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WAITUNA CREEK INSTREAM RESTORATION TRIAL ASSESSMENT: THE EFFECT OF INSTREAM HABITAT STRUCTURES ON THE FISH COMMUNITY

WAITUNA CREEK INSTREAM RESTORATION TRIAL ASSESSMENT: THE EFFECT OF INSTREAM HABITAT STRUCTURES ON THE FISH COMMUNITY

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EXECUTIVE SUMMARY

This report describes the native fish population's response to a stream rehabilitation trial in Waituna Creek, the main tributary of the Waituna Lagoon (Southland). Annual quantitative fish population data have been collected in association with the trial for 8 years. Rehabilitation actions included reshaping a (previously) trapezoid channel into a two-stage channel, installation of large woody structures and riparian planting along two (approximately) 200-m long stream reaches.

The native fish community responded positively to the rehabilitation actions. Three years after the rehabilitation actions were completed, there was significantly higher diversity, density and biomass of native fish around the large woody structures when compared to upstream control patches that were typical of unrestored habitat in the wider river segment.

At the reach scale, we found a significant increase in the biomass of giant kōkopu and large longfin eels in one of the two rehabilitation reaches. In addition, juvenile lamprey were present in one of the rehabilitation reaches for the first time (over a seven year period) after the rehabilitation actions were completed. Overall, from the perspective of improving native fish habitat, the rehabilitation project can be considered successful, as evidenced by highly valued native fish species preferentially selecting the habitat(s) created by the rehabilitation trial.

At the end of this report, the local and national value of the Waituna Creek fish population dataset is discussed. In addition, we provide recommendations for how the fish monitoring project could be continued, in a less resource-intensive manner, to enable an assessment of the effects of catchment-scale ecosystem health improvement initiatives on native fish populations.

TABLE OF CONTENTS

1. INTRODUCTION 1
1.1. Purpose of this report 1
1.2. Background 1
1.3. Waituna Creek fish community 2
2. METHODS 4
2.1. Rehabilitation actions 4
2.1.1. Bank recontouring to form a 'two-stage' channel 5
2.1.2. Installing instream wood structures 5
2.1.3. Riparian planting 7
2.2. Measures of rehabilitation success 8
2.3. Fish monitoring regime 9
2.3.1. Fish community data collection 9
2.4. Data processing and analysis 11
2.4.1. Reach scale analysis 11
2.4.2. Patch scale analysis 12
2.4.3. Single pass vs. total population estimate analysis 12
3. RESULTS 13
3.1. Patch scale survey results 13
3.2. Reach-scale results 16
3.3. Electric fishing data analysis to inform down-scaled long-term monitoring programme 20
4. STUDY CONCLUSIONS 25
5. RECOMMENDED FUTURE MONITORING 26
5.1. National value of monitoring programme 26
5.2. Value of monitoring programme to the Waituna catchment 26
5.3. Recommendations for the ongoing fish population monitoring in Waituna Creek 27
5.3.1. Locations 27
5.3.2. Methods 28
5.3.3. Periodicity 28
6. REFERENCES 30
7. APPENDICES 32

LIST OF FIGURES

Figure 1. An aerial perspective of the lower Waituna Creek (taken prior to the rehabilitation trial) showing similar and continuous 'slow-run' type habitat for about a kilometre 2
Figure 2. The Waituna catchment showing the locations of the two impact / rehabilitation reaches (Site 0 and 2) and upstream control reaches. 4
Figure 3. Waituna Creek showing examples of the logs (top and middle) and manuka bundles (bottom) installed within the rehabilitation trial reaches to improve fish habitat (figures reproduced from Holmes 2019a). 6
Figure 4. Conceptual sketch of log placement (left) and hydraulic modelling of the restoration reach without logs (middle) and with logs (right) 7
Figure 5. The Site 2 rehabilitation reach showing recent plantings and two-stage channel design, photograph taken in 2018 from bank-full looking downstream. 8
Figure 6. Average values for mean fish diversity determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. 13
Figure 7. Average values for mean total fish biomass (grams/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. 13
Figure 8. Average values for mean total fish density (fish/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. 14
Figure 9. Average values for mean longfin eel biomass (g/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. 14
Figure 10. Average values for mean biomass (grams/m^2) of all fish except for eels, determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' stream bed patches. 15
Figure 11. Longfin eel biomass (grams/m^2) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. 18
Figure 12. Longfin upper quartile weight (in grams) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. 18
Figure 13. Giant kokopu biomass (grams/m^2) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. 19
Figure 14. Juvenile lamprey density (fish / m^2) results at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. 19
Figure 15. The relationship between total fish density predicted from first pass density data only (predicted) and the total fish population density estimate based depletion count curve fitting (observed). Blue line represents the model fit and the red line represents the 1:1 relationship. Model parameters Nash-Sutcliffe efficiency coefficient (NSE), root mean square deviation (RMSD) and model bias are displayed. 21
Figure 16. Total biomass estimates at Site 2 for all three species of bullies combined (common, redfin and giant bullies) calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). 22
Figure 17. Total biomass estimates (fish/m^2) at Site 4 for all three species of bullies (common, redfin and giant), calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). 23
Figure 18. Total density estimates (fish/m^2) at Site 2 for longfin eel, calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). 24

LIST OF TABLES

Table 1. The freshwater fish community in the Waituna Lagoon catchment. 3
Table 2. The averages, ranges and P-values for the mean differences in fish diversity, density (fish/m^2), longfin eel biomass, and total fish biomass—excluding longfin eels (grams/m^2). 15
Table 3. The P-values from an ANOVA analysis looking at the pooled years for ‘before’ and ‘after’ the completion of the rehabilitation treatment at Site 2. 17
Table 4. Species-specific multipliers to apply to single-pass electric fishing data collected from sites 0 and 4 to estimate total fish density and biomass and associated error. 28

LIST OF APPENDICES

Appendix 1. New Zealand Map Grid GPS coordinates for all sites sampled in association with the rehabilitation project since 2014. 32
Appendix 2. All sites along the Waituna Creek sampled in association with the rehabilitation project since 2014. 33

1. INTRODUCTION

1.1. Purpose of this report

This report describes the fish community response to a stream rehabilitation trial in the lower Waituna Creek. Annual quantitative fish population data have been collected in association with the rehabilitation project since 2014. We also provide recommendations for how the fish community monitoring could be continued long-term and suggest ways in which data could be used to inform local and national management of lowland native fish communities.

1.2. Background

Waituna Lagoon (Southland) is part of the wider Awarua Wetlands, which are one of the few remaining large, (relatively) unmodified coastal wetlands in New Zealand. The Waituna Lagoon is part of the Department of Conservation (DOC) estate; however, the inflowing catchments are intensively farmed. Waituna Creek contributes approximately 90% of freshwater inflows to Waituna Lagoon. To support farming, Waituna Creek and its tributaries have been straightened and lowered, by between 2 to 4 m in places, to promote land drainage (Figure 1). In addition, farms within the catchment have an extensive under-field drainage network using mole and / or tile drains. To maintain drainage capacity, the Waituna Creek and its tributaries undergo periodic bank reshaping and mechanical clearing of aquatic weeds and deposited sediment using diggers. All these ongoing channel modifications have had negative consequences for the amount and quality of habitat for stream life (Allibone & Hudson 2015). For example, it is estimated that Waituna Creek is now a third of its natural length because of channel straightening (Beech 2016).

In response to the long-term loss of fish habitat in the Waituna Creek, Arawai Kākāriki and DOC-Fonterra Living Water programmes have funded habitat restoration work. Scoping of the rehabilitation project began in 2014. After a lengthy design phase over a five-year period, two approximately 200-m reaches were chosen to trial various physical stream habitat rehabilitation actions. The objective of the rehabilitation trial was to test an alternative way to manage the stream channel so that native fish habitat is improved, while acceptable erosion rates, land drainage and the capacity of the channel to carry floods is maintained. The restoration actions included installing a ‘two-stage’ channel, large instream woody structures, and riparian planting (described in Section 2.1). These actions were undertaken in a segment of DOC-managed marginal strip in the lower Waituna Creek.

This report tested the hypothesis that the quality of native fish habitat will be improved in the rehabilitation reaches because habitat heterogeneity is increased. In particular, we expected that there would be an increase in the biomass and abundance of coverloving native fish species, such as large longfin eels and giant kōkopu. The increased habitat diversity was also hoped to provide improved habitat conditions for juvenile lamprey and various native bully species. Overall, we expected that total fish abundance and biomass would increase within the restored reaches, relative to unrestored upstream control reaches (that were surveyed concurrently).

Figure 1. An aerial perspective of the lower Waituna Creek (taken prior to the rehabilitation trial) showing similar and continuous 'slow-run' type habitat for about a kilometre (Holmes 2019a). Photo credit: Bruce Green.

1.3. Waituna Creek fish community

There are 12 freshwater fish species in the Waituna catchment (Table 1). The lagoon catchment is noted for its abundance of longfin eels (tuna) and giant kōkopu, with the latter being most abundant in the smaller tributaries and drains (Atkinson 2008). Lamprey are also present in the catchment. All three of these fish are considered taoka, and both longfin eel and lamprey are important contemporary mahinga kai species. Lamprey also have very high conservation values, being considered 'Nationally vulnerable' to extinction (Dunn et al. 2017). For context, 'Nationally vulnerable' is the same extinction threat category given to blue ducks (Robertson et al. 2017).

Table 1. The freshwater fish community in the Waituna Lagoon catchment. Conservation threat rankings are also shown (Dunn et al. 2017). Sources: Atkinson (2008) and Holmes et al. (2019a).

Common name	Conservation threat ranking
Shortfin eel	Not threatened
Longfin eel	At risk – declining
Giant kōkopu	At risk – declining
Banded kōkopu	Not threatened
Īnanga	At risk – declining
Kanakana / Lamprey	Threatened – nationally vulnerable
Common bully	Not threatened
Giant bully	At risk – naturally uncommon
Redfin bully	Not threatened
Common smelt	Not threatened
Black flounder	Not threatened
Brown trout	Introduced and naturalised

2. METHODS

2.1. Rehabilitation actions

The rehabilitation trial was begun in two approximately 200-metre-long reaches of the lower Waituna Creek during February–March 2018. One rehabilitation reach is located at the end of White Pine Road, the other is located approximately 500 m upstream (of White Pine Road) (Figure 2).

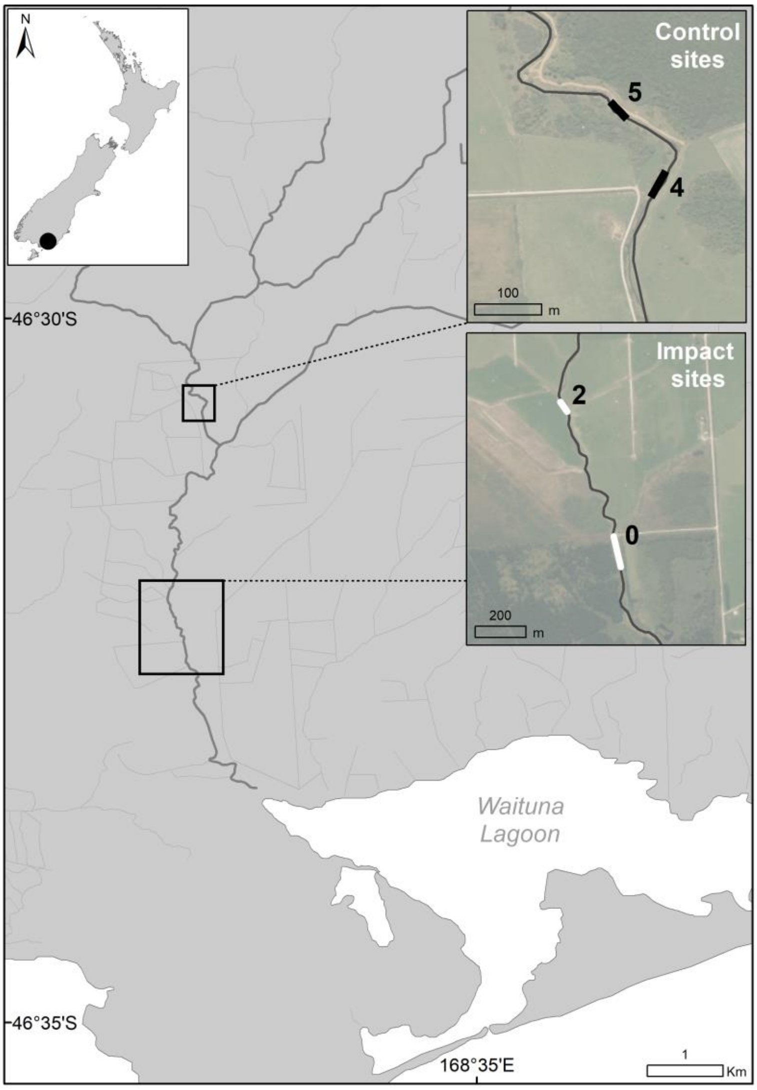

Figure 2. The Waituna catchment showing the locations of the two impact / rehabilitation reaches (Site 0 and 2) and upstream control reaches.

The rehabilitation trial consisted of three different actions: (1) bank recontouring to form a ‘two-stage’ channel, (2) installing instream wood structures, and (3) riparian planting.

2.1.1. Bank recontouring to form a ‘two-stage’ channel

The low-flow channel edge to bank-full was recontoured using diggers to form a ‘first-stage’ bench or ‘mini flood plain’. The new first-stage part of the channel had a gentler slope than the previous trapezoid channel configuration. As described in Powell et al. (2007), a two-stage channel shape can:

1. increase the capacity of the channel to carry flood flows
2. provide a ‘bench’ for planting stream-edge vegetation and
3. provide some insurance against bank erosion (i.e. when erosion does occur, there is less bank volume to undercut, so less sediment enters the stream).

At the White Pine Road site (hereafter Site 0), only the true left bank was recontoured to form a two-stage channel. At the upstream rehabilitation reach (hereafter Site 2), both left and right banks were recontoured.

2.1.2. Installing instream wood structures

To increase instream habitat diversity, large logs (approximately 4 m long and 0.5 m in diameter) and tightly packed bundles of manuka sticks were installed directly onto the stream bed. A condition of the restoration trial consent was that the structures were ‘removable’. Accordingly, steel pipes and warratahs were used to fix the logs and manuka bundles in place, respectively (Figure 3).

Figure 3. Waituna Creek showing examples of the logs (top and middle) and manuka bundles (bottom) installed within the rehabilitation trial reaches to improve fish habitat (figures reproduced from Holmes 2019a).

Before a final arrangement of structures was chosen, the potential effects of different log configurations on velocity variation, upstream impoundment and bank erosion were modelled by the National Institute of Water and Atmospheric Research (NIWA) (Figure 4) (Walsh et al. 2017).

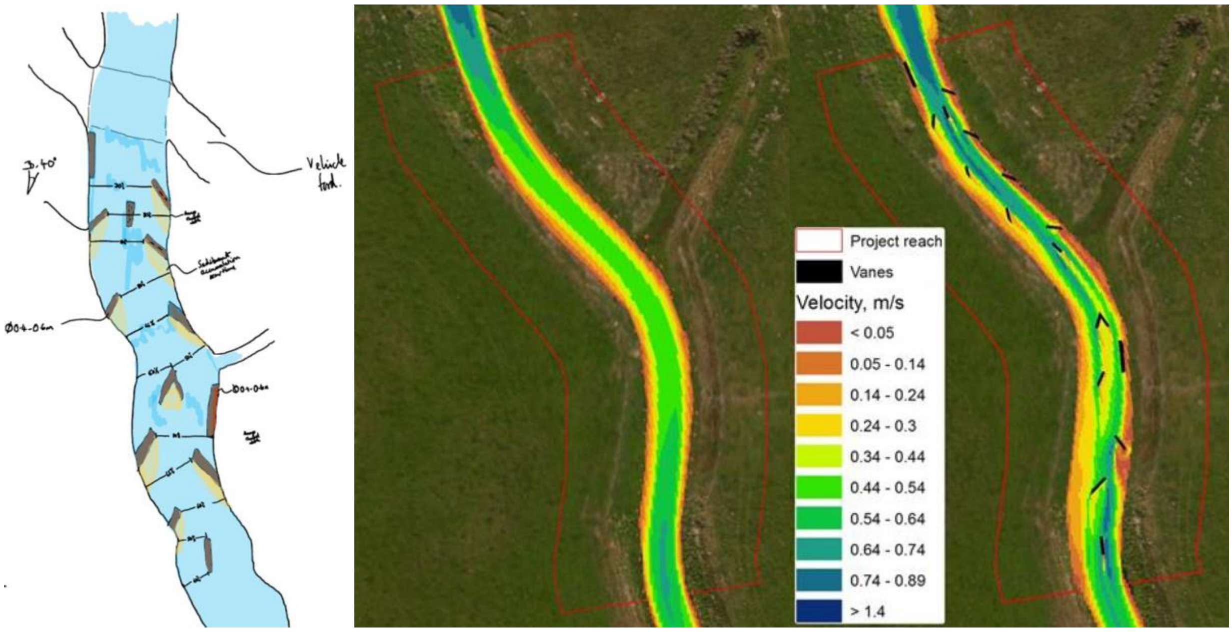

Figure 4. Conceptual sketch of log placement (left) and hydraulic modelling of the restoration reach without logs (middle) and with logs (right). Colours show water velocity gradient from slow (red) to fast (blue) figure reproduced from Walsh et al. (2017).

2.1.3. Riparian planting

In conjunction with creating a two-stage channel and installing woody habitat structures, native riparian planting and weed control is ongoing in the segment of creek containing the rehabilitation reaches. Planting below the bank-full channel was limited to low-stature grasses such as *Carex secta* (Figure 5). This was a requirement of the project trial consent conditions to ensure the flood capacity of the channel is maintained. Some larger-stature shrubs and trees have been planted on the upper bank above the bank-full channel.

Figure 5. The Site 2 rehabilitation reach showing recent plantings and two-stage channel design, photograph taken in 2018 from bank-full looking downstream.

2.2. Measures of rehabilitation success

The outcomes of the restoration trial on erosion and drainage potential are discussed in detail in Hudson (2021). In terms of ecological success measures, three fish species were of specific interest to the project—longfin eels, giant kōkopu and lamprey. An increase in the local (reach-scale) abundance and / or biomass of these fish would signal a successful trial. Secondary success indicators included increases in overall native fish diversity, abundance and / or biomass.

The rehabilitation trial was not expected to have detectable effects on macroinvertebrates. The distribution and abundance of these animals in Waituna Creek will be largely determined by catchment scale factors, such as non-point source sediment and nitrogen loading. Overriding catchment scale influences on water quality attributes were not addressed by this reach-scale trial. An investigation into the short-term disturbance effects of the rehabilitation trial on macroinvertebrates was conducted by Funnell et al. (2020).

At the time of writing this report, the primary driver for any potential fish community responses to the rehabilitation trial was likely to be the woody structure additions (as opposed to the two-stage channel re-shaping or riparian planting). This is because the woody structure additions have (to date) had the most profound effect on physical habitat conditions in the rehabilitation reaches (Hudson 2021). The riparian plantings have not established to the degree where they might have an appreciable effect on fish habitat quality (pers. obs. by lead author). Likewise, the two-stage channel design is likely to have had a lesser effect on the fish habitat quality because only the channel *above* the low-flow wetted edge was manipulated. Nevertheless, the potential effect of the two-stage channel and riparian plantings on the fish habitat cannot be separated from the woody structure additions, as the three actions occurred simultaneously.

2.3. Fish monitoring regime

2.3.1. Fish community data collection

Over the period 2014 to 2021 the Waituna Creek fish population has been monitored annually during mid-late March at between four and eleven (approximately 40–50 m) stream reaches. The exception was 2020, when no sampling occurred due to restrictions imposed by the COVID-19 pandemic response. The GPS coordinates and locations of all sites sampled over the course of the project are provided in Appendices 1 and 2.

Reach-scale data collection

At each monitoring reach, stop-nets (6-mm mesh) were simultaneously placed at the upstream and downstream boundaries of the monitoring reaches. The fish populations within stop-netted reaches were sampled by electric fishing using the multiple depletion-pass method (Johnson et al. 2007). Two Smith-Root electric fishing machines were used in tandem to undertake at least three passes at each reach. Passes were repeated (in some cases up to five times) until a minimum of a 20% abundance depletion between passes was recorded for eels, trout and bullies. All fish were individually identified to species level and weighed and measured. However, on occasion, bullies and īnanga were so numerous that a separated recording procedure was necessary. The first 50 of these fish were weighed, measured and identified to species level to determine a site/year-specific average weight and species ratio (in the case of bullies) for a site. Following this, bullies and īnanga were weighed in batches of approximately 200 grams. The average weight and species ratio at each reach were used to determine abundances from the total batch weights.

The total wetted area of the stream between the stop-nets was measured to allow conversion of fish abundance and total weights into densities and biomass per square metre (respectively) for all species. A full description of the sampling methods is provided in Holmes et al. (2019a).

Patch-scale survey around woody structures and 'no-structure' areas of stream bed

To investigate if fish in Waituna Creek were preferentially occupying the patch-scale habitat created by woody structure additions, we undertook a separate (one-off) study during the 2021 monitoring occasion. Prior to fishing the entire rehabilitation reaches, as described above in Section 2.3, six structures were selected from each rehabilitation reach to be representative of structures present on the left and right bank and midstream (i.e. 12 structures in total, six from each rehabilitation reach).

At each selected structure, single-pass electric fishing was undertaken. The structures were approached quietly from downstream, so as to reduce disturbance to any fish around the logs. Four pole nets were placed around and alongside the downstream end of the structure before commencing electric fishing. On approaching the structure, the area of stream around the log was observed carefully to note any disturbed fish during the approach (no fish were seen). Two electric fishing machines were then used to fish around the structure, with captured fish being identified, weighed and measured. Fish were held aside to add to the first pass of the reach-scale fish monitoring (as described above).

Each woody structure patch was paired with the similar-sized patch of streambed (7 m^2) that contained *no-structure.* The no-structure patches were located within two 50 m long reaches located 50–100 m upstream of each of the rehabilitation reaches. These no-structure patches were fished in exactly the same manner as the stream bed patches containing woody structures. The no-structure patches were selected to mirror the left, right and mid-stream configuration of the structure patches that were sampled in the rehabilitation reaches. The start point of the no-structure reach was selected at random within the first area of fishable stream above the rehabilitation reach. This study design enabled a control–rehab/impact assessment for 12 paired patches (i.e. 24 patches were fished in total).

During electric fishing at the first woody structure patch, we observed that eels of various sizes were trapped within the macrophytes associated with the logs and could not be captured. To account for these fish, the eels that were observed (but not captured) were assigned conservative weight categories of 'medium size' (200 g) and 'large size' (400 g), depending on the size of the eels as estimated by the electric fishers. These weight categories were conservative because most of the 'large' eels observed were likely to be substantially heavier than 400 grams, with some eels observed likely to be well over 1000 grams. All observed but not captured eels were assumed to be longfin eels. This is because during the 7 years of monitoring, across all reaches, over 98% of all eels captured have been longfins. Observed but uncaptured eels from the patch-scale survey were not included in the multi-pass reach-scale data.

2.4. Data processing and analysis

The years of interest for assessing the fish community response to the rehabilitation actions include: monitoring occasions in 2014—the first monitoring occasion shortly before a wide-scale channel reshaping event occurred in the catchment (Holmes et al. 2019); 2017 or 1 year before the instream habitat rehabilitation; and the subsequent monitoring events in 2019 (one year after rehabilitation) and 2021 (three years after). At least four of the same reaches were sampled on each of these monitoring occasions—including the two treatment / rehabilitation reaches and two upstream control reaches (Figure 2). This enabled a Before-After-Control-Impact (BACI) comparison, albeit with very limited replication (i.e. N = 2 for the treatment samples). The initial trial was planned to occur at three or more reaches; however, this was reduced to two reaches during the consenting process. The low replication of the study design was outside of our control.

2.4.1. Reach scale analysis

For the reach-scale data, total fish abundance was estimated from depletion counts using the maximum weighted-likelihood approach (Carle & Strub 1978) in R (R Core Team 2021). Densities and biomasses of fish per square metre were the main fish population metrics used in statistical analysis.

Exploratory analyses were conducted using ANOVA to assess the effects of time (irrespective of rehabilitation treatment or control 'reach type'), the effect of reach type (irrespective of sampling occasion) and the interaction between time and reach type (i.e. was the before / after effect different at control and treatment sites). A significant interaction between time and reach type indicated an effect of the rehabilitation treatment. This analysis was run for two before-after comparisons, one between 2021 (after) and 2017 (one year before the rehab / treatment) and between 2021 (after) and 2014 (8 years before). Only the 2021 data were used to investigate 'after effects' during the exploratory analysis. This is because this occasion was three years after the rehabilitation works and so represents the longest period available for the fish to find the rehabilitation reaches and become established.

It is important to note that the two rehabilitation reaches were not manipulated in an identical manner. At Site 0, only one bank was rebattered and about half as many woody structures were installed within the reach. This compares with Site 2 where both banks were rebattered and more woody structures were installed (with less distance between them). In general terms, Site 2 had about twice the amount of habitat manipulation as Site 0. To account for differences in the level of rehabilitation treatment between sites, each site was analysed separately using an ANOVA to compare two sampling events (i.e. 2019 and 2021), after the completion of the rehabilitation works, with the five 'before' sampling events. Sampling in year 2018 occurred during or immediately after the rehab works (i.e. within 1 week), therefore, this monitoring occasion was excluded from this analysis. This omission was made because the fish populations cannot be expected to react to change in the habitat conditions (in a positive manner) within one week.

2.4.2. Patch scale analysis

For the patch scale analysis, fish population metrics derived from the woody structure and ‘no-structure’ patches were pooled to create 12 control-impact comparisons. The differences between the means of the fish population metrics of the two groups (structure vs. no-structure patches) were assessed using the Student’s T-test assuming independent groups. This analysis was conducted with Statistica software.

2.4.3. Single pass vs. total population estimate analysis

We compared the accuracy of total fish density and biomass estimates derived from single pass data (i.e. the first electric fishing pass at each reach) with the total population estimates derived from the multiple-pass depletion method. This was done by extracting just the first-pass counts and biomass values for each species on every fishing occasion at all reaches. These additional estimates of abundance and biomass were compared to the more sophisticated estimates derived by the multi-pass depletion-curve fitting method of Carle and Strub (1978) (which are more costly in terms of field effort). For each species and sampling occasion, a multiplier factor was calculated, to derive the full depletion count estimate from the single pass count data. This set of multiplier factors was averaged across all sampling years at each site to obtain a set of reach- and species-specific scaling factors to indicate what proportion of the total abundance was likely to be fished out on the first pass. The standard deviation of this set of scaling factors was also calculated, to allow for estimation of uncertainty, when deriving total abundance estimates from single pass counts. The average and standard deviation values obtained were used to generate total abundance estimates (and confidence intervals), from the single-pass counts, of total abundance (density and biomass). The estimates derived from single-pass counts were graphically compared with full multi-pass depletion estimates (with their respective confidence intervals).

3. RESULTS

3.1. Patch scale survey results

The woody structure patches had higher average fish diversity (Figure 6), biomass (Figure 7) and abundance (Figure 8) when compared to the no-structure patches. Comparison of means shows that all these differences were statistically significant (Table 2).

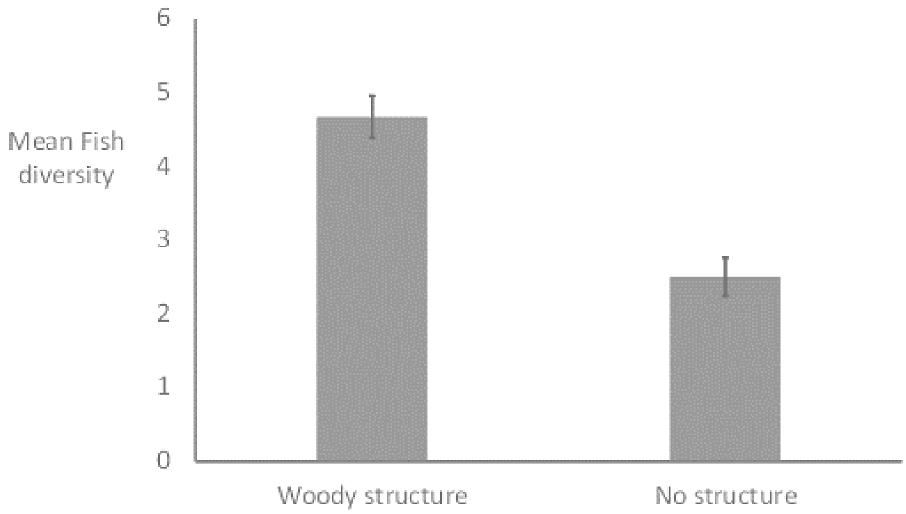

Figure 6. Average values for mean fish diversity determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. Error bars represent standard error of the mean.

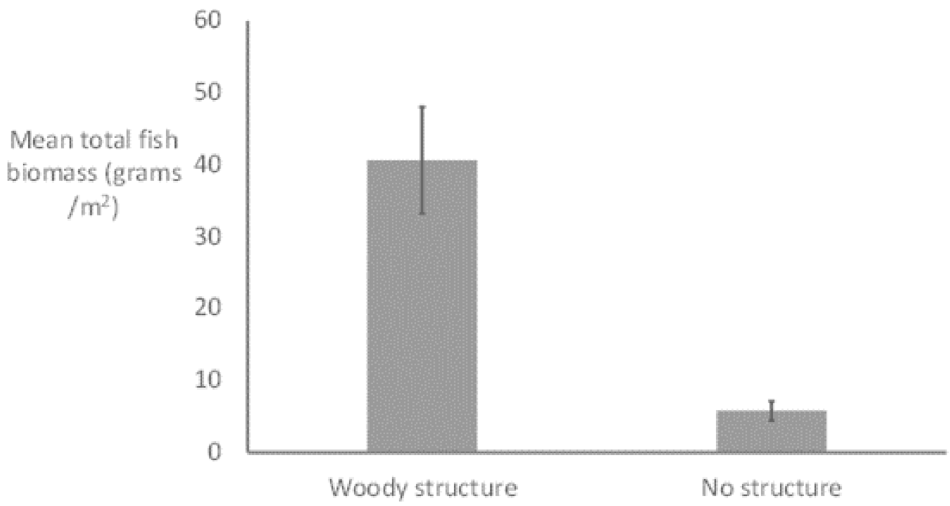

Figure 7. Average values for mean total fish biomass (grams/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. Error bars are standard errors.

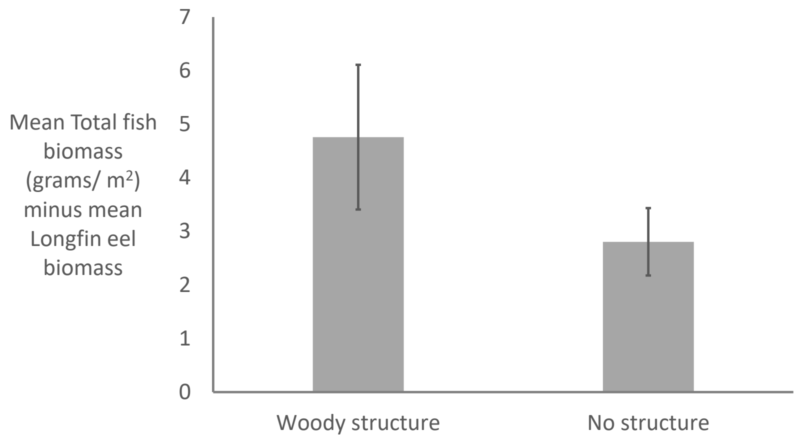

Figure 8. Average values for mean total fish density (fish/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. Error bars are standard errors.

Overall, longfin eel biomass was around ten times higher in the patches of stream around the installed woody structures—when compared with the no-structure patches (Figure 9). Fish biomass with eels subtracted (i.e. total biomass of all fish except for eels) was around a 40% higher in the structure patches; however, this difference was not statistically significant (Figure 10).

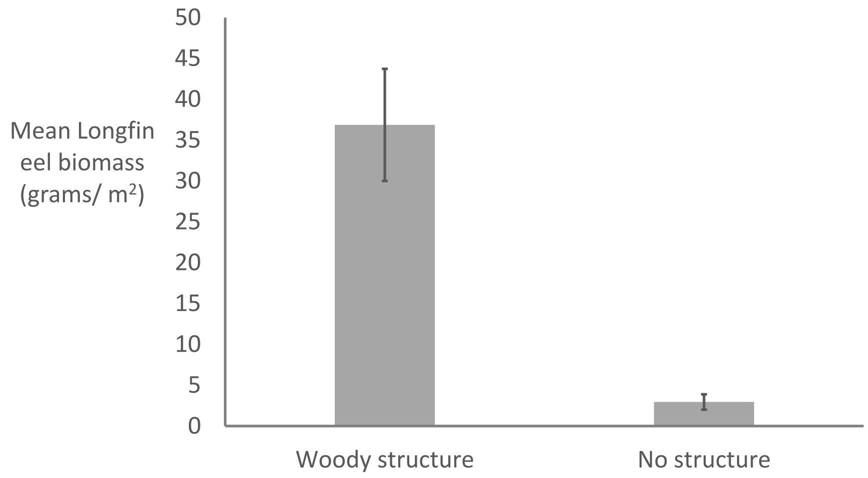

Figure 9. Average values for mean longfin eel biomass (grams/m^2) determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' streambed patches. Error bars are standard errors.

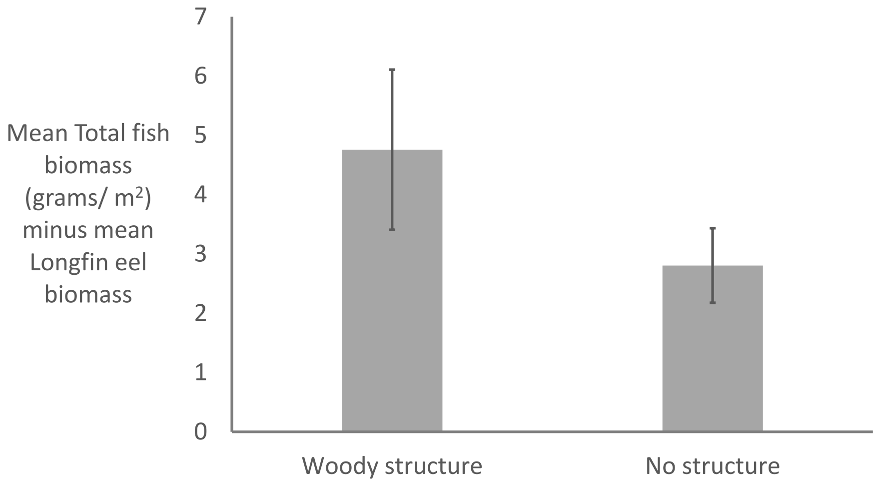

Figure 10. Average values for mean biomass (grams/m^2) of all fish except for eels, determined from electric fishing in the 12 stream patches containing installed woody structures and 12 paired 'no structure' stream bed patches. Error bars are standard errors.

Table 2. The averages, ranges and P-values for the mean differences in fish diversity, density (fish/m^2), longfin eel biomass, and total fish biomass—excluding longfin eels (grams/m^2). The P-values presented were determined from a Student T-test analysis (assuming independent groups), n = 12 per treatment. Significant results (at < 0.05) are shown in bold.

	Woody structure patch		'No-structure' patch		P-value
Metric	Average	Range	Average	Range	
Diversity (number of species)	4.7	3–6	2.5	1–4	**< 0.001**
Density (fish/m^2)	2.3	1.4–3.7	1.1	0.3–3.5	**0.008**
Total biomass (grams/m^2)	40.6	10.2–91.4	5.6	0.5–13.6	**0.001**
Longfin eel biomass (grams/m^2)	36.9	0–71.4	2.9	0–7.3	**0.02**
Total biomass excluding longfin eel (grams/m^2)	4.8	1.4–15.0	2.8	0.5–6.6	0.20

The logs and manuka bundles are being preferentially occupied by a variety of fish species. The patch scale survey results provide clear evidence that the areas of streambed underneath and around the installed woody structures have higher diversities and abundances of native fish when compared with areas of streambed patches that were typical of habitat within the surrounding Waituna Creek segment. While it was expected that eels would be occupying the structures, the degree of increased abundance and biomass was somewhat surprising (i.e. an order of magnitude increase in biomass (Figure 9)). These results show that the premise of the rehabilitation project, which was the addition of structures will increase the habitat quality in the lower Waituna Creek, is valid.

Submerged and emergent macrophytes are ubiquitous throughout the lower Waituna Creek and are available as a form of daytime cover for fish. However, the clear preference of native fish for the installed woody structures suggests that macrophytes do not provide 'optimal' cover for fish. Perhaps the woody structures were favoured over the abundant macrophyte cover because the fish have a high affinity for more 'permanent' cover that is less vulnerable to disturbance (e.g. through flooding or winter senescence). Of note, is that during the most recent sampling event at Site 2, two of the large giant kōkopu were caught from underneath the large log structures. This proves that these fish were using the cover provided by the structures (pers. obs. by lead author).

3.2. Reach-scale results

When both rehabilitation reaches were looked at together, there were no significant differences in any of the fish population metrics of interest. However, it is important to note that the power of the pooled ANOVA analysis to detect a difference was extremely low, given there were only two replicate rehabilitation treatments. The results of this analysis are not shown.

When the rehabilitation reaches were looked at *individually* there were significant differences found before and after the rehabilitation at Site 2 but not at Site 0. Qualitatively, Site 0 received about half as much habitat manipulation as Site 2. In addition, the stream at Site 0 is wider, meaning any patch-scale effects of the structure additions could be obscured by the relatively large areas of the reach that were not manipulated. Given that there were patch-scale responses detected within Site 0 (Section 3.1), the lack of a detectable response within the reach-scale analysis at Site 0 can be interpreted as a failure to create enough habitat improvements to elicit a detectable response at the reach scale with the relatively low statistical power of this study (results of this analysis are not shown).

In contrast to the lack of response at Site 0, we found a positive impact of the rehabilitation measures on all three of our key success indicators at Site 2. There was a significant increase in longfin eel biomass—driven by the occurrence of a few relatively large eels occurring in the reach (Table 3, Figure 11). This is shown by the significant increase in the upper quartile weight of longfin eels after the rehabilitation treatment (Figure 12). Giant kōkopu biomass increased significantly at Site 2 (from a baseline of zero during all years prior to rehabilitation) (Figure 13). For both eels and giant kōkopu there were no substantial changes in biomass at the control sites in the years after the rehabilitation. This indicates an effect of the rehabilitation treatment, rather than an effect of some other catchment scale change, such as a good recruitment year for these fish. There were no significant effects for overall density or biomass of fish, native bully species or introduced trout (results not reported).

Low numbers of juvenile lamprey were found, for the first time, at Site 2 during both of the years following the rehabilitation. However, relatively large numbers of juvenile lamprey also occurred at the control site during these two years (Figure 14). Therefore, the occurrence of juvenile lamprey at Site 2 after the rehabilitation, may be due to good lamprey recruitment in the wider catchment during these years. Nevertheless, a good recruitment year occurred in 2016 and no lamprey were found at Site 2 that year (prior to rehabilitation). While not conclusive, this result provides some evidence that the rehabilitation actions created habitat that can support some juvenile lamprey.

Table 3. The P-values from an ANOVA analysis looking at the pooled years for 'before' and 'after' the completion of the rehabilitation treatment at Site 2. A significant difference in the 'Over time and between sites' column indicates an effect of the rehabilitation treatment.

	Comparison		
Metric	Over time (all sites)	Between rehab and control sites	Over time and between sites
Longfin eel biomass (grams/m^2)	0.19	0.06	**< 0.00**
Longfin eel upper quartile weight (grams)	**0.03**	0.06	**0.03**
Giant kokopu biomass (grams/m^2)	0.48	0.55	**0.01**
Juvenile lamprey density (fish/m^2)	**0.05**	**< 0.00**	0.29

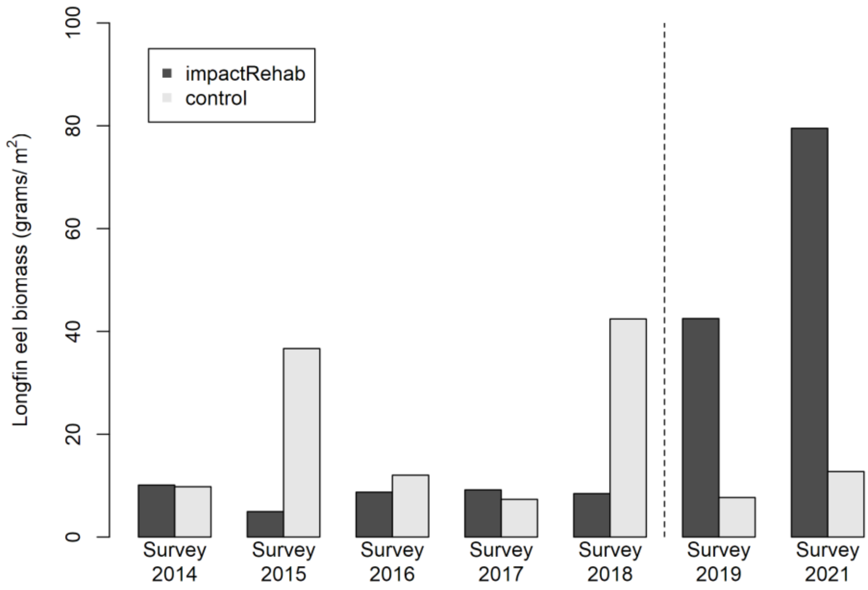

Figure 11. Longfin eel biomass (grams/m²) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. Dotted line shows the point in time when rehabilitation works were completed.

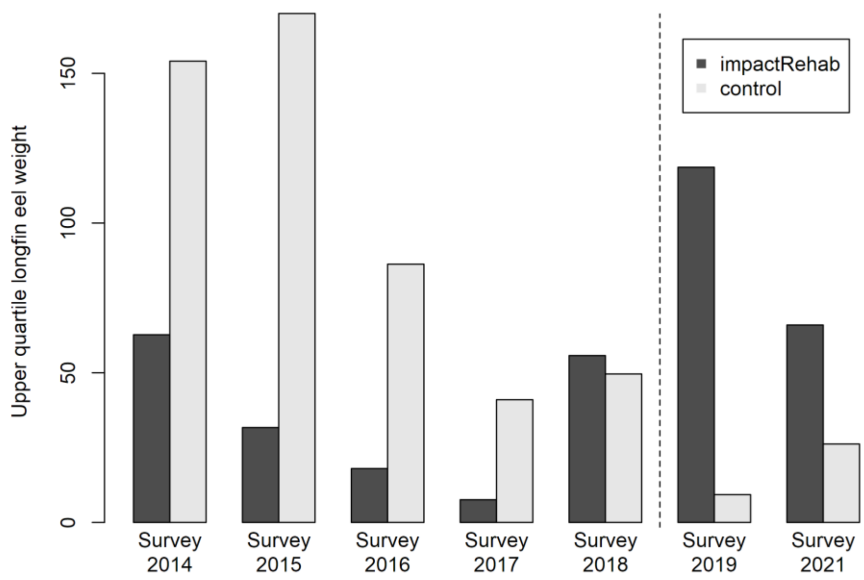

Figure 12. Longfin upper quartile weight (in grams) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. Dotted line shows the point in time when rehabilitation works were completed.

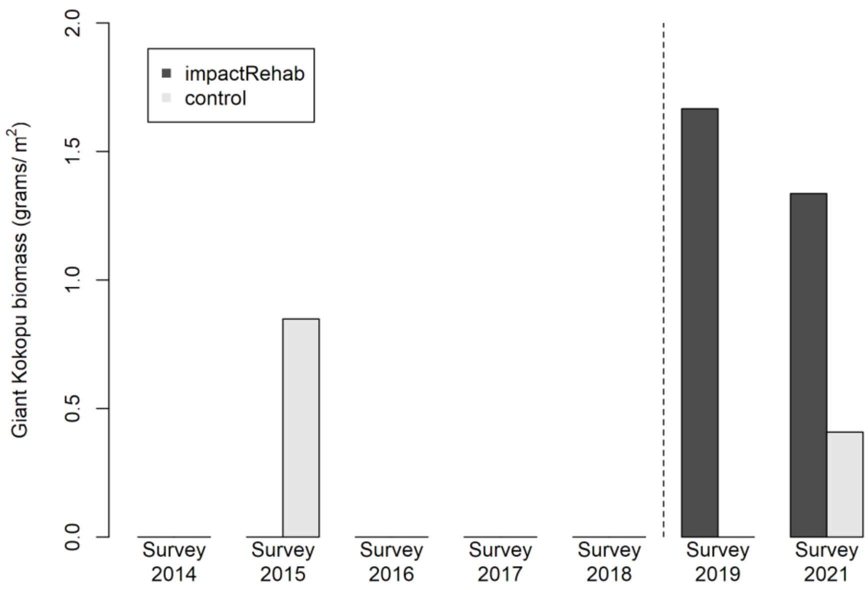

Figure 13. Giant kokopu biomass (grams/m^2) at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. Dotted line shows the point in time when rehabilitation works were completed.

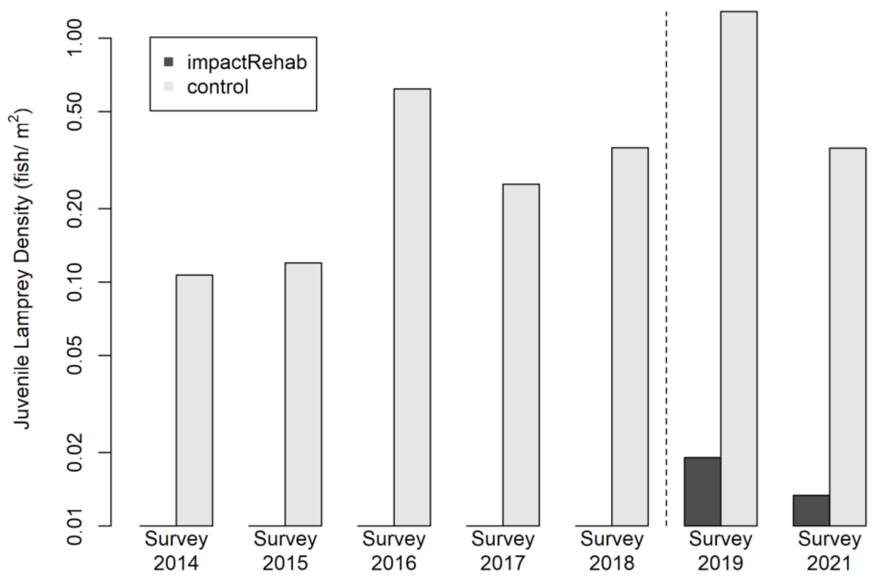

Figure 14. Juvenile lamprey density (fish / m^2) results at Site 2 and the upstream control sites (average of sites 4 and 5) for all monitoring years. Dotted line shows the point in time when rehabilitation works were completed. Densities are plotted on a log scale to enable visualisation of low densities of lamprey detected at Site 2, after the rehabilitation treatment.

In the case of large longfin eels and giant kōkopu, the results at Site 2 are consistent with the expected habitat improvements for these species. Both species are known to have a high affinity for structural daytime hiding cover (e.g. Jowett et al. 2009). Giant kōkopu may have also benefited from the increased diversity of velocities within the rehabilitation reach that were created by the large logs (i.e. eddies and areas of flow constriction, see Figure 2, top). Giant kōkopu are drift-feeding fish that exploit 'velocity shear zones' in streams; these are areas of relatively high velocity adjacent to low velocity areas. Velocity shear zones enable drift-feeding fish to conserve energy in the slow flowing water whist watching for drifting food items that are delivered to them at a relatively high rate in the adjacent faster flowing water (Piccolo et al. 2014). The log structures would also support 'ambush feeding' methods for both eel and giant kōkopu, enabling them to hide and capture passing prey fish, such as īnanga, by surprise.

The evidence for improved lamprey habitat in the Site 2 rehabilitation reach is less conclusive. The woody structures did create a more variable depth profile along the reach through scouring behind and around the logs (Hudson 2021). This would have increased near-bed velocities in some streambed patches within the reaches, particularly on the upward sloping areas of scour holes present immediately below the large logs. Higher near-bed velocities would enable more efficient benthic filter-feeding by juvenile lamprey.

3.3. Electric fishing data analysis to inform down-scaled long-term monitoring programme

An exploratory analysis was undertaken on the entire Waituna fish population data set to determine if single pass data could be used as a surrogate for multi-pass data. In essence, this was done to determine if the electric fishing results undertaken to date (with multiple passes) could inform and reduce monitoring effort in the future (to single pass data collection). In general, across all sites and all years, the abundance of fish determined from the first pass was a good predictor of total abundance predicted from the multi-pass data (Figure 15).

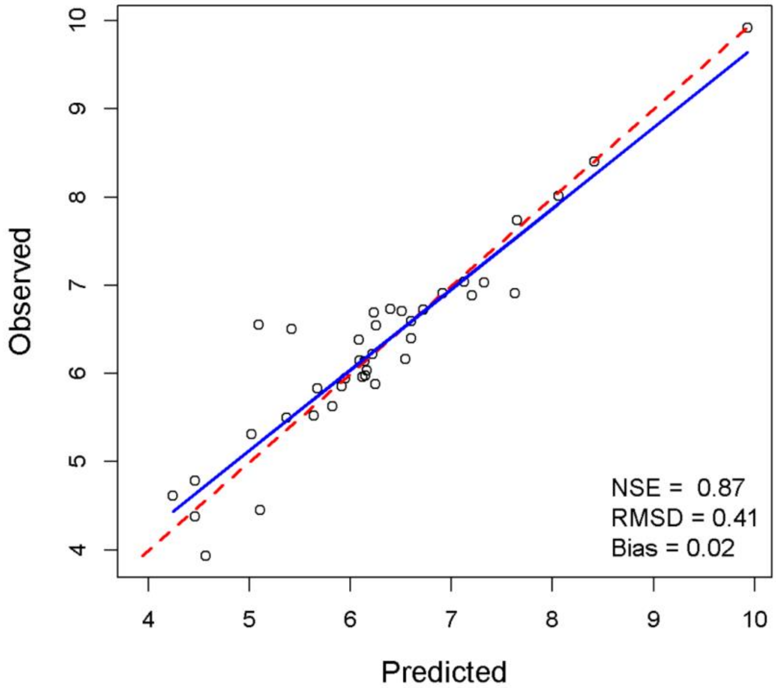

Figure 15. The relationship between total fish density predicted from first pass density data only (predicted) and the total fish population density estimate based depletion count curve fitting (observed). Blue line represents the model fit and the red line represents the 1:1 relationship. Model parameters Nash-Sutcliffe efficiency coefficient (NSE), root mean square deviation (RMSD) and model bias are displayed.

However, both ‘site’ and ‘time’ were significant terms within the predictive model. This indicates that the reliability of using the single pass method will vary depending on the reach or the year. For example, at Site 2, the potential confidence intervals around bully biomass (all species combined) are very wide for the total population estimate based on the single pass data. If monitoring were based on single pass data at this site, a very large change in biomass would be needed before a difference in the population could be detected (e.g. an order of magnitude increase or decrease over many years) (Figure 16). In contrast, both methods of estimating the total population for bullies at Site 4 (single pass vs. depletion count) showed the same general pattern in biomass changes overtime. The estimated error increased under the single pass method, but not to the degree that would prevent detection of trends overtime (Figure 17).

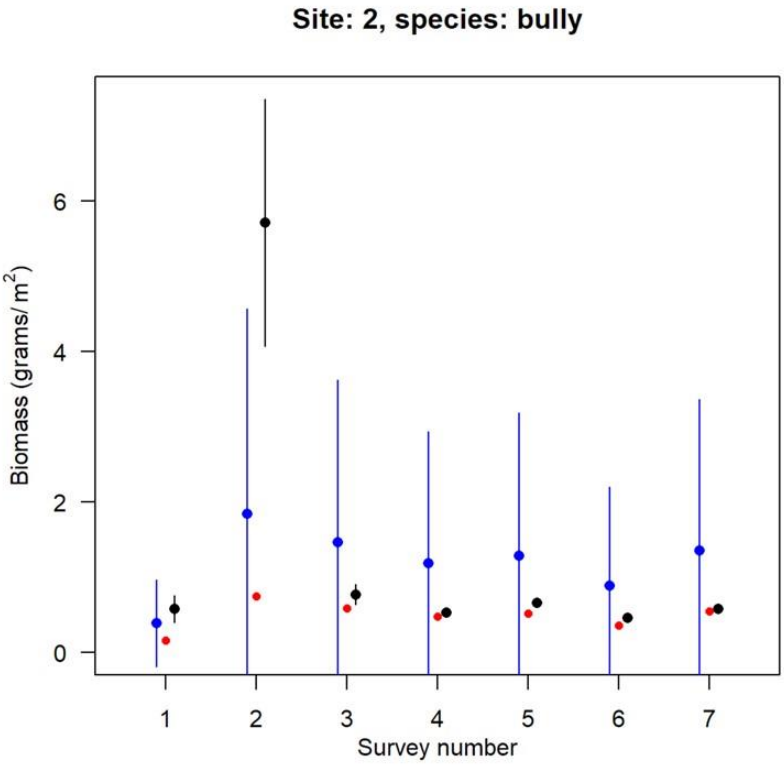

Figure 16. Total biomass estimates at Site 2 for all three species of bullies combined (common, redfin and giant bullies) calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). The red dot shows the biomass from the first pass. Bars represent 95% confidence intervals for the population estimates.

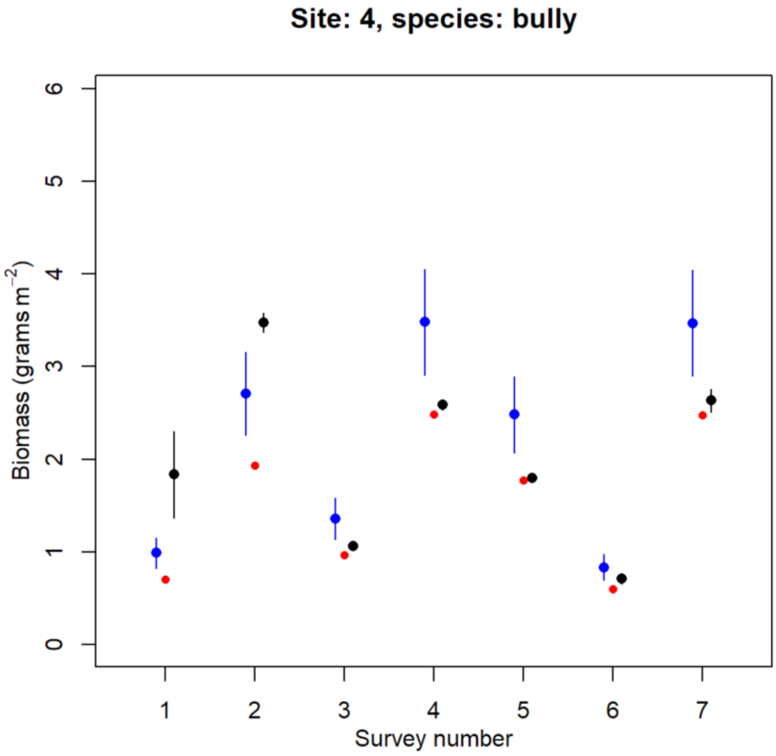

Figure 17. Total biomass estimates (fish/m²) at Site 4 for all three species of bullies (common, redfin and giant), calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). The red dot shows the biomass from the first pass. Bars represent 95% confidence intervals for the population estimates.

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At most sites, longfin eel density estimates derived from our single pass vs. multiple pass total population estimates appeared to give a similar level of accuracy. For example, Figure 18 shows the comparison of total population estimate methods for longfin eel density at Site 2.

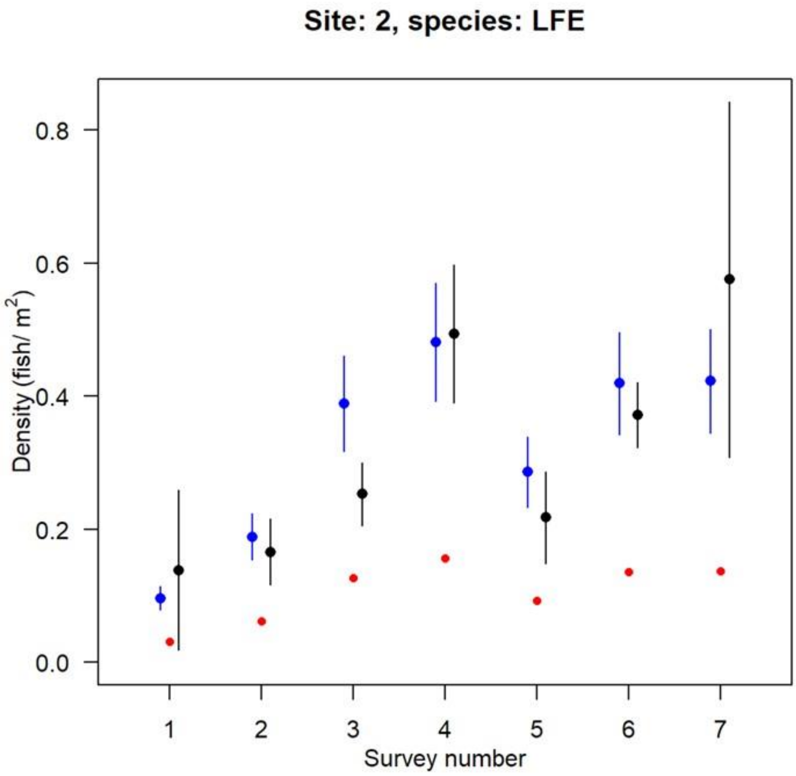

Figure 18. Total density estimates (fish/m^2) at Site 2 for longfin eel, calculated from single pass (blue dots) and the multi-pass depletion count method (black dots). The red dot shows the biomass from the first pass. Bars represent 95% confidence intervals for the population estimates.

Overall, the comparative analysis of single pass vs. multi-pass data shows that the accuracy of single pass total population estimates is site- and species-specific. This has important implications for the way fish are monitored nationally; in particular, this data set could be used to determine causal mechanisms for why there are large differences among sites. For example, habitat complexity (i.e. the amount of structural cover or macrophytes) may play an important role in the accuracy of electric fishing for certain species of native fish. We observed in the field that eels were harder to capture in the habitat created by the log structures. A more in-depth analysis of these data would help determine how native fish respond to electric fishing in lowland streams, advancing knowledge on fish population monitoring methods in New Zealand. However, investigating these issues is beyond the scope of this report. Specific recommendations for ongoing monitoring in Waituna Creek, based in part on the above exploratory analysis, are provided in Section 5.

4. STUDY CONCLUSIONS

At both of the rehabilitation reaches, the patch-scale survey found that native fish diversities, abundances, and biomasses were higher in patches of stream around the installed woody structures relative to 'typical' stream bed patches. At one of the two rehabilitation reaches, our hypothesis that the rehabilitation actions would improve native fish habitat was supported by an increase in biomass from all three of the native fish of interest. We found no significant reach-scale responses of the fish population at the other rehabilitation reach (Site 0).

The reach-scale response of the fish population at Site 2, but not at Site 0, suggests there may be a minimum level of habitat improvement required to benefit fish populations. Site 2 was the most intensively modified (rehabilitated) site. Future attempts to improve fish habitat in Waituna Creek should replicate about the amount of habitat improvements undertaken at Site 2. Broadly speaking this included two-stage channels and logs placed along both banks with about 10 individual structures per 50 m of stream reach.

These survey results can only show that the habitat improvements *attract* fish. We cannot assess if there has been an increase in the wider catchment population because of the rehabilitation actions. Nevertheless, it is reasonable to assume that if fish are preferentially occupying habitat created by the woody structures it is because the structures confer a survival and / or growth benefit. Increased growth and survival will ultimately contribute to wider fish population resilience over time. Regardless of the potential benefit to the wider fish populations in the catchment, our results suggest that providing stable, permanent woody structures improved fish habitat quality in Waituna Creek. Within three years of installing the structures, the fish 'voted with their fins' about where they wished to reside. We suggested that this positive response is likely to be applicable to other lowland streams that lack habitat diversity because of extensive modification for farm drainage—provided there are source populations of fish nearby to take advantage of habitat improvements (as is the case in the Waituna Lagoon catchment).

5. RECOMMENDED FUTURE MONITORING

5.1. National value of monitoring programme

The Waituna fish population data set represents eight years of (near) continuous annual monitoring using the quantitative electric fishing method. To our knowledge, the Waituna dataset is currently unique within New Zealand, being the only ongoing quantitative long-term fish population monitoring project within a lowland stream. Currently, long-term fish monitoring projects tend to use 'presence-absence' methods such as environmental DNA or single-pass electric fishing. While these methods are less resource intensive, in many instances the trade-off is that only very crude changes in biomass or densities can be detected in relation to environmental change. Moreover, if changes are detected, such as a localised absence of species, the potential window to address the causes of species loss may have passed. For example, some land use changes are practically irreversible. The history of quantitative fish population data collection in Waituna Creek means these data are an important national asset for freshwater fish science. Because these data exist in the Waituna catchment, where a substantial catchment scale effort is underway to improve ecosystem health, the data set is nationally valuable for assessing how native fish respond to catchment management. These data also show promise for investigating and further developing electric fishing sampling methods for native species in lowland streams.

5.2. Value of monitoring programme to the Waituna catchment

Substantial resources have been devoted to the protection of Waituna Lagoon and its catchment through various programmes and agencies, including the Awarai Kakariki, DOC-Fonterra Living Water programmes and the Whakamana Te Waituna Charitable Trust.

The monitoring project associated with the restoration trial could be effectively repurposed to assess the effects of the ongoing catchment-scale efforts to maintain and improve the health of the Waituna Lagoon (and the wider catchment). For example, these fish data are already being used to inform diadromous fish management in relation to proposed changes to the lagoon's opening and closing regime (Holmes 2019b; Robertson et al. 2021).

Native fish are of critical importance in the Waituna ecosystem in their own right, from cultural and conservation perspectives, and because of the important function that they play within the wider ecosystem. For example, fish such as īnanga and smelt likely move substantial quantities of marine-derived nutrients upstream to support predators such as wetland birds (e.g. the threatened Australasian bittern). Consequently, fish ought to be included as a key measure to evaluate the outcome of environmental protection and improvement initiatives in the catchment. The data set assembled during the restoration trial represents an important scientific asset for assessing outcomes of catchment-scale actions in Waituna Lagoon.

Currently, data are collected at significant expense; two electric fishing machines and a field team of 9 people are required for (at least) four days to complete the survey in 4–6 reaches. Below we suggest how the survey could be continued but in a less intensive manner.

5.3. Recommendations for the ongoing fish population monitoring in Waituna Creek

In our recommendations below we have attempted to strike a balance between effort (cost) and the benefits that the fish monitoring data set could provide. The proposed monitoring design below is put forward as a draft. To ensure it is fit for purpose, we recommended further refinement of the monitoring programme, through workshopping with local rūnaka and other agents responsible for managing the catchment.

5.3.1. Locations

We recommend continued annual fish population monitoring at Sites 0 and 4.

Sampling at the (control) Site 4 should be continued, conditional on landowner consent, for the following reasons:

1. This site has been unaffected (directly) by channel maintenance for nearly 20 years, and so represents the fish community in an area subject to minimal (ongoing) channel modification.
2. This site is relatively shallow and fast flowing, which makes it conducive to effective electric fishing. It also had the most accurate single-pass population estimates across the range of species of interest (determined from the exploratory analysis described in Section 3.3).
3. Of all the sites, this site has consistently recorded the highest numbers of juvenile lamprey. This means it has the best potential for tracking changes in lamprey recruitment in the catchment over time.

Monitoring at Site 0 should be continued because large numbers of diadromous fish, such as īnanga and smelt, have been detected there, likely because this site is near the lagoon. Continuation of monitoring at this site will give some indication of the abundances of migratory fish in the catchment and if they are changing in relation to management actions. For example, through changes to the lagoon opening regime to enable the lagoon to remain closed to the sea more often (Robertson et al. 2021).

5.3.2. Methods

Based on an exploratory analysis of single pass vs. multi-pass data, we recommend shifting the monitoring programme to a modified *single pass* data collection method (during most years). We suggest continuing to electric fish 40–50-metre-long reaches using stop-nets installed at both ends of the reach. The first pass should be undertaken *as if* the multi-pass method is being used. Two subsequent passes should be undertaken but fishers should focus only on 'rare fish' such as large longfin eels (> 500 mm), lamprey, giant kōkopu —or any fish species that were not caught on the first pass. All other fish can be ignored on the second and third passes. Once all three passes have been completed, the fish can be weighed, measured and returned to the reach by the same team that undertook the electric fishing. Using this method, both sites ought to be able to be completed with a field crew of 5 people in about 8-10 hours (inclusive of breaks). This represents a substantial reduction in effort from previous surveys which required a field team of 9 people for at least 4 days.

The species-specific multipliers in Table 4 (below) allow total fish species densities and biomasses to be estimated from single pass data generated from future surveys at sites 0 and 4. The associated error statistics (SD and SE) can be used to determine confidence intervals around the estimates. Using the multiplies in Table 4 to estimate total population and its associated error, will enable continued long-term monitoring to leverage off the existing seven-year dataset.

Table 4. Species-specific multipliers to apply to single-pass electric fishing data collected from sites 0 and 4 to estimate total fish density and biomass and associated error.

	Site 0			Site 4		
Fish population metric	**Multiplier**	**SD**	**SE**	**Multiplier**	**SD**	**SE**
Total fish density	2.77	1.04	0.52	2.38	0.76	0.29
Total fish biomass	2.55	0.87	0.52	1.82	0.56	0.29
Bully density (all species combined)	2.73	1.07	0.54	1.94	0.37	0.14
Longfin eel density	3.17	1.41	0.70	2.01	0.60	0.23
Longfin eel biomass	2.73	0.92	0.70	2.12	1.13	0.23
Brown trout density	N/A	N/A	N/A	1.78	0.73	0.30
Lamprey	N/A	N/A	N/A	7.73	5.23	1.98

5.3.3. Periodicity

We recommend that Sites 0 and 4 are surveyed annually in late February-March (inclusive). If resources allow, a wider-scale survey should be undertaken every five years to include six sites (i.e. sites 0 and 4, and an additional four sites). The location of these sites should replicate the survey design in Holmes et al. (2019) and include sites 0, 1, 2, 3, 4, and 5 as described there. The five-yearly more extensive survey will enable any potential trends observed during annual monitoring to be validated over a wider spatial range. Reporting should coincide with the completion of the five-yearly more extensive survey. Reporting should consider any events occurring in the catchment that could impact upon the fish community; for example, changes to the lagoon opening regime, significant shifts in land use, wide-scale implementation of on-farm environmental improvements or large-scale channel management / maintenance events.

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7. APPENDICES

Appendix 1. New Zealand Map Grid GPS coordinates for all sites sampled in association with the rehabilitation project since 2014. GPS positions mark the true-right downstream corner of each 40 m study reach. Sites marked with an asterisk underwent rehabilitation treatment.

Site	Site type	Easting	Northing
-1	Impact	2167686	5397904
0	Impact*	2167566	5398271
0.5	Impact	2167534	5398477
1	Impact	2167415	5398659
2	Impact*	2167363	5398816
3	Impact	2167412	5399096
4	Control	2167854	5401437
5	Control	2167780	5401531
6	Control	2167653	5401568
7	Control	2167597	5401750
8	Control	2167688	5401933

Appendix 2. All sites along the Waituna Creek sampled in association with the rehabilitation project since 2014.