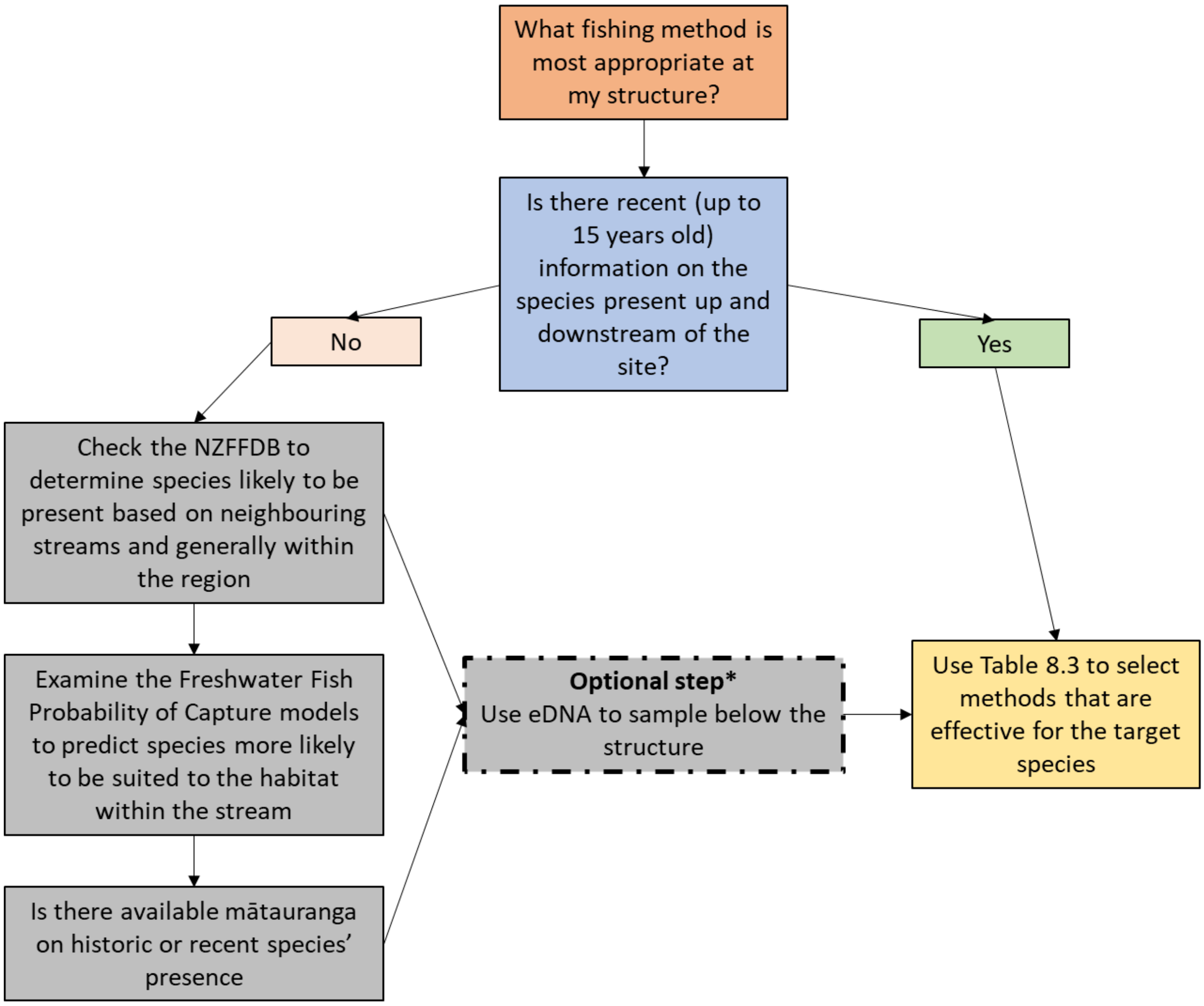


Figure 5-1: Guidelines on fishing method selection[3]. Desktop tools to determine appropriate target species. Abbreviations: NZFFD, New Zealand Freshwater Fish Database. * As eDNA detects species present upstream of the sampling location, Melchior & Baker (2023) recommend surveying 300 – 500 m below the instream structure to effectively sample DNA from fish resident within the waterway as well as those congregating below, or delayed by, the structure.

[3] Use the following link to download all records held in the NZFFDB (https://nzffdms.niwa.co.nz/search). The NZ species DB (downloadable from Jowett Consulting - NZ Species DB) is a useful tool for visualising records from the NZFFDB. The probability of capture models by Crow et al. (2014) can be accessed through NZ River Maps.

Table 5-1: Effective methods for target fish species. The species included in the table below are the main species that would be targeted for monitoring fish passage past instream structures along with some key resident non-migratory species. For swimming and climbing modes of movement, the strength of their ability is indicated in parentheses for those species where data exists. Abbreviations: C, capable of climbing; S, must swim past obstacles; E, effective method; U, can be used but underestimates abundances; FF, fine mesh fyke net; CF, coarse mesh fyke net; GM, Gee minnow trap; G, gill net.

Species	Life stage	Swimming/ climbing ability	Electro-fishing*	Trapping/ netting	Spotlighting	Seining
Native species						
Longfin & shortfin eels	Elver	C (strong)	E	U (FF)		
	Adult	S	U	E (FF & CF)		
Īnanga	All	S (weak)	U	E (GM), U (FF)ᵠ		
Smelt	All	S (moderate)	U	U (FF)ᵠ		E
Banded kōkopu	All	C (good)	U	E (FF)	E	
Giant kōkopu	All	C	U	E (FF)	E	
Shortjaw kōkopu	All	C	U	E (FF)	E	
Kōaro	All	C (strong)	E	U (FF)	U	
Redfin bully	All	C (weak)	E	U (FF & GM)	U	
Common bully	All	S (weak)	E	E (GM), U (FF)ᵠ	U	
Bluegill bully	All	S	E	U (FF & GM)	U	
Torrentfish	All	C	E	U (FF & GM)		
Lamprey	Juvenile	S	E			
	Adult	C (strong)		E (FF)	E	
Mullet	All	S		E (G)		
Non-migratory bullies	All	S (weak)	E	E (GM)		
Non-migratory galaxiids	All	S	E		E	
Introduced species						
Salmonids	All	S (strong)	E*	E (G)		
Catfish	All	S		E (FF), U (G)		
Perch	All	S	E*	E (G)		
Koi/amur carp	All	S		U (G)**		
Goldfish	All	S		E (G)		
Rudd	All	S		E (G)		

*wadable stream only. For non-wadable streams an alternative method will be required such as boat electrofishing or netting.

**in lakes and deep water, boat electrofishing is likely the most effective method of capture.

ᵠCan be effectively captured in fyke nets when eel excluders are utilised. Without preventing eel entry, the presence of large predatory eels can influence the behaviour and capture efficiencies of these prey species.

Quantitative fishing methods

If the performance measure requires an understanding of species richness and a robust assessment of population structure and abundance upstream and downstream of the structure, quantitative fishing methods are required. Here, fyke netting, Gee minnow trapping, gill netting and multi-pass depletion electrofishing are the appropriate survey methods with selection contingent upon target species and habitat at the site.

Qualitative fishing methods

If the performance measure requires an understanding of species richness and relative abundance of species upstream and downstream of the structure, but a robust assessment of population structure and abundance is unnecessary, then qualitative fishing methods can be employed. Here, fyke netting, Gee minnow trapping, gill netting are still appropriate if they are the effective method for the target species. However, spotlighting and the standardised (single pass) electrofishing protocol can be implemented.

The standardised electrofishing method (David and Hamer, 2010; Joy et al. 2013) utilises a single pass of 150 m reach and provides the relative abundance of fish species. The method was designed primarily for detecting maximum reach scale diversity (species richness) across a variety of stream types ensuring all instream habitats are sampled, rather than a robust assessment of species densities over a shorter stream length.

Spotlighting is an effective method for detecting non-migratory and large galaxiids, however, we do not recommend spotlighting as a quantitative method for assessing the effectiveness of fish passage remediation. This is because the observer's skill level strongly influences the effectiveness of the spotlighting technique. In addition, walking upstream creates vibrations detectable by the fishes' lateral line and/or vestibular systems, which can cause a proportion of the nocturnal fish being targeted to dart or move to cover. This predator avoidance response can vary within and between fish species contingent upon environmental factors (e.g., lunar cycle), and between stream types depending upon the riparian margins and ease with which the stream banks can be navigated. Should spotlighting be undertaken as a survey method, then pairing it with fyke netting or eDNA is recommended to reduce the potential impacts of observer bias.

Environmental DNA (eDNA)

eDNA is a relatively new technology that has yet to be validated for use in monitoring fish passage efficacy at instream structures. However, for structures that likely form a severe impediment to fish passage, eDNA sampling could be useful for examining differences in species diversity downstream and upstream of a structure. eDNA monitoring cannot determine if certain size classes of fish species were restricted by the instream structure, nor is there currently enough information to translate DNA reads into an accurate measure of abundance or density. Consequently, eDNA is not a quantitative assessment method, but it could provide evidence for presence/absence of weak-swimming fish such as īnanga before and after remediation of an obstacle. It can also help identify if undesirable fish species start penetrating past the instream structure after remediation. As eDNA reads do not correlate directly to fish abundance, it should be noted that if the instream structure is an impediment but passable intermittently, eDNA sampling may not conclusively determine a change in species richness after remediation.

In-situ monitoring

If the performance measure requires understanding the species and size classes passing the structure, but quantitative information on the size structure of populations upstream and downstream of the structure is not a focus, then in-situ monitoring by setting traps at the structure inlet and outlet can be undertaken. This method is only effective if the entire stream immediately upstream of the structure and at the outlet can be completely blocked off. In this regard, it is most suited for examining movements of fish through low head structures such as culverts. In general, rigid A-Frame or whitebait traps, or double winged fyke nets have been successfully utilised at low head structures for mark-and-recapture studies (e.g., Franklin and Bartels, 2012; Amtstaetter et al. 2017; Jones and O'Connor, 2017) and would be the recommended option for this short-term in-situ monitoring.

Setting traps at the entrance and exit of the structure can determine if the fish population (diversity, abundance, and size classes) entering the structure is comparable to those successfully exiting the structure (e.g., Jones and O'Connor, 2017; Bice et al. 2017). In Australia, trapping the entrance and exit of a fishway is generally the first method of assessment utilised (Jones and O'Connor, 2017). Here, a qualitative assessment of the effect of the fishway can generally be attributed to any differences in the fish population captured at the entrance and the exit.

Sampling the entrance and exit of the structure before and after remediation provides a proxy for a control and impact for fish passage success. The control is the entrance of the structure, which typically represents the fish population downstream of the barrier, while the exit is the treatment, or the impact for the fish trying to pass the structure (Jones and O'Connor, 2017). This method does not represent a true control as it does not sample downstream away from the influence of the structure. In addition, it will only capture fish actively migrating through the structure, so the monitoring period may not represent all species and life stages attempting passage.

Setting traps simultaneously upstream and downstream must be avoided as the capture of fishes in the downstream trap influences their movements, which can have effects on motivation, behaviour and swimming ability if physical damage is incurred during the trapping and handling process. These unquantified impacts on fish movements can also vary between species. For example, fragile species such as smelt die from brief exposure to air and stress due to confinement.

In some situations, trapping at the entrance to a structure may not be feasible. Here, setting the traps upstream of the obstacle still provides valuable information on the fish population (diversity, abundance, and size classes) passing the structure over the monitoring period. This can be directly compared to that observed before remediation of the structure. However, by setting traps only at the inlet (i.e., upstream end) of the structure, this Before-After (BA) method of monitoring does not determine if all fish moving upstream are able to successfully pass the structure as it doesn’t document those that fail. To determine if the structure is restricting fish passage to stronger individuals, trapping should be paired with physical fishing survey methods outlined above or mark-and-recapture surveys.

5.2 Mark-and-recapture methods

Mark-and-recapture studies allow quantification of the proportion of fish that pass a structure (i.e., passage efficiency). Passage efficiency (attraction, entrance & exit) is used globally as a benchmark for evaluating fish passage success. Information on passage efficiency is valuable as it allows the relative performance of different structure types or fish passage solutions in each situation to be established. This is essential for optimising fish passage outcomes at a site because the best solution for optimising fish passage can be more readily identified.

A mark-and-recapture study is recommended to:

- establish the performance and operating range of a fish passage solution that is to be installed across a range of sites,
- quantify the effectiveness of a solution that has not been demonstrated in practice, or
- to evaluate the relative influence of different components of a structure on overall fish passage success. For example, remediation of perched culverts commonly entails retrofitting a fish pass to the culvert outlet, yet the culvert barrel or transition from the fish pass to inside the culvert may still represent an impediment or barrier to certain fish species.

The trial design is dependent on the structure type and layout, and the performance measure being assessed. If the performance measure relates to understanding what proportion of fish arriving at the structure are successfully passing, then assessing passage across the entire structure is important (e.g., up a fish ramp and through a culvert). However, if fish are failing to pass a structure, then assessing passage rates across individual components of the structure provides greater insight into the main constraints on fish movements and the appropriate mitigation actions to improve fish passage. If only one component of a structure is remediated, or the implemented solution has not been robustly tested, then testing each component separately is recommended.

If the performance measure is to determine if the structure delays or restricts fish passage, then having a control for testing the structure alongside is imperative. Here, a true control involves sampling either downstream or upstream of the instream structure to determine the migration rate of fish in the absence of an impediment.

Because of the small size of New Zealand's freshwater fish species during their migratory stage there are limited options available for marking individuals. Based on laboratory and field studies, staining fish with Rhodamine B or Bismarck Brown is recommended over Visual Implant Elastomers (VIE) tagging, or other types of individual marking (e.g., coded tags, fin clips) where anaesthesia and handling is required. For example, laboratory studies utilising juvenile īnanga stained with Rhodamine B have found no reduction in swimming performance compared with unmarked control īnanga ($p = 0.68$) (Franklin et al. 2024b). In contrast, juvenile īnanga with VIE tags swam at less than half the speed of unmarked control fish in critical swimming speed tests ($p = 0.005$) (Franklin et al. 2024b). In addition, mark-and-recapture investigations at Bankwood Stream culvert, Hamilton (Franklin et al. 2024b) found no significant difference in the number of īnanga stained with Rhodamine B and unmarked fish successfully passing the culvert ($p = 0.501$). Collectively, these data indicate that the staining marking procedure does not unduly influence the behaviour or passage ability of īnanga compared to fish that were not subjected to the staining procedure.

If all fish can be effectively removed from the barricaded test area and are unlikely to be able to migrate back inside the nets, then staining or tagging fish may not be essential for recapture trials. Unmarked fish can be released downstream of the structure and monitored for passage success.

5.2.1 Biotelemetry technology

Biotelemetry has been extensively used for monitoring fish passage worldwide and provides a way of marking and monitoring individual fish movements without needing to recapture fish. However, biotelemetry technology requires fish to be tagged with either active or passive tags that can be internally implanted or externally attached. As such the use of biotelemetry is limited by target fish size, whereas mark-and-recapture surveys using Rhodamine B or Bismarck Brown can be carried out on any sized individual. There are three main technologies utilised: Passive Integrated Transponder (PIT) telemetry, radio telemetry, and acoustic telemetry.

> PIT, radio and acoustic tags require surgical implantation. Surgically implanting any tag into fish is a difficult procedure that requires appropriate permits and animal ethics approvals. For these reasons, detailed methods on the tagging procedures are not provided in this manual as they should only be implemented by a trained expert.

The biggest limitations of using biotelemetry are the cost of the monitoring equipment and the size of the tag that can be attached to or implanted in individuals. The general rule of thumb is that the tag size represents no more than 2% of the individual's wet weight (Jepsen et al. 2003), although recent studies suggest this is a conservative limit for some species (Jepsen et al. 2003; Smircich and Kelly, 2014; McKenna et al. 2021). However, the small bodied species and juvenile life stages that migrate upstream in New Zealand generally restricts the applicability of biotelemetry to monitoring adult fish (e.g. lamprey, downstream migrating tuna) or large elvers (>120 mm) (Figure 5-2).

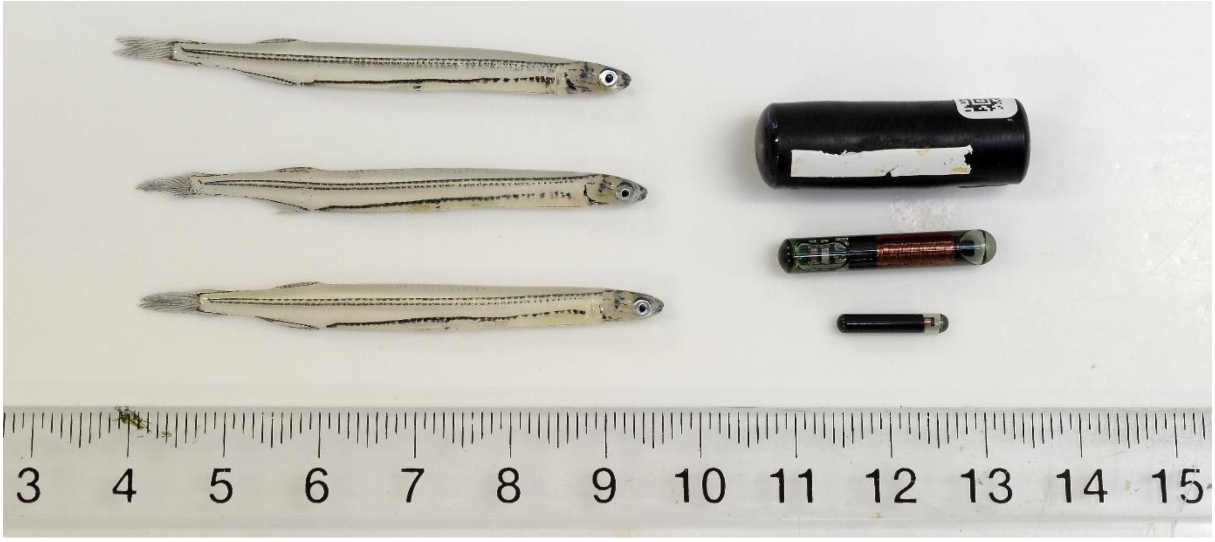


Figure 5-2: Application of biotelemetry methods to the study of many migratory species/life stages in New Zealand is limited by relative tag size. Juvenile galaxiids alongside an acoustic tag (top) and 23 mm (middle) and 12 mm (bottom) HDX PIT tags.

Passive Integrated Transponder (PIT) telemetry

Over the past two decades Passive Integrated Transponder (PIT) systems have become widely used by ecologists to study fish behaviours such as habitat selection and migration (Roussel et al. 2000; Cucherousset et al. 2005; Aymes & Rives 2009; Baker et al. 2017). PIT tags can be advantageous over active transmitters (e.g. radio and acoustic telemetry) as they are small, cost effective, require no battery and, therefore, have an unlimited lifespan (Bond et al. 2007).

The performance of PIT telemetry is a function of tag size and transmission type (Cucherousset et al. 2010). There are two modes of transmission; full-duplex (FDX) and half-duplex (HDX). A FDX system receives and transmits data simultaneously whereas a HDX system separates data transmission and reception. HDX systems are, therefore, simpler, more affordable and can also be utilised with larger antenna (Barbour et al. 2011; Baker et al. 2017). For these reasons, HDX systems tend to be used in New Zealand for monitoring fish migrations. However, reducing the size of HDX tags is limited by the need for an internal capacitor and thus they tend to be larger than FDX tags. Presently, the smallest sized PIT tags available are 8 mm and 12 mm for FDX and HDX, respectively. The 12 mm HDX PIT tag has expanded the application of this system to smaller bodied fish species and a wider range of life stages over the larger 23 mm and 32 mm tags (Figure 5-3).

PIT reader systems used to monitor fish passage generally consist of a number of strategically placed antennae, each attached to an external tuner board that connects back to a control box containing readers and a logger system. As a PIT tagged fish passes through an antenna, its tag is charged, and it transmits a unique code back to the readers. The logging system then allocates a date and time stamp alongside the reader number and tag code. The logged data is either manually downloaded or automatically sent back to a central location via a mobile network for later processing.

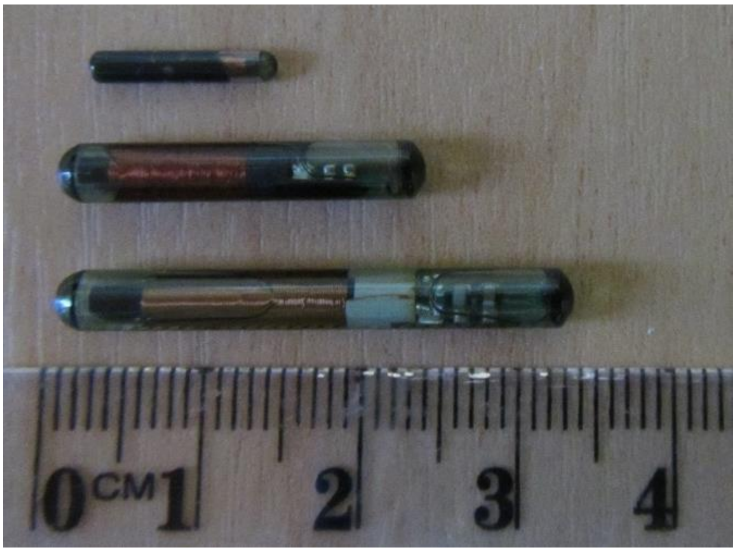


Figure 5-3: 12 mm, 23 mm and 32 mm Half Duplex PIT tags.

Radio and acoustic telemetry

Both radio and acoustic telemetry actively emit a signal and must contain an internal battery to operate. The size of the tag generally relates to the length of operation and both types of tags are generally larger than PIT tags (Figure 5-4). Radio telemetry is effective in shallow freshwater environments, whereas acoustic transmitters are more effective in deep water environments (Cooke et al. 2013). Radio telemetry cannot track fish accurately in 3D, and generally, manual tracking is undertaken either by foot or plane, although fixed receivers can be used (Figure 5-5).

Acoustic telemetry has the capability of determining 3D positions with high accuracy and temporal resolution. For this reason, acoustic telemetry is often used to examine fish behaviour at high head dams (Nielsen and Szabo-Meszaros, 2022). The deployment of acoustic receivers will vary for each unique situation and range testing is required to determine appropriate locations for triangulating tag signals (Figure 5-6).

The detailed design of monitoring protocols for radio and acoustic telemetry is site-specific and requires specialised knowledge of the equipment. Consequently, monitoring protocols for using radio and acoustic telemetry are not covered in this manual.

Figure 5-4: Advanced Telemetry Systems (ATS) external radio tag (F1960) mounted on an adult lamprey. Top photo shows the attachment harness.

Figure 5-5: Tracking radio tagged lamprey in Canal Reserve Drain, Christchurch.

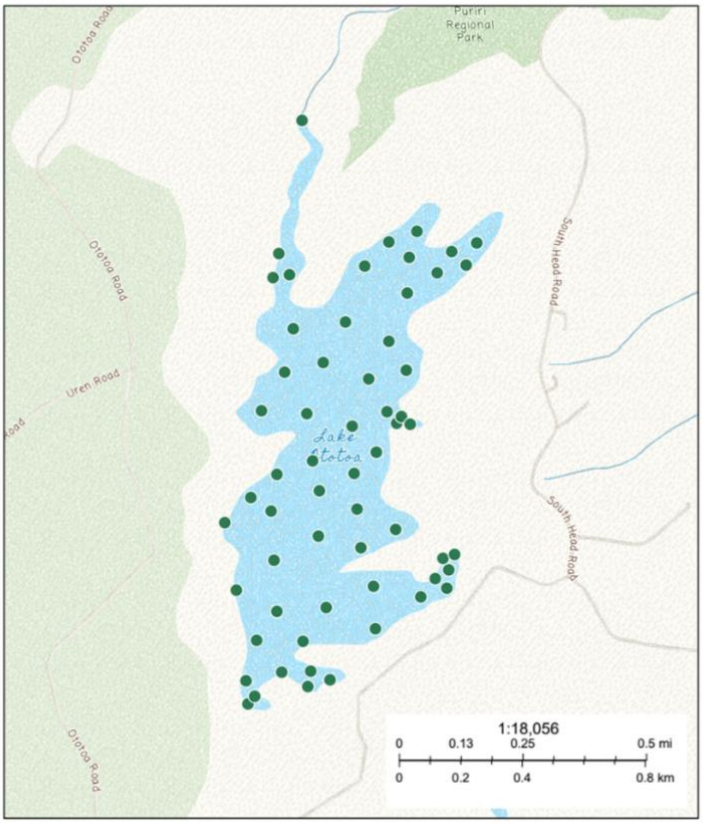


Figure 5-6: Acoustic receiver array (green circles) utilised for tracking perch movements in Lake Rototoa, Auckland.

6 Survey protocols

6.1 BACI

6.1.1 Fishing survey

A minimum of one survey reach upstream and one survey reach downstream of the structure is required for a BACI survey. As far as practicable, the two survey reaches should have similar habitat types and be of a similar size. This helps to minimise the potential influence of habitat availability and stream size on differences in fish communities between the control and impact sites. Consideration should also be given to locating the downstream survey reach slightly away from the immediate vicinity of the structure. Upstream migrant fish may aggregate immediately downstream of a barrier as they attempt to move upstream, so if the downstream survey reach includes these aggregations, fish population estimates can be biased and over-exaggerate the relative differences in fish community composition.

Table 6-1 outlines the protocols for each of the recommended survey methods. Use the guidelines in Sections 4 - 6 above to determine the appropriate monitoring approach and survey method based on the performance measure(s) at the site. Additional information on using each technique is detailed below.

Table 6-1: Reach size and fishing details for each survey method. The recommended reach lengths are the minimum required. Larger reaches can be utilised if preferrable.

Method	No. nets/traps	Baited	Reach length (m)	General guidelines
Fyke nets (coarse and fine mesh)	6	No	200	Set fyke nets in deeper pools or slow-moving water. For single leader nets, if possible, bisect the stream setting the leader hard against one stream bank and secure the cod end across the stream against the opposite bank. For double winged nets, if possible, span the width of the stream with the opening facing downstream.
Gee minnow trap	20	Yes	200	Bait with marmite or trout pellets. Set traps approximately 10 m apart. The exact location will be dictated by habitat availability, e.g., pools or slow-moving runs.
Electrofishing (multi-pass)	-	-	50	Set a stop net across the stream at the top and bottom of the reach. Fish all habitat in an upstream direction being careful to disturb as little sediment upstream of the fishing area as practicable. Remove all captured fish and repeat fishing of the reach until a 50% reduction from the previous pass is achieved in every species or 5 passes are undertaken.
Electrofishing (single pass)	-	-	150	Follow the protocols outlined below. Fish all habitat in an upstream direction being careful to disturb as little sediment upstream of the fishing area as practicable. Remove all captured fish and process at 15 m intervals (10 sub-reaches per site).
Gill nets	6	No	300	Set gill nets in the habitat utilised by target species. If possible, bisect the stream setting the net hard against one stream bank and secure across the stream against the opposite bank.

Method	No. nets/traps	Baited	Reach length (m)	General guidelines
Spotlighting	-	-	200	Keep reach length and effort (time taken to sample the 200 m reach) consistent for all monitoring i.e., before, after, control and impact.

Nets & traps

Standardisation of sampling gear within and across monitoring programmes is important for obtaining robust data that can be compared spatially and temporally. In general, most agencies are utilising the same fyke nets (5 mm mesh stretched with eel excluders) and Gee minnow traps (3 mm mesh). Coarse mesh (12 mm stretch mesh) fyke nets are sometimes used in preference to fine mesh nets when only targeting eels. The fine mesh fyke nets and 3 mm Gee minnow traps have been rigorously field tested and will accurately document the population structure and size classes of fish successfully passing the instream structure. We recommend mesh sizes are, therefore, not increased over those previously stated as capturing all size classes of the target fish species forms one performance measure. It is also important to note that if equipment differs from that held by most regional councils and government agencies this restricts comparability of data and generalisation of results. Although size of the net opening, leader length and number, and other design attributes can differ between nets, the most important factor is consistency between reaches. That is, whatever fyke or minnow trap is used in the before monitoring must be used in both the upstream and downstream reaches in both the before and after monitoring. Changing net types within a BACI sampling programme will change catch efficiency and can lead to false conclusions being drawn.

Gill nets are effective at capturing pelagic fish species but are most frequently used in deep open water such as lakes. However, they can be effectively deployed in large rivers and wadable rivers to capture pelagic species. For example, gill nets may be used to examine the effectiveness of built barriers at preventing trout or pest species' access to upstream habitats. The capture efficiency of gill nets is strongly influenced by the characteristics of the net used, such as mesh size and filament diameter. There is no standard gill net type used in New Zealand freshwaters so comparability of results using this method is limited. It is important to remember that gill nets are a destructive fishing method, with captured fish having very high mortality rates. For invasive or nuisance exotic species gill net mortality is not an issue, but it should be considered when targeting mullet or sports fish. In addition, diving birds can frequently get caught in gill nets and suffer unintended mortality. In general, the type of gill net (panel or single) and the size of the mesh should be selected based on the target species and life stage(s). As stated above, the most important factor is utilising the same net for all survey reaches and sampling occasions within the BACI monitoring programme.

Survey protocol:

1. Select a reach upstream and downstream of the structure (minimum of 200 m or 300 m dependent upon net/trap type used).
2. Walk each reach to determine the suitable areas for net/trap deployment and record the GPS location of the top and bottom of each reach.
3. Actual set locations will be dictated by the presence of suitable habitat (e.g., pools and slow-moving runs). However, aim to spread the nets as evenly as practicable through each reach (Figure 6-1). That is, Gee minnow traps will be spaced approximately 10 m apart, with fyke nets spaced 30 – 35 m apart and gill nets approximately 50 m apart.

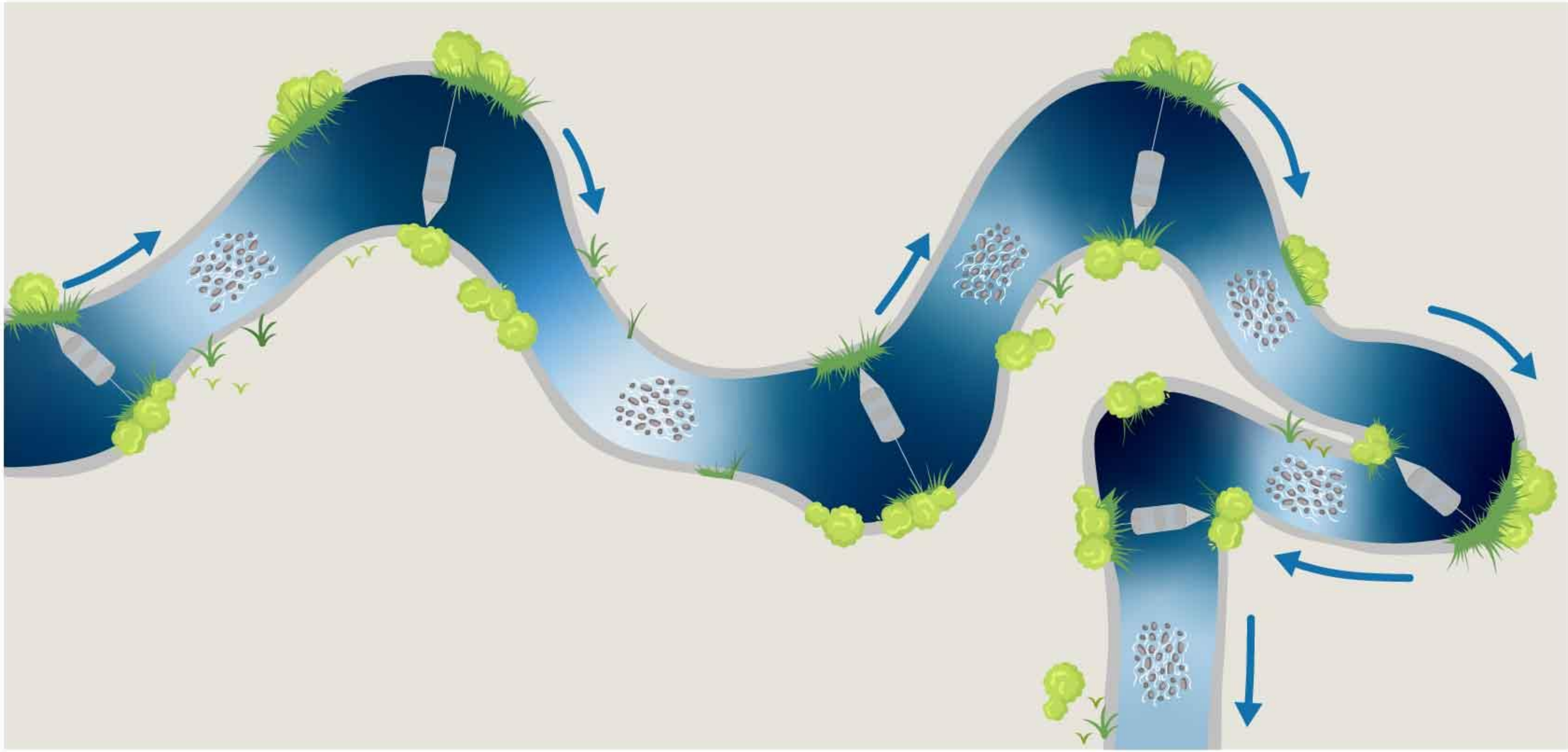


Figure 6-1: Conceptual layout of six fyke nets set within a hypothetical survey reach. Riffle sections are signified by the cobbles with pools and runs indicated with deeper blue shading. Arrows indicate the direction of flow.

4. Setting nets/traps:

   4.1 *Fyke nets*. Set fyke nets in deeper pools, edges of pools, or slow-moving water. For single leader nets, where possible, bisect the stream setting the leader hard against one stream bank and secure the cod end across the stream against the opposite bank (Figure 6-2). In clean streams, net openings can face in any direction (upstream, downstream, or perpendicular to the bank) as long as the leader is set hard against one stream margin. For streams with high debris loads, face the opening either perpendicular to the stream flow or in a downstream direction as debris can enter the net and clog the opening. For double winged nets, if possible, span the width of the stream with the opening facing downstream.

Figure 6-2: Fyke nets set in a large (A) and small (B) river.

   4.2 *Gee minnow traps*. Set Gee minnow traps upon the substrate in runs or pools with their long axis in-line with the flow (i.e., trap openings face directly upstream and downstream). This allows fish tracking the odour from the bait to easily enter the trap rather than needing to search for the opening. Tie each trap to bankside vegetation or a stake in the bank (Figure 6-3).

Figure 6-3: Gee minnow trap set in a pool of a small stream. The trap openings are parallel to the stream flow (i.e., facing upstream and downstream).

4.3 *Gill nets.* Target the feeding habitat utilised by the desired species. If possible, bisect the stream setting the net hard against one stream bank and secure across the stream against the opposite bank (Figure 6-4).

Figure 6-4: Panel gill net set across a stream at the head of a large pool.

5. If the stream is deemed to be degraded such that low dissolved oxygen could be present overnight (e.g., stream choked with macrophytes, sluggish to no flow and high summer temperatures), then fyke nets and Gee minnow traps should be set with an air gap at the top to enable captured fish to move to the water surface to extract oxygen from the air, if required.

6. Record the GPS coordinates of each fyke and gill net location. For Gee minnow traps, note the GPS coordinates at the top and bottom of each reach.

7. Set nets/traps in the afternoon and leave to fish overnight. If diving birds are present in the area, then caution is needed and nets should be checked frequently during daylight hours and removed before dawn. For areas without diving birds, fyke and gill nets should be lifted the following morning. Gee minnow traps can be left for 24 hours to capture diurnal species. Record the set and lift times for each net/trap.

8. Process all fish captured to species (see Section 7).

9. Record the wetted width and a minimum of three depths across the stream at equal intervals (e.g. every 20 m for a 200 m survey). This will allow the calculation of the area fished in m^2 and give an indication of water depths and change in flow between sampling. Utilise the standardised data sheet in Baker et al. (2024a), with one sheet used for each reach (upstream and downstream). Record GPS locations for the top and bottom of the upstream and downstream reaches and fill out NZFFD summary habitat assessment.

10. Data sheets can be custom-made or follow the format in Appendix F.

Electrofishing

For all electrofishing, whether single or multi-pass, the following general protocol should be adhered to:

- Walk each reach to determine the suitable areas for electrofishing and record the GPS location of the top and bottom of each reach.
- Choose your machine settings. This will be determined by the conductivity of the survey water and target species. Use fish response as an indicator of effective settings. Fish should be stunned and able to be captured within a hand net without swimming away, but with a quick recovery to swimming upright and balanced inside the holding bucket upon exiting the electric field. The recommended starting settings of 30 pps (pulse rate frequency in pulses per second) with a pulse width of 2 milliseconds (ms) are conservative and should not over shock large fish. If target fish are not effectively stunned increase the pulse frequency to 60 pps (pulses per second) and the pulse width to 3 ms.
- Use two or three people to fish the site, one operating the machine, one holding a pole (or push) net downstream of the fisher, and if possible, a third to hold the bucket and a hand-held dip net to help capture shocked fish.

- The fisher starts on the edge of either bank, fishing in a downstream direction towards the pole net covering between 1–2 linear metres of stream. If visibility is poor and/or fish are escaping, shorten the length of the fished area accordingly. If the stream is wider than a pole net width, the pole netter and the fisher then move horizontally across the stream one pole net width to fish the next section of water, continuing this protocol until reaching the opposite bank. In wider streams, and if capacity allows, multiple pole nets can be set and fished, or multiple fishers can be used, each with a pole netter.
- Once reaching the opposite bank, the pole netter and fisher move upstream so the pole netter is situated at the top of the area just fished and repeat the procedure continuing in an upstream direction and from bank to bank.
- Process all fish captured to species (see Section 7).

When electrofishing is undertaken in conjunction with netting or trapping, the survey reach should be adjacent to the netting/trapping reach and not overlap.

Single pass

The standardised electrofishing protocol is a single pass survey without the use of stop nets at the top and bottom of the reach. As such, the results generated are the relative abundance of fish species, which is not equivalent to fish density and can only be used for a relative comparison of species diversity or richness at a site over time.

Survey protocol:

1. Utilise a 150 m reach at each site.
2. Use a hip chain during fishing or measure 10 x 15 m sub-reaches within the 150 m reach. Flagging tape can be set along the stream margins to delineate each 15 m sub-reach.
3. At the end of each 15 m sub-reach, process all fish captured.
4. Measure the wetted width of the stream at the end of each sub-reach.
5. Continue fishing until all sub-reaches are fished and fish are processed. Record the number of sub-reaches sampled on the collection form (Appendix F). Ideally, 10 sub-reaches will always be fished but if habitat is limited or other factors restrict the number of sub-reaches possible, check the appropriate circle, e.g. 5-9 sub-reaches, <5 sub-reaches on the collection form (Appendix F).
6. Record the total shock time (elapsed time on the back of the fishing machine), the voltage used, along with the actual start and finish time for the total reach. This allows sampling effort to be calculated and compared between sites.

Utilise the data collection form provided in Appendix F.

Multi-pass depletion fishing

If the objective is to quantify changes in fish numbers over time in response to changes to a structure, multi-pass depletion fishing is required to generate population estimates and true estimates of fish density. This allows a quantitative comparison of fish communities before and after remediation of the passage barrier within and between sites, and improved detection of population trends over time.

Survey protocol:

1. Utilise a 50 m reach at each site.
2. Set stop nets at the top and bottom of each reach before fishing ensuring that fish cannot enter or leave the reach.
3. Carry out multiple electrofishing passes until there is at least a 50% reduction in the catch of the main fish species compared with the previous pass or a maximum of five passes, whichever is reached first. Generally, three passes are the minimum necessary.
4. Fish and habitat information (e.g., fish lengths, wetted stream widths) should still be collected, but with five 10 m sub-reaches assessed instead of ten reaches.
5. Record the total shock time (elapsed time on the back of the fishing machine), the voltage used, along with the actual start and finish time for the total reach. This allows sampling effort to be calculated and compared between sites and passes.

For three pass depletion fishing, population estimates for each species in the reach can then be calculated using the explicit approximation of the maximum likelihood formulae from Cowx (1983):

$$N_o = \left(6X^2 - 3XY - Y^2 + \left(Y \times \sqrt{(Y^2 + 6XY - 3X^2)}\right)\right) / \left(18 \times (X - Y)\right) \tag{1}$$

Where N_0 = population estimate, $X = 2c_1 + c_2$ and $Y = c_1 + c_2 + c_3$ and c_n = the number of fish captured in pass *n*. Population estimates for multiple pass fishing surveys can also be calculated using the method of Zippin (1958) as executed in the removal function (http://www.rforge.net/FSA/) in R (http://www.R-project.org).

The density of each fish species in each section can then be calculated by dividing the population estimate by either the length of stream fished, to give the number of fish per linear metre of stream, or the stream area, to give the number of fish per metre square.

Spotlighting

Spotlighting surveys should be paired with fyke netting or eDNA to reduce observer bias. As such, to be consistent with fyke netting protocols (see Table 6-1) reach length should be at least 200 m. Ideal spotlighting conditions are a calm overcast night on a new moon when stream flows are low, and the water is clear. Avoid nights where there is rain or strong winds that affect the water surface. Even small spots of rain can affect the clarity of the stream and result in biased data. Under a full moon and a bright night, some fish species have been noted to be easily spooked and more difficult to capture (Allibone, 2013).

Survey protocol:

1. Walk the site during daylight hours to ensure there are no additional fish passage barriers, adjoining tributaries or other factors that would deem the reach unsuitable for monitoring.

2. Delineate a 200 m reach upstream and downstream of the targeted instream structure. Wherever possible try and ensure similar meso-habitat is present both upstream and downstream, and that reaches avoid the outlet pool downstream of the structure. Measure the wetted width and minimum of three depths of the stream at 20 m intervals to give 10 width measurements and 10 sets of three water depths along each reach. This will allow the calculation of the area fished in m^2 and give an indication of water depths and change in flow between sampling. Reach length can be increased to accommodate site-specific factors; however, a minimum length of 200 m is recommended.

3. Ensure the water clarity is adequate for spotlighting. If streams are heavily tannin stained, have high levels of iron flocculant or suspended sediment, spotlighting is likely to be ineffective and netting or trapping should be carried out instead.

4. Utilise the standardised electrofishing and spotlighting data sheet in Appendix F[4], with one sheet used for each reach (upstream and downstream). Record GPS locations for the top and bottom of the upstream and downstream reaches.

5. Prepare all equipment away from the stream to prevent noise and light affecting/spooking the fish.

6. Begin the spotlighting surveys around 45 minutes after sunset. Record the start time of each reach. Walk in an upstream direction. Walk on the stream bank if possible. If working in teams in wide streams, divide up the stream channel to ensure all the width is covered and quietly move upstream together. Here, walking within the stream will be necessary.

7. Shine the spotlight 1–2 m ahead and sweep from bank to bank. Do not scan the beam more than 4 m ahead to avoid spooking fish further upstream. As fish are sensitive to vibrations and noise, if you need to stop, stop beside a riffle where the chances of fish moving upstream is reduced.

8. Try to move at a slow but constant pace examining all habitats carefully for both pelagic and benthic fish species. Identify and count all fish you see in each of the 10 x 20 m subreaches. If fish are seen but can't be identified record them as "unknown" or identify them to the lowest taxonomic level possible such as "unidentified bully", "unidentified eel" and "unidentified kōkopu". If you can, capture fish to accurately record their length. If fish that cannot be captured can be conclusively identified, then record an estimate of their length.

9. If fish evade capture, turn all torches off and remain motionless for around 2 minutes. In some instances, fish will reemerge and a second chance at capture can be

[4] The electrofishing form is designed for 10 x 15 m long subreaches with a total reach length of 150 m. As spotlighting will cover a 200 m reach utilise the same form and maintain 10 subreaches but space these at 20 m intervals.

attempted. It is useful for each person to have a 30-50 watt spotlight and also a dim or red head lamp. This is because once a fish is seen it can be easier to catch without spooking with lower light levels.

10. Record the start time of each 20 m subreach and the time upon completion of the full 200 m reach. This allows total effort to be calculated along with identifying if any subreach was more difficult to navigate and required additional effort (time).

Each repeat spotlighting should be carried out within the same calendar month, at the same time of the night and sample the same 200 m reach. As far as practical, carry out repeat surveys under similar stream conditions and lunar phase. Try to keep the time taken to survey the reach the same between sampling occasions to keep fishing effort similar for each subsequent survey. Of all the methods described here, spotlighting is most susceptible to the influence of operator bias. Consequently, as far as practicable, the same observer(s) should be used for each survey.

6.1.2 Environmental DNA (eDNA)

Melchior and Baker (2023) have developed a living guideline document for using eDNA to sample lotic freshwater environments. Refer to Melchior and Baker (2023) for current and complete protocols on using eDNA to sample above and below fish passage barriers. Key protocols are outlined below.

To ensure that data are collected in a consistent, standardised and reproducible way, for both the control and impact reaches, and before and after remediation:

- Sampling should be carried out when the target fish species are migrating and likely to have reached the site (based on the distance inland).
- Sampling upstream and downstream of the structure should be carried out on the same day and the before and after surveys are carried out at the same time of year (i.e., within the recommended December to March timeframe).
- The same sites are used for each repeat survey.
- Sampling is carried out under similar low flow conditions.

To maximise detection of the species present, it is recommended that for each of the before, after, control and impact samples:

- Utilise the 6 × 1 L replicate or 6 × passive sampler method.
- Samples should be taken at the thalweg (deepest part of the stream) of the stream or as close to the thalweg as possible.
- Samples upstream of the structure should be taken where the stream is unimpacted by the structure itself, i.e., upstream of any impoundment of the stream.

Fish migrations are highly variable and can occur in pulses or triggered by specific environmental cues. Consequently, migration past the structure will also be highly variable and as such, eDNA sampling at one point in time may lead to false conclusions being drawn from one-off or short-term sampling. To increase the likelihood of drawing valid conclusions from eDNA monitoring of fish passage remediation success, we recommend the following:

- One pre-remediation sampling at each site.
- Annual sampling at each site for three years post-remediation, with samples taken at the same location, flow conditions and calendar month as pre-remediation sampling.

Indicator species

At each site, the target species for passage may influence when to use eDNA sampling for assessing the effectiveness of barrier remediation over traditional fishing techniques. For example, īnanga is a weak-swimming fish and used as an indicator species for fish passage remediation because if īnanga can pass the obstacle, it is likely that all other species will also be able to navigate the impediment. Īnanga are primarily an annual species with adults migrating downstream to the salt wedge to spawn. Peak spawning typically occurs in autumn and most adults die after spawning. As such, over winter there will be markedly less īnanga DNA present above instream structures that are located upstream of spawning grounds. Consequently, the majority of īnanga eDNA detected upstream of instream structures during the recommended December to March sampling period is likely to originate from upstream migrating juveniles successfully passing the structure that season. In this regard, where populations are present, īnanga may be an effective indicator species in eDNA monitoring of barrier remediation.

6.1.3 In-situ monitoring

Timing

In-situ monitoring targets fish migrating upstream past the instream structure. As such, monitoring needs to be carried out during the target species' migration period(s). Determining the appropriate timing for monitoring considers not only the migration season, but also the period the target species reach the site. For example, īnanga will reach sites further inland or at higher altitudes later in, or even after, the whitebait season. In the Waikato River, at locations greater than 50 km inland, peak runs of īnanga can occur in December or January. If there is no prior knowledge on when key species reach the site, pilot studies should be carried out, or alternatively, monitoring can be carried out across several months. After determining the appropriate timing to monitor the target species, carry out the monitoring early in the migratory window to ensure the movement of the smallest fish reaching the site are included.

Replicate

All native migratory species have a diel pattern in their migratory movements. For example, all five whitebait species are diurnal with their main migration undertaken during daylight hours (McDowall 2011; Baker and Smith 2014), whereas elvers, bullies and lamprey are nocturnal and mainly move during the night (McDowall 2011). To account for different periodicities across migratory species, a sample replicate of 24 hours is recommended, which is commonly used in Australia for in-situ monitoring (Jones and O'Connor, 2017).

Sampling period

Fish migrations are highly variable and can occur in pulses or be triggered by specific environmental cues, as such, migration past the structure will also be highly variable. Figure 6-5 provides an example of the natural variability that occurs in migratory fish movements and the false conclusions that can be drawn from short-term sampling. Monitoring upstream of an instream structure 12 consecutive days before and after remediation shows that banded kōkopu were the only one of four species to exhibit significantly higher passage success after remediation with the structure still an impediment to īnanga. However, if monitoring was only undertaken for five consecutive days before and after the remediation, the data indicates that īnanga and banded kōkopu have significantly higher passage post-remediation. As īnanga are a weak-swimming fish that is commonly used as a representative species for successful remediation of migration barriers, it is important that valid conclusions are drawn from the monitoring data.

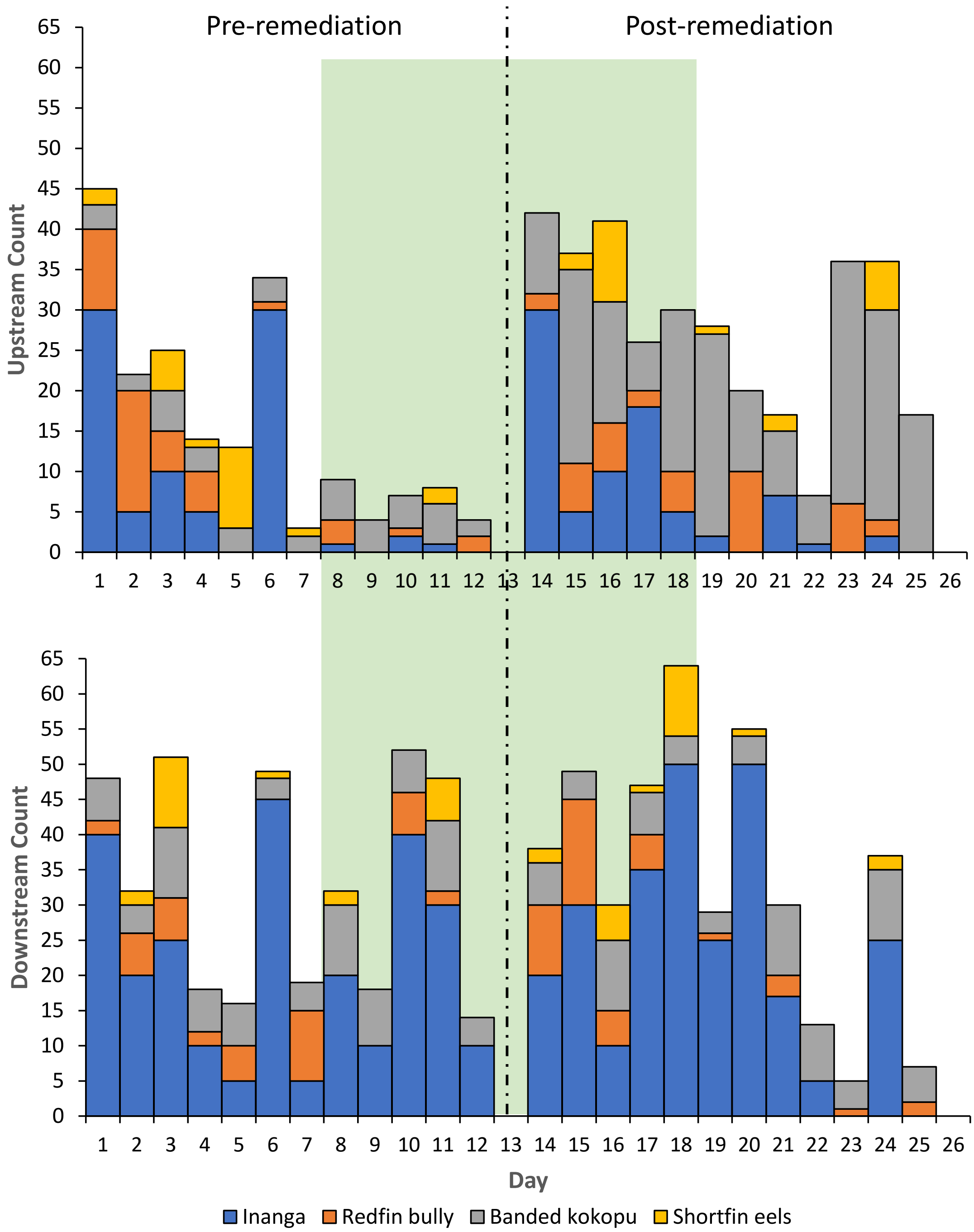


Figure 6-5: Example catch data sampling upstream and downstream of an instream structure 12 days before and 12 days after remediation. The green shaded area represents short term monitoring of five days before and after the remediation. Banded kokopu are the only species of the four shown to have significantly higher passage after 12 days of consecutive monitoring before and after remediation.

To account for the variations in fish movements, a minimum of 12 replicates is recommended with a longer sampling period encouraged. For example, between 14 and 40 replicates have been commonly employed to examine fish passage past vertical-slot fishways (Stuart and Mallen-Cooper, 1999; Stuart et al. 2008; Baumgartner et al. 2010). The minimum of 12 replicates needs to be undertaken both *before* and *after* the planned remediation to reduce the likelihood of false conclusions being drawn from the monitoring data (i.e., the sampling design should be balanced). The before trapping should never have a lower number of replicates than the after trapping.

Survey protocol:

- Determine the number of days sampling will occur (minimum of 12 days) both before and after remediation of the structure.
- It is recommended to sample the entrance and exit of the instream structure. If multi-barrel culverts are present, then a trap would be set at the upstream inlet of every culvert. To trap downstream of a ford or multi-barrel culvert, setting one double wing fyke net/trap spanning the stream width may be the most practical option.
- Placement of traps, particularly upstream of the structure, should aim to minimise any backwatering effect that could influence water velocities over the structure and bias fish passage results.
- In some situations trapping at the entrance to a structure may not be feasible. Here, trapping the exit location (upstream end of the obstacle) can be undertaken. The recommended 12 replicates should be carried out on consecutive days both before and after remediation (Figure 6-6).
- For the 12 replicates, there is no set protocol for the order in which each end of the structure should be surveyed. The entrance (downstream end) and exit (upstream end) replicates can be randomised across the sampling period, or surveyed alternating between locations. **It is essential that the entrance and exit are not surveyed at the same time as this will confound the results**.
  - A recommended protocol is to trap at the exit then entrance of the structure for four consecutive days at each location, repeating this sequence three times (Figure 6-6). Changing from entrance to exit trapping needs to account for the time taken for fish to pass the instream structure, which will vary according to species, length of structure, modifications present and water flow (i.e., water depths and velocities present). The break in trapping, however, should not allow a pulse of fish to move through/over the structure undetected. Therefore, a 24 h period between entrance and exit trapping is recommended to best account for the differences between sites.
- Trap fish for 24 h periods. Traps should be checked at least once every 24 h period and this timeframe should be utilised as a replicate. In streams with high debris loads, check and clear the trap every 12 h.
  - When clearing the traps: remove all fish and debris accumulated in/on the trap. Process all fish captured to species. For each 24 h sample, record the length of the first 50 fish of each species, counting the rest of the individuals. Once 150 individuals of a species are measured carry out counts for subsequent catches.

- If trapping is carried out across multiple years, then monitoring must occur at the same time of the year and within the same month for each repeat survey.

Exit only																									
Exit				Entrance					Exit				Entrance					Exit				Entrance			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

Consecutive days *before* modification/treatment

Exit only																									
Exit				Entrance					Exit				Entrance					Exit				Entrance			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

Consecutive days *after* modification/treatment

Figure 6-6: Recommended protocol for in-situ monitoring before and after remediation of a fish barrier. The sampling period for trapping at the entrance and exit of a structure and just sampling the exit only is provided. Exit refers to where fish exit the structure (e.g., culvert inlet) and entrance represents where fish enter the structure (e.g., culvert outlet).

6.2 Mark-and-recapture

6.2.1 Target species

To ensure the fish pass is effective for all target species, mark-and-recapture trials should utilise the weakest species that requires passage. If passage of swimming fish is desirable, juvenile īnanga are the benchmark species to use if present in the catchment. Common bullies are also a good species to test if present at the site. If passage of climbing fish is the objective, then juvenile redfin bullies are considered the least adept climbing species. If redfin bullies are not present in the catchment, then utilise juveniles of the weakest climbing galaxiid(s) present. Of the four diadromous galaxiids capable of climbing, their ability to surmount instream obstacles in ascending order would be: giant kōkopu, shortjaw kōkopu, banded kōkopu, and kōaro. As obtaining large numbers of identifiable shortjaw and giant kōkopu whitebait is difficult and/or costly, either banded kōkopu or kōaro juveniles are recommended. The location of the instream structure (distance inland) will dictate the target fish species, with juvenile īnanga utilised at structures closer to the coast and banded kōkopu or kōaro juveniles utilised at sites further inland. Multiple target fish can be used and tested if available.

6.2.2 Fish capture and maintenance

It is important to test the life stage of the target species that is expected to be present at the instream obstacle. For example, īnanga reaching many inland culverts will be pigmented, feeding fish (post-whitebait/juvenile) with stronger swimming abilities than fresh-run whitebait captured in estuaries and lower (more coastal) freshwater reaches. In this regard, the site of capture for test fish should be representative of the test location.

It is desirable to capture test fish using nets and traps rather than electrofishing. This is to minimise the physiological impact on fish that is likely to influence passage performance.

If possible, setting traps/nets downstream of the test structure to capture fish is recommended. Although the target species is often īnanga or banded kōkopu, capturing a wide range of species present at the site and testing all individuals able to be captured will provide more information about the passability of the structure. If you are collecting fish from a different catchment and transferring them to the structure location, then approval from MPI, DOC and/or Fish and Game is likely required.

To reduce stress and increase performance of the test fish, it is recommended to hold all fish in the stream they are to be tested in. This is because previous trials carried out by NIWA have indicated that fish held in a different water supply to that of the test system, display reduced upstream movement. This loss of motivation could relate to detectable changes in water quality. We recommend holding fish in purpose built live-bins that provide an adequate transfer of fresh aerated stream water (Figure 6-7). Bins should be secured in a pool that provides deep water without excessive water velocities (Figure 6-7). Ensure the lids are cable tied onto the bins otherwise fish can push their way out. Test fish should be held for at least 24 hours to habituate and recover from capture and handling prior to colouring in the dye solution. Although experimental releases should be timed with appropriate weather and flow conditions, it is advisable to not hold fish for longer than a week before using in trials.

Figure 6-7: Live-bin deployed to maintain īnanga for fish passage trials. Inset shows close up of live-bin.

6.2.3 Fish marking procedure

Mark test fish by immersion in a solution of Rhodamine B[5] or Bismarck Brown[6]. By colouring fish with two different dyes, it can provide two replicates of test fish that can be trialled simultaneously, under the same environmental conditions. In the case study of the Upper Kingston culvert (Appendix A), where no īnanga could be captured in Kara Stream at the time of carrying out the mark-and-recapture trials, unmarked īnanga could also be released as a third replicate. These fish also act as a control for the marked fish as they have not had the additional stress of staining and are less visible to predators. Unmarked fish should only be used as test fish in situations where fish can be removed from the test reaches and these fish are not naturally occurring in high numbers and, therefore, cannot infiltrate the test reach and confound results.

In a trial evaluating fish passage through a standard single culvert in a wadeable stream, between 100 and 200 fish per replicate would typically be used. However, if only low numbers of test fish are available (e.g. such as banded kōkopu whitebait) then using 30-50 fish per replicate will suffice. At more complex structures, or structures in larger streams (e.g., a weir across a stream), it may be necessary to increase the number of fish used per replicate to increase the probability of capture during the trial.

To stain fish:

- In a shaded area adjacent to the stream, set up a separate bin containing 50 litres of stream water (to stain up to 1 kg fish) for each dye solution.
- Ensure aquarium salts are added to the solution (sold in pet shops to make salt water) to produce a salinity of c. 15‰. This is vital to buffer the solution, otherwise fish will suffer a high mortality rate. A refractometer is necessary to test the salinity of solution.
- Add 10 g of Rhodamine B (0.2 g/L) or 2.5 g Bismarck Brown (0.05g/L) to the part saline solution. Wear gloves when handling the dyes. Refer to the material safety data sheet (MSDS) for each compound to ensure safe practices are adhered to. Rhodamine B colours fish pink, and Bismarck brown colours fish orange (Figure 6-8).
- Aerate the solution well with a portable air supply system. A dive cylinder and adapted regulator or portable 12 volt air compressor unit would be suitable.
- Determine the stream water temperature and add ice as necessary to the dye solutions to maintain the water at ambient stream temperature.
- For fish in Rhodamine B, remove after 2 hours, and for fish in Bismarck Brown, remove after 1.5 hours. Wear gloves while removing fish using a dip net.
- After the marking procedure is completed, discard the waste solution according to the protocols outlined in the MSDS[7]. Do not pour it into the stream or on the stream bank.
- Hold coloured fish overnight in live bins to recover before trials.

[5] http://www.sigmaaldrich.com/catalog/product/sigma/r6626?lang=en&region=NZ&gclid=Cj0KEQiAwPCjBRDZp9LWno3p7rEBEiQAGj3KJgIsyxGXuruPdLVT5O5k7MEP9-rFYmNe--7qRJcTBOIaAkMt8P8HAQ

[6] https://www.sigmaaldrich.com/NZ/en/product/sial/861111

[7] msds (fishersci.com); msds (fishersci.com)

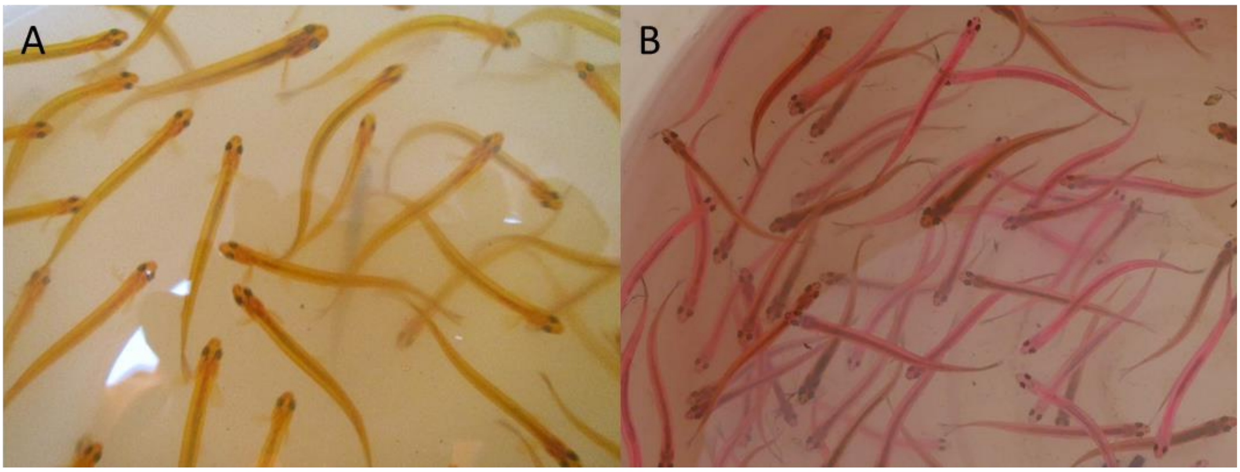


Figure 6-8: Fish coloured orange with Bismarck Brown (A) and pink with Rhodamine B (B).

6.2.4 Stop nets and trap

Install a stop net (5 mm mesh) barricade at the bottom of the test site to prevent test fish escaping downstream or non-test fish moving upstream. A seine net or whitebait mesh form suitable barriers (Figure 6-9 & Figure 6-10). Alternatively, a double-winged fyke net can be used if it spans the full stream width. It is important to dig the bottom of the fyke net mesh or stop net into the substrate and cover with boulders to try and create a secure barrier. If possible, the top of the fyke net mesh or stop net can be secured to trees on the stream banks (Figure 6-10A & B), otherwise waratahs or stakes will need to be used (Figure 6-9 & Figure 6-10C & D). Installing a second stop net downstream as a back-up is also advisable (Figure 6-10). The barrier should be installed below a pool at the base of the structure (i.e. downstream of the structure) to provide fish with a low velocity area to rest before ascent.

If the pool downstream of the structure is too large (i.e. there is a significant perch of the culvert and a deep pool downstream) or is not feasible to barricade the stream for other reasons, then using the barrier net to create a small pool for holding test fish will be necessary (Figure 6-9). Note: it is desirable to create a pool at the base of any remediated fish migration barrier to dissipate energy and prevent erosion.

At the top end of the test site, a whitebait trap and barrier net (or fine mesh fyke net) also need to be installed (Figure 6-11). Ensure the trap is weighted down to avoid any movement with increases in water flow. For structures with multiple culverts, a separate trap and whitebait mesh should be used at the inlet of each culvert. Once nets and traps are set it is preferable to minimise disturbance of the stream bed within the barricaded area to reduce the likelihood of debris being mobilised and clogging the nets.

Figure 6-9: Sock net used to create a pool downstream of a floating ramp to hold test fish within. Photo: Sjaan Bowie.

Figure 6-10: Downstream (bottom end of the test site) barricades installed across a range of study sites. A) Mangakotukutuku Stream, Hamilton. B) Bankwood Stram, Wymer Terrace, Hamilton. C) Reservoir Creek, Tasman. D) Oldham Creek, Nelson.

Figure 6-11: Whitebait trap installed at the culvert inlet (top end of the test site) in Oldham Creek.

6.2.5 Measurements

Flow

It is important to record the flow at the time of the trials. If the study stream does not have a water level recorder installed, a flow gauging can be carried out on each day the trials are being undertaken.

Water velocity

It is also advisable to measure the average water velocity over each section of the instream structure (e.g., culvert and rock-ramp). This will help inform or predict potential problem areas for fish passage, as well as provide some comparative information between sites. The most commonly used method to calculate average water velocity is to time how long a float takes to travel a set distance. A mandarin or orange makes an excellent float as it is easy to see, can withstand knocking into rocks, and it floats almost submerged, so the wind does not influence its movement. It is advisable to measure the average water velocity on each of the trial days.

Trial length

As each instream structure and stream system is different, the appropriate trial length will be determined during the monitoring, but based on results from previous studies, it is recommended that fish are given a minimum of 24 hours to pass an instream structure. The trap can be inspected after 12 and 24 hours to determine if extending the trial to 36 or 48 hours is warranted.

6.2.6 Sampling protocol

- Initiate trials in the early morning. This may require the barricades to be installed the previous day.
- Prior to releasing the marked fish, electric fish the test reach to remove any resident fish that could confound trial results. Utilise multi-pass fishing until no fish are captured.
- Release the marked fish at the base of the structure inside the barricade (Figure 6-12).
- Check barrier nets periodically throughout the trial to ensure they remain functional. However, do not walk adjacent to the stream edge to prevent spooking the fish.
- If testing passage over a structure with multiple components, i.e., a culvert and rock-ramp, at the conclusion of the trial install a temporary stop net at the base of the culvert to prevent upstream and downstream fish movement between each section of the structure.
- Empty the upstream trap into a bucket or fish bin to hold fish for processing.
- At the end of the trial, electric fish each component of the structure separately, in a downstream direction to collect fish that failed to pass. Use multi-pass fishing until no fish are collected over several passes. Keep fish collected from each section of the structure in a separate bucket.
- Anaesthetise fish in each bucket and record their length and colour. Alternatively, utilise a photarium to view and measure individual fish. If time allows, record the

length of every recaptured fish, otherwise ensure lengths are measured for at least 50 successful and 50 unsuccessful fish from each replicate (e.g., pink, orange and unmarked). This will determine if fish size influenced passage success over the instream structure. Carry out counts of the remaining fish where lengths are not measured.

Figure 6-12: Releasing marked īnanga below the culvert in Mangakotukutuku Stream.

6.3 Biotelemetry - PIT tagging

Surgically implanting a PIT tag requires appropriate training, permits and animal ethics approvals. Protocols for PIT tagging fish are, therefore, not provided in this manual and trained experts should be engaged when utilising biotelemetry.

6.3.1 Antenna placement

The placement of PIT antennae will vary contingent upon the structure being examined and site-specific factors. A general guide to antenna arrays for several common structure types is provided below.

Technical fishway

To effectively document passage efficiency of a technical fishway or offline channel, a minimum of four antennae are recommended (Figure 6-13). One at the entrance to the pass, one on the first slot or cell, one on a slot or cell mid-way through the pass and one at the top of the pass. This array will determine how many tagged fish:

- Enter the fishway
- Exit the fishway entrance after entry as conditions are not suitable
- Proceed upstream after entering the fishway
- Successfully exit the fishway.

For those entering, but are unsuccessful at passing the fishway, the midpoint antenna will help determine how far individuals progressed in the fishway. The midpoint and exit antenna also determine the time for passage, with all antennae documenting the time spent in different sections of the fishway. An optional fifth antenna could be placed at the end slot or cell (Figure 6-13) if it is suspected that fish may be drawn back into the exit or to discern directionality of movements.

If downstream moving fish are the target life stage, the antennae layout in Figure 6-13 will document their movements through the fish pass effectively. The two antennae at the downstream entrance and first cell of the fishway will document directionality of downstream moving fish (i.e. whether they turn back upstream or exit the fishway).

For upstream migrating fish, if a large number of individuals cannot be tagged and released downstream of the fishway, testing the attraction efficiency of the fishway can be removed from the study design and passage efficacy of the fishway itself can be tested by releasing fish directly into the fishway. Here, fish would be released in the first cell between the dual antennae at the fishway entrance (Figure 6-13). The antennae array will then determine how many fish leave the fishway via the entrance or proceed upstream, with the overall passage efficiency documented alongside time taken to successfully pass the structure.

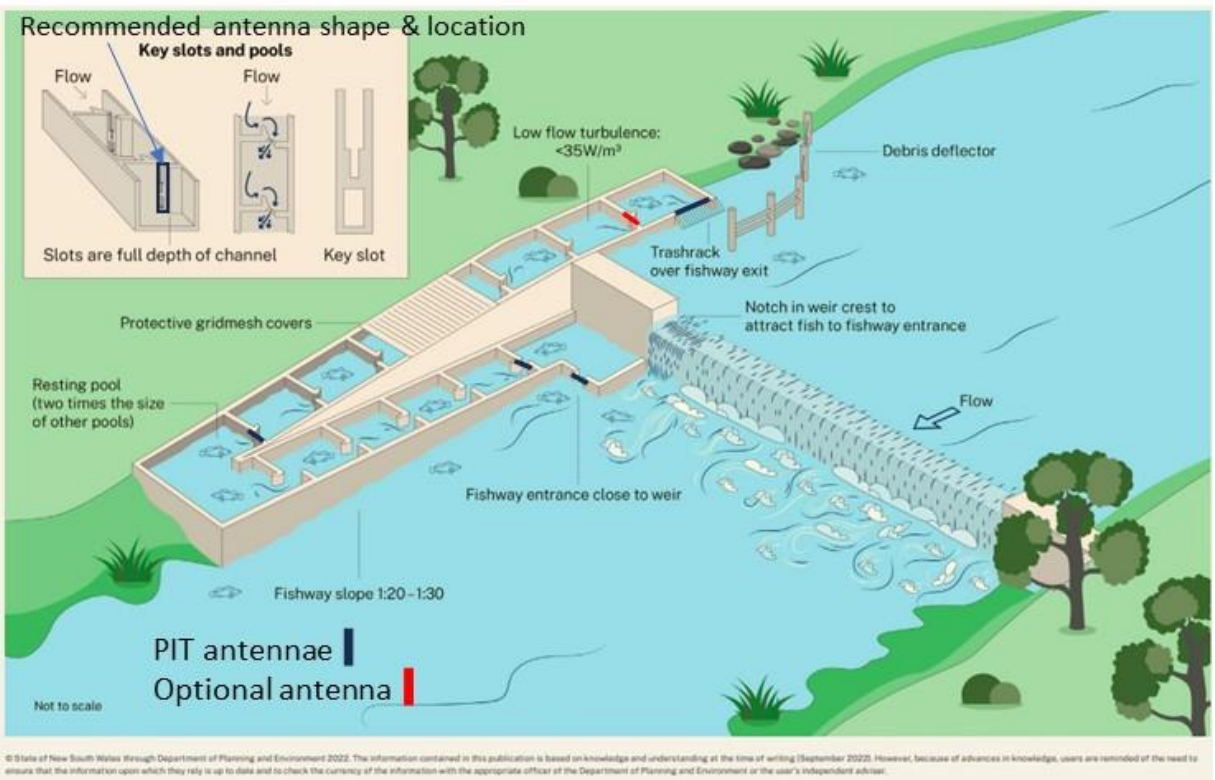


Figure 6-13: Passive Integrated Transponder (PIT) antenna setup at a vertical slot fishway. Figure modified from Department of Planning and Environment, NSW (2022).

Culverts

To document passage efficiency past a culvert, a minimum of two antennae is necessary (Figure 6-14B); one at the culvert inlet and one at the outlet. If the culvert is >50 m long and can be safely entered on foot, then positioning an antenna at the midpoint will enable an estimate of the distance that fish failing to pass the culvert have been able to navigate (Figure 6-14Figure 6-13B). In addition, if the culvert has an apron that has high water velocities or a perch, then positioning an antenna at the end of the apron will allow passage efficiency across the apron to be recorded separately from passage efficiency through the culvert barrel (Figure 6-14B & C). This layout will also be effective for monitoring the movements of downstream moving life stages.

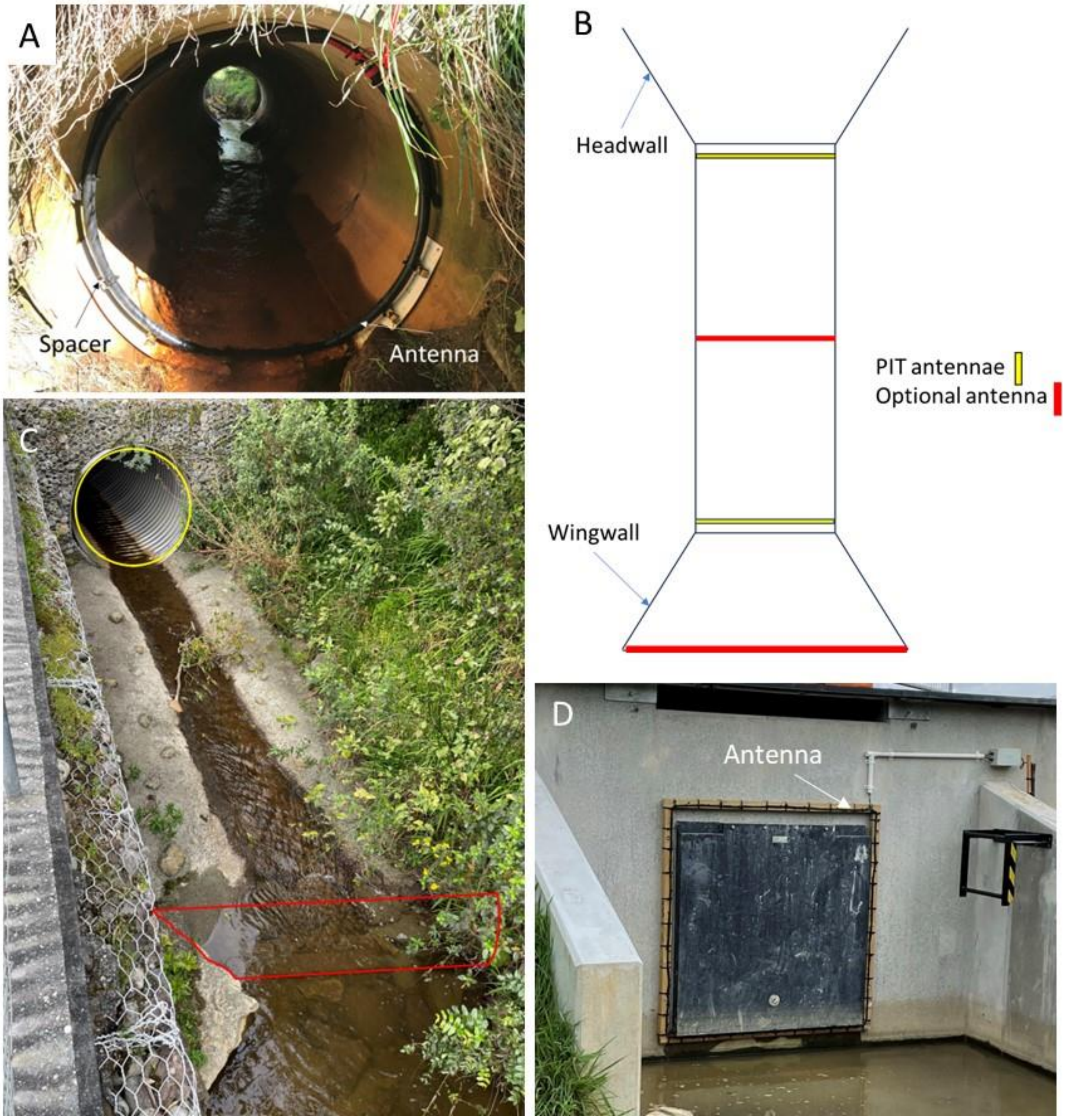


Figure 6-14: Passive Integrated Transponder (PIT) antenna setup at a culvert. A, PIT antenna installed inside a pipe culvert. Note the spacer necessary to avoid the electromagnetic field being dampened by the steel reinforcing inside the culvert. Although the antenna wires are raised from the culvert base, the read range of the antenna extends to the culvert floor. B, Plan view of a typical culvert arrangement showing the conceptual placement of PIT antenna to monitor fish movements over the apron and through the culvert barrel. C, Mark-up of a pipe culvert and rock ramp showing the placement of an antenna at the base of the rock ramp and inside the culvert outlet. With an antenna at the culvert inlet, this system will determine passage efficiency across the rock ramp separately from passage efficiency through the culvert barrel. D, antenna placed around the outside of a metal gate at a pump station culvert outlet.

When positioning antennae within culvert barrels, a wooden or non-metallic spacer is required to situate the antenna wires away from the reinforced concrete as the metal dampens the antenna signal and reduces its function. The easiest way to overcome this dampening effect is to keep the entire antenna from touching the culvert. With this layout, although the antenna wires are raised from the culvert base, the read range of the antenna extends to the culvert floor, and fish are able to pass the antennae either underneath the wires or by burst swimming over the top.

For culverts fitted with flood or tide gates, an effective field can be created by positioning the antenna on the outside of the outlet around the gate (Figure 6-13D). This design is also functional for culverts with suitable space on the head and tail walls. For these designs, the base of the antenna can be attached directly to the culvert apron and secured with a piece of flat HDPE (high density polyethylene) or LDPE (low density polyethylene) to reduce the impediment created by the antenna wires.

Flood pump station

Figure 6-15 provides an overview of a PIT antenna array used to monitor downstream adult eel movements at Steiners flood pump station (see Mahlum et al. 2022). Steiners pump station contains two channels, one where the flood pumps are operational and alongside a channel with a gravity bypass. In this situation we recommend five PIT antennae be deployed. The first antenna should be set up across the stream, upstream of where the channel splits into the gravity and pump outlet channels (i.e., Antenna 1, Figure 6-15). This antenna will allow quantification of the time between when migrating fish arrive at the downstream end of the channel and when they successfully exit the system (either via the pumps or bypass). The remaining four antennae are set up in paired systems at the upstream and downstream sides of both the gravity outlet and pump station outlet (Figure 6-15). Use of two paired systems determines the number of fish that pass through the pump or bypass to exit the catchment and allows determination of which direction the fish are moving through.

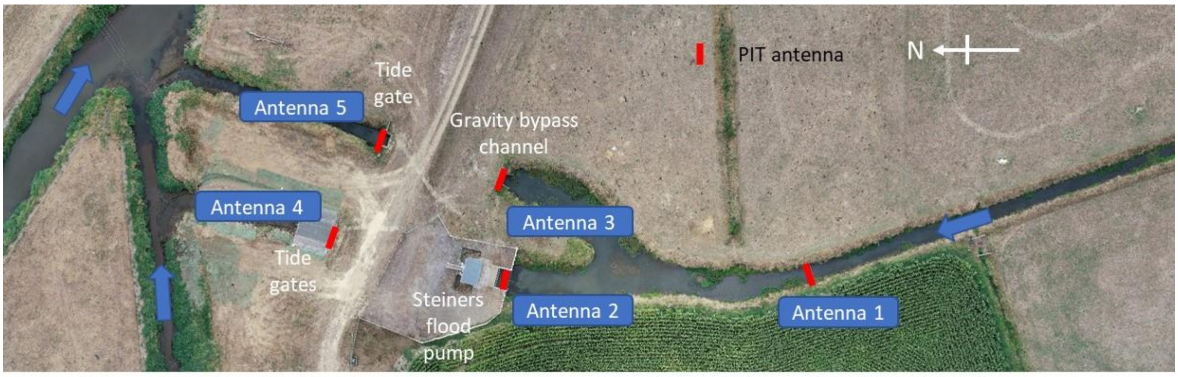


Figure 6-15: Passive Integrated Transponder (PIT) antenna setup at Steiners flood pump station with a gravity bypass. Blue arrows indicate direction of flow. Figure modified from Mahlum et al. (2022).

If the intake channel is long enough, paired antennae (as opposed to single antenna) can be used at the upstream end to help to determine directionality of fish movements and any avoidance of the intake after initiating passage. However, once fish pass Antenna 1 their subsequent movements and exit from the system will be documented by either Antenna 1, 2 or 3.

If the pump station doesn't contain a gravity bypass, then four antenna would be recommended (Figure 6-16). The layout would include an antenna across the stream, upstream of the intake channel (Antenna 1), two antennae in the intake channel (Antenna 2 & 3) and one at the outlet of the pump (Antenna 4; Figure 6-16). In a single channel system, where there is no other downstream escape route, two antennae are recommended in the intake channel to document any avoidance of fish towards the pump.

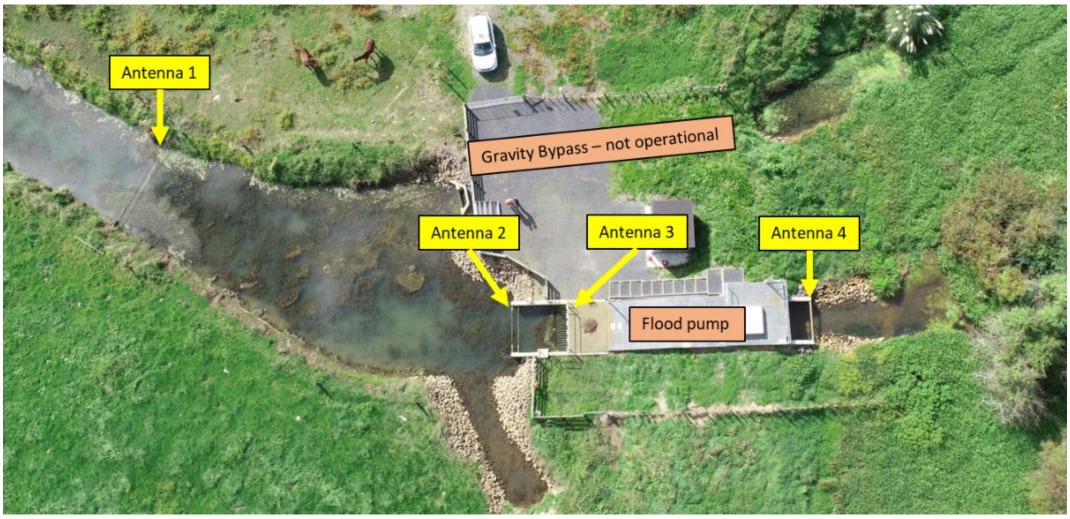


Figure 6-16: Passive Integrated Transponder (PIT) antenna setup at a flood pump station without an operational gravity bypass. Figure modified from Mahlum et al. (2023). Photo courtesy of Waikato Regional Council. Flow moves from the left to the right of the picture.

To monitor upstream fish movements at flood pump stations, a similar antenna array would be utilised except the double antenna to document directionality of movements would be placed downstream of the pump station.

6.3.2 Antenna design

For any PIT system, antennae with a high detection efficiency is vital for ensuring valid results are obtained. Unlike radio or acoustic telemetry where receivers are commercially purchased, each PIT antenna is handmade and site-specific. As such, a variety of PIT antenna designs can be used (Figure 6-17 & Figure 6-18). We recommend two styles of antenna, contingent upon size, which have been proven to work effectively in difficult/noisy environments (e.g., electrical noise from pump stations, metal dampening the electromagnetic field, etc.).

Figure 6-17: Double coil PIT antenna design. Antenna wire is housed within conduit piping for mechanical protection. Abbreviations: AWG, American wire gauge.

For small antennae (<2 m x 1.5 m) we recommend two coils of tightly wound 12 AWG (American wire gauge) held together by conduit pipe or other material that provides physical protection (Figure 6-17). If antennae are placed inside culvert pipes or box culverts where metal reinforcing is used, increasing the coil number to 3 or 4 is recommended to overcome the dampening effect of the metal.

For large antennae (>2 m in height or length) we recommend two coils of 4 or 8 AWG (American wire gauge), with each coil separated by 0.4 m (Figure 6-18). This configuration can be used on antennae up to 10 m in length. If stream widths or areas extend between 10 and 20 m, the same design can be utilised, but the height of the coils cannot exceed 1 m. The base wire does not need to be flat but instead can follow the contour of the stream as shown in Figure 6-18. Wires can be held in place by cable ties attached to wooden pegs hammered into the stream bed and margins. Metal warratahs can be used at the four corner points for structural integrity of the antenna. Ratchet tiedown straps can be used to provide a strong attachment point for the two top wires (Figure 6-18).

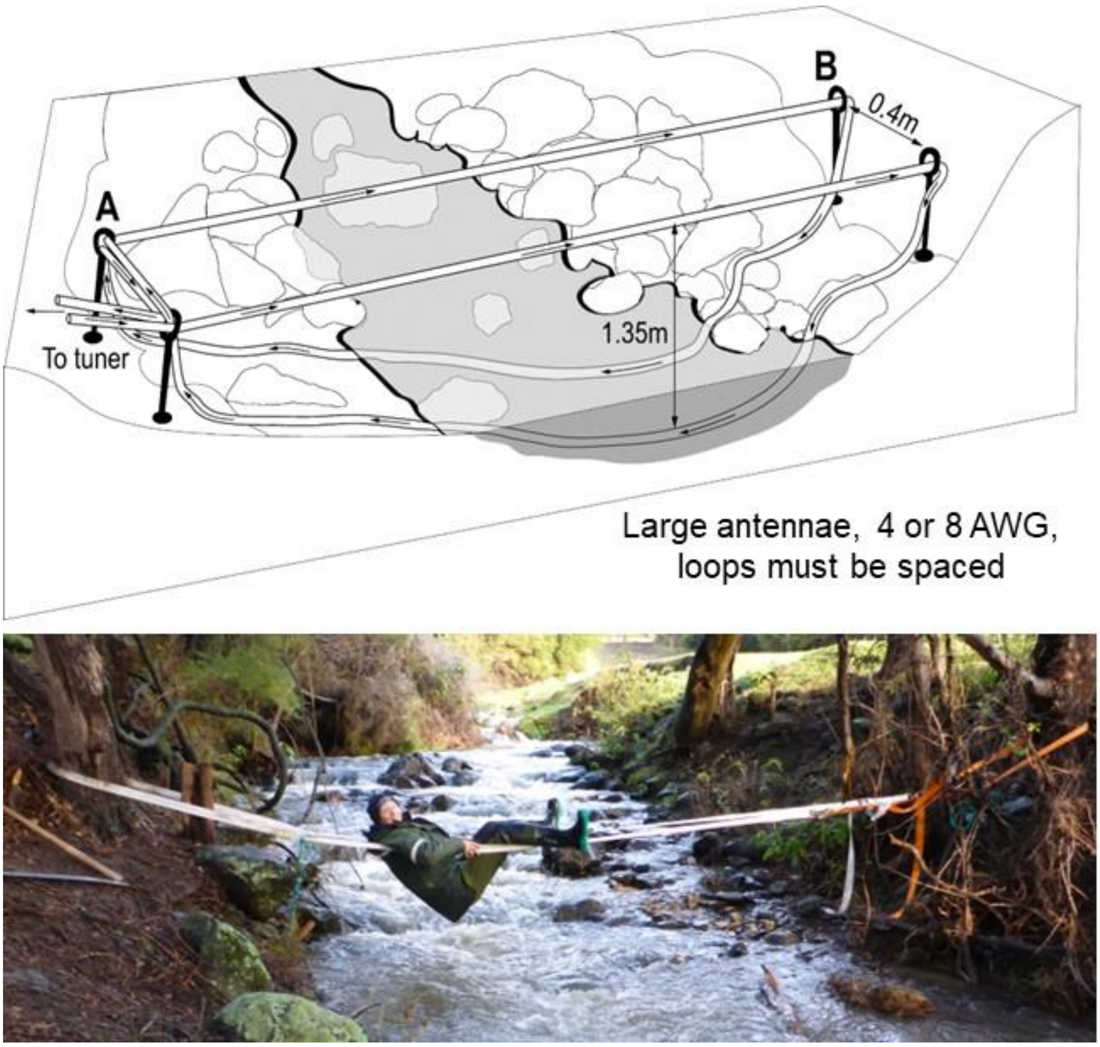


Figure 6-18: Spaced double coil PIT antenna design. Coils have the same orientation with a spacing of 0.4 m. The antenna width (A to B) can be up to 10 m in length. The base of each coil followed the contours of the stream channel with a maximum height of 1.35 m for antenna <10 m in length. For antenna >10 m in length, the maximum height cannot exceed 1 m. The antenna wires should be strongly secured (e.g., with tiedown straps as pictured) but can remain flexible. Abbreviations: AWG, American wire gauge. Figure modified from Baker et al. (2017).

7 Fish processing

7.1 BACI fishing survey

Regardless of fishing method utilised (e.g., electrofishing, fyke netting, Gee minnow trapping), process all fish captured to species. This is critical to enable passage efficiencies to be determined for each species reaching an instream structure. For species that are similar in appearance (e.g., juvenile whitebait or non-migratory galaxiids), photograph fish inside a photarium or take a sub-sample to identify under a microscope, and ensure someone with the appropriate expertise identifies the species (Figure 7-1). Accurate identification of swimming and climbing species is crucial for drawing valid conclusions on passage efficacy and passability of a structure.

Record the **total length** (nose to distal end of the caudal fin; mm) of the first 50 fish of each species in each sampling reach, counting the rest of the individuals. Size of fish plays an important role in passage success for all species, so recording the size of fish upstream and downstream of an instream structure is a vital component of any BACI survey. Kōura (*Paranephrops planifrons*) and shrimp are counted rather than measured. Record exact numbers of kōura captured and record shrimp (*Paratya* sp.) into one of the following categories: 1–10, 11–100, 101–1000, 1000+.

Figure 7-1: NIWA Photarium that can be used to identify fish species and measure their length without anaesthetic.

Small fish such as īnanga and bullies are often measured but not weighed, unless the protocol specifies for weight to be included. For larger fish such as eels, adult kōkopu and all exotic species the weight (g) of the first 50 fish of each species is also collected. This allows condition factor to be calculated.

Condition factor is a measure of the weight of the fish relative to its length (standardising for the influence of length) and is calculated using the formula:

Condition factor = $(W/(L/10)^3) \times 100$,

Where *W* is the wet weight in grams and *L* is the total length in millimetres.

For all netting and trapping, it is important to accurately record the net/trap number each fish was captured from to provide a catch per unit effort, where effort is defined as an individual fyke net, gill net or Gee minnow trap within each reach. For electrofishing, fish will either be recorded within sub-reaches (single pass) or passes (multi-pass depletion fishing).

7.2 Mark-and-recapture surveys

Anaesthetise fish in each bucket (successful, unsuccessful and in transit) and record their length and colour. Alternatively, utilise a photarium to view and measure individual fish (Figure 7-1). If time allows, record the length of every recaptured fish, otherwise ensure lengths are measured for at least 50 successful and 50 unsuccessful fish from each replicate (e.g., pink, orange and unmarked) in each bucket (i.e. successful, unsuccessful and in transit). This will determine if fish size influenced passage success over the instream structure. Count the remaining fish where lengths are not measured.

8 Survey timing

8.1.1 BACI fishing survey

At any given site, there is considerable temporal variation in most fish species' abundances. This is largely due to annual variation in the recruitment of diadromous fish species, and the seasonal migration and movement patterns of different fish species. In addition, abiotic and biotic factors can influence the efficacy of a given species capture rates. For these reasons we recommend carrying out fish surveys **between December and April inclusive**, with any repeat monitoring carried out in the same month.

The December to April timing ensures sampling is carried out when fish are most active, however, it is important to note that species such as smelt and īnanga undertake downstream spawning migrations to the lower river/estuary during autumn and early winter. The timing of these downstream spawning migrations are contingent upon latitude but peak movements generally occur between March and May. In this regard, if smelt and īnanga are target species, then monitoring should be carried out between December to February inclusive.

8.1.2 Mark-and-recapture surveys

A critical aspect of mark-and-recapture trials is timing with two key factors to consider, season and flow. As migratory galaxiids are usually used as target species for mark-and-recapture trials, we recommend carrying out trials **between September and March inclusive.** This window represents the peak upstream migration season and the timing that whitebait recruit into streams across summer**.** We do not recommend testing īnanga whitebait later than March as the downstream spawning migration can be initiated and confound trial results.

Site location will be important when considering trial timing. For sites close to the coast where whitebait, and particularly īnanga, reach the site from August/September, then mark-and-recapture trials utilising īnanga whitebait are best carried out in September or October to reflect the performance abilities of fresh sea run fish. If whitebait are not arriving at the site until fully pigmented feeding fish, then mark-and-recapture surveys should reflect the timing that fish usually arrive at the site. Capturing the test fish from close to the instream structure will ensure the appropriate life stage is tested. Repeat monitoring should either be carried out in the same month, or within four weeks of the control/baseline survey.

It is crucial to carry out the trials during base flow in the study stream, under a high pressure front that will limit rainfall and subsequent rises in stream discharge over the trial period. This is not only because the barricades and traps can get washed out, but also because instream structures are generally harder for fish to pass at low flows. In this regard, trials carried out at base flow won't overestimate the proportion of fish able to successfully pass the structure.

9 Defining success

The performance of any fish pass will vary with the type of pass and target species, as well as specific site conditions. As highlighted with the case study at Bankwood Stream (see Appendix D), fish passage performance can vary according to the size and condition of the fish as well as with environmental variables such as flow. The relationship between passage performance and flow will likely change throughout the migration season and between years, and this needs to be considered when interpreting passage success. Although the efficiency of a fish pass is a quantitative measure of its performance, it needs to be considered in the context of the efficiency required to maintain upstream communities. In general, for any site and species, the two main factors influencing the required efficacy of passage past the structure will be the carrying capacity of the upstream habitats and the number of recruits reaching the base of the structure. In Bankwood Stream, approximately 30% passage efficiency of īnanga past the culvert is maintaining species such as smelt and īnanga in the upstream habitats. However, because of an additional migration barrier to non-climbing fish species, only around 160 m of linear stream is currently accessible to swimming fish species, meaning that upstream habitat is limited.

To provide context for passage efficiency measurements, Table 9-1 provides an overview of a range of mark-and-recapture studies undertaken to assess īnanga passage efficacy past remediated and non-remediated instream structures. It is important to note that each trial represents different conditions with respect to flow, timing and age of fish tested. Consequently, results are not directly comparable but they do provide an indication of passage efficacy for īnanga based on remediation type and severity of the instream structure in restricting īnanga passage.

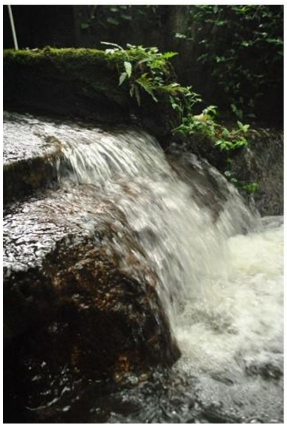
Table 9-1: Passage efficiency of īnanga past a range of remediated and non-remediated structures.

Bankwood Stream, River Road, Hamilton

Structure:	Culvert
Retrofit:	Spoiler baffle sheets
Length:	74 m
Average gradient:	0.81° (max 2.55°)
Trial time:	24h
% passage success īnanga	28

Bankwood Stream, Wymer Terrace, Hamilton

Structure:	Culvert
Retrofit:	None, concrete ramps and smooth culvert barrels
Length:	33 m
Average gradient:	0.26°
Trial time:	24 h
% passage success īnanga	9.5



Kara Stream, Manawatu

Structure:	Culvert
Retrofit:	Weir baffles
Length:	20 m
Average gradient:	1.66°
Trial time:	20.5 h
% passage success īnanga	31

Mangakotukutuku Stream, Hamilton

Structure:	Culvert
Retrofit:	None, natural sediment
Length:	42 m
Average gradient:	0.17°
Trial time:	24 h
% passage success īnanga	75

Unnamed Stream, Westgate, Auckland

Structure:	Stormwater riser
Retrofit:	Baffled ramp
Length:	c. 14 m
Average gradient:	15°
Trial time:	24 h
% passage success īnanga	3

Oldham Creek, Nelson

Structure:	Culvert
Retrofit:	Rubber ramp & spat rope
Length:	7.5 m
Average gradient:	~1°
Trial time:	48 h
% passage success īnanga	0

Todd Valley, Tasman

Structure:	Culvert
Retrofit:	Flexible baffles
Length:	9.6 m
Average gradient:	2.9° to 4.8°
Trial time:	64 h
% passage success īnanga	20

Reservoir Creek, Tasman

Structure:	Culvert
Retrofit:	Flexible baffles
Length:	136 m
Average gradient:	Majority 1.3° to 3.4°, steep section 16.7° for 1 m
Trial time:	48 h
% passage success īnanga	0

The results of any passage efficiency study should also be considered in a catchment context. The cumulative effect of individual fish passes or structures can have a multiplicative impact on the proportion of successful fish recruits reaching upstream habitats. This is illustrated in Figure 9-1 for several hypothetical examples of multiple structures with passage efficiencies of 10% – 90%. For example, if upstream migrants are required to pass a series of five culverts, where passage efficacy at each culvert is 50%, then only 3.1% of fish will successfully reach upriver habitats. Consequently, passage efficiency at each individual structure may need to be higher to account for the cumulative effects of multiple structures on the fish community composition.

Too few fish pass solutions have been monitored at present to provide guidelines on the required passage efficiency necessary to maintain upstream fish communities relative to distance inland and carrying capacity of different sized catchments. The appropriate threshold will likely vary depending on life stage, stream habitat availability and quality, location in the catchment and the species present. Ideally, an instream structure should not impede or change the passage of any fish from that of the adjacent stream reaches.

As a rule of thumb, for any waterway, a remediated or new instream structure should pass all fish species and life stages present under all migration flows or flows upon which movements between critical habitats are carried out.

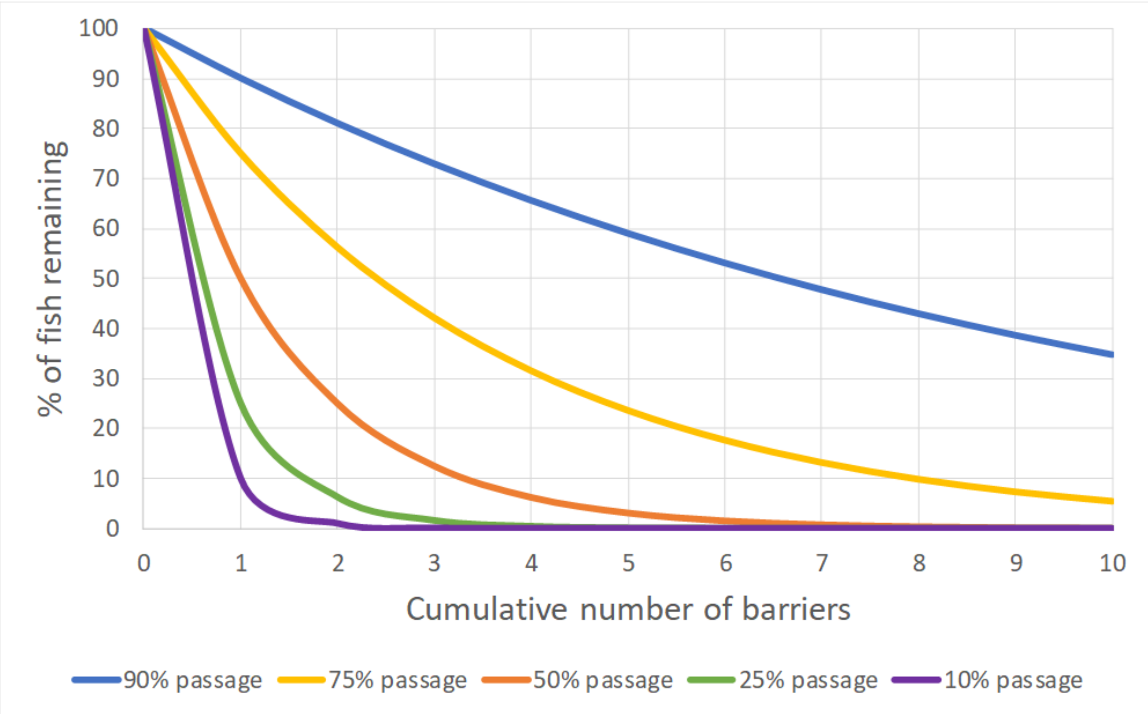
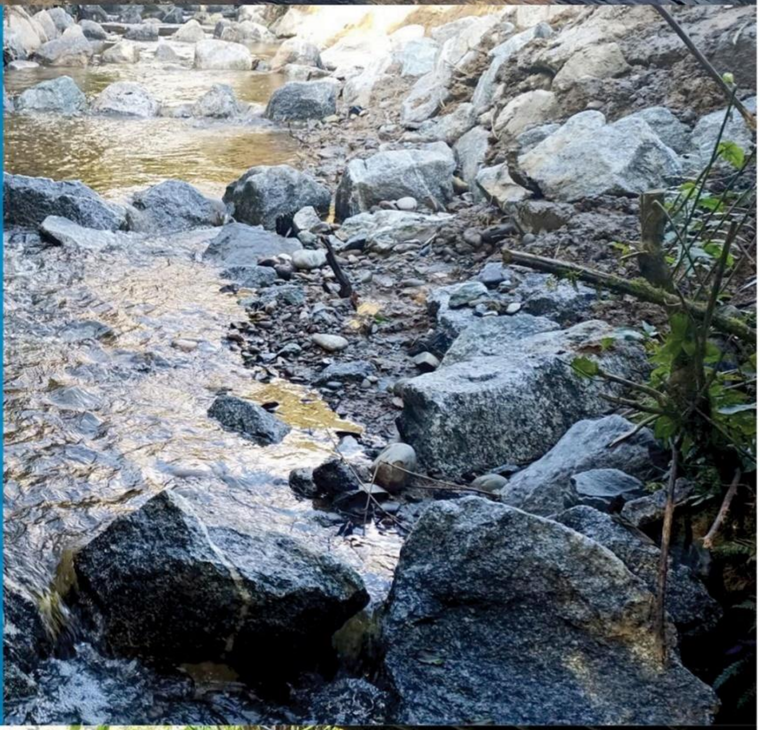
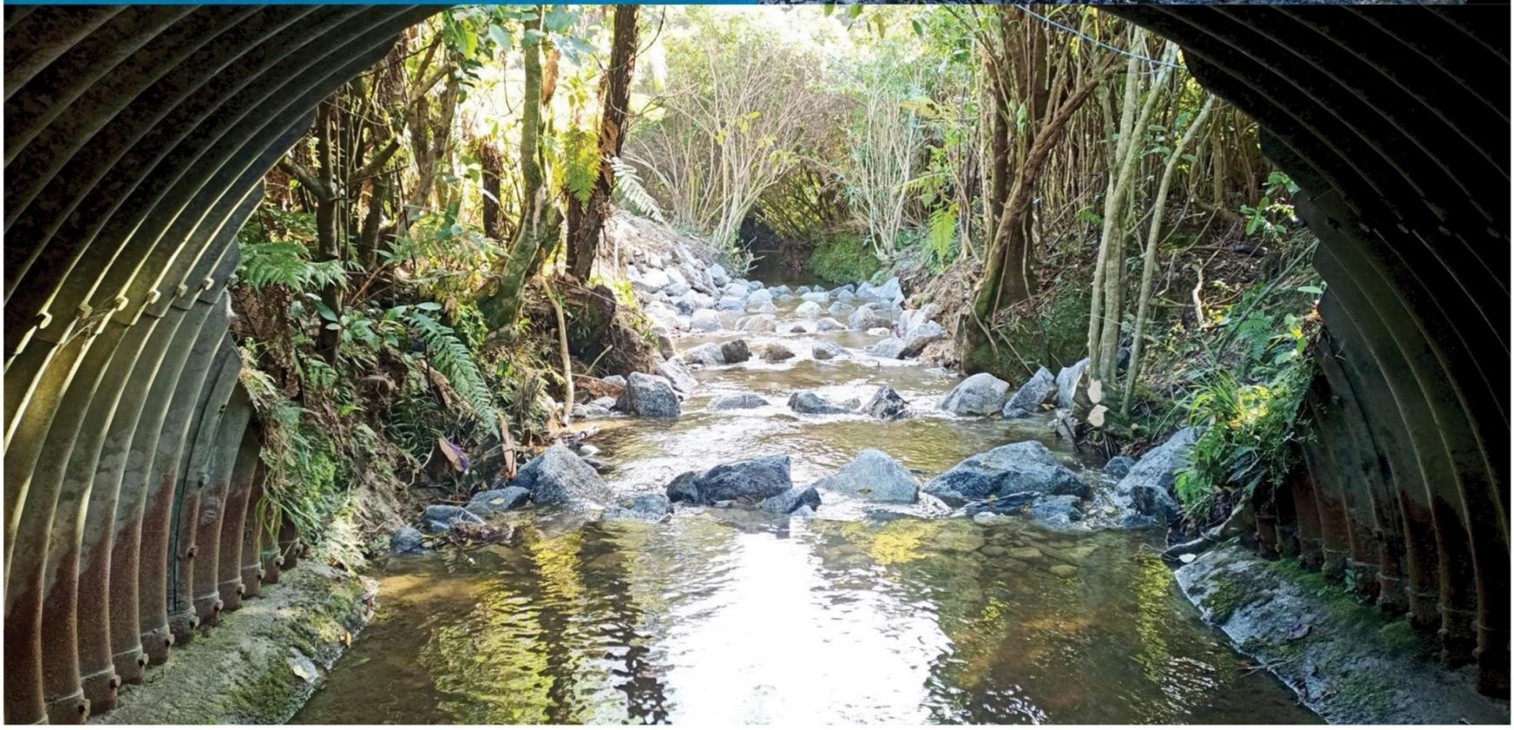


Figure 9-1: Illustration of hypothetical cumulative effects of multiple instream barriers with varying passage rates.

Physical and hydraulic monitoring





10 Physical & hydraulic monitoring

Means objectives for fish passage projects may include physical and/or hydraulic objectives alongside biological objectives (see Section 2.3). Physical and/or hydraulic objectives are often used as the basis of defining design criteria for new fish passage structures. For example, Section 5.5.3 of the New Zealand Fish Passage Guidelines sets out a range of physical and hydraulic design parameters for rock ramp fishways including pool size, pool to pool head loss, and energy dissipation (Franklin et al. 2024a). Likewise, section 6.4 of the Guidelines outlines physical design considerations for exclusion barriers intended to prevent the movement of undesirable species (Franklin et al. 2024a). Many of these physical and hydraulic characteristics are easily translated into physical/hydraulic performance measures that can be used as the basis for evaluating the effectiveness of fish passage interventions.

Monitoring of physical/hydraulic parameters is often more straightforward than evaluating biological performance measures and is an important way to identify any maintenance requirements. However, **it is important to recognise that achieving physical/hydraulic performance standards does not guarantee achievement of associated biological objectives and performance standards**. As such, physical/hydraulic monitoring should be deployed alongside biological monitoring techniques rather than being considered as an alternative to biological monitoring.

Physical/hydraulic performance measures are typically used for two main purposes:

1. checking a newly constructed fish pass or instream structure against design specifications, and
2. as part of an ongoing risk-based surveillance/maintenance monitoring programme.

10.1 Evaluation of newly constructed fish passes or instream structure

After a new fish pass or instream structure has been completed, a range of physical/hydraulic measurements should be taken to ensure that the constructed fish pass or instream structure is consistent with the design specifications and tolerances established during the detailed design phase and/or guidelines for design (e.g., Franklin et al. 2024a). The purpose of the commissioning assessment is to ensure that the fish pass physical/hydraulic parameters accurately reflect the design/guidelines specifications.

Jones & O’Connor (2017) identified and defined a range of hydraulic parameters relevant to evaluating fish pass designs as summarised in Table 10-1. Measurements should be taken at all pools and baffles to check for consistency across the fish pass. In most cases, a tolerance of ≤5% departure from the design/guidelines will be acceptable, but for technical fishways (e.g., vertical slot fishways) deviation in key parameters such as the pool volume, slot width, slope and head loss should be constrained to within ≤2%. In addition to measurements of physical/hydraulic conditions within the new fishway, it may also be important to take measurements of key physical/hydraulic parameters within or across associated infrastructure (e.g., the culvert that is being remediated) that are also important for ensuring fish are able to pass the structure. Key parameters would include water depth and water velocities inside the culvert, for example.

It is recommended that commissioning assessments be carried out across the specified operating range of the structure to ensure that performance remains within design specifications throughout the operating range. These measurements will typically require use of tape measures, a water velocity meter, and a laser level and measuring rod. Once it has been established that the fish pass meets the physical/hydraulic design specifications, biological evaluation can commence.

Table 10-1: Example of physical/hydraulic performance measures relevant to assessing fish pass design. Modified from Jones & O'Connor (2017).

Parameter	Definition
Target water depth	Water depth of each pool and at the slot
Minimum pool volume	Volume of the pool based on minimum target depths (L × W × H)
Minimum slot width	Width of the slot at all baffles
Maximum water velocity at vena contracta[8]	Maximum water velocity at the vena contracta (i.e. jet of water at the slot)
Slope	Slope of the fish pass between the entrance and exit
Head loss	Difference in water height between pools
Minimum head loss at fishway entrance	Difference between river height at entrance and first pool
Maximum water velocity at fishway exit	Maximum water velocity at the exit
Entrance and exit flow vectors	Angle/direction of flow at the entrance and exit
Entrance/exit location	Location of the entrance/exit at the upstream migration limit
Water velocity within culvert	Average and maximum water velocities within the culvert
Water depth within the culvert	Average and minimum water depth within the culvert
Culvert substrate	Visual assessment of percent coverage of different substrate types within the culvert

10.1.1 Example: a rock ramp fishway and culvert

Full-width rock ramp fishways are the recommended solution for overcoming excessive fall heights at instream barriers in New Zealand (Franklin et al. 2024a). They consist of a series of rock ridges and pools that break down the overall head drop into smaller incremental steps that are surmountable by a wide range of fish species and life stages across a range of flow conditions (Figure 10-1). Critical physical/hydraulic design parameters for rock ramp fishways include pool size, pool depth, pool to pool head loss, slot width between ridge rocks and water velocity at the slots.

The New Zealand Fish Passage Guidelines set out performance standards for each of these physical/hydraulic performance measures (see Table 10-2 or section 5.5.3 of Franklin et al. 2024a). It is essential that during the commissioning process for the structure that these parameters are evaluated and checked against the detailed design specifications for the site. As illustrated in Figure 10-1, these measurements must be made at each ridge and pool throughout the fishway to ensure

[8] A point in a fluid stream, just downstream from a restriction like an orifice, where the stream's cross-sectional area is at its smallest and the fluid velocity is at its highest. This phenomenon is significant in fish passage as it represents the highest velocity point in the flow, which could impede fish movement if the velocity is too high.

that the as-built specification meets the detailed design specifications. As far as practicable, these measurements should be undertaken during the building process so that construction can be kept on track and corrected, if necessary, while in progress.

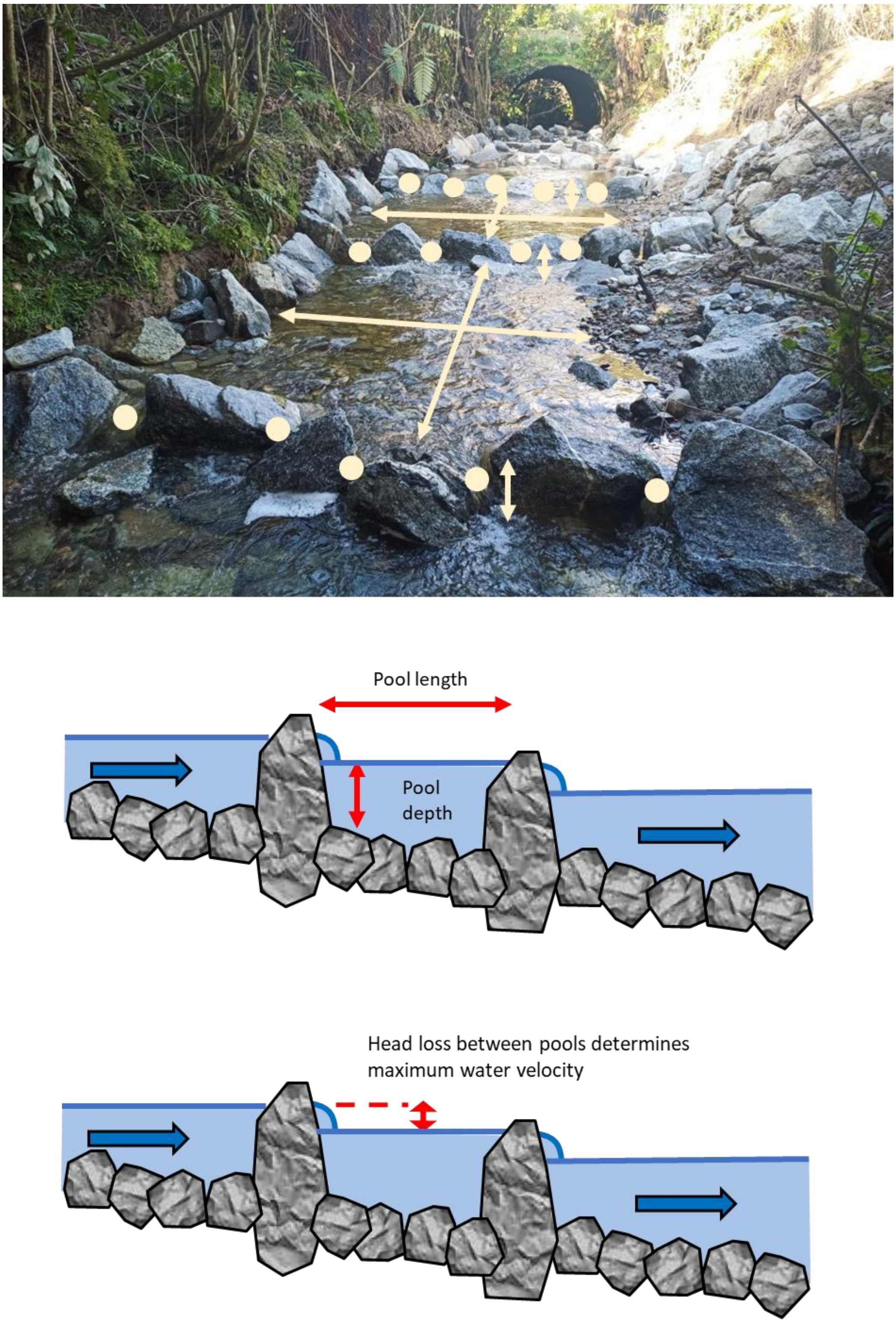


Figure 10-1: Illustration of some of the key physical/hydraulic performance measures for a rock ramp fishway. Photo: Koen Beets, West Coast Regional Council.

Table 10-2: Hydraulic design parameters for a rock ramp fishway. See Section 5.5.3 in Franklin et al. (2024a) for further details.

Minimum fish length (mm)	Minimum pool depth (m)	Minimum pool length (m)	Target turbulence (W/m^3)	Maximum slot water velocity (m/s)	Maximum pool to pool head loss (mm)	Within culvert mean water velocity (m/s)
20	0.3	2.5	25	<1.2	50	0.3
50	0.3	2.5	40	<1.2	100	0.3
100	0.3	2.5	60	<1.4	150	0.3

Following completion of the works, the site should be revisited over time and these key performance measures re-evaluated to ensure that they remain within the design specifications. Particular focus should be given to the ridge rocks and the toe of the ramp, which are the areas most susceptible to shifting in a dynamic environment (see Section 10.2 for surveillance monitoring).

In addition to measurements of the rock ramp features, it is recommended that physical/hydraulic conditions within the remediated culvert are also characterised. This will determine whether the efforts to backwater the culvert, and hence reduce water velocities and increase water depth, have been successful. This should include measurement of both average water velocity through the culvert and cross-sectional water velocity and depth profiles at the culvert inlet, outlet, and where safe to do so, within the culvert. Visual estimates of substrate coverage may also be required if an objective is to increase the coverage of natural substrate within the culvert.

10.2 Risk-based physical/hydraulic surveillance monitoring

An advantage of physical/hydraulic monitoring over biological monitoring is that physical/hydraulic parameters are often (relatively) easily and quickly measured. As such, they can play a valuable role as part of a risk-based surveillance monitoring framework. In this context, physical/hydraulic measurements are taken on an ongoing basis to determine whether the structure or fish pass remains within the design specifications or guidelines for the site, or whether change is occurring over time. Where changes in the physical/hydraulic performance measures are identified, this can be used as an indicator of an increased risk that fish passage is being impeded and trigger more detailed investigations and/or biological monitoring, or management interventions (Figure 10-2).

The Fish Passage Action Plan Template (MfE 2022) suggests all instream structures should be checked annually and/or after significant natural events to ensure that they continue to meet the required fish passage objectives of the NPS-FM. It is unrealistic and, in most cases, unnecessary to require that biological monitoring be undertaken annually on an ongoing basis or following every significant natural event. However, physical/hydraulic surveillance monitoring is often practicable and could be carried out alongside/as part of standard infrastructure maintenance checks.

The Fish Passage Assessment Tool (FPAT; https://fishpassage.niwa.co.nz/) can be used as one tool for tracking basic information about the physical characteristics of structures that is relevant to fish passage risk. However, the FPAT was not designed to capture detailed information on remediation interventions like the physical/hydraulic performance measures set out in Table 10-1. As such, more targeted physical/hydraulic monitoring aligned with design or guidelines specifications may be more suited for ongoing surveillance monitoring of fish passage interventions. Where the selected physical/hydraulic performance measures are found to be consistent between assessments and aligned with the design specifications, an assumption can be made that overall performance remains consistent. Where changes are identified over time, particularly where they exceed physical/hydraulic performance standards (i.e., they fall outside of the design specifications), more detailed assessment should be triggered (Figure 10-2), including biological assessments as outlined in Sections 5 to 9.

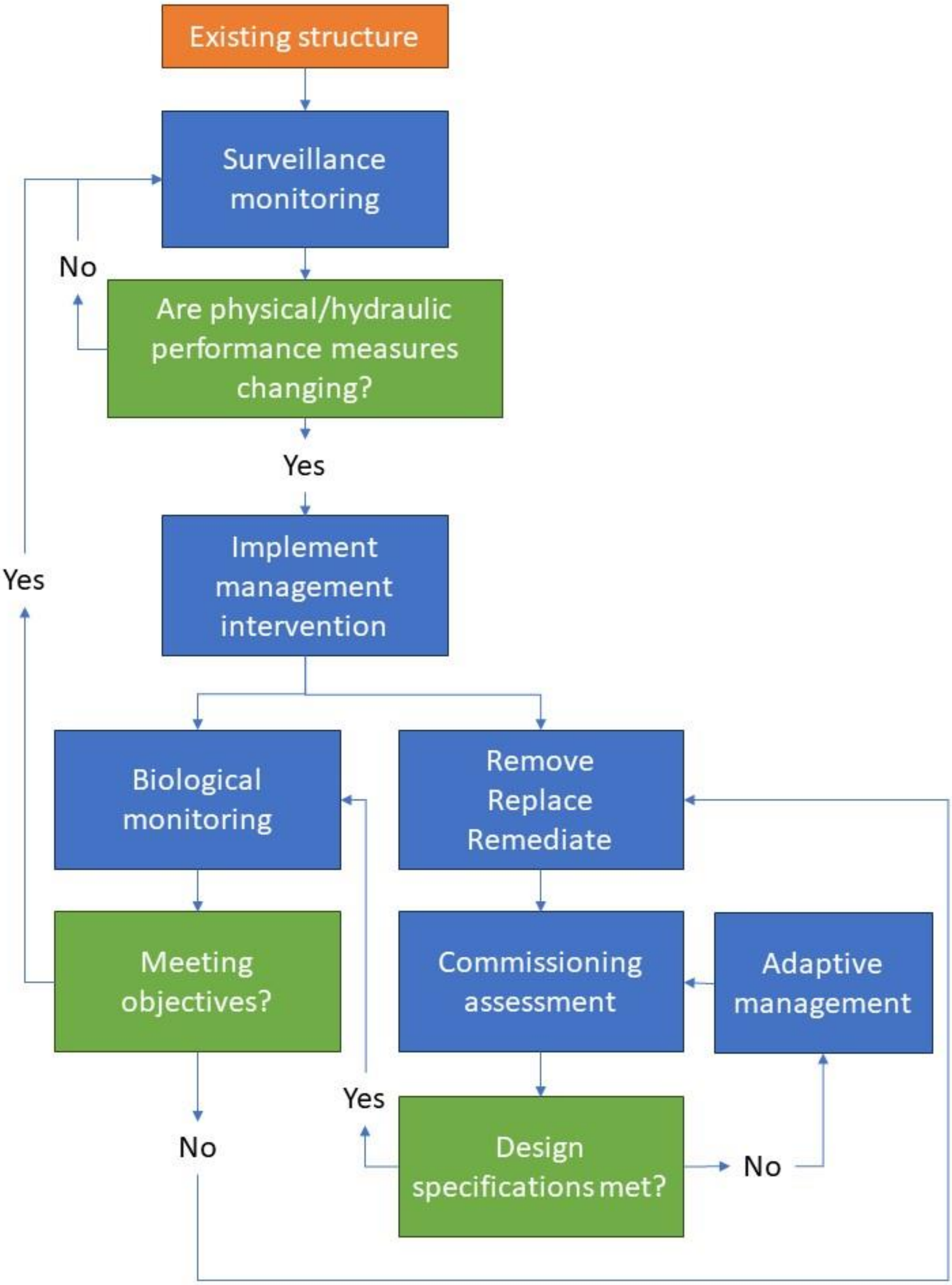


Figure 10-2: Decision support diagram illustrating the links between commissioning assessments and surveillance monitoring.

Appendix, acknowledgements, and references

11 Acknowledgements

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Appendix A Case study – Flexible ramps

Oldham Creek – Mark & recapture trials

This case study describes the results of mark-recapture trials undertaken by Baker et al. (2024) to assess the effectiveness of remediated culvert on an unnamed tributary of Oldham Creek, Atawhai, Nelson.

Study site

A 7.5 m long perched culvert (drop height of approximately 180 mm) was retrofitted with a 440 mm wide rubber ramp and two strands of mussel spat rope that ran along the length of the culvert and over the ramp (Figure A-1). The spat ropes were attached at the upstream end above the culvert inlet but were not attached at the downstream end and floated freely upon reaching the water surface downstream of the culvert outlet (Figure A-1). The rubber ramp was also not attached to the stream substrate so may have changed with different stream discharges but at the time of testing it was >45 degrees.

To determine if the rubber ramp and spat rope within the culvert barrel were effectively promoting passage of swimming fish, mark-and-recapture trials using fresh run īnanga whitebait were carried out between the 11 and 14 September 2018. The marking methods used follow the procedures outlined in Section 6.

Figure A-1: Rubber ramp and spat rope installed at the outlet of a perched culvert on an unnamed tributary of Oldham Creek, Atawhai, Nelson.

Whitebait were collected from fishermen and stained with either Rhodamine B (pink fish) or Bismarck Brown (orange fish) on 11 September 2018. The fish were left in a live bin within the stream overnight before being released into the pool below the culvert at 7:30am on 12 September 2018. They were given 48 hours to pass the culvert, with the top trap checked each subsequent morning.

Control fish

Approximately 200 īnanga marked in Rhodamine B, Bismarck Brown or unmarked (clear) were held in live bins for the length of the trial (48 h) as control fish to examine any undue mortality attributable to the marking and handling procedures. Low mortality was found in all three replicates (6% pink, 3% orange and 2% clear) with the marking procedure not causing undue mortality in experimental fish.

Results

After 48 hours no īnanga successfully passed the culvert and only four fish (0.79%) successfully passed the ramp and were located within the culvert at the conclusion of the trial (Figure A-2. Insufficient īnanga passed the ramp to determine whether there was any statistically significant effect of fish size on success, but the four fish that passed the ramp had a mean length (51.3 mm) and weight (0.39 g) greater than the mean of all fish released (Table A-1).

Table A-1: Summary of īnanga numbers and sizes used in the mark-recapture study. Note that lengths and weights were only measured for a subset of individuals (pink (n=18), orange (n=22), clear (n=15)).

Fish colour	Number released	Mean total length (mm)	Total length range (mm)	Mean weight (g)	Weight range (g)
Pink	138	50.8	44-55	0.38	0.23-0.45
Orange	175	50.4	42-53	0.38	0.26-0.46
Clear	193	50.3	48-55	0.37	0.30-0.46

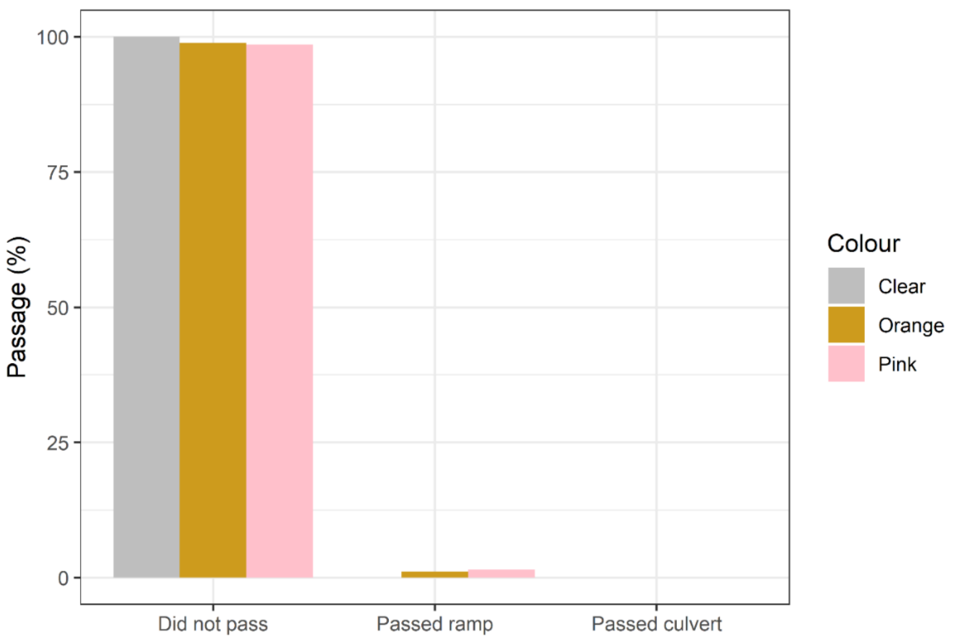

Figure A-2: Percentage of individuals that did not pass, passed the ramp, and passed the culvert at the completion of the trial (48 hrs). Colours represent different marked groups.

Mean water velocity through the culvert at the time of the trial was 0.55 m s^{-1}, which is approximately double the mean critical swimming speed of *G. maculatus* (0.28 m s^{-1}), but less than the modelled median maximum allowable velocity (0.61 m s^{-1}) for a 7.5 m culvert (R. Crawford, unpublished data). However, spot measurements of water velocities on the rubber ramp averaged 0.89 m s^{-1} (range: 0.52-1.34 m s^{-1}) outside of the spat ropes and 0.57 m s^{-1} (range: 0.19-0.82 m s^{-1}) between the spat ropes.

Williams Creek – In-situ monitoring

This case study describes the results of in-situ trapping undertaken to assess the effectiveness of the remediation of twin culverts on Williams Creek, Moutere Inlet, Tasman Bay.

Study site

Williams Creek is a small tributary of Tasman Valley Stream which flows into the Moutere Inlet in Tasman Bay. A pair of perched culverts are situated approximately 20 m upstream of the confluence of Williams Creek with Tasman Valley Stream (Figure A-3). The culverts are the first instream structure migratory fish must navigate within the system, with the culverts located approximately 1 km inland from the coast. Both culverts are 1.2 m in diameter, 18 m long with a gradient up to 2% (Olley et al. 2023).

At the start of monitoring on 26 September 2023, both culverts were undercut 0.05 m, with drop heights of 0.38 m on the true right and 0.4 m on the true left (Olley et al. 2023). Remediation consisted of installing flexible baffles inside the culvert pipes and a rubber ramp with spat rope at the culvert outlets (Figure A-4). A total of seven flexible baffles were secured within each of the culvert pipes. All fourteen baffles were 450 mm wide and 100 mm high. Baffles were spaced at 2.4 m intervals where culvert gradients were 0-1%, and 1.2 m intervals where gradients were between 1-2%. The most downstream baffle was a V-baffle (Olley et al. 2023). Flexible ramps made of reinforced PVC rubber (900 mm wide by 1500 mm in length), were installed at the outlet of both pipes (Figure A-4). Both ramps had a bundle of four strands of looped mussel spat rope fixed to the ramp invert.

Figure A-3: Perched culverts at Williams Creek pre-remediation. Photo: Tim Olley.

Figure A-4: **Post-remediation at the Williams Creek culverts, showing two flexible rubber ramps with mussel spat rope**. Photo: Tim Olley.

Before monitoring commenced, both culvert barrels were searched to ensure that no fish were present within the structure. All fish located within the barrels were removed from the culverts and released upstream (Olley et al. 2023). An A-frame trap was set downstream of each structure, immediately below the plunge pool, to capture fish as they moved up towards the culverts. An A-frame trap was set at the inlet (upstream end) of each culvert barrel to capture fish as they moved out of the structure (Olley et al. 2023).

The traps were checked every 24 h, with all fish collected, identified to species and released. Fish caught in the downstream net were released upstream into the culvert plunge pool, while the fish caught in the upstream net were released upstream of the structure (Olley et al., 2023).

This method of simultaneous trapping upstream and downstream differs from that recommended in Section 6 of this manual for in-situ monitoring. Setting traps simultaneously upstream and downstream is not recommended as the capture of fishes in the downstream trap influences their movements (see Section 5.1).

Results

After 14 days of monitoring upstream of each culvert in conjunction with downstream of the twin culvert structure, banded kōkopu and īnanga were the two most prevalent species captured alongside a few kōaro (Figure A-5). Banded kōkopu were the only species captured upstream of the two culverts with īnanga only caught in the downstream trap and a few kōaro retrieved from within the culverts at the conclusion of the control trials (Figure A-5). After remediation of the culverts no increase in banded kōkopu passage through the culverts was recorded, and īnanga failed to pass either culvert, continuing to only be captured downstream of the structure (Figure A-5). Pulses of both eel species, giant kōkopu, redfin bully and kōaro moved past the culverts after remediation but were not captured prior to remediation, nor in sufficient numbers to determine if the rubber ramps and spat rope influenced the movement of these species.

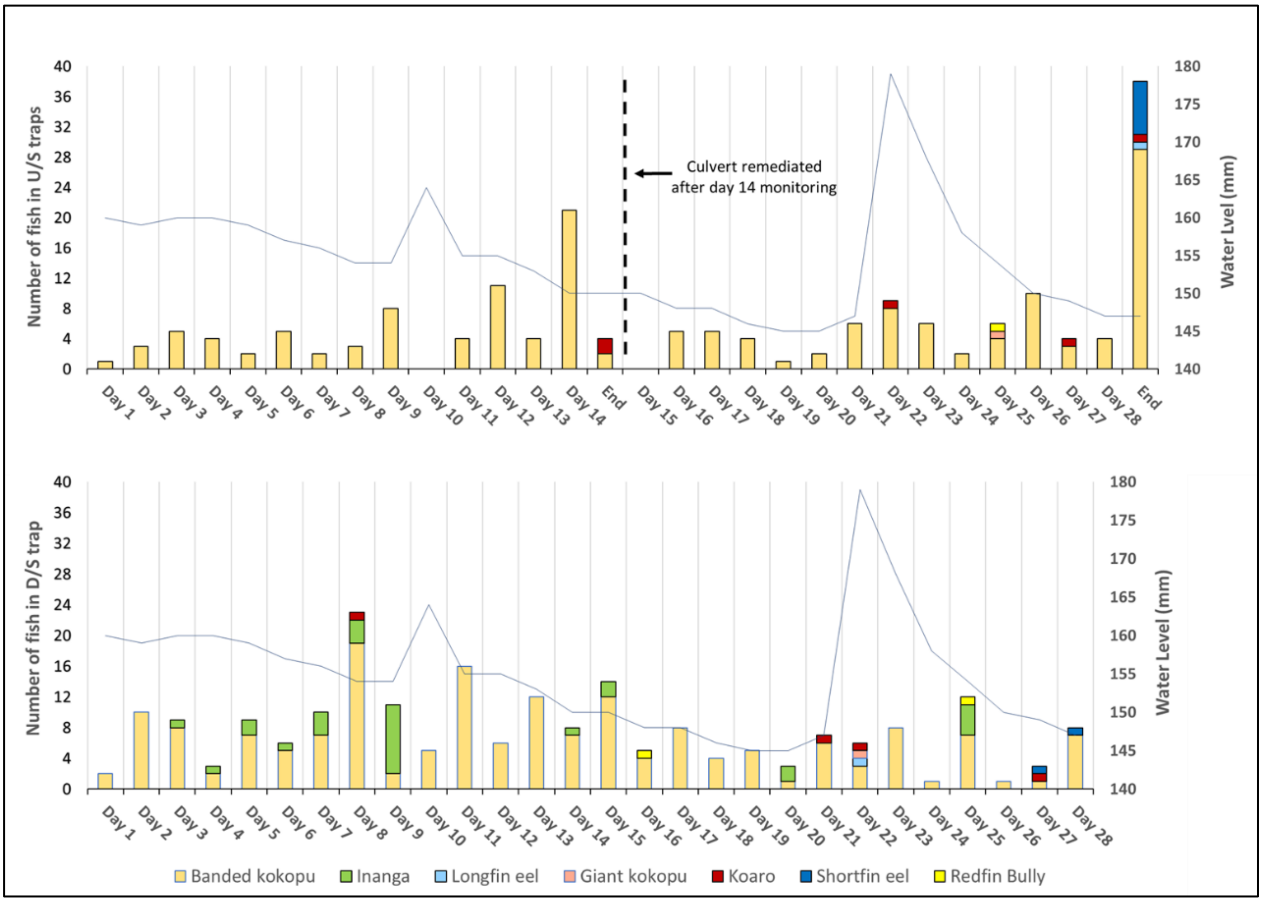

Figure A-5: In-situ trapping upstream and downstream of Williams Creek culverts, pre- and post-remediation. The top graph shows the combined numbers of fish caught from the upstream (U/S) traps set at the inlet of the true left and true right culverts before and after remediation. The data on the bar labelled 'End' (after days 14 and 28) refers to fish removed from the culvert barrels at the termination of both the pre- and post-remediation trial periods. The bottom graph shows the number of fish caught in the trap set downstream (D/S) of the structure over the trial period. Remediation of the structure occurred after day 14 and is indicated by a black dotted line. Fish species are colour coded and displayed as a stacked total for each day. Water level throughout the entire trial period is shown as a blue line. Figure reproduced from Olley et al. (2023).

Conclusions

At both sites, no īnanga successfully passed the test culverts after remediation with rubber ramps and spat rope. Based on these observations and the results of previous studies on fish ramps, we hypothesise that the slope and smooth surface were the main factors that were contributing to the poor passage efficiency measured for īnanga. Previous studies with both climbing and non-climbing species have shown consistently that fish ramps with smooth surfaces achieve significantly poorer passage efficiency than ramps with roughened surfaces for (Baker and Boubée, 2006, Jellyman et al. 2017, Lagarde et al. 2021). The flexible rubber ramps have a smooth surface and at Oldham Creek, high water velocities were observed across much of the ramp surface. The flexible nature of the rubber ramps mean that ramp slope can be highly variable across the length of the ramp and at times can be near vertical. Depending on how the ramp is installed, the slope of the flexible ramp also has the potential to vary over time likely contributing to inconsistencies in passage efficiency.

At the Williams Creek site, passage of banded kōkopu was recorded prior to the remediation with no increase in passage rates for this species after remediation was carried out. Baker and Boubée (2006) and Baker (2014), have shown that the presence of a wetted margin and continuity of the wetted surface are key factors promoting climbing fish species passage. At both culverts in Williams Creek, wetted edges were present on the surrounding concrete and on the rocks immediately below the outlets. It is likely that the combination of a small drop height and wetted edges were as effective as the remediations for juvenile banded kōkopu.

Deployment of flexible rubber ramps to remediate fish passage at perched culverts has recently become common practice in several regions of New Zealand, despite the absence of any evidence-base to support their use. Results from using two different monitoring methods at Williams Creek and Oldham Creek both indicated that the flexible rubber ramps are ineffective at remediating culverts for weak swimming fish passage relative to other ramp designs. As īnanga grow into adult fish they become stronger swimmers and can burst swim up larger drop heights (Baker 2003; Baker and Boubée 2006). Some adult īnanga may, therefore, negotiate these structures as their swimming abilities increase, however, the rubber ramps still present an impediment to passage and there are alternative fish ramp designs that practitioners can have considerably greater confidence in for achieving restoration goals.

Appendix B Case study – Rock ramp & culvert baffles

Kara Stream, Manawatu

This case study describes the results of mark-recapture trials undertaken at a culvert on Kara Stream, Manawatu, which has been retrofitted with a rock-ramp and culvert baffles. This case study helps to illustrate the practical limitations of applying the mark-and-recapture methodology, but also how monitoring can inform design improvements to increase the efficacy of a structure.

Study design

During the remediation works, it was deemed unfeasible to build the rock-ramp on top of the existing culvert apron (Figure B-1). As such, one aim during the trials was to determine if the apron presented a bottleneck for fish passage and, therefore, also required retrofitting (Figure B-3). In addition, there was no documented field tests of the plastic baffles (0.18 m in height) installed at 1.24 m intervals along the length of the culvert barrel (Figure B-2). Consequently, to ensure each component of the instream structure was effective at promoting īnanga passage, the culvert was assessed independently from the rock-ramp. To achieve these aims, three mark-and-recapture trials with juvenile īnanga were carried out between 15th and 19th September 2014:

Trial 1 - Rock-ramp + culvert: Examining fish passage over the rock-ramp, unmodified apron and through the culvert.

Figure B-1: Remediated culvert on Kara Stream, Upper Kingston Road. Inset shows the unmodified culvert apron.

Trial 2 - Culvert: Examining fish passage through the culvert only.

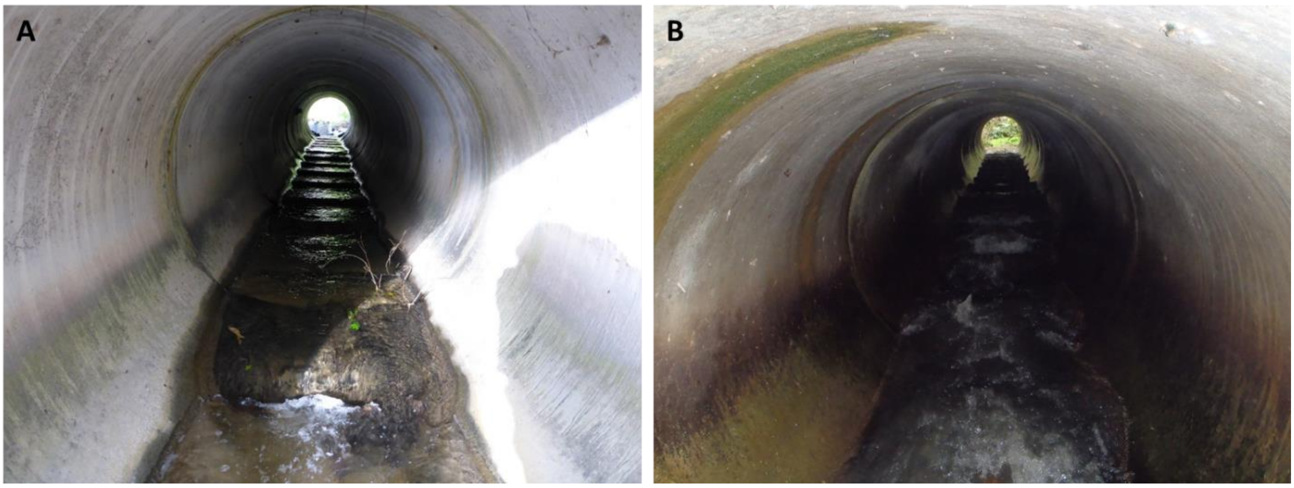

Figure B-2: Culvert under Upper Kingston Road. A) at low flow. B) at high flow.

Trial 3 - Rock-ramp + mod apron + culvert: Examining fish passage over the rock-ramp, modified apron and culvert.

Figure B-3: Culvert apron at Upper Kingston Road. A) unmodified. B) modified using boulders as baffling elements.

Because of logistics in co-ordinating NIWA and Horizons staff for testing the effectiveness of the fish pass at Upper Kingston Road, these trials were carried out under sub-optimal flow conditions. This unfortunately led to the final trial of the entire structure with the modified apron being washed out in rising flood water, but it does provide a good example of issues that can occur when undertaking mark-and-recapture experiments.

Control fish

For each of the three trials, īnanga were marked in Rhodamine B and Bismarck Brown the day prior to release. After marking, between 30 and 50 fish of each colour were held as control fish. For all three sets of control fish, no mortality was observed after 48 hours. Īnanga marked on the 15th September for the first trial, were held till the 19th September with no mortality recorded. This shows the marking procedure was not causing mortality in experimental fish.

Trial 1: Rock-ramp + culvert (24 h)

Three replicates containing 200 īnanga (pink, orange and uncoloured (clear)) were released in the pool below the rock-ramp (see Figure 6-12). Each replicate was sequentially released at 30 minute intervals from 8:20am on 16th September 2014, and given 24 hours to pass the rock-ramp and culvert. For all three replicates, fish size ranged between 45 and 59 mm.

At the conclusion of the trial the proportion of fish that were recaptured in each section of the in-stream structure, missing and dead fish were relatively similar between marked (pink and orange) and uncoloured replicates (Figure B-1). This indicates that the marking procedure did not unduly influence behaviour or passage ability compared to īnanga that were not subjected to the marking procedure.

After 24 hours, no īnanga had successfully passed the instream structure, and no īnanga were found inside the culvert itself (Figure B-1). Close to half of the īnanga released were recaptured on the rock-ramp, in the pool below the rock-ramp, or below the first barrier net in the pools created by the rock weirs before the secondary stop net (Figure B-1; see Figure 6-10B & C for stop net positioning).

However, around half of the test fish were missing with a small proportion found dead in the barrier net (Figure B-1). As the trials were carried out at higher than base-flow conditions, it is likely that īnanga were attempting to move downstream into quieter waters and were successful at passing the barrier nets. The small proportion of dead fish are most likely fish that succumbed to the cumulative stressors of capture, handling, and release into an area where they were vulnerable to damage or getting trapped by the barrier net when trying to move downstream.

The high proportion of fish moving downstream during the trial could also have been influenced by the fact that they were unable to move upstream and pass the structure. No īnanga passed the culvert apron, even though īnanga were observed reaching the apron and resting on the apron margins (Figure B-2). The average water velocity over the apron was considerably higher than that inside the culvert or over the rock-ramp (Table B-1). On average, 50-70 mm īnanga can burst swim at 1.5 m s^{-1} for 4 sec, and 2 m s^{-1} for 2 sec (Stevenson and Baker 2009). Therefore, at the trial flows, water velocity over the apron (>1.5 m s^{-1}; Table B-1) would have been a limiting factor for juvenile īnanga passage.

A further impediment for īnanga is likely caused by the transition between the culvert apron and the baffling inside the culvert barrel, where a weir is formed immediately at the culvert outlet (Figure B-3). Should īnanga successfully burst swim over the apron, there is no low velocity water or rest area prior to the requirement to burst swim over the weir. Consequently, the cumulative effect of water velocity over the apron and the weir at the culvert outlet are likely to be the key factors presently preventing īnanga passage past the culvert. It should be noted, however, that species capable of climbing, such as banded and shortjaw kōkopu, (that are also found in Kara Stream) will not be prevented from passing over the apron and into the culvert as the wetted margin is sufficient for allowing passage of these species.

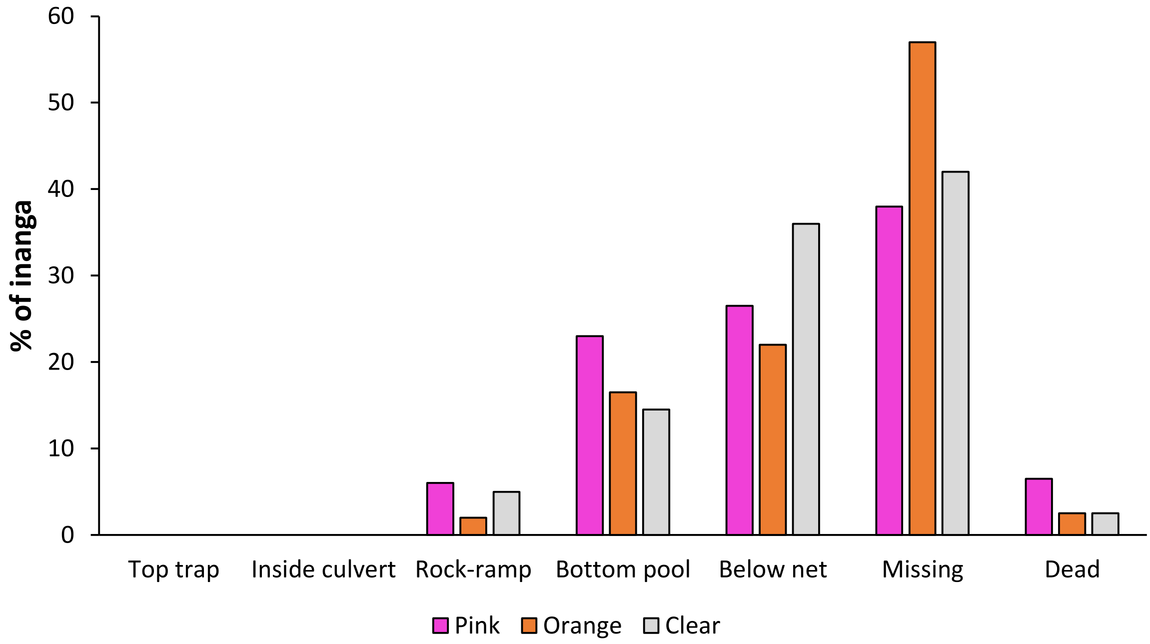

Figure B-1: Percentage of īnanga successfully passing the rock-ramp and culvert, recaptured in different sections of the structure, dead or unaccounted for. 'Bottom pool' represents īnanga in the pool at the base of the rock-ramp. 'Below net' represents īnanga captured in the pools above the second barrier net. Results after 24 hours.

Figure B-2: Pink īnanga resting on the culvert apron (red circle).

Table B-1: The flow ($m^3 s^{-1}$) of Kara Stream and mean water velocity ($m s^{-1}$) through the culvert, and over the apron and rock-ramp during each day of the trials. The float used for calculating the average velocity (mandarin or stick) is also provided. For each day, the velocity given is the average of six replicates. - indicates measurements were not recorded that day. † The float over the rock-ramp needed to be changed from the mandarin because of issues with the mandarin getting stuck in the small pools on the ramp.

Date	Trial start	Flow ($m^3 s^{-1}$)	Mean water velocity ($m s^{-1}$)			
			Rock-ramp	Unmodified apron	Culvert	Modified apron
			Stick†	Mandarin	Mandarin	Mandarin
15 Sept		0.017	0.50	1.53	0.36	-
16 Sept	Rock-ramp + culvert	0.025	0.45	1.52	0.34	-
17 Sept	Culvert	0.019	-	-	0.43	-
18 Sept	Rock-ramp + mod apron + culvert	0.015	-	-	-	0.25
19 Sept		0.180	-	-	-	-

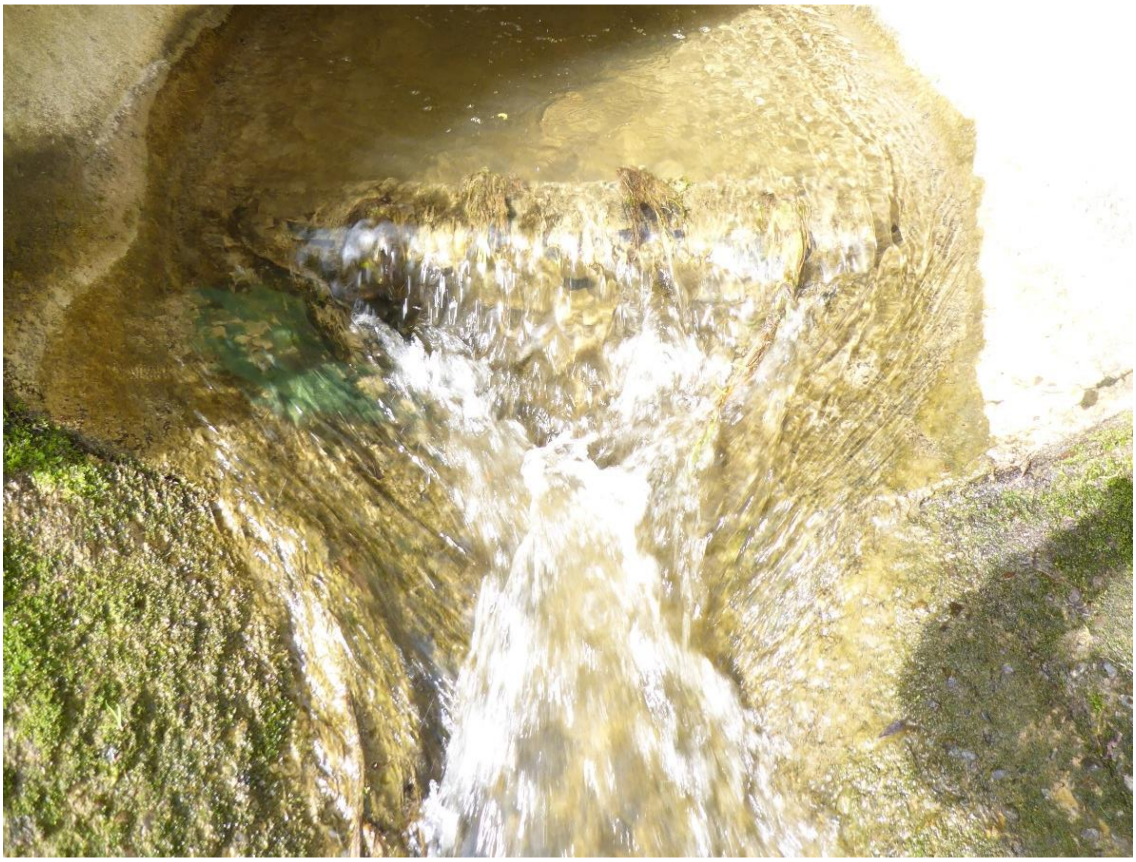

Figure B-3: Weir created by the baffle at the transition point between the culvert outlet and apron.

Trial 2: Culvert only (20.5 h)

Three replicates of fish (198 pink īnanga, 200 orange īnanga and 179 uncoloured (clear) īnanga) were released at 12:30 pm on 17th September 2014, and given 20.5 hours to pass the culvert. All fish were released into the pool formed between the first and second baffles inside the culvert barrel. For all three replicates, fish size ranged between 45 and 75 mm. These juvenile and post-juvenile īnanga were captured further inland than those used in Trial 1 and are more representative of the size of īnanga that would be reaching the culvert at Upper Kingston Road.

In line with Trial 1, at the conclusion of the trial the proportion of fish that had passed the culvert or were still migrating within the culvert, and those unsuccessful, missing or dead fish were relatively similar between marked (pink and orange) and uncoloured replicates (Figure B-1). These data again support the notion that the marking procedure did not unduly influence behaviour or passage ability compared to īnanga that were not subjected to the marking procedure.

On average, 31% of īnanga successfully passed the culvert after 20.5 hours, with 10% of fish still migrating upstream within the culvert barrel (Figure B-1). In comparison, the trap was inspected after 5 hours and only a handful of īnanga were visible. This suggests that passage through the culvert was slow and, therefore, īnanga may need to be left for longer than 24 hours to accurately assess passage over the rock-ramp and culvert.

In contrast to Trial 1, the majority of īnanga (around half of the fish released) were found dead against the barrier net (Figure B-1). The barrier net was set against the upstream end of the last weir baffle and based on observations during the trial, the large recirculation zone between the upstream weir baffle and the barrier net disorientated fish and they swam into the reversed flow leading downstream into the barrier net. The high death rate is most likely a result of smaller weaker fish swimming into the barrier net and once pinned against the mesh, the fast water velocities would make it difficult if not impossible for small fish to free themselves (Figure B-2).

An examination of fish size successfully passing the culvert compared to those dead in the barrier net supports this notion (Figure B-3). For the orange and clear īnanga, those successfully passing the culvert were significantly larger than those found dead in the barrier net ($p<0.05$; Figure B-3). Collectively, the pink īnanga were significantly smaller than those in the clear and orange replicates ($p<0.019$), and although the larger of the pink fish were more successful at passing the culvert, the smaller variation in fish size within the cohort meant the difference was not significant (Figure B-3).

The effect of fish size on passage success suggests the culvert baffles may be less effective for small īnanga. However, the size effect may have been partially biased from carrying out the trial under higher flows, which would result in stronger water velocities within the culvert. As such, these fish were less likely to be able to undertake repeated attempts at passage over the weir before exhaustion. At lower flows, it would be anticipated that the more of the īnanga would have successfully passed the culvert.

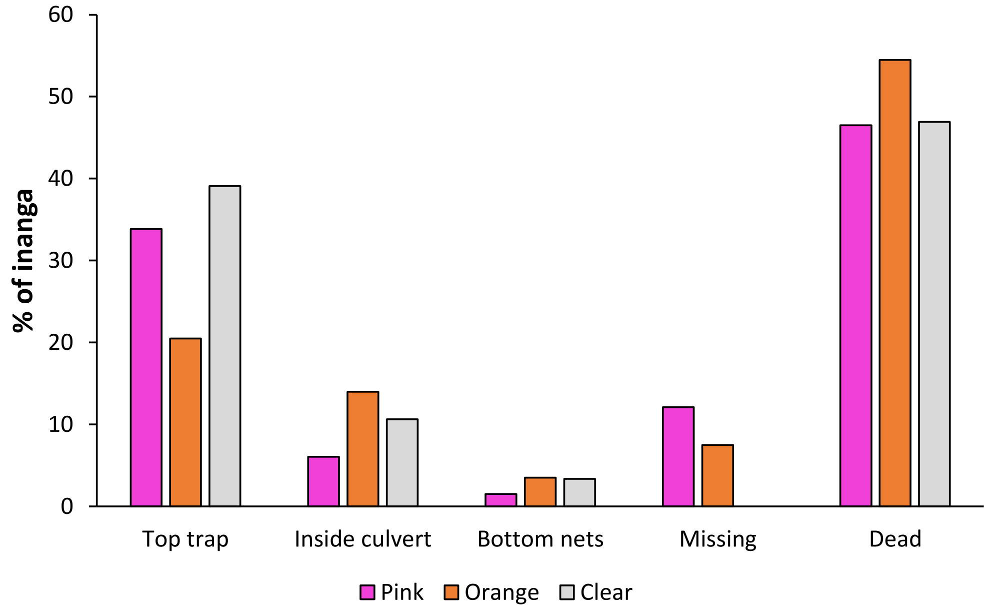

Figure B-1: Percentage of īnanga in each state at the completion of the trial. Top trap = percentage of īnanga successfully passing the culvert, Inside culvert = still migrating upstream inside the culvert, Bottom nets = caught in the bottom barrier nets, and fish either unaccounted for (missing) or found dead after 20.5 hours.

Figure B-2: Barrier net set upstream of the baffle at the culvert outlet.

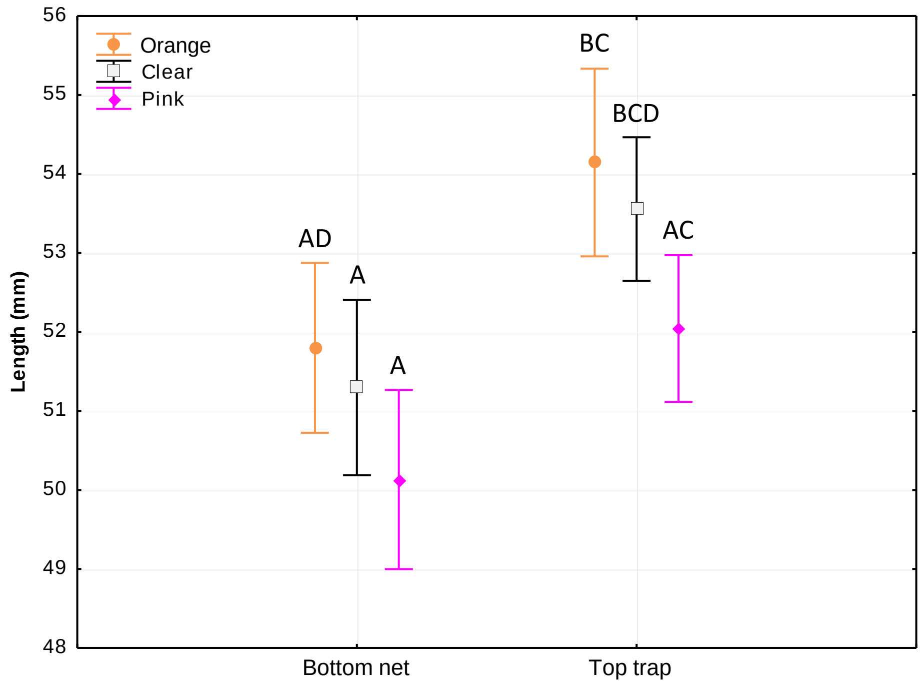

Figure B-3: Mean length (mm) of īnanga successfully and unsuccessfully passing the culvert in 20.5 hours. 'Bottom net' represents expired fish collected in the first barrier net at the culvert outlet. Error bars denote ±95% confidence intervals. Different letters signify significant differences between means (Factorial ANOVA & Tukey HSD test, P<0.05).

Trial 3: Rock-ramp + mod apron + culvert (12 h)

Three replicates of fish (199 pink īnanga, 199 orange īnanga and 143 uncoloured (clear) īnanga) were released at 10:30 am on 18th September 2014. Fish sizes were similar to Trial 2, ranging from 45 to 75 mm. However, 20 large adult īnanga (85 - 120 mm) that were captured with the juvenile īnanga were also released for comparative purposes. Of these, 15 were uncoloured and 5 were coloured in Bismarck Brown.

Because of high rainfall and concerns over the integrity of the trap and barricades in rising flows, the top trap was checked after 12 hours to determine if the modified apron had promoted īnanga passage. In total, 24 īnanga had successfully passed the rock-ramp and culvert with the modified apron. Of these, 12 were from the smaller juvenile and post-juvenile fish (45 – 75 mm), and consisted of 6 pink fish (51 – 53 mm), 4 orange fish (51 – 74 mm) and 2 uncoloured fish (50 & 51 mm). Of the 20 large adult īnanga released, 10 uncoloured īnanga (85 – 110 mm) and 2 orange īnanga (105 & 117 mm) successfully passed the structure in the 12 hour window.

Based on the slower movement of juvenile īnanga in Trial 2, it was anticipated that fish may require 36 hours to pass the rock-ramp and the culvert in Trial 3. However, nature intervened and the flow of Kara Stream rose around tenfold overnight (Table B-1). By 24 hours, the trap and barrier nets had been washed out and the trial had to be abandoned (Figure B-1 to Figure B-3). It should be noted that the trial results suggest passage of adult īnanga is considerably quicker than for smaller fish, as over 50% of the adult fish released had successfully passed the rock-ramp and culvert within 12 hours.

Although the flood waters prevented an accurate assessment of īnanga passage past the rock-ramp and culvert with the baffled apron, the successful passage of both small (50 mm) and large (>85 mm) īnanga recorded after 12 hours confirmed that the culvert apron is the key factor limiting swimming fish passage. Consequently, retrofitting baffles to the apron was recommended to enhance fish passage past the culvert.

Figure B-1: Top trap during increasing flood waters at the conclusion of Trial 3.

Figure B-2: Flow through the culvert and over the rock-ramp at the conclusion of Trial 3.

Figure B-3: Bottom barricades at the conclusion of Trial 3.

Based on best practice guidelines, the culvert apron was subsequently baffled by anchoring wooden spoiler baffles (0.25 m length, 0.12 m width and 0.12 m height) in staggered rows (Figure B-4). This has created resting areas for fish behind the baffles as well as producing low velocity margins (Figure B-4).

Figure B-4: Rectangular spoiler baffles anchored to the Upper Kingston Road culvert apron.

Conclusions

Although the Upper Kingston culvert has been used as a case-study for examining the effectiveness of rock-ramp retrofits in promoting passage of īnanga, it provides an opportunity to fully document the success of the fish passage solution. The combined approach of BACI surveys and mark-and-recapture trials would provide the most comprehensive assessment of fish passage success. After retrofitting the spoiler baffles, further mark-and-recapture trial can be carried out to assess the effectiveness of the final solution. As electrofishing surveys were carried out below and above the culvert prior to remediation, completion of the BACI surveys can be undertaken to document changes to the fish community upstream of the remediated structure and, therefore, assess the effectiveness of the solution across a range of fish species. Ideally, electrofishing surveys above and below the culvert should be carried out annually in January until changes to the upstream fish community are clear.

Appendix C   Case study – Backwater and apron baffling

Mangakotukutuku Stream - Before After Control Impact (BACI) monitoring

This case study describes the Before After Control Impact (BACI) monitoring results undertaken to assess the effectiveness of a remediated perched culvert in Mangakotukutuku Stream, Hamilton.

Study site

The Mangakotukutuku Stream catchment is located in southern Hamilton and drains an area of approximately 23 km^2 on the true left of the Waikato River. Historical surveys indicate that the Mangakotukutuku Stream is an important rearing habitat for adult whitebait, particularly banded and giant kōkopu (Aldridge & Hicks 2006). To improve connectivity in the catchment a perched culvert with high-water velocities (>1 $m\ s^{-1}$) across the apron (Figure C-1) was remediated to improve fish access to around 8 km of stream (close to 25% of total stream length).

Figure C-1: The outlet of the Waterford Road culvert. Perching of the apron at low flows (left) and high water velocities across the apron (right) create a barrier to upstream passage of fish.

In November 2018, rock baffles were installed on the culvert apron to slow water velocities, and two rock ramps were built downstream of the culvert to backwater the downstream end of the culvert and eliminate the drop in water level between the culvert and the pool immediately below it (Figure C-2 & Figure C-3). Rocks with holes drilled through were bolted to the culvert apron to create baffles using spacing and sizes recommended in the NZ Fish Passage Guidelines (Franklin et al. 2024a). The two downstream ramps were created using TerraLock Environmental Erosion Control System soil containers filled with AP40. The bags were overlaid with large river stones to give the ramps small-scale hydraulic variability.

Figure C-2: After remediation of the culvert apron and installation of baffles in Waterford Road culvert in Mangakotukutuku Stream, 2019. View from downstream looking upstream through the culvert.

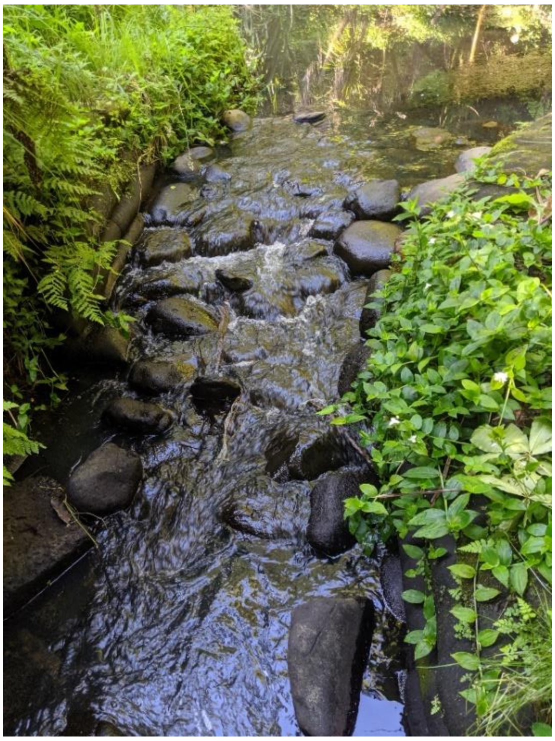

Figure C-3: Rock ramp installed below the pool downstream of the culvert to backwater the culvert.

Fish surveys were carried out in Mangakotukutuku Stream prior to the remediation in 2014 and 2018 and following the 2019 remediation works in 2020 and 2021. Quantitative multiple pass depletion electrofishing in a 50 m reach downstream and upstream of the culvert was used to estimate fish populations (Zippin 1958). As the stream has deep pools where electrofishing can be ineffective, to determine catch per unit effort (CPUE) of pool dwelling species, six fine mesh fyke nets (unbaited) were set overnight both upstream and downstream of the culvert in 2018, 2020, and 2021.

Population estimates of the two reaches in Mangakotukutuku Stream were calculated using the "removal" function in the "FSA: Simple Fisheries Stock Assessment Methods" package in R, following the equation 7 from Carle and Strub (1978). Fish density was calculated per 100 m^2 for each reach.

Results

A comparison of fish species found downstream and upstream of the Waterford Road culvert in 2014 and 2018 found that while most species were present at both sites, there was a clear difference in the abundance of the weaker swimming species, such as īnanga and smelt, with fewer individuals being found upstream of the culvert (Figure B-4 & Figure B-5). For example, 62.5 smelt per 100 m^2 were captured downstream of the culvert in 2014, but only 7.1 per 100 m^2 were captured in the reach upstream of the culvert. Similarly, in 2018, 18.2 smelt per 100 m^2 were captured downstream of the culvert and 1.2 smelt per 100 m^2 were captured in the reach upstream of the culvert. Comparable results were seen in the 2018 fyke net surveys, where prior to remediation īnanga were twice as abundant downstream of the culvert, with a CPUE of 22 compared to a CPUE of 9 upstream (Figure B-6 & Figure B-7). In addition, the CPUE of smelt was 16 times greater downstream of the culvert than upstream in 2018.

In contrast to īnanga and smelt, species with climbing abilities (e.g., redfin bullies, eels) were not recorded in lower densities upstream of the structure prior to remediation.

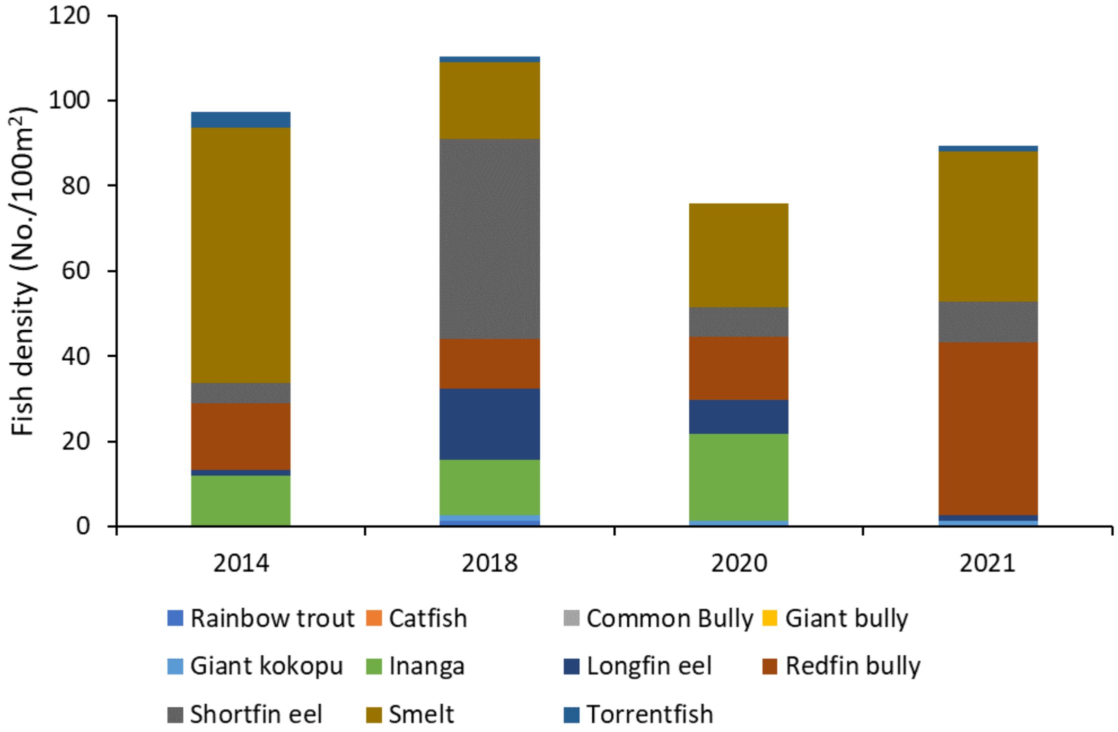

Figure B-4: Results of long-term electrofishing surveys downstream of the Waterford Road culvert in Mangakotukutuku Stream.

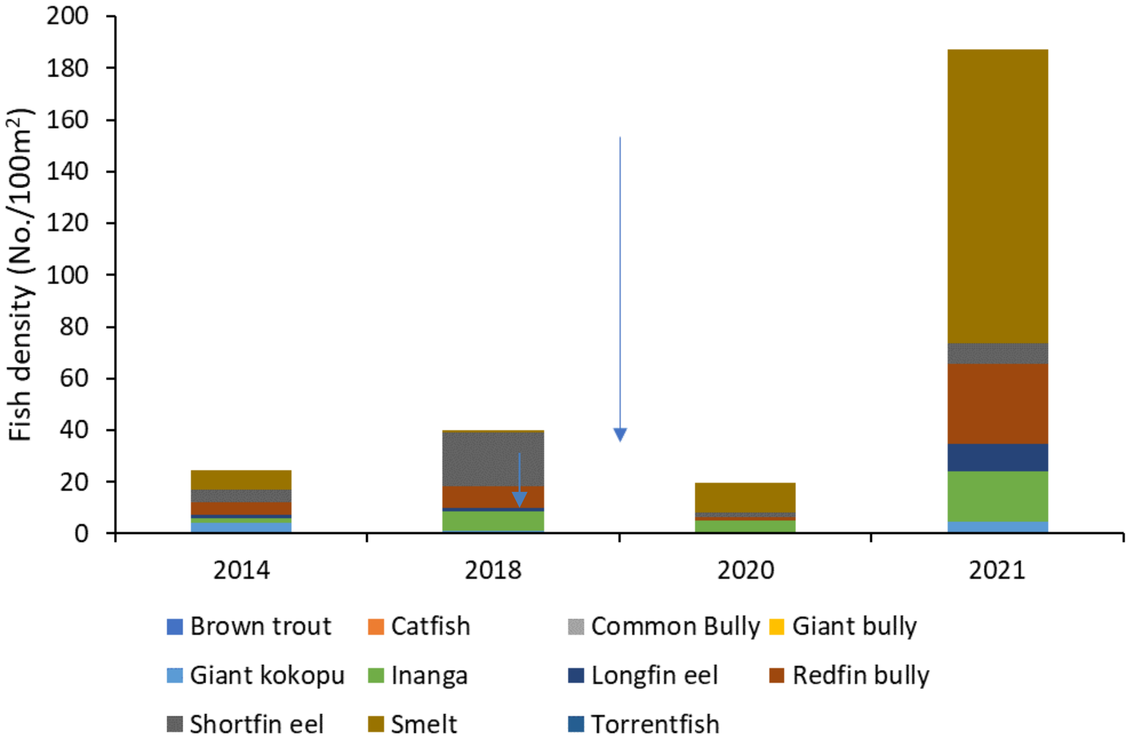

Figure B-5: Results of long-term electrofishing surveys upstream of the Waterford Road culvert in Mangakotukutuku Stream. Arrow indicates culvert remediation in November 2018. Note the difference in the y-axis between downstream and upstream reaches.

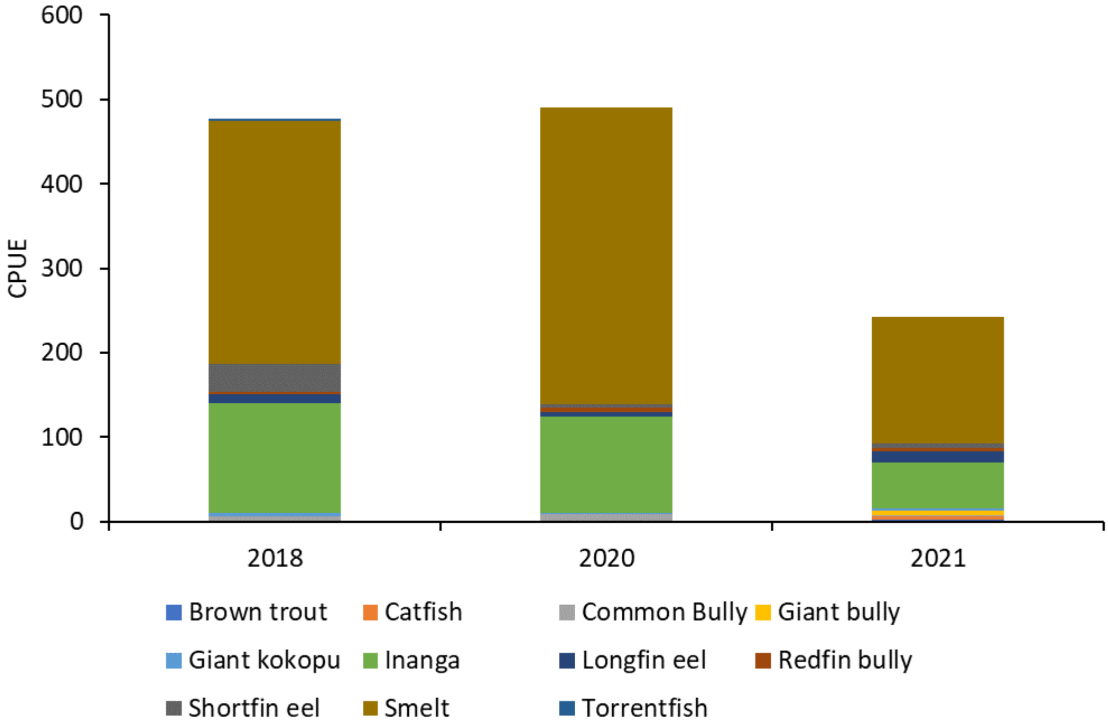

Figure B-6: Results of long-term fyke netting surveys downstream of the Waterford Road culvert in Mangakotukutuku Stream.

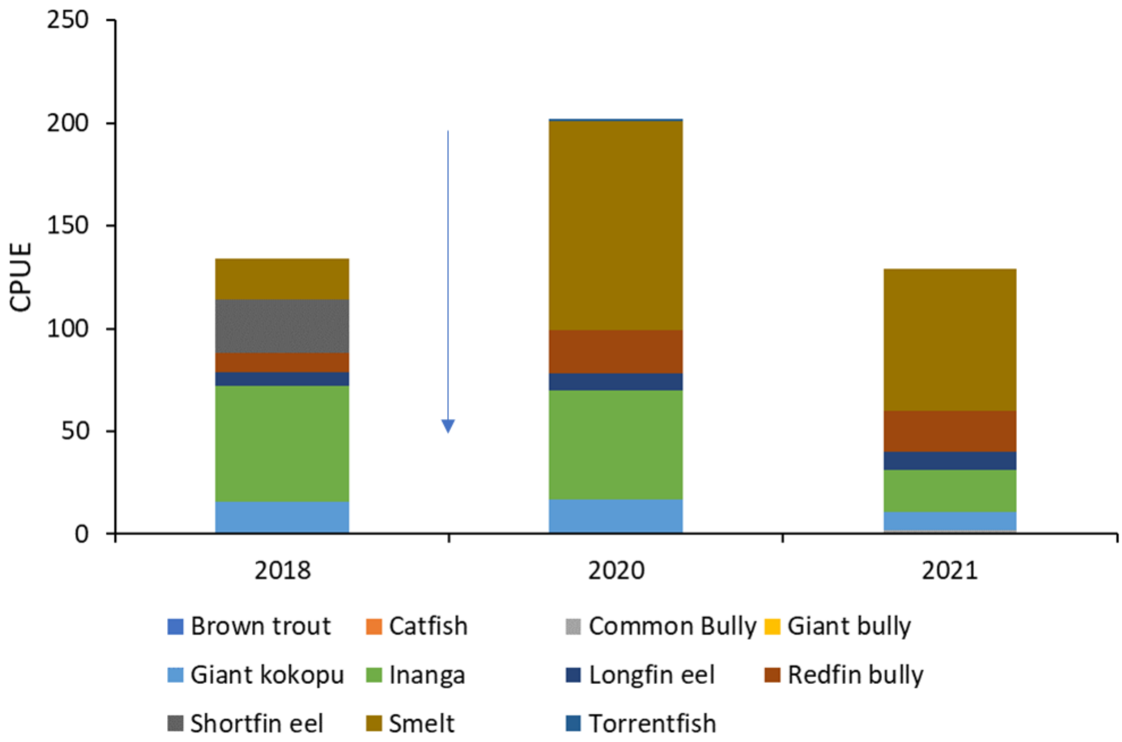

Figure B-7: Results of long-term fyke netting surveys upstream of the Waterford Road culvert in Mangakotukutuku Stream. Arrow indicates culvert remediation in November 2018. Note the difference in the y-axis between downstream and upstream reaches.

After remediation, an increase in the abundance of smelt and īnanga was found upstream of the culvert. Differences in smelt densities upstream of the culvert after remediation were more pronounced than for īnanga (Figure B-5 & Figure B-7). For example, 35 smelt per 100 m^2 were captured downstream of the culvert in 2021, whilst 113 smelt per 100 m^2 were captured in the reach upstream of the culvert. No īnanga were recorded downstream of the culvert in 2021 whereas 20 per 100 m^2 were captured in the reach upstream that year.

A comparison of the lengths of īnanga captured upstream and downstream of the culvert found that, on average, larger īnanga tended to be captured upstream of the culvert both before and after remediation (Table C-1). However, īnanga were only significantly larger upstream of the culvert in 2020 after remediation (P=0.012). A similar pattern in size was seen with smelt, where larger fish tended to be captured upstream of the culvert compared to downstream (Table C-2). Statistically significant increases in smelt size upstream of the culvert were found both before and after remediation in 2014 and 2021 (P<0.05). Of interest is that in 2018 the average size of both smelt and īnanga was smaller upstream of the culvert.

Table C-1: Size of īnanga captured downstream and upstream of the culvert in Mangakotukutuku Stream. Remediation of the culvert was carried out in 2019.

Year	Site	Mean īnanga length (mm)	Standard error (mm)	Sample size
2014 pre-remediation	Downstream	61.0	4.5	10
	Upstream	101.0	10.2	2
2018 pre-remediation	Downstream	68.7	1.2	139
	Upstream	67.5	1.8	62
2020 post-remediation	Downstream	67.5	1.3	126
	Upstream	75.2	1.9	56
2021 post-remediation	Downstream	77.2	1.9	55
	Upstream	80.2	2.4	37

Table C-2: Size of smelt captured downstream and upstream of the culvert in Mangakotukutuku Stream. Remediation of the culvert was carried out in 2019.

Year	Site	Mean smelt length (mm)	Standard error (mm)	Sample size
2014 pre-remediation	Downstream	67.4	1.5	40
	Upstream	81.0	3.5	7
2018 pre-remediation	Downstream	69.8	0.5	319
	Upstream	63.6	4.2	5

Year	Site	Mean smelt length (mm)	Standard error (mm)	Sample size
2020 post-remediation	Downstream	67.5	0.5	370
	Upstream	69.7	0.9	109
2021 post-remediation	Downstream	69.7	0.7	174
	Upstream	74.5	0.8	154

Conclusions

Monitoring prior to remediation indicated that the Waterford Road culvert was only a partial barrier to some fish species, however, it was clearly restricting upstream access for weaker swimming species smelt and īnanga. The results of the BACI surveys since the 2019 retrofit of the Waterford Road culvert show that there has been a significant increase in native species richness and density. By retrofitting the culvert apron and installing baffles to reduce flow within the culvert, upstream access for smelt and īnanga has been improved, which will likely help to reduce delays in migration and associated increased risk of predation. Continued differences in the size of smelt and īnanga upstream and downstream of the Waterford Road culvert pre- and post-remediation were difficult to interpret. Given the increased abundance of both species post-remediation, drivers of differences in the size of smelt and īnanga may relate to habitat rather than culvert passage.

Appendix D Case study – Rock ramp & spoiler baffles

Bankwood Stream, Hamilton

This case study, which expands on the results of Franklin and Bartels (2012), highlights the combined approach of BACI surveys and mark-and-recapture trials for assessing the effectiveness of retrofitting a perched culvert on Bankwood Stream, Hamilton. The results also illustrate the importance of trial length, timing and the fish marking procedure in carrying out mark-and-recapture trials.

Remediation

Several indigenous fish species were excluded from Bankwood Stream by a perched concrete culvert (1.5 m diameter; 73.8 m length; gradient 0.3-2.55°) at the confluence with the Waikato River. To overcome the barrier posed by the perched culvert, in April 2007 a fish ramp and receiving pool were installed at the culvert outlet (Figure D-1). The 16 m long concrete ramp (0.9 m wide with a slope of 5.7°) was embedded with cobbles and angled laterally (5°) (Figure D-1). A receiving pool (1.7 m wide and 2.0 m long with a minimum depth of 0.2 m) was installed at the top of the ramp. However, the fish ramp alone was ineffective at providing passage for non-climbing fish species into the upstream habitats and baffling of the culvert barrel was subsequently undertaken to lower water velocities within the culvert (Figure D-2). Consequently, in January 2009, 36 UV stabilized polyethylene spoiler baffle sheets (2 x 0.9m) with baffles (0.25 x 0.10 x 0.12 m) spaced 0.10 m apart laterally and 0.25 m longitudinally were secured to the culvert base. Based on best practice, the baffles were configured in alternating offset rows of 3-4 baffles (Figure D-2).

Figure D-1: The receiving pool and fish ramp operating under summer low flow conditions.

Figure D-2: The culvert barrel following installation of the spoiler baffle sheets.

BACI Monitoring

The BACI monitoring carried out since 2006 has effectively documented the fish community response to the remediation of the perched culvert. The monitoring has utilised two reaches, one located immediately upstream of the culvert entrance, and the other approximately 80 m upstream of the culvert. To enable population estimates to be calculated, multiple pass electrofishing was carried until there was a 50% reduction in the abundance of the most common fish species.

Prior to the retrofit, three species of indigenous fish were recorded upstream of the culvert in Bankwood Stream; longfin and shortfin eels, and giant kōkopu (Figure D-1). In the November 2007 and January 2009 surveys, following construction of the fish ramp at the culvert outlet, two additional indigenous fish species, common bully and torrentfish, were recorded in the stream above the culvert in low abundance (Figure D-1), but neither of the target fish species, smelt or īnanga, were captured.

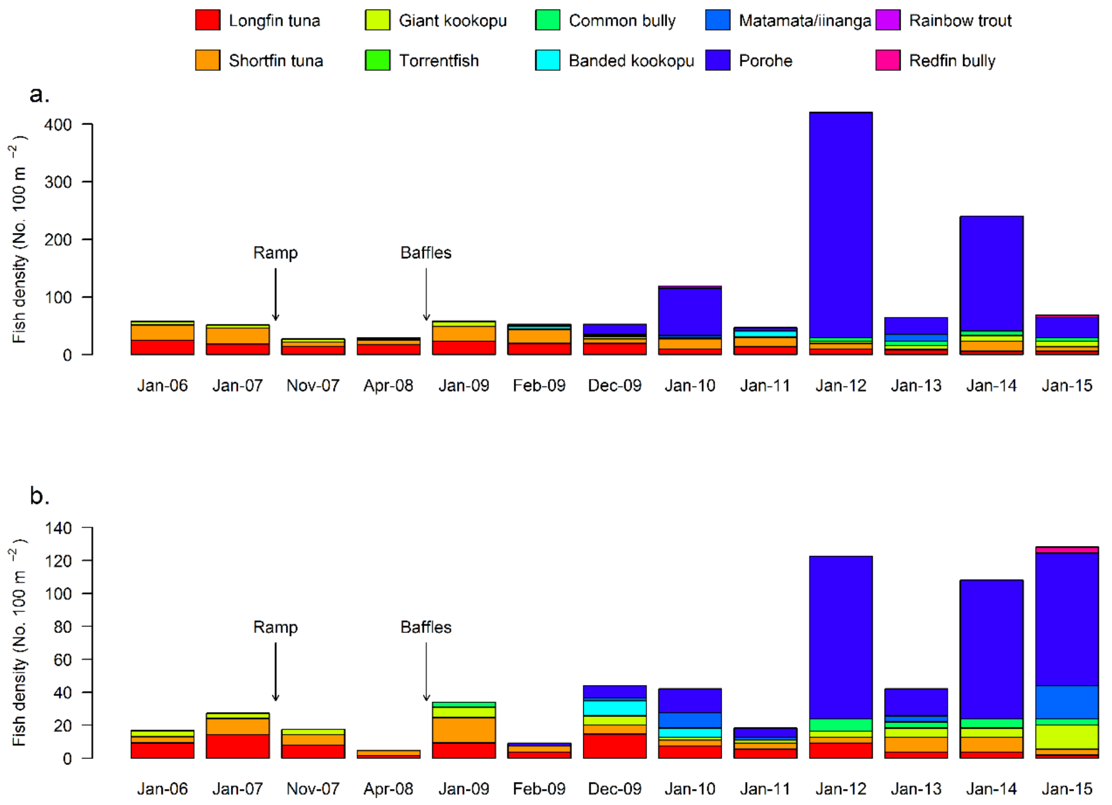

Figure D-1: Results of fish community monitoring upstream of the culvert. a. Reach 1 – immediately upstream of the culvert; and b. Reach 2 – downstream limit c. 60 m upstream of the culvert.

Surveys immediately following the installation of the spoiler baffles (February 2009 and April 2009 for Reaches 1 and 2 respectively) indicated that both smelt and īnanga had gained access to the stream above the culvert (Figure D-1), the first record of these species since monitoring began in 2006. Follow-up surveys since January 2010 have shown that both smelt and īnanga have continued to be present in the survey reaches. Species such as juvenile rainbow trout, torrentfish and common bullies have not been consistently captured within the stream. A further species that appears to have become established in the reach upstream of the culvert since it was retrofitted is banded kōkopu, which has been present in at least one of the survey reaches in every survey since the installation of the spoiler baffles (Figure D-1).

Mark-and-recapture studies

The BACI monitoring has required several years to confirm the remediation has been effective for enhancing upstream fish communities. In contrast, mark-and-recapture surveys can provide immediate results on the effectiveness of the retrofit and also examine passage of the target species over each component of the structure independently. To obtain more detail on the efficacy of the culvert retrofits for enhancing fish passage into Bankwood Stream, mark-and-recapture trials on both the ramp and baffled culvert were carried out using migratory īnanga in 2009, with passage through the culvert retested in 2015.

To ensure the īnanga tested were the same life stage reaching Bankwood Stream, in 2009 fish were caught using whitebait traps in the Waikato River at Huntly and in 2015, īnanga were captured using Gee minnow traps in Hamilton tributaries of the Waikato River.

General procedures followed those outlined in Section 6, except for the marking method and trial length. In 2009, īnanga were tagged with Visual Implant Elastomers (VIE) (Northwest Marine Technology). In 2015, fish were batch marked using Rhodamine B, with unmarked īnanga tested as a second replicate and control for the stained fish. After both marking procedures, fish were left to recover in live bins within Bankwood Stream for 24 hours prior to testing. An examination of the impacts VIE and Rhodamine B immersion staining has on the critical swimming speed and passage efficiency of īnanga are reported in Franklin et al. (2024b). Results are also summarised below.

Rock-ramp

Īnanga first reached the pool between 60 and 90 minutes after release (mean = 5.6% of marked fish; s.e. = 1.5%) (Table D-1). After nine hours a mean of 27.1% (s.e. = 4.5%) of marked īnanga had passed the full length of the fish ramp. There was no statistically significant difference in the length of fish reaching the top of the ramp relative to those released (p = 0.115).

Table D-1: Summary of īnanga (elastomer tagged) passage over the rock ramp. Reproduced from Franklin and Bartels (2012).

Trial date	Marked fish released (n)	Average length (±se) at release (mm)	Total trial time (hours)	Time īnanga first recorded at top of ramp (hours)	Proportion of fish past ramp after 9 hours	Average length (±se) of fish that passed ramp (mm)
17-Dec-09	59	60.5 (± 0.15)	9.0	1.5	18.6	57.6 (± 0.46)
17-Dec-09	59	61.2 (± 0.15)	9.0	1.5	28.8	61.1 (± 0.48)
17-Dec-09	59	60.1 (± 0.14)	9.0	1.5	33.9	57.8 (± 0.31)

Culvert

In the 2009 trials examining VIE tagged īnanga passage through the culvert, it took between five and six hours for the first īnanga to surpass the culvert (Table D-2). After twelve hours, a mean of only 6.2% (s.e. = 1.4%) of fish had reached the top of the culvert (Table D-2). At this stage, it was decided to leave the trial running overnight to check whether mean passage time was greater than the initial 12 h trial period. Following 24 h, the mean number of fish to have reached the top of the culvert had only increased to 7.9% (s.e. = 1.5%). There was again no statistically significant difference in the length of fish reaching the top of the culvert relative to those released (p = 0.307).

Table D-2: Summary of īnanga passage through the culvert. Modified from Franklin et al. (2024b).

Trial date	Marked fish released (n)	Marking method	Total trial time (hours)	Flow ($m^3 s^{-1}$)	Average length (±se) at release (mm)	% of fish passing the culvert	Average length (±se) of fish that passed culvert (mm)
16-Dec-09	59	Elastomer tag	12	0.034	56.5 (± 0.08)	8.5	59.4 (± 0.87)
16-Dec-09	59	Elastomer tag	12	0.034	59.1 (± 0.12)	3.4	60.5 (± 3.18)
16-Dec-09	59	Elastomer tag	12	0.034	58.5 (± 0.12)	6.8	60.3 (± 1.05)
31-Mar-15	200	Rhodamine B	24	0.026	65.2 (± 0.91)	28	65.1 (± 0.93)
31-Mar-15	200	Unmarked	24	0.026	64.1 (± 0.83)	27	64.5 (± 0.95)

In 2015, trial length was increased to 24 hours and after this time, 28% of pink and 27% of unmarked īnanga had successfully passed the culvert (Table D-2). To determine if 24 h was an adequate trial length for passage through the 73.8 m culvert, the trial was extended to 48 h. Between 24 and 48 h a further 5.5% of pink and 6.5% of unmarked īnanga had successfully passed the culvert, giving at total of 33.5% passage for both replicates. For both replicates, there was no statistically significant difference in the size of īnanga passing the culvert relative to those released and there was no statistically significant difference between the size or number of pink and unmarked fish successfully passing the culvert ($p = 0.501$). This supports the findings from Kara Stream and laboratory swimming tests (Franklin et al. 2024b) in that the marking procedure did not unduly influence the behaviour or passage ability of īnanga compared to fish that were not subjected to the marking procedure.

Conclusions

Overall, the installation of the fish ramp and spoiler baffles in Bankwood Stream culvert was an effective remediation measure for enhancing upstream fish communities. In particular, weak swimming fish species such as īnanga and common smelt have been consistently recorded upstream of the culvert since remediation. Close to a five-fold difference in the passage efficiency of īnanga through the culvert was observed between the 2009 and 2015 trials. The main factor likely to be influencing īnanga passage success between trial years was the fish marking method. Based on critical swimming speed tests, īnanga stained with Rhodamine B had found no reduction in swimming performance compared with unmarked control īnanga ($p = 0.68$), yet īnanga with VIE tags swam at less than half the speed of unmarked control fish ($p = 0.005$; Franklin et al. 2024b). Secondary factors influencing passage success between trial years would likely be the increased size of īnanga utilised in 2015 and the lower stream discharge compared to 2009.

Appendix E Gear lists

General equipment for all methods	Packed
PPE (e.g., waders, raincoat, sunhat, sunscreen, water)	
Clipboard and data sheets on waterproof paper	
Spare waterproof paper	
Pencils, permanent marker pens, scissors	
GPS device & any previous GPS points loaded in	
Water quality meter (key attributes: conductivity, dissolved oxygen, water temperature)	
Watch or timer	
Waterproof camera (i.e., cell phone)	
Measuring boards (30 cm for small fish and 1 m for large fish)	
Scales (weighing up to 5 kg, accurate to 0.01g)	
Hanging scales or large scales (weighing up to 20 kg, accurate to 0.1 or 1g)	
Container for holding fish on scales	
Photarium for measuring fish (small and large sizes)	
Paper towels (to dry photarium window)	
Anaesthetic & 10 l bucket	
4 x 20 l buckets with lids	
Portable battery powered aerators with tubing and air stones	
Flagging tape	
Fish bin x 2	
Eel holding bags x 6, optional lamprey holding bags	
Mesh live bin or mesh bag for holding fish in the stream for recovery	
Measuring tape (50 or 100 m fibreglass)	
Solid 1 m ruler (can be folding) for measuring water and sediment depth	
Small aquarium dip net x 2	
Electrical tape (general repairs and protecting battery terminals)	

General equipment for all methods	Packed
Gloves (latex &/or nitrile)	
Fish identification book	

Electrofishing surveys

Equipment	Packed
Kainga EFM300 or Smith Root backpack electrofishing machine	
Polarised sunglasses (optional but recommended to reduce glare)	
Hip chain	
Batteries (including spares)	
2 x dip nets (1 mm x 1 mm mesh) with long handles	
2 x stop nets for top and bottom of reaches (depletion fishing only)	
Hand-held pole/push net	
For lamprey fishing, 3 m long weighted rope with articulated lengths of 500 mm	

Spotlighting

Equipment	Packed
Spotlight (handheld, 30 – 50 watt), plus a spare	
Batteries (including spares)	
Head torch (one per person) with dim or red light mode	
Long handled dip net (at least two)	

Netting and trapping

Equipment	Packed
Fyke nets (six per site)	
Gee minnow traps, bait pottles and ropes (20 per site)	
Gill nets (six per site)	
Wooden stakes for each fyke net leader and gill net margin edge	

Equipment	Packed
Mallot	
Bait for Gee minnow traps	
2kg weights with shark clips (for cod end of fyke net and end of gill nets)	
Floats for gill nets	

Appendix F Data sheets

FISH COLLECTION FORM – ELECTROFISHING DEPLETION – WADABLE STREAMS AND RIVERS

Team members: ____________________

Lat/Long (GPS bottom): ____________________

Lat/Long (GPS top): ____________________

Site ID ____________ Date ___ / ___ / ______ Page ____ of ____

Total EFM passes:

Fish sample ID ____________ Total shock (button) time (min) ______ Fishing time start ______ finish ______ Sample distance (m) ______ Area Fished (m²) ______

EFM machine # & type (eg. Smith Root # 1) :

Water visibility ○ good ○ average ○ poor Water temp. (°C) ______ Cond (uS) ______

EFM Volts (x100) ______ **Spotlight** (watts) ______ **Pulse Rate** (pps or Hz) ______ **EFM Pulse Width (ms)** ______ **EFM anode** ○ big ○ small **DO** ______ mg/L ______ %

Transect #	Wetted Width (m)	Channel Width (m)	Depth (m)
1			
2			
3			
4			
5			

Comments:

Pass	Fishing time	Species	Length (mm)		Pass	Fishing time	Species	Length (mm)		Pass	Fishing time	Species	Length (mm)

Site ID ______________ Date ____ / ____ / ______ Page ______ of ______

Pass	Fishing time	Species	Length (mm)		Pass	Fishing time	Species	Length (mm)		Pass	Fishing time	Species	Length (mm)

FISH COLLECTION FORM –ELECTROFISHING & SPOTLIGHTING – WADABLE STREAMS AND RIVERS

Team members: ____________________

Lat/Long (GPS bottom): ____________________

Lat/Long (GPS top) : ____________________

Site ID ____________________ Date ___ / ___ / _____ Page ___ of ___

○ not fished other ○ fished none collected ○ fished all 10 subreaches ○ fished 5-9 subreaches ○ fished <5 subreaches ☐ flag for fished/not fished

Fish sample ID ____________ Total shock (button) time (min) ______ Fishing time start ______ finish ______ Sample distance (m) ________ Area Fished (m²) ________ Wetted width(m) A____ B____ C____ D____ E____ F____ G____ H____ I____ J____

Sampling gear ○ spotlight ○ EFM ○ netting net type ________ net No. ________ net type ________ net No. ________

Water visibility ○ good ○ average ○ poor Water temp. (°C) ________ Cond (uS) ________

EFM anode ○ big ○ small distance inland (km) ______ altitude (m) ________ gradient(°) ________ REC seg ID(s) ________ ☐ FLAG for other Sampling Information

EFM Volts (x100) ______ **Spotlight** (watts) ______ **Pulse Rate** (pps or Hz) ______ **EFM Pulse Width (ms)** ______ **FISH QIBI** Score

Common Name	Subreach Tally										Total count	Anom. count	Vouch. count	LENGTH (mm) *		Mortality count	Flag
	A	B	C	D	E	F	G	H	I	J				Minimum	Maximum		

Flag	Comment	Flag	Comment

Flag codes: K = No measurement made, U = Suspect measurement., F1,F2, etc. = flags assigned by each field crew. Explain all flags in commentx. LENGTH* - Enter single fish as minimum.

Environment Waikato REGIONAL COUNCIL

Subreach size class information (mm) ☐ Actual length ☐ Category lengths

Common Name	A	B	C	D	E	F	G	H	I	J

Habitat type %	A	B	C	D	E	F	G	H	I	J	Total	Common name	T	S	M	L
Still																
Backwater																
Pool																
Run																
Riffle																
Rapid																
Cascade																

GEE MINNOW TRAPPING FIELDSHEET

Project: ……………………………………………

Site: ………………………………………………

Date: ……………………………………………..

Team Members: ……………………………

Set time: …………………………………………

Water quality:	
pH:	Temp:
Cond:	Turb:
DO%:	DO mg/l:

GPS start of reach: Easting………………………………………………Northing……………………………………………………

GPS end of reach: Easting………………………………………………Northing……………………………………………………

Lift time: …………………………………………

Minnow trap #	**Species**	**Length (mm)**

Minnow trap #	Species	Length (mm)

FYKE NETTING FIELDSHEET

Project: ……………………………………………

Site: ………………………………………………

Date: ……………………………………………..

Team Members: ……………………………

Set time: …………………………………………

Water quality:	
pH:	Temp:
Cond:	Turb:
DO%:	DO mg/l:

GPS start of reach: Easting………………………………………………Northing……………………………………………………

GPS end of reach: Easting………………………………………………Northing……………………………………………………

GPS Fyke 1: Easting………………………………………………Northing……………………………………………………

GPS Fyke 2: Easting………………………………………………Northing……………………………………………………

GPS Fyke 3: Easting………………………………………………Northing……………………………………………………

GPS Fyke 4: Easting………………………………………………Northing……………………………………………………

GPS Fyke 5: Easting………………………………………………Northing……………………………………………………

GPS Fyke 6: Easting………………………………………………Northing……………………………………………………

Lift time: …………………………………………

Net #	Species	Length (mm)	Weight (g)	Net #	Species	Length (mm)	Weight (g)

Net #	Species	Length (mm)	Weight (g)	Net #	Species	Length (mm)	Weight (g)

GILL NETTING FIELDSHEET

Project: ....

Site: ....

Date: ....

Team Members: ....

Set time: ....

Water quality:

pH: Temp:

Cond: Turb:

DO%: DO mg/l:

GPS start of reach: Easting..Northing...

GPS end of reach: Easting..Northing...

GPS Gill net 1: Easting..Northing...

GPS Gill net 2: Easting..Northing...

GPS Gill net 3: Easting..Northing...

GPS Gill net 4: Easting..Northing...

GPS Gill net 5: Easting..Northing...

GPS Gill net 6: Easting..Northing...

Lift time: ....

Net #	Panel #	Species	Length (mm)	Weight (g)	Notes

Net #	Panel #	Species	Length (mm)	Weight (g)	Notes


NIWA
Taihoro Nukurangi