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**Remediating small-scale migratory fish barriers with floating fish ramps**

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

**Master of Science (Research) in Environmental Sciences**

at

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by

**Daniel Fake**



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## Abstract

Instream barriers are a well-documented stressor for diadromous fish species, and can be numerous and costly to remediate. In New Zealand, previous experiments have investigated the swimming ability of indigenous migratory fish over small ramps, but this work has not led to the development of cost-effective ramps that can be deployed by river managers. This study built on previous research and investigated the effect of ramp surface type on the swimming ability of two species of diadromous fish; inanga (*Galaxias maculatus*) a weak swimmer, and redfin bully (*Gobiomorphus huttoni*) a moderate climber, in an effort to inform the design of a floating plastic ramp that could be installed at low head instream barriers. Three phases of tank trials in the Hawke's Bay tested different ramp substrates, including rock climbing holds, and small and large raised Miradrain® cusps. The results indicated that a linear arrangement of small cusps provided an optimal surface for swimming species such as inanga while redfin bully passage rates did not differ between the surfaces tested. The addition of spat rope reduced velocities and increased depth on all surfaces, and increased passage rates for inanga on ramps with large cusps, and redfin bullies on both cusp sizes. Fish surveys were conducted at 4 lowland streams in Hawke's Bay in order to characterise fish communities, investigate the impact of barriers on their distribution, and evaluate the success of ramp installations in facilitating passage. Fish communities were impacted by barriers to varying degrees depending on the climbing ability of different species present. Inanga and redfin bully abundances were lower above the barriers, whereas eel abundances were similar between upstream and downstream reaches. Rotomoulded plastic floating ramps lined with small cusps were installed at barriers on 2 streams, the Awanui and the Irongate. Inanga were found above the barrier in

the Awanui Stream 12 months after a ramp was installed, but fish did not pass over the wooden weir on the Irongate Stream. Buoyancy issues with the Irongate ramp are thought to have reduced its utility and potentially hindered fish passage. The buoyancy issues have since been overcome, and further monitoring is required to assess whether fish passage is consequently improved. These results show that floating rotomoulded ramps can be an effective and cost-effective tool for remediating small scale instream barriers to migratory fish.

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## Chapter One

# General Introduction

## 1.1 The global problem of lost connectivity

Worldwide, a myriad of anthropogenic activities have had adverse impacts on freshwater ecosystems. Among these, the reduction of connectivity as a result of man-made barriers is one of the most significant (FAO/DVWK, 2002; Sala *et al.*, 2000; Williams *et al.*, 2012), although as David *et al.* (2014) suggest, it is also one of the easiest to remedy within short timescales. For many freshwater fish and invertebrate species, the introduction of migration barriers such as dams, weirs, culverts and floodgates has dramatically affected instream passage, negatively impacting life cycle success and in some cases eliminating species completely from certain river systems (FAO/DVWK, 2002; Gibson *et al.*, 2005; McDowall, 1998; Stuart and Mallen-Cooper, 1999; Williams *et al.*, 2012; Yasuda *et al.*, 2004).

Longitudinal (and lateral) connectivity within river systems is not only important for maintaining ecosystem function but is also crucial for diadromous fish species that need access between the sea and freshwater to complete their life cycle, as well as for non-migratory species which move up and down river systems. Three forms of diadromy were described by McDowall (1988). *Anadromy* where adult fish migrate to fresh water to spawn (as in salmonid species); *Amphidromy* where juvenile fish go to sea upon hatching, and migrate back to fresh water (as in several of New Zealand's galaxiid species); and *Catadromy* where adults migrate to sea to spawn and progeny return to fresh water as juveniles to grow and mature (as in eels, Anguillidae spp.).

Efforts to restore riverine connectivity date back hundreds of years. In the thirteenth century, the Count of Jülich ordered that all weirs on the Rur River, Germany, be opened for salmon migrations (FAO/DVWK, 2002). Clay (1995) notes that the earliest

fish passes were recorded some 300 years ago. Over the past century, the focus has remained on providing passage for high value salmonid species (Williams *et al.*, 2012), particularly over large-scale barriers such as hydroelectric dams in North America and Europe, resulting in solutions like fish lifts, hydraulic locks, vertical slot and denil fishways, and bypass channels (Clay, 1995; FAO/DVWK, 2002). In recent years, some research has steered towards providing passage for a wider range of species as society's appreciation for indigenous biodiversity has developed (MacDonald and Davies, 2007; Stuart and Mallen-Cooper, 1999; Mallen-Cooper and Stuart, 2007; Williams *et al.*, 1999; Voegtle *et al.*, 2002; Yasuda *et al.*, 2004).

On a smaller scale, much research has gone into identifying and investigating the impacts of barriers such as culverts on the spawning migrations of salmonid species in streams (Burford *et al.*, 2009; Gibson *et al.*, 2005; O'Hanley and Tomberlain, 2005; Poplar-Jeffers *et al.*, 2008), and the consequent passage requirements of these fish when designing new culverts or retrofitting old ones (Baker and Votapka 1990; Bates, 1999). Internationally, there exists a lack of work on providing passage for smaller fish species and thus a lack of comparability with the challenges managers in New Zealand face when understanding requirements for the relatively small, weaker-swimming native species.

## **1.2 Fish passage issues in New Zealand**

Freshwater habitat connectivity is a major management issue in New Zealand with Boubée *et al.* (1999) stating that, aside from habitat loss and degradation, anthropogenic migration barriers are one of most significant causes of the decline in

freshwater fish populations. There are 54 species of freshwater fish native to New Zealand, and of these 18 are classified as diadromous (Goodman, 2003). The importance of restoring instream passage for these species is highlighted when one considers their conservation status, as shown in Table 1.1.

Table 1.1. Conservation status of the 18 diadromous native freshwater fish species in NZ.

Adapted from Goodman, 2013.

Common Name	Scientific Name	Threatened Status
Grayling	<i>Prototroctes oxyrhynchus</i> Günther	Extinct
Lamprey	<i>Geotriidae Geotria australis</i> Gray	Nationally Vulnerable
Longfin eel	<i>Anguilla dieffenbachii</i> Gray	Declining
Shortfin eel	<i>Anguilla australis</i> Richardson	Not Threatened
Common smelt	<i>Retropinna retropinna</i> Richardson	Not Threatened
Stokell's smelt	<i>Stokellia anisodon</i> Stokell	Naturally Uncommon
Inanga	<i>Galaxias maculatus</i> Jenyns	Declining
Giant kokopu	<i>Galaxias argenteus</i> Gmelin	Declining
Banded kokopu	<i>Galaxias fasciatus</i> Gray	Not Threatened
Shortjawed kokopu	<i>Galaxias postvectis</i> Clarke	Nationally Vulnerable
Koaro	<i>Galaxias brevipinnis</i> Giinther	Declining
Torrentfish	<i>Cheimarrichthys fosteri</i> Haast	Declining
Redfin bully	<i>Gobiomorphus huttoni</i> Ogilby	Declining
Common bully	<i>Gobiomorphus cotidianus</i> McDowall	Not Threatened
Bluegill bully	<i>Gobiomorphus hubbsi</i> Stokell	Declining
Giant bully	<i>Gobiomorphus gobioides</i> Valenciennes	Not Threatened
Black flounder	<i>Rhombosolea retiaria</i> Hutton	Not Threatened

In addition to their ecological importance, many of New Zealand's native fish species are valued recreationally and culturally as food. The migrating juveniles of 5 galaxiid species, commonly referred to as 'whitebait' and dominated by inanga (*Galaxias maculatus*), are a prized catch for thousands of New Zealanders and a delicacy for consumers, with market prices at times reaching as much as \$160/ Kilo (Environment Southland, 2013). Eels, both in pre- and post-European times, have

been a significant food resource for Māori. In recent years a commercial fishery has been established, with significant export earnings (NIWA, 2018).

Successful management efforts to remediate barriers and restore connectivity require an appreciation for the species present in the system, as well as an understanding of their life histories and swimming abilities (Boubée *et al.*, 1999; David and Hamer, 2012; Williams *et al.*, 2011). The indigenous freshwater fish species of New Zealand have many characteristics that differ from salmonid species, which limits the local applicability of much of the international research on fish passage. These differences include their smaller size, age at migration, swimming styles and abilities, and habitat preferences (Boubée *et al.*, 1999; Franklin and Bartels, 2012; Mitchell, 1989). The high proportion of diadromous fish species in New Zealand means that, relative to the adult spawning migrations of anadromous salmonids, it is the small, weaker-swimming juvenile life stages of fish that undertake upstream migrations.

Table 1.2. Locomotory styles of New Zealand's native fish species. Adapted from Boubée *et al.* (1999).

<b>Locomotory Style</b>	<b>Common Name</b>	<b>Comment</b>
<u>Swimmers</u> - Confined to swimming in 'burst speed' around obstacles, relying on low velocity zones to rest	Common smelt Stokell's smelt Inanga Common bully Bluegill bully Giant bully Stokell's smelt	
<u>Jumpers</u> - Leap using waves at falls and rapids	Common smelt Inanga	Small falls < 50mm Small falls < 50mm
<u>Climbers</u> - Adhere to wetted margins with surface tension	Lamprey Giant kokopu Banded kokopu Shortjawed kokopu Koaro Shortfin eel Longfin eel Redfin bully Common bully	Juvenile Juvenile Juvenile Juvenile Juvenile Elvers Elvers Juvenile (limited extent) Juvenile (limited extent)
<u>Anguilliforms</u> - Worm their way through interstices in stones or vegetation either in or out of water. They can respire atmospheric oxygen if their skin remains damp.	Shortfin eel Longfin eel Banded kokopu Shortjawed kokopu Koaro	Juvenile Juvenile Juvenile Juvenile Juvenile

There are 4 locomotory styles that New Zealand's freshwater fish species exhibit (Table 1.2); 'swimmers', 'anguilliforms', 'jumpers' and 'climbers' (Mitchell, 1989). Anguilliforms such as eels (*Anguilla* spp.) and climbers such as banded kokopu (*Galaxias fasciatus*) are able to overcome vertical barriers by negotiating wetted margins, often scaling waterfalls of significant heights. However, species such as inanga and some bullies (*Gobiomorphus* spp.) are limited to swimming and therefore susceptible to falls resulting from slight changes in bed form height (Baker, 2003), as well as high velocity barriers where fish do not possess the stamina to burst swim through, such as culverts or weirs with fast laminar flow (Mitchell, 1989).

To understand the effect of water velocities on the swimming abilities of these species, three forms of swimming need to be understood (Nikora *et al.*, 2003): (i) burst

swimming, which fish use to pass areas of high velocity, is a short, high speed anaerobic motion that cannot be maintained for long periods, (ii) sustained swimming is an aerobic motion that can be maintained for an indefinite period, and finally (iii) prolonged swimming involves both aerobic and anaerobic processes of energy supply. Tailoring fish pass design to cater for the passage needs of the weakest species should ensure success for stronger swimming species.

### **1.3 Approaches to fish passage enhancement at small barriers in New Zealand**

Small, high-order streams are not only preferred habitats for adults of many of New Zealand's freshwater fish, but in many cases they are the only habitats displaying original fish fauna as a result of the absence of introduced salmonid predators (Stevenson *et al.*, 2008). A common form of barrier occurs where roads or farm/forestry tracks cross small streams, and culverts are installed as a low-cost alternative to bridges (Boubée *et al.*, 1999; Gibson *et al.*, 2011). These culverts are often installed with hydraulic capacity in mind, with little or no consideration for fish passage (Boubée *et al.*, 1999; Franklin and Bartels, 2012; Stevenson *et al.*, 2008). Culverts can create barriers to fish passage through a number of ways, including high water velocities both downstream and within the culvert itself (Haro *et al.*, 2004), and an impassable vertical undercut drop (perch) at the culvert outlet (David *et al.*, 2009; Doehring *et al.*, 2011). Many investigations have been undertaken by territorial authorities in New Zealand to quantify the number of instream structures posing a barrier to fish migration (Cameron, 2010; James and Joy, 2009; Kelly and Collier, 2007). Perhaps the most in depth of

these, the report by Kelly and Collier (2007), reviewed a total of 1614 structures (36% of public road stream crossings) in 6 areas of the Waikato Region. Of these, they identified 845 structures (52%) as posing some form of barrier to fish migration.

Despite being a long-term objective for managers, and a statutory requirement under the Freshwater Fisheries Regulations 1993, permanent remediation of small barriers by way of culvert replacement, weir removal or redesign can be a costly and time-consuming challenge, amplified by the large numbers of small barriers existing within catchments. Retrofitting barriers with low-cost solutions that enable fish passage has received some attention; for example, several studies have looked at retrofitting culverts with baffles to overcome velocity barriers within culvert barrels, and many of these installations have proven effective at re-instating fish passage (Ead *et al.*, 2002; Franklin and Bartels, 2012; MacDonald and Davies, 2007). Where a culvert outlet has become perched, the addition of mussel spat rope has been shown to be an effective mechanism in facilitating the passage of climbing species such as juvenile banded kokopu (David and Hamer, 2012).

Ramps have also been identified as a tool for enabling passage for swimming or weaker-climbing species over vertical barriers. While products already available in the New Zealand market, such as fiberglass and stainless steel fish ladders (Fishladders.co.nz), apparently provide for successful fish passage, the costs involved may be an impediment to their widespread implementation. These costs are not only limited to the initial installation, but also involve maintenance or replacement following damage and loss given the high energy environments that flood events can create. Recent research has acknowledged the need for a low-cost, novel, semi-permanent solution for facilitating passage for swimming species, and several studies have found success using ramps (Baker and Boubée, 2006; Baker, 2014; Doehring, 2012) but,

despite these studies, no effective, low-cost, commercially-available products have yet been developed. Baker and Boubée (2012) and Baker (2012) demonstrated that Miradrain®, a TC Mirafi (Pendergrass, Georgia USA [www.mirafi.com](http://www.mirafi.com)) ground drainage product, can be an effective baffling media on ramps, with favourable passage rates for inanga and redfin bullies. C. Baker (pers. comm., NIWA) suggested that there is scope for further experimentation with alternative baffling media to broaden existing knowledge around ramp substrates.

## **1.4 Thesis research and structure**

My thesis research aimed to build on existing knowledge around this ramp concept by testing a series of substratum types on prototype ramps both in a tank and real-world setting. Three week-long tank trials were undertaken to investigate the passage efficacy of an array of substratum types on several native diadromous freshwater fish species. The results of these tank trials informed the design and build of a working floating plastic ramp, of which 2 were installed in Hawke's Bay streams which had migration barriers present. Before and after surveys of the fish community composition were undertaken upstream and downstream at these sites and control sites with no ramps, and the effect of ramp presence on fish community assemblage post-treatment was investigated.

I aimed to test several hypotheses over the course of this study, and these are described in more detail in the specific chapters. During my 3 weeks of tank trials (Chapter 3) I expected that passage success rates would vary among species between ramp surfaces, given their differing baffling effect on the water flowing down

the ramp. In my field trials (Chapter 4), my objectives were to i) characterise the fish communities in 4 lowland streams with scarce fish community data; ii) evaluate the effect of instream barriers on fish communities in these streams; and iii) test the efficacy of these ramps in providing passage for inanga past instream barriers. Chapter 3 and 4 are presented in the style of scientific papers, so there is some repetition (e.g., Introduction) with preceding chapters. The thesis also includes a chapter describing my study area with a description of the study streams (Chapter 2). The thesis ends with a general discussion (Chapter 5) which draws together findings from the 2 experimental chapters, considers limitations to my research and further knowledge gaps on fish ramps, and provides advice for those considering use of floating ramps to overcome low-head barriers.

## Chapter Two

# Study Area

## 2.1 Hawke's Bay

This study was conducted in the Hawke's Bay Region, on the East Coast of the North Island of New Zealand. Hawke's Bay extends from Cape Turnagain in the south to Mahia Peninsula in the northeast, and is bordered in the west by the Ruahine, Kaweka and Huirau Ranges which run south to north and encompass part of Te Urewera National Park. The land in Hawke's Bay is predominantly rolling hill country, apart from the relatively flat Heretaunga and Ruataniwha Plains. The climate of Hawke's Bay is temperate with high sunshine hours, which provides ideal conditions for an array of agricultural, vinicultural, and horticultural/ cropping land-uses. Indeed, the Heretaunga Plains are some of the most productive cropping areas in New Zealand (Wilding, 2016).

As mentioned previously, this thesis comprises 2 main sets of experiments, tank trials (Chapter 3) and field trials (Chapter 4) of a floating fish ramp. The tank trials were conducted at 2 locations described in Section 2.2. Three of the field trial sites – the Irongate, Awanui and Raupare Streams – are located within the Heretaunga Plains, in the Karamu catchment. The fourth site – the Waingongoro Stream – flows into the coast south of Cape Kidnappers (Fig. 2.1).

Hawke's Bay is known to support 17 of New Zealand's 54 native species. Notably absent are non-migratory fish, with the exceptions of Crans bully *Gobiomorphus basalis*, upland bully *Gobiomorphus breviceps*, and dwarf galaxias *Galaxias divergens*. The absence of many other non-migratory taxa found elsewhere in the North Island is thought to be a result of the deleterious effects of historical

volcanism in the central North Island from the Taupo eruption, c.180 AD (Hughey *et al.*, 2012).

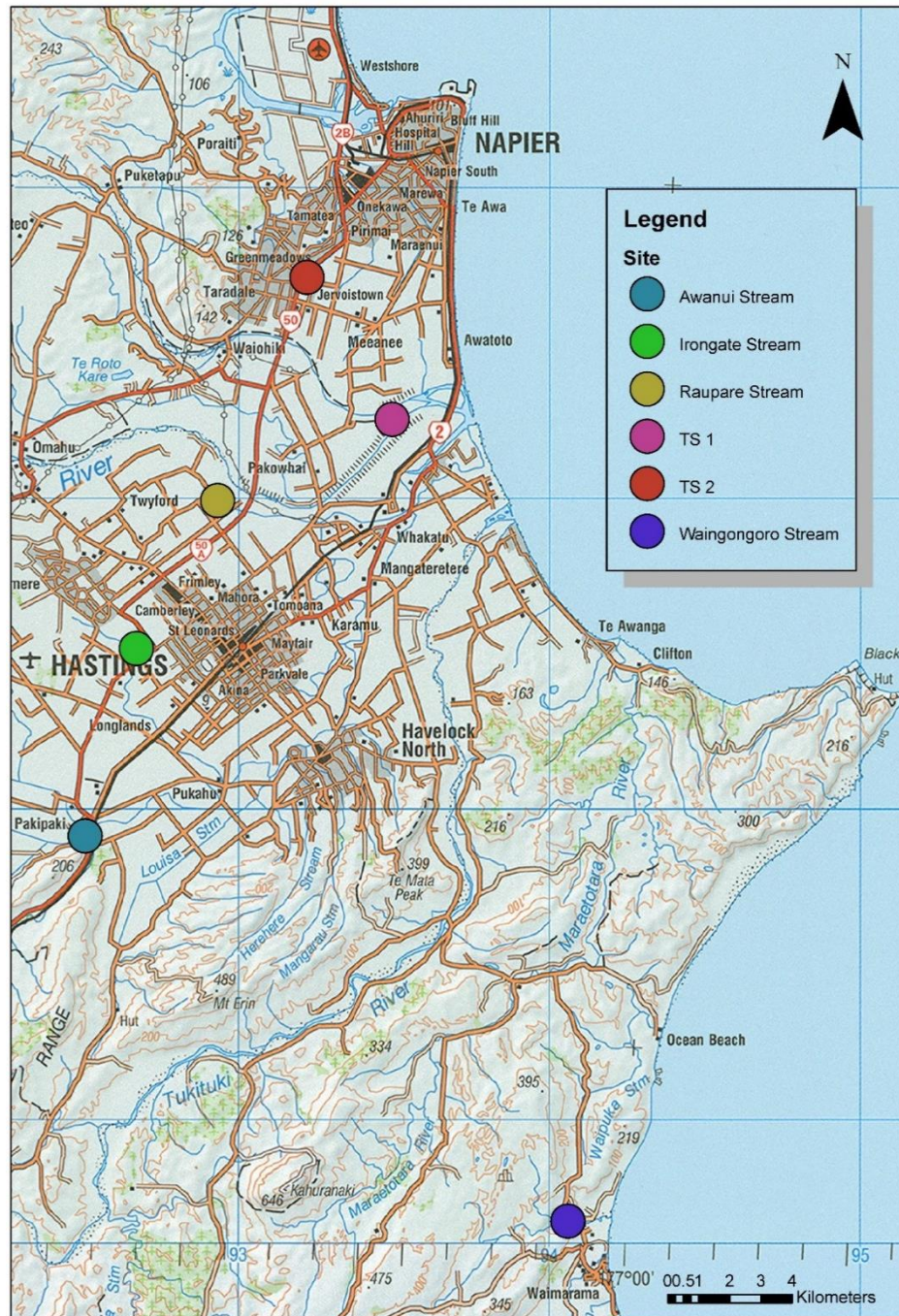


Figure 2.1: Map of Hawke's Bay showing the study sites sampled: Tank sites (TS): 1 and 2, and field sites: Raupare Stream (control no barrier), Irongate and Awanui Streams (fish ramps installed) (Karamu catchment) and Waingongoro Stream (control with barrier) (Waingongoro catchment).

## 2.2 Tank trials

Three rounds of tank trials were conducted at 2 sites in Hawke's Bay, the first 2 located at the Brookfields pump station, at the end of the Palleson Drain (39.575885, 176.882458), and the third at the Hawke's Bay Fish and Game property in Meeanee, Napier (39.539143, 176.849191).

Land-use upstream of Brookfields pump station is predominantly orchards and vineyards. In the experiment, water was pumped from the drain into the header tanks where it flowed through the concrete pipes, then down test ramps and into the lower tanks. The trial site was relocated to a site with access to cool bore water for the third round of trials, as spot measurements of drain water temperatures the week prior to trials were in excess of 26°C, which were deemed too warm to house and trial fish (Richardson *et al.*, 1994 found that inanga prefer temperatures around 18°C). The Hawke's Bay Fish and Game site was chosen for its access to an artesian bore water supply, with much cooler, consistent water temperatures relative to the previous site at the Palleson Drain.

## 2.3 Field trials

### 2.3.1 Karamu catchment

Three field sites were located in the Karamu catchment; Awanui, Irongate and the Raupare Streams (Fig. 2.1). The Karamu catchment is approximately 490,000 ha in size, and drains the Poukawa Basin, the Kohinurakau, Kaokaoroa and Raukawa

Ranges and a large part of the Heretaunga Plains. Due to its temperate climate, high sunshine hours and flat fertile land, the catchment provides ideal conditions for an array of agricultural and horticultural land-uses, and has been extensively developed for primary production.

The geology of the Heretaunga Plains (and hence much of the Karamu catchment) is deposited alluvial gravels from the last 500,000 years, which have been overlain in times of higher sea levels in the eastern (seaward) parts. This has resulted in a largely unconfined aquifer to the west, which is confined in the east (Baalousha, 2010). Many diffuse springs surface along the boundary between the unconfined and confined aquifers, and these feed many of the streams in the Karamu catchment (Wilding, 2009). These streams have been extensively modified, channelised and straightened for drainage and flood protection. They are currently suffering from nuisance macrophyte and algal growths (Haidekker, 2016), and have changed from what would have naturally been gravel bottomed to mud/ silt bottomed due to years of agriculturally-sourced siltation (Stansfield, 2009).

Haidekker (2016) found that Macroinvertebrate Community Index (MCI) values in the catchment were significantly lower than other streams on a regional and national scale, and attributed this to high maximum water temperatures, low dissolved oxygen minima (resulting from excess respiration from macrophytes and insufficient reaeration from the atmosphere), and poor habitat quality. Fish data in the catchment is relatively scarce, with 5 records from the New Zealand Freshwater Fish Database (NZFFD). Species recorded include yellow eye mullet *Aldrichetta forsteri*, lamprey *Geotria australis*, estuarine triplefin *Grahamina* sp., and unidentified Galaxiidae.

### Irongate Stream

The Irongate Stream (Fig. 2.2) is a spring-dominated and located 27 km inland in the Karamu catchment and drains 6212 ha of horticultural, cropping, pastoral and urban/industrial land. The substrate at the study site was deep mud/silt supporting extensive growth of macrophytes, primarily *Elodea canadensis*. Riparian vegetation alongside most of the studied sub-reaches consisted of orchard shelterbelts of *Casuarina* or She-Oak trees along the northern true-left bank, providing a high degree of stream shading throughout the day. Along this bank the grass growth was rank, often overhanging banks into the water. The vegetation on the true-right bank consisted of mown grass. The uppermost 2 sub-reaches sampled had rank grass covered banks, and the stream had been straightened and channelised. In 1964, a weir was constructed in the upper sections of the stream to regulate downstream water levels as part of a drainage project. The weir has a vertical drop height of c.0.5 m, posing a significant barrier to migratory fish, particularly swimming species. However, it is likely that climbing species such as eel elvers could ascend the wetted margins of the wooden weir.



Figure 2.2: Irongate Stream, showing weir.

### *Awanui Stream*

The Awanui (Fig. 2.3) is a runoff-dominated stream 23 km inland in the Karamu catchment, draining a 6165 ha mixture of horticultural, cropping, and pastoral land. Compared with the Irongate, macrophyte coverage was sparse. The substrate was dominated by shallow mud/silt and sand. The riparian vegetation on both sides of the stream was predominantly grass which at times overhung the stream, but was occasionally grazed on the true right bank which had sparse tree cover. At the time of pre-treatment sampling, stock had unimpeded access to the stream, but this had been fenced by the time post-treatment sampling commenced.

The stream runs under Old Main Rd in Paki, through an 8 m long piped culvert. Upstream of the culvert, the stream has been straightened and channelised, while downstream the river is more naturally sinuous. The culvert apron on the downstream end is raised above the stream water level for the majority of flows, creating a c. 0.4 m vertical drop into a pool at low flows. This apron is a barrier to swimming species at low-medium flows, but climbing species would be able to ascend the wetted margins of the concrete as it is not undercut. In higher flood flows, the water level overtops the apron, but it is likely that internal culvert velocities would pose an additional barrier to swimmers during flood events.



Figure 2.3: Awanui Stream, upstream of culvert. Note: Reaches downstream of bridge have more natural channel form and sinuosity.

### Raupare Stream

The Raupare (Fig. 2.4) is a spring-dominated stream 10 km inland in the Karamu catchment, draining a 2362 ha mixture of horticulture, viticulture, cropping and pasture land. The substrate was deep mud/ silt, and the stream was dominated by macrophyte beds, namely *Elodea canadensis*, which are routinely cut using a weed boat to maintain an efficient drainage channel for flood control. The riparian vegetation was grass, which in places is mown for flood control purposes. No physical barriers to fish passage are present. This stream was selected as a control site owing to its lowland position and similar characteristic to the treatment sites other than the absence of physical impediments to migrating fish.



Figure 2.4: Raupare Stream.

### 2.3.2 Waingongoro catchment

The Waingongoro catchment is much smaller in size than the Karamu, at 2125 ha. The catchment is a mixture of steep to rolling hillsides, and the predominant land-use is pastoral farming. The geology is hard sedimentary limestone. No records exist in the NZFFD for this catchment. The Waingongoro Stream (Fig. 2.5) is fed from a mixture of springs and runoff, which drain the steep coastal hill country in the Waimarama area of Hawke's Bay. Adjacent land-use is predominantly extensive sheep and beef. The substrate consisted of small boulders, cobbles and gravel, with some sand/ silt. Macrophytes, predominantly *Apium nodoflorum*, existed on the stream edge in places. The riparian vegetation consisted of established willow trees *Salix* spp. interspersed with regenerating tutu *Coriaria arborea*, providing considerable shading to the stream for the entire day.

Waimarama Road crosses the stream via a steel beam bridge, which was part of strengthening works carried out in 2006 when a concrete pad was laid on the stream bed (Fig. 2.6). A large flood event in 2011 scoured the downstream stream bed and as a result the pad is now perched by c. 0.7m at low flows, posing a significant barrier to swimming species, but climbing species would likely be able to ascend the wetted margins. Under low flow conditions, the shallow, fast, laminar flow over the concrete pad would likely pose an additional barrier to swimmers, even if they were to somehow ascend the wetted margin of the concrete pad. Consequently, in a high flow event when floodwaters reach the height where the culvert apron is inundated, the culvert velocities would almost certainly be impassable to swimming species. This site was chosen as a control site with low fish access where passage remediation was not implemented, to compare with treatment sites.



Figure 2.5: Waingongoro Stream.



Figure 2.6: Pictures showing degree of perching on the downstream end of concrete pad in Waingongoro Stream, pre-flood event (left) and post-flood event (right).

## **Chapter Three**

# **Testing optimal ramp surfaces for facilitation of passage for New Zealand migratory freshwater fish**

### 3.1 Introduction

Man-made instream obstructions such as dams, weirs, floodgates and culverts are well-documented stressors on freshwater fish communities, impacting on life-cycle success by disrupting access to key habitats and creating migration bottlenecks that lead to increased predation vulnerability, competition for resources and disease (Baker, 2014; Boubée et al., 1999; Doehring *et al.*, 2012; Stuart and Mallen-Cooper, 1999). Diadromous fish are particularly affected by instream barriers as they require connectivity between the sea and upstream habitat for populations to be sustained by recruitment (FAO/DVWK, 2002; McDowall, 1988). Consequently, barriers to fish passage have seen diadromous species eliminated from some river systems in many parts of the world (McDowall, 1993; Williams *et al.*, 2012).

Instream connectivity is especially important in New Zealand, where 16 of the 54 Native freshwater fish are diadromous, 10 of these being amphidromous (McDowall, 1993; 1995). Indeed, Boubée *et al.* (1999) state that “*Aside from the loss and degradation of habitat, one of the most significant causes of the decline in freshwater fish populations in New Zealand are anthropogenic migration barriers*”. Some indigenous juvenile species such as banded kokopu (*Galaxias fasciatus*) have adapted climbing strategies and can negotiate wetted margins around obstacles (Boubée *et al.*, 1999). However, high water velocities, turbulence or vertical drops associated with culverts, weirs and bridge aprons can prove to be impassable for species that do not possess climbing abilities such as inanga (*Galaxias maculatus*), 1 of 5 diadromous species that make up New Zealand’s whitebait fishery (Baker and Boubée, 2006; McDowall, 1988; Rowe *et al.*, 2002). Restoring the connectivity for native freshwater species is important not only for the maintenance of the populations

themselves, many of which are listed as 'threatened' or 'declining' (DOC, 2013), but also for ensuring a food supply for native predatory bird and fish species (Jowett, 2002; Rowe *et al.*, 2002)

Overseas, the issue of anthropogenic barriers to fish passage has been recognised for some time (Clay, 1995). Much modern research has gone into restoring passage for high value salmonid species on large-scale hydroelectric dams in North America and Europe (Clay, 1995; FAO/DVWK, 2002), but barriers on smaller tributary streams are also important management issues as small streams are often utilised as habitat for smaller fish species and spawning grounds for larger salmonid species (Bates, 1999; Burford *et al.*, 2009). In the case of New Zealand, first-order streams not colonised by larger introduced salmonid predators often display the original fish fauna (Stevenson *et al.*, 2008), highlighting the need for caution when restoring passage in case upstream habitat is made accessible for non-indigenous species.

In New Zealand, freshwater fish pose particular barrier management challenges as many migrate upstream as small juveniles, in contrast to the anadromous upstream spawning migration of stronger-swimming adult salmonids. Consequently, international fish passage solutions have limited applicability to New Zealand's native fish species which need low velocity zones in order to cater for all swimming abilities (Baker and Boubée, 2006). Several surveys undertaken in the North Island found barriers totalling into the several hundreds at the regional scale (Cameron, 2010; James and Joy, 2008; Kelly and Collier, 2007), highlighting the widespread issues they potentially cause for fish passage. The large number of small barriers present on headwater streams calls for low-cost, retrofit solutions to be developed in order to address the problem.

Recent work has looked at using ramps as a means to overcome low-head obstacles such as perched culverts, weirs and bridge aprons (Baker, 2014; Baker and Boubée, 2006; Doehring *et al.*, 2012; Franklin and Bartels, 2012). The design of fish passes that can provide passage for an array of species needs to take into account the different swimming abilities of those species (Williams *et al.*, 2012). Research on ramps has thus far focussed on the weak-swimming species inanga, common bullies (*Gobiomorphus cotidianus*), and redfin bullies (*Gobiomorphus huttoni*) – a species that exhibits both climbing and swimming behaviour when negotiating barriers (Baker, 2014; Baker and Boubée, 2006; Doehring *et al.*, 2012). Findings have shown that Miradrain<sup>®</sup>, a plastic drainage product with raised cusps on a flat surface (each cusp 24 mm high and 16 mm apart) (Baker and Boubée, 2006), is an effective ramp surface for these species, leading to recommended ramp lengths of no more than 3 m in length, sloped no more than 15° (Baker, 2014).

Other recent research has found the addition of mussel spat ropes to be an effective, low-cost solution for improving passage for banded kokopu, a strong climber, both in laboratory (David *et al.*, 2009) and instream settings (David and Hamer, 2012), with young-of-the-year-fish successfully surmounting a 2.4 m perched culvert by climbing the rope. Despite the apparent success for this species, the installation of the ropes did not provide passage for redfin bullies, a weaker climber. Thus, it could be inferred that these ropes may not be an effective passage solution for species with lesser climbing abilities than banded kokopu, at least in a perched setting. In non-perched culverts, however, where the barrier to passage exists due to the high barrel velocities and homogenous flow conditions, David *et al.* (2014) found that the addition of ropes improved passage not only for adult inanga, but also juvenile rainbow trout *Oncorhynchus mykiss* and the migratory shrimp *Paratya curvirostris*.

The present study follows three phases of experimental ramp trials by testing an array of additional ramp surfaces, building on learnings from Baker and Boubée (2006), Baker (2014) and Doehring *et al.* (2012) to inform fish ramp design that best aids the passage of inanga and redfin bullies. By designing a ramp that enables upstream passage for the weaker swimming and climbing species, it should inherently cater for all migratory juveniles more adept at negotiating barriers. I hypothesised that passage success rates would vary among species between ramp surfaces, given their differing baffling effect on the water flowing down the ramp. For example, (i) the provision of greater lateral baffle spacings was expected to allow wider-bodied fish like torrentfish (*Cheimarrichthys fosteri*) to pass the ramp, whilst still providing flow conditions that would enable passage for inanga; and (ii) the addition of mussel spat rope was expected to improve passage success for the climbing redfin bully.

## **3.2 Methodology**

### **3.2.1 Fish capture and maintenance**

Adult inanga were captured from Grange Creek, Haumoana (39°36'31"S; 176°56'20"E) using a handheld stop net to drive schools downstream into a fine (4mm) mesh fyke net. Adult redfin bullies were captured in the Maraetotara River, Te Awanga (39°38'21"S; 176°59'15"E), using an electric fishing machine (Smith-Root LR20B).

After capture, fish were transported in 45 L chilly bins to the test facilities (maximum travel time 20 minutes). Fish were slowly acclimatised to holding tank conditions by periodically adding holding tank water (the same water used in trials) to the chilly bins. Tanks of 1000 L capacity were used to house fish for the duration of

the trials and were filled with water from the same source as used for the experiments. Fish were held captive for a minimum of 24 hours prior to experimentation. In trial phases 1 and 2, holding tank water was changed twice daily to maintain dissolved oxygen (DO) levels above 70% saturation, as measured using a YSI Pro Plus handheld meter. In phase 3, a submersible pump was placed at the bottom of each tank to circulate the tank water and thus provide oxygenation.

### **3.2.2 Experimental apparatus and testing procedure**

The experimental design was based on the recirculating systems used by Baker and Boubée (2006) and Doehring (2011). Water was pumped from a nearby drain via a 5 L/s submersible electric pump and split into 2 parallel 500 L 'upper' heading tanks, from where it flowed through 2 1.5 m sections of concrete culvert pipe and down the test ramps into 2 500 L 'lower' holding tanks (see Fig. 3.1). Test ramps were constructed from stainless steel and measured 2.4 m long by 0.56 m wide. They were bent down the centreline by 10° to maintain sufficient depth in the middle for swimming fish, and a wetted margin on each side for climbing fish to utilise.

Testing occurred over 2 weeks in November 2015 (phase 1), March 2016 (phase 2) and March 2017 (phase 3) following experimental procedures of Baker and Boubée (2006) (see below for detailed description of methodology for each phase). Fish were placed in the lower holding tank and given 15 minutes to adjust to the conditions. Pumps were then switched on and ramp passage attempts were observed from behind a mesh curtain. After 3 hours, pumps were switched off. Fish in the lower and upper tanks were counted and fork length was measured to the nearest mm.

At the cessation of each trial phase, water velocities for each surface type were measured using Rhodamine dye. Two drops of dye from a plastic 3 mL transfer pipette

were added to the water at the top of ramp and a stopwatch was used to measure the time it took for the first trace of dye to reach the bottom of the ramp. This was repeated 3 times to provide an average ramp velocity. Ramp depths were not recorded for phase 1, nor for the 50/50 surface in phase 2 (see below), due to the turbulent effect that rock holds imparted on flowing water and the consequent large variability in depths across a point. Depth was, however, measured at evenly-spaced points along ramps for the Miradrain® and Miradrain® + spat rope surfaces in phase 2 (see below), and this was repeated in phase 3 for both surfaces.



Figure 3.1: Fish ramp experiment showing dual header tanks (right of picture), ramps (centre) and lower tanks (left).

### 3.2.3 Phase 1

Phase 1 involved the testing of a range of ramp substrates with inanga only, with the assumption that the provision of passage for this weak-swimming species would in turn cater for species with stronger climbing abilities. Earlier testing by Baker and Boubée (2006), and Baker (2012), showed Miradrain® to be an effective substrate for inanga and redfin bully passage. C. Baker (pers. comm., NIWA) subsequently recommended the testing of additional substrates such as rock climbing holds. Consequently, the following substrates were tested on stainless steel ramps paired with Miradrain® in phase 1 (see Fig. 3.2):

- Rock holds attached to stainless steel with magnets
- 50/50 split of Miradrain® on one side and rock holds on alternate side of ramp
- Miradrain® with rock holds inset.



Figure 3.2: Miradrain® (left) and rock holds (right) used in the 4 surface types trialled in phase 1. Surfaces also included a 50/50 surface with Miradrain® on one side and rock holds on the other side of the ramp; and a surface with rock holds inset into the Miradrain®.

Two 3-hour trials (am and pm) were run per day over 4 days on the 2 ramps, yielding 4 replicates of each surface type. Each substrate was assigned a number (1-4), and a random number generator was used to decide testing order (am or pm) and ramp position (left or right) over the 4 days. Ramps were set at 15°, based on results from Baker's (2012) study. A total of 60 inanga were used in each trial (30 trialled against each ramp). Fish were used only once. Successful passage was measured as the total number of individuals in the upper tank at the end of the 3-hour trial.

### 3.2.4 Phase 2

Based on the results of phase 1, it was clear that passage success was greatest on the Miradrain<sup>®</sup> surface, followed by the Miradrain<sup>®</sup> with inset rock holds and the 50/50 surface (see Results), although the latter surface had high variability in passage success. Phase 2 of testing involved 4 surfaces, the Miradrain<sup>®</sup> and 50/50 ramp surfaces from phase 1, with and without spat rope attached. The type of rope used was UV stabilised 'Super Xmas Tree' type, (Donaghys Industries, Christchurch, New Zealand). Spat ropes were laid down the wetted margins and centre of the Miradrain<sup>®</sup> ramp (3 strands total), and only down the wetted margins of the 50/50 ramp (2 strands total) to allow fish to switch between surfaces.

In addition, phase 2 expanded the species tested to include the climbing redfin bully and the wide-bodied yellow-eye mullet, a species untested in published fish ramp experiments to date. Experimental design was identical to that used in phase 1. Again, 4 replicates of each surface were conducted randomly over the course of 4 days. For each trial, 100 inanga, 20 redfin bullies and 30 yellow-eye mullet were tested. However, significant mortality occurred in tanks holding yellow-eye mullet so these data are not presented here. Again all fish that were trialled were used only once. In an attempt to increase passage motivation by adding inanga and redfin bully odours to the attractant flow, a submersible 380 L/hr pump was used to circulate lower tank water up to the header tank and down the ramp.

### 3.2.5 Phase 3

The results from phases 1 and 2 led to 2 different plastic, vacuum-formed substrate panels being created and tested. The first surface type, hereafter referred to as 'small mira', imitated the dimensions of Miradrain<sup>®</sup> cusps except height was increased to 25 mm to impart more of a baffling effect at greater depths. The second surface type,

'large mira', had enlarged cusps (35 mm high x 40 mm wide) and cusp spacing widened to 30 mm apart (Fig. 3.3) The ramp surfaces were attached to rotomoulded plastic ramps which were the same length as the stainless ramps used in phases 1 and 2.



Figure 3.3: 'Small mira' (left) and 'large mira' (right) surfaces trialled in phase 3.

For phase 3, the trial was relocated to a site with access to cool artesian water because of concerns over (i) temperatures of the water which, in the week prior to commencing phase 3, exceeded 25 °C, and (ii) suitability of phase 1 and 2 water as an attractant flow given that the source was unlikely habitat for redfin bullies and torrentfish. This concern was based on low passage success rates for redfin bullies, relative to other studies (Baker and Boubée, 2006; Baker 2014). Experimental design in phase 3 otherwise followed phases 1 and 2, except for sample sizes which were 60 for inanga, 20 for redfin bullies and 20 for torrentfish per trial. However, torrentfish chose to remain

in the bottom of the test tank and did not undertake upstream movement, so data for that species are not presented.

### **3.2.6 Statistical analyses**

ANOVA was used to test whether ramp surface had a significant effect ( $P < 0.05$ ) on water velocity, followed by Tukey HSD tests to compare pairs of ramps. Due to lack of data normality, Kruskal-Wallis non-parametric tests were used to test for differences in passage rates for all species across all ramp surfaces in all phases, and Conover-Inman pairwise comparisons were used to test for pairwise significance. All analyses were conducted in Statistica 13.

To investigate the effect of fish size on passage success, fish were split into size classes based on those used in Baker and Boubée (2006) and Baker (2014). For inanga, these were  $< 60$  mm and  $\geq 60$  mm to represent small and large adults. For redfin bullies, these were  $< 40$  mm for post-juveniles and  $\geq 40$  mm for adults. In previous studies, a third class of redfin bullies was used whereby fish  $< 20$  mm were classed as small, fresh-run, migratory juveniles. As no redfin bullies  $< 20$  mm were caught and subsequently used in my trials, only the 2 size classes above were used. Mann-Whitney U tests were used to test whether difference in passage success for small and large adults were significant ( $P < 0.05$ ) for each ramp type.

## 3.3 Results

### 3.3.1 Phase 1

#### Ramp hydraulics

Ramp type had a significant effect on water velocity measured using a dye tracer ( $F_{3,8} = 17.2$   $P = < 0.01$ ) even though mean ramp velocities spanned a narrow range (Table 3.1). The cusp arrangement on the Miradrain® surfaces was most effective at slowing water velocities, with Miradrain® and Rock in Miradrain® showing the slowest velocities (Table 3.1). There was no significant difference between these 2 surfaces (Tukey HSD test;  $P = 0.98$ ). Rock and 50/50 surfaces had the fastest velocities, and there were no significant differences between these (Tukey HSD test;  $P = 0.34$ ). Depth was not measured in phase 1.

Table 3.1: Mean, 1SE and statistical similarity of water velocities measured for ramp surfaces trailed in phase 1. For 'similarity', surfaces with same letter were not significantly different. RM = Rock in Miradrain®.

Surface	Mean velocity (m/s)	SE	Similarity	<i>n</i>
Miradrain®	0.82	0.015	A	3
Rocks	1.00	0.020	B	3
50/50	0.94	0.015	B	3
RM	0.83	0.029	A	5

### Fish behaviour

Upon being placed into tanks, inanga quickly formed shoals and took refuge beneath the ramp overhang. Exploration of the holding tank was soon observed, although the time it took for shoals to begin exploring and finding the current at the bottom of the ramp varied between the 2 tanks and between trials, with some shoals observed swimming in the current at the base of the ramp in under 5 minutes, while others took up to 15 minutes. Shoals were often led by 1 or 2 individuals with the rest following closely behind. The same pattern was observed with passage attempts, as it was often the leading few fish seen swimming in the current directly at the base of the ramp that made the initial attempts.

It became clear that the channels between cusps on the Miradrain<sup>®</sup> ramp were of an optimal width for inanga, as each fish would utilise 1 channel and ascend the ramp in 1 burst swim, making the top with surprising speed. The larger rock hold baffles in the remaining ramp surfaces were observed to be less effective, as fish would often swim straight into them which either slowed their progress as they moved laterally to choose a new route, or prompted them to stop and be taken back down the ramp in the current. The baffling effect of the rock holds imparted a much more turbulent and erratic flow pattern than the smaller, more numerous cusps on the Miradrain<sup>®</sup> ramp, and this was evident in the observed reduction in individual speed and ultimate success rate of passage. No inanga were observed resting on the wetted margin, as observed by Baker and Boubée (2006) or Baker (2014).

### Passage success

Kruskal-Wallis results showed an overall effect of ramp surface on inanga passage ( $H = 17.2$ ,  $P = 0.0006$ ). Miradrain<sup>®</sup> and Rock in Miradrain<sup>®</sup> surfaces had the highest passage success rates, with averages of 19-20% of fish passing from the bottom tank

to the top tank (Fig. 3.4). The difference between these 2 surfaces was not statistically significant (Conover-Inman statistic = 0.416 ,  $P = 0.686$  ), indicating the presence of rock climbing holds as baffles did not facilitate a greater proportion of fish successfully negotiating ramps. The 50/50 surface had high variability in percent passage success, with individual results of 20, 10, 0 and 0% passage success for each of the 4 trials.

The rock hold surface had zero passage success in all trials. Only for the Miradrain® surface was there a significant difference between the passage success of each size class, with an average 51% of large fish compared with 12% of small fish passing the ramp (Mann-Whitney U = 0.00,  $P = 0.03$ ) (Fig. 3.5).

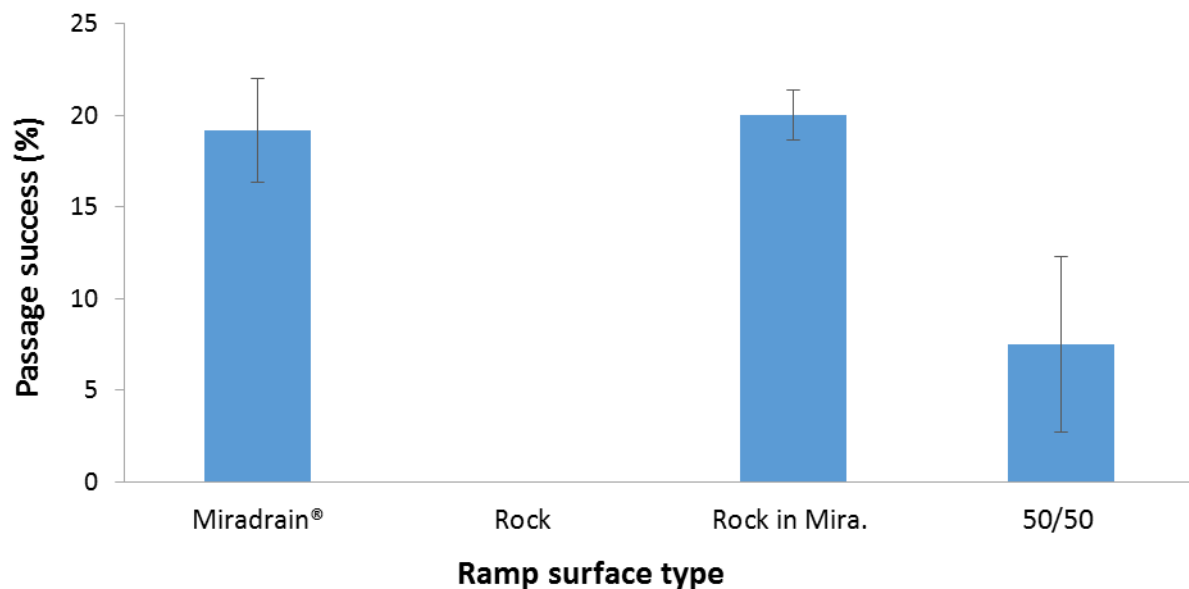


Figure 3.4: Mean  $\pm$  1SE passage success of inanga for each ramp type from phase 1 trials.

Rock in Mira. = Rock holds inset into Miradrain®; 50/50 = half rock and half Miradrain®

(Mira.).

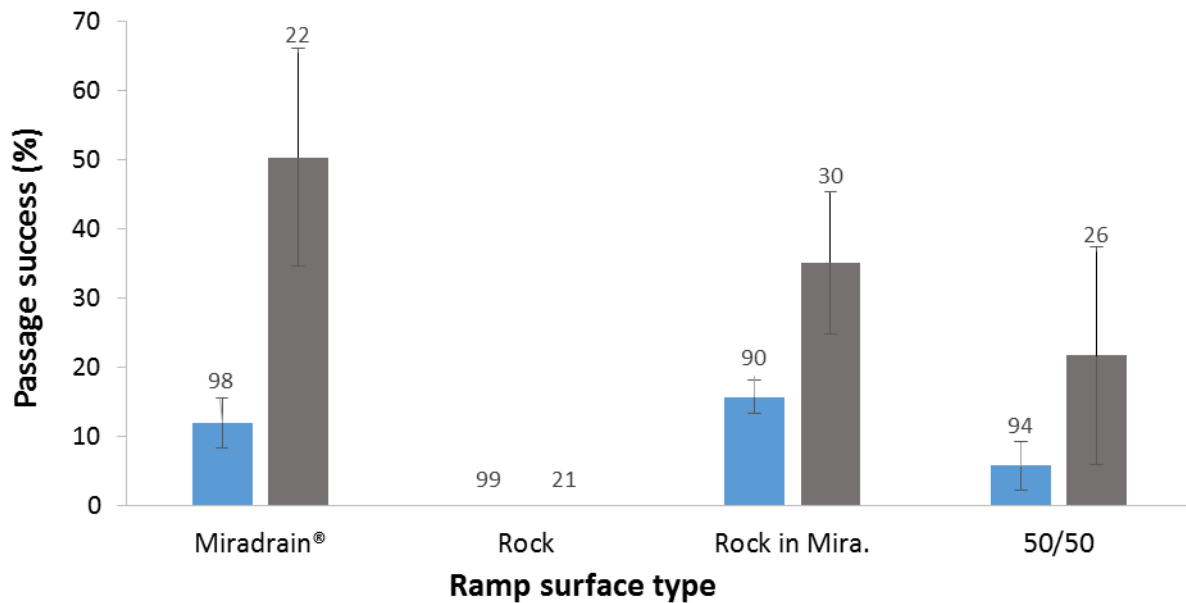


Figure 3.5: Mean  $\pm$  1SE passage success of each size class of inanga from phase 1 trials; Size class 1 = < 60 mm (blue); 2 =  $\geq$ 60 mm (grey) for each of the ramp types. Total number of fish in each size class trialled against each surface is shown above each bar. Rock in Mira. = Rock holds inset into Miradrain®; 50/50 = half rock and half Miradrain®.

### 3.3.2 Phase 2

#### Ramp hydraulics

Mean water velocities for the Miradrain® and 50/50 ramp were similar to those in phase 1 (Table 3.2). The addition of spat rope to each surface decreased velocity significantly, as indicated by an overall effect of ramp surface type ( $F_{3,8} = 22.2$   $P = 0.0003$ ). Accordingly, spat ropes decreased water velocity significantly for Miradrain® and 50/50 surfaces (Tukey HSD  $P = 0.002$  and  $0.005$ , respectively), by around 0.3 m/s (Table 3.2). Spat ropes also increased the mean depth of the Miradrain® surface from 12.95 mm to 19.73 mm (Table 3.2).

Table 3.2: Mean and 1SE for water velocities and depths, and statistical similarity for water velocities measured for ramp surfaces trialled in phase 2. For 'similarity', surfaces with same letter were not significantly different. 50/50 = half rock and half Miradrain®.

Surface	Mean Velocity (m/s)	SE	Similarity	<i>n</i>	Mean Depth (mm)	SE
Miradrain®	0.87	0.057	A	3	12.95	0.79
Miradrain + Spat	0.56	0.013	B	3	19.73	1.06
50/50	0.92	0.050	A	3	Not measured	N/A
50/50 + Spat	0.61	0.020	B	3	Not measured	N/A

### Fish behaviour

#### *Inanga*

Inanga behaviour was similar to that observed in phase 1, with fish swimming on the Miradrain® making largely successful attempts, and no fish seen to successfully negotiate the rock-hold side of the 50/50 ramp. The effect of the spat rope on behaviour was difficult to judge as fish were difficult to see, but on 4 occasions fish were seen swimming in a channel that had strands of rope protruding through it, and these fish were seen to be successful in passing the ramp.

#### *Redfin bullies*

It was difficult to observe the passage of redfin bullies due to their natural camouflage against the black Miradrain®, and the relatively low numbers attempting passage. Over the 8 trials involving 160 redfin bullies, only 7 fish were observed making a passage attempt. All redfin bullies seen were resting on the wetted margin of the ramp, and took between 0.5 and 1.5 hours to ascend, using their pectoral fins to climb in small bursts. On 2 occasions, redfin bullies were seen resting against or slightly under spat

rope at the edge of the ramp. On 3 occasions a bully was found on the ramp at the cessation of trials, and these were not counted as being successful.

### Passage success

#### *Inanga*

Kruskal-Wallis results showed that passage success varied among treatments ( $H = 7.75$ ,  $df = 3$ ,  $P = 0.05$ ). The Miradrain<sup>®</sup> + spat rope treatment had the highest passage success, with 63% of inanga negotiating these ramps. Miradrain<sup>®</sup> success rates were slightly lower at 45%, although this was not a statistically significant difference (Conover-Inman statistic = 1.58,  $P = 0.14$ ) (Fig. 3.6). The 50/50 + spat rope ramps displayed significantly lower passage rates compared with Miradrain<sup>®</sup> + spat rope, with 39% of fish ascending this ramp (Conover-Inman statistic = 2.28,  $P = 0.015$ ). The 50/50 surface also had significantly lower passage rates than Miradrain<sup>®</sup> + spat rope, at 34% (Conover-Inman statistic 3.26,  $P = 0.007$ ). The addition of spat rope did not significantly affect passage rates for inanga on Miradrain<sup>®</sup> and 50/50 surfaces (Conover-Inman statistic = 1.58 and 0.431,  $P = 0.14$  and 0.674, respectively). Inanga size had no significant effect on passage success for any of the ramp surfaces in phase 2 (Mann-Whitney U,  $P > 0.05$  for all surfaces), although as in phase 1 more larger fish on average negotiated the Miradrain<sup>®</sup> ramp (Fig. 3.7).

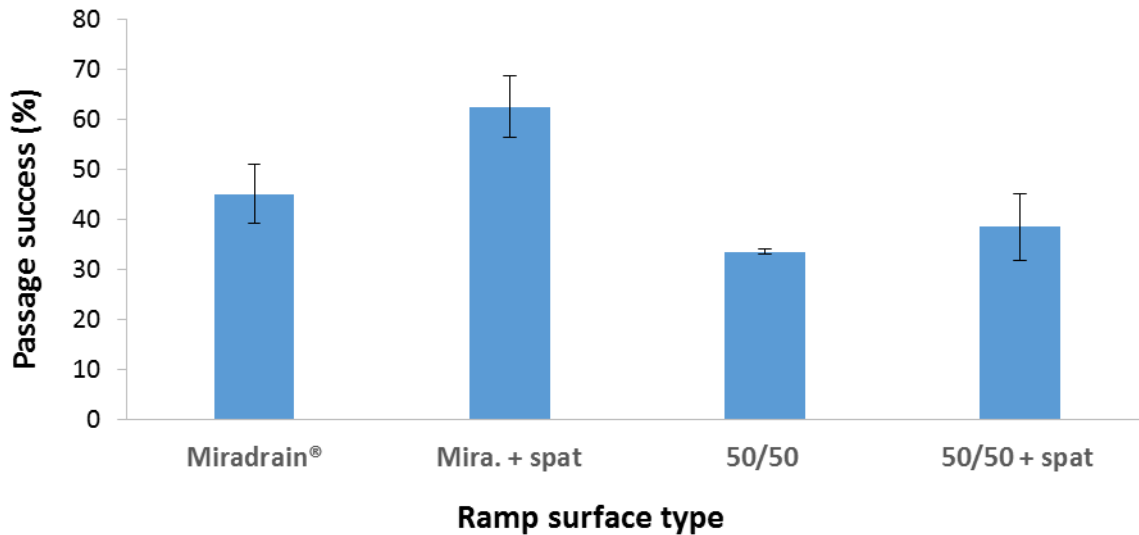


Figure 3.6: Mean  $\pm$  1SE passage success of inanga for each ramp type from phase 2 trials.

Mira. + spat = Miradrain® with spat rope; 50/50 = half rock and half Miradrain®; 50/50 + spat = half rock and half Miradrain® with spat rope.

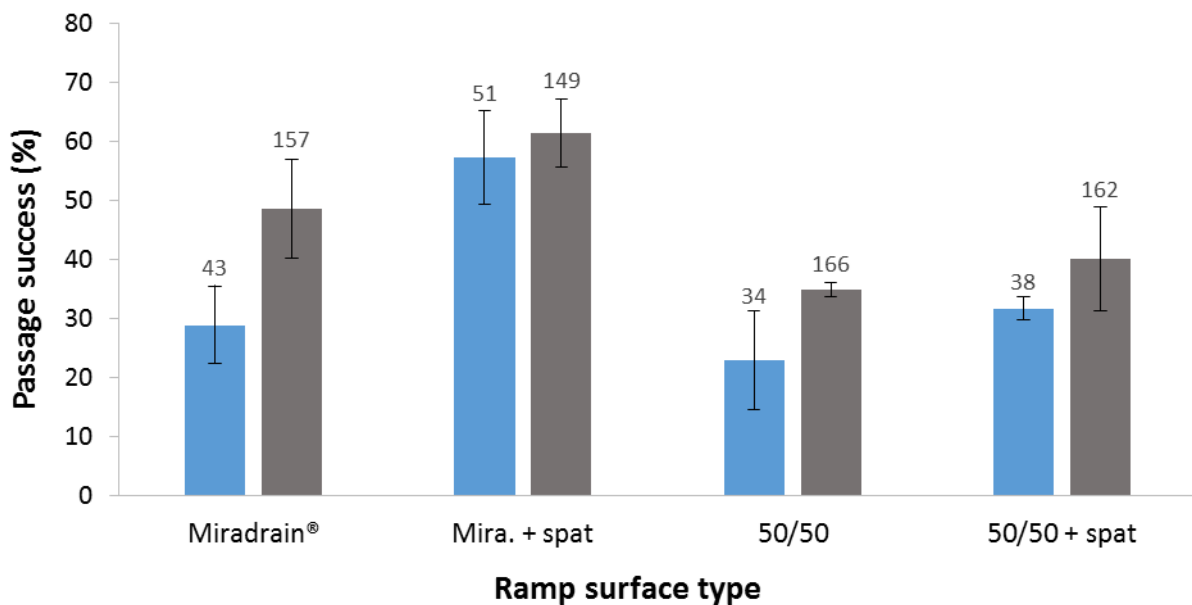


Figure 3.7: Mean  $\pm$  1SE passage success of each size class of inanga from phase 2 of trials; size class 1 = < 60 mm (blue); 2 =  $\geq$  60 mm (grey) for each of the ramp types. The total number of each size class trialled against each surface is shown above each bar.

Mira. + spat = Miradrain® with spat rope; 50/50 = half rock and half Miradrain®; 50/50 + spat = half rock and half Miradrain® with spat rope

### Redfin bullies

Less than 15% of redfin bullies successfully negotiated ramps and there was no significant difference in successful passage between any of the treatment surfaces (Kruskal-Wallis  $H = 2.16$ ,  $df = 3$ ,  $P = 0.53$ ) (Fig. 3.8). Redfin size had no effect on passage success for any of the ramp surfaces in phase 2 (Mann-Whitney U,  $P > 0.05$  for all surfaces) (Fig. 3.9).

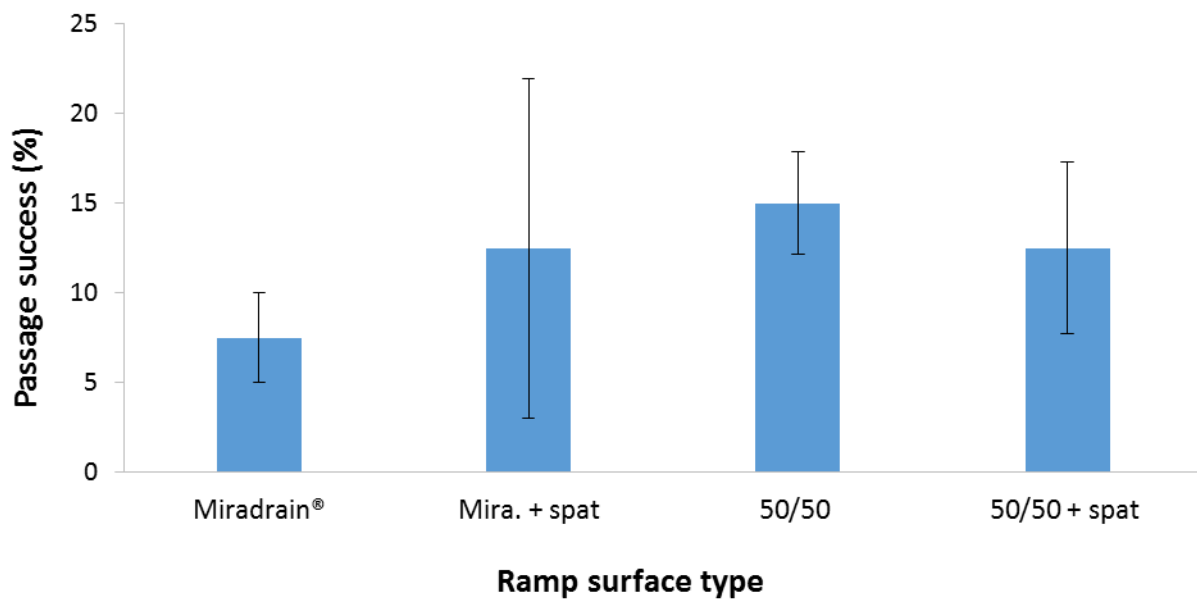


Figure 3.8: Mean  $\pm$  1SE passage success of redfin bullies for each ramp type from phase 2 trials. Mira. + spat = Miradrain® with spat rope; 50/50 = half rock and half Miradrain®; 50/50 + spat = half rock and half Miradrain® with spat rope.

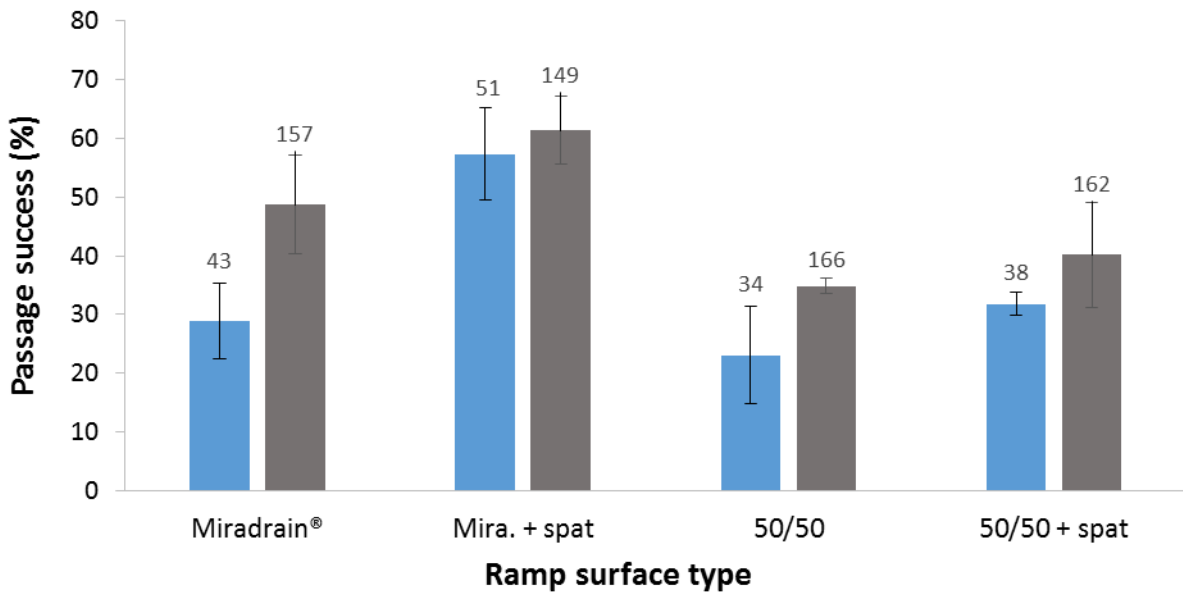


Figure 3.9: Mean  $\pm$  1 SE passage success of each size class of redfin bullies from phase 2 trials; size class 1 = < 60 mm (blue); 2 =  $\geq$ 60 mm (grey) for each of the ramp types. The total number of each size class trialled against each surface is shown above each bar. Mira. + spat = Miradrain® with spat rope; 50/50 = half rock and half Miradrain®; 50/50 + spat = half rock and half Miradrain® with spat rope.

### 3.3.3 Phase 3

#### Ramp hydraulics

As in phase 2, ramp surface had a significant effect on water velocities ( $F_{3,16} = 241.3$   $P = 0.000$ ), which were significantly reduced with the addition of spat rope for both small and large ‘mira’ surfaces (Table 3.3). Small mira with spat rope and large mira with spat rope surfaces had the slowest water velocities, and the difference between these 2 treatments was not significant (Tukey HSD  $P = 0.16$ ). Small mira had slower ramp velocity than large mira, and water flowed over both these surfaces significantly faster than both spat rope surfaces (Tukey HSD  $P < 0.05$  for both).

Table 3.3: Mean and 1SE for water velocities and depths, and statistical similarity for water velocities measured for ramp surfaces trialled in phase 3. For 'similarity', surfaces with same letter were not significantly different.

Surface	Mean velocity (m/s)	SE	Similarity	<i>n</i>	Mean depth (mm)	SE
Small mira	0.88	0.016	A	5	13.17	1.14
Small mira + Spat	0.57	0.283	B	5	18.20	0.88
Large mira	1.28	0.026	C	5	7.00	0.71
Large mira + Spat	0.64	0.025	B	5	10.79	0.95

### Fish behaviour

#### *Inanga*

On the small mira and small mira + spat rope ramps, observed inanga behaviour was similar to that seen in phases 1 and 2. On the large mira ramp surfaces, inanga were observed taking longer to surmount the ramp, with many reaching around two-thirds the way up the ramp before fatiguing and being swept down current.

#### *Redfin bullies*

Redfin bully behaviour was similar to that observed in phase 2. Fish were seen resting on the wetted margin of both ramp surfaces, and on 1 occasion a fish was observed resting directly against spat rope on the small mira surface.

### Passage success

#### *Inanga*

Kruskal-Wallis results showed that ramp type had a significant effect on passage success for inanga ( $H = 12.84$ ,  $df = 3$ ,  $P = 0.005$ ). Small mira + spat rope had the highest passage rates for inanga with an average success rate of 55%, followed by

small mira with 53%, although the difference between the 2 was not statistically significant (Conover-Inman statistic = 0.35,  $P = 0.731$ ) (Fig. 3.10). Large mira + spat rope had significantly fewer inanga pass the ramp than both the small mira and small mira + spat rope ramps (Conover-Inman statistic = 6.9; 7.2,  $P < 0.01$  for both comparisons respectively), but had significantly more fish pass than large mira (Conover-Inman statistic = 2.81,  $P = 0.016$ ) which indicates that the presence of spat rope aided passage on the large mira surface only. Inanga size had no effect on passage success for any of the ramp surfaces in phase 3 (Mann-Whitney U,  $P > 0.05$  for all surfaces) (Fig. 3.11).

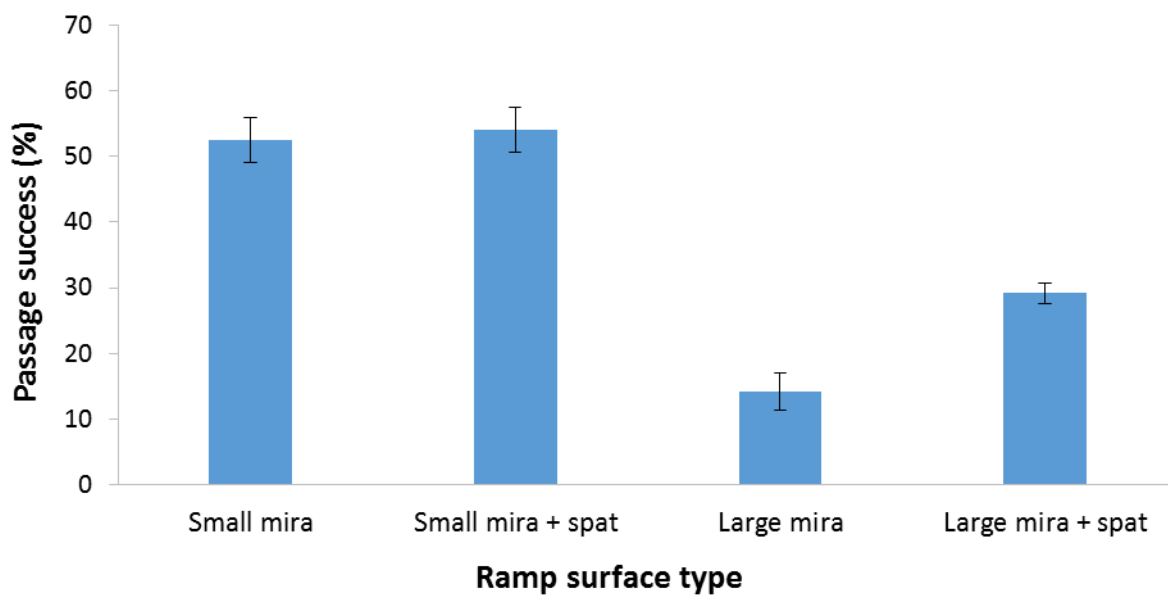


Figure 3.10: Mean  $\pm$  1SE passage success of inanga for each ramp type from phase 3 trials. See text for description of 'Small mira' and 'Large mira'.

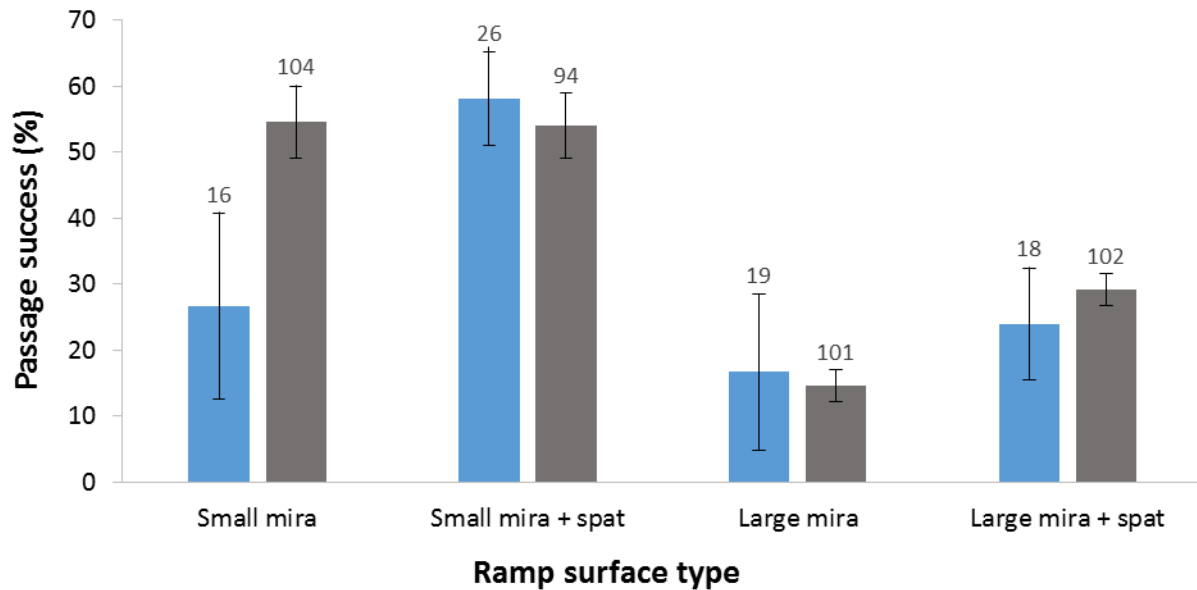


Figure 3.11: Mean  $\pm$  1SE percentage of each size class of inanga from phase 3 trials; size class 1 = < 60mm (blue); 2 =  $\geq$ 60mm (grey) for each of the ramp types. The total number of each size class trialled against each surface is shown above each bar. See text for description of 'Small mira' and 'Large mira'.

### *Redfin bullies*

Overall, passage responses were low for small redfin bullies compared to inanga. Nevertheless, Kruskal-Wallis results showed that ramp type had a significant effect on passage success for redfin bully ( $H = 12.7$ ,  $df = 3$ ,  $P = 0.007$ ). Small mira + spat rope had the highest passage success with 40%, followed by large mira + spat at 33%, although there was no significant difference between these 2 treatments (Conover-Inman statistic = 1.57,  $P = 0.14$ ) indicating that ramp type did not affect passage success for this species (Fig. 3.12). The addition of spat rope on both ramp surfaces in this trial showed a significant improvement in passage rates for redfin bullies (Conover-Inman statistic 4.154,  $P < 0.01$  for both treatments). Redfin size had a significant effect on passage success for small mira (Mann-Whitney  $U = 0.00$ ,  $P = 0.03$ ) and large mira + spat rope (Mann-Whitney  $U = 0.00$ ,  $P = 0.02$ ) treatments in

phase 3. However, limited numbers of small fish were available for these trials so these size class results should be treated with caution.

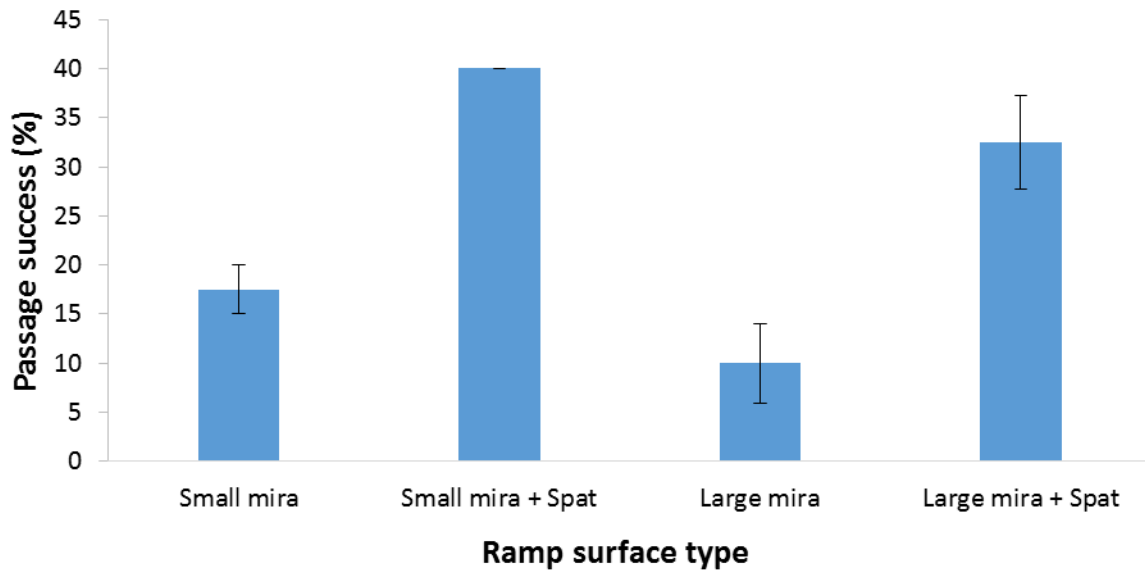


Figure 3.12: Mean  $\pm$  1SE passage success of redfin bullies for each ramp type from phase 3 trials. See text for description of 'Small mira' and 'Large mira'.

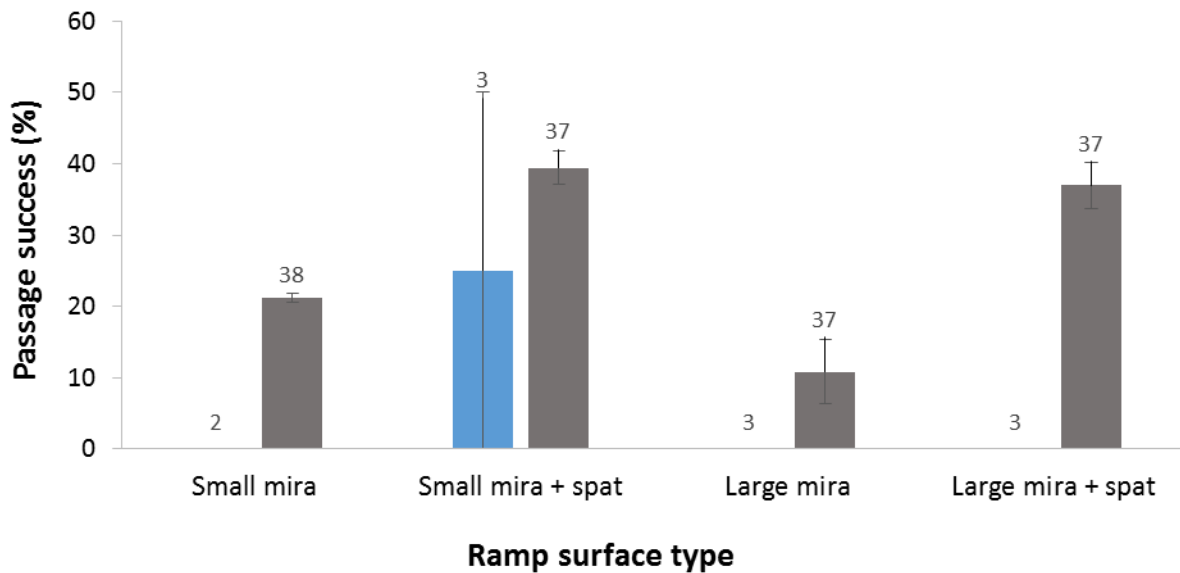


Figure 3.13: Mean  $\pm$  SE percentage of each size class of redfin bullies from phase 3 trials; size class 1 = < 60 mm (blue); 2 =  $\geq$  60 mm (grey) for each of the ramp types. The total number of each size class trialled against each surface is shown above each bar. See text for description of 'Small mira' and 'Large mira'.

## 3.4 Discussion

### 3.4.1 Effects of ramp surface

Ramp surface type influenced the passage success of inanga across all 3 trials. Miradrain<sup>®</sup> and small mira surfaces consistently showed the highest passage success rates. This is consistent with a previous study by Baker and Boubée (2006) who found highest inanga passage rates from Miradrain<sup>®</sup>, attributing it to the increased roughness coefficient of the ramp (Manning's  $N$ ), increased water depth, and reduced water velocities compared to other trialled substrates. Indeed, in my study Miradrain<sup>®</sup> and small mira both displayed the greatest mean depth and slowest velocities out of all surfaces trialled. Water depth has been shown to be an important factor affecting the swimming performance of rainbow trout *Oncorhynchus mykiss*, with water depths < 3 times a fish's body depth reducing swimming speeds by between 30 and 50% as a result of energy loss through bow wave formation (Webb *et al.*, 1991). The effect of depth on the swimming performance of native species like inanga is not known, although Baker and Boubée (2006) suggested that the 3-times body depth rule did not preclude inanga from passing their ramps. It is, however, perhaps reasonable to assume that, given the findings from Webb *et al.* (1991), small swimmers like inanga may more efficiently swim through deeper ramp water.

While depth may be a less well understood effect on the performance of small native fish, there exists some data on the swimming performances (and thus the effect of velocity on passage success) of native species. Boubée *et al.* (1999) found that the average burst speed for small (< 50 mm) inanga was 1.07 m/s, and 1.35 m/s for large

(> 70 mm) fish. In addition, the study found that the maximum of burst speed swimming distance of inanga decreased with an increase in velocity, from 6.2 m at 0.35 m/s to 2.1 m at 1.0 m/s. The higher passage success of the Miradrain® and small mira surfaces, relative to other surfaces tested therefore may be partially explained by the lower velocities observed.

However, phase 3 of testing showed that velocity itself may not be the sole determinant of passage success of inanga, with significantly more fish passing up the small mira than the large mira surface, both with spat rope, despite having statistically similar velocities. Observations of fish behaviour in my study indicate that the inter-cusp channels on the Miradrain® and small mira surfaces are of an optimal width for narrow-bodied swimmers such as inanga. Fish were observed burst swimming up these channels, their lateral movement restricted by the rows of cusps on either side, guiding individuals in an upstream direction.

Observations of passage attempts on other surfaces, such as the rock and 50/50 surfaces, where rocks were in more of a staggered arrangement, found rock holds to be a sub-optimal baffle compared to Miradrain® as they formed obstacles to inanga movement. Fish were seen swimming directly into the rock holds and immediately lost momentum, meaning they had to change course and often turned back into the flow before being swept back down the ramp into the bottom tank.

Despite high success variability in phase 1, the 50/50 surface was re-tested in phase 2 due to concerns around the ability of wider-bodied fish to utilise the narrow inter-cusp channels on the Miradrain® surface. Torrentfish, a wider-bodied native diadromous species, was selected to test this hypothesis. However, from the early rounds of trials it was clear that passage attempts were not being made by this

species, and instead individuals chose to remain in the bottom of the test tank, potentially an artefact of the dimensions of my experimental apparatus and set-up (discussed later).

In contrast to inanga, ramp surface type did not affect the passage success of redfin bullies. This is consistent with findings from Baker and Boubée (2006) who also showed no significant difference in redfin bully passage at 15° between 6 surface types, including a bare stainless steel surface. Redfin bullies were observed in my trials utilising the wetted margins to either climb the ramp in stages using their large pectoral fins, or burst swim and rest. These observations are consistent with previous studies which have described resting of fish and crustaceans on fish passes, and stresses the importance of the provision of a wetted margin in fishway design (Baker and Boubée, 2006; Baker, 2014; Haro *et al.*, 2004; Voegtle *et al.*, 2002; Yasuda *et al.*, 2004).

My study is the first to look at the effect of mussel spat rope in combination with other materials on the passage success of fish ascending ramps. Spat ropes have been proven to be an effective addition to both the outlet of perched culverts (David and Hamer, 2012) and to within non-perched culverts (David *et al.*, 2014). The addition of spat rope to ramps in my study increased the depth (when measured) and reduced water velocities for all surface types. Passage success for redfin bullies increased with the presence of spat rope on both surface types in phase 3, and fish were seen utilising the low velocity zones alongside the ropes in phases 2 and 3. The effect of spat rope on inanga success was less pronounced, with increased passage as a result of spat ropes only found for large mira in phase 3.

### 3.4.2 Trial conditions

Although experimental design and species selection generally mimicked earlier studies (Baker and Boubée, 2006; Baker, 2014), passage rates for both inanga and redfin bullies were much lower in this study. There may be several factors that contributed to this result. Firstly, the configuration of the ramp set-up and lower holding tanks differed markedly between studies. The current study had large 500 L lower tanks, with water depths of c. 450 mm, compared to previous studies where holding tanks were much smaller at 90 L (Baker and Boubée, 2006; Baker, 2014). This led to fish having greater opportunity to hide or shoal, and less incentive to attempt passage.

In addition, the earlier studies had ramps fixed to the bottom of the holding tank, with netting on the sides preventing fish from swimming around the back (C. Baker, NIWA, pers. comm.). In my study, ramps were floating c. 440 mm above the bottom of the tank. As a result of this and the larger tank size, fish had much more room for exploration and hiding, and in the case of benthic dwellers, such as bullies and torrentfish, less chance of finding the ramp in the 3-hour trial period. This may explain why benthic species did not respond as well as pelagic inanga in my study, and why neither species performed as well as in previous studies.

Secondly, the volume of water flowing down the test ramps was set at 2.5 L/s, compared with 1.1 L/s used in the studies of Baker and Boubée (2006) and Baker (2014). Consequently, ramp water velocities for Miradrain<sup>®</sup> surfaces were greater in my study, at 0.82 L/s compared with 0.58 L/s in the other studies mentioned. Although average velocities for my ramps did not exceed the maximum burst swimming speed for juvenile inanga of 1.07 m/s, as described by Boubée *et al.* (1999), increasing water velocity reduces the distance that inanga can travel in burst swimming mode (same study). This may partially explain the low passage successes for inanga in my study

compared with previous work, and highlights key caveats for ramp installations in real-world applications, where ramp velocities may exceed those tested to date in tank experiments.

### **3.4.3 Effects of fish size**

Inanga size was not a factor influencing passage success for any ramp surfaces trialled in my experiments, except for Miradrain<sup>®</sup> in phase 1. This result is at odds with Baker and Boubée (2006) and Baker (2014), who found that with a slope of 15°, larger inanga (> 60 mm) were more capable of passing Miradrain<sup>®</sup> ramps than smaller (< 60 mm) fish. Many low-head barriers such as perched culverts and weirs occur close to the coast, and will therefore be encountered by inanga early into their juvenile life stage. Thus when assessing the efficacy of fish remediation works for amphidromous species, the performance of the smallest juveniles is arguably the most important consideration.

Redfin bully length had a statistically significant effect on passage for the small mira and large mira with spat rope surfaces in phase 3, although sample sizes were skewed with only 2-3 (out of 40) small redfin bullies trialled against these surfaces over the 4 replicate rounds. Baker and Boubée (2006) and Baker (2014) found no difference between the passage success of small (< 40 mm) medium (40-60 mm) and large (> 60 mm) redfin bullies over a variety of surfaces at 15°. Interestingly, they found that, when ramp slope was increased to 30° and 45°, small (< 40 mm) bullies had significantly higher success on ramps lined with sand and gravel (although not with Miradrain<sup>®</sup>). The authors suggested that perhaps smaller redfin bullies may have a greater migratory urge, or that they simply are better climbers than larger fish. As I was not able to collect large numbers of small redfin bullies for my study, my size class results for this species should be treated with caution, and require further testing.

### 3.4.4 Conclusion and future work

This study has added to previous knowledge on the suitability of fish ramp surfaces for migratory New Zealand fish species, by trialling new surface types, a larger flow volume and the effect of spat rope in combination with other surfaces on passage success. My results confirm that the cusp configurations on Miradrain® provide ideal hydraulic conditions for the passage of inanga and redfin bullies up ramps. However, the hypothesis around the efficacy of the Miradrain® cusp configuration for wider-bodied species remains untested due to experimental artefacts.

Learnings from the first 2 phases of prototype ramp trials informed the design of a moulded plastic ramp and 2 vacuum-formed plastic substrate types – ‘small mira’, a Miradrain®-inspired surface with heightened cusps, and ‘large mira’, a surface with enlarged cusp dimensions and spacings. This third phase of trials showed that the large mira surface was less effective than the smaller one for swimming species, although the addition of spat rope significantly improved the efficacy, effectively doubling mean passage rates for inanga to 29%. This rate is much lower than the mean passage for the small mira surface with spat rope (59%), but it may be considered an acceptable success rate if indeed future testing found that wider-bodied fish could not fit in the channels of the small mira surface, but were able to successfully swim up the larger surface. As each ramp fits 4 panels (2 per side), managers have the option of a multi-surface ramp with both small and large mira surfaces to cater for a wider range of species.

This study provides evidence that supports the addition of spat ropes to fish ramp installations to increase ramp water depth and reduce velocity. Spat ropes increased passage rates for inanga on the large mira surface, and redfin bullies on both surfaces tested in phase 3. In addition, the zones beneath the ropes may provide

shelter and protection for resting climbing species from predators such as birds. Future testing could investigate the optimal amount of spat rope on the ramp, as more strands would likely further deepen and slow ramp water, potentially resulting in increased efficacy. A trade-off would be expected, however, as excessive debris accumulation on ropes could negatively affect fish passage by creating blockages.

Much potential exists for further design and experimentation of new surfaces, as the creation of new substrate panels for testing is relatively inexpensive (vacuum moulds for the 2 panel designs cost ~\$500 each to build, and each panel costs ~\$20). New surfaces could involve changing the size and or shape of mira cusps or perhaps a panel with alternating columns of small and large cusps. Doehring *et al.* (2012) tested the passage efficacy of ramps lined with artificial grass on inanga, and found encouraging results, although passage rates were lower than in the current study and indeed those of Baker and Boubée (2006) and Baker (2014). Nonetheless, the testing of a mira-type surface with the addition of artificial grass, particularly along the wetted margins could be beneficial.

Further experimentation could include investigating the passage ability of new species on the 'small mira' and 'large mira' surfaces. These could include wider-bodied native species, such as adult torrentfish or other migratory galaxiids (other than inanga); juvenile and adult trout; and exotic, invasive species such as common carp *Cyprinus carpio* and goldfish *Carassius auratus*. Although the primary objective of these ramps is to facilitate the passage of migratory juveniles, the provision of passage for adult native species is undoubtedly an important secondary outcome. Conversely, the prevention (via unsuccessful ramp passage) of invasive non-native species (and indeed trout in some circumstances) from entering systems where they may be at low densities or absent would be seen as a positive outcome for managers.

It is recommended that further testing of these ramps in a tank setting should be done in an experimental set-up closely mirroring that of Baker (2014). In particular, the bottom holding tank should be much shallower than in my study, and efforts should be made so that fish are concentrated at the base of the ramp and are not allowed to hide behind or underneath the bottom of the ramp. However, I believe the volume of water trialled in my experiment more closely represented real world settings compared to those of Baker and Boubée (2006); Baker (2014) and Doehring *et al.* (2012), and thus I see value in future trialling of flow rates at or exceeding 2.5 L/s.

This study has tested and proven the efficacy of a low-cost, floating fish ramp in an outdoor controlled setting. Further investigation into the robustness and effectiveness of the ramp designs in real world settings is required, and this aspect is addressed in Chapter 4.

## Chapter Four

# **Investigating the remediation effect of floating fish ramps in Hawke's Bay streams**

## 4.1 Introduction

The negative impacts of instream migration barriers on diadromous fish populations is well described (Clay, 1995; FAO/DVWK, 2002; Williams *et al.*, 2012), and in New Zealand such barriers are considered one of the most significant causes of fish population decline (Boubée *et al.*, 1999). Low-head barriers to movement are potentially also the easiest constraint to address in the short term, with significant gains likely where extensive areas of upstream habitat are made accessible (David *et al.* 2014). The importance of remediating these barriers is clear in New Zealand given the common occurrence of diadromous species that are listed as ‘threatened’ or ‘declining’, including most of the 5 species making up the highly-valued whitebait fishery (McDowall, 1988; DOC, 2013).

Whilst there exists a large amount of work internationally on salmonid fish passage, it is limited in its applicability in a New Zealand context owing to the relatively weaker swimming abilities of native amphidromous species (Boubée *et al.*, 1999). As these species often occur in small streams and rivers (Stevenson *et al.*, 2008), New Zealand fish passage research has recently focused on remediating small barriers such as culverts and weirs. Culverts are a common structure encountered in New Zealand waterways, particularly on smaller streams as costs are favourably low compared with bridge construction. However, culverts often disrupt migrations of fish as they change the hydraulic conditions of the stream, both within and downstream of the culvert itself. In particular, concentrating stream flows can lead to increased barrel velocities within the culvert, and homogenisation of the flow conditions with a lack of low velocity zones (Haro *et al.*, 2004). In addition, high hydraulic energy at the culvert exit can lead to scouring of the bed downstream, resulting in ‘perching’ that prevents

upstream access for fish (Stevenson *et al.*, 2008). Weirs also restrict fish passage either by creating swift laminar flows, or by creating an unnatural water fall.

Given the high cost of culvert and weir replacement, and the large number of these structures in streams nationwide (Cameron, 2010; James and Joy, 2008; Kelly and Collier, 2007), recent research has focused on low-cost, novel retrofit solutions to facilitate passage at these barriers. Solutions investigated have included (i) baffles (Amtstaetter *et al.*, 2015; Franklin and Bartels, 2012; MacDonald and Davies, 2007; Stevenson *et al.*, 2008) and spat rope (David *et al.*, 2014) for overcoming velocity barriers within culverts; (ii) spat ropes for climbing fish at perched culverts (David and Hamer, 2012); (iii) investigations into optimal weir notch shape for swimming species (Baker, 2003); and (iv) using ramps to provide passage for swimming species at culverts (Baker and Boubée, 2006; Baker, 2014; Doehring, 2012; Franklin and Bartels, 2012). Whilst the uptake of baffles and spat ropes for culvert remediation has been significant, insight gained from research has thus far not resulted in the widespread uptake of ramps as a remediation tool.

A crucial and often neglected part of fish passage management is the monitoring of fish communities to test the efficacy of fish passage structures (Agostinho *et al.*, 2007; Clay, 1995; Pelicice and Agostinho, 2008; Roscoe and Hinch, 2010). Fish community monitoring should be undertaken before and after treatment to investigate the degree (if any) of fragmentation caused by the structure, and, if passage remediation efforts are undertaken, to analyse the efficacy of such works (David and Hamer, 2012). In the previous study chapter, which built on current fish passage research in New Zealand, I trialled an array of surface types on 2.4 m long ramps against a swimming species, inanga *Galaxias maculatus* and a climbing species, redfin bully *Gobiomorphus cotidianus*. Initial findings led to the testing of a

rotational moulded plastic ramp that, coupled with spat rope, provided passage for 55% of inanga and 40% of redfin at a 15° angle over a 3-hour trial period.

Chapter 4 presents the field trial phase of the rotational moulded plastic ramps from Chapter 3, which were installed in 2 lowland streams in Hawke's Bay, New Zealand, over a 19-month period. Fishing surveys were conducted at these 2 'treated' sites as well as an additional 2 'control' sites on multiple occasions, in order to i) document the composition of communities that may potentially be affected by barriers in these poorly-sampled streams with scant fish data (see Chapter 2); ii) evaluate the impact of instream barriers on fish communities in these streams; and iii) test the efficacy of rotational moulded plastic ramps in providing passage past instream barriers for a relatively weak-climbing species, inanga.

## **4.2 Study Sites**

Four lowland streams in Hawke's Bay were selected for fish community monitoring: the Raupare, Irongate, Awanui and Waingongoro streams (see Fig. 2.1). Migration barriers exist on the Irongate, Awanui and Waingongoro streams, and the first 2 of these sites were selected for treatment with a fish ramp, with the latter being chosen as an untreated control site. Raupare Stream had no barrier present along the study reach. Detailed descriptions of the study sites are covered in Chapter 2.

## 4.3 Methodology

### 4.3.1 Fish sampling

At the Raupare, Awanui and Irongate sites, fyke net surveys were deemed the most effective fishing method due to slow water velocities, deep water, dense macrophyte cover and deep silt/ mud rendering them unsuitable for backpack electro-fishing. For the Waingongoro site, electro-fishing backpack surveys were conducted because the stream was shallower and stony. Electro-fishing of the Waingongoro Stream was conducted using a Smith–Root LR-20b electro-fishing backpack. Sampling design for both electro-fishing and net surveys involved 6 sub-reaches (15 m apart) downstream and upstream of the barrier (Fig. 4.1). For the Raupare control site where no barrier existed, a bridge crossing was chosen to define upstream and downstream reaches. Netting occurred over 2 nights, with 3 sequential upstream and 3 sequential downstream sub-reaches fished each night.

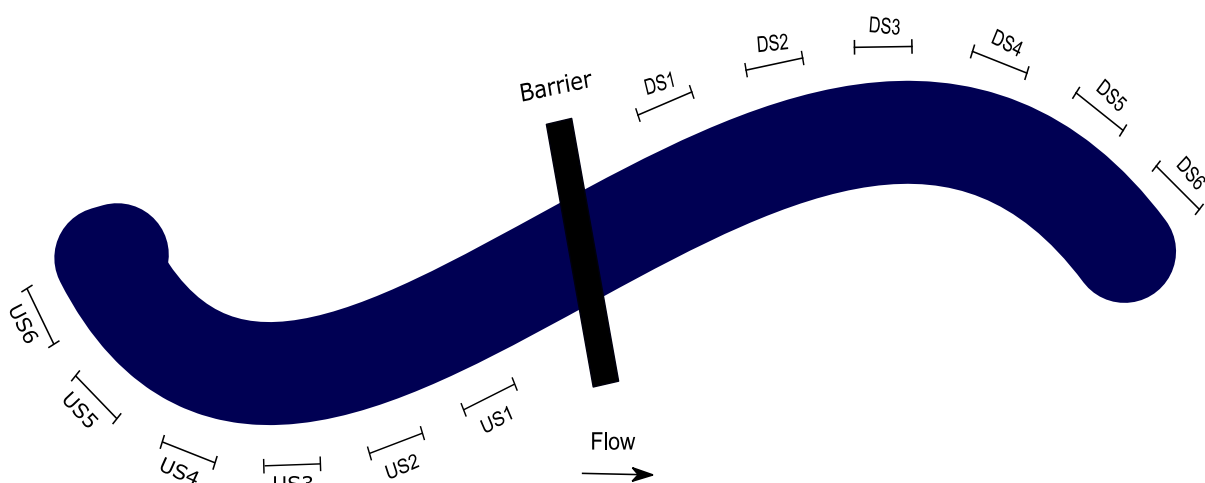


Figure 4.1: Depiction of experimental design, showing upstream (US) and downstream (DS) sub-reaches.

In each sub-reach, 2 fine-meshed (4 mm) fyke nets and 4 Gee's minnow traps were set. Fyke net mouths faced downstream, and the nets contained an exclusion grill for small fish to pass through in order to minimise predation risk from large eels. Nets were anchored against the stream bank, with the mesh screen reaching across on an angle to the opposite bank. Nets were set on alternate banks, so that within each sub-reach both the true left and true right banks had nets present. Two Gee's minnow traps were attached to each end of the fyke nets. Each morning, nets and traps were emptied. Catches from the 2 fyke nets and 4 Gee's minnow traps were pooled for efficiency in sample processing. All fish were identified and counted, and fork lengths measured to the nearest millimetre. Fish caught in nets on night 1 were retained in holding nets for night 2 to avoid recapture. Holding nets were located upstream and downstream of the barrier to avoid transporting fish above the barrier. All fish were eventually released downstream of the reach they were caught.

Surveys are referred to as 'pre-treatment' and 'post-treatment' for all sites, including the control sites, Raupare and Awanui Streams, where no treatment occurred. Pre-treatment surveys were conducted at each site in April of 2016, and post-treatment surveys in April 2017 and November 2017. High flows prior to April 2017 resulted in poor catches for the Raupare, Irongate and Awanui Stream nets relative to those in the pre-treatment survey, and so these data were not used in the analyses of ramp effectiveness. The Waingongoro Stream was unaffected by the April 2017 rain event, and as catch rates were similar to those in pre-treatment a second survey was deemed unnecessary.

### 4.3.2 Ramp installation

Rotomoulded plastic ramps, lined with 'small mira' panels as designed and trialled in the previous chapter, were installed in the Awanui and Irongate Streams in November 2016. A 250 mm long x 550 mm wide conveyor belt rubber hinge was attached to the upper end of each ramp with stainless m10 bolts to secure it to instream structures using stainless steel 5 mm diameter mushroom spikes. Panels were fixed to the ramps with countersunk stainless screws. Mussel spat rope (UV stabilised Super Xmas Tree' type, Donaghys Industries, Christchurch, New Zealand) was strewn down the centre and margins of the ramps and fixed with 'p' clips.

Ramps were offset to the side of the structures as much as possible to minimise ramp velocities and maximise the chance of being located by fish, and were left floating at the downstream end to minimise the risk of flood debris collecting on or damaging fixing points. This design enabled ramps to move laterally and up and down with floodwaters, reducing the shear stress that mounts would undergo if the bottom were fixed in place. On the Awanui Stream, as shown in Figure 4.2, a row of textured panels was fixed to the concrete apron above the ramp and to the culvert wall, at the low flow wetted margin with 5 mm stainless steel mushroom spikes. A length of spat rope was also laid from the culvert exit to the top of the ramp, fastened with 'p' clips and mushroom spikes. These additional measures were installed as it was hypothesised that the homogenous and swift velocities within the culvert and on the concrete apron would be presenting a further barrier to fish that had ascended the ramp.



Figure 4.2: Ramp installations in the Awanui Stream (left) and Irongate Stream (right).

### 4.3.3 Statistical analysis

In order to display spatial and temporal patterns in community composition for the study streams, non-metric multi-dimensional scaling plots (nMDS) based on  $\log(x + 1)$  transformed abundance data for all species were created in Primer version 7. A resemblance matrix was calculated using the Bray-Curtis similarity index.

Inanga, shortfin and longfin eels were selected as species to test for the impact the barrier was having on fish communities in the Raupare, Irongate and Awanui streams as they were the most numerous across the 3 sites. At the Waingongoro site, redfin bullies, shortfin and longfin eels were used to test the effect of the fish passage barrier, again due to this species being the most numerous. Mann-Whitney U tests were used to test (i) whether the barrier was impacting the distributions of these species (upstream vs downstream pre-treatment); (ii) whether there was a difference in abundances as catch per unit effort between pre- and post-surveys within each site; and (iii) whether ramp installation increased abundances of selected species upstream

of the barriers compared to downstream. Kolmogorov–Smirnov tests were used to test for differences in size distributions upstream and downstream of barriers and between sampling occasions.

## **4.4 Results**

### **4.4.1 Ramp durability**

Hydrological records for the treatment period on the Awanui and Irongate Streams show the ramps were subject to several flood events, with the largest events at each site approaching or exceeding the mean annual maximum flow (14.1 m<sup>3</sup>/s, 11.6 m<sup>3</sup>/s for Awanui and Irongate Streams, respectively) (Figs 4.3 and 4.4). At each site, ramps remained attached to structures, with panels in place for the duration of the trial. On the Irongate ramp, the fixings for the centre and true right strands of spat rope were dislodged, however. Buoyancy issues occurred on the Irongate ramp, the bottom half of which became submerged over time, resulting in a steeper ramp angle than when originally installed. Efforts to rectify it are described in the discussion.

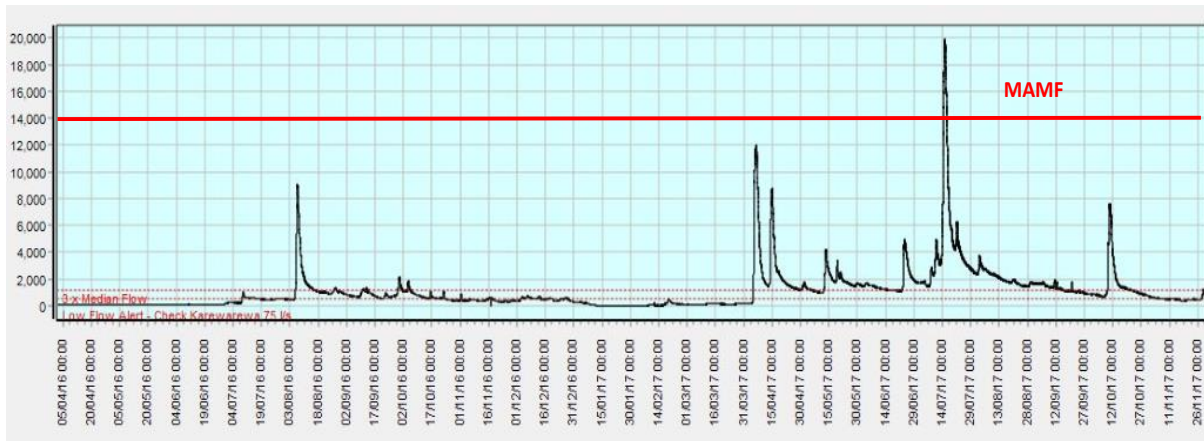


Figure 4.3: Flow record for the Awanui Stream at Flume, for the period between ramp installation and the post-treatment survey. Red line indicates mean annual maximum flow (MAMF). Note: Flow recorder site is located 1 km downstream of treatment site, below 2 tributaries.

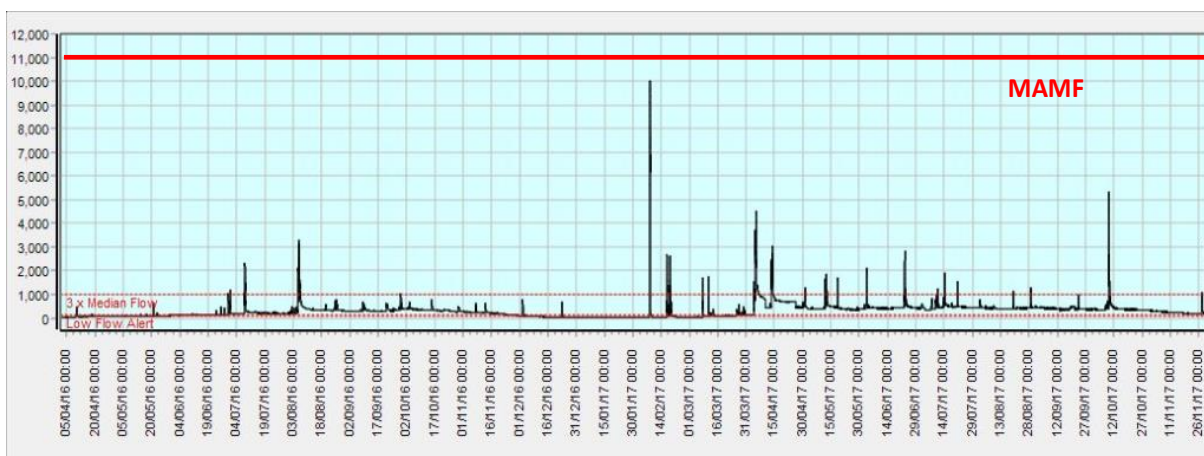


Figure 4.4: Flow record for the Irongate Stream at Clarke's Weir, for the period between ramp installation and the post-treatment survey. Red line indicates mean annual maximum flow (MAMF).

#### 4.4.2 Fishing surveys

##### Fish community composition

Data from the fishing surveys revealed differing community compositions between the 3 sites in the Heretaunga plains (Raupare, Irongate and Awanui Streams), and the Waingongoro Stream. This is evident in the non-metric multi-dimensional scaling

(MDS) plot (Fig. 4.5), where the 3 Heretaunga plains sites showed fish fauna typically associated with slow flowing, lowland streams. These sites were largely dominated by inanga and shortfin and longfin eels. The 'control' site Raupare Stream displayed a close cluster of points for both pre- and post-sampling rounds, and in upstream and downstream reaches, reflecting the lack of an instream barrier. The upstream and downstream points on the Awanui Stream are some distance apart for pre-treatment sampling, but shift closer together in post-treatment sampling, due to greater overall abundance of inanga following ramp installation (Table 4.1). For the Irongate Stream, the upstream and downstream sub-reaches remained close-by in ordination space for pre- and post-treatment sampling, reflecting no increase in inanga abundance upstream of the weir in the post-treatment sampling.

The Waingongoro Stream fauna more closely represented species favouring coarse substrates and swifter water such as redfin bullies, torrentfish and koaro. This is shown in the separate cluster of points for this site in Figure 4.5. The upstream and downstream reach points are widely separated in ordination space for both treatment rounds, reflecting the impact of the barrier on some species, and the lack of treatment through ramp installation. Downstream points are located closer to redfin bully, torrentfish and bluegill bully overlay trajectories, which corresponds with the barrier effect on these species, as shown in Table 4.1

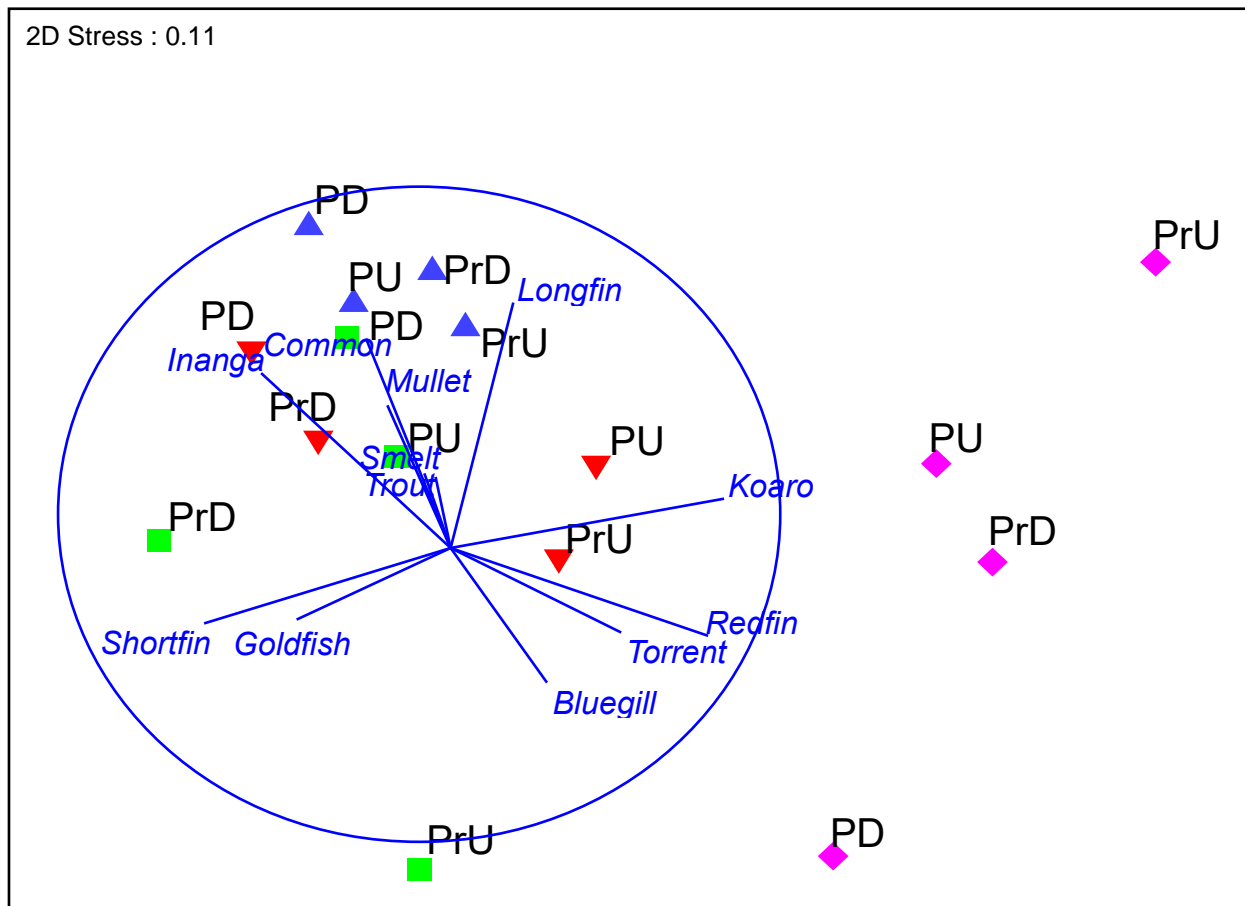


Figure 4.5: Non-metric multi-dimensional scaling plot based on fish abundances (all samples combined within a sub-reach; log transformed data) showing the distribution of sites in two-dimensional ordination space. Species vectors show associations resolved at Pearson correlation  $\Rightarrow 0.2$ . ▲ = Raupare Stream, ■ = Awanui Stream, ▼ = Irongate Stream, ◆ = Waingongoro Stream, Pr = pre-treatment sample, P = post-treatment sample, U = Upstream, D = Downstream.

Table 4.1: Species abundance (totals for all nets or electric fishing passes with a sub-reach) for the 4 treatment sites, split into upstream and downstream reaches for the pre- and post- treatment sampling rounds. S.fin = shortfin eel, L.fin = longfin eel, Cmn = common bully, R.fin = redfin bully G.fish = goldfish, Muller = yellow-eye mullet. Smelt = common smelt, Trrnt = torrentfish, R.bow = rainbow trout, B.gill = bluegill bully.

Site	Treatment	Sample	Location	Inanga	S.fin	L.fin	Cmn	R.fin	Koaro	G.fish	Mullet	Smelt	Trrnt	R.bow	B.gill
Raupare	No Barrier	Pre	Upstream	6	28	16	30	0	0	0	1	0	0	1	0
Raupare	No Barrier	Pre	Downstream	22	23	17	22	0	0	0	0	4	0	0	0
Raupare	No Barrier	Post	Upstream	191	26	13	4	0	0	0	2	0	0	0	0
Raupare	No Barrier	Post	Downstream	515	12	4	7	0	0	0	1	0	0	0	0
Irongate	Ramp	Pre	Upstream	0	37	10	0	0	0	0	0	0	0	0	0
Irongate	Ramp	Pre	Downstream	20	19	17	1	0	0	20	0	0	0	0	0
Irongate	Ramp	Post	Upstream	0	15	13	1	0	0	0	0	0	0	0	0
Irongate	Ramp	Post	Downstream	504	14	12	1	0	0	5	0	0	0	0	0
Awanui	Ramp	Pre	Upstream	0	18	0	0	0	0	0	0	0	0	0	0
Awanui	Ramp	Pre	Downstream	44	14	0	0	0	0	2	0	0	0	0	0
Awanui	Ramp	Post	Upstream	32	60	13	0	0	0	0	0	0	0	0	0
Awanui	Ramp	Post	Downstream	117	94	19	7	0	0	0	0	0	0	0	0
Waingongoro	Barrier	Pre	Upstream	0	0	10	0	14	13	0	0	0	0	0	0
Waingongoro	Barrier	Pre	Downstream	1	3	13	0	237	3	0	0	0	11	0	0
Waingongoro	Barrier	Post	Upstream	0	6	8	0	37	4	0	0	0	0	0	0
Waingongoro	Barrier	Post	Downstream	2	11	8	0	144	0	0	0	0	2	0	1

### Raupare Stream

Raupare Stream had the highest fish diversity of the 4 study streams, with 8 species present in surveys, 6 being native and diadromous (Table 4.1). The 3 most abundant species caught were inanga, shortfin eels and common bullies. There was significantly more inanga caught in the November 2017 post-treatment survey, with 28 and 706 fish caught in the pre- and post-treatment rounds, respectively (Mann-Whitney  $U = 2.0$ ,  $P < 0.001$ ). Overall, inanga in the post-treatment round were significantly smaller (Kolmogorov-Smirnov test,  $P < 0.001$ ) (Fig. 4.6). Pre-treatment fishing showed no significant difference in inanga abundance between upstream and downstream reaches (Mann-Whitney  $U = 0$ ,  $P = 1.0$ ). In the post-treatment round there were significantly more inanga caught in the downstream sub-reaches (Mann-Whitney  $U = 1.5$ ,  $P = 0.01$ ).

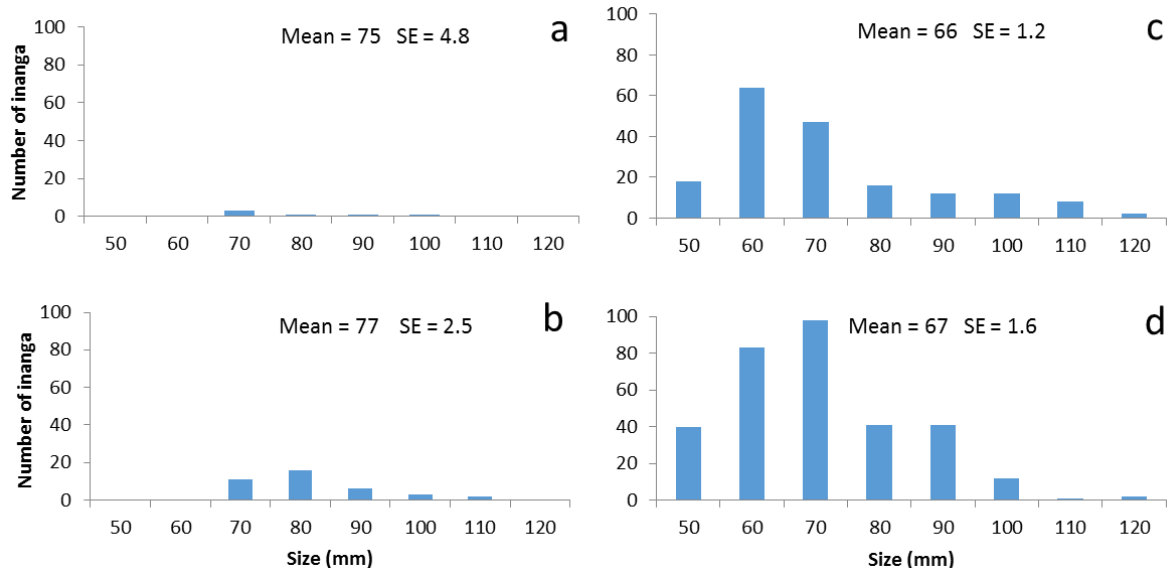


Figure 4.6: Size-frequency graphs of inanga abundance in the Raupare Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

There was no difference in shortfin eel abundance (Mann-Whitney  $U = 49.5$ ,  $P = 0.2$ ) between the pre- and post-treatment sampling rounds (Table 4.1). Abundances in pre-treatment sampling were also similar for the upstream and downstream reaches (Mann-Whitney  $U = 15$ ,  $P = 0.68$ ), however, shortfin eel were more numerous in upstream reaches in post-treatment sampling (Mann-Whitney  $U = 4.5$ ,  $P = 0.037$ ). There was no differences in average sizes for shortfin eels either between sampling rounds, or between upstream and downstream reaches over the 2 sampling rounds (Kolmogorov-Smirnov test,  $P > 0.1$ ) (Fig. 4.7).

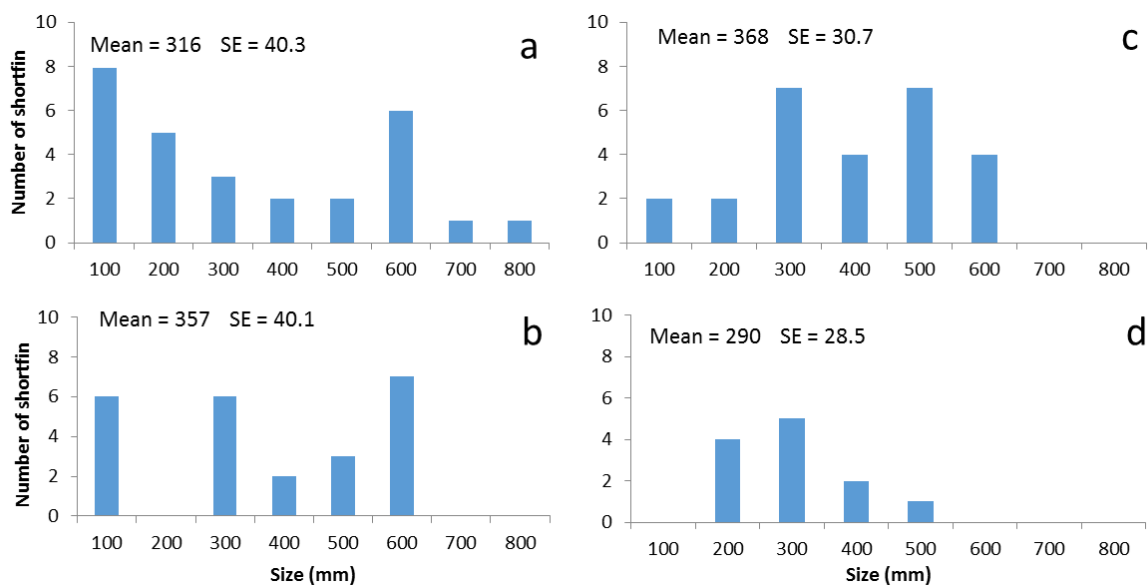


Figure 4.7: Size-frequency graphs of shortfin eel abundance in the Raupare Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

There was no difference in longfin eel abundance between the pre- and post-treatment sampling rounds (Mann-Whitney  $U = 0.5$ ,  $P = 0.2$ ). Abundances were also similar for the upstream and downstream reaches in pre-treatment sampling (Mann-Whitney  $U = 15$ ,  $P = 0.74$ ), and post-treatment sampling (Mann-Whitney  $U = 7.5$ ,  $P =$

0.11). There was no difference in average sizes for longfin eels between either between sampling rounds, or between upstream and downstream reaches over the 2 sampling rounds (Kolmogorov-Smirnov  $P = > 0.1$ ) (Fig. 4.8).

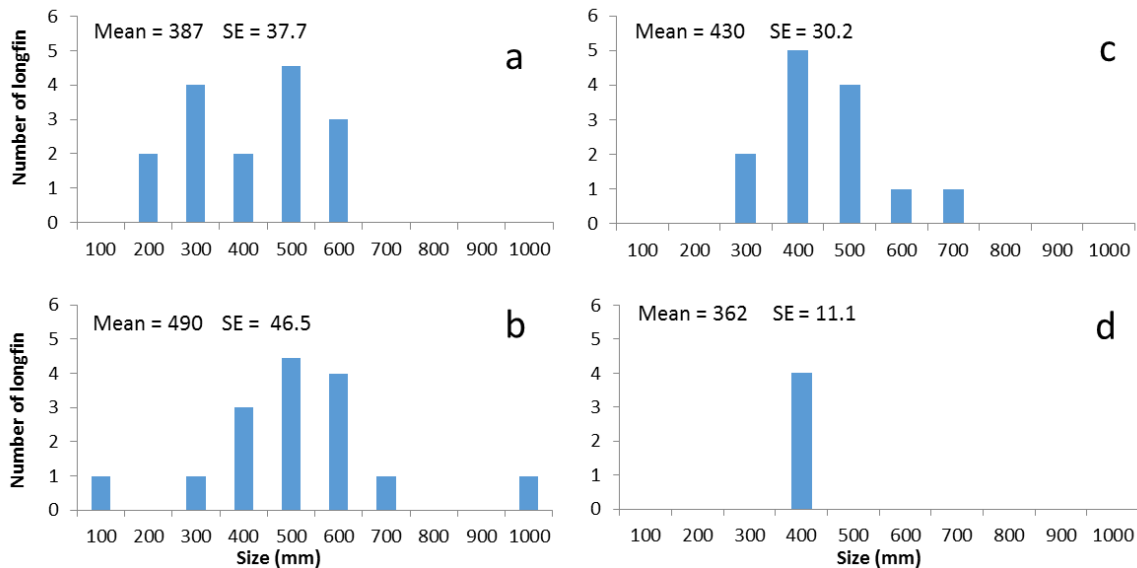


Figure 4.8: Size-frequency graphs of longfin eel abundance in the Raupare Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

### Waingongoro Stream

The Waingongoro Stream also had relatively high fish diversity, with 7 species present, all of them native and diadromous (Table 4.1). The most abundant species was redfin bully, and this was used as a test species to investigate the impact of the perched culvert, in the absence of sufficient inanga. As depicted in Figure 4.5, the species assemblages were unique among the trial streams, with 4 species; redfin bullies, koaro, torrentfish, and bluegill bullies found only in the Waingongoro. The perched apron appeared to be a barrier to swimming species, as only climbers such as eels, koaro and some redfin bullies were encountered upstream. Redfin bullies were larger

and less abundant above the barrier in pre-treatment (Mann-Whitney  $U = 0$ ,  $P = 0.005$ ; Kolmogorov-Smirnov test,  $P < 0.05$ ) and post-treatment (Mann-Whitney  $U = 2.5$ ,  $P = 0.015$ ; Kolmogorov-Smirnov test,  $P < 0.05$ ) rounds (Fig. 4.9). There was no difference in overall (upstream and downstream) abundances for redbfin bullies between the 2 surveys (Mann-Whitney  $U = -0.11$ ,  $P = 0.90$ ). Torrentfish, were only encountered in the downstream sub-reaches, and this upstream / downstream difference in numbers was significant (Mann-Whitney  $U = -2.3$ ,  $P = 0.01$ ). Inanga, bluegill bullies and shrimp were only encountered in downstream sub-reaches in low numbers.

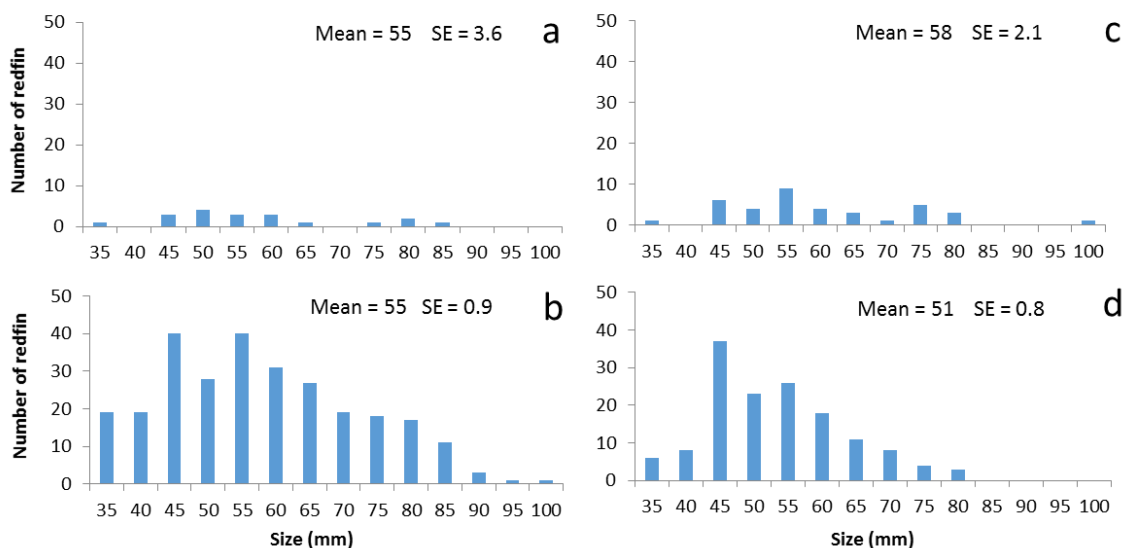


Figure 4.9: Size-frequency graphs of redbfin bully abundance in the Waingongoro Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

The culvert apron on the Waingongoro Stream appeared not to be a barrier to longfin eels, with no difference in abundance or size in the pre-treatment (Mann-Whitney  $U = 15$ ,  $P = 0.22$ ; Kolmogorov-Smirnov  $P > 0.1$ ) and post-treatment rounds (Mann-Whitney  $U = 15$ ,  $P = 0.22$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) (Fig. 4.10). There

was no difference in abundance of longfin eels between pre- and post-treatment sampling.

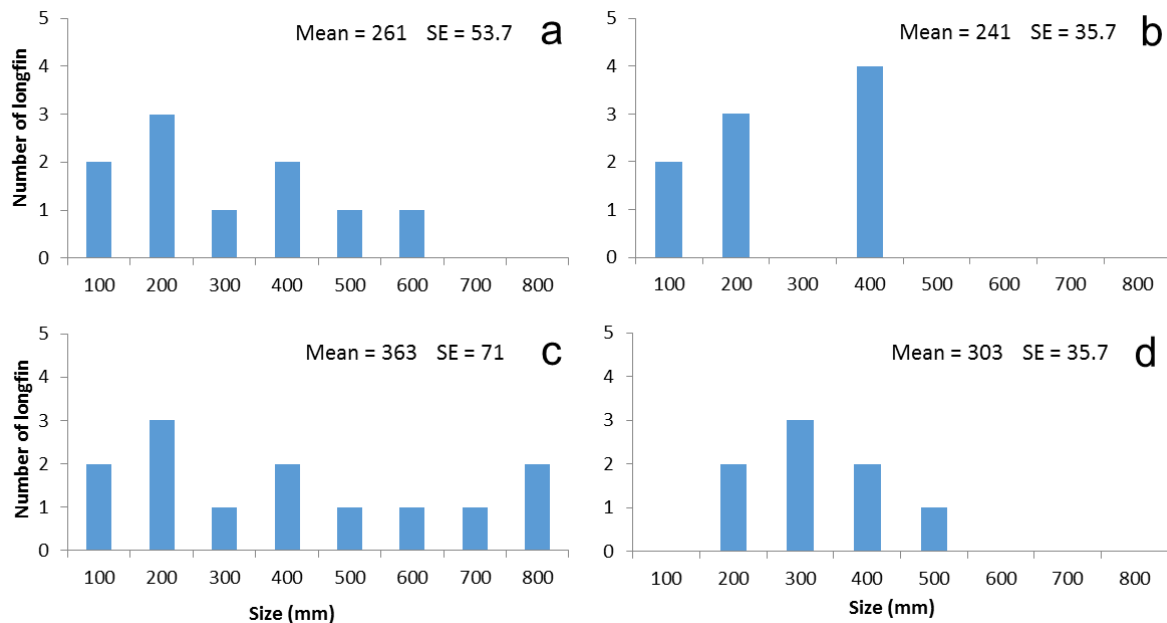


Figure 4.10: Size-frequency graphs of longfin eel abundance in the Waingongoro Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

There were much fewer shortfin than longfin eels in the Waingongoro Stream. In the pre-treatment round, only 3 were caught below the culvert with 0 above, although this difference was not significant (Mann-Whitney  $U = 15$ ,  $P = 0.68$ ). Significantly more shortfin eels were caught below the culvert than above in post-treatment fishing (Mann-Whitney  $U = 2.5$ ,  $P = 0.01$ ), but upstream and downstream fish were the same size (Fig. 4.11). As there was no ramp installation at this site and data were from the first post-treatment sampling occasion, difference in abundance between dates can be attributed to temporal variations.

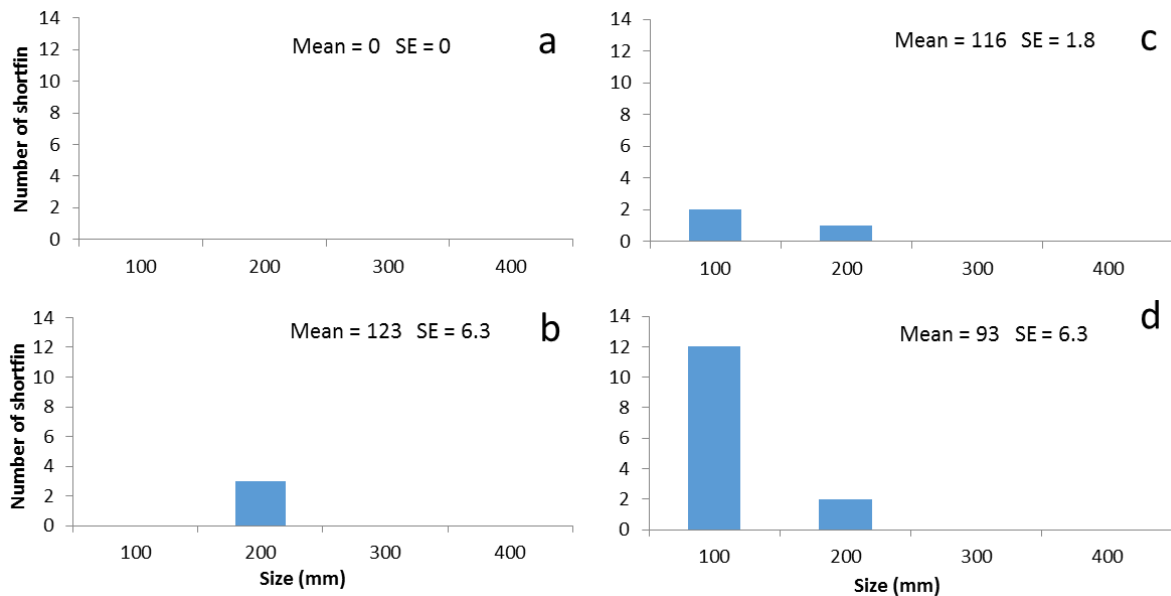


Figure 4.11: Size-frequency graphs of shortfin eel abundance in the Waingongoro Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

### Awanui Stream

Relative to the Raupare and Waingongoro sites, overall fish diversity was lower in the Awanui, with only 7 species encountered, 4 of these being native migratory species (Table 4.1). The most abundant species were inanga and shortfin eels. Pre-treatment monitoring indicated the perched apron to be a probable barrier to swimming species, with only eels and the non-migratory gambausia *Gambusia affinis* caught in the upstream sub-reaches, although gambausia were not counted. Inanga, common bully and the goldfish *Carassius auratus* were only caught in downstream sub-reaches.

In total, 44 inanga were caught downstream of the culvert and 0 upstream in pre-treatment fishing, although this difference in abundance was not significant (Mann-Whitney  $U = -1.36$ ,  $P = 0.17$ ) because several upstream nets had no inanga. There were significantly more inanga encountered in post-treatment sampling (Mann-

Whitney  $U = 22.5$ ,  $P = 0.003$ ), and these fish were of a smaller size than in pre-treatment sampling (Kolmogorov-Smirnov test,  $P > 0.1$ ) Post-treatment monitoring found 117 inanga downstream and 32 inanga upstream (Table 4.1). Again this difference in abundance was not significant (Mann-Whitney  $U = 0.16$ ,  $P = 0.87$ ). However, the abundance of inanga upstream of the culvert significantly differed between pre- and post-treatment rounds (Mann-Whitney  $U = -2.32$ ,  $P = 0.02$ ), suggesting the ramp treatment was successful in providing passage. Inanga sizes upstream and downstream of the culvert were similar in post-treatment fishing (Kolmogorov-Smirnov  $P = > 0.1$ ) (Fig. 4.12).

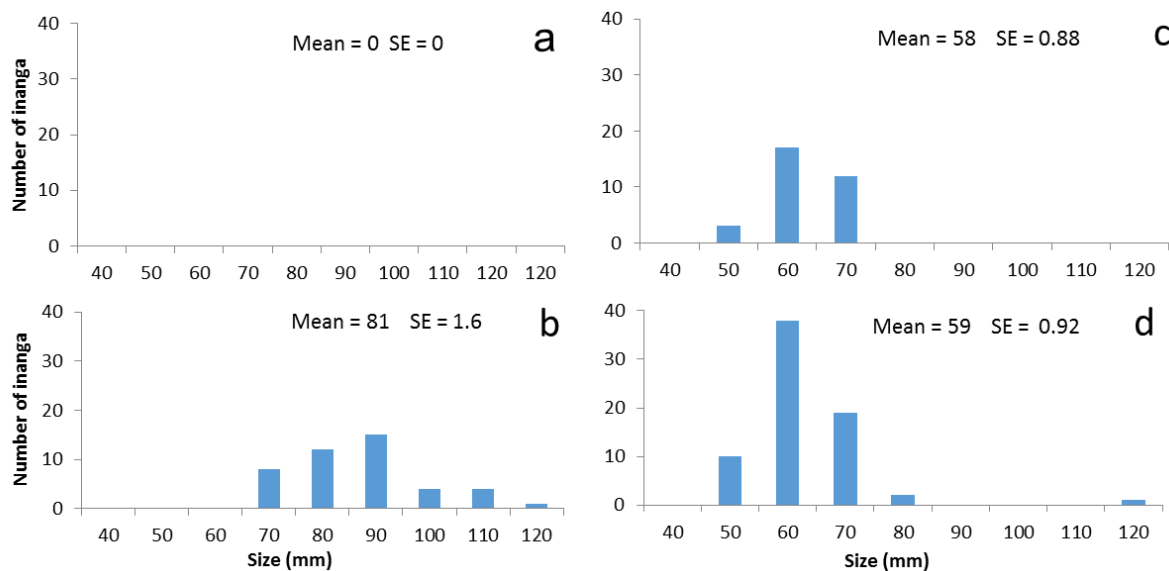


Figure 4.12: Size-frequency graphs of inanga abundance in the Awanui Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

The perched culvert apron on the Awanui Stream did not appear to be a barrier to shortfin eels. There was no significant difference in abundance or size in pre-treatment (Mann-Whitney  $U = 17.5$ ,  $P = 1$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) or post-

treatment samples (Mann-Whitney  $U = 14$ ,  $P = 0.57$ ; Kolmogorov-Smirnov test,  $P = > 0.1$ ). There were more shortfin eels caught in post-treatment sampling (Mann-Whitney  $U = 36$ ,  $P = 0.04$ ) but size ranges were the same as in pre-treatment sampling (Kolmogorov-Smirnov test,  $P = > 0.1$ ) (Fig. 4.13).

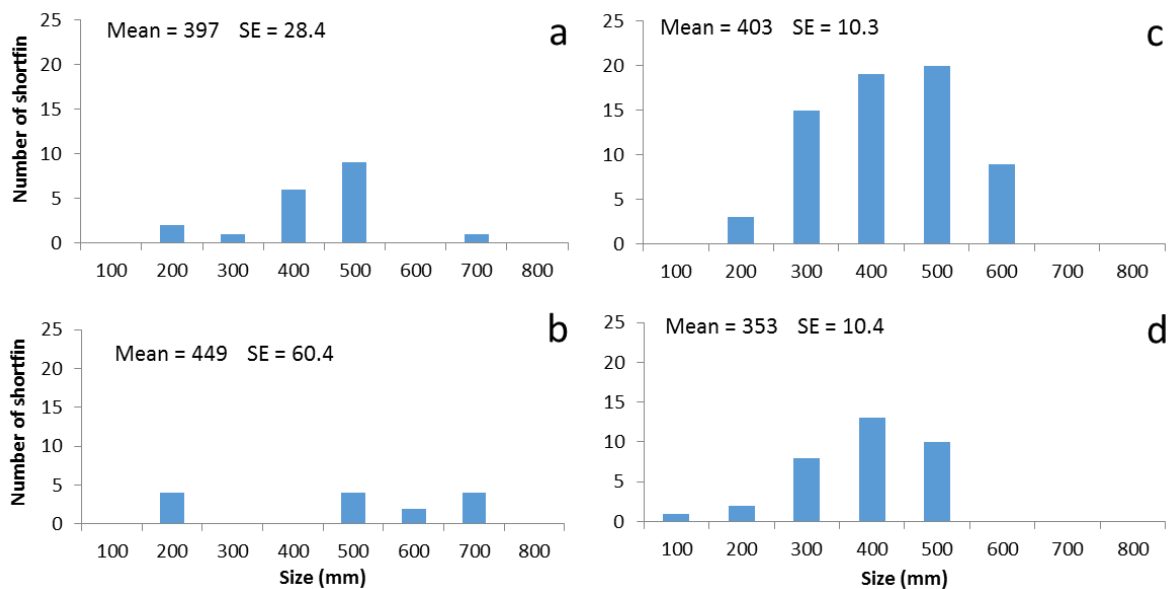


Figure 4.13: Size-frequency graphs of shortfin eel abundance in the Awanui Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

Longfin eels were much less common in the Awanui Stream than shortfin eels, and none were encountered in pre-treatment sampling (Table 4.1). In total, 32 were caught in post-treatment fishing, a significant increase over pre-treatment numbers (Mann-Whitney  $U = 30$ ,  $P = 0.002$ ), with no difference in abundance or size above and below the culvert (Mann-Whitney  $U = 49.5$ ,  $P = 0.2$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) (Fig. 4.14), indicating that the structure was not impairing longfin eel passage.

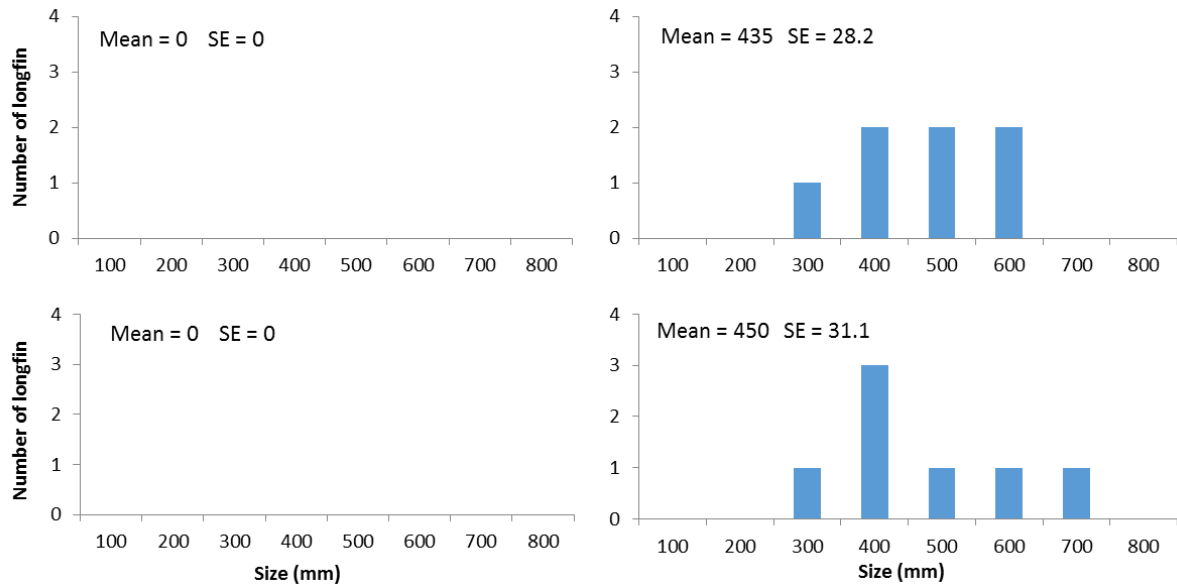


Figure 4.14: Size-frequency graphs of longfin eel abundance in the Awanui Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

### Irongate Stream

The fish community in the Irongate Stream was similar to that in the Awanui, with the same 7 fish species present (Table 4.1). Inanga were the most abundant species, followed by shortfin eels. Pre-treatment sampling showed the weir structure to be a significant barrier to swimming species, with only eels and gambusia caught in the upstream reaches. Inanga, goldfish, common bully and shrimp were only encountered in downstream reaches. Post-treatment monitoring revealed the same absence of swimming species in upstream sub-reaches. For inanga, the difference between upstream and downstream abundances was significant, with no fish caught in upstream reaches in both rounds (Mann-Whitney  $U = 3$ ,  $P = 0.02$  for pre-treatment and  $U = 5$ ,  $P = 0.05$  for post-treatment). Significantly more inanga were caught in post-

treatment sampling (Mann-Whitney  $U = 0$ ,  $P = 0.005$ ), and a significant difference in sizes was detected (Kolmogorov-Smirnov test,  $P < 0.05$ ) (Fig. 4.15).

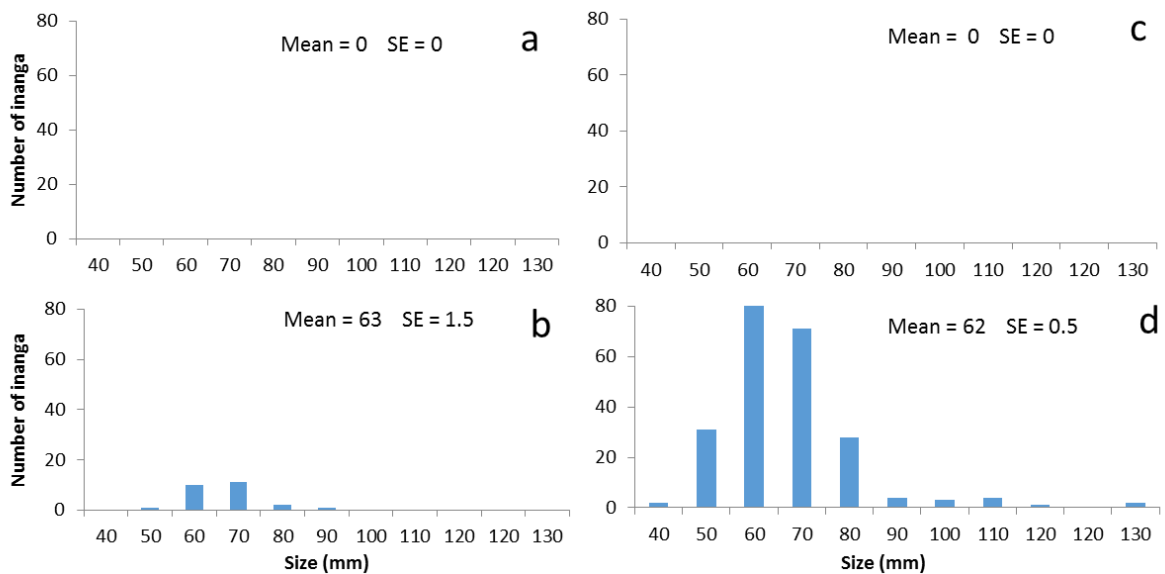


Figure 4.15: Size-frequency graphs of inanga abundance in the Irongate Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

The Irongate weir did not appear to be impairing passage of shortfin eels. Abundance and sizes were similar above and below the structure in pre-treatment (Mann-Whitney  $U = 14$ ,  $P = 0.57$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) and post-treatment (Mann-Whitney  $U = 16.5$ ,  $P = 0.87$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ), and also for both sampling rounds (Mann-Whitney  $U = 66.5$ ,  $P = 0.28$ ; Kolmogorov-Smirnov test,  $P = > 0.1$ ) (Fig. 4.16).

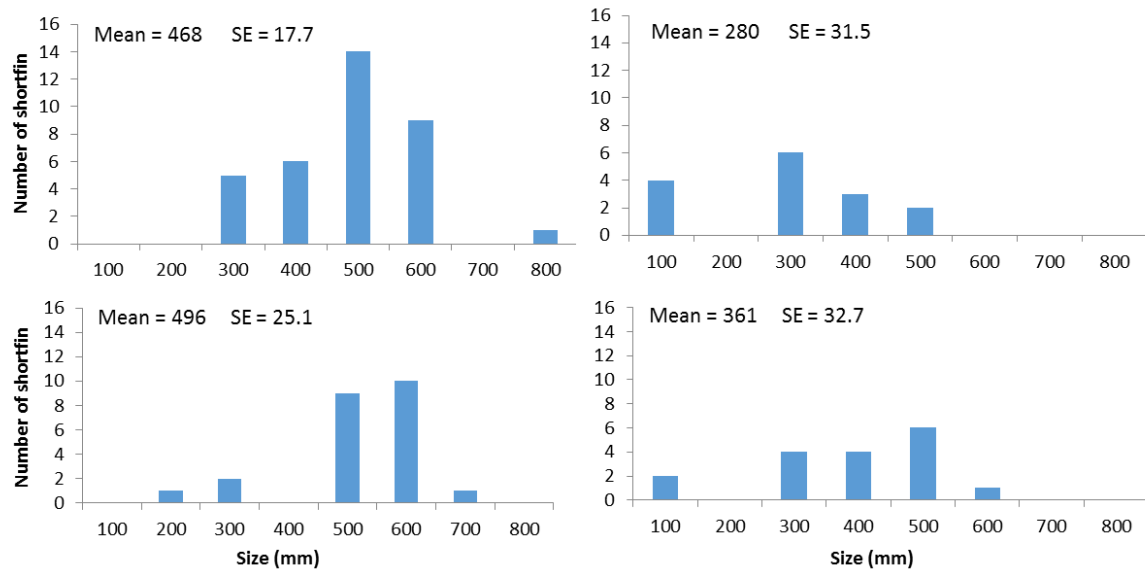


Figure 4.16: Size-frequency graphs of shortfin eel abundance in the Irongate Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

As with shortfin eels, the weir did not appear to be preventing longfin eels from accessing upstream habitat. There was no significant difference in abundance or size of longfin eels above and below the structure in pre-treatment (Mann-Whitney  $U = 16$ ,  $P = 0.81$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) and post-treatment (Mann-Whitney  $U = 14.5$ ,  $P = 0.64$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ), and similarly for both sampling rounds (Mann-Whitney  $U = 64$ ,  $P = 0.7$ ; Kolmogorov-Smirnov test,  $P > 0.1$ ) (Fig. 4.17).

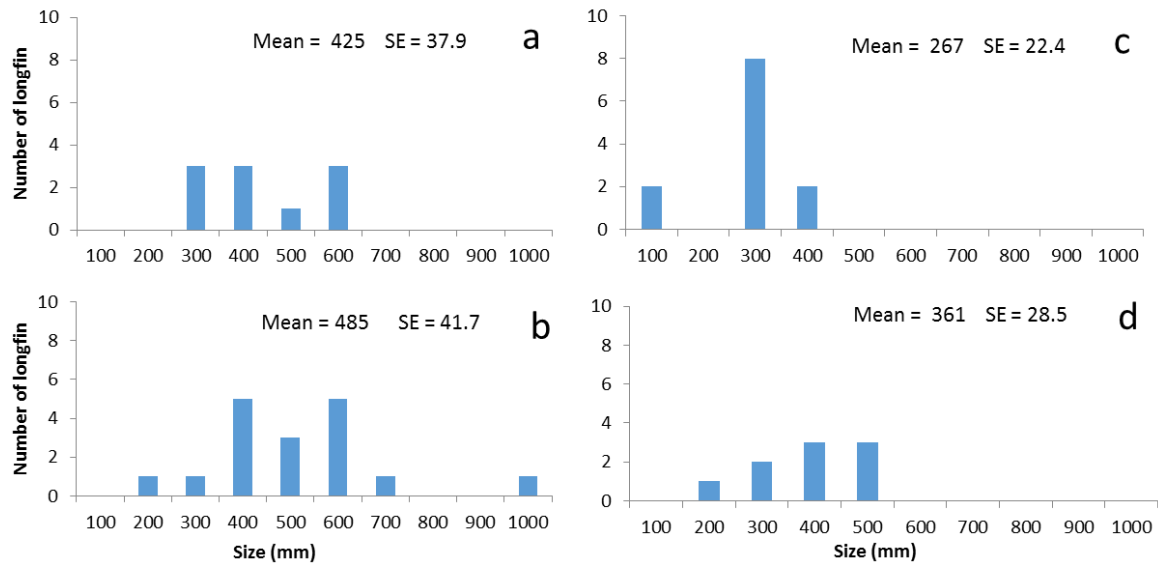


Figure 4.17: Size-frequency graphs of longfin eel abundance in the Irongate Stream. a) Pre-treatment, upstream sub-reach; b) Pre-treatment, downstream sub-reach; c) Post-treatment, upstream sub-reach and d) Post-treatment, downstream sub-reach. SE = standard error.

## 4.5 Discussion

### 4.5.1 Fish community composition

This study provides valuable species composition data for the 4 study streams which to date were not represented in the New Zealand Freshwater Fish Database (NZFFDB). Lowland streams in agricultural landscapes are often seen as degraded due to high turbidity, abundance of macrophytes and a dominance of fine bed substrates (Collier *et al.*, 1998). The Raupare, Irongate and Awanui Streams, despite being highly degraded (Haidekker, 2016), supported a range of native diadromous fish species, some of which are listed as threatened or declining (DOC, 2013). The 3 streams were all dominated by inanga and shortfin eels. Common bullies were frequently encountered in the Raupare site and less abundant at the Irongate and

Awanui. Inanga are the most commonly caught species in the highly prized whitebait fishery (McDowall, 1988). The abundance of this species at these sites highlights the important role that even apparently 'degraded' streams play as adult habitat, and emphasises the need to manage habitat and connectivity to support these populations.

The Waingonoro was dominated by redfin bullies, with torrentfish, longfin and shortfin eels and koaro also present. Redfin bullies, torrentfish and koaro were not present at the other 3 study sites, likely an artefact of stream habitat characteristics. Redfin bullies prefer streams with large gravel / cobble substrates, while torrentfish prefer swift water velocities and koaro prefer both coarse substrates, swift water, and often occupy streams with overhead forest cover (Jowett and Richardson, 1995; McDowall, 1990). Whilst redfin bullies and torrentfish are relatively common in Hawke's Bay, the scarcity of koaro in lowland streams regionally (Hughey *et al.*, 2012) highlights the value of this stream not only for regional fish biodiversity but also as a reference site for future monitoring.

Inanga abundance differed greatly between the pre-treatment sampling in April 2016 and post-treatment sampling in November 2017. This difference may be partially explained by timing of migrations for this species. The peak upstream migration period for juvenile inanga is August-November, while the peak of downstream spawning migrations of adult inanga occurs between March and July (Smith, 2014). Although fish were still reasonably abundant in the April pre-treatment sampling, the absence of inanga from the 2 downstream sub-reaches on the Awanui resulted in weaker power to detect a barrier impact. Pre- and post-treatment monitoring targeted at this species should therefore be conducted between December and February in order to better represent the inanga population in each stream.

#### **4.5.2 The impacts of instream barriers on fish**

Pre-treatment sampling revealed that species richness and abundance was much lower upstream of the barriers in the Irongate, Awanui and Waingongoro Streams. On the Irongate and Awanui Streams, the only migratory species encountered in the upstream reaches were longfin and shortfin eels, both strong climbers in their elver phase. Swimming species such as inanga were only encountered in downstream reaches, although on the Awanui, the difference between upstream and downstream inanga communities was statistically insignificant, likely due to inanga being absent from 2 sub-reaches downstream.

On the Waingongoro, the perched apron was shown to be acting as a barrier to redfin bullies and torrentfish, with significant differences in upstream/downstream populations. Indeed, torrentfish were only found in downstream reaches. For redfin bullies, the most abundant species occurring in the stream, significantly fewer fish were caught in upstream relative to downstream sub-reaches on both sampling occasions. Redfin bullies mature at 2 years at around 45 mm in length (McDowall, 1990), and possess some climbing ability, often occurring above modest falls (McDowall, 1988). Given the small number of young-of-the-year 35 mm fish in upstream sub-reaches, it could be inferred that the structure on the Waingongoro was not acting as a complete barrier to this species, and that limited recruitment was occurring. Figure 2.8 shows that the perching of the bridge apron in this stream was the result of a large flood event in 2011, so it is possible that some of the larger individuals are a remnant population from pre-2011 when connectivity was intact.

#### **4.5.3 Effect of ramp installation on fish**

Post-treatment monitoring showed that the addition of a rotomoulded floating ramp increased the abundance of inanga upstream of the perched culvert apron on the

Awanui Stream, but did not do so upstream of the weir on the Irongate Stream. Several factors are discussed below as to the efficacy or otherwise of the ramps in each stream which may have influenced their effectiveness, including i) ramp positioning ii) ramp angle and iii) retrofitting of the Awanui culvert

### Ramp positioning

The velocity of water on a ramp will directly affect the ability of fish to pass it, as increased velocities have been shown to reduce the burst swim distances of inanga (Boubée *et al.*, 1999). The ramp on the Awanui Stream was able to be positioned to the side of the main flow, in the low velocity margin. This was due to the culvert apron being wider than the culvert exit. Consequently the energy of the flows exiting the culvert will dissipate as it spreads laterally, resulting in a small portion of the overall stream discharge flowing down the ramp. Having the ramp positioned on the low velocity margin also meant that less water was spilling over the apron perch at each side of the ramp, minimising aeration and turbulence at the ramp entrance. The effect of excessive aeration on fish passage performance is well documented, with Haro and Kynard (1997) suggesting that the migratory motivation of fish may be disrupted by high turbulence, upwelling and aeration below weirs. Indeed, Baker (2003) also noted that turbulence as a result of fall height may decrease the passage performance of inanga and common bullies over experimental weirs.

Baker (2003) also noted the importance of low velocity margins on weir structures for inanga and common bully passage. On the Irongate, the weir walls are narrower than the stream channel, which concentrate flows over the lip. This results in an absence of a low velocity margin to position the ramp, and a consequent large portion of stream discharge spilling over onto it, relative to the Awanui. As depicted in 4.2, the plunge pool below the weir on the Irongate is highly aerated and turbulent.

The effect of aeration and turbulence of plunge pools on fish passage was discussed above. There is therefore cause to suspect that this aeration may be a factor that prevented fish from passing this ramp. In addition to the turbulent conditions, the depth of the plunge pool (c.1.5 m) and distance of the bottom of the ramp from the terminal weir wall may mean that fish are less likely to find the bottom of the ramp. Clay (1995) stressed that one of the most crucial aspects of fish passes is that shoals must be able to find the entrance promptly. If fish do not find the entrance, it may lead to delayed migration, or even resulting in no fish passing the ladder altogether (Agostinho et al., 2007).

I described this mechanism, albeit on a smaller scale, in Chapter 3 when comparing exploration of trial fish in my bottom large tanks compared with previous ramp studies where fish had no room to explore (Baker and Boubée, 2006; Baker, 2014). Although from a trial over a 3-hour period, the observed inability of fish to locate ramps could occur over longer time scales in real world settings if factors such as turbulence and aeration in combination with a deep plunge pool are considered. It is conceivable that the chance of ramp encounter and thus passage success of fish may be less in these conditions, relative to the calm, shallow stream margin in which the Awanui ramp was situated. While this is less likely to affect a pelagic swimmer such as inanga which may do more exploration of surface waters, the efficacy of the ramps for benthic species in these settings may be limited. The presence of a lone young-of-the-year common bully in an upstream sub-reach in the first post-treatment monitoring (when data was not used due to low overall catch rates) does, however, suggest that passage is at least possible for this species in settings such as the Irongate.

### Ramp angle

The height of a structure relative to the downstream water level will determine the angle at which the ramp will operate, and the angle of the ramp will affect the velocity of water flowing down it (Doehring *et al.*, 2012). Baker (2014) showed that ramp angle is a strong determinant in passage success of inanga. The previous chapter showed that 55% of inanga were able to surmount a ramp lined with 'small mira' panels at a 15° angle. As the perch height of the concrete apron on the Awanui is around 0.4 m at low flows, maximum ramp angle encountered by fish in the Awanui will be c.10°.

The height of the drop on the Irongate weir at low flows is c.0.5 m. Given this, a 2.4 m ramp which is floating as per designed will be sitting at c.13°, which is less than the suggested 15° maximum slope for baffled ramps suggested by Baker and Boubée (2006). Unfortunately, buoyancy issues plagued the ramp at the Irongate site. Although the plastic ramps have a certain amount of inherent buoyancy, a number of combined factors including leakage from panel screw holes, the volume and thus weight of water flowing over the ramp, and aeration of the plunge pool below the weir likely resulted in around half of the ramp being submerged, creating a steeper ramp angle, perhaps as steep as c.30°. This in turn meant that velocities were increased, which would have impacted passage success of swimming species such as inanga as velocities may have exceeded the thresholds 1.07 m/s for small adults or 1.35 m/s for large adults to negotiate passage, as described by Boubée *et al.* (1999). Alternatively, velocities may have been such that fish were unable to burst swim the c.1.2 m of ramp above the water. Although Baker (2014) found large inanga were still able to surmount Miradrain® ramps at 30°, the flow rate on the Irongate ramp, although not measured, is likely to be well in excess of the 1.1 L/s tested in the study mentioned and therefore

passage is likely to be more difficult. These buoyancy issues and efforts to resolve them are discussed in greater detail in Chapter 5.

### *Awanui culvert retrofit*

As described earlier, unfavourable conditions for fish passage existed above the perched apron (and therefore the ramp) on the Awanui Stream, with laminar flow across the 2.6 m long concrete apron and throughout the 8 m long culvert. Other studies have shown that retrofit solutions such as baffling media and spat rope can aid in inanga passage through culverts (Amtstaetter *et al.*, 2015; David *et al.*, 2014; Franklin and Bartels, 2012; MacDonald and Davies, 2007; Stevenson *et al.*, 2008). In the Franklin and Bartels (2012) study, fish community response upstream of a 74 m long perched culvert on the Bankwood Stream, Waikato, remained unchanged despite the installation of a 16 m long baffled concrete ramp with a 5.7° slope. Further monitoring of the pool at the top of the ramp revealed that fish were in fact passing the ramp but were unable to pass through the culvert due to the hydraulic conditions within. Installation of spoiler baffles within the culvert resulted in 6.2% of inanga passing the culvert over 12 hours. As noted by the authors, this rate is relatively low compared to the results from studies mentioned above, perhaps an artefact of the overall culvert length. MacDonald and Davies (2007) found 80% of inanga were able to pass a 5.5 m long culvert fitted with spoiler baffles, compared to the 8 m long culvert in the present study.

Elsewhere, Stevenson *et al.* (2008) showed that Stripdrain™, a drainage product similar to Miradrain®, can be an effective baffling medium in small culverts for the provision of low velocity zones for inanga passage. In my study, similar efforts were undertaken to improve hydraulic conditions for passage within the culvert. 'Small mira' panels (the same as used on the ramp) were fixed with 5 mm stainless

mushroom spikes to the wall of the culvert, and from the culvert exit down to the top of the ramp. Spat rope was also laid from the culvert exit to the top of the ramp. In the absence of any targeted before-and-after monitoring of these measures, however, the effect on inanga passage in my study is speculative. Stevenson *et al.* (2008) also noted the limitation of the Stripdrain™ surface for wider-bodied species, a concern similar to my observations of Miradrain®. ‘Large mira’, with its wider cusp spacing, could potentially remedy this. Further studies should be conducted on the efficacy of both ‘small mira’ and ‘large mira’ panels as a culvert baffling media for wide-bodied species.

#### **4.5.4 Conclusion**

The study has provided important information on the composition of lotic fish communities in this part of the Hawkes Bay region, and highlighted that even apparently degraded waterways can provide important habitat for valued fish species. My sampling has also highlighted that culverts can have significant effects on upstream passage for some species, although results varied among sites depending on the characteristics of the barrier. Overall, the Awanui ramp showed that Miradrain® can be an effective remediation tool for enabling small, migratory fish past low-head barriers, particularly where ramps can be offset from the main flow. Inanga are considered a weak swimmer, and have been used as a benchmark species for fish passage experiments (Baker, 2003; Baker and Boubée, 2006; MacDonald and Davies, 2007). Thus, if inanga are able to surmount barriers using these ramps, it could be inferred that they would be effective in allowing more adept swimming and climbing diadromous species to pass in such settings. The lack of passage success for inanga on the Irongate Stream introduces potential caveats for ramps where excessive turbulence, aeration and a lack of low velocity margins exist. It also highlights the

importance of thorough pre- and post-treatment monitoring to evaluate the efficacy or otherwise of remediation efforts.

## Chapter five

# General Discussion

## 5.1 Introduction

The aim of this thesis project was to build on previous work on ramps as a fish passage tool for migratory species. I did this by experimenting with previously untested surfaces in a controlled environment to inform the design and production of a low-cost, functioning ramp unit that could be trialled in a real world setting over a migration season. Two phases of tank trials culminated in a mould for a rotational moulded plastic ramp, and 2 textured vacuum-formed plastic panel moulds, called 'small mira' and 'large mira' based on the cusps configuration of a drainage product called Miradrain®. The use of rotomoulding and vacuum forming techniques meant that additional ramps, complete with fixed textured panels could be produced for under \$300. The third phase of tank trials showed that both of these surfaces were successful (to varying degrees) in the upstream passage of inanga and redfin bullies over the ramps at a 15° angle. Spat rope added to these ramps was also shown to improve passage rates for redfin bullies, but not inanga.

To test in-situ ramp efficacy for inanga, ramps were installed at barriers in 2 lowland sites. Pre- and post-treatment fishing surveys were undertaken in sub-reaches upstream and downstream of barriers on these streams, as well as on 2 control streams. Results from these surveys gathered valuable fish species data from these streams where it was previously absent, and shed light into the effect that migration barriers were having on migratory fish communities. Finally, this work proved that these ramps can be an effective, robust and low-cost tool for the remediation of low-head obstacles in small streams, and highlighted various installation and maintenance issues requiring attention.

## 5.2 Tank trials and ramp production

### 5.2.1 Ramp surface effect

As mentioned above, 3 phases of tank trials aimed to build on and refine existing knowledge around ramps, looking to find an optimal textured panel that could be fixed to ramps to best facilitate the upstream passage of small migratory species. Results found that Miradrain® was most effective in enabling passage of inanga, as in previous works by Baker and Boubée (2006) and Baker (2012). Efforts to remediate barriers and restore connectivity require an appreciation for the species present in the system, as well as an understanding of their life histories and swimming abilities (Clay, 1995; David and Hamer, 2012; Williams *et al.*, 2011). As in previous works (Baker and Boubée, 2006; Baker, 2014), inanga, a weak 'swimmer' (Mitchell, 1999), and redfin bullies, a weak 'climber' (Boubée *et al.*, 2000), were used as benchmark test species with the assumption that if these species can pass the ramps, then stronger species should also be successful in doing so.

The velocity encountered by fish on a ramp will affect their ability to pass it (especially swimming species such as inanga), as swimming against a swifter current requires more energy, and reduces the distance that they can cover using burst swimming (Boubée *et al.*, 2000). Phases 1 and 2 showed that the Miradrain® (including the 'rock and mira' ramp from phase 1 which had rock holds inset in Miradrain® panels) surfaces had both the slowest velocities and highest passage success for inanga. However in phase 3, 'small mira' ramps with spat rope had significantly higher passage rates for inanga, despite having velocities that were not significantly different to 'large

mira' ramps with spat rope. This indicates that velocity alone is perhaps not the key driver of passage success for these ramps.

Stevenson *et al.* (2008) found that a staggered arrangement of rectangular spoiler baffles were most effective in slowing water velocities and promoting passage of inanga through large (0.8 m) culverts. The creation of a vacuum formed surface with staggered (rather than the linearly arranged rows on Miradrain<sup>®</sup>) cusps for phase 3 was mooted early on in experimental planning, although in phases 1 and 2 inanga were observed to utilise inter-cusp channels to good effect, their lateral movements were restricted by the cusps on either side. Rock holds, trialled in phases 1 and 2, were observed to serve as barriers to burst swimming inanga which were often seen swimming directly into them. These observations suggest that, although a surface with staggered cusps would likely be more effective at slowing water velocities, benefits of the unimpaired passage up higher velocity channels between linear cusp rows perhaps outweigh this.

The 'large mira' surface trialled in phase 3, with wider cusp spacings, allowed inanga to zig zag laterally across the ramp, increasing the distance and therefore time of passage attempt. Many more fish were observed tiring before making the top of the ramp compared with the 'small mira' surface, and these observations are further reflected in passage results. Although the 'small mira' inter-cusp channels may be an optimal width for inanga, consideration must be given to wider-bodied species such as torrentfish and other galaxiids, and whether they too are capable of utilising these channels. This is discussed further in Section 5.5.

Several studies have demonstrated mussel spat rope to be an effective and low-cost fish passage remediation tool (David and Hamer, 2007; David *et al.*, 2009;

2014). My study showed that average velocity decreased, depth increased and redfin bully passage increased with the addition of spat rope down the centre and wetted margins of ramps. It is therefore recommended that spat rope be included in ramp installations. Debris accumulation is likely to occur, and in some circumstances may add to the baffling effect of the media, perhaps a positive outcome for fish passage. Excessive debris build up, however, may lead to cusp channel blockage or rope fixings being blown out. This is something to consider for streams with high macrophyte / woody debris drift, and managers may decide to remove or not replace damaged or lost strands.

### **5.2.2 Comparison with other studies**

Overall, passage success for both species was low relative to similar studies by Baker and Boubée (2006) and Baker (2014). Two key differences between my study and the ones mentioned were discussed in Chapter 3 in terms of (i) flow rates and (ii) experimental set-up. The flow rates (and consequent velocities) in my study were greater than in previous works (2.5 L/s compared with 1.1 L/s; 0.82 m/s compared with 0.52 m/s). The effect of velocity on swimming performance is discussed above.

It is prudent that laboratory trials replicate as much as possible, conditions that may exist in real world scenarios. Given that most of New Zealand's diadromous species migrate upstream in spring when base flows may be higher due to seasonal rainfall (McDowall, 1995), and that low-head barriers occur on a wide range of stream sizes, there is considerable value in investigating passage performance under higher flow volumes such as those used in my trials. A key consideration for ramp installation in streams then becomes ensuring that they are set to the margin of the stream, out of the main flow. In addition, the installation of a spoiler or diverter baffle fixed to the structure above the ramp may be a practical measure in reducing ramp flow rates.

The difference in lower holding tank set-ups may be another factor influencing the lower passage success in my study. One of the key considerations of fish passage works is that fish are able to find the entrance promptly (Agostinho *et al.*, 2007; Clay, 1995). Much larger tanks provided greater scope for exploration or hiding, and having my ramps floating rather than fixed to the bottom may have resulted in reduced passage motivation, particularly for benthic species. Again, this is likely more representative of a real world scenario, where fish are not guaranteed to locate the ramp entrance, although is arguably a sub-optimal experimental design for testing passage ability considering the 3 hour timeframes for trials.

## **5.3 Field trials**

### **5.3.1 Species composition and the impact of barriers on distribution**

Netting and electro-fishing surveys revealed valuable species composition data for the data-poor study streams, and shed light into the impact that the 3 barriers were having on migratory species. Results from the 3 streams in the Karamu catchment revealed species assemblages typical of gently-flowing lowland streams, most commonly inanga, eels and common bullies, all of which are diadromous. Instream barriers on the Awanui and Irongate streams appeared to be impairing upstream passage of inanga, but not that of eels. Inanga were numerous in downstream sub-reaches and absent from all upstream reaches in pre-treatment sampling. Eels were present in similar numbers and sizes in both upstream and downstream sub-reaches. This is somewhat expected given the climbing ability of eels who would be able to climb the wetted margins of both structures as elvers.

The Waingongoro Stream showed species assemblages more typical of cobble-dominated, steep, fast-flowing habitat characteristics (Jowett and Richardson, 2003). The most common species encountered in the Waingongoro were redfin bullies, eels, torrentfish and koaro, all of which are diadromous. The perched bridge apron appeared to be hindering passage for redfin bullies and torrentfish, with significantly fewer bullies and zero torrentfish encountered in the upstream reaches over the 2 sampling rounds. Eel numbers were similar between upstream and downstream reaches, however, indicating that they were unhindered by perched culvert apron.

### **5.3.2 Effect of ramps on fish barriers**

Post-treatment monitoring showed that the ramp successfully enabled inanga to access upstream habitat in the Awanui Stream, significantly increasing the abundance of this species above the perched culvert apron. In the Irongate, however, inanga were absent from all sub-reaches upstream of the culvert, despite being abundant in downstream reaches, indicating that the ramp was unsuccessful in facilitating passage for this species. In Chapter 4, I listed several differences between the sites that may explain the differing successes of these installations. These differences included (i) ramp angle and position, and (ii) depth, aeration and turbulence of the plunge pool.

In my opinion, one of the key factors influencing the effectiveness of the Awanui ramp was the position of the ramp. Being able to install the ramp in the low velocity margin of the stream meant that velocities of water flowing over the ramp appeared (although not directly measured) to be much lower than those on the Irongate ramp which, due to the lack of a low velocity margin, was installed in swift water. The effect of velocity on the swimming performance of fish has been discussed above. Further impacting this velocity difference would be ramp angle, which on the Awanui was lower

than the Irongate, owing to the perch height of each structure. The Irongate ramp also suffered buoyancy issues, sinking slightly as a result of gradual leakage around panel screws, the weight of water flowing over the ramp (again potentially a function of a lack of low velocity margin), and the highly aerated plunge pool. Due to the slow leakage, it is not known how long this took to occur, and consequently it went unnoticed for some time. Efforts to rectify this are discussed later, but recent buoyancy upgrades have resulted in the ramp floating as designed. It is recommended that further sampling of the upstream and downstream sub-reaches is undertaken after the next migration season to investigate whether these remediation measures have increased the efficacy of the ramp in this setting.

Haro and Kynard (1997) suggested that the passage motivation of fish may be disrupted by excessive turbulence, upwelling and aeration of the plunge pool. Baker (2003) also discussed this effect on inanga attempting to pass experimental weirs. Figure 4.2 shows the differences in aeration and turbulence of plunge pools between the 2 sites. On the Awanui Stream, the culvert apron spreads laterally from the culvert exit, allowing flows to dissipate which, combined with a shorter fall height, means that aeration of the plunge pool is less than on the Irongate. Baker (2003) suggested that newly-constructed weirs be wide enough to allow plunge pools to have low velocity margins for fish to rest before attempting passage. The weir structure on the Irongate is narrower than the upstream channel, which concentrates flows over the weir and thus the ramp, resulting in a lack of low velocity zones and a high degree of plunge pool aeration (Fig. 4.2) which may mean fish are less likely to find the ramp, let alone attempt to pass it.

## 5.4 Ramp design and production

Cost is a major prohibiting factor in the widespread uptake of remediation works, given the high numbers of barriers occurring at road crossings nationally, and the prohibitive cost of replacing and or repairing fish passage structures that have been lost or damaged in flood events. Rotational moulding of the ramp and vacuum forming of the textured panels yielded several benefits to the project, including low unit costs, natural buoyancy, future-proofing surface options, and a potential additional use for textured panels and baffling media for culverts. Besides the initial mould costs, rotomoulding and vacuum forming enable the repeated production of ramp units for under \$300, a truly low-cost solution when compared with the cost of culvert replacement, weir removal, construction of a concrete ramp (Lariner, 2002), or the cost of a custom-built fish ladder such as those existing in the New Zealand market to date.

Plastic ramps have a certain degree of inherent buoyancy, an attribute which is integral to the unique way that they are designed to function. Having a ramp attached to the structure via a flexible rubber hinge at the upstream end, with the bottom end floating in the water has many advantages over ramps fixed in place by poles embedded into the stream bed. Firstly, upright poles have the potential to accumulate flood debris and can become either undermined from excessive scouring, a common issue for bridge pillars in event flows (Pagliara, & Carnacina, 2007), or damaged by way of a direct hit from flood debris. These issues would not occur with a floating ramp. Secondly, a flexible hinge allows ramps to rise and fall with floodwaters (meaning as water levels increase, ramp angles decrease), or to sink if larger substrates are washed over them in flood events (Fig. 5.6). Ramps can also move laterally in flood eddies, reducing strain on fixing points, and can be cut to optimal length using a

handsaw where plunge pool length and or depth may dictate that a standard 2.4 m long ramp is too long (Fig. 5.1).



Figure 5.1: A 'Half ramp' which has been cut down to 1.2 m in order to fit in the short plunge pool of the Brook Stream, Nelson. Note blue colouration of plastic panels from early manufacturing runs. Panels are now black.

As eluded to previously, the start-up mould costs for rotational moulding and vacuum forming plastic products are high. The creation of a ramp mould cost \$4500, and each of the 2 panel moulds cost \$1125. By having textured panels attached to ramps, rather than a textured ramp, I was able to experiment with 2 ramp surfaces for a lower cost. This has not only resulted in users being able to choose from 2 surface options (or a multi-surface ramp featuring both types of panels), but facilitates a degree of future-proofing by allowing the further testing of new surface designs, which would cost \$1125 for a panel mould as opposed to \$4500 if roughening elements were on the ramp itself.

Stripdrain™, a drainage product featuring raised cusps similar to Miradrain®, has been shown to be effective in improving passage success of inanga in small culverts (Stevenson *et al.*, 2008), with fish swimming in inter-cusp channels to pass the obstacle. One major concern with any instream installation must be the robustness and ability to withstand damage from bedload and debris in high flow events. Being designed to withstand diffuse pressure as a subterranean drainage product, the thickness of Miradrain® and Stripdrain™ sheeting is such that cusps are unlikely to retain their structural integrity upon sustained impact from moving cobbles or boulders in a flood event for example. Several thicknesses of textured panels were produced and tested for their cusp strength, with 4 mm thick sheets decided upon as they could withstand acceptable pressure from above. These panels were installed in the culvert on the Awanui Stream, secured in place with 5 mm mushroom spikes. Upon post-treatment monitoring 12 months after installation, all panels were found to be intact and undamaged, although as the substrate of the Awanui is dominated by a lack of coarse particles, the impact resistant aspect of these panels for this application remains untested. Further testing of these panels in a culvert setting is recommended.

## **5.5 Ramp installation and monitoring**

Ramps are held in place via a 560 mm wide x 300 mm long strip of 10 mm thick conveyor belt rubber which acts as a hinge. This is attached to the top of the ramp with 6 m8 stainless hexbolts, the holes for which are cast in the ramp mould. Conveyor belt rubber has a high tensile strength, whilst also being flexible enough to allow the ramp to rise and fall and move sideways under eddy currents in flood events. The

strength and effectiveness of this hinge design is apparent when one considers the flood resilience of these ramps both in the field trials, and other examples around New Zealand, discussed later in Section 5.6.

The simplicity of the attachment mechanism is another advantageous aspect of the overall ramp design, in that installation costs are kept at a minimum. In a typical culvert or apron setting such as the Awanui, holes are drilled in the concrete and the rubber hinge is fixed using 5 mm stainless mushroom spikes which are hammered into place (Fig. 5.2). In the Awanui installation, this process was able to be completed by 2 people in less than 15 minutes. In swifter conditions, the process may require additional assistance to steady the ramp. For the Irongate weir, a steel bracket was constructed which spanned the top of the weir and was fixed to the upstream weir wall on either side, to which the rubber hinge was attached, again with stainless steel m8 hexbolts.



Figure 5.2: The author using a slide punch to hammer in mushroom spikes during installation of the Awanui ramp. Note the absence of textured panels at this stage of the installation.

Baffles can be used to manipulate the volume and rate of water flowing over the ramp (Figs 5.3, 5.5). These can serve to direct a larger amount of water over ramps in low flows, or conversely to direct water away in high flows. In a small culvert setting where the majority of the stream flows down the ramp, a baffle or series of baffles upstream of the ramp will reduce both the velocity of water above and on the ramp.



Figure 5.3: Flexible baffles (ATS Environmental) directing water over a floating fish ramp in Nelson.  
Photo credit: Tim Olley, Fish and Wildlife Services.

The buoyancy issues on the Irongate ramp highlight the need for inspection of any fish passage remediation structures. Inspections should be carried out at the beginning of the peak migratory period for species at a minimum (Adams and Whyte, 1990), but where possible post-flood event inspections are prudent given that many species such as inanga have been documented to migrate year-round (McDowall, 1965). Inspections should investigate not only ramp and panel presence, but also the integrity of the rubber hinge and spat rope additions, as well as ramp buoyancy. In the Irongate scenario, HBRC staff who visit the site regularly were only instructed to report on ramp presence, and not angle. This resulted in a critical delay in discovering the buoyancy issues. This issue highlighted a key design flaw for situations where a large

mass of water flows over the ramp. Although the plastic ramps have a certain inherent buoyancy, gradual infiltration of water around panel screw holes will result in the ramp filling with water, causing more of the ramp to be submerged. This is then compounded with the weight of water on the ramp at any given time, and potentially by high aeration of the plunge pool.

The first attempt to rectify this problem took place after the initial post-treatment round of monitoring when it was first discovered. The bottom end of the ramp was removed with a handsaw, and foam noodles were inserted in the hollow internal cavity. Unfortunately, upon the next round of post-treatment sampling, the ramp was again found to be partially submerged. Closer inspection revealed that some of the foam, although tightly wedged into place when first installed, had travelled further inside the ramp and become lodged above the water line where it was offering no additional buoyancy at the desired angle. This has since been rectified with the use of plastic cable ties to hold the foam in place (Fig. 5.4), resulting in the ramp sitting at the desired angle long term. All future ramp installations should consider these modifications.



Figure 5.4: Buoyancy improvements to ramps – opening up of the bottom end of ramp to allow leaked water to flow out, and installation of foam noodles. Photo Credit: Kelly Hughes, ATS Environmental.

## 5.4 Crowd funding and collaboration in design process

Given the shared nationwide problem of low-head fish barriers, and the high start-up mould costs, funding and design input was sought from a range of parties from around New Zealand at the start of this project. Initially, trial results from phase 1 and 2 of ramp experiments, along with a funding proposal, was shared with key personal from Regional, City and District councils around the country, as well as the National Institute of Water and Atmospheric Research (NIWA), DOC and ATS Environmental. Accompanying this proposal was a letter of endorsement from the New Zealand Fish Passage Advisory Group (NZFPAG) who had reviewed the project and results.

In the proposal, parties were offered subsidised rotomoulded ramp units in exchange for a share of the initial mould production costs. A total of \$18,000 of funding

was received from 9 authorities including Waikato Regional Council, Gisborne District Council, Hawke's Bay Regional Council, Horizons Regional Council, Greater Wellington Regional Council, Tasman District Council, Nelson City Council, Environment Canterbury and Environment Southland. These authorities, as well as NIWA, DOC and ATS Environmental were all consulted on experimental direction for phase 3 trials, including the design of the 'large mira' surface, vacuum formed panels versus textured ramps, and the overall design of the ramp itself. The \$18,000 received was well in excess of the mould production costs, and each council chose to use their leftover funds as credit towards ramp and panel units. This collaborative approach provided excellent cost-effectiveness and information sharing, and has resulted in the installation of scores of ramps in low-head obstacles around New Zealand.

## 5.5 Future research

Questions still remain about the effectiveness of the 'small mira' surface in facilitating passage of wider-bodied species, in terms of their ability to physically fit in the inter-cusp channels of this surface. This concern was also raised by Stevenson *et al.* (2008) with Stripdrain™ as a culvert baffling media, who recommended a media with cusp spacings of 40–50 mm to cater for these wider fish. The 'large mira' surface in phase 3 featured these wider cusp spacings, and results showed that inanga were less able to pass this surface with 39% passage compared with 'small mira' at 55% passage. Further experimentation of both of these surfaces should be conducted, expanding the species mix to juvenile and adults of species such as torrentfish and other galaxiids such as koaro and banded kokopu. If it is indeed found that the passage of wider-

bodied species is hindered by 'small mira' cusp channels, then managers may concede reduced passage success to be an acceptable trade-off for allowing passage to a wider mix of species. Another option for managers is a multi-surface ramp with 'small mira' panels on one side and 'large mira' panels on the opposing side of the ramp to cater for a wider range of species.

Further research into optimal spat rope strands for fish passage is also recommended. My research found that depths increased, velocities decreased, and the passage success of redfin bullies increased with the addition of spat rope strands down the centre and margins of the ramp. Additional strands would likely deepen and slow velocities further, potentially having a positive impact on fish passage. However, a trade-off will exist given the likelihood of ropes to catch debris. While small amounts of debris may add to the baffling effect of the ropes, large amounts may create blockages and become impediments to fish passage. Furthermore, these blockages may cause rope fixings to fail under the sheer weight of the water behind them.

Another key consideration for this application is the ability of introduced species to pass the ramps. Described by McDowall (1990) as 'the least desirable fish in the New Zealand fish fauna', due to their negative impacts on water quality and aquatic habitat, koi carp *Cyprinus carpio* are one species where the exclusion from upstream habitats such as small lakes and ponds would be a desirable management outcome. A ramp surface that facilitated passage for native fish species and excluded pest fish would be beneficial, and future testing of the passage success of invasive species such as koi carp, redfin perch *Perca fluviatilis*, and brown bullhead catfish *Ameiurus nebulosus* over the 'small mira' and 'large mira' surfaces is recommended.

Rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* are other species where exclusion from upstream habitat may be deemed appropriate. The deleterious effect of trout on native fish is well documented (Deans *et al.*, 2004; McIntosh, 2000; Townsend, 1996). Conversely, settings may occur where barriers are preventing adult trout from entering prime spawning habitat. Both of these scenarios call for the swimming abilities of adult and juvenile trout to be tested on 'small mira' and 'large mira' surfaces.

As mentioned earlier, Stevenson *et al.* (2008) demonstrated that the addition of Stripdrain™ assisted in the culvert swimming ability of inanga. In my study, 'small mira' panels were laid along the wetted margin of the 8 m culvert in the Awanui Stream, however, it is not clear whether this addition aided in the passage of inanga through the culvert as no 'before and after' experimentation occurred. Laboratory testing of the 'small mira' and 'large mira' panels for this purpose is also recommended. While the panels withstood the increased barrel velocities of a significant rain event over the duration of the 18-month trial period, the robustness of the panels in terms of bedload damage was untested, as the substrate of the Awanui Stream is fine silt. Trialling both panels in a stream with larger substrate sizes is recommended to assess this.

## 5.6 Afterword

The collaborative funding and design approach has resulted in the production of a low-cost, robust and effective ramp unit which has been installed in streams in both the North and South Islands of New Zealand. Two ramps in particular speak to the robustness of the design. The first ramp, in a tributary of the Matahina River, Rangitaiki catchment, Edgecumbe, withstood severe flooding during Cyclone Debbie on the 6<sup>th</sup> April 2017. The Rangitaiki River peaked at 828 m<sup>3</sup>/s, a 1-in-500 year event. The Matahina ramp was inspected post-event, and found to be in working order (Fig. 5.5). The substrate of the stream is dominated by coarse gravel/cobble (K. Hughes, ATS Environmental, pers. comm.), and therefore the ramp would likely have been subject to much bedload contact.

The second ramp was installed in the Saxton Stream in Nelson, at a gravel trap structure (Fig. 5.6). During a storm event in February 2017, the ramp was subject to a high degree of bedload movement, with large gravels and boulders being transported over the gravel trap and down the ramp. Upon inspection post-event, the ramp was found buried under a considerable amount of large gravels and cobbles, but still attached to the wooden gravel trap structure and 100% intact. This speaks not only to the impact resistance of the materials, but also the floating design which allowed the ramp to sink under the weight of the substrate.



Figure 5.5: Floating fish ramp in the Kakahotoa Stream, Matahina catchment, Edgumbe. Photo taken post Cyclone Debbie. Note flexible baffles directly above the ramp. Photo credit: Kelly Hughes, ATS Environmental.



Figure 5.6: Before (left) and after (right) flood event photos for the ramp fixed to the gravel trap on the Saxton Stream, Nelson. Although obscured by substrate, the ramp and hinge are still attached to the wooden wall of the trap. Note blue 'large mira' panels from first batch of panels. Panels are now black.

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